

# Dark Matter Decoded? New Quantum Gravity Theory Reimagines Einstein's Spacetime

BY QUEEN MARY UNIVERSITY OF LONDON APRIL 8, 2025



In a groundbreaking study, Professor Ginestra Bianconi proposes that gravity emerges from quantum relative entropy, offering a new framework that unifies quantum mechanics and general relativity. The theory also introduces the G-field, a novel concept that could provide a quantum-based explanation for dark matter.

**A new theory links gravity to quantum entropy and introduces the G-field, possibly explaining dark matter and cosmic expansion.** In a recent study published in *Physical Review D*, Professor Ginestra Bianconi, a Professor of Applied Mathematics at [Queen Mary University of London](#), presents a groundbreaking framework that may transform our understanding of gravity and its connection to quantum mechanics. The study introduces a

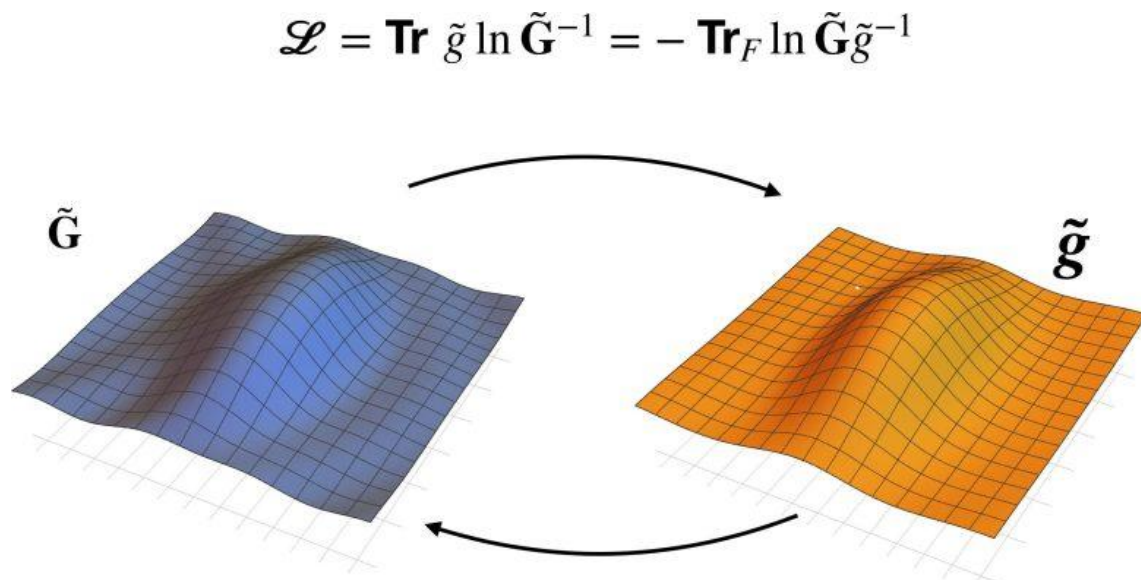
new approach that derives gravity from quantum relative entropy, offering a potential bridge between two foundational but historically incompatible theories: quantum mechanics and Einstein’s general relativity.

## The challenge of quantum gravity

For decades, physicists have grappled with the challenge of unifying quantum mechanics and general relativity, two foundational theories that operate on vastly different scales. Quantum mechanics explains the behavior of particles at the subatomic level, while general relativity describes gravity and the structure of spacetime on cosmic scales. Bridging the gap between these frameworks remains one of the most difficult and important problems in theoretical physics. Professor Bianconi’s research introduces a novel approach by reinterpreting the spacetime metric, a central element of general relativity, as a quantum operator. By applying quantum relative entropy, a concept from quantum information theory, her framework captures the interaction between spacetime geometry and matter in a fundamentally new way.

## The role of entropy and the G-field

The study introduces a new entropic action, which quantifies the difference between the metric of spacetime and the metric induced by matter fields. This approach leads to modified Einstein equations that, in the low coupling regime i.e. low energies and small curvature, reduce to the classical equations of general relativity. However, the theory goes further, predicting the emergence of a small, positive cosmological constant – a value that aligns with experimental observations of the universe’s accelerated expansion much better than for other pre-existing theories.



Diagrammatic representation of the entropic quantum gravity action. The action for gravity is given by the quantum relative entropy between the metric of the manifold and the metric induced by the matter field and the geometry. Credit: Ginestra Bianconi

A key feature of the theory is the introduction of the *G-field*, an auxiliary field that acts as a Lagrangian multiplier. The G-field not only plays a crucial role in the modified equations of gravity but also opens the door to new interpretations of dark matter – a mysterious substance that makes up a significant portion of the universe’s mass but has yet to be directly observed.

The implications of this research are profound. By linking gravity to quantum information theory, the study provides a potential pathway to a unified theory of quantum gravity. Moreover, the G-field could offer new insights into the nature of dark matter, a long-standing puzzle in cosmology.

“This work proposes that quantum gravity has an entropic origin and suggests that the G-field might be a candidate for dark matter,” explains Professor Bianconi. “Additionally, the emergent cosmological constant predicted by our model could help resolve the discrepancy between theoretical predictions and experimental observations of the universe’s expansion.” While further research is needed to fully explore the implications of this theory, the study represents a significant step forward in the quest to understand the fundamental nature of the universe.

Professor Bianconi’s work challenges conventional wisdom and opens up exciting new avenues for exploration. By treating spacetime as a quantum entity and leveraging the power of entropy associated to the spacetime metrics, this research could pave the way for a deeper understanding of gravity, quantum mechanics, and the cosmos itself.

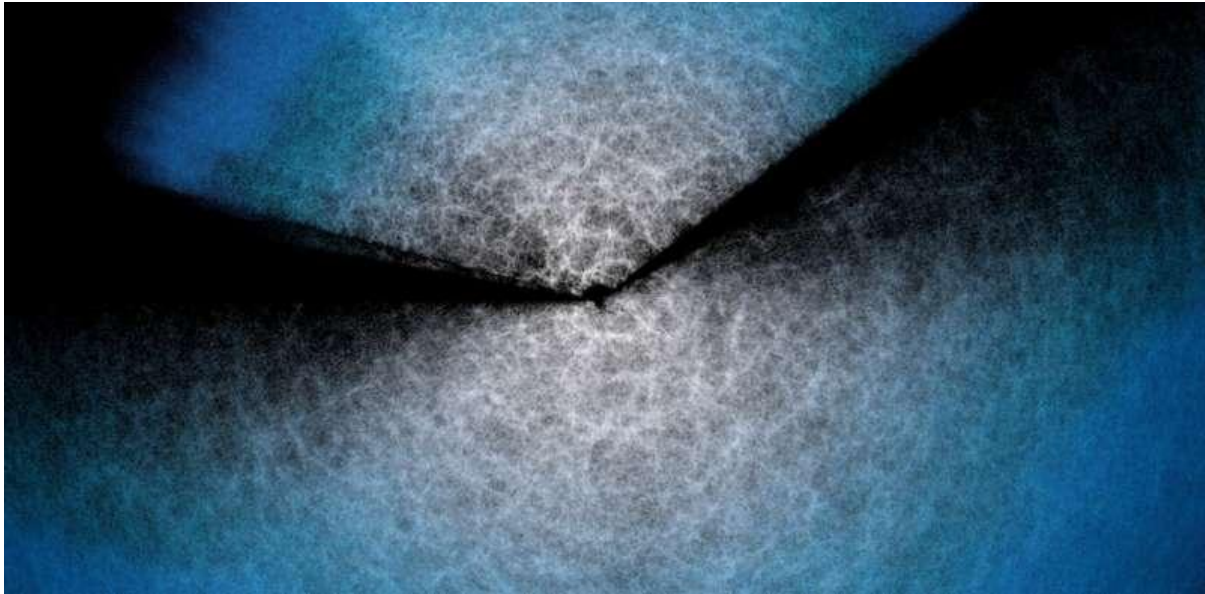
Reference: “Gravity from entropy” by Ginestra Bianconi, 3 March 2025, *Physical Review D*.  
DOI: [10.1103/PhysRevD.111.066001](https://doi.org/10.1103/PhysRevD.111.066001)  
[Gravity](#)[Quantum Mechanics](#)[Quantum Physics](#)[Queen Mary University of London](#)

---

APRIL 3, 2025

# Dark energy may not be constant—this discovery could undermine our entire model of cosmological history

by Bernard J.T. Jones, Licia Verde, Vicent J. Martínez and Virginia L Trimble, [The Conversation](#)



DESI has made the largest 3D map of our universe. The Earth is at the central vertex, and every dot is a galaxy. Credit: DESI collaboration and KPNO/NOIRLab/NSF/AURA/R.

Proctor, [CC BY-SA](#)

The great Russian physicist and Nobel laureate [Lev Landau](#) once remarked that "cosmologists are often in error, but never in doubt." In studying the history of the universe itself, there is always a chance that we have got it all wrong, but we never let this stand in the way of our inquiries.

A few days ago, a [new press release](#) announced groundbreaking findings from the Dark Energy Spectroscopy Instrument ([DESI](#)), which is installed on the Mayall Telescope in Arizona. This vast survey, containing the positions of 15 million galaxies, constitutes the largest three-dimensional mapping of the universe to date. For context, the light from the most remote galaxies recorded in the DESI catalog was emitted 11 billion years ago, when the universe was about a fifth of its current age.

DESI researchers studied a feature in the distribution of galaxies that astronomers call "[baryon acoustic oscillations](#)." By comparing it to observations of the very early universe and supernovae, they have been able to suggest that dark energy—the mysterious force propelling our universe's expansion—is not constant throughout the history of the universe.

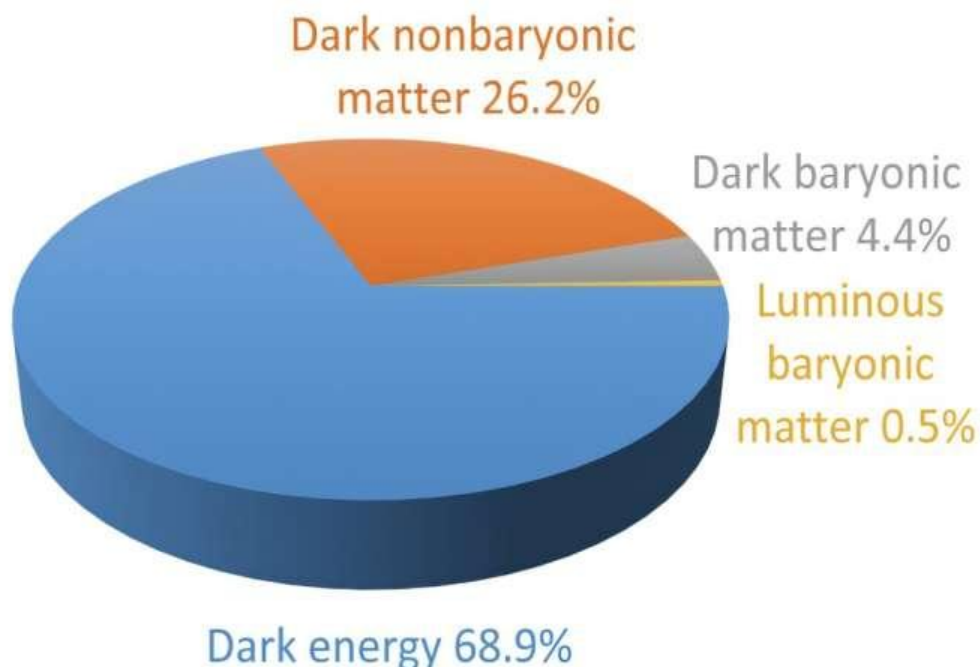
An optimistic take on the situation is that sooner or later the nature of dark matter and dark energy will be discovered. The first glimpses of DESI's results offer at least a small sliver of hope of achieving this.

However, that might not happen. We might search and make no headway in understanding the situation. If that happens, we would need to rethink not just our research, but the study of cosmology itself. We would need to find an entirely new cosmological model, one that works as well as our current one but that also explains this discrepancy. Needless to say, it would be a tall order.

To many who are interested in science, this is an exciting, potentially revolutionary prospect. However, this kind of reinvention of cosmology, and indeed all of science, is not new, as argued in the 2023 book [The Reinvention of Science](#).

## The search for two numbers

Back in 1970, [Allan Sandage](#) wrote a [much-quoted paper](#) pointing to two numbers that bring us closer to answers about the nature of cosmic expansion. His goal was to measure them and discover how they change with cosmic time. Those numbers are the Hubble constant,  $H_0$ , and the [deceleration parameter](#),  $q_0$ .



The Cosmic Inventory: the different components of the universe derived from the Planck Satellite observations of the CMB. Image from Jones, Martínez and Trimble, "The Reinvention of Science." Credit: [CC BY-SA](#)

The first of these two numbers tells us how fast the universe is expanding. The second is the signature of gravity: as an attractive force, gravity should be pulling against cosmic expansion. Some data has shown a deviation from the [Hubble-Lemaître Law](#), of which Sandage's second number,  $q_0$ , is a measure.

No significant deviation from Hubble's straight line could be found until breakthroughs were made in 1997 by [Saul Perlmutter's Supernova Cosmology Project](#) and the [High-Z SN Search Team](#) led by [Adam Riess](#) and [Brian Schmidt](#). The goal of these projects was to search for and follow supernovae exploding in very distant galaxies.

These projects found a clear deviation from the simple straight line of the Hubble-Lemaître Law, but with one important difference: the universe's expansion is accelerating, not decelerating. Perlmutter, Riess, and Schmidt attributed this deviation to Einstein's [cosmological constant](#), which is represented by the Greek letter Lambda,  $\Lambda$ , and is related to the deceleration parameter.

Their work earned them the [2011 Nobel Prize in Physics](#).

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.

Subscribe

## Dark energy: 70% of the universe

Astonishingly, this Lambda-matter, also known as dark energy, is the dominant component of the universe. It has been speeding up the universe's expansion to the point where the force of gravity is overridden, and it accounts for almost 70% of the total density of the universe.

We know little or nothing about the [cosmological constant](#),  $\Lambda$ . In fact, we do not even know that it is a constant. Einstein first said there was a constant energy field when he created his first cosmological model derived from General Relativity in 1917, but his solution was neither expanding nor contracting. It was static and unchanging, and so the field had to be constant.

Constructing more sophisticated models that contained this constant field was an easier task: they were derived by the Belgian physicist [Georges Lemaître](#), a friend of Einstein's. The standard cosmology models today based on Lemaître's work, and are referred to as  $\Lambda$  Cold Dark Matter ( [\$\Lambda\$ CDM](#)) models.

The DESI measurements on their own are completely consistent with this model. However, by combining them with observations of cosmic microwave background and supernovae, the best fitting model is one involving a dark energy that evolved over cosmic time, and that will (potentially) no longer be dominant in the future. In short, this would mean the cosmological constant does not explain dark energy.

# The Big Crunch

In 1988, the 2019 physics Nobel laureate [P. J. E. Peebles](#) wrote a paper with [Bharat Ratna](#) on the possibility that there is a cosmological constant that varies with time. Back when they published this paper, there was no serious body of opinion about  $\Lambda$ .

This is an attractive suggestion. In this case the current phase of accelerated expansion would be transient and would end at some point in the future. Other phases in cosmic history have had a beginning and an end: inflation, the radiation-dominated era, the matter-dominated era, and so on.

The present dominance of dark energy may therefore decline over cosmic time, meaning it would not be a cosmological constant. The new paradigm would imply that the current expansion of the universe could eventually reverse into a "[Big Crunch](#)."

Other cosmologists are more cautious, not least [Carl Sagan](#), who wisely said that "[extraordinary claims require extraordinary evidence](#)". It is crucial to have multiple, independent lines of evidence pointing to the same conclusion. We are not there yet.

Answers may come from one of today's ongoing projects—not just DESI but also [Euclid](#) and [J-PAS](#)—which aim to explore the nature of [dark energy](#) through large-scale galaxy mapping.

While the workings of the cosmos itself are up for debate, one thing is for sure—a fascinating time for cosmology is on the horizon.

Provided by [The Conversation](#)

This article is republished from [The Conversation](#) under a Creative Commons license. Read the [original article](#).

APRIL 9, 2025

# Our understanding of the physical properties of galaxies could be wrong

by Andy Tomaswick, [Universe Today](#)



Image of the Milky Way at night.

Up until recently, astronomy was reliant entirely on electromagnetic waves. While that changed with the confirmation of gravitational waves in 2016, astronomers had developed fundamental frameworks in the electromagnetic spectrum by that point.

One critical framework broke the spectrum into three categories based on their wavelength—infrared, optical, and ultraviolet. To astronomers, each of these categories was created by a different physical phenomenon, and monitoring each gave its insight into what that phenomenon was doing, no matter what the other spectra said.

This was especially prevalent when researching galaxies, as infrared and [optical wavelengths](#) were used to analyze different aspects of galaxy formation and behavior. However, Christian Kragh Jespersen of Princeton's Department of Astrophysics and his

colleagues think they have found a secret that breaks the entire electromagnetic framework—the optical and infrared are connected.

That is the simple title of a [new paper](#) the researchers released on the *arXiv* preprint server that describes their remarkable feat. They predicted the infrared values of galaxies surveyed by the Wide-Field Infrared Explorer (WISE) by using [optical data](#) collected by the Sloan Digital Sky Survey (SDSS).

There is an assumption underlying most galaxy astronomy—that different "components" of a galaxy (i.e., its super-massive black hole or the stars on the edge of its spiral arms) are "separable" from one another since they emit across different wavelengths. This separation is simplified into a value called a spectral energy distribution, or SED, fitting code. They are commonly used to characterize the physical properties of the galaxies they are used to describe.

Video describing the Sloan Digital Sky Survey—one of the data sources for the paper.

Credit: American Museum of Natural History YouTube Channel

Unfortunately, according to the paper's analysis, the assumption underlying the SED codes of existing galaxies—that of the "separability" of galaxy components—is fundamentally wrong. As the paper says, "We conclude that [IR emitting and optical emitting] processes must be strongly coupled. This may or may not surprise the reader, but it violates the assumptions of current SED models."

To prove their point, the researchers looked at data collected by the SDSS and WISE. They collected data on over 500,000 different galaxies and then, after some training and validation of an algorithm, used the optical data collected by SDSS to predict the infrared data collected from WISE for each individual galaxy. That process was made easier since there were already indexes tying the WISE and SDSS data together on a per-galaxy basis.

The results were striking—the algorithm could predict the infrared value based solely on the optical input with very little noise. To further prove their point, the authors utilized two SED coding tools, CIGALE and prospector. Both missed the mark widely when attempting to calculate the correct value, allowing the authors to label a series of graphs showing how bad their estimations were with "Overconfident and biased."

This video reviews some of the infrared images that came from WISE—the other data source for the paper. Credit: Science Magazine YouTube Channel

On the other hand, their own data matched up precisely with the observed data from the WISE database. To the author's credit, they point out some weak points in their argument, such as the fact that WISE and SDSS were taken with different aperture sizes, which could influence the fit of their algorithm. However, the overwhelming preponderance of evidence points to a simple conclusion—that the "separability" assumption that underpins much of our understanding of the physical properties of [galaxies](#) is wrong.

The paper is only in preprint on *arXiv* and hasn't been accepted in a peer-reviewed journal yet. But if it is, it seems poised to impact our understanding of our universe fundamentally and, more importantly, what frameworks we use to understand it.

**More information:** Christian K. Jespersen et al, The optical and infrared are connected, *arXiv* (2025). DOI: [10.48550/arxiv.2503.03816](https://doi.org/10.48550/arxiv.2503.03816)

**Journal information:** [arXiv](#)

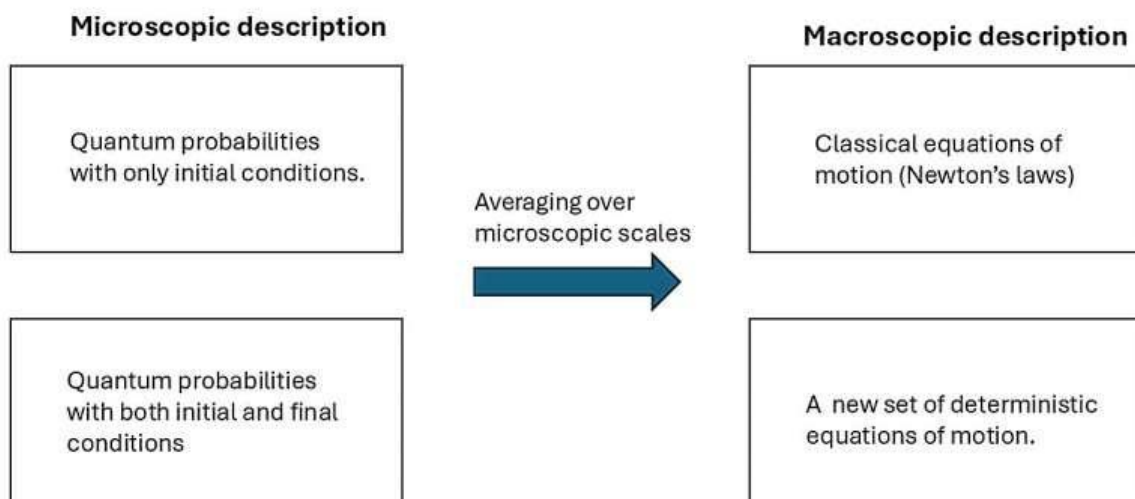
Provided by [Universe Today](#)

---

APRIL 7, 2025

# Quantum cosmology with final states can explain the accelerated expansion of the universe

by Charis Anastopoulos



The logic in the derivation of deterministic equations for systems with final conditions.

Credit: Charis Anastopoulos

Teleology is the idea that some processes in nature are directed toward a goal or an end. Today, it is commonly asserted that teleology is a remnant of antiquated ways of thinking about causation, and that it is not compatible with modern science, because it is fundamentally untestable.

In my opinion, such claims fail to take modern physics into account. Quantum theory involves a complex notion of causation, and it can naturally incorporate final conditions. However, to work with final conditions that are not imposed by external agents, we need to move into the realm of quantum cosmology, in which the whole universe is treated as a quantum system.

With this issue in mind, I studied final conditions in quantum cosmology. I found that cosmologies with such conditions generally predict a universe with accelerated expansion. Cosmic acceleration is a well-established fact, and also one of the most puzzling features of modern cosmology.

Its explanation requires controversial assumptions about new physics: either a very small but non-zero cosmological constant, an exotic form of matter (dark energy), or a radical modification to our theory of gravity. The postulate of a final quantum cosmological condition provides a novel explanation that requires no new physics.

Ever since Newton, [time evolution](#) in physics has been understood as an initial value problem. This means that we identify the initial positions and momenta of all particles in the system and then we solve Newton's equations of motion to obtain the positions and momenta at any future (or past) time.

The same applies to relativistic theories, with one exception: the cosmological singularities of general relativity. In cosmology, the solution of the equations of motion toward the past stops abruptly after a finite time, at the Big Bang singularity. Since nothing can be defined at the singularity, there is literally no initial condition to evolve forward in time.

A major motivation for quantum cosmology research is to resolve the singularities through quantum effects. But [quantum theory](#) brings its own bag of problems. The time evolution of the quantum state is very different from the causal evolution of classical physics, because quantum states do not express properties of individual quantum systems.

In most interpretations of quantum theory, the quantum state is solely an informational object for probabilistic bookkeeping. Furthermore, quantum probabilities have a natural generalization with both an initial and a final quantum state describing a physical system.

This generalization is well confirmed experimentally, and it has found many applications. In experiments, final states are implemented via post-selection, i.e., we keep only runs of the experiment that satisfy a specific final condition.

In quantum cosmology, we treat the universe as a single, closed [quantum system](#), so any initial or final state must be viewed as a component of the fundamental probability assignment. They are laws of nature that fix how the universe starts and how it ends.

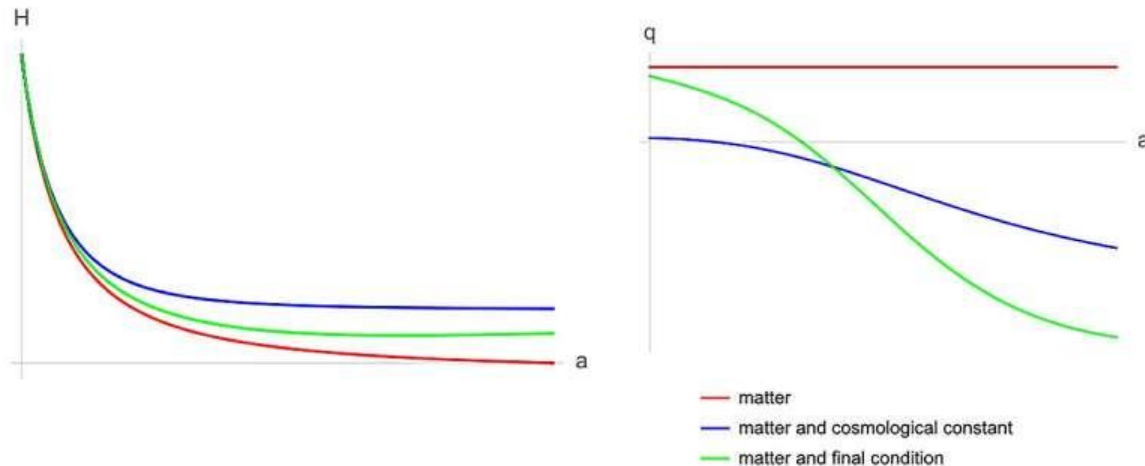
The majority of work on quantum cosmology focuses on specifying an initial state and ignores the possibility of a final state. One notable exception was Steven Hawking's research in the 1980s, which suggested final conditions for a Big Crunch that fully mirror initial conditions at the Big Bang.

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.  
Subscribe

He wanted to show that the thermodynamic arrow of time coincides with the arrow of cosmological expansion. This did not work, and eventually, the discovery of [cosmic acceleration](#) in the late 1990s made cosmologies with a Big Crunch implausible.

My analysis started from the derivation of the "deterministic limit" of quantum probabilities with both initial and final conditions, which is obtained by averaging microscopic quantum processes. If we only have initial conditions, the deterministic limit gives the equations of classical physics, for example, Newton's laws.

I derived the corresponding equations in the presence of quantum final conditions. These equations are novel, but they can still be expressed with the mathematics of classical physics, and they are largely independent of the properties of the underlying quantum theory. The latter result is both fortunate and unexpected: It enables specific cosmological predictions with no reference to highly speculative quantum gravity theories. These findings are [published](#) in the journal *Physical Review D*.



The left graph plots the Hubble constant  $H$  (a measure of the velocity of the expansion of the universe) as a function of the size  $a$  of the Universe, for three different models: ordinary matter, matter plus cosmological constant, and matter subject to quantum final conditions. The parameters of the models are chosen so that  $H$  and  $a$  are the same at some time in the past. The right graph plots the deceleration parameter  $q$  of the universe as a function of  $a$ . Matter subject to quantum final conditions predicts strong acceleration ( $q < 0$ ), similarly to the model with the cosmological constant, but with a stronger swing from a decelerating to an accelerating epoch. Credit: Charis Anastopoulos

It turns out that the deterministic limit of teleological quantum cosmologies (i.e., quantum cosmological models with both initial and final conditions) generically describes a universe undergoing accelerated expansion.

The universe transitions from a nonaccelerating to an accelerating epoch, in agreement with recent observations. No cosmological constant, dark energy or modified gravity needs be involved. Cosmic acceleration is generated solely by the imposition of final conditions at the quantum level. In this sense, cosmic acceleration is a genuine macroscopic quantum effect.

Further research is needed in order to see how teleological quantum [cosmology](#) fares observationally versus the alternative accounts of cosmic acceleration. A limitation of the existent analysis is that the deterministic limit does not work near the Big Bang.

To probe the [early universe](#), we need the full quantum description. Even a simplified model will enable us to analyze cosmological inhomogeneities in the early universe, and thereby to connect with observations of the cosmic microwave background and of primordial gravitational waves.

*This story is part of [Science X Dialog](#), where researchers can report findings from their published research articles. [Visit this page](#) for information about Science X Dialog and how to participate.*

**More information:** Charis Anastopoulos, Final states in quantum cosmology: Cosmic acceleration as a quantum postselection effect, *Physical Review D* (2025). DOI: [10.1103/PhysRevD.111.064045](#). On *arXiv*: DOI: [10.48550/arxiv.2401.07662](#)  
**Journal information:** [Physical Review D](#) , [arXiv](#)

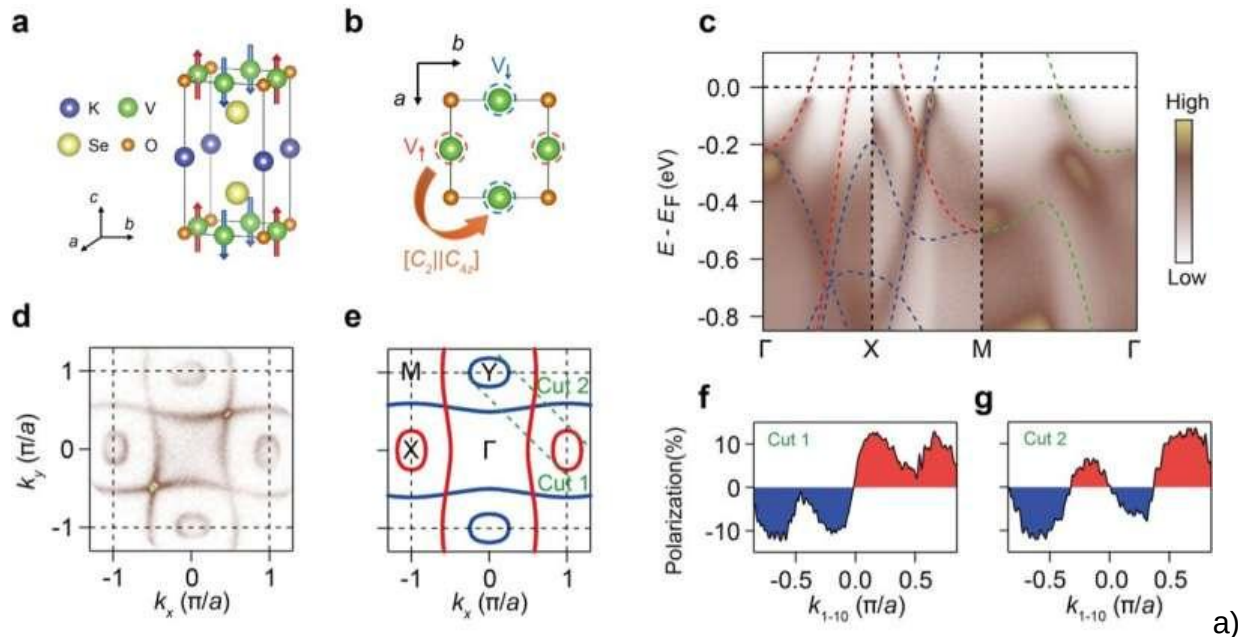
Charis Anastopoulos is an associate professor on Quantum Foundations at the University of Patras, Greece. Anastopoulos has a Ph.D. on theoretical physics from Imperial College, London, and has worked as a researcher at the universities of Barcelona, Maryland, and Utrecht. Anastopoulos is the chair of the EU-funded Action "Relativistic Quantum Information," a network of more than 250 researchers to explore the implications of quantum information to fundamental physics, and is the author of the books "Particle or Wave: The evolution of the concept of matter in modern physics" (Princeton University Press, 2008), and "Quantum Theory, a Foundational Approach" (Cambridge University Press, 2023).

---

APRIL 7, 2025

# Physicists uncover a metallic altermagnet with d-wave spin splitting at room temperature

by Ingrid Fadelli , Phys.org



Crystal structure and magnetic structure of KV<sub>2</sub>Se<sub>2</sub>O. b) Top view of the V<sub>2</sub>O plane, where opposite-spin V sublattices are connected by the [C<sub>2</sub>][C<sub>4z</sub>] operation. c) ARPES intensity plot, showing band dispersions along  $\Gamma$ -X-M- $\Gamma$ . Dashed curves are the calculated bands. d) ARPES intensity plot at the Fermi level, showing Fermi surfaces in the  $k_x$ - $k_y$  plane. e) Calculated spin-resolved Fermi surfaces in the  $k_z = 0$  plane. f,g) Momentum-dependent spin polarizations along Cut 1 (f) and Cut 2 (g). Credit: Jiang et al. (*Nature Physics*, 2025). For many years, physics studies focused on two main types of magnetism, namely ferromagnetism and antiferromagnetism. The first type entails the alignment of electron spins in the same direction, while the latter entails the alignment of electron spins in alternating, opposite directions.

Yet recent studies have discovered a new kind of magnetism, referred to as altermagnetism, which does not fit into either of the previously identified categories. Altermagnetism is characterized by the breaking of time-reversal symmetry (i.e., the symmetry of physical laws when time is reversed) and spin-split band structures, in materials that retain a zero net magnetization.

Researchers at the Chinese Academy of Sciences and other institutes in China recently uncovered a new material that exhibits altermagnetism at room temperature, namely KV<sub>2</sub>Se<sub>2</sub>O. Their findings, [published](#) in *Nature Physics*, highlight the promise of KV<sub>2</sub>Se<sub>2</sub>O both for the study of altermagnetism and for the development of spintronic devices.

"KV<sub>2</sub>Se<sub>2</sub>O belongs to a broad family of compounds containing the [T<sub>2</sub>Q<sub>2</sub>O]<sup>2-</sup> layers, where T denotes a 3d transition metal and Q represents S, Se, As, Sb, or Bi," Tian Qian, senior author of the paper, told Phys.org. "This family exhibits a variety of many-body phenomena, including superconductivity, Mott insulating state, charge or spin density wave (CDW/SDW)."

The initial objective of the recent study by Qian and his colleagues was to further explore the origin of the unconventional superconductivity observed in KV<sub>2</sub>Se<sub>2</sub>O, which is known to be associated with a SDW-like transition at temperatures around 100 K.

To achieve this, the researchers synthesized high-quality single crystals of KV<sub>2</sub>Se<sub>2</sub>O and then collected various measurements (i.e., resistivity, [magnetic susceptibility](#), [specific heat](#), ARPES, NMR and STM measurements), while also performing band structure calculations.

"NMR measurements indicate that V atoms establish a long-range magnetic order above room temperature, with spins aligned antiparallel along the c axis," explained Qian.

"This collinear compensated magnetic order is essential for altermagnets. ARPES experiments reveal a metallic electronic band structure. By comparing with band calculations under different magnetic configurations, we find that the calculated band structure of the altermagnetic order closely matches the ARPES results."

The researchers also collected spin-resolved ARPES measurements on the KV<sub>2</sub>Se<sub>2</sub>O and observed a momentum-dependent spin polarization with a d-wave symmetry. While they did not detect superconductivity in the material, they thus found that its band structure exhibits altermagnetic spin splitting with a magnetic ordering temperature well above room temperature.

"The most notable finding of our study is the discovery of a metallic altermagnet with d-wave spin splitting at room temperature," said Qian.

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.

Subscribe

"Due to its highly anisotropic C<sub>2</sub>-symmetry spin-polarized Fermi surfaces, this material is expected to generate highly polarized electric current and giant spin current, making it a promising platform for high-performance spintronic devices."

The new metallic room-temperature altermagnet uncovered by Qian and his colleagues could be a promising platform for exploring the many-body effects associated with altermagnetism. In the future, it could also potentially prove valuable for the development of quantum technologies and spintronic devices.

"Our future research aims to explore novel physics arising from the interplay between altermagnetism and other quantum states of matter," added Qian.

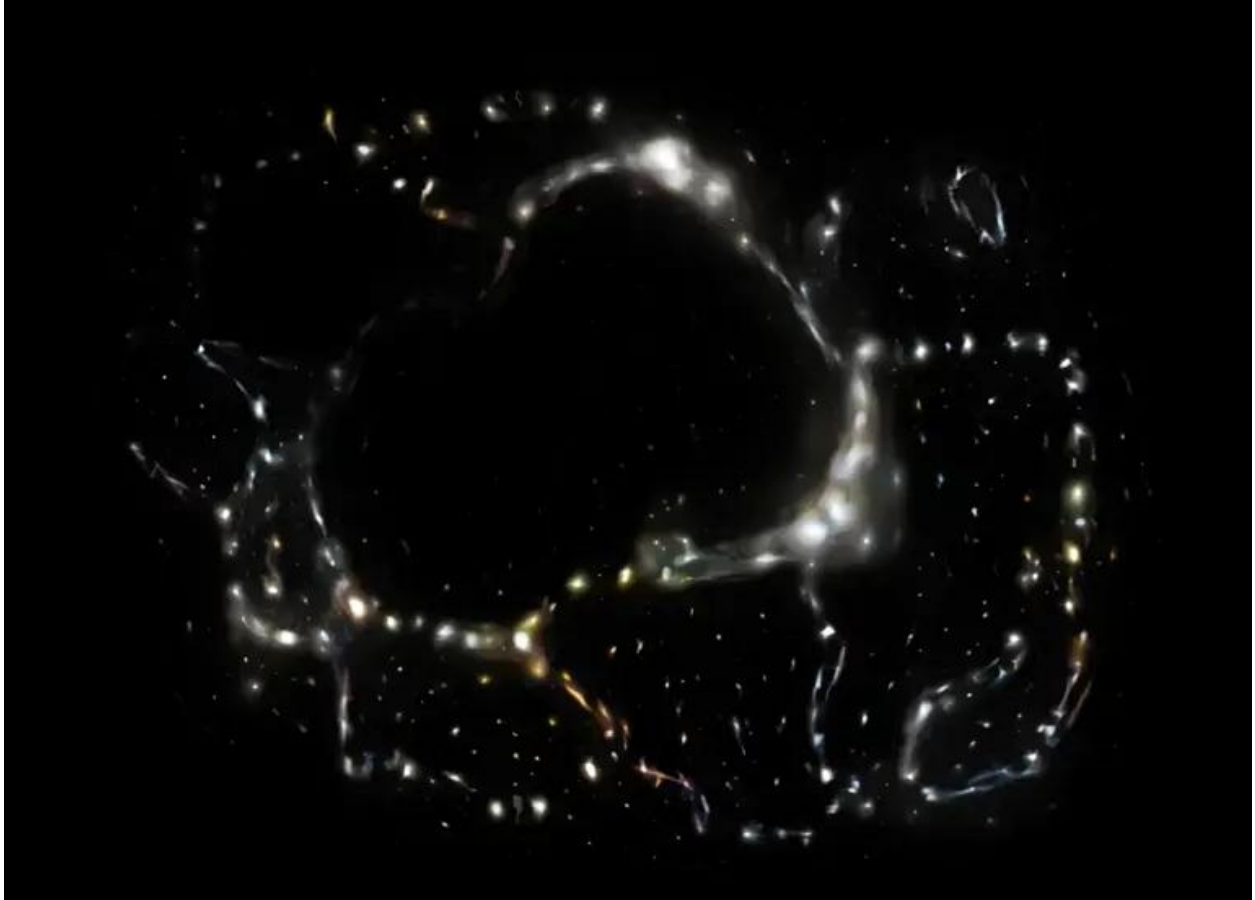
"For instance, the  $\text{V}_2\text{O}$  plane has an anti- $\text{CuO}_2$  structure, making the d-wave altermagnet  $\text{KV}_2\text{Se}_2\text{O}$  structurally compatible with d-wave cuprate superconductors. This compatibility opens new avenues for investigating interfacial physics between unconventional superconductors and altermagnets."

**More information:** Bei Jiang et al, A metallic room-temperature d-wave altermagnet, *Nature Physics* (2025). DOI: [10.1038/s41567-025-02822-y](https://doi.org/10.1038/s41567-025-02822-y).

**Journal information:** [Nature Physics](#)

© 2025 Science X Network

# The Milky Way exists in a cosmic void that breaks the laws of cosmology



KBC Void in an immense, comparatively empty region of space containing the Local Group, and a large part of the Laniakea Supercluster - 2,000 million ly diameter sphere with its center about 250 million ly away - Galaxies inside the void experience a gravitational pull from outside yielding a larger local value for the Hubble constant (redshift). (CREDIT: Wikipedia / Pablo Carlos Budassi)© The Brighter Side of News

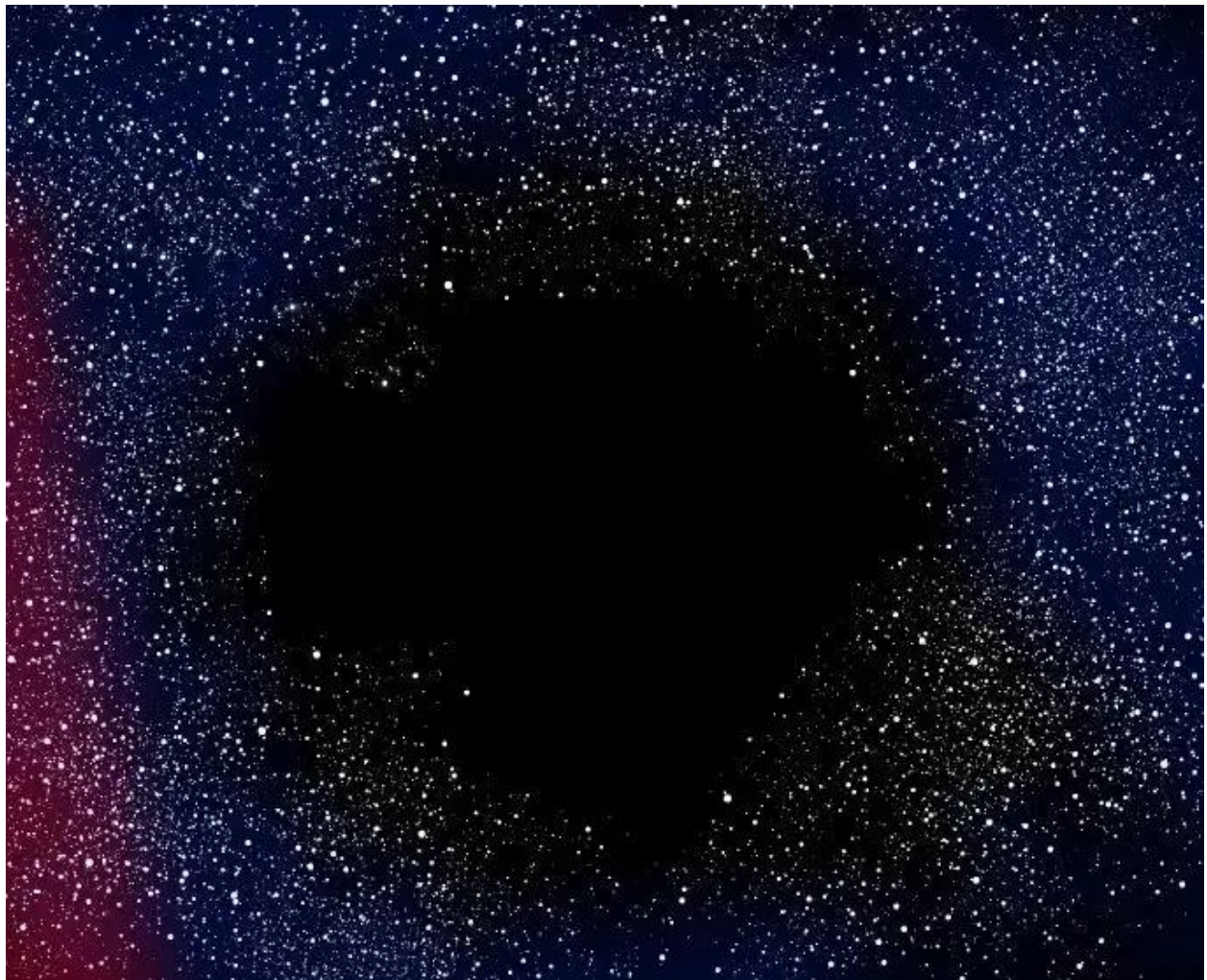
In recent years, one of the most troubling puzzles in astrophysics has grown more urgent. Scientists have realized that the universe seems to be expanding faster than expected, throwing a wrench into long-standing cosmological theories. This problem, known as the Hubble tension, challenges the most widely accepted explanation of the universe's structure and evolution—what's called the [Lambda Cold Dark Matter \( \$\Lambda\$ CDM\) model](#), or  $\Lambda$ CDM.

At first glance, it may sound like a simple disagreement over a number. But this discrepancy runs deep. If the faster expansion rate is real, it could mean the universe is younger than previously calculated. That directly clashes with

estimates based on the oldest known stars. It's not just a math problem—it's a sign that something might be wrong with our understanding of how the cosmos works.

## A Conflict That Won't Go Away

The tension comes from two types of measurements. One approach looks far back in time, using the cosmic microwave background—the faint light left over from the Big Bang. The other relies on nearby observations, such as supernovae and stars called Cepheids. These local measurements consistently suggest that the universe is expanding about 10% faster than the early-universe data would suggest.



The KBC void may explain the Hubble tension, a cosmic puzzle showing faster-than-expected local expansion. (CREDIT: CC BY-SA 4.0)© The Brighter Side of News

Astrophysicist Adam Riess, who won a Nobel Prize for his work on [cosmic expansion](#), summed up the issue: “Our measurements keep getting more precise, and the tension doesn’t go away.” For years, the hope was that better data would solve the problem. Instead, the gap has only widened.

This has led scientists to search for new explanations—ideas that could bring the numbers into agreement without rewriting all of modern cosmology. One of the most promising and controversial ideas involves a vast empty region of space that could be skewing the measurements from our part of the universe.

## The Cosmic Void That Might Hold the Answer

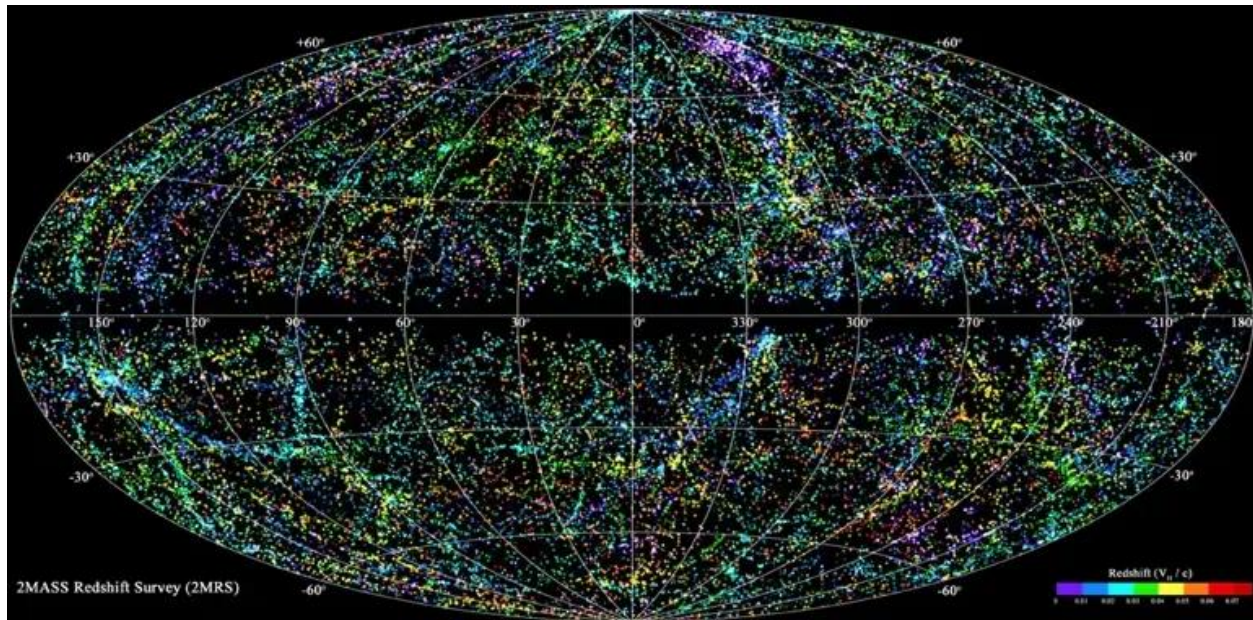
This idea revolves around something called the KBC void. Named after the astronomers who first described it—Keenan, Barger, and Cowie—this massive underdensity stretches across nearly two billion light-years of space. That makes it the largest void ever observed.

Multiple surveys across optical, infrared, X-ray, and radio wavelengths support the existence of this vast low-density region. Some estimates suggest that within about a billion light-years, the matter density could be as much as 50% below the cosmic average.

If our galaxy lies inside such a void, that could explain why local measurements of the Hubble constant seem too high. Galaxies inside a void experience a gravitational pull outward, flowing toward denser regions. That motion would make it look like the universe is expanding faster in our area, even if the overall rate matches predictions.

Astrophysicist Indranil Banik, from the [University of St. Andrews](#), has studied this possibility in depth. He points out that such a void would naturally create a “hill” in the gravitational potential, causing galaxies to move outward more rapidly. “By now, it’s pretty clear that we are in a significant underdensity,” Banik explains.

In one of his recent studies, Banik calculated that the KBC void could cause a local Hubble constant about 11% higher than the global average. That’s just the amount needed to bring local and distant measurements into harmony.



The 2MASS Redshift Survey (2MRS) has catalogued more than 43,000 galaxies within 380 million light-years from Earth ( $z$ ). (CREDIT: T.H. Jarrett (IPAC/SSC)© The Brighter Side of News)

## Why This Challenges the Standard Model

The  $\Lambda$ CDM model assumes that on scales larger than a few hundred million light-years, the universe is smooth and uniform. That makes a huge void like the KBC a serious challenge. For such a large underdensity to form in  $\Lambda$ CDM, early density fluctuations would have to be extremely rare—about a one-in-a-billion event.

Yet the data suggest that the KBC void is real. And if it is, it likely means that the standard model doesn't describe large-scale cosmic structure as well as once thought. This has led some researchers to look at alternative models that could more easily produce such voids.

One of those models is the neutrino Hot Dark Matter, or  $\nu$ HDM, framework. It builds on something called Milgromian dynamics, or MOND, which alters the way gravity behaves at very low accelerations. MOND has already been successful in explaining the motion of stars in galaxies without invoking invisible dark matter.

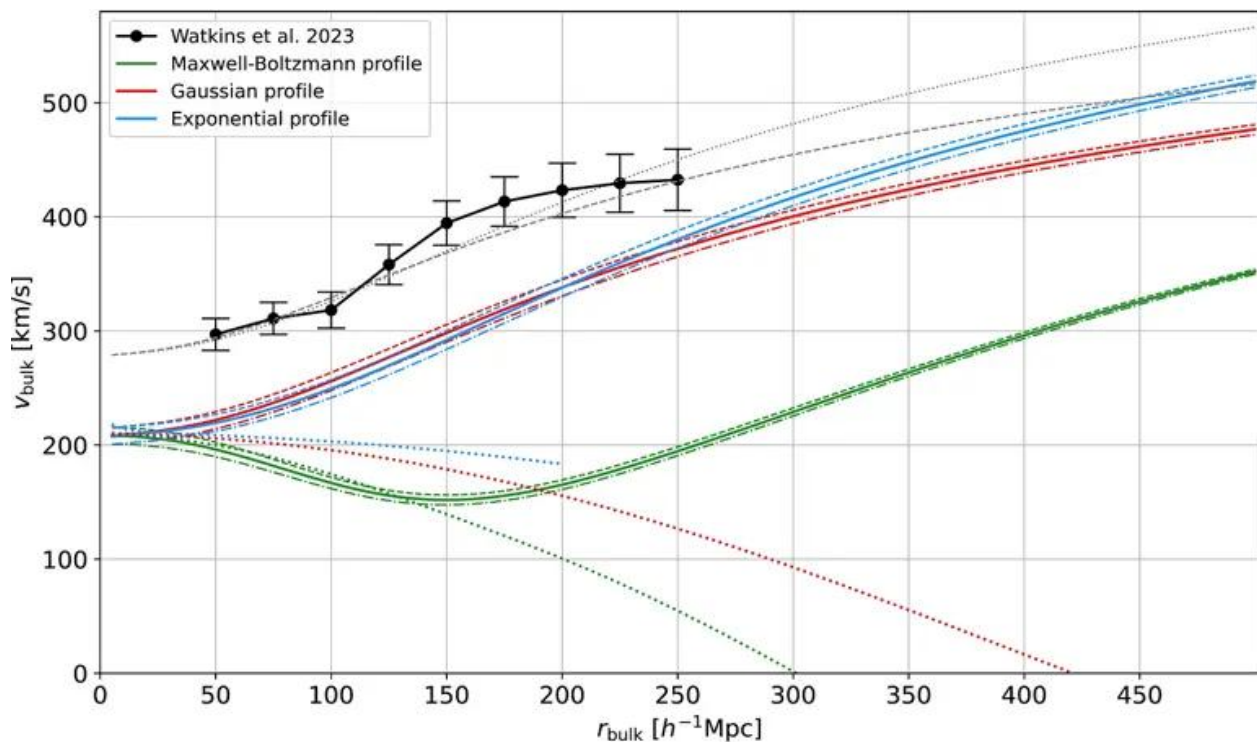
In  $\nu$ HDM, an extra type of neutrino is added—one with a rest energy of 11 electron volts. This sterile neutrino helps the model match other key features of the universe, including galaxy cluster behavior and patterns in the cosmic microwave background.

Unlike  $\Lambda$ CDM, the  $v$ HDM model naturally allows for deeper voids and stronger flows of galaxies over large distances.

## Testing the Theory with Bulk Flows

If the KBC void is real and causing an increased local expansion rate, then it should also affect the motion of galaxies. Specifically, galaxies should show faster bulk flows—movements that represent the average velocity of many galaxies in a given region.

Recent work by Watkins and colleagues using the CosmicFlows-4 catalog supports this idea. They found that bulk flows on scales of hundreds of millions of light-years are significantly higher than expected under the  $\Lambda$ CDM model. In fact, their results create a 4.8-sigma tension with the standard theory, a statistically significant mismatch.



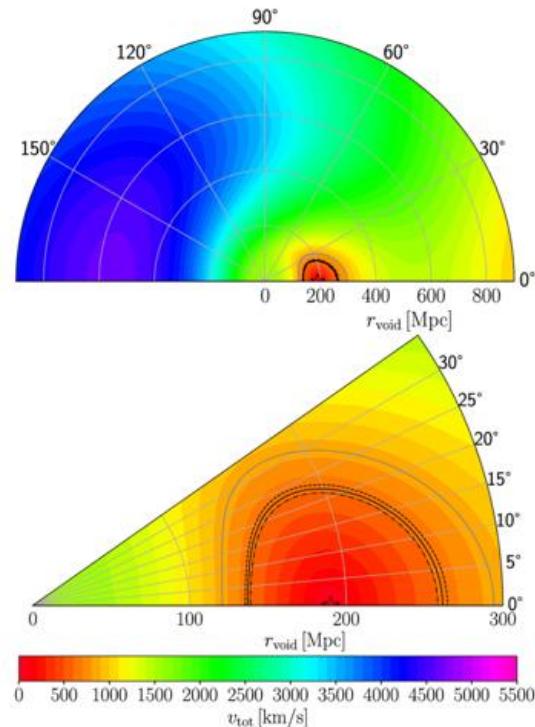
Bulk flows in spheres of different radii around an observer with a suitable CMB-frame velocity for the Maxwell–Boltzmann, Gaussian, and Exponential density profiles (green, red, and blue curves, respectively). (CREDIT: Monthly Notices of the Royal Astronomical Society)© The Brighter Side of News

What's striking is that Banik's vHDM model predicts these rapid bulk flows. His model, developed before these bulk flow data became available, wasn't adjusted to fit them. Yet when tested against the new results, it matches them well—especially when the observer's position is placed within a structure like the KBC void.

Other scientists have noticed this, too. A separate study by Whitford and colleagues using the same data found similar tensions with  $\Lambda$ CDM, further confirming that this isn't a fluke. The results support the idea that both the high local expansion rate and the fast galaxy motions could come from the same cosmic cause.

## **A New Direction for Cosmology?**

Not all scientists are convinced. Some argue that the KBC void only solves part of the problem—namely, why local measurements seem too high. It doesn't explain the global structure of the universe. Brian Keating, a cosmologist at UC San Diego, agrees that the void is worth studying but remains cautious. "If the local void isn't representative of the wider cosmos," he warns, "this may only provide a local solution, not a global one."



Map of the total velocity  $v_{\text{tot}}$  in the CMB frame resulting from the Maxwell–Boltzmann void density profile. (CREDIT: Monthly Notices of the Royal Astronomical Society)© The Brighter Side of News

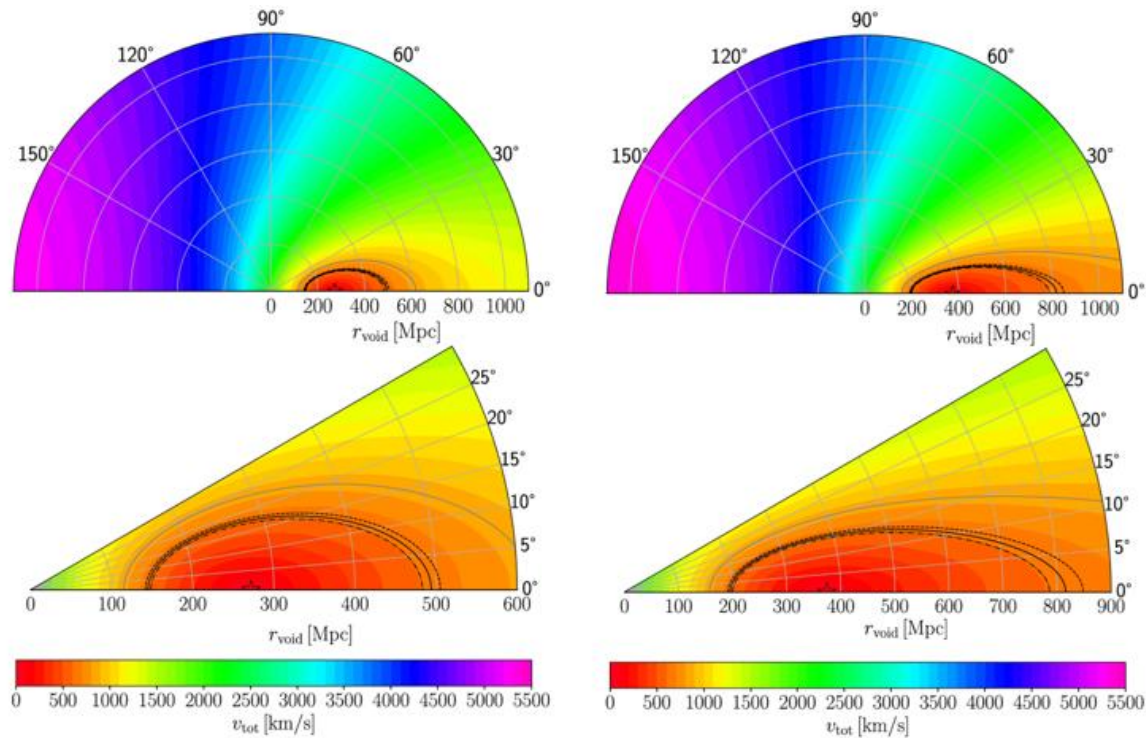
There are other competing ideas as well. One is early dark energy—a short burst of expansion that may have occurred soon after the Big Bang. This could shift the universe’s growth rate and bring the two sets of Hubble constant measurements closer together. However, it adds complexity to the model and may not match all observational data.

Still, the void hypothesis is gaining attention because of how naturally it explains multiple tensions. It also predicts a range of cosmic behaviors, like peculiar velocities—motions of galaxies that deviate from the expected expansion pattern.

The Local Group, which includes the Milky Way, has a peculiar velocity of about 627 kilometers per second. In the  $v\text{HDM}$  model, this value fits nicely within the predicted range, due to the way gravitational fields from nearby and distant structures interact. Sometimes these forces cancel out, leading to lower velocities for observers in certain regions.

## What Happens Next

Banik and his colleagues continue to test the predictions of the vHDM model. One future study will focus on supernova data from outside the void. If the Hubble constant in those areas matches the global predictions, it would further support the idea that our local region is unique.



Map of the total velocity  $v_{\text{tot}}$  in the CMB frame resulting from the Gaussian and Exponential density profiles. (CREDIT: Monthly Notices of the Royal Astronomical Society)© The Brighter Side of News

Resolving the Hubble tension could change how scientists think about the universe's age, composition, and the laws that govern it. Whether it's a rare void, an overlooked energy component, or new physics altogether, solving the puzzle will likely reshape cosmology.

"Each new observation brings us closer to unraveling the complexities of our universe," Banik says. And with every new discovery, the cosmic picture becomes a little clearer.

Research findings are available online in the journal [Monthly Notices of the Royal Astronomical Society](#).

# ***NO BIG BANG? GROUNDBREAKING NEW THEORY COULD UPEND THE STANDARD MODEL OF COSMOLOGY***

APRIL 8, 2025

The universe's [expansion](#) may be driven by “transient temporal singularities” — rapid, invisible bursts of energy — rather than [dark matter](#) or [dark energy](#), according to new research that challenges the widely accepted [standard model of cosmology](#).

The theory, proposed by Dr. Richard Lieu, a professor of physics at The University of Alabama in Huntsville (UAH), argues that the “steps” of these singularities offer a better explanation for the [universe's origins](#) than the idea of a single [Big Bang](#).

The groundbreaking theory proposes that these fleeting bursts could help resolve longstanding questions about cosmic expansion and [galaxy formation](#), without having to rely on theoretical constructs like dark matter and dark energy, which are widely featured in existing models attempting to explain such phenomena.

“This new paper proposes an improved version of the earlier model, which is also radically different,” Lieu said in a recent [statement](#).

“The new model can account for both structure formation and stability, and the key observational properties of the expansion of the universe at large, by enlisting density singularities in time that uniformly affect all space to replace conventional dark matter and dark energy.”

## **A NEW CHALLENGE TO THE STANDARD MODEL OF COSMOLOGY**

Lieu's model is an extension of previous research that already put forward a remarkable possibility: that [gravity may be able to exist independently from mass](#). Unlike other speculative theories that attempt to account for unexplained phenomena in our universe, Lieu's new work avoids exotic components such as negative mass or

negative density, arguing instead that sudden, discreet “transient temporal singularities” are responsible for filling the universe with matter and energy.

These mysterious bursts remain undetected by astrophysicists because of the incredible speed and infrequency of their occurrence, allowing them to evade detection. Unlike the steady-state theory, a concept proposed by Sir Fred Hoyle that argues the ongoing creation of matter in our universe, Lieu’s new theory avoids violating the mass-energy conservation laws.

“In the current theory, the conjecture is for matter and energy to appear and disappear in sudden bursts,” Lieu says. “These singularities are unobservable because they occur rarely in time and are unresolvedly fast, and that could be the reason why dark matter and dark energy have not been found.”

## **SOLVING THE RIDDLE OF COSMIC ACCELERATION**

Another longstanding cosmic mystery—what drives cosmic acceleration—is also accounted for by Lieu’s new theory, thanks to “negative pressure” that results from the generation of these undetectable singularities. Intriguingly, Lieu says that the phenomenon in question is described in Einstein’s early work, and may arise from energy densities like magnetic fields, thereby contributing to universal expansion.

“Einstein also postulated negative pressure in his 1917 paper on the Cosmological Constant,” Lieu says. “When positive mass-energy density is combined with negative pressure, there are some restrictions which ensure the mass-energy density remains positive with respect to any uniformly moving observer, so the negative density assumption is avoided in the new model.”

## ARE DARK ENERGY AND DARK MATTER “OMNIPRESENT”?

While many regard dark energy and dark matter as being ubiquitous throughout the universe, Lieu challenges this widely accepted idea, arguing they “are not omnipresent” but instead “only appear in brief instances during which the matter and energy do fill the entire universe uniformly, apart from random spatial density variations which grow to form bound structures like galaxies.”

In between these cosmic occurrences, Lieu says dark energy and dark matter “are not to be found anywhere.” However, Lieu argues that there is only one fundamental difference between what his new theory proposes and the currently accepted [standard model](#), which comes down to timing. The standard model assumes a single, one-time singularity—the Big Bang—whereas Lieu’s model envisions multiple singularities unfolding throughout cosmic history.

## NO NEED FOR ADVANCED SPACE OBSERVATORIES FOR TESTING

As an added benefit to his groundbreaking theory, Lieu says that the alternative framework he puts forward could be tested using Earth-based instruments, as opposed to having to rely on advanced space-based observatories. Good candidates for testing his theory include the Keck Observatory in Hawaii or the Isaac Newton Group of Telescopes in Spain, which he says could conduct deep-field observations sliced by redshift to detect anomalies in cosmic expansion.

“Given sufficient redshift (or, equivalently, time) resolution effected by the redshift slicing, one might just find that the Hubble diagram exhibits jumps in the redshift distance relation, which would be very revealing,” Lieu said.

The new [study](#), “Are dark matter and dark energy omnipresent?” was published in the journal *Classical and Quantum Gravity*.

---

APRIL 10, 2025

## Simulating quantum magnetism with a digital quantum computer

by Ingrid Fadelli , Phys.org



Optics of the H2 quantum computer. Credit: Quantinuum.

Quantum computers, which process information leveraging quantum mechanical effects, have the potential to outperform classical computers in some optimization and computational tasks. In addition, they could be used to simulate complex quantum systems that cannot be simulated using classical computers.

Researchers at Quantinuum and other institutes in Europe and the United States recently set out to simulate the digitized dynamics of the quantum Ising model, a framework that describes [quantum magnetism](#) in materials, using an advanced quantum computer.

Their simulations, outlined in a [paper](#) on the *arXiv* preprint server, led to the observation of a transient state known as Floquet prethermalization, in which systems appear locally stable before approaching full equilibrium, in regimes that are inaccessible to classical computers.

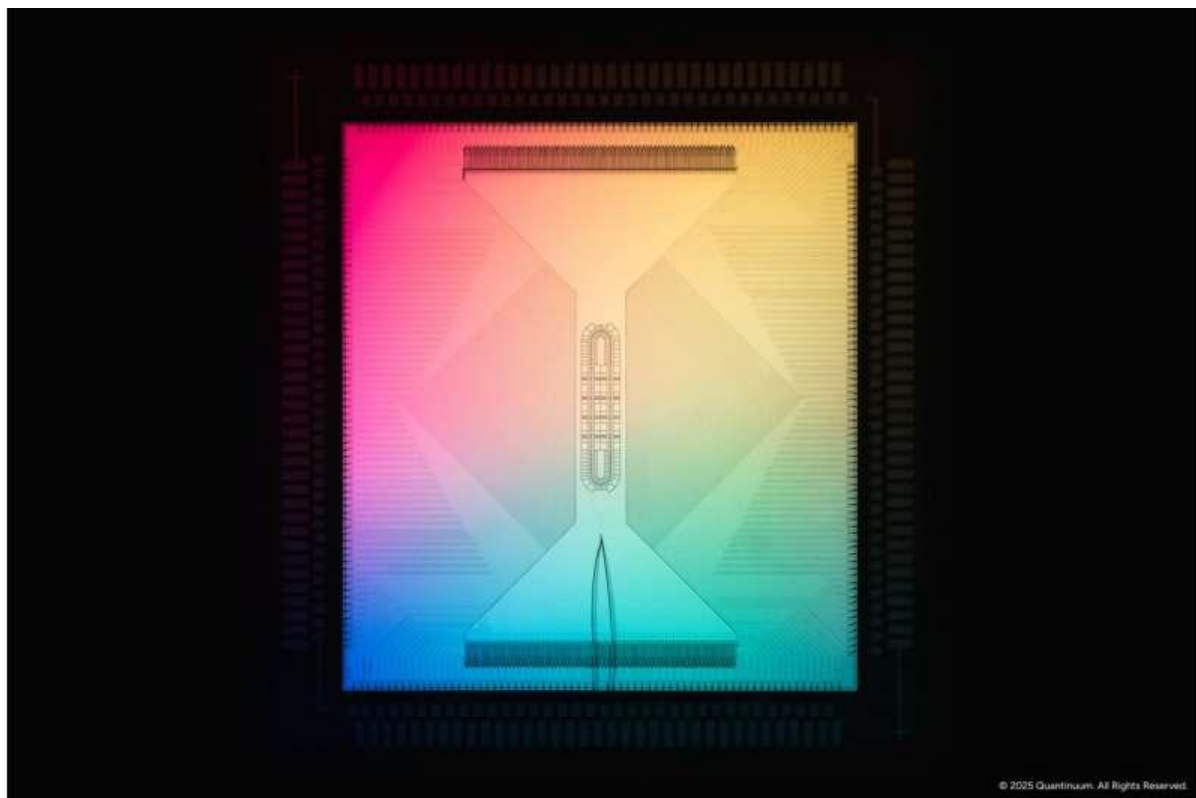
"Simulating continuous time evolution on digital quantum computers has been a longstanding goal in the field of quantum computation, thus we are certainly not the first or only people wanting to do this," Michael Foss-Feig, a researcher at Quantinuum and lead author of the paper, told Phys.org.

"However, achieving this at a scale that rivals or exceeds the best classical methods is much more challenging than achieving quantum advantage in more contrived scenarios, such as random-circuit-sampling, and had not yet been achieved."

Last year, Foss-Feig and his colleagues at Quantinuum successfully used a quantum computer they developed to complete random circuit sampling tasks that could not be completed by classical computers, with unprecedented fidelities. This achievement inspired them to explore the potential of quantum computers for completing a wider range of problems.

"These early results, together with progress in our gate fidelities over the last year, convinced us to start thinking seriously about whether beyond-classical quantum [simulation](#) might be within reach," explained Foss-Feig.

As part of their recent study, the researchers used H2, a quantum computer developed at Quantinuum, to simulate the dynamics of the quantum Ising model. The quantum Ising model is a standard model used to study magnetism, quantum phase transitions and emergent physics in complex systems.



System model of the H2 quantum computer. Credit: Quantinuum.

"In real systems, time passes smoothly, and simulating realistic dynamics on a digital quantum computer requires 'discretizing' this smooth time evolution into the set of quantum gates that one has available," said Foss-Feig. "Discretization is never perfect, but we did it well enough to observe many of the hallmark features of real physical systems.

"In particular, the smoothness of time is ultimately responsible for energy being conserved in real systems, which causes them to naturally relax to an equilibrium state after being pushed far out of equilibrium."

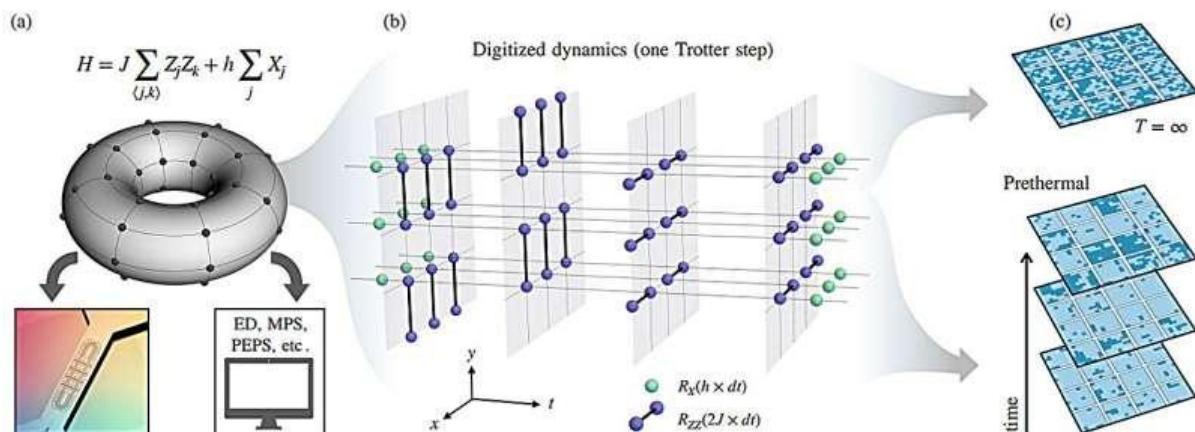
The simulations run by Foss-Feig and his colleagues digitally reproduce continuous-time dynamics, thus showing how quantum systems evolve over time. In their simulations, the researchers observed characteristic signatures of these systems when they are approaching a state of equilibrium, such as the emergence of a hydrodynamic energy transport.

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.

Subscribe

"The most important achievement of this work is that we were able to keep this continuous time-evolution relatively noise-free (and therefore accurate) out to timescales where even the best classical simulation methods appear to really struggle," said Reza Haghshenas, a researcher at Quantinuum leading the classical benchmarking efforts.

"I say 'struggle,' and not 'fail,' because we believe that with substantial classical resources (i.e., running the best classical algorithms with super-computer scale resources) it may well be possible to perform comparably accurate simulations classically. However, we also believe this to be possible only because of the limited number of qubits (56) we used in these simulations."



Digitizing an Ising quantum magnet. Credit: *arXiv* (2025). DOI: 10.48550/arxiv.2503.20870  
This recent study by Foss-Feig and his colleagues demonstrates the potential of quantum computers for the realistic simulation of complex quantum systems, which are difficult or impossible to simulate using classical computers. The researchers are now working on

further advancing and upscaling quantum computers, which could further boost their ability to simulate quantum systems.

Their recent work shows that the current gate fidelities of the H2 quantum computer are already high enough to simulate physical systems in regimes that are difficult to access using classical computers. Future quantum computers based on even greater numbers of qubits could simulate even larger and more [complex systems](#), which could in turn improve the understanding of their underlying physics.

"Moderate increases in system sizes (qubit numbers) should enable simulations that are more definitively out of reach of current classical methods, and we are very much looking forward to releasing our next system, Helios, with 96 qubits," added Foss-Feig.

"We view this as an incredibly exciting point in time. Many important technologies have emerged from our (limited) ability to classically simulate [quantum systems](#), and advances in simulation methods can have broad impacts: Quantum computers may soon be capable of validating and augmenting classical simulations in settings where classical methods are infeasible or unreliable."

**More information:** Reza Haghshenas et al, Digital quantum magnetism at the frontier of classical simulations, *arXiv* (2025). DOI: [10.48550/arxiv.2503.20870](https://doi.org/10.48550/arxiv.2503.20870)

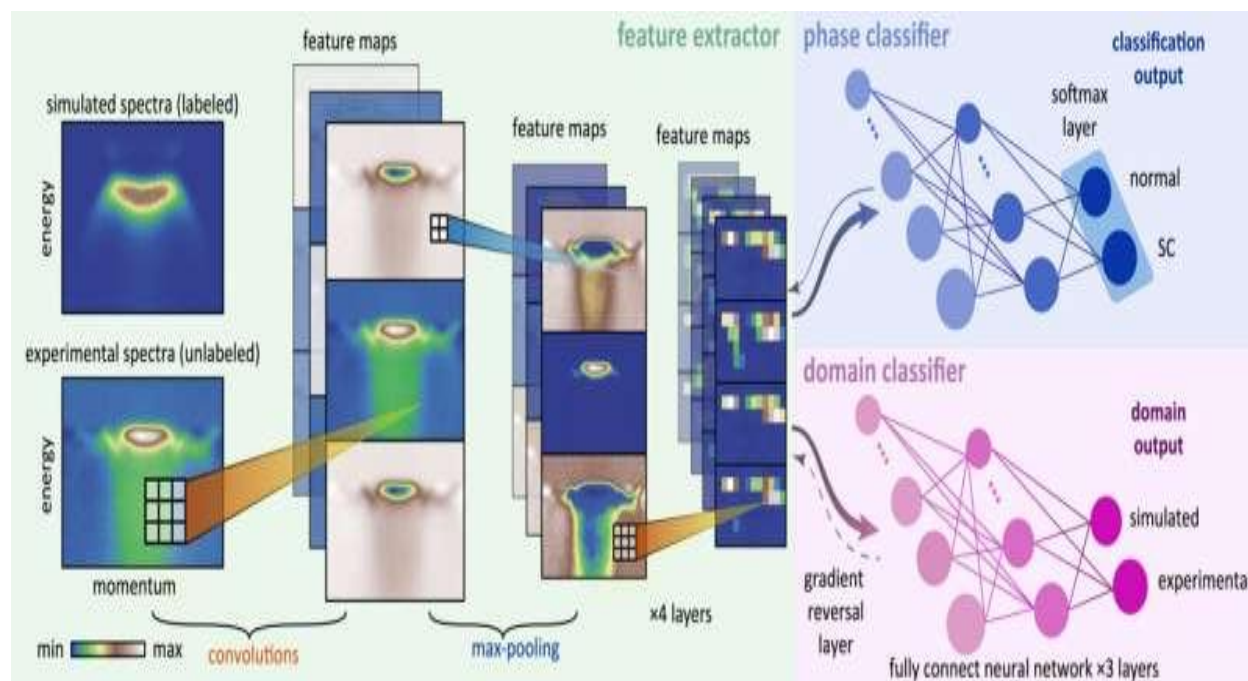
**Journal information:** [arXiv](#)

© 2025 Science X Network

APRIL 10, 2025

# New AI tool set to speed quest for advanced superconductors

by [Emory University](#)



Model architecture. Credit: *Newton* (2025). DOI: 10.1016/j.newton.2025.100066

Using artificial intelligence shortens the time to identify complex quantum phases in materials from months to minutes, finds a new study [published](#) in *Newton*. The breakthrough could significantly speed up research into quantum materials, particularly low-dimensional superconductors.

The study was led by theorists at Emory University and experimentalists at Yale University. Senior authors include Fang Liu and Yao Wang, assistant professors in Emory's Department of Chemistry, and Yu He, assistant professor in Yale's Department of Applied Physics.

The team applied [machine-learning techniques](#) to detect clear spectral signals that indicate [phase transitions](#) in quantum materials—systems where electrons are strongly entangled. These materials are notoriously difficult to model with traditional physics because of their unpredictable fluctuations.

"Our method gives a fast and accurate snapshot of a very complex phase transition, at virtually no cost," says Xu Chen, the study's first author and an Emory Ph.D. student in chemistry. "We hope this can dramatically speed up discoveries in the field of superconductivity."

One of the challenges in applying machine learning to quantum materials is the lack of sufficient high-quality experimental data needed to train models. To overcome this, the researchers used high-throughput simulations to generate large amounts of data. They then combined these simulation results with just a small amount of experimental data to create a powerful and efficient machine-learning framework.

"This is like training self-driving cars," Liu explains. "You might test them extensively in Atlanta, but you want them to perform reliably in New Haven, or really, anywhere. So, the question is: how do we make the learning both transferable and understandable?"

Their framework allows machine learning models to recognize phases in experimental data—even from just a single spectral snapshot—by applying the insights gained from simulations. This approach tackles the ongoing challenge of limited experimental data in scientific machine learning and opens the door to faster, more scalable exploration of quantum materials and molecular systems.

Other contributors to the study include Yuanjie Sun, a former undergraduate at Clemson University; Eugen Hruska, a former postdoctoral researcher at Emory; Vivek Dixit, a former postdoctoral researcher at Clemson; and Jinming Yang, a Ph.D. student at Yale.

## Quantum fluctuations: Angel and demon

Quantum materials are a special class of materials in which particles like electrons and atoms behave in ways that defy classical physics. One of their most fascinating features is a quantum phenomenon called entanglement, where particles influence each other at a far distance. A popular analogy is Schrödinger's cat—a thought experiment in which a cat can be both alive and dead at the same time. In quantum materials, electrons can behave similarly, acting collectively rather than individually.

These unusual correlations, or more precisely fluctuations, are what give quantum materials their remarkable properties. One of the best-known examples is [high-temperature superconductivity](#) found in copper-oxide compounds, or cuprates, where electricity flows without resistance under certain conditions.

But while fluctuations often accompany these powerful properties, they also make many physical properties incredibly difficult to understand, measure and design. Traditional methods for identifying phase transitions in materials rely on something called the spectral gap—the energy needed to break superconducting electron pairs. However, in systems with strong fluctuations, this method breaks down.

"Instead, it is the level of global coordination between gazillions of superconducting electrons, or the quantum 'phase,' that governs the transition," says He, who recently published a separate study revealing a surprisingly wide extent of this effect.

"It's like moving to a different country where everyone speaks a different language—you can't just rely on what worked before," Wang adds.

This means scientists can't easily determine the [transition temperature](#)—the point at which superconductivity kicks in—just by looking at the spectral gap. Finding better ways to characterize these transitions is crucial for efficiently discovering new quantum materials and designing them for real-world applications.

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.

Subscribe

## High-temperature superconductivity

Superconductivity—the ability of certain materials to conduct electricity with zero energy loss—is one of the most fascinating phenomena in quantum physics. It was discovered in 1911, when scientists found that mercury completely lost its electrical resistance at 4 Kelvin (-452°F), a temperature colder than any natural place in our solar system.

It wasn't until 1957 that scientists were able to fully explain how superconductivity works. At everyday temperatures, electrons in a material move independently and frequently collide with atoms, losing energy in the process. But at very low temperatures, electrons can team up and form a new state of matter. In this paired state, they move in perfect sync, like a well-choreographed dance, allowing electricity to flow without resistance.

A major breakthrough came in 1986 with the discovery of cuprate superconductors. These materials can superconduct at temperatures as high as 130 Kelvin (-211°F), which, while still cold, is warm enough to be reached using inexpensive liquid nitrogen. This made practical applications of superconductivity much more realistic.

However, cuprates belong to the class of quantum materials, where the behavior of electrons is governed by entanglement and strong quantum fluctuations. These material phases are complex and hard to predict using traditional theories, making them both exciting and challenging to study.

Today, scientists around the world are racing to unlock the full potential of superconductors. The ultimate goal is to create materials that can superconduct at room temperature. If successful, this could revolutionize everything from power grids to computing—allowing electricity to flow with perfect efficiency, without heat or waste.

## A new approach

The researchers wanted to use a machine learning model to overcome this obstacle.

Machine learning models, however, need training on vast quantities of labeled data to learn how to effectively distinguish a particular feature from surrounding noise. The catch, of course, is the low volume of [experimental data](#) on phase transitions in correlated materials.

The researchers took the approach of a domain-adversarial neural network (DANN), an image-recognition training approach similar to that used in the technology behind self-

driving cars. Rather than input millions of images of cats into the machine learning model, it's more practical to identify and extract key features of cats. For instance, simple, simulated, 3D images showing the essential features of a cat can be photographed from many different angles to capture the synthetic data needed to train a model to recognize a real cat.

"In the same way, by simulating data for the essential features of the thermodynamic phase transition we can train a machine learning model to recognize it," Chen says.

"And that opens up a lot of new space that we can explore much more quickly than we can through real-life experiments. As long as we have an understanding of the key characteristics in a system, we can rapidly generate thousands of images to train a machine learning model to identify this pattern."

These patterns, he adds, are directly applicable to probing the superconducting phase of real experimental spectra.

Their novel, data-driven approach leverages the limited amount of experimental spectroscopy data on correlated materials by combining it with large amounts of simulated data. The key signatures for phase transition used in the model make the AI decision-making process underlying it transparent and explainable.

## Validating the model

The Yale team of physicists tested the machine learning model through experiments with a cuprate. The results showed that the method can distinguish between superconducting and non-superconducting phases with nearly 98% accuracy.

And unlike traditional machine-learning, assisted-feature extraction in spectroscopy, the new method pinpoints phase transitions based on characteristic spectral features inside an energy gap, making it more robust and generalizable to a range of materials. That boosts the model's potential for high-throughput analyses.

By demonstrating the power of machine learning to overcome experimental limitations for data, the work overcomes a long-standing challenge in [quantum materials](#) research, clearing the path for faster discoveries that could impact everything from energy-efficient electronics to next-generation computing.

**More information:** Xu Chen et al, Detecting thermodynamic phase transition via explainable machine learning of photoemission spectroscopy, *Newton* (2025). DOI: [10.1016/j.newton.2025.100066](https://doi.org/10.1016/j.newton.2025.100066)  
Provided by [Emory University](#)

---

APRIL 10, 2025

# Einstein's dream of a unified field theory accomplished?

by Jussi Lindgren

Andras Kovacs, Jussi Lindgren and Jukka Liukkonen. Credit: Jukka Liukkonen  
During the latter part of the 20th century, string theory was put forward as a unifying theory of physics foundations. String theory has not, however, fulfilled expectations. That is why we are of the view that the scientific community needs to reconsider what comprises elementary forces and particles.

Since the early days of general relativity, leading physicists, like Albert Einstein and Erwin Schrödinger, have tried to unify the theory of gravitation and electromagnetism. Many attempts were made during the 20th century, including by Hermann Weyl.

Finally, it seems that we have found a unified framework to accommodate the theory of electricity and magnetism within a purely geometric theory. This means that electromagnetic and [gravitational forces](#) are both manifestations of ripples and curvatures in [spacetime geometry](#).

## Dreams of a unified field theory

Einstein's aim was to explain electromagnetism as a geometric property of four-dimensional spacetime. He continued this work until his death in 1955. The work was not completed. Arthur Eddington, Theodor Kaluza and others have also put forward their theories on how to unify gravity and electromagnetism, but none of these theories have been universally accepted.

Schrödinger, the father of quantum mechanics, put forward his unified field theory in the 1940s, but without complete success. Many different approaches have been proposed, including five-dimensional theories and theories based on asymmetric metrics.

## A new perspective, new nonlinear Maxwell's equations

In our approach, electric charge and [electric currents](#), as well as [electromagnetic forces](#), are seen as purely geometrical and immanent properties of spacetime itself, and not as some external objects. This approach was supported by the late physicist John Wheeler, in his vision of geometrodynamics. It turns out that the four-dimensional electromagnetic potential is really a building block of the metric tensor of spacetime.

Utilizing an approach from calculus of variations, we have put forward an aesthetically appealing geometric formulation of electromagnetism. When the variation of the metric tensor is optimized using functional derivatives, the necessary optimality conditions yield a

new, nonlinear generalization of Maxwell's equations. Our work is [published](#) in the *Journal of Physics: Conference Series*.

In the classical theory of electromagnetism, Maxwell's equations governing electric and magnetic fields are linear partial differential equations. In our approach, optimal metrics are required to be harmonic, which gives nonlinear field equations for the electromagnetic potentials and Maxwell's equations as a special linear case. The field equations then give the correct dynamics for the [electromagnetic field](#).

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.

Subscribe

## A generalization of geometry solves the riddle

When Albert Einstein formulated his theory of gravity, he used mathematics known as pseudo-Riemannian differential geometry. We found in our research that pseudo-Riemannian geometry is not sufficiently general for a purely geometric theory of electromagnetism. A more general differential geometry was needed.

A purely local geometry was invented in 1918 by the famous German mathematician Weyl. We took Weyl's ideas and combined them with our earlier research on this subject, and the puzzle seemed to open to us. In a Weyl geometry, lengths are local properties of spacetime, so it is in line with the principles of relativity theory.

We found out that Weyl geometry allowed us to inspect the local compression of spacetime. The same results are produced in our research using the so-called geometric algebra. Geometric algebra and Weyl geometry therefore seem to be equally usable in formulating a geometric theory of electromagnetism.

## Electric charge as a local compression of spacetime

We discovered that on top of the new nonlinear field equations, [electric charge](#) is related to the local divergence or compression of spacetime. Charge is therefore a field, which has its own laws of motion.

The familiar Lorentz force law governing forces on charged particles is shown to be a condition for the test particle to travel on geodesics, just as in general relativity. This feature completes the geometric description of electromagnetism.

## Conclusions

Our results indicate that light and all of electromagnetic radiation are really oscillations of spacetime itself. In terms of the older theories of "aether," it seems that Einstein was correct when he concluded that the "aether" is the spacetime. Electric charge is a local

compression of spacetime and the forces on electric charges correspond to motion on the shortest paths, that is, on geodesics.

We believe that a sufficiently complete geometric theory of [electromagnetism](#) is now available for further research. Furthermore, assuming spacetime fluctuations in the metric tensor at Planck scales leads to randomly fluctuating electromagnetic field in the vacuum.

The model predicts random fluctuations of the electromagnetic field at Planck scales and thus random creation and annihilation of charge at Planck scale due to the random covariant divergence of the electromagnetic four-potential. Finally, our theory predicts "forces" acting on charges even without an electromagnetic field, that is, it explains and predicts the Aharonov-Bohm effect.

*This story is part of [Science X Dialog](#), where researchers can report findings from their published research articles. [Visit this page](#) for information about Science X Dialog and how to participate.*

**More information:** Jussi Lindgren et al, Electromagnetism as a purely geometric theory, *Journal of Physics: Conference Series* (2025). DOI: [10.1088/1742-6596/2987/1/012001](https://doi.org/10.1088/1742-6596/2987/1/012001)

Jussi Lindgren works at the Ministry of Finance Finland, and he holds a D.Sc. degree from Aalto University in applied mathematics.

Andras Kovacs works at the ExaFuse start-up company, in applied physics based energy research role. He studied physics at Columbia University.

Jukka Liukkonen holds a PhD in applied physics, and he works full-time at Nuclear and Radiation Safety Authority, STUK, Vantaa, Finland.

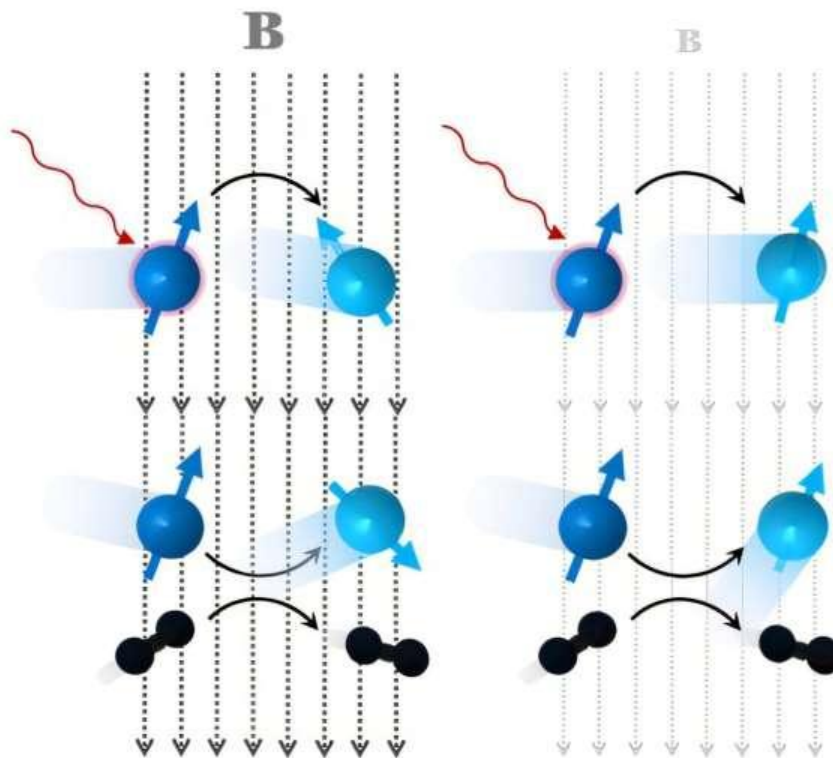
---

---

APRIL 10, 2025

# Scientists discover new way to keep quantum spins coherent longer

by [Hebrew University of Jerusalem](#)



Low magnetic fields suppress spin decoherence in alkali-metal vapors, extending coherence time and enhancing quantum sensor performance. Credit: Mark Dikopoltsev and Avraham Berrebi

A new study shows that electron spins—tiny magnetic properties of atoms that can store information—can be protected from decohering (losing their quantum state) much more effectively than previously thought, simply by applying low magnetic fields.

Normally, these spins quickly lose coherence when they interact with other particles or absorb certain types of light, which limits their usefulness in technologies like [quantum sensors](#) or atomic clocks. But the researchers discovered that even interactions that directly relax or disrupt the spin can be significantly suppressed using weak magnetic fields.

This finding expands our understanding of how to control [quantum systems](#) and opens new possibilities for developing more stable and precise quantum devices.

The study from researchers at the Hebrew University of Jerusalem and Cornell University reveals a powerful new method to significantly suppress spin decoherence in alkali-metal

gases, potentially revolutionizing quantum sensing and information technologies. The findings, [published](#) in *Physical Review Letters*, demonstrate an order-of-magnitude reduction in spin relaxation rates at low magnetic fields.

The study was led by Mark Dikopoltsev and Avraham Berrebi, under supervision of Prof. Uriel Levy from the Hebrew University's Institute of Applied Physics and Nano Center and Prof. Or Katz from Cornell University.

Spin decoherence, the process by which quantum spin information is lost due to environmental interactions, is a key obstacle in the development of quantum technologies. This research specifically examined the decoherence of hot cesium spins, which are primarily affected by spin-rotation interactions during collisions with nitrogen molecules and through absorption of near-resonant light.

The team demonstrated that these decoherence effects can be dramatically suppressed by applying low magnetic fields—achieving an order-of-magnitude reduction in spin relaxation rates. This suppression extends beyond previously known regimes such as spin-exchange relaxation-free (SERF), showing that magnetic fields can also control mechanisms that relax [electron spins](#), rather than just conserve them.

"Our results show that low magnetic fields are not just useful for avoiding decoherence from random, spin-conserving interactions," said Dikopoltsev. "They can actively suppress more damaging relaxation processes, giving us a powerful tool for preserving spin coherence."

This discovery enhances fundamental understanding of spin dynamics and provides new strategies for controlling quantum states in hot atomic vapors. It lays the groundwork for future advancements in [atomic clocks](#), quantum memory, magnetometry, and other technologies where long spin coherence times are critical.

**More information:** Mark Dikopoltsev et al, Suppressing the Decoherence of Alkali-Metal Spins at Low Magnetic Fields, *Physical Review Letters* (2025). DOI: [10.1103/PhysRevLett.134.143201](https://doi.org/10.1103/PhysRevLett.134.143201). On arXiv: DOI: [10.48550/arxiv.2209.12236](https://doi.org/10.48550/arxiv.2209.12236)  
**Journal information:** [Physical Review Letters](#) , [arXiv](#)  
Provided by [Hebrew University of Jerusalem](#)

---

APRIL 10, 2025

## Proving quantum computers have the edge

by Whitney Clavin, [California Institute of Technology](#)

This illustration depicts a quantum computer (lower left) beating out a classical computer in solving a physics problem that involves finding a material's low-energy states, called local minima. Researchers want to find these lowest-energy, or stable, states of materials to

make predictions about how the materials will behave. The problem is a difficult one for classical computers, but researchers at Caltech have developed a new quantum algorithm that could in theory readily solve the problem, giving it a proven advantage over classical counterparts. Credit: Chi-Yun (Claudia) Cheng

Quantum computers promise to outperform today's traditional computers in many areas of science, including chemistry, physics, and cryptography, but proving they will be superior has been challenging. The most well-known problem in which quantum computers are expected to have the edge, a trait physicists call "quantum advantage," involves factoring large numbers, a hard math problem that lies at the root of securing digital information.

In 1994, Caltech alumnus Peter Shor (BS '81), then at Bell Labs, developed a [quantum algorithm](#) that would easily factor a large number in just seconds, whereas this type of problem could take a classical computer millions of years. Ultimately, when quantum computers are ready and working—a goal that researchers say may still be a decade or more away—these machines will be able to quickly factor large numbers behind cryptography schemes.

But, besides Shor's algorithm, researchers have had a hard time coming up with problems where quantum computers will have a proven advantage. Now, reporting in a recent *Nature Physics* study titled "Local minima in [quantum systems](#)," a Caltech-led team of researchers has identified a [common physics problem](#) that these futuristic machines would excel at solving. The problem has to do with simulating how materials cool down to their lowest-energy states.

"In nature, we can put a material in a refrigerator to cool it down to its lowest-energy state," says John Preskill, the Richard P. Feynman Professor of Theoretical Physics, the Allen V. C. Davis and Lenabelle Davis Leadership Chair of Caltech's Institute for Quantum Information and Matter (IQIM), and an Amazon Scholar at the AWS Center for Quantum Computing based at Caltech. "But modeling how this occurs is challenging for a quantum computer and even harder for a classical computer."

In the new study, the team formulated a quantum algorithm (a set of computer instructions) that can be used in theory to find low-energy states—what physicists call local minima—of any material. Their study theoretically proves that the algorithm will perform much better than its classical counterparts.

"This is a new way to test quantum advantage," says co-author Hsin-Yuan (Robert) Huang (Ph.D. '24), a senior research scientist at Google Quantum AI who joined the Caltech faculty in early April as an assistant professor of theoretical physics. "There are a couple of other ways to test for quantum advantage besides Shor's algorithm, but it's not clear how practical they are. Here we have a test tailored to a broad family of physics fields that includes materials science, condensed matter physics, high-energy physics, and chemistry."

Researchers want to find the lowest-energy, or most stable, states of materials to make predictions about how the materials will behave. Chemists, for example, would use computers to calculate a molecule's local-minimum energy states when evaluating it for

pharmaceutical applications. Computer models would be used to predict how the molecule will bind to its biological target, accelerating the drug-discovery process.

The very lowest-energy state of a material is called its ground state. When you cool down a material in a refrigerator, it will reach low-energy plateaus along the way, before it hits the ground state. "It's like hiking downhill and trying to find the lowest spot. You might stop at a flat plateau on the way down, a local minimum," Preskill says. "For classical computers, finding these local minima can be a really hard problem."

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.

Subscribe

The classical computers "get stuck in what they think is a local minimum, but it's not," Huang explains. "It's as if the classical computer thinks it's as low as it can go and cannot go any further to find a true local minimum."

Quantum computers—which are based on bizarre properties of the subatomic world such as entanglement and superposition—are better at problems like this. As is the case with factoring prime numbers, they have the ability to test out options inaccessible to classical computers. "Quantum computers won't get stuck on these fictitious low-energy plateaus imagined by classical computers and can find ways to go further," Huang says. "They are better at navigating the energy landscape."

Co-author Chi-Fang (Anthony) Chen, a former graduate student working with Fernando Brandão, Bren Professor of Theoretical Physics at Caltech and director of applied science at AWS Center for Quantum Computing, had previously been developing quantum algorithms to speed up local minima queries for materials. In this new study, the team went a step further to tailor an algorithm in such a way to prove definitively that it works better than classical algorithms.

"This paper is about constructing a well-motivated class of physics problems where there is a [quantum advantage](#)," Preskill says. "Quantum computers aren't ready to use today, but this is an area where they will make better predictions."

In a related work also [published](#) in *Nature Physics*, titled "Time-hidden magnetic order in a multi-orbital Mott insulator," David Hsieh, Caltech's Donald A. Glaser Professor of Physics, along with Gil Refael, the Taylor W. Lawrence Professor of Theoretical Physics, and their colleagues show how local minima can be experimentally accessed starting from the ground state. As a demonstration platform, they used a crystal of  $\text{Ca}_2\text{RuO}_4$ , whose ground state features electron spins that are aligned antiparallel from one lattice site to the next.

By stimulating the crystal with an ultrashort burst of light lasting less than one picosecond, researchers were able to excite the material into a local-energy minimum in which the spins are aligned in a parallel fashion between sites. This parallel-aligned state persists well beyond microseconds, indicating that the system is stably trapped in the local minimum.

According to Preskill, "having a way to compute and experimentally access local minima by driving systems far from thermal equilibrium could be a way to transform quantum materials properties on demand."

**More information:** Chi-Fang Chen et al, Local minima in quantum systems, *Nature Physics* (2025). DOI: [10.1038/s41567-025-02781-4](https://doi.org/10.1038/s41567-025-02781-4)

Xinwei Li et al, Time-hidden magnetic order in a multi-orbital Mott insulator, *Nature Physics* (2025). DOI: [10.1038/s41567-024-02752-1](https://doi.org/10.1038/s41567-024-02752-1)

**Journal information:** *Nature Physics*

Provided by [California Institute of Technology](https://www.caltech.edu/)



***DARK ENERGY'S EARLY UNIVERSE BEHAVIOR WAS  
MORE EXOTIC THAN EXPECTED, NEW DESI DATA  
SUGGEST***

Seventy percent of the [cosmic energy](#) budget is currently in the form of [dark energy](#). The repulsive gravity induced by [dark energy](#) drives the accelerated expansion of the Universe. The nature of dark energy is unknown, but its properties can be inferred from its impact on the history of [cosmic expansion](#).

The latest information [from the DESI collaboration](#) was recently documented in [a set of papers](#) that provide a new analysis of dark energy, based on maps of the spatial distribution of nearly 15 million galaxies and quasars. The DESI observations were combined with data from studies of the cosmic microwave background, supernovae, and weak gravitational lensing.

The [standard model of cosmology struggles](#) to explain all the observations when taken together, but a model in which the dark energy density had an unusually exotic negative pressure when the Universe was a few times younger fits all current data well.

The implied negative pressure of dark energy in the early Universe exceeds in magnitude its energy density. Such an exotic substance violates the so-called “null energy condition,” which asserts that energy cannot be negative even if it flows at the speed of light.

Although such a substance is not forbidden, it often leads to theoretical pathologies, such as instabilities stemming from its lack of a minimum energy state and unphysical ghost states. Given these problems, one may wonder whether it is possible to assign the exotic nature implied by DESI from the dark energy sector to the dark matter sector.

In the [early universe](#), dark matter was denser and constituted a larger fraction of the cosmic budget than it does today. Assigning a negative pressure to it could, in principle, account for the anomaly implied by the latest DESI analysis.

I discussed with my brilliant colleague Xingang Chen over the past week whether a significant fraction of dark matter could have negative pressure. This morning, before my sunrise jog, I realized that what we know about the Universe does not allow such a possibility.

As I found out, dark matter with a large negative pressure would be extremely unstable to gravitational fragmentation. It would have quickly produced collapsed objects on all scales out to the cosmic horizon.

It is easy to understand the origin of this fragmentation instability. A small enhancement in the density of exotic dark matter would have reduced its pressure to an even more negative value. This implies that its larger outside pressure would have pushed more exotic matter inwards and made the central pressure even more negative. This runaway process triggers an instability driven by the negative pressure.

In the standard cosmological model, however, the clumping of matter is driven by gravity and suppressed by positive pressure, as described in detail in my textbook, "[The First Galaxies in the Universe](#)." The standard growth of collapsed objects out of initial density perturbations occurs on a timescale comparable to the age of the Universe.

However, for exotic dark matter with a large negative pressure, the fragmentation could be much faster. The corresponding growth is exponential in time and occurs over a timescale of order, such as the light-crossing time of the length scale of the collapsing region. This timescale is shorter than the age of the Universe by the ratio between the scale of the object and the scale of the cosmic horizon.

As a result of this instability, exotic dark matter with a large negative pressure would have quickly collapsed into objects that could be as big as the cosmic horizon. This expectation is in conflict with the observed properties of the Universe.

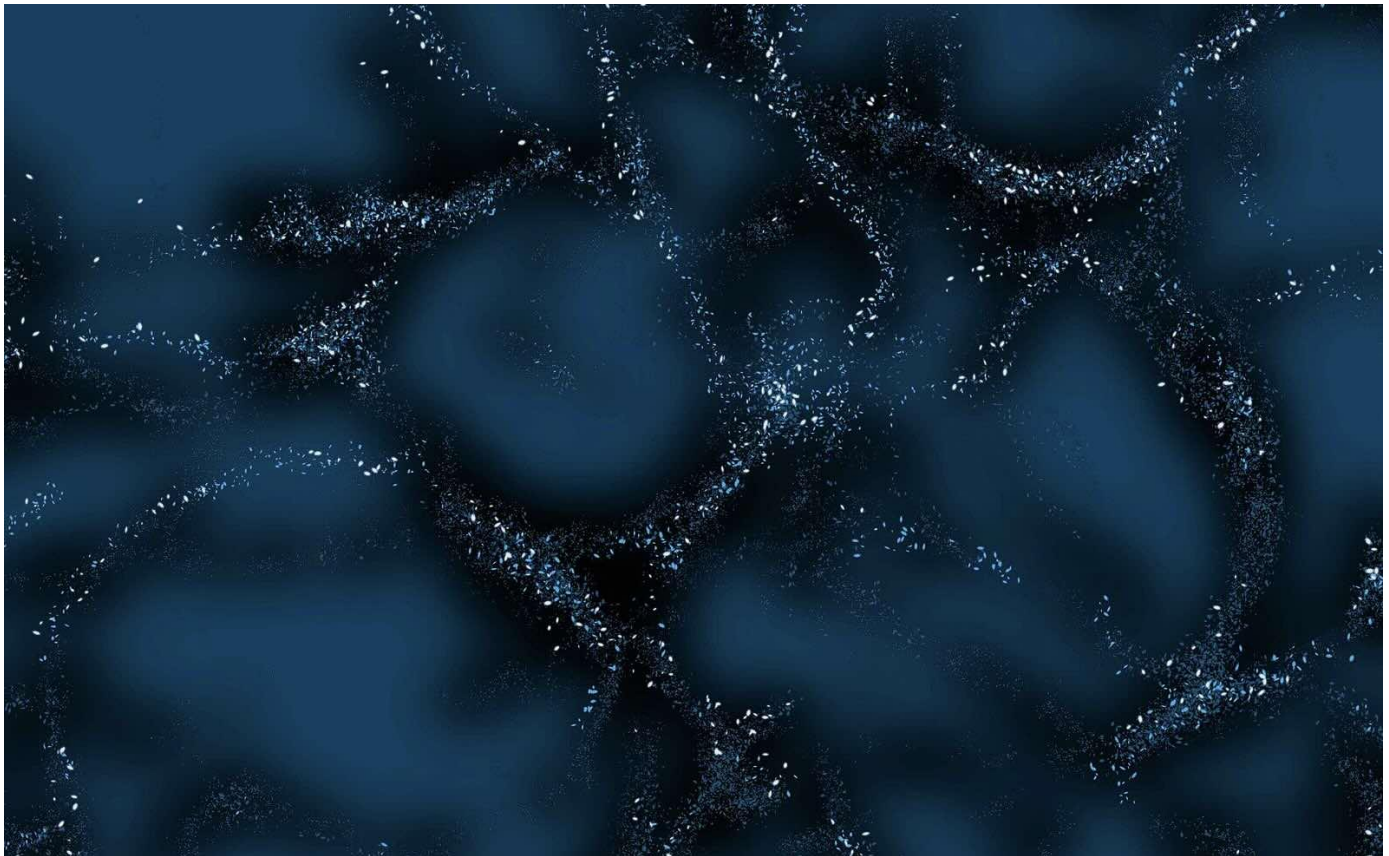
The largest collapsed objects are observed to be on the scale of clusters of galaxies, whose size is smaller than the cosmic horizon by a factor of ten thousand. If larger collapsed objects existed, they would have imprinted a large anisotropy in the brightness of the cosmic microwave background, which is not detected in the real Universe.

Exotic dark matter with a large negative pressure is ruled out by the observed large-scale structure of the Universe, which features only small density fluctuations on scales much bigger than clusters of galaxies. The fluctuations are of the order of one part in a hundred thousand on the scale of the cosmic horizon.

The fragmentation of exotic dark matter relies only on its large negative pressure and is not influenced by gravity from other constituents of cosmic matter, which are slower to collapse.

In conclusion, the exotic properties inferred by DESI are more likely to apply to dark energy than dark matter. The true nature of dark energy is yet to be discovered.

*Avi Loeb is the head of the Galileo Project, founding director of Harvard University's Black Hole Initiative, director of the Institute for Theory and Computation at the Harvard-Smithsonian Center for Astrophysics, and the former chair of the astronomy department at Harvard University (2011–2020). He is a former member of the President's Council of Advisors on Science and Technology and a former chair of the Board on Physics and Astronomy of the National Academies. He is the bestselling author of "[Extraterrestrial: The First Sign of Intelligent Life Beyond Earth](#)" and a co-author of the textbook "[Life in the Cosmos](#)", both published in 2021. The paperback edition of his new book, titled "[Interstellar](#)", was published in August 2024.*



Artist's concept of dark matter influence on the large scale structure of the universe (Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA/J. Pinto).

## ***'COSMIC RADIO' DETECTOR MAY SOON END THE HUNT FOR ELUSIVE DARK MATTER***

APRIL 21, 2025

What if detecting [dark matter](#), one of the most mysterious and elusive substances in the universe, were as easy as tuning your car's radio to your favorite station?

According to the authors of a new study, a new method of [detecting this mysterious non-luminous material](#) inspired by the tuning mechanics of an automobile's radio could soon help to solve the dark matter mystery.

This promising development in the hunt for answers to one of modern astronomy's [greatest unresolved issues](#) was reported in a new study by researchers from King's College London, Harvard University, UC

Berkeley, and other institutions, revealing a new method of detecting [hypothetical particles](#) known as [axions](#).

By using material that can emit light when “tuned” to the right frequency, the research team believes the most accurate dark matter detector ever made could soon be on the horizon.

## THE DARK MATTER MYSTERY

Dark matter represents one of modern astrophysics’ greatest mysteries. The existence of this [invisible material](#) is inferred from its effects on visible matter and [light](#). Based on such observations, dark matter is believed to account for close to 85% of all the mass in our universe. Despite its ubiquity, the true nature of this mysterious nonluminous material remains unknown.

Among the more promising modern research avenues seeking to resolve the mystery are studies involving axions—very light, but weakly interacting particles that in many ways behave like [electromagnetic waves](#).

“We can now build a dark matter detector that is essentially a cosmic car radio, tuning into the frequencies of the wider galaxy until we find the axion,” said Dr. David Marsh, co-author and Ernest Rutherford Fellow at King’s College London.

“We already have the technology,” he added. “Now it’s just a matter of scale and time.”

## TUNING TO DARK MATTER’S FREQUENCY

In Marsh and his team’s new study, they introduced a novel detector constructed around what they call the Axion Quasiparticle (AQ), which describes a material structure capable of emitting very small amounts of light, but only when its frequency matches that of an axion.

Essentially, the detector the team designed operates in the highest ranges of the terahertz spectrum, where many theorists believe axions are probably most likely to be located.

Using manganese bismuth telluride ( $\text{MnBi}_2\text{Te}_4$ ), a quantum material with unique magnetic and electronic properties, the team was able to successfully construct the AQ. Since this compound is highly sensitive to air, the team layered it down to just a few atomic sheets to fine-tune its properties.

“This means we get to see this kind of interesting physics, and see how it interacts with other quantum entities like the axion,” said Jian-Xiang Qiu, lead author from Harvard University.

Combining a two-dimensional electronic device and what the team calls ultrafast pump–probe optics, they report the observation of a coherent oscillation “which is uniquely induced by its out-of-phase antiferromagnetic magnon.”

“This represents direct evidence for the presence of the [dynamical axion quasiparticle],” the team writes in a new study detailing their work. Going forward, Marsh and his colleagues hope to scale up its novel AQ detector, a process which is likely to take around five years.

## **EXTENDED TIMELINE FOR SOLVING THE MYSTERY**

However, it could still take another decade or more spent scanning terahertz frequencies before any potential axion signal is located.

Although it may be a long and tedious process from here, Marsh and his team remain excited about the prospects of their new detection method, and what the eventual detection of dark matter could mean in terms of expanding our understanding of the cosmos.

“This is a really exciting time to be a dark matter researcher,” Marsh said, reaffirming the conviction of his team that axion investigations offer a promising path toward resolving the dark matter mystery.

“We’re closing in on the axion—and fast,” he says.

The team’s [paper](#), “Observation of the axion quasiparticle in 2D  $\text{MnBi}_2\text{Te}_4$ ,” appeared in the journal *Nature* on April 16, 2025.



Artist's concept of the Hercules–Corona Borealis Great Wall (Credit: Jorge Ernesto Horvath/Horváth et al. 2015).

# ***ASTRONOMERS JUST MADE A BIG DISCOVERY ABOUT THE UNIVERSE'S LARGEST COSMIC STRUCTURE***

APRIL 21, 2025

The largest cosmic structure ever observed by astronomers is revealing its biggest cosmic secrets yet, with a little help from powerful [gamma-ray bursts](#).

The [most energetic explosions](#) observed in our universe, new research that leverages the power of gamma-ray bursts is helping astronomers chart [the immense architecture of the cosmos](#), offering new ways of testing foundational assumptions about the structure of the universe.

These incredibly powerful blasts of cosmic energy, first detected by U.S. military satellites in the late 1960s, have long intrigued astrophysicists due to their remarkable power, which can outshine the Sun by a factor of close to one *quintillion* (that number, for reference, is one followed by eighteen zeroes).

The origins of gamma-ray bursts (GRBs) are now believed to be linked to the [death of massive stars](#) when they collapse, and [collisions between neutron stars](#) or [black holes](#). However, new research suggests these cosmic powerhouses could have another purpose: illuminating the [large-scale structure](#) of the universe.



Artist's concept of a gamma-ray burst (Credit: NASA/Swift/Cruz deWilde)

This, according to a team of scientists from Hungary and the United States led by Professor Istvan Horvath of the National University of Public Service in Budapest, who have proposed a novel means of using GRBs as cosmological probes.

Based on their findings, outlined in a new study published in *Universe*, these fleeting, but incredibly brilliant flashes could help astronomers identify massive clusters of galaxies and cosmic walls, structures that are so incomprehensibly massive that they challenge existing models of the universe's uniformity.

## THE GREAT WALL OF THE COSMOS

The standard Cosmological Principle dictates that the universe should be homogeneous and isotropic on large scales—in other words, the stuff from which the cosmos are composed should be more or less uniform, and look the same in all directions and when seen from all locations.

However, some large-scale cosmic structures challenge these expectations. Observations that have revealed structures like the Sloan Great Wall, the South Pole Wall, and the Hercules–Corona Borealis Great Wall (HerCrbGW)—an enormous galactic feature estimated to stretch across 10 billion light-years—have thrown a cosmic wrench into things, to borrow a famous axiom.

Since GRBs are extremely bright—so luminous that they can be seen across distances greater than 13 billion light years away—Horvath and his colleagues believe they could provide an extremely beneficial tool for identifying such gargantuan formations.

According to the team's new study, the Hercules–Corona Borealis Great Wall cluster, which is recognized as the largest of the known universal structures, was examined in past research that “used an increasing gamma-ray burst database to show that the cluster was unlikely to have been caused by statistical sampling uncertainties.”

# THE LARGEST COSMIC STRUCTURE IS LARGER THAN WE THOUGHT

Continuing that work, Horvath and the team revisited burst clustering in the northern galactic hemisphere with the help of a new method, which revealed something surprising: the Hercules-Corona Borealis Great Wall cluster is even larger than previous estimates had determined.

“The extension of this cluster’s size does not appear to have been due to statistical variations or sampling biases,” the team writes in their study.

full extent of this massive structure’s size, Horvath’s team analyzed 542 GRBs with well-documented positions and redshifts, sourced from NASA’s Swift and Fermi observatories and multiple global databases.

Paying close attention to the the Hercules-Corona Borealis Great Wall cluster’s home region, known as the northern galactic hemisphere, the team found that a new cluster of between 110 to 120 GRBs existed, spanning a wide range of redshifts. Based on earlier findings, the new estimates of the cluster’s size show that exceeds past estimates of its boundaries, revealing an even greater radial depth than previously known.

## COSMIC ANOMALIES PERSIST

Although the team’s new findings are promising, they nonetheless caution that current GRB datasets are limited, and therefore still could be subject to observational biases. Additionally, the fact that GRBs are so fleeting and show irregular distribution throughout the universe means that some cosmic anomalies could exist, although they may have evaded other data sets.

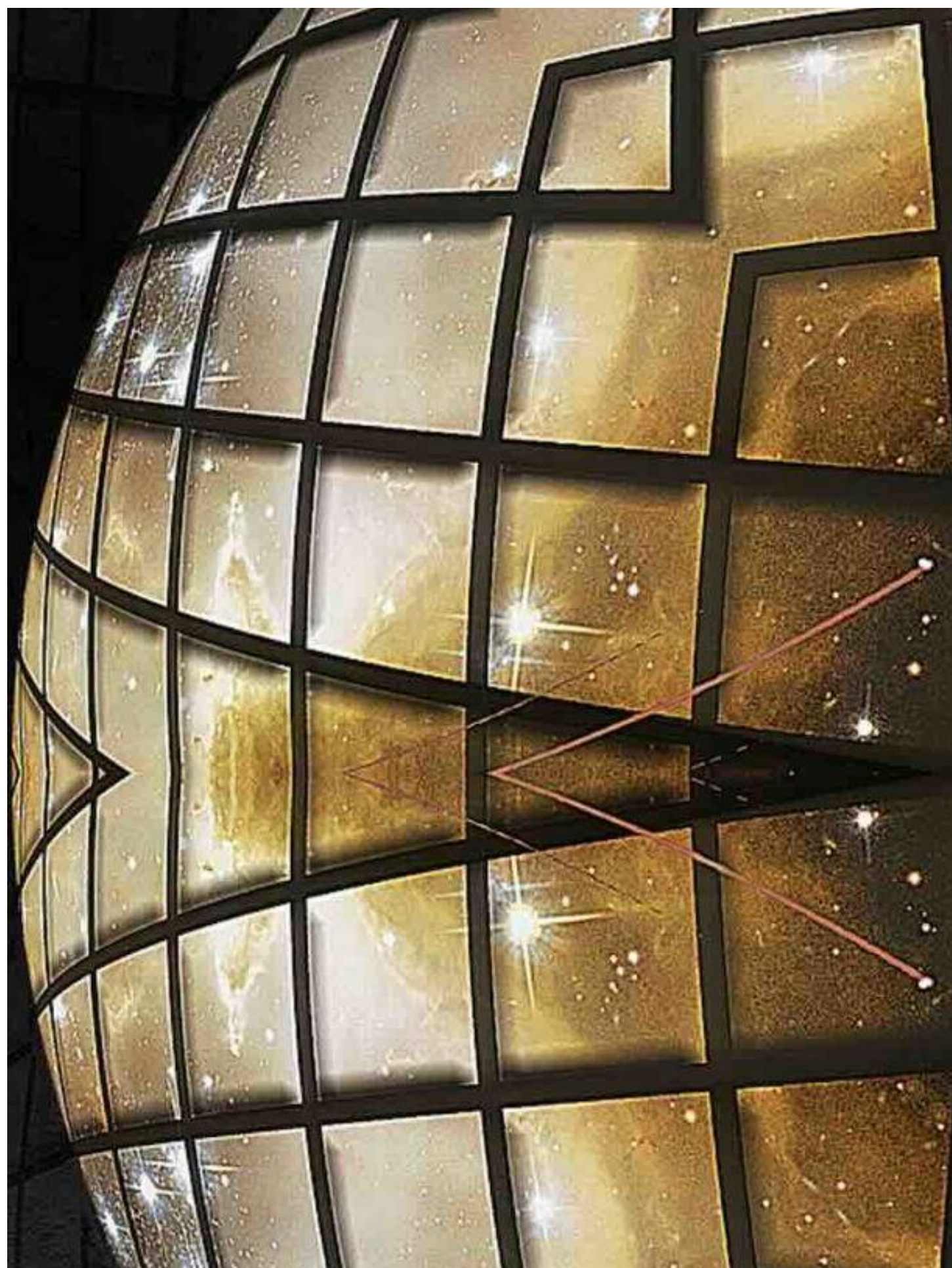
“Large-scale anomalies in the GRB spatial distribution can exist which are not necessarily seen in other cosmic objects,” the authors write in their paper, adding that further observations will be crucial in terms of resolving lingering questions about these massive formations, and ultimately refining models of cosmic structure.

The team’s paper, “Scanning the Universe for Large-Scale Structures Using Gamma-Ray Bursts,” appeared in *Universe* on April 6, 2025.

- 

- [About](#)

- - 
    - 
    - 
    - 
    -



(Pixabay)

# ***“SCIENTISTS DON’T YET FULLY UNDERSTAND” THESE INTRIGUING NEW GRAVITATIONAL WAVE DETECTORS DESIGNED BY AI***

APRIL 20, 2025

A series of promising designs for new [gravitational wave detectors](#) have been developed with a helping hand from [artificial intelligence](#), which have left scientists with new [questions about the cosmos](#).

Urania, an AI developed by a team led by Dr. Mario Krenn of the [Artificial Scientist Lab](#) at the [Max Planck Institute for the Science of Light](#), produced the new detector designs, which they say have already shown promise to exceed the capabilities of existing human-made concepts.

Intriguingly, Urania did more than merely replicate existing strategies scientists rely on for the detection of these cosmic features first predicted by Einstein more than a century ago. According to a statement released by Krenn’s lab, the AI created [entirely new ones](#), “some of which scientists don’t yet fully understand.”

The team’s results could mark the beginning of a future where [intelligent machines](#) commonly produce new discoveries about our cosmos, leaving the remaining job of interpreting them to humans.

## **FROM EINSTEIN’S VISION TO AI’S IMAGINATION**

Physicist [Albert Einstein](#) initially predicted the existence of gravitational waves in 1916. One century later, scientists finally succeeded in directly detecting them with the aid of detectors developed by the Laser Interferometer Gravitational-Wave Observatory (LIGO) project.

Working alongside LIGO researchers, Krenn and his team hoped to expand on current concepts for gravitational wave detector designs by employing artificial intelligence.

Specifically, the team aimed to produce cutting-edge new gravitational wave detector designs involving interferometry, which measures very subtle changes in how waves interfere with each other once they interact.

The result of this collaboration was Urania, which can produce such next-level interferometric detector designs—a demanding process, which involves many layers of work that include dialing in the parameters of the detectors, as well as optimizing their layout.

By using machine learning to help remedy the need for ongoing optimization, Urania was able to assist the team in creating a range of novel experimental designs for gravitational wave detectors.

## **NEW “ALIEN” DETECTOR DESIGNS**

Remarkably, some of the AI’s new designs appear to outperform even some of the best existing concepts for detectors that physicists hope to build in the coming years, greatly improving their sensitivity and widening the overall detectability range of the target gravitational wave signals.

While much of Urania’s concepts revealed known processes upon analysis, some of the AI’s designs were very unconventional, and suggested new applications that scientists don’t yet fully understand, and which may potentially help shape the next generation of detector technology.

“After roughly two years of developing and running our AI algorithms, we discovered dozens of new solutions that seem to be better than experimental blueprints by human scientists,” Krenn said in a statement.

See Also

Krenn and the team say that they have assembled a collection of 50 of the best performing designs and made them publicly available in a “Detector Zoo” to promote further research, although many of the “tricks” the AI appears to have used in creating these novel designs remain a bit baffling, for now.

“We are in an era where machines can discover new super-human solutions in science, and the task of humans is to understand what the machine has done,” Krenn said of the work his team and Urania have accomplished.

“This will certainly become a very prominent part of the future of science,” Krenn added.

The team published their findings [in a paper](#), “Digital Discovery of Interferometric Gravitational Wave Detectors,” published in *Physical Review X* on April 11, 2025.

- [ut](#)

- 
- 
- 
- 
- 
-



CREDIT: NASA

## ***NEW ‘SPINNING UNIVERSE’ THEORY COULD EXPLAIN A DECADES-OLD COSMOLOGICAL MYSTERY***

APRIL 18, 2025

The entire [universe](#) may be rotating—just like its individual components, from massive [galaxies](#) to [solar systems](#) and [planets](#)—a possibility that could help explain the long-standing “[Hubble tension](#)” that has puzzled scientists for years.

None of the currently accepted models of the universe account for any overall [spin](#). Instead, they describe it as expanding uniformly in all directions. However, these [models](#) run into trouble with the so-called Hubble tension, a discrepancy where different methods of measuring the [universe’s expansion](#) yield conflicting results.

“To paraphrase the Greek philosopher Heraclitus of Ephesus, who famously said ‘Panta Rhei’—everything moves—we thought that perhaps Panta Kykloutai—everything turns,” [said](#) István Szapudi of the University of Hawai‘i at Mānoa, co-author of the new study.

## MEASURING THE EXPANSION

Astrophysicists currently rely on two main techniques to measure how fast the universe is expanding. One involves observing relatively recent events, such as supernovae and distant galaxies, to measure expansion over the last few billion years. The other looks much farther back—about 13 billion years—by studying relic radiation from the Big Bang.

“The Hubble tension, the inconsistency of the late and early time measurements of the universe’s expansion rate, emerges as the most significant chink in the otherwise shiny armour of the concordance Lambda cold dark matter (CDM) model,” the authors write in their paper.

The “Hubble constant”—a term first proposed by astronomer Edwin Hubble in 1929—defines the universe’s rate of expansion. Yet researchers have long struggled to agree on a precise value, with measurements consistently producing different results. Despite increasing observational data, the Hubble constant has remained elusive. This growing inconsistency is considered the most significant flaw in the prevailing CDM model of the universe.

“The discrepancy has been established in a wide range of data sets,” the authors add.

## MODELING THE UNIVERSE

The research team began with a conventional mathematical model of the universe based on expected behavior. Their innovation was to introduce a small degree of rotation. When tested against existing measurements, the modified model proved surprisingly accurate.

“Much to our surprise, we found that our model with rotation resolves the paradox without contradicting current astronomical measurements. Even better, it is compatible with other models that

assume rotation. Therefore, perhaps, everything really does turn. Or, Panta Kykloutai!” said Szapudi.

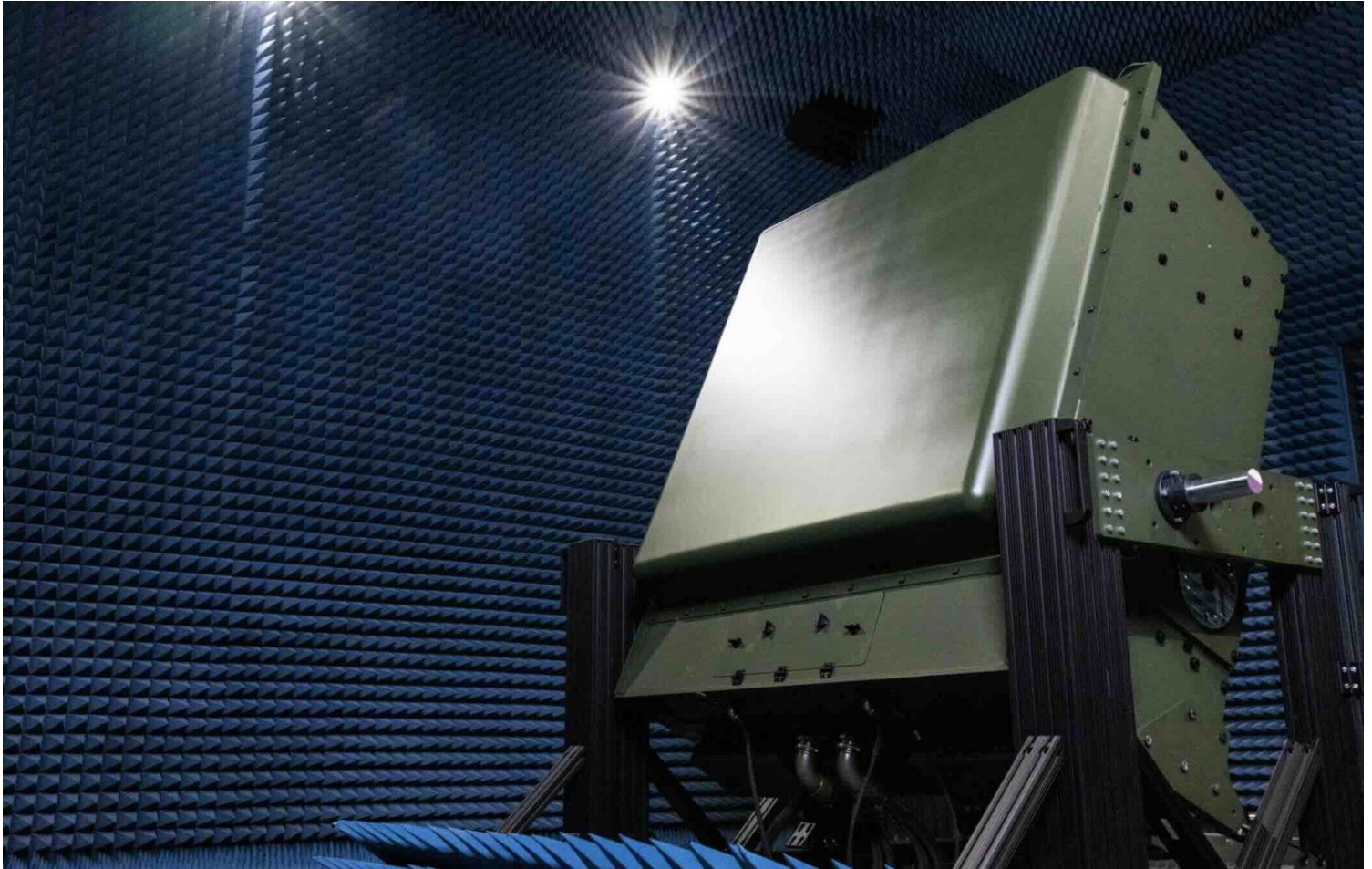
## A SLOW SPIN

In their revised model, the universe rotates slowly—completing a full revolution once every 500 billion years. While such a slow spin would be extremely difficult to detect, it may account for the discrepancies observed in current measurements of universal expansion. The model doesn’t fundamentally alter the laws of physics but suggests a different overall shape or motion for the universe.

The researchers also constrained their model to ensure the rotational speed remains below the speed of light. Intriguingly, they found that “the allowed maximal rotation is approximately the same as the one required to solve the Hubble Puzzle.”

To continue their work, the team plans to enhance their computer model. The current version relies on Newtonian physics, which is sufficient for initial exploration but will need to incorporate general relativity for more accurate modeling. Proving that the universe spins will be a far greater challenge—scientists don’t yet know how such a slow rotation could be directly observed.

The paper “[Can Rotation Solve the Hubble Puzzle?](#)” appeared on March 21, 2025 in *Monthly Notices of the Royal Astronomical Society*.



The Leonidas H2O High-Powered Microwave Weapon (Credit: Epirus, Inc.)

# ***NEW HIGH-ENERGY MICROWAVE WEAPON NEUTRALIZES 'ATTACKING' VESSELS IN A MILITARY FIRST***

APRIL 17, 2025

Defense contractor [Epirus Inc.](#) has announced the successful demonstration of the first-ever high-energy, high-powered microwave weapon, resulting in a perfect 'kill' of all four 'attacking' nautical vessels.

A self-described leader in advancing "the frontiers of technology to meet the asymmetric challenges of the future," Epirus says the Leonidas H2O platform expands on its existing directed energy

weapons developed for the U.S. Army and the U.S. Marine Corps to counter small vessels, UAVs, and [drone swarms](#).

“Epirus has leveraged our innovations in advanced electronics to create a first-of-its-kind *high-energy*, high-power microwave technology platform,” explained the company’s Senior Manager, Strategic Communications, Andrew Wargofchik, in an email to *The Debrief*. “We are offering a working solution to immediately fill DoD’s identified capability gap of countering small vessels.”

## **HIGH-POWERED MICROWAVE WEAPON JOINS GROWING DIRECTED ENERGY OPTIONS**

When discussing the development timeline of the Leonidas directed energy weapons family, Wargofchik noted that the U.S. Navy’s desire to use non-kinetic weapons to stop marine vessels dates to the 2019 [solicitation](#) of the Vessel Incapacitating Power Effect Radiation (VIPER) program, which is part of the Naval Surface Warfare Center’s Joint Non-Lethal Weapons Directorate (JNLWD).

Several [directed energy technologies](#) designed to [counter drones](#) and other weapons have been demonstrated in recent years. After announcing the development of [a high-powered microwave weapon, Thor’s Hammer](#), in 2022, the U.S. Army successfully demonstrated the technology’s effectiveness in 2023 by [“dominating” an enemy drone swarm](#) in a simulated attack.

A similar directed energy microwave system [under development by Raytheon](#) is also at the prototype stage. Still, according to Wargofchik, six years after the VIPER solicitation for a DEW capable of stopping small marine vessels, “no system has been fielded, and no known successes have entered the public domain.”

Numerous directed energy weapons are also under development, including several combat lasers. Last year, the U.S. Army began [testing a combat laser prototype](#) in the Middle East. In recent months, the

Ukrainian Unmanned Systems Forces Commander, Vadym Sukharevsky, claimed [the country had its own combat-ready laser](#).

Following the successful demonstration of Leonidas H2O at the U.S. Navy's Advanced Naval Technology Exercise Coastal Trident (ANTX-CT) program in August of last year, Epirus believes its prototype is ready to advance to the next stage. If successful, Leonidas H2O could become the first-ever high-energy, high-powered microwave weapon designed to counter marine attacks to be deployed in the field.

The Leonids H2O high-powered microwave weapon successfully disabled four distinct aquatic motor types, ranging from 40 to 90 horsepower. Image Credit: Epirus Inc.

## **CLASSIFIED POWER AND EXPANDED CAPABILITIES**

In a [press release](#) announcing the successful demonstration of Leonidas H2O, the company explained that the tested prototype faced several limiting factors that added to the challenge. For example, the system's power was limited to roughly 50% of its overall capacity. The company said Leonidas H2O was also restricted to a specific range of waveforms sent out by the weapon's microwave emitter.

Wargofchik told *The Debrief*, "The max power output of our systems is classified." However, he could explain what made Leonidas different from other high-powered microwave systems in development.

"Our energy-based HPM systems output incredibly high amounts of energy, which manifests in duration of effect and cumulative energy on targets, allowing us to disable electronic targets at much lower peak power and with much more advantageous size, weight, and mobility than legacy HPM systems," Wargofchik said.

During the August tests, the Leonidas H2O prototype responded to a simulated attack by four vessel motor types, ranging from 40 to 90 horsepower. The company said all four vessels' motors were stopped, resulting in a perfect score.

Actual videos of the tests were not made available. However, Epirus provided *The Debrief* with several video animations of their high-powered microwave weapon at work.

(Promo VIDEO)

## **LEONIDAS H2O JOINS ARMY AND MARINE CORPS DIRECTED ENERGY PLATFORMS**

Although the H2O prototype was tested against marine attacks, the company has already delivered a prototype weapon to the U.S. Army to counter airborne attacks. According to Wargofchik, the Army has received four Leonidas-derived, semi-fixed systems “to support the Indirect Fire Protection Capability—High-Power Microwave (IFPC-HPM) program.” Those directed energy weapons are undergoing additional testing at Combatant Commands.

Epirus is also expanding its leading-edge technology to meet the Marines’ needs. Dubbed [Leonidas Expeditionary](#), that application features what Wargofchik described as “a compact energy-based HPM system developed to support USMC Expeditionary Advanced Base Operations (EABO) and cUxS (counter-unmanned systems) missions in austere environments.”

“All of our Leonidas systems leverage Epirus’ energy-based HPM technology platform, and our phased array architecture allows us to easily scale up or down to meet various customer requirements,” Wargofchik told *The Debrief*.

## **SCALING UP AND 2025 DEMONSTRATIONS**

After the successful tests and demonstration last August, the company was again selected to participate in ANTX CT 25. Wargofchik states that the prestigious invitation is “a reflection of our ongoing conversations with the US Navy and US Coast Guard on the benefits of

Epirus high-energy HPM for maritime interdiction and counter-UxS.”

“Leonidas H2O is yet another example of the unprecedented scalability of Epirus’ Leonidas technology platform,” the company told *The Debrief*. “We have leveraged the Leonidas high-energy HPM platform to develop and validate multiple form factors to support the mission requirements of multiple US Department of Defense services.”

“The Department of Defense has spent years of research and development and poured tens of millions of dollars into developing a non-kinetic vessel stop solution, with no operational system deployed to date,” added Andy Lowery, Epirus CEO. “With Leonidas H2O, we are bringing forth a proven technology with demonstrated effectiveness to fill this capability gap today.”

- [ns](#)
- [About](#)

- 
- 
- 
- 
- 
-



(Credit: Iñigo Ezcurdia 2025)

## ***VIDEO: INTERACTIVE 3D HOLOGRAM ALLOWS USERS TO MANIPULATE VIRTUAL OBJECTS WITH THEIR HANDS***

APRIL 11, 2025

A team of researchers has built the first-ever interactive three-dimensional (3D) [hologram](#), FlexiVol, that allows users to manipulate virtual objects with their hands. Although some commercially available interactive holograms already exist, FlexiVol is the first to allow users to manually interact directly with [virtual objects](#) projected into thin air rather than using an external controller.

“We are quite excited about [FlexiVol’s] combination of volumetric displays (to provide natural understanding of 3D graphics) and direct interaction (to allow for intuitive manipulation of 3D objects),” lead researcher Azier Marzo of the Institute of Smart Cities told *The Debrief*.

The team is currently working on several hardware and software upgrades designed to improve the resolution and functionality of their interactive 3D hologram system. They also hope to integrate tactile sensation feedback so users can “feel” the objects.

According to Marzo, the goal is to create an interactive artistic installation “so that people can experience this combination firsthand and start a more end-user approach to design target applications.”

## **INTERACTIVE 3D HOLOGRAMS ARE MORE ‘NATURAL AND INTUITIVE’**

Since the first 3D hologram was created in the 1940s, engineers have looked for ways to improve the quality of the images while exploring potential commercial applications. For example, integrating the technology onto portable devices has gone from a [concept](#) to a [smartphone capable of generating 3D holograms](#) within just a few years.

Efforts to find practical uses for 3D holograms have also resulted in [the first-ever augmented reality 3D holographic headset](#) and a realistic [3D holographic zoo that lets visitors “walk” with the dinosaurs](#). Still, while technologies to [improve the resolution of holograms](#) continue to advance, directly interacting with virtual objects has mostly remained in the realm of science fiction.

“We are used to direct interaction with our phones, where we tap a button or drag a document directly with our finger on the screen – it is natural and intuitive for humans,” Marzo explained. “[That means] being able to insert our hands to grab and drag virtual objects.”

The desire to create this type of intuitive holographic display motivated Marzo and his fellow researchers to create FlexiVoo. Based on the team's recently released video, they appear to have broken the 3D hologram interaction barrier by creating the world's first interactive 3D holographic display.

## **ELASTIC DIFFUSER IS THE 'MAGIC' COMPONENT**

Like all currently available volumetric displays, FlexiVol uses a fast-oscillating projection surface called a diffuser. Because the diffuser typically oscillates at a high speed, the images projected onto it appear as a complete volume. However, diffusers are generally rigid, so if someone tried to interact with them, it could cause serious injury.

To combat this limitation, the team, which included Marzo and Iñigo Ezcurdia of the Institute of Smart Cities, Doctor Elodie Bouzbib, from Public University of Navarra (UPNA), and Iosune Sarasate, Unai Fernández, Manuel López-Amo, Iván Fernández, explored several elastic diffuser options. After testing different materials to determine which possessed the best optical and mechanical properties, they settled on the final design seen in the video.

Because elastic materials deform when touched, the team employed image correction software to maintain image quality and resolution. Marzo told *The Debrief* that an improved version with higher-resolution cameras "that capture in synch with the strip oscillation so that the frame is captured when the strips are below the hand" should improve this significantly.

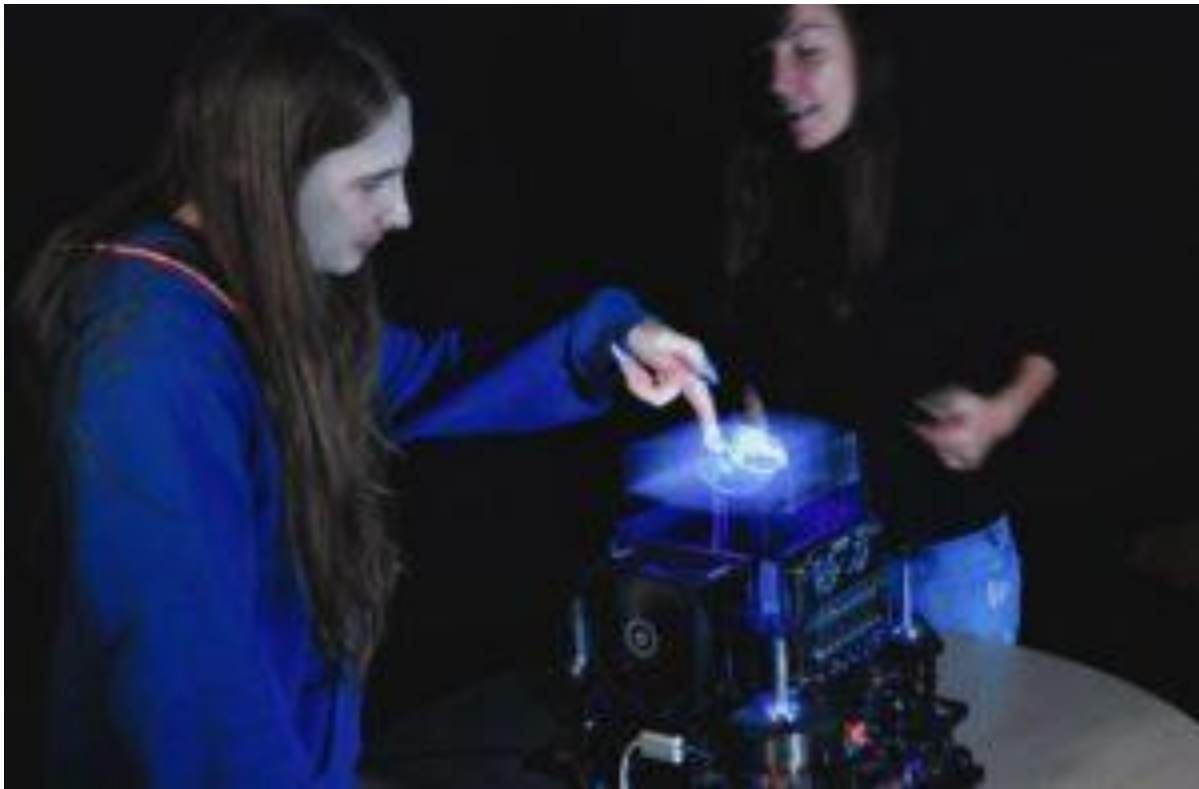
## **PLANNED IMPROVEMENTS INCLUDE LARGER SIZE, CRISPER IMAGES & TACTILE SENSATIONS**

Along with higher-resolution cameras, the team is exploring other potential improvements to increase their system's size, clarity, and functionality. According to Marzo, the most important step is

increasing the size of the relatively small 19x19x8 cm display volume, which only allows users to use one hand, to accommodate larger, more complex holograms.

“We want to increase the volume to at least 1 square meter, mainly to study applications and artistic installations where various users collaborate,” Marzo told *The Debrief*.

Another limitation of the current design is that the user’s hand can only be inserted from the top. Marzo said the team wants to explore oscillating the strips from two sides “so that people can interact from the top, the sides, and perhaps from below.” They are also considering a new silicon composite with tiny spheres to make the strips lighter and more elastic.



This is an image of two people observing a 3D hologram of a human skull. One of them is touching the eyehole. Image credit: Iñigo Ezcurdia 2025

Several times during the video, the 3D hologram becomes distorted when the hand touches the strips. The team leader said that planned improvements in the software should correct that. The team is also

exploring using brighter projectors so FlexiVol can operate more effectively in regular lighting conditions.

Perhaps the most intriguing improvement under consideration is making the interactive aspects of the experience more realistic. According to Marzo, that includes potentially adding specialized feedback so that “when you grab or touch the holograms, you feel some tactile sensations on the contact points.”

## **POTENTIAL APPLICATIONS AND AN INTERACTIVE ARTISTIC DISPLAY**

The team says several limitations in current technology still need to be overcome for finer control of 3D holograms. According to Marzo, hand-tracking technology still needs to improve to capture fine finger movements. This issue is even more challenging for FlexiVol since the elastic strips pass around the hand, “causing occlusions.”

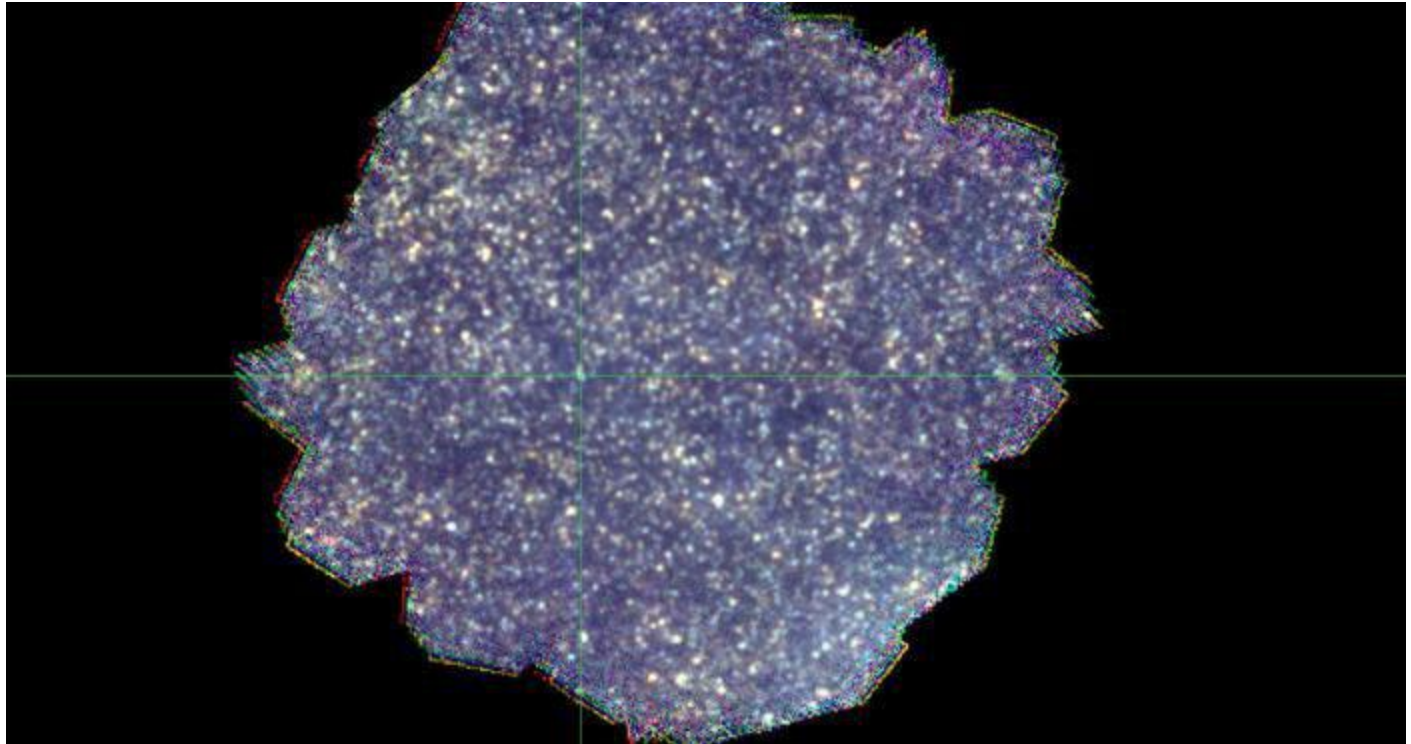
“[Our system] can detect accurately pointing with the index finger, and pinching between thumb and index,” Marzo told *The Debrief*. “But we cannot detect subtle shifts between the fingers or small variations in the grip.”

When discussing potential applications, the team highlighted several intriguing possibilities. For example, FlexiVol could help students visualize and assemble the parts of an engine or other complex machinery. The team also suggested that multiple users could interact with the display at once without virtual headsets, opening up applications for museums and interactive marketing displays “where visitors can simply approach and interact with the content.”

Marzo told *The Debrief* that the team is working on an interactive artistic installation that will allow everyday individuals and engineers to explore an even wider range of potential uses that his team hasn’t even dreamed of yet.

“We have some applications in mind,” the researcher said, “but we are sure that users will provide another perspective.”

The FlexiVol will be presented at the [CHI 2025](#) conference in Yokohama (Japan) between April 26th and May 1st. Over 4,000 researchers, including representatives from companies like Microsoft, Meta, Apple, and Adobe, are expected to attend this event. A [video of the team’s results and the presentation](#) is available on YouTube.



CREDIT: CHRIS PEARSON ET AL.

## ***HIDDEN GALAXIES COULD “BREAK ALL OF OUR CURRENT MODELS” OF GALACTIC EVOLUTION, ASTRONOMERS SAY***

APRIL 11, 2025

New research suggests that hidden [galaxies](#) offering a glimpse into the past could reveal previously unknown secrets of the [universe](#), potentially forcing scientists to reconsider current models of [galactic](#) evolution.

These [galaxies](#) may also account for the production of [infrared](#) light, helping to balance the universe's energy budget to match the maximum observed levels. A team of researchers from STFC RAL Space and Imperial College London has found possible evidence of concealed [galaxies](#) in long far-[infrared](#) wavelengths, as observed in the deepest image of the [universe](#) ever created.

## **SPIRE**

During the European Space Agency's 2009–2013 Herschel Space Observatory mission, the SPIRE instrument captured the longest wavelengths of infrared light. Throughout the mission, SPIRE required continual calibration against a dark test region of sky near the North Ecliptic Pole, which resulted in an area of sky being densely imaged. The team combined 141 images collected during these calibration tests to produce a massive composite.

“This work has pushed the science with Herschel to its absolute limit, probing far below what we can normally discernibly see and potentially revealing a completely new population of galaxies that are contributing to the very faintest light we can observe in the universe,” said lead author Dr Chris Pearson of STFC RAL Space.

## **THE DARK FIELD COMPOSITE**

Named the Herschel-SPIRE Dark Field, the image is the deepest far-infrared sky image ever created by Herschel—five times deeper than any previous image. As astronomers stacked the images, a dusty, star-forming region of galaxies came into view, allowing researchers to track changes in brightness and gauge the fluctuating number of galaxies. This information helped scientists measure how galaxies contribute to the universe's energy output.

“What we found was possible evidence of a completely new, undiscovered population of faint galaxies hidden in the blur of the image, too faint to be detected by conventional methods in the

original analysis, said the lead author of the second paper, Thomas Varnish, of MIT.

“If confirmed, this new population would effectively break all of our current models of galaxy numbers and evolution,” Varnish added.

## **CHALLENGES IN THE DEEP FIELD**

Researchers at STFC RAL Space also encountered significant challenges. Due to the extreme depth and density of galaxies, it became difficult to distinguish individual objects in the image, complicating data analysis.

“We employed statistical techniques to get around this overcrowding, analysing the blurriest parts of the image to probe and model the underlying distribution of galaxies not individually discernible in the original image,” Varnish said.

## **PURSUING HIDDEN GALAXIES**

“When we look at starlight through normal telescopes, we are only able to read half of the story of our universe, the other half is hidden, obscured by the intervening dust,” Dr Pearson said.

“In fact, roughly half of the energy output of the universe is from starlight that has been absorbed by dust and re-emitted as cooler infrared radiation. To fully understand the evolution of our universe we need to observe the sky in both optical and longer wavelength infrared light,” Pearson added.

To confirm their findings, the researchers plan to use telescope observations captured across multiple wavelengths to verify the presence of the newly identified galaxies.

## **EUROPEAN SPACE MISSIONS TO CONTINUE**

“These results show just how valuable the Herschel archive is,” Dr David Clements of Imperial College London. “We’re still getting great new results more than 10 years after the satellite stopped operating.

“What we can’t get, though, is more data at these wavelengths to follow up these fascinating new results. For that we need the next generation far-IR mission, PRIMA, currently being proposed to NASA,” Clements concluded.

RAL Space is also participating in the proposed PRIMA mission, alongside the University of Sussex, Imperial College London, and Cardiff University. PRIMA will be a 1.8-meter far-infrared imaging and spectroscopy telescope, designed to operate in the scientific gap between the James Webb Space Telescope and radio telescopes. NASA is currently considering both PRIMA and MIT’s AXIS Deep Extragalactic Survey for its \$1 billion Probe Explorer’s Program grant, with a decision expected next year.

The papers “[The Herschel-SPIRE Dark Field I: The Deepest Herschel Image of the Submillimetre Universe](#)” and “[The Herschel-SPIRE Dark Field – II. A P\(D\) Fluctuation Analysis of the Deepest Herschel Image of the Submillimetre Universe](#)” both appeared on April 10, 2025 in *Monthly Notices of the Royal Astronomical Society*.



CREDIT: UMASS AMHERST

# ***CURIOUS GRAD STUDENT ACCIDENTALLY DISCOVERS SHAPE-CHANGING LIQUID THAT BENDS THE LAWS OF THERMODYNAMICS***

APRIL 9, 2025

University of Massachusetts Amherst researchers have discovered a surprising “shape-changing” [liquid](#) that seems to bend the laws of [thermodynamics](#).

The strange compound—made of [oil](#), [water](#), and [magnetic nickel](#) particles—was first assembled by a graduate student who was merely curious to see what might happen. To his surprise, when the [liquid](#) was shaken, the [magnetic](#) particles quickly reformed into a shape resembling a [Greek](#) urn.

## **EMULSION AND THERMODYNAMICS**

“Imagine your favorite Italian salad dressing,” [says Thomas Russell](#), Silvio O. Conte Distinguished Professor of Polymer Science and Engineering at UMass Amherst and one of the paper’s senior authors. “It’s made up of oil, water and spices, and before you pour it onto your salad, you shake it up so that all the ingredients mix.”

While water and oil normally separate, they can combine through a process called emulsion, where small bits of a third material enter the mix, reducing surface tension between the two normally incompatible substances. The emulsion process works as described by the laws of thermodynamics.

## **PLAYING AROUND IN THE LAB**

A wide range of technologies and applications make use of emulsification. While experimenting with emulsions in the lab, UMass

Amherst graduate student Anthony Raykh mixed magnetized nickel with oil and water just to see what might happen.

“Because you can engineer all sorts of interesting materials with useful properties when a fluid contains magnetic particles,” says Raykh. “And, in a complete surprise, the mixture formed this beautiful, pristine urn-shape.”

Despite repeated, vigorous shaking, the mixture consistently returned to a shape resembling an urn. Even altering the size of the magnetic particles did not change the effect.

“I thought ‘what is this thing?’ So, I walked up and down the halls of the Polymer Science and Engineering Department, knocking on my professors’ doors, asking them if they knew what was going on,” Raykh continued.

None of the UMass Amherst researchers could immediately explain the phenomenon. Two of Raykh’s professors, David Hoagland and Thomas Russell, took an interest and joined the investigation.

## **INVESTIGATING A PERPLEXING LIQUID**

As the small team began conducting experiments, they expanded their collaboration to include researchers from Tufts and Syracuse universities for help with simulations. The growing team of experts across the Northeast ultimately concluded that strong magnetism was behind the liquid’s unusual behavior.

“When you look very closely at the individual nanoparticles of magnetized nickel that form the boundary between the water and oil,” says Hoagland, “you can get extremely detailed information on how different forms assemble. In this case, the particles are magnetized strongly enough that their assembly interferes with the process of emulsification, which the laws of thermodynamics describe.”

The liquid's magnetic action reverses the normal emulsion process. Instead of decreasing the tension between oil and water, as normally occurs when introducing a third particle, the magnets increase the surface tension. As a result, the boundary separating the oil and water forms a curve.

Additionally, modifying the ratio of oil to water in the vial changed the shape from an urn to something more like a ball.

“When you see something that shouldn't be possible, you have to investigate,” says Russell.

The team has yet to identify a practical application for the unexpected discovery, but they anticipate its influence on soft-matter physics.

The paper “[Shape-recovering Liquids](#)” appeared on April 4, 2025 in *Nature Physics*.

# Postage stamp-sized artificial leaf converts CO<sub>2</sub> into fuel using sunlight

The self-contained carbon-carbon producing system combines the catalytic power of copper with perovskite from solar panels.

Apr 28, 2025



A blue, gloved hands puts a perovskite and copper-based device in line with other copper-based devices. Closeup of the perovskite and copper-based devices developed by a multi-institutional collaboration working to develop the tools needed to turn sunlight into liquid fuel.

Researchers have made an outstanding step towards sustainable energy solutions after they developed an artificial leaf capable of converting carbon dioxide into liquid fuels and other valuable chemicals using sunlight alone.

The team of experts from the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) and their international collaborators brought science one step closer to replicating the incredible productivity of natural photosynthesis, but with the added potential for industrial-scale application.

By harnessing copper's catalytic power alongside perovskite – a calcium titanium oxide mineral widely used in solar panels – they developed a self-contained system that captures sunlight and converts carbon dioxide (CO<sub>2</sub>) into carbon-carbon (C<sub>2</sub>) molecules.

These C<sub>2</sub> molecules – a green, gaseous inorganic chemical also known as diatomic carbon – are essential building blocks for various industries, including fuel production and plastics.

## Efficient carbon conversion

A part of the [Liquid Sunlight Alliance](#) (LiSA), a Department of Energy-funded initiative led by Caltech in close partnership with Berkeley Lab, the project draws on the expertise of over 100 scientists from institutions including SLAC, the National Renewable Energy Laboratory, UC Irvine, UC San Diego, and the University of Oregon. To further its mission, LiSA aims to advance technologies that turn sunlight, CO<sub>2</sub>, and water into fuels.

“Nature was our inspiration,” said Peidong Yang, PhD, a senior faculty scientist in Berkeley Lab's material sciences division and UC Berkeley professor of chemistry and [materials science](#) and engineering.

“We had to work on the individual components first, but when we brought everything together and realized that it was successful, it was a very exciting moment.”

Lin uses an artificial light to activate the postage stamp-sized device to convert carbon dioxide into C<sub>2</sub>, a valuable precursor chemical in everyday products.

Credit: [Marilyn Sargent/Berkeley Lab](#)

Yang and his team followed the natural processes in the leaf of a plant to build the postage stamp-sized device that mimics the way green plants [harvest energy](#) from the sun. However, instead of chlorophyll – a natural compound found in green plants that gives them their color and plays a key role in the [process of photosynthesis](#) – the scientists used lead halide perovskite photoabsorbers to capture sunlight.

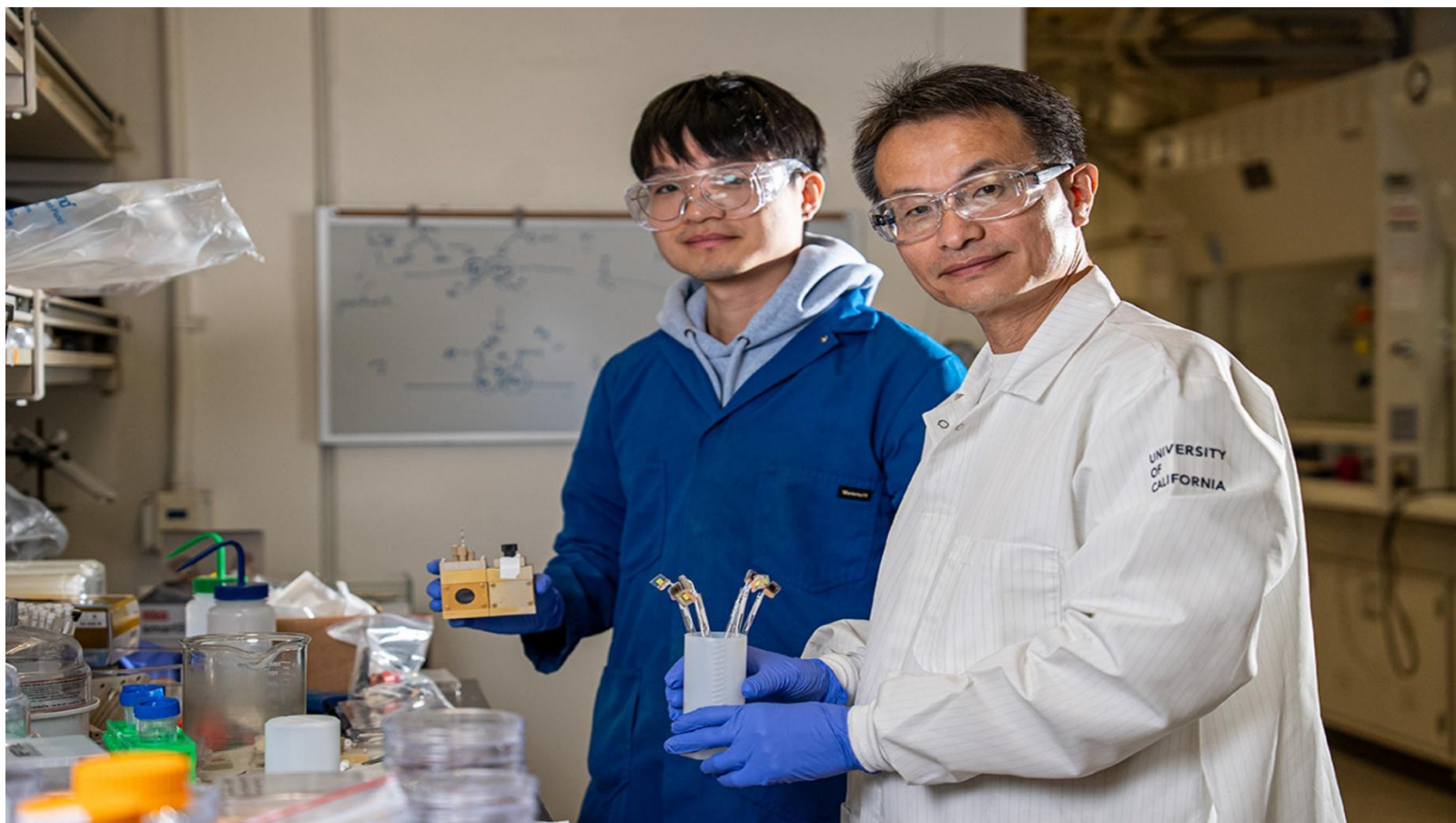
These were paired with finely engineered copper electrocatalysts – designed to resemble tiny flowers – to drive chemical reactions. The electrocatalysts were reportedly inspired by enzymes that regulate photosynthesis in nature. Yang explained how each individual component of a leaf's [photosynthesizing elements](#) had to be carefully replicated and refined.

## C<sub>2</sub> molecule production

Even though other experiments have achieved [artificial photosynthesis](#) using biological materials, Yang's team chose copper, an inorganic material with lower selectivity for desired chemical reactions than biological catalysts. However, copper offers significant

advantages such as greater durability, stability, and longer operational life, all critical for scaling up future applications.

While LiSA experts developed the device's cathode and anode components, the integration with metal contacts was carried out using instruments at Berkeley Lab's Molecular Foundry. During testing, [a solar simulator](#) replicating continuous sunlight demonstrated that the system could efficiently convert CO<sub>2</sub> into carbon-carbon (C<sub>2</sub>) molecules, essential building blocks for a wide range of industries.



Peidong Yang (right) and Jia-An Lin, a graduate researcher, used lead halide perovskite photoabsorbers, which imitate a leaf's light-absorbing chlorophyll, and electrocatalysts made of copper that resemble tiny flowers.

Credit: [Marilyn Sargent/Berkeley Lab](#)

Building on earlier advances, the scientists successfully triggered an [organic oxidation reaction](#) in the photoanode chamber while producing C<sub>2</sub> molecules in the photocathode chamber. This achievement resulted in a realistic artificial-leaf architecture, condensed into a device about the size of a postage stamp, that converts CO<sub>2</sub> into C<sub>2</sub> molecules using only sunlight.

**RECOMMENDED ARTICLES**

The team said that the artificial leaf's ability to produce C2 chemicals may soon lead to precursory ingredients for industries that manufacture essential products, from [plastic polymers](#) to fuels for heavy transport like airplanes, which remain difficult to electrify. Yang and his team hope to improve the system's efficiency and expand the device's size, moving closer to scaling the technology for practical use.

## Cosmic twist: New study suggests the universe could be spinning

Researchers at the University of Hawai'i explore universe rotation, potentially resolving Hubble tension in expansion rates.

From University of Hawaii at Manoa 22/04/25 (first released 16/04/25)

The Whirlpool Galaxy, M51, is a spiral galaxy located 31 million light-years away. (Image credit: NASA) Credit: NASA

A new study in [Monthly Notices of the Royal Astronomical Society](#) by researchers including István Szapudi of the University of Hawai'i [Institute for Astronomy](#) suggests the universe may rotate—just extremely slowly.

The finding could help solve one of astronomy's biggest puzzles.

“To paraphrase the Greek philosopher Heraclitus of Ephesus, who famously said “Panta Rhei”—everything moves, we thought that perhaps Panta Kykloutai—everything turns,” said Szapudi.

Current models say the universe expands evenly in all directions, with no sign of rotation.

This idea fits most of what astronomers observe.

But it doesn't explain the so-called “Hubble tension”—a long-standing disagreement between two ways of measuring how fast the universe is expanding.

### Supernovae, Big Bang

One method looks at distant exploding stars or supernovae, to measure the distances to galaxies, and gives an expansion rate for the universe throughout the past few billion years.

The other method uses the relic radiation from the Big Bang and gives the expansion rate of the very early Universe, about 13 billion years ago. Each gives a different value for the expansion rate.

Szapudi's team developed a mathematical model of the universe.

First, it followed standard rules. Then they added a tiny amount of rotation. That small change made a big difference.

“Much to our surprise, we found that our model with rotation resolves the paradox without contradicting current astronomical measurements.

Even better, it is compatible with other models that assume rotation.

Therefore, perhaps, everything really does turn.

Or, *Panta Kykloutai!* ” noted Szapudi.

Their model suggests the universe could rotate once every 500 billion years—too slow to detect easily, but enough to affect how space expands over time.

The idea doesn't break any known laws of physics.

And it might explain why measurements of the universe's growth don't quite agree.

The next step is turning the theory into a full computer model—and finding ways to spot signs of this slow cosmic spin.

## Can rotation solve the Hubble Puzzle?

Balázs Endre Szigeti , István Szapudi , Imre Ferenc Barna , Gergely Gábor Barnaföldi

[Author Notes](#)

*Monthly Notices of the Royal Astronomical Society*, Volume 538, Issue 4, April 2025,  
Pages 3038–3041, <https://doi.org/10.1093/mnras/staf446>

**Published:**

21 March 2025

### ABSTRACT

The discrepancy between low and high redshift Hubble constant  $H_0$  measurements is the highest significance tension within the concordance  $\Lambda$  cold dark matter paradigm. If not due to unknown systematics, the Hubble Puzzle suggests a lack of understanding of the universe's expansion history despite the otherwise spectacular success of the theory. We show that a Gödel inspired slowly rotating dark-fluid variant of the concordance model resolves this

tension with an angular velocity today  $\omega_0 \approx 2 \times 10^{-3} \text{ Gyr}^{-1}$ . Curiously, this is close to the maximal rotation, avoiding closed time-like loops with a tangential velocity less than the speed of light at the horizon.

[distance scale](#), [large-scale structure of Universe](#), [cosmology: observations](#)

## Issue Section:

[Article](#)

# 1 INTRODUCTION

---

The Hubble tension, the inconsistency of the late and early time measurements of the universe’s expansion rate, emerges as the most significant chink in the otherwise shiny armour of the concordance Lambda cold dark matter ( $\Lambda$ CDM) model (see e.g. for reviews by Verde, Treu & Riess [2019](#); Di Valentino et al. [2021a](#); Kamionkowski & Riess [2023](#)). The discrepancy has been established in a wide range of data sets and reached a  $5\sigma$  significance between cepheid-calibrated local supernovae and cosmic microwave background (CMB) measurements (for counterpoint and calibration uncertainties see Freedman et al. [2024](#)).

The CMB constraints at recombination are indirect: they assume an expansion history governed by the  $\Lambda$ CDM model. The latest analyses of Planck CMB maps imply a Hubble constant  $H_{\text{CMB}} = 67.4 \pm 0.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$  (Aghanim et al. [2020](#)).

Type Ia supernovae directly constrain the late-time (local) expansion rate. In a definitive study of Riess et al. ([2022](#)) used the *Hubble Space Telescope* (*HST*) to observe Cepheid variables in the host galaxies of 42 Type Ia supernovae (SNe Ia) crucial for calibrating the local Hubble constant ( $H_{\text{SNe}}$ ). They utilized all suitable SNe Ia discovered at redshift  $z \leq 0.01$  over the past four decades, significantly expanding the sample size with observations from over 1000 *HST* orbits. They performed geometric calibration of Cepheids using *Gaia* EDR3 parallaxes, masers in NGC 4258, and detached eclipsing binaries in the Large Magellanic Cloud. Their baseline result is  $H_{\text{SNe}} = 73.04 \pm 1.07 \text{ km s}^{-1} \text{ Mpc}^{-1}$ , with systematic

uncertainties, closely aligned with the median of various analysis variants. Notably, they found a significant  $5\sigma$  discrepancy with the Planck CMB analysis.

A burst of activity resulted, including alternative (tip of the red giant branch) calibrations by Freedman et al. (2019), and extensions or modifications of  $\Lambda$ CDM by Di Valentino, Melchiorri & Silk (2020a), such as massive neutrino or weakly interacting massive particles (WIMP) models of Pan & Knox (2015), dark photon of Aboubrahim, Klasen & Nath (2022), and an extended dark sector by Di Valentino et al. (2020b). Next, we propose rotating space–time as a novel solution. Gödel (1947) introduced a rotating universe followed by Heckmann & Schücking (1955, 1956a, b) and Heckmann (1961) later Silk (1966) and Hawking (1969). Visualization of the Gödel’s universe is made by Buser, Kajari & Schleich (2013). While anisotropies in a variety of Bianchi models with large vector perturbations corresponding to rotation are tightly constrained from Planck CMB data by Saadeh et al. (2016), generalizations of the Gödel model by Obukhov (2000) with global rotation are still viable and free of the pathologies of the original. This paper considers a Newtonian approximation of these models in the context of the Hubble anomalies.

All objects within our universe rotate, including planets, stars, solar systems, galaxies, and galaxy clusters. Moreover, black holes, spherically symmetric objects with horizons, display near maximal rotation as presented by Daly (2019). The idea that everything revolves (παντα κυκλoutai)<sup>1</sup> naturally extends to the whole universe, as hinted by recent claims of anisotropic Hubble expansion in X-ray observations by Migkas et al. (2021). Furthermore, a plausible syllogism is that the universe has near-maximal rotation, motivated by cosmologies where the universe is the interior of a black hole (Pathria 1972). There are many proposed solutions to the Hubble Puzzle (e.g. Di Valentino et al. 2021b) and any modification of the standard model expansion and growth history has to consider the entire concordance model (e.g. Knox & Millea 2020). Nevertheless, as we show later, the average rotation effect has a similar functional form to that of dark photons (Fabbrichesi, Gabrielli & Lanfranchi 2021;

Aboubrahim et al. 2022), one of the promising contenders (Cyr-Racine, Ge & Knox 2022) for solving the Hubble Puzzle. Therefore, exploring how a rotating model would affect the Hubble constant is worthwhile. In the next section, we outline our methodology, Section 3 presents the results, while the last section contains our conclusions.

## 2 METHODOLOGY

---

The expansion history of Newtonian cosmological simulations is in precise agreement with Friedmann models (e.g. R      et al. 2018). Thus, we expect that the classical framework is sufficient for an initial estimate of rotational effects on the Hubble constant; we leave general relativistic considerations for future work.

Describing the evolution of the Hubble parameter in Newtonian non-rotating and rotating universe models is still challenging. The Sedov–von Neumann–Taylor blast wave models inspired us to construct a non-relativistic dark fluid model. We apply a non-linear partial differential equation system describing a non-viscous, non-relativistic, and self-gravitating fluid with zero thermal conductivity (Euler–Poisson system) and solve it with a time-dependent Sedov-type self-similar *ansatz*. This analytic approach incorporates various scaling mechanisms and describes different time decay scenarios of Taylor (1950). The resulting dynamical model is consistent with direct solutions from the Friedmann equations by Szigeti, Barna & Barnaf  ldi (2023). We generalize our method of intermediate asymptotic analysis of the hydrodynamical description for the rotating dark-fluid universe to investigate the effect of rotation on the Hubble-constant anomaly. Our partial differential equations read as follows:

$$\partial_t \rho + \text{div}(\rho \mathbf{u}) = 0, \quad (1a)$$

$$\partial_t(\rho \mathbf{u}) + \text{div}(\rho \mathbf{u} \otimes \mathbf{u}) = -\nabla P(\rho) - \rho \nabla \Phi + \rho \mathbf{g}^*, \quad (1b)$$

$$\nabla^2 \Phi = 4\pi G \rho, \quad (1c)$$

where  $\rho, u, P, \Phi, g$  are the fluid density, the fluid velocity vector, the pressure, the gravitation potential and the external force, respectively. This system has been investigated previously by Deng, Xiang & Yang (2003) and Wong, Yeung & Yuen (2020). Goldreich & Weber (1980) studied the homologously collapsing stellar cores with an adiabatic exponent. Later Yuen (2009) gave analytically periodic solutions to the 3-dimensional Euler–Poisson equations of gaseous stars with negative cosmological constants, commonly used to describe a dark-fluid system. In this model, dark matter and dark energy are two different aspects of the same substance, the ‘dark fluid’ Farnes (2018). As illustrated in Fig. 1, the self-similar solution using the specific dark fluid equation of state (EOS) yields results consistent with  $\Lambda$ CDM within the relevant time range.

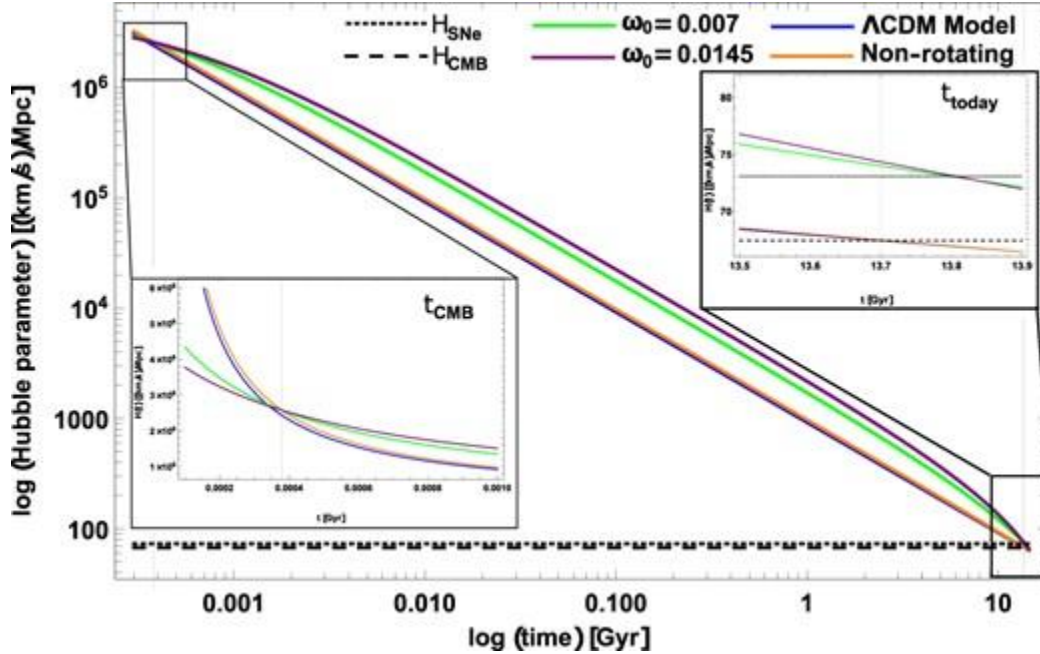


**Figure 1.**

Time evolution (log–log scale) of the Hubble parameter for non-rotating (analytical) and rotating (numerical) solutions at different  $\omega_0$  rotation parameter values as of today. Small figures show the evolution (normal scale) at the decoupling period  $t_{\text{CMB}}$  and today  $t_0 = t_{\text{today}}$ .

- Spherical symmetry: Initially, we assumed an ideal fluid with spherical symmetry. Therefore, the multidimensional partial differential equation system reduces to a one-dimensional, radius-dependent ordinary system. We assume a linear EoS by Horedt (2004),  $P(\rho)=w\rho$  with the effective  $w$  asymptotically tending to  $-1$  at  $t\infty$ . The resulting dark-fluid models describe a mixture of dark matter and dark energy in a non-rotating, expanding universe (Szigeti et al. 2023), as long as we neglect dark matter fluctuations (see extensive studies by Guo & Zhang 2007). The Euler–Poisson equation in the spherical limit is the following:

$$\partial_t \rho + (\partial_r \rho)u + (\partial_r u)\rho + 2u\rho r = 0 ,$$

(2)

$$\partial_t u + (u\partial_r)u = -1/\rho \partial_r P - \partial_r \Phi(r) + g^* ,$$

(3)

$$1/r^2 d/dr(r^2 \partial_r \Phi) = 4\pi\rho ,$$

(4)

where the  $u(r,t)$  radial flow velocity. Equations (1a)–(1c) are reduced to equations (2)–(4) due to the high similarity of the system as demonstrated by Sedov (1959).

- Cylindrical symmetry: If the rotation becomes significant enough, assuming spherical symmetry is no longer adequate. We assumed that the system is fully symmetric in the  $z$  direction. Thus, we extend our previous analyses of spherical flows to the Euler–Poisson equation in a cylindrical coordinate system.

$$\partial_t \rho + (\partial_r \rho)u + (\partial_r u)\rho + u\rho r = 0 ,$$

(5)

$$\partial_t u + (u\partial_r)u = -1\rho\partial_r P - \partial_r \Phi(r) + g^* ,$$

(6)

$$1/r \partial_r(r\partial_r \Phi) = 4\pi\rho .$$

(7)

Holden et al. (2009) studied self-similar solutions for the infinite cylindrical collapse. Self-similar exponents similar to the spherical case exist orthogonal to the  $z$ -axis. The  $u(r,t)$  again has a similar meaning as defined in the spherical symmetric case.

We solved both sets of the equations by using the Sedov–Taylor ansatz for the velocity field  $u(r,t)$ , the density  $\rho(r,t)$ , and the gravitational potential density field  $\Phi(r,t)$  in both system. For spherical symmetry we applied the  $u(r,t)=t^{-\alpha}f(\eta)$ ,  $\rho(r,t)=t^{-\gamma}g(\eta)$ , and  $\Phi(r,t)=t^{-\delta}h(\eta)$  notation, where  $f(\eta)$ ,  $g(\eta)$ , and  $h(\eta)$  are the shape functions of the reduced ordinary differential equation system with the reduced variable,  $\eta=r/t^\beta$ . The analogous shape functions for cylindrical symmetry depend on the  $z$  coordinate:  $u(z,t)=t^{-\alpha}k(\xi)$ ,  $\rho(z,t)=t^{-\gamma}l(\xi)$ , and  $\Phi(z,t)=t^{-\delta}h(\xi)$ , where  $\xi=z/t^\beta$ .

The real parameters  $\alpha, \beta, \gamma$ , and  $\delta$  are the self-similar exponents responsible for the solution's temporal decay and spreading. The numerical values of the exponents:  $\alpha=0$ ,  $\beta=1$ ,  $\gamma=2$ , and  $\delta=0$ . We assumed similarly to the spherical case for the cylindrical case that the dynamical variables depend only on the  $\eta=r/t^\beta$  variables. We performed all calculations in physical (non-expanding) rotating coordinates. The scale factor is the solution of the differential equation of  $a'(t)=u(r(t),t)$  (for details, see technical Szigeti et al. 2023), i.e. the approximately uniform streaming of the particles in physical coordinates represents the expansion of the universe. We restricted to expanding solutions of

equations (2)–(7) with  $r \propto a(t)$ . Consequently, the Hubble parameter is expressed as usual  $H(t) = \dot{a}/a$ .

We solved the two systems under equivalent initial conditions in  $\eta$ . We have seen that the two systems exhibit analogous behaviour in regions where the intermediate-asymptotic behaviour yields a valid solution. Thus, we will use the spherically symmetric limit in our following analyses (see in Fig. 1). We assumed spherical symmetry for our self-similar solutions of the Euler–Poisson system. This is justifiable far from the boundary, and it is numerically more stable Yuen (2009) and Peng & Lien (2012).

The same mathematical framework describes the Hubble parameter for the non-rotating ( $g^*=0$ ) and the rotating model ( $g^* \neq 0$ ) by setting initial conditions for the density, the velocity and the gravitational field:  $u(\eta_{IC})=0.5$  and  $\rho(\eta_{IC})=0.01 \text{ l P}^{-1}/\text{m}^3$  in geometrized units ( $G=c=1$ ) at  $t_{\text{CMB}}=t_{IC}=380 \text{ kyr}$  to determine the shape functions.<sup>2</sup> Similarly, in case of cylindrical symmetric system the  $k(\xi_{IC})=0.5$  and  $l(\xi)=0.01$ . These initial conditions are consistent with al. (2020), and, as we have shown, they reproduce the no-rotation Friedman solutions. These initial conditions are consistent with the Planck initial conditions at the decoupling period. We can add an effective rotational term to equation (1b),

$$(8) \quad g^* = 2r\omega^2(t)\sin^2(\theta),$$

where the angular velocity is  $\omega(t) = (\omega_0/t_0)/t$  and  $\theta$  is the polar angle. The effective centrifugal force is given in a non-inertial rotating frame. The Coriolis force vanishes since the velocity from expansion is always perpendicular to the rotation axis. Slow rotation can still be consistent with present observations. A slight global rotation still preserves a uniform CMB (Obukhov 2000; McEwen et al. 2013; Saadeh et al. 2016). Soon, such a rotation might be constrained by comparing the local inertial frame with that of quasars in Szapudi (2021).

### 3 RESULTS AND DISCUSSION

---

We numerically calculate the evolution equations following Szigeti et al. (2023), transforming the equations into the co-moving frame and applying the constraints detailed in Section (5). Fig. 1 shows the time dependence of the Hubble parameter for various angular frequencies from recombination until the present. Different initial rotations result in different  $H_0$  values today, but all solutions converge to zero at the asymptotic limit,  $t \rightarrow \infty$ . The evolution of the Hubble parameter with initial rotation in  $\omega(t) \rightarrow 0$  limit approaches the non-rotating model. However, the limit is extrapolated due to numerical instabilities for extremely small  $\omega_0$  values today. As a test, the black solid line displays the standard  $\Lambda$ CDM result, in perfect agreement with our formalism (the orange solid line labelled non-rotating). The non-rotating self-similar solution is consistent between  $t_{\text{CMB}}$  and  $t_{\text{today}}$ . Fig. 2 displays the Hubble constant ( $H_0$ ) for the non-rotating (analytical) and various slowly rotating (numerical) cases as a function of the rotational parameter  $\omega_0$ . The solid grey curve represents interpolation to the numerical calculations (markers), while the dashed curve is an extrapolation for  $\omega_0 \rightarrow 0$ . Numerical extrapolation for the Hubble constant,  $H_0$  with  $\omega_0 = 0.002 - 0.0009 + 0.001 \text{ Gyr}^{-1}$  predicts a value today comparable to the measured by HSNes. The present day  $\omega_0$  rotation corresponds to an initial,  $\omega(t_{\text{CMB}}) = 3.54 - 1.2 + 1.3 \text{ Myr}^{-1}$ , where  $H_{\text{CMB}}$  is measured at  $t_{\text{CMB}} = 380 \text{ kyr}$ . In Fig. 3, we illustrate the rotating universe. Its angular rotation parameter,  $\omega(t)$ , is approximately

$$|\omega(t)| = \omega_0 a^{-2}(t) \quad (9)$$

from angular momentum conservation during matter domination, consistently with equation (8). Next, we estimate the maximal rotation of a dark-matter-filled universe and compare it with  $\omega_0 \approx 0.002$  solving the Hubble tension. We require that the speeds remain below the speed of light within the observable horizon,

hence  $\omega \lesssim H$ , during the universe's entire history. Taking  $H(a) \sim a^{-3/2}$ , we limit  $\omega_0$  today as,

$$(10) \quad \omega_0 \lesssim H_0 a^{1/2}(t_{eq}) \approx 0.002 \text{ Gyr}^{-1},$$

where  $t_{eq}$  is the time of matter–radiation equality. Note that since at earlier times  $H(a) \approx 1/a^2$  and  $\omega(a) \approx 1/a$ , the above condition is satisfactory for the entire evolution of the universe. Most remarkably, *the allowed maximal rotation is approximately the same as the one required to solve the Hubble Puzzle*. Our simplified argument neglected any late effects of Dark Energy on angular momentum, but there should be a reasonable estimate for our calculation. Our results are consistent with Heckmann & Schücking (1955, 1956a, b) and Heckmann (1961), despite the differences in techniques and their original motivation of removing the initial singularity at the big bang. The required a *minimal* rotation,  $\omega \approx 0.03 \text{ Gyr}^{-1}$ , is an order of magnitude larger than the *maximal* rotation avoiding closed time-like loops within the horizon.

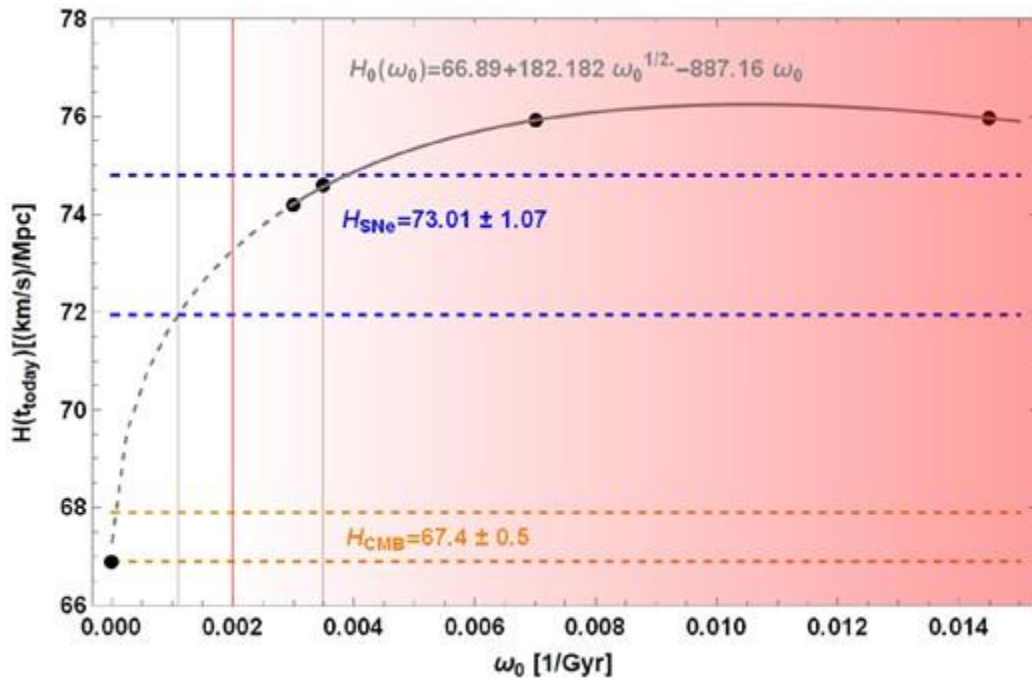


**Figure 2.**

The predicted  $H_0$  values from non-rotating (analytical) and rotating (numerical) models evaluated at different  $\omega_0$  values today. The solid curve interpolates the calculated values (markers). The continuing dashed curve extrapolates the  $\omega_0 \rightarrow 0$  case. The lower dashed (HCMB) (Aghanim et al. 2020) and the upper dashed (HSNe) (Riess et al. 2022) lines correspond to measurements with  $2\sigma$  uncertainty ranges. The shading approximates the prohibited region exceeding maximal rotation.

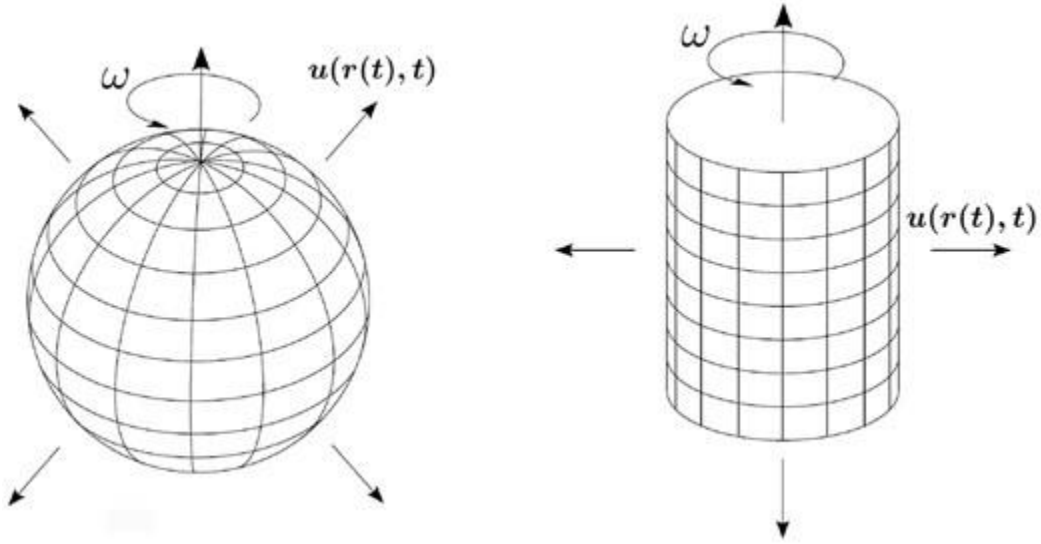


**Figure 3.**

Schematic view of the rotating (non-expanding) spherical and cylindrical physical coordinate systems, where the outflow of the particles,  $u(r(t), t)$  determines the expansion rate through  $\dot{a}(t) = u(r(t), t)$ ;  $\omega$  refers to the angular velocity. Even though  $u(r(t), t)$  has a formal dependence on  $r$ , our solutions produce an outflow uniform enough that it is well described by a single expansion rate,  $a(t)$ .

## 4 CONCLUSION

---

We analyse the time evolution of the Hubble parameter within the Euler–Poisson model with a self-similar time-dependent Sedov-type scaling for a linearized dark-fluid EOS. This model is consistent with a Newton–Friedmann cosmology

when the angular momentum is zero and facilitates the analysis of cosmologies with slow rotation.

We found that an angular speed near the maximal rotation  $\omega_0 \lesssim 0.002 \text{ Gyr}^{-1}$  today predicts a Hubble constant consistent with local measurements when starting from an expansion rate consistent with the CMB. Extrapolation to the initial rotation of the early universe gives the values of  $\omega(t_{\text{CMB}}) \approx 3.54 - 1.2 + 1.3 \text{ Myr}^{-1}$  for the time of the origin of the CMB. These tantalizing initial results have the caveat that we only focused on the Hubble constant. Further investigations contrasting the rotating model against the entire intertwined network of the concordance model observations, confirmation and development of numerical models using rotating cosmological  $N$ -body simulations<sup>5</sup>, and extension for a general relativistic treatment are left for future work.

---

# Researchers discover a new type of quantum entanglement

by [Technion - Israel Institute of Technology](#)



Conversion occurring in a nanometric system of two photons into an entangled state in their total angular momentum. Credit: Shalom Buberan, Shultz3d

A study from Technion unveils a newly discovered form of quantum entanglement in the total angular momentum of photons confined in nanoscale structures. This discovery could play a key role in the future miniaturization of quantum communication and computing components.

Quantum physics sometimes leads to very unconventional predictions. This is what happened when Albert Einstein and his colleagues, Boris Podolsky and Nathan Rosen (who later founded the Faculty of Physics at Technion), found a scenario in which knowing the state of one particle immediately affects the state of the other particle, no matter how great the distance between them. Their historic 1935 paper was nicknamed EPR after its three authors (Einstein–Podolsky–Rosen).

The idea that knowing the state of one particle will affect another particle located at a huge distance from it, without physical interaction and information transfer, seemed absurd to Einstein, who called it "spooky action at a distance."

But groundbreaking work by another Technion researcher, Research Prof. Asher Peres from the Faculty of Physics, showed that this property can be used to transmit information in a hidden way—[quantum teleportation](#), which is the basis for quantum communication. This discovery was made by Prof. Peres with his colleagues Charles Bennett and Gilles Brassard.

The phenomenon later received the scientific name [quantum entanglement](#), and for its measurement and implications, which include the possibility of quantum computing and quantum communication, the 2022 Nobel Prize in Physics was awarded to Profs. Alain Aspect and Anton Zeilinger, who previously received honorary doctorates from the Technion, and their colleague Prof. John Clauser.

Quantum entanglement has been demonstrated so far for a wide variety of particles and for their various properties. For photons, particles of light, entanglement can exist for their direction of travel, frequency (color), or the direction in which their electric field points. It can also exist for properties that are harder to imagine, such as angular momentum.

This property is divided into spin, which is related to the photon's rotation of the electric field, and orbit, which is related to the photon's rotational motion in space. This is intuitively similar to Earth, which rotates on its axis and also orbits the sun in a circular path.

It is easy for us to imagine these two rotational properties as separate quantities, and indeed, photons bound in a beam of light much wider than their wavelength. However, when we try to put photons into structures smaller than the photonic wavelength—which is the endeavor of the field of nanophotonics—we discover that it is impossible to separate the different rotational properties, and the photon is characterized by a single quantity, the total angular momentum.

So why would we even want to put photons into such small structures? There are two main reasons for this. One is obvious—it will help us to miniaturize devices that use light and thus squeeze more operations into a small area cell, similar to the miniaturization of electronic circuits.

The other reason is even more important: this miniaturization increases the interaction between the photon and the material through which the photon is traveling (or is near), thus allowing us to produce phenomena and uses that are not possible with photons in their "normal" dimensions.

In a study [published](#) in the journal *Nature*, the Technion researchers, led by Ph.D. student Amit Kam and Dr. Shai Tsesses, discovered that it is possible to entangle photons in [nanoscale systems](#) that are a thousandth the size of a hair, but the entanglement is not carried out by the conventional properties of the photon, such as spin or trajectory, but only by the total angular momentum.

The Technion researchers revealed the process that photons undergo from the stage in which they are introduced into the nanoscale system until they exit the measurement system, and found that this transition enriches the space of states that the [photons](#) can reside in.

In a series of measurements, the researchers mapped those states, entangled them with the same property unique to nanoscale systems, and confirmed the correspondence between photon pairs that indicates quantum entanglement.

This is the first discovery of a new quantum entanglement in more than 20 years, and it may lead in the future to the development of new tools for the design of photon-based [quantum communication](#) and computing components, as well as to their significant miniaturization.

**More information:** Amit Kam et al, Near-field photon entanglement in total angular momentum, *Nature* (2025). DOI: [10.1038/s41586-025-08761-1](https://doi.org/10.1038/s41586-025-08761-1)

**Journal information:** [Nature](#)

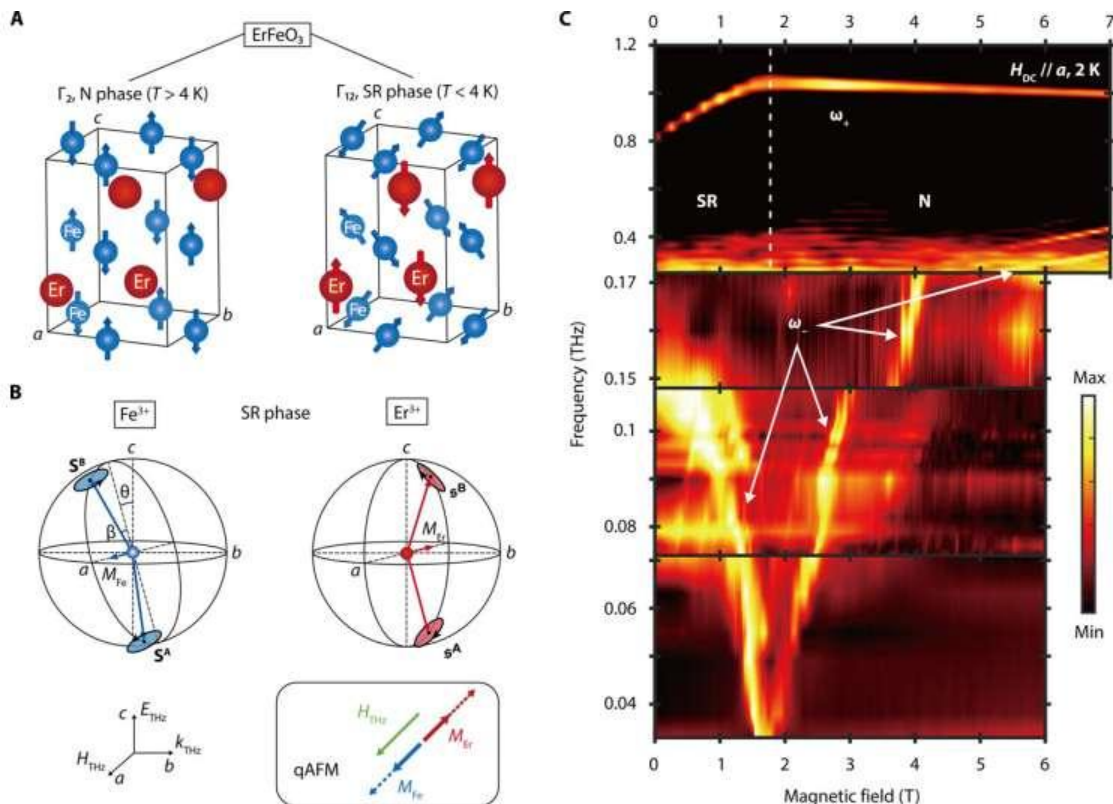
Provided by [Technion - Israel Institute of Technology](#)

---

APRIL 14, 2025

# Scientists observe exotic quantum phase once thought impossible

by [Rice University](#)



Spectroscopic evidence for the magnonic SRPT in  $\text{ErFeO}_3$ . Credit: *Science Advances* (2025). DOI: 10.1126/sciadv.adt1691

A team of Rice University researchers reported the first direct observation of a surprising quantum phenomenon predicted over half a century ago, opening pathways for revolutionary applications in quantum computing, communication, and sensing.

Known as a superradiant phase transition (SRPT), the phenomenon occurs when two groups of quantum particles begin to fluctuate in a coordinated, collective way without any external trigger, forming a new state of matter.

The discovery was made in a crystal composed of erbium, iron, and oxygen that was cooled to minus 457 Fahrenheit and exposed to a powerful magnetic field of up to 7 tesla (over 100,000 times stronger than Earth's magnetic field), according to [a study](#) published in *Science Advances*.

"Originally, the SRPT was proposed as arising from interactions between quantum vacuum fluctuations—[quantum light](#) fields naturally existing even in completely empty space—and matter fluctuations," said Dasom Kim, a Rice doctoral student in the Applied Physics Graduate Program who is a lead author on the study.

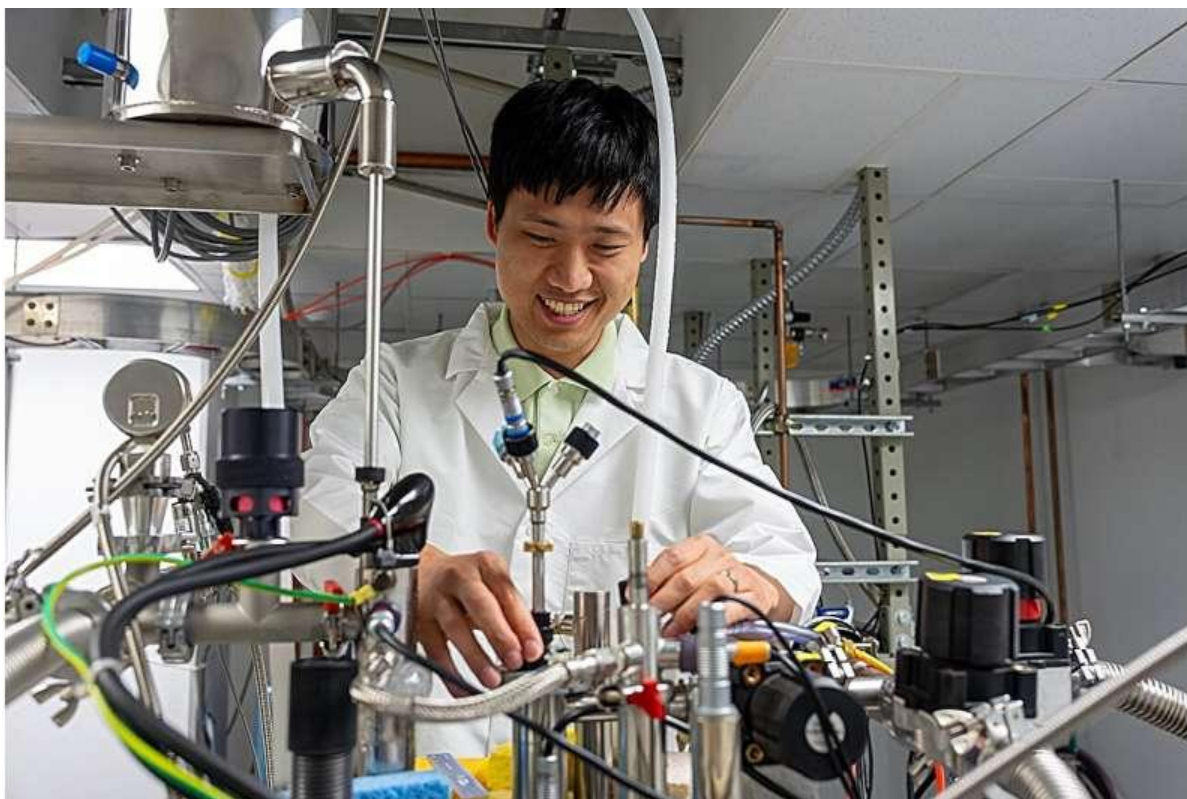
"However, in our work, we realized this transition by coupling two distinct magnetic subsystems—the spin fluctuations of iron ions and of erbium ions within the crystal."

Spin describes the magnetic poles of electrons or other particles and can be envisioned as a tiny arrow attached to each particle, constantly twirling and pointing in a given direction. When spins align, they create magnetic patterns across a material. When the pattern of spins ripples across the material like a wave, the resulting collective excitation is known as a magnon.

Until now, whether or not an SRPT could actually take place was subject to debate as it runs against a limitation—called "no-go theorem" in [theoretical physics](#)—arising in light-based systems. By staging an SRPT in a magnetic crystal based on the interactions between two spin subsystems, the researchers were able to get around this barrier, creating a magnonic version of the phenomenon.

Specifically, the iron ions' magnons play the role traditionally attributed to vacuum fluctuations, and the erbium ions' spins represent matter fluctuations.

Using advanced spectroscopic techniques, the researchers observed unmistakable signatures of an SRPT, with the energy signal of one spin mode vanishing and another showing a clear shift or kink. These spectral fingerprints match exactly what theory predicts for entering the superradiant phase, giving the team high confidence that they had indeed coaxed the long-sought state into being.



Dasom Kim. Credit: Jorge Vidal/Rice University

"We established an ultrastrong coupling between these two spin systems and successfully observed an SRPT, overcoming previous experimental constraints," Kim said.

Researchers are excited not just because a 50-year-old physics prediction has been confirmed but also because of what this could mean for quantum technology. Collective quantum states at the SRPT have unique properties that could be harnessed for next-generation quantum technologies.

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.

Subscribe

"Near the quantum critical point of this transition, the system naturally stabilizes quantum-squeezed states—where quantum noise is drastically reduced—greatly enhancing measurement precision," Kim said. "Overall, this insight could revolutionize quantum sensors and computing technologies, significantly advancing their fidelity, sensitivity, and performance."

Sohail Dasgupta, a graduate student at Rice working with Kaden Hazzard, associate professor of physics and astronomy, theoretically modeled the SRPT, building on a model developed by their collaborator and co-author Motoaki Bamba, a professor at Yokohama National University.

"Although the basic mathematical model was already laid out before by Motoaki, we needed to account for some of the specific magnetic properties of the material to obtain the precise

results. When your theory matches the [experimental data](#) – which happens rather rarely – it is the best feeling for a scientist," Dasgupta said.

Hazzard said the achievement shows that concepts from quantum optics can be translated into solid materials.

"This opens a new way to create and control phases of matter using ideas from [cavity quantum electrodynamics](#)," Hazzard said.

Moreover, the crystal used in this study is one example of a broader class of materials, which means the research paves the way for exploring quantum phenomena in other materials with similarly interacting magnetic components.

"Demonstrating a form of SRPT driven entirely by coupling two internal matter fluctuations marks a significant breakthrough in [quantum physics](#), establishing a new framework for understanding and exploiting intrinsic quantum interactions within materials," said Junichiro Kono, the Karl F. Hasselmann Professor of Engineering, professor of electrical and computer engineering and materials science and nanoengineering and the study's corresponding author.

**More information:** Dasom Kim et al, Observation of the magnonic Dicke superradiant phase transition, *Science Advances* (2025). DOI: [10.1126/sciadv.adt1691](https://doi.org/10.1126/sciadv.adt1691)

**Journal information:** [Science Advances](#)

Provided by [Rice University](#)

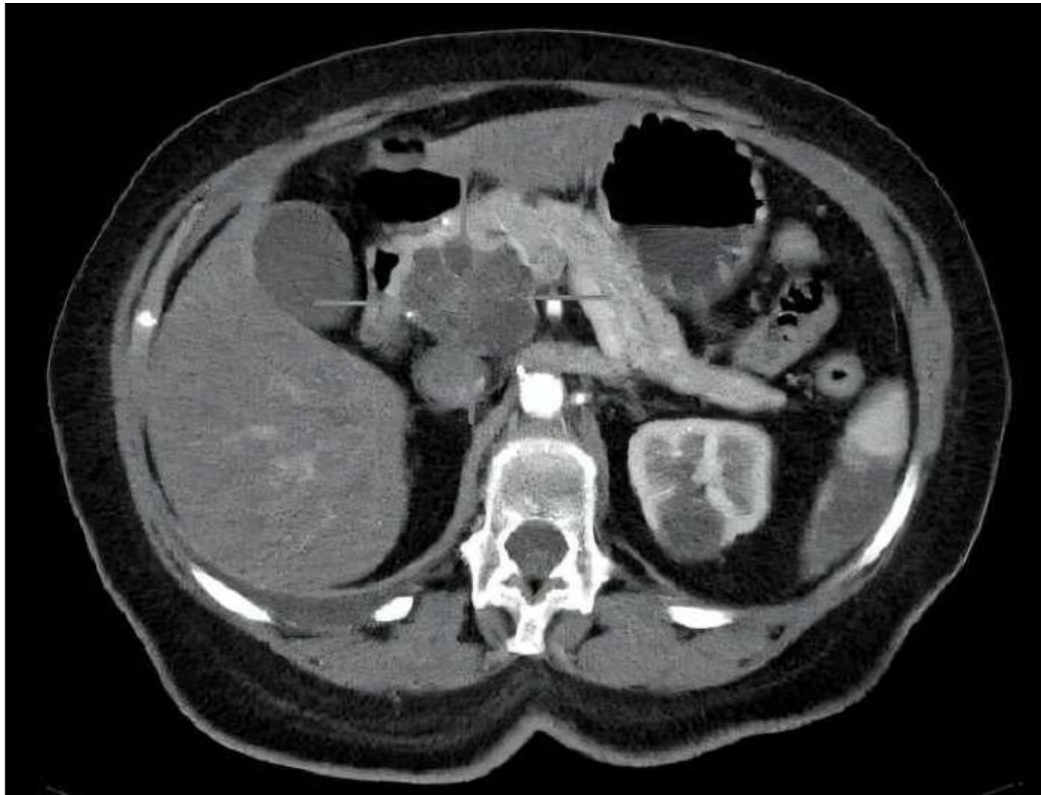
---

---

APRIL 15, 2025

# Key to the high aggressiveness of pancreatic cancer identified

by IMIM (Hospital del Mar Medical Research Institute)



Axial CT image with i.v. contrast. Macrocystic adenocarcinoma of the pancreatic head.

Credit: Public Domain

Pancreatic cancer is one of the most aggressive cancers and has one of the lowest survival rates—only 10% after five years. One of the factors contributing to its aggressiveness is its tumor microenvironment, known as the stroma, which makes up the majority of the tumor mass and consists of a network of proteins and different non-tumor cells. Among these, fibroblasts play a key role, helping tumor cells to grow and increasing their resistance to drugs.

Now, a study led by researchers from the Hospital del Mar Research Institute, IIBB-CSIC-IDIBAPS, Mayo Clinic, Instituto de Biología y Medicina Experimental (CONICET, Argentina) and CaixaResearch Institute, has identified a new key factor contributing to this feature of [pancreatic cancer](#): a previously unknown function of Galectin-1 protein inside the nuclei of fibroblasts.

This discovery, [published](#) in the journal *PNAS*, offers new insights into the role of these cells in the progression of pancreatic cancer.

"The stroma is considered a key component in the aggressive nature of pancreatic cancer, as it interacts with tumor cells, protects them, and hinders the action of drugs. Moreover, [stromal cells](#), particularly fibroblasts, produce substances that support [tumor growth](#) and dissemination," explains Dr. Pilar Navarro, coordinator of the Cancer Molecular Targets Research Group at the Hospital del Mar Research Institute and IIBB-CSIC-IDIBAPS.

Until now, fibroblasts were known to secrete Galectin-1, a protein with pro-tumoral properties. This study, however, shows that the molecule is also located inside fibroblasts—specifically in their nuclei—where it plays a key role in gene expression regulation.

The presence of this molecule activates fibroblasts, making them support tumor cell development. The researchers also discovered that "Galectin-1 can regulate [gene expression](#) in these cells at a highly specific level without altering the DNA sequence, through epigenetic control. One of the genes it regulates is KRAS, which plays a critical role in pancreatic tumors," explains Dr. Navarro.

This gene is also present in tumor cells in 90% of patients, though in this case it is mutated. It is considered one of the main drivers of uncontrolled growth and tumor aggressiveness.

## Designing new strategies

The team behind the study had previously identified the prominent role of Galectin-1 in pancreatic cancer. However, the newly discovered functions now pave the way for developing new strategies to tackle this type of tumor.

"Until now, efforts have focused on inhibiting Galectin-1 secreted by the stroma surrounding the tumor. Now, we see that we also need to block the protein inside the fibroblast nuclei," says Dr. Neus Martínez-Bosch, researcher at the Hospital del Mar Research Institute.

"We need to find new inhibitors that work inside fibroblasts, not just on the protein they secrete," she adds.

To carry out the study, researchers worked with [tissue samples](#) from pancreatic cancer patients, allowing them to analyze the presence and function of Galectin-1 in fibroblast nuclei.

They also performed in vitro experiments with human fibroblast cell lines, investigating the effects of inhibiting both the protein and the KRAS gene, and observed deactivation of these cells—effectively halting their cooperation with [tumor cells](#).

Dr. Judith Vinaixa, also a researcher at the Hospital del Mar Research Institute and first author of the study, highlights the importance of these results: "We have confirmed the key

role of Galectin-1 in the [fibroblast](#) cell nucleus, where it regulates the expression of multiple genes critical for cell behavior."

Dr. Gabriel Rabinovich, researcher at IBYME (CONICET) and the CaixaResearch Institute, adds, "The next steps will involve exploring therapeutic combinations that inhibit both extracellular and intracellular Galectin-1. This protein also participates in key processes such as blood vessel formation and resistance to immunotherapy. Therefore, this strategy becomes particularly relevant given the multiple antitumoral effects of Galectin-1 inhibition."

The study also involved contributions from the Pathology Department at Hospital del Mar and researchers from the Cancer Area of CIBER (CIBERONC).

**More information:** Judith Vinaixa et al, Nuclear Galectin-1 promotes KRAS -dependent activation of pancreatic cancer stellate cells, *Proceedings of the National Academy of Sciences* (2025). DOI: [10.1073/pnas.2424051122](https://doi.org/10.1073/pnas.2424051122)

**Journal information:** [Proceedings of the National Academy of Sciences](#)  
Provided by IMIM (Hospital del Mar Medical Research Institute)

---

APRIL 15, 2025

# AI reimagines gravitational wave detection with innovative designs

by Edda Fischer, [Max Planck Institute for the Science of Light](#)

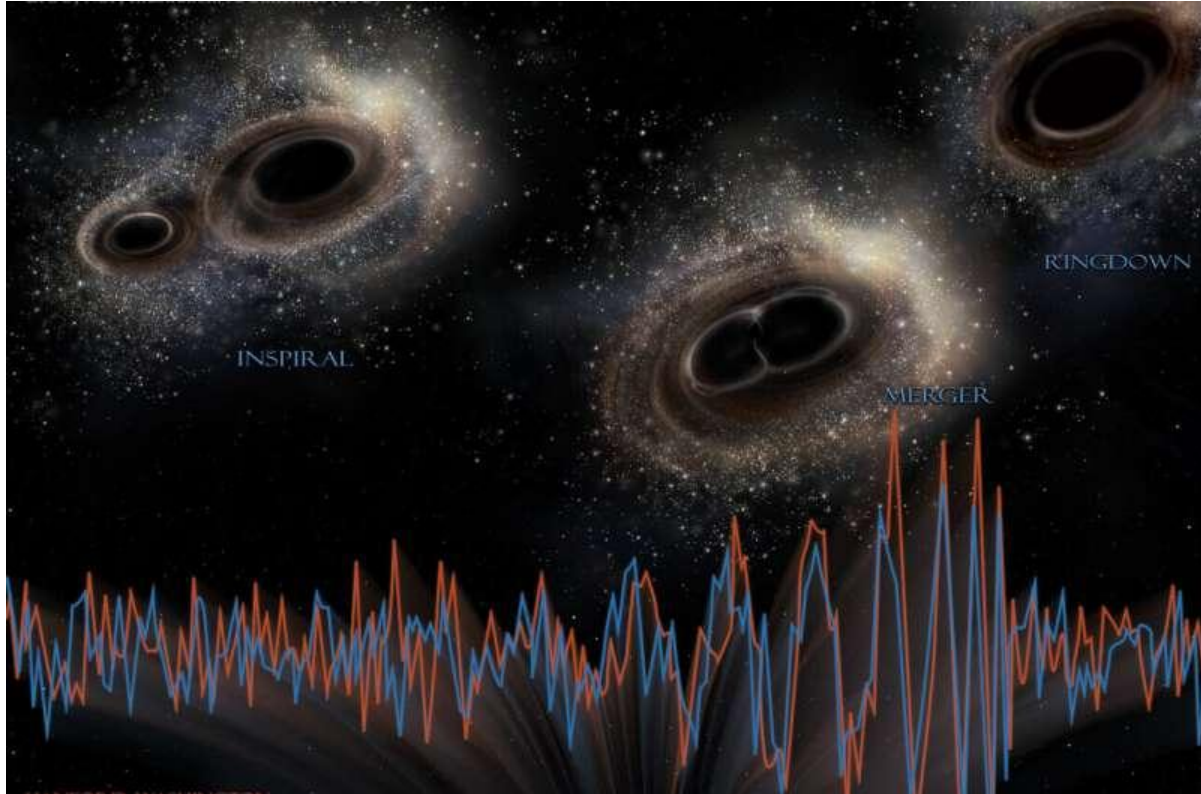


Illustration of the first gravitational wave event observed by LIGO. The detected wave forms from LIGO Hanford (orange) and LIGO Livingston (blue) are superimposed beneath illustrations of the merging black holes. Credit: Aurore Simmonet (Sonoma State University), Courtesy Caltech/MIT/LIGO Laboratory

Extreme cosmic events such as colliding black holes or the explosions of stars can cause ripples in spacetime, so-called gravitational waves. Their discovery opened a new window into the universe. To observe them, ultra-precise detectors are required, but designing them remains a major scientific challenge for humans.

Researchers at the Max Planck Institute for the Science of Light (MPL) have been working on how an artificial intelligence system could explore an unimaginably vast space of possible designs to find entirely new solutions. The results were recently [published](#) in the journal *Physical Review X*.

More than a century ago, Einstein theoretically predicted gravitational waves. They could only be directly detected in 2016 because the development of the necessary detectors was extremely complex.

Dr. Mario Krenn, head of the research group Artificial Scientist Lab at MPL, in collaboration with the team of LIGO ("Laser Interferometer Gravitational-Wave Observatory"), who built those detectors successfully, has designed an AI-based algorithm called "Urania" to [design](#) novel interferometric gravitational wave detectors.

Interferometry describes a measurement method that uses the interference of waves, i.e., their superposition when they meet. Detector design requires optimizing both layout and parameters. The scientists have converted this challenge into a continuous optimization problem and solved it using methods inspired by modern machine learning.

They have found many new experimental designs that outperform the best known next-generation detectors. These results have the potential to improve the range of detectable signals by more than an order of magnitude.

## Nonconformist and creative: That's what Urania discovered

In the algorithm's solutions, the researchers rediscovered numerous known techniques. Urania also proposed unorthodox designs that could reshape our understanding of [detector](#) technology. "After roughly two years of developing and running our AI algorithms, we discovered dozens of new solutions that seem to be better than experimental blueprints by human scientists. We asked ourselves what humans overlooked in comparison to the machine," says Krenn.

The researchers expanded their scientific approach to understand the AI-discovered tricks, ideas, and techniques. Many of them are still completely alien to them. They have compiled 50 top-performing designs in a public "Detector Zoo" and made them available to the scientific community for further research.

The recently published work shows that AI can uncover novel detector designs and inspire human researchers to explore new experimental and theoretical ideas. More broadly, it suggests that AI could play a major role in designing future tools for exploring the universe, from the smallest to the largest scales.

"We are in an era where machines can discover new superhuman solutions in science, and the task of humans is to understand what the machine has done. This will certainly become a very prominent part of the future of science," says Krenn.

**More information:** Mario Krenn et al, Digital Discovery of Interferometric Gravitational Wave Detectors, *Physical Review X* (2025). DOI: [10.1103/PhysRevX.15.021012](https://doi.org/10.1103/PhysRevX.15.021012)

**Journal information:** [Physical Review X](#)

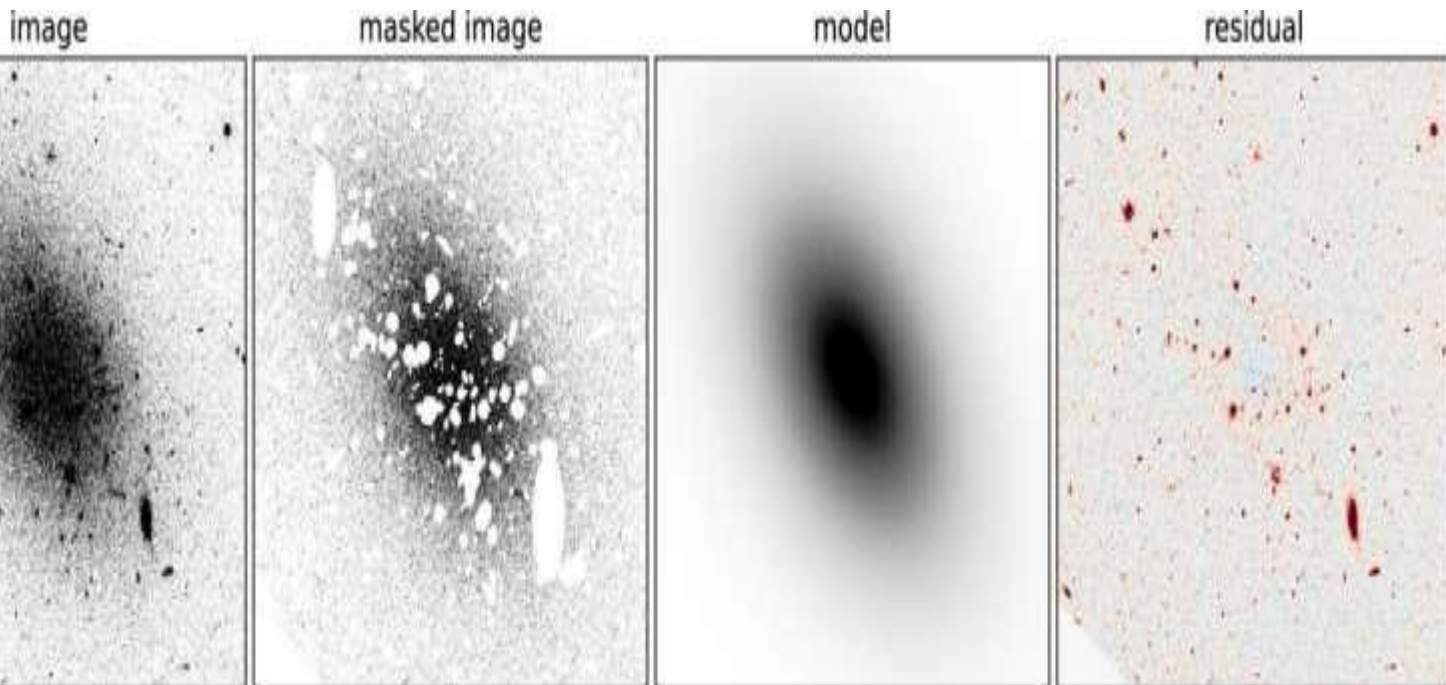
Provided by [Max Planck Institute for the Science of Light](#)

---

APRIL 15, 2025

# Evidence of dark matter-free dwarf galaxy challenges conventional galaxy formation models

by [W. M. Keck Observatory](#)



FCC 224  $g_{475}$  image as an example of our GALFIT modeling. From left to right, the three panels show the original image, the masked image, the model, and the residuals. The images shown here have sizes of 3 times the major-axis  $R_e$  of FCC 224, while the actual input images to GALFIT include the entire UVIS chip ( $\sim 155'' \times 75''$ ). Credit: *The Astrophysical Journal* (2025). DOI: 10.3847/1538-4357/adae11

Astronomers using W. M. Keck Observatory on Maunakea, Hawai'i Island have found compelling evidence of a dark matter-deficient dwarf galaxy, FCC 224. This ultra-diffuse galaxy is located on the outskirts of the Fornax Cluster, approximately 60–65 million light-years from Earth.

The discovery challenges the traditional cosmological paradigm, which assumes dark matter is a fundamental component in [galaxy formation](#). Previously, dark matter-deficient galaxies without any ongoing star formation had only been claimed in one other place, the NGC 1052 group, and the new observations suggest such objects may be more widespread than previously thought.

The unusual galaxy was profiled in two complementary studies. The first study, led by Doctoral Candidate Yimeng Tang of the University of California, Santa Cruz and [published](#) in the *Astrophysical Journal*, analyzes FCC 224's unique globular star cluster system.

The second, led by Doctoral Candidate Maria Luísa Buzzo of Swinburne University and of the European Southern Observatory, and [published](#) in *Astronomy & Astrophysics*, explores the dark matter content of the galaxy and possible scenarios for its formation.

"Globular clusters are often used as a proxy to estimate the amount of dark matter a galaxy contains," said Buzzo. "For some reason this galaxy (FCC 224) has an unusual number of luminous clusters and no dark matter, at least within its inner regions. No existing galaxy formation model within our standard cosmological paradigm can currently explain how this galaxy came to be."

Buzzo's research investigated the dark matter content of FCC 224 using high-resolution spectroscopy from Keck Observatory's Keck Cosmic Web Imager (KCWI). She explored its similarities to previously claimed dark matter-free dwarf galaxies DF2 and DF4, located within the NGC 1052 galaxy group, to determine whether or not FCC 224 belongs to the same class of galaxies.

Buzzo's research builds upon the initial findings of Tang, who, using imaging from NASA's Hubble Space Telescope (HST), found that FCC 224 has star clusters similar to other dark matter-deficient galaxies. Their research suggests that these types of star clusters may be linked to a lack of dark matter, challenging conventional models of galaxy formation. The Keck Observatory/KCWI data was obtained through a Swinburne University proposal under Principal Investigator (PI) Duncan Forbes, while the HST data was acquired through a program led by PI Aaron Romanowsky.

"The new high-resolution red arm of KCWI enabled us to measure very precisely the motions within the galaxy, which can be used to trace its dark matter content," explained Buzzo. "KCWI's high spectral resolution allowed us to precisely measure the motions (velocity dispersion) within FCC 224's stars and [globular clusters](#)," said Tang. "These measurements confirmed that the galaxy exhibits an extremely low velocity dispersion—a hallmark of dark matter deficiency."

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.

Subscribe

Both teams highlight the need for further observations to understand the mechanisms behind FCC 224's formation. One leading hypothesis is that an external interaction, such as a high-velocity collision, may have separated the galaxy's dark and visible matter, a formation scenario known as 'the bullet-dwarf model.' However, additional data is required to test this theory.

"FCC 224 serves as a crucial data point in our effort to identify and study other dark matter-deficient galaxies," Buzzo added. "By expanding the sample size, we can refine our

understanding of these rare galaxies and of the role of dark matter in dwarf galaxy formation."

The discovery of FCC 224 outside the NGC 1052 group suggests that dark matter-deficient galaxies may be more common than previously believed, raising fundamental questions about the necessity of [dark matter](#) in shaping galaxies. As observational capabilities improve, astronomers aim to conduct larger surveys to identify similar galaxies and investigate their origins.

**More information:** Yimeng Tang et al, An Unexplained Origin for the Unusual Globular Cluster System in the Ultradiffuse Galaxy FCC 224, *The Astrophysical Journal* (2025). DOI: [10.3847/1538-4357/adae11](https://doi.org/10.3847/1538-4357/adae11)

Maria Luisa Buzzo et al, A new class of dark matter-free dwarf galaxies?, *Astronomy & Astrophysics* (2025). DOI: [10.1051/0004-6361/202453522](https://doi.org/10.1051/0004-6361/202453522)

**Journal information:** [Astronomy & Astrophysics](#) , [Astrophysical Journal](#)

---

APRIL 15, 2025

# Ambisonics algorithm helps create rich virtual soundscapes using a domed array of loudspeakers

by [American Institute of Physics](#)



The AudioDome, a loudspeaker that can reproduce an entire surrounding acoustic field as if the listener is immersed in a real-life soundscape. Credit: sonible GmbH, Graz, Austria  
Surround-sound speakers can immerse you in a multimedia experience, but what if there was a speaker that could completely re-create a three-dimensional soundscape?

The AudioDome is more than just a loudspeaker arrangement—it's a dome of speakers that can create an immersive [sound](#) experience that reproduces sound sources at any [location](#) when the listener is placed in the middle.

In *The Journal of the Acoustical Society of America*, researchers from Western University in London, Ontario decided to test the limits of ambisonic sound reproduction through their "AudioDome" loudspeaker array.

Ambisonic rendering is a way to simulate the precise locations of sounds in 3D, using an array of loudspeakers. The ambisonics [algorithm](#) has allowed researchers to create rich virtual "soundscapes," with each sound appearing to come from precisely the location it occurred in the recording.

"The ambisonics technology promises highly focal sound source reproduction, which is enormously valuable to researchers wishing to maintain tight experimental control while also studying human auditory spatial perception in the type of complex, dynamic, three-dimensional soundscapes that the auditory system evolved to handle," said researcher Nima Zargarneshad.

However, whether the ambisonics algorithm that the AudioDome uses to simulate soundscapes is appropriate for studying human perception is unknown. It depends on how precisely and focally it can simulate sound location, and how well it can reproduce the energy composition of sounds.

Since Zargarneshad's team is interested in performing human experiments using the setup, they wanted to validate the effectiveness of the AudioDome's ambisonics technology to simulate real life.

"We already knew that some reconstruction errors were theoretically predicted and confirmed with simulations, but we did not know how and to what extent they would affect human perception of sound location and identity," Zargarneshad said.

Our ability to distinguish between stimuli in different locations, known as spatial acuity, is high in front of our faces but decreases around the sides of our head. The researchers' experiments obtained very similar results from listeners in the AudioDome, proving that the loudspeaker array can reproduce sound locations at a spatial scale beyond the human limits of perception.

They also found that the accuracy and precision of a sound's simulated location doesn't depend on how far it is from an actual speaker location, which suggests that the [spatial resolution](#) of the ambisonics algorithm is appropriate for studying [human perception](#) nearly everywhere in three-dimensional space.

However, they also observed that the ambisonics algorithm accurately reproduced sound energy up to about 4 kilohertz in frequency, sufficient to reproduce speech although it would sound somewhat degraded, as though heard over a telephone.

They showed that the erroneous reproduction of higher frequencies fakes localization cues related to the perception of sound sources' elevation, and sound sources with high frequency components are perceived from an unexpected altitude.

"We conclude that the ambisonics algorithm can accurately reproduce the identity and location of many common sounds, including speech, at a spatial resolution that is at the level of human spatial acuity, if not better," said Zargarneshad. "This is sufficient to ensure the reproduced soundscapes are accurately simulating the real world."

**More information:** Focality of sound source placement by higher (ninth) order ambisonics and perceptual effects of spectral reproduction errors, *The Journal of the Acoustical Society of America* (2025). DOI: [10.1121/10.0036226](https://doi.org/10.1121/10.0036226)

**Journal information:** [Journal of the Acoustical Society of America](#)  
Provided by [American Institute of Physics](#)

---

APRIL 16, 2025

## Rare exoplanet orbits twin stars in 'Star Wars'-like twist

by [University of Birmingham](#)

A hypothetical office overlooking the Paranal Observatory in Chile, with the European Southern Observatory's VLT visible with its laser on the hill, and the four small SPECULOOS telescopes nearer the foreground. In the sky is a depiction of the orbital configuration of the 2M1510 system with the two brown dwarf stars in red orbiting one another, and the inferred exoplanet on a polar orbit in white. Within the office, a poster celebrating the original discovery of 2M1510's two brown dwarfs is on the wall, while diagrams and patterns showing the apsidal precession of the brown dwarf's orbit caused by the planets are shown on the table the roof and the floor. Credit: University of Birmingham / Amanda Smith

Astronomers have discovered a planet that orbits at a 90-degree angle around a rare pair of strange stars—a real-life 'twist' on the fictional twin suns of Star Wars hero Luke Skywalker's home planet of Tatooine.

The exoplanet, named 2M1510 (AB) b, orbits a pair of young [brown dwarfs](#)—objects bigger than gas-giant planets but too small to be proper stars. Only the second pair of eclipsing brown dwarfs known—this is the first exoplanet found on a right-angled path to the [orbit](#) of its two host stars.

An international team of researchers led by the University of Birmingham made the surprise discovery using the European Southern Observatory's Very Large Telescope (VLT). The brown dwarfs produce eclipses of one another, as seen from Earth, making them part of an "eclipsing binary."

[Publishing their discovery](#) in *Science Advances*, the researchers note that this is the first time such strong evidence for a "polar planet" orbiting a stellar pair has been collected.

Thomas Baycroft, a Ph.D. student at the University of Birmingham who led the study commented, "I'm particularly excited to be involved in detecting credible evidence that this configuration exists."

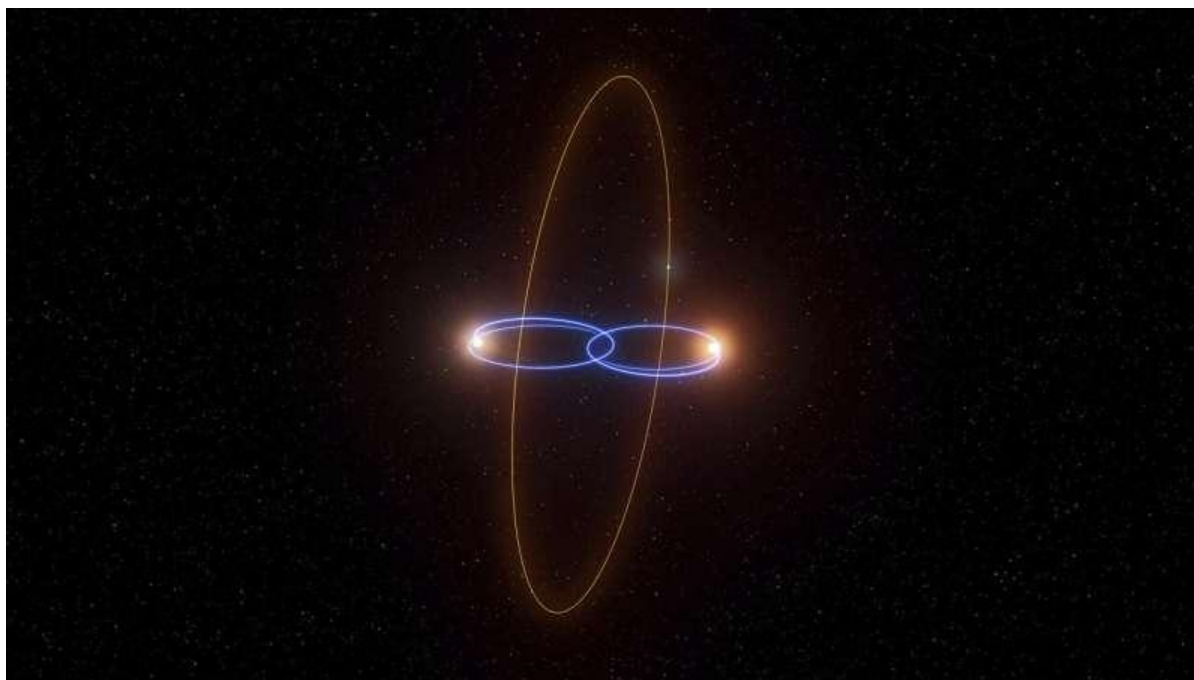


This artist's illustration provided by the European Southern Observatory shows an exoplanet orbiting around two brown dwarfs, celestial objects that are lighter than stars, but heavier than gas giant planets. Credit: M. Kornmesser/ESO

"We had hints that [planets](#) on perpendicular orbits around [binary stars](#) could exist, but until now we lacked clear evidence of this type of polar planet. We reviewed all possible scenarios, and the only consistent with the data is if a planet is on a polar orbit about this binary."

The team found this planet while refining the orbital and physical parameters of the two brown dwarfs by collecting observations with the Ultraviolet and Visual Echelle Spectrograph (UVES) instrument on the VLT at Paranal Observatory, Chile.

The astronomers observed the orbital path of the two stars in 2M1510 being pushed and pulled in unusual ways, leading them to infer the existence of an exoplanet with its strange orbital angle.



This artist's illustration provided by the European Southern Observatory shows the possible orbit of a new exoplanet around two brown dwarfs, or failed stars, 120 light years away.

Credit: L. Calçada/ESO

The pair of brown dwarfs, known as 2M1510, were detected in 2018 by Professor Amaury Triaud and others with the Search for habitable Planets EClipsing ULtra-cOOl Stars (SPECULOOS) that the University of Birmingham partially owns.

Co-author Professor Triaud, from the University of Birmingham, commented, "A planet orbiting not just a binary, but a binary brown dwarf, as well as being on a polar orbit is rather incredible and exciting.

"The discovery was serendipitous, as our observations were not collected to seek such a planet, or orbital configuration. As such, it is a big surprise and shows what is possible in the fascinating universe we inhabit, where a planet can affect the orbits of its two stars, creating a delicate celestial dance."

The discovery was made possible thanks to pioneering data analysis developed at Birmingham by Dr. Lalitha Sairam (now at the University of Cambridge), who developed new methods that improved precision by a factor of 30.

Dr. Sairam explains, "From variations in velocity of the two brown dwarfs, we can measure their physical and orbital parameters, however being faint, these measurements and therefore their parameters were uncertain. Thanks to that improvement, we noticed the orbits of the two brown dwarfs around one another were being delicately affected."

**More information:** Thomas Baycroft, Evidence for a polar circumbinary exoplanet orbiting a pair of eclipsing brown dwarfs, *Science Advances* (2025). DOI: [10.1126/sciadv.adu0627](https://doi.org/10.1126/sciadv.adu0627). [www.science.org/doi/10.1126/sciadv.adu0627](https://www.science.org/doi/10.1126/sciadv.adu0627)

## New study rejects Big Bang theory, says universe grew via cosmic energy bursts



New study rejects Big Bang theory, says universe grew via cosmic energy bursts

Forget one Big Bang — try many. A bold new theory pokes holes in the popular origin story, suggesting the universe evolves through a series of lightning-fast bursts, rewriting what we know about cosmic expansion.

Rather than a one-time, universe-making explosion, this model envisions the cosmos growing through countless rapid-fire events called temporal singularities.

Each of these brief, invisible bursts injects fresh energy and matter into space, gradually shaping the galaxies, stars, and structures we see today — no dark matter or dark energy required.

This alternative framework, published by Dr. Richard Lieu, a physics professor at The University of Alabama in Huntsville, challenges long-held assumptions in cosmology.

In his new paper, Lieu argues that these singularities, though unobservable, could be the true engines of cosmic evolution, offering a radically different explanation for how the universe expands and organizes itself.

The paper builds on Lieu's 2024 model, which controversially proposed that gravity might exist without mass — a theory that sparked intense debate and drew over 41,000 reads.

The latest version refines that idea, introducing temporal singularities as a more complete alternative to the Big Bang, and dropping the need for invisible cosmic ingredients that have long puzzled scientists.

## **Revised model for cosmic expansion**

"The new model can account for both structure formation and stability, and the key observational properties of the expansion of the universe at large, by enlisting density singularities in time that uniformly affect all space to replace conventional dark matter and dark energy," Lieu said.

According to Lieu, this series of step-like bursts happens so rapidly that they are difficult to observe as these singularities wink in and out of existence.

Lieu also references Sir Fred Hoyle's opposition to the Big Bang, noting that Hoyle's steady-state model proposed constant creation of matter and energy, which conflicted with mass-energy conservation laws.

"But that hypothesis violates the law of mass-energy conservation. In the current theory, the conjecture is for matter and energy to appear and disappear in sudden bursts and, interestingly enough, there is no violation of conservation laws," he said.

"These singularities are unobservable because they occur rarely in time and are unresolvedly fast, and that could be the reason why dark matter and dark

energy have not been found. The origin of these temporal singularities is unknown – safe to say that the same is true of the moment of the Big Bang itself.”

## Space-wide singularities and negative pressure

These space-wide singularities, acting as stand-ins for dark matter, also produce what’s known as negative pressure — a form of energy density similar to dark energy. This repulsive force pushes against gravity, driving the universe to expand at an accelerating rate.

“Einstein also postulated negative pressure in his 1917 paper on the Cosmological Constant. When positive mass-energy density is combined with negative pressure, there are some restrictions which ensure the mass-energy density remains positive with respect to any uniformly moving observer, so the negative density assumption is avoided in the new model,” Lieu said.

## Fleeting forces and cosmic expansion

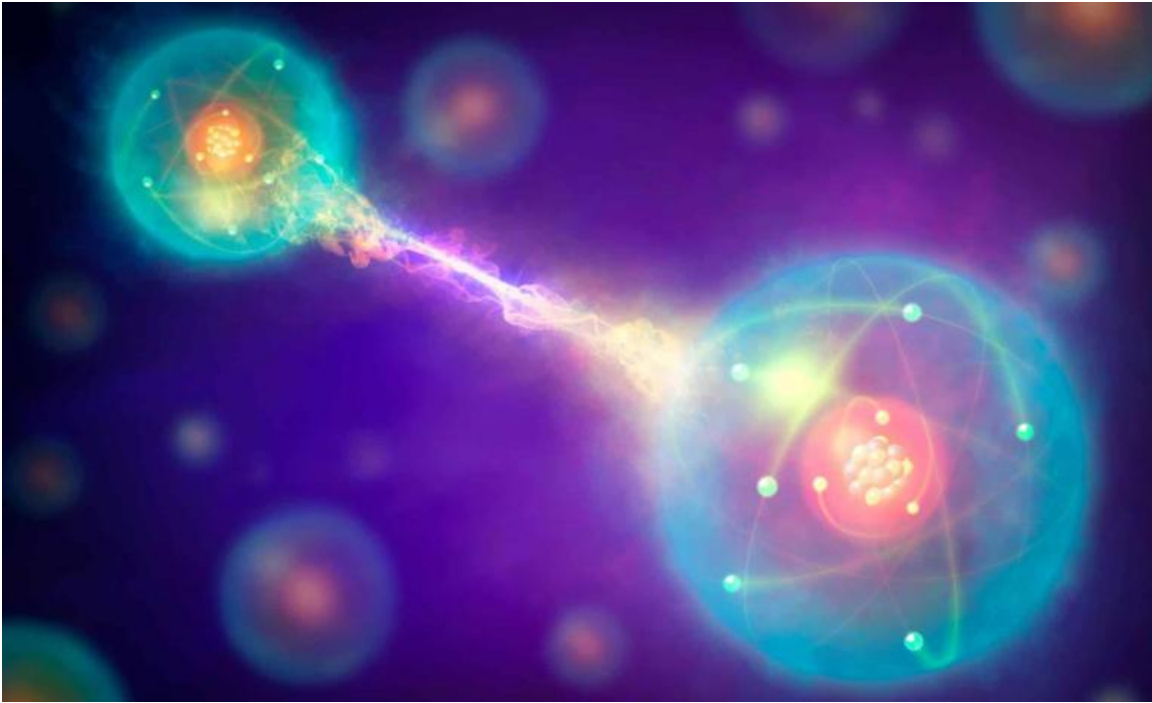
The new theory argues that dark matter and [dark energy](#) are not omnipresent, but appear only during brief instances when matter and energy fill the universe uniformly, aside from small spatial fluctuations that eventually grow into galaxies and other structures. Outside of these fleeting moments, the forces are entirely absent.

A key difference between this model and the standard one is its treatment of temporal singularities. While the standard cosmological model assumes a single event — the Big Bang — this framework proposes that such bursts occur multiple times across the [universe’s](#) history.

Future efforts to validate the theory could rely on data from Earth-bound instruments, rather than space telescopes like the [James Webb](#).

The paper has been published in [Classical and Quantum Gravity](#).

# 125-Year-Old Physics Puzzle Finally Cracked by Mathematicians



Physics Puzzle Finally Cracked by Mathematicians. Credit: Canva | The Daily Galaxy --Great Discoveries Channel© Daily Galaxy UK

Mathematicians have recently **solved a problem** that has eluded scientists **for over 125 years**, bridging three key theories that describe the motion of fluids. This milestone addresses a long-standing challenge in unifying different levels of fluid dynamics.

## The Problem Posed by David Hilbert

[According to Live Science](#), the significance of this discovery lies in its connection to the famous list of unsolved mathematical problems proposed by legendary mathematician **David Hilbert** in 1900.

At the [International Congress of Mathematicians](#), held at the Sorbonne in Paris, Hilbert presented **23 challenging problems**, one of which was focused

on **axiomatizing physics**. His sixth problem called for determining the minimum mathematical assumptions that underpin all physical theories.

Hilbert's problem was ambitious, in fact, that mathematicians have been working on its resolution for over a century.

The task of grounding physics in mathematics is **not easy**, and the path to achieving this goal has been paved with incremental steps and advancements.

## Uniting Three Theories of Fluid Dynamics

In March 2025, mathematicians **Yu Deng** from the University of Chicago and **Zaher Hani** and **Xiao Ma** from the University of Michigan published a paper suggesting that they had cracked a crucial part of this problem.

They claim to have found a way to unify three fundamental theories that describe fluid motion at different scales.

These theories, while immensely useful in engineering applications such as **aircraft design** and **weather prediction**, have historically rested on assumptions that hadn't been rigorously proven until now.

The breakthrough doesn't alter the theories themselves but provides a solid mathematical foundation for them.

## From Microscopic to Macroscopic: The Three Theories

The breakthrough addresses the need to unite three perspectives of fluid motion, each describing the same phenomenon but from different scales.

At the microscopic level, fluids are made up of individual particles, and **Newton's laws of motion** are effective in modeling their behavior.

However, this microscopic view becomes less practical when considering the collective behavior of **vast numbers of particles**.

In 1872, **Ludwig Boltzmann** tackled this challenge by developing the **Boltzmann equation**, which uses a statistical approach to model the typical behavior of particles in a fluid.

At the **macroscopic level**, fluids are treated as a continuous substance rather than a collection of individual particles. Here, the **Euler and Navier-Stokes equations** come into play, accurately describing fluid movement and how physical properties interrelate without considering particles at all.

## The Mathematical Link

Physicists have long **struggled to unify theories** explaining fluid dynamics at different scales. Deng, Hani, and Ma's breakthrough addresses this challenge by linking the statistical behavior of individual particles to the collective behavior of fluids.

Their proof involves three major steps. This work unifies **Newton's laws**, **Boltzmann's equation**, and the **Euler and Navier-Stokes equations**, marking a significant step toward solving a key problem in mathematical physics.

If confirmed, it would provide a rigorous foundation for future advancements in **physics**, as envisioned by **Hilbert** over a century ago.

# Mathematicians just solved a 125-year-old problem, uniting 3 theories in physics

By [Jack Murtagh](#) published April 25, 2025

## A breakthrough in Hilbert's sixth problem is a major step in grounding physics in math

Mathematicians suggest they have figured out how to unify three physical theories that explain the motion of fluids. (Image credit: Floriana via Getty Images)

When the greatest mathematician alive unveils a vision for the next century of research, the [math](#) world takes note. That's exactly what happened in 1900 at the International Congress of Mathematicians at Sorbonne University in Paris. Legendary mathematician [David Hilbert](#) presented [10 unsolved problems](#) as ambitious guideposts for the 20th century. He later expanded his list to include [23 problems](#), and their influence on mathematical thought over the past 125 years cannot be overstated.

Hilbert's sixth problem was one of the loftiest. He called for "axiomatizing" physics, or determining the bare minimum of mathematical assumptions behind all its theories.

Broadly construed, it's not clear that [mathematical physicists](#) could ever know if they had resolved this challenge. Hilbert mentioned some specific subgoals, however, and researchers have since refined his vision into concrete steps toward its solution.

In March mathematicians Yu Deng of the University of Chicago and Zaher Hani and Xiao Ma of the University of Michigan posted a new paper to the preprint server arXiv.org that [claims to have cracked one of these goals](#). If their work withstands scrutiny, it will mark a major stride toward grounding physics in math and may open the door to analogous [breakthroughs in other areas of physics](#).

In the paper, the researchers suggest they have figured out how to unify three physical theories that explain the motion of fluids. These theories govern a range of engineering applications from aircraft design to weather prediction — but until now, they rested on assumptions that hadn't been rigorously proven. This breakthrough won't change the theories themselves, but it mathematically justifies them and strengthens our confidence that the equations work in the way we think they do.

Each theory differs in how much it zooms in on a flowing liquid or gas. At the microscopic level, fluids are composed of particles — little billiard balls bopping around and occasionally colliding — and [Newton's laws of motion](#) work well to describe their trajectories.

But when you zoom out to consider the collective behavior of vast numbers of particles, the so-called mesoscopic level, it's no longer convenient to model each one individually. In 1872 Austrian theoretical physicist Ludwig Boltzmann [addressed this when he developed what became known as the Boltzmann equation](#). Instead of tracking the behavior of every particle, the equation considers the *likely* behavior of a *typical* particle. This statistical perspective smooths over the low-level details in favor of higher-level trends. The equation

allows physicists to calculate how quantities such as momentum and thermal conductivity in the fluid evolve without painstakingly considering every microscopic collision.

Zoom out further, and you find yourself in the macroscopic world. Here we view fluids not as a collection of discrete particles but as a single continuous substance. At this level of analysis, a different suite of equations — the [Euler and Navier-Stokes equations](#) — accurately describe how fluids move and how their physical properties interrelate without recourse to particles at all.

The three levels of analysis each describe the same underlying reality — how fluids flow. In principle, each theory should build on the theory below it in the hierarchy: the Euler and Navier-Stokes equations at the macroscopic level should follow logically from the Boltzmann equation at the mesoscopic level, which in turn should follow logically from Newton's laws of motion at the microscopic level. This is the kind of "axiomatization" that Hilbert called for in his sixth problem, and he explicitly referenced Boltzmann's work on gases in his [write-up of the problem](#). We expect complete theories of physics to follow mathematical rules that explain the phenomenon from the microscopic to the macroscopic levels. If scientists fail to bridge that gap, then it might suggest a misunderstanding in our existing theories.

Unifying the three perspectives on fluid dynamics has posed a stubborn challenge for the field, but Deng, Hani and Ma may have just done it. Their achievement builds on decades of incremental progress. Prior advancements all came with some sort of asterisk, though; for example, the derivations involved only worked on short timescales, in a vacuum or under other simplifying conditions.

The new proof broadly consists of three steps: derive the macroscopic theory from the mesoscopic one; derive the mesoscopic theory from the microscopic one; and then stitch them together in a single derivation of the macroscopic laws all the way from the microscopic ones.

The first step was previously understood, and even Hilbert himself contributed to it. Deriving the mesoscopic from the microscopic, on the other hand, has been much more mathematically challenging. Remember, the mesoscopic setting is about the collective behavior of vast numbers of particles. So Deng, Hani and Ma looked at what happens to Newton's equations as the number of individual particles colliding and ricocheting grows to infinity and their size shrinks to [zero](#). They proved that when you stretch Newton's equations to these extremes, the statistical behavior of the system — or the likely behavior of a "typical" particle in the fluid — converges to the solution of the Boltzmann equation. This step forms a bridge by deriving the mesoscopic math from the extremal behavior of the microscopic math.

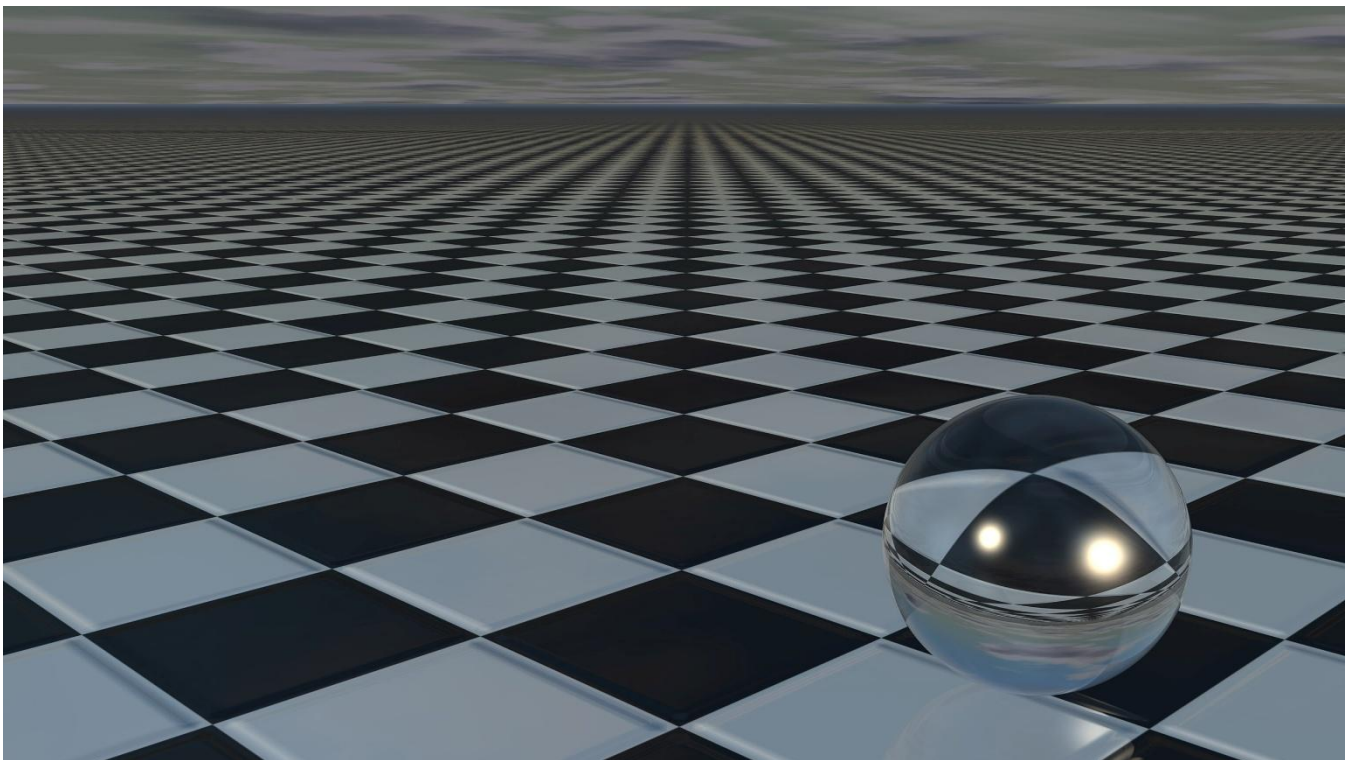
The major hurdle in this step concerned the length of time that the equations were modeling. [It was already known](#) how to derive the Boltzmann equation from Newton's laws on very short timescales, but that doesn't suffice for Hilbert's program, because real-world fluids can flow for any stretch of time. With longer timescales comes more complexity: more collisions take place, and the whole history of a particle's interactions might bear on

its current behavior. The authors overcame this by doing careful accounting of just how much a particle's history affects its present and leveraging new mathematical techniques to argue that the cumulative effects of prior collisions remain small.

Gluing together their long-timescale breakthrough with previous work on deriving the Euler and [Navier-Stokes equations](#) from the Boltzmann equation unifies three theories of fluid dynamics. The finding justifies taking different perspectives on fluids based on what's most useful in context because mathematically they converge on one ultimate theory describing one reality. Assuming that the proof is correct, it breaks new ground in Hilbert's program. We can only hope that with just such fresh approaches, the dam will burst on Hilbert's challenges and more physics will flow downstream.

## Centuries-old 'impossible' math problem cracked using the strange physics of Schrödinger's cat

By [Stephanie Pappas](#) published January 20, 2022



The mathematics problem is a bit like Sudoku on steroids.

A math problem developed 243 years ago can be solved only by using [quantum entanglement](#), new research finds.

The [mathematics](#) problem is a bit like Sudoku on steroids. It's called Euler's officer problem, after Leonhard Euler, the mathematician who first proposed it in 1779. Here's the puzzle: You're commanding an army with six regiments. Each regiment contains six different officers of six different ranks. Can you arrange them in a 6-by-6 square without repeating a rank or regiment in any given row or column?

Euler couldn't find such an arrangement, and later computations proved that there was no solution. In fact, a paper published in 1960 in the [Canadian Journal of Mathematics](#) used the newfound power of computers to show that 6 was the one number over 2 where no such arrangement existed.

Now, though, researchers have found a new solution to Euler's problem. As [Quanta Magazine's Daniel Garisto](#) reported, a new study posted to the preprint database [arXiv](#) finds that you can arrange six regiments of six officers of six different ranks in a grid without repeating any rank or regiment more than once in any row or column ... if the officers are in a state of quantum entanglement.

The paper, which has been submitted for peer review at the journal Physical Review Letters, takes advantage of the fact that quantum objects can be in multiple possible states until they are measured. (Quantum entanglement was famously demonstrated by the [Schrödinger's cat](#) thought experiment, in which a cat is trapped in a box with radioactive poison; the cat is both dead and alive until you open the box.)

In Euler's classic problem, each officer has a static regiment and rank. They might be a first lieutenant in the Red Regiment, for example, or a captain in the Blue Regiment. (Colors are sometimes used in visualizing the grids, to make it easier to identify the regiments.)

But a quantum officer might occupy more than one regiment or rank at once. A single officer could be either a Red Regiment first lieutenant *or* a Blue Regiment captain; a Green Regiment major *or* Purple Regiment colonel. (Or, theoretically, any other combination.) The key to solving Euler's problem with this identity switcheroo is that the officers on the grid can be in a state of quantum entanglement. In entanglement, the state of one object informs the state of another. If Officer No. 1 is, in fact, a Red Regiment first lieutenant, Officer No. 2 must be a major in the Green Regiment, and vice versa.

Using brute-force computer power, the authors of the new paper, led by Adam Burchardt, a postdoctoral researcher at Jagiellonian University in Poland, proved that filling the grid with quantum officers made the solution possible. Surprisingly, the entanglement has its own pattern, study co-author Suhail Rather, a physicist at the Indian Institute of Technology Madras, told Quanta Magazine. Officers are only entangled with officers of ranks one step below or above them, while regiments are also only entangled with adjacent regiments.

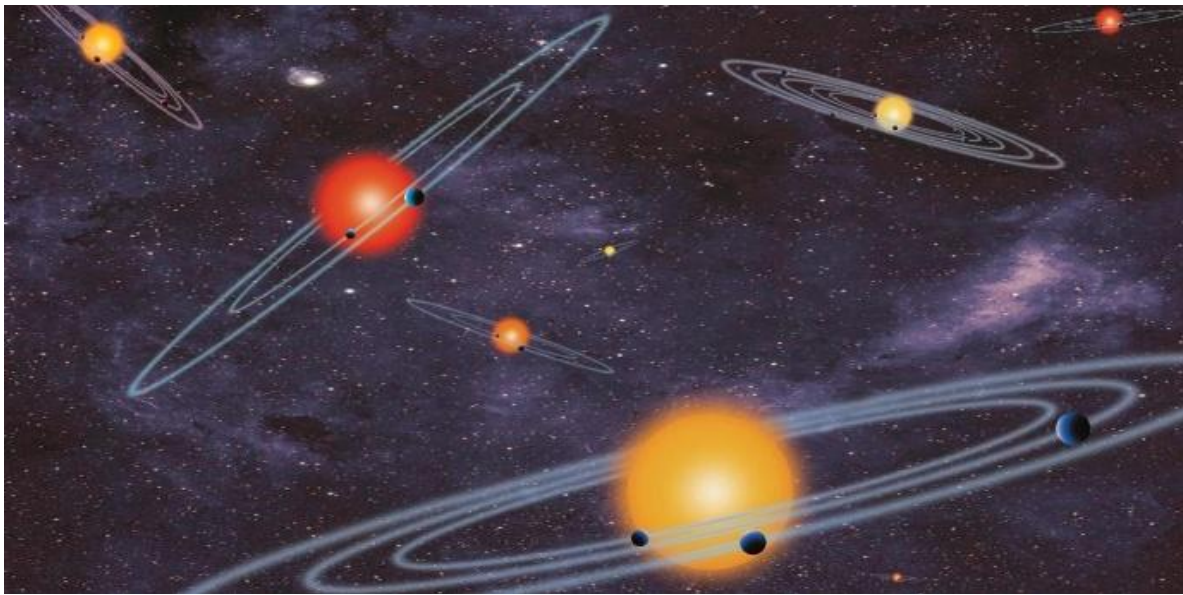
The results could have real impacts on quantum data storage, according to Quanta Magazine. Entangled states can be used in quantum computing to ensure that data is safe even in the case of an error — a process called quantum error correction. By entangling 36 quantum officers in a state of interdependent relationships, the researchers found what is

called an absolutely maximally entangled state. Such states can be important for resilient data storage in quantum computing.

## Mathematicians find 12,000 new solutions to 'unsolvable' 3-body problem

By [Briley Lewis](#) published September 15, 2023

Calculating the way three things orbit each other is notoriously tricky — but a new study may reveal 12,000 new ways to make it work.



One planet orbiting a star? No problem. Two or more planets orbiting a star? Now that's one of the biggest problems in astrophysics. (Image credit: NASA)

The [three-body problem](#) is a notoriously tricky puzzle in physics and mathematics, and an example of just how complex the natural world is. Two objects orbiting each other, like a lone planet around a star, can be described with just a line or two of mathematical equations. Add a third body, though, and the math becomes much harder. Because each object influences the others with its gravity, calculating a stable orbit where all three objects get along is a complex feat.

Now, an international team of mathematicians claims to have found 12,000 new solutions to the infamous problem — a substantial addition to the hundreds of previously known scenarios. Their work was [published as a preprint to the database arXiv](#), meaning it has not yet undergone peer review.

More than 300 years ago, [Isaac Newton](#) wrote down his foundational laws of motion, and mathematicians have been working on solutions to the three-body problem pretty much ever since. There is no single correct answer; instead, there are many orbits that can work within the laws of physics for three orbiting objects.

Unlike our planet's simple loop around the sun, orbits for the three-body problem can look twisted and tangled, like pretzels and scribbles. The 12,000 newly discovered ones are no exception — the three hypothetical objects start at a standstill and, when released, are pulled into various spirals toward one another via [gravity](#). They then fling past one another, moving farther away, until the attraction takes over and they once again come together, repeating this pattern over and over again.

The orbits "have a very beautiful spatial and temporal structure," lead study author [Ivan Hristov](#), a mathematician at Sofia University in Bulgaria, told [New Scientist](#). Hristov and colleagues found these orbits using a supercomputer, and he's confident that with even better tech, he could find "five times more."

Three-body systems are quite common in the universe; there are plenty of star systems with multiple planets, or even multiple stars orbiting each other. In theory, these new solutions could prove extremely valuable to astronomers trying to explain the cosmos. But they're only useful if they're *stable*, meaning the orbital patterns can repeat over time without breaking apart, [flinging one of the component worlds off into space](#). Just because they're theoretically stable doesn't mean they'll stand up to the many other forces present in a real star system.

"Their physical and astronomical relevance will be better known after the study of stability — it's very important," Hristov said.

## High school students who came up with 'impossible' proof of Pythagorean theorem discover 9 more solutions to the problem

By [Sascha Pare](#) published October 27, 2024

In a new peer-reviewed study, Ne'Kiya Jackson and Calcea Johnson outlined 10 ways to solve the Pythagorean theorem using trigonometry, including a proof they discovered in high school.

Ne'Kiya Jackson and Calcea Johnson came up with an "impossible" proof to the Pythagorean theorem when they were high school seniors. (Image credit: Calcea Johnson)

Two students who discovered a seemingly impossible proof to the Pythagorean theorem in 2022 have wowed the math community again with nine completely new solutions to the problem.

While still in high school, Ne'Kiya Jackson and Calcea Johnson from Louisiana [used trigonometry to prove the 2,000-year-old Pythagorean theorem](#), which states that the sum of the squares of a right triangle's two shorter sides are equal to the square of the triangle's longest side (the hypotenuse). Mathematicians had long thought that using trigonometry to prove the theorem was unworkable, given that the fundamental formulas for trigonometry are based on the assumption that the theorem is true.

Jackson and Johnson came up with their "impossible" proof in answer to a bonus question in a school math contest. They presented their work at an American Mathematical Society meeting in 2023, but the proof hadn't been thoroughly scrutinized at that point. Now, a new paper published Monday (Oct. 28) in the journal [American Mathematical Monthly](#) shows their solution held up to peer review. Not only that, but the two students also outlined nine more proofs to the Pythagorean theorem using trigonometry. "To have a paper published at such a young age — it's really mind-blowing," Johnson, who is now studying environmental engineering at Louisiana State University, said in a statement emailed to Live Science. "I am very proud that we are both able to be such a positive influence in showing that young women and women of color can do these things."

By proving [Pythagoras'](#) theorem using trigonometry, but without using the theorem itself, the two young women overcame a failure of logic known as circular reasoning. Trigonometry is a branch of [mathematics](#) that lays out how the sides, lengths and angles in a triangle are related, and as such, the discipline often includes expressions of the Pythagorean theorem. But Jackson and Johnson managed to prove the theorem using a result of trigonometry called the Law of Sines, dodging circular reasoning. In the new study, and on top of their initial proof, the young mathematicians described four new ways to prove Pythagoras' theorem using trigonometry, as well as a novel method that revealed five more proofs, totaling 10 proofs.

Jackson and Johnson are only the third and fourth people known to have proven the Pythagorean theorem using trigonometry and without resorting to circular reasoning. The two other people were professional mathematicians, according to the statement.

"I didn't think it would go this far," Jackson, who currently studies pharmacology at the Xavier University of Louisiana, said in the statement. "I was pretty surprised to be published."

In the paper, Jackson and Johnson say there are two ways to present trigonometry and its functions sine and cosine, but these versions are often conflated into one. Sine and cosine are ratios that are defined in the context of a triangle's right angle, and they can be presented according to either the trigonometric method or a method that uses polynomials of complex numbers, according to the paper.

The conflation means that "trying to make sense of trigonometry can be like trying to make sense of a picture where two different images have been printed on top of each other," Jackson and Johnson wrote.

By teasing the two methods apart, researchers can discover "a large collection of new proofs of the Pythagorean theorem," the young mathematicians added.

# 'Can you predict the future? Yes, of course you can.': Inside the 1 equation that can predict the weather, sporting events, and more

By [Tom Chivers](#) [Contributions from Alexander McNamara](#) published October 12, 2024

"Life isn't chess, a game of perfect information, one that can in theory be 'solved.' It's poker, a game where you're trying to make the best decisions using the limited information you have. "



(Image credit: Yuichiro Chino/Getty Images)

Whether the sight of an equation makes you jump for joy or run to the hills, there is no doubting that so much of science is guided by the principles laid out in these [beautiful collections of symbols and numbers](#). But from medical testing to [artificial intelligence](#), one mathematical rule guides much of the modern world — Bayes' theorem.

To this day, the seemingly simple equation, developed by an 18th-century Presbyterian minister and amateur mathematician, is used in modeling and forecasting to help us

predict everything from future weather events, fluctuations in the stock market to the winners of sporting events.

The book "Everything is Predictable," by award-winning science writer [Tom Chivers](#) is a captivating tour of this curious theorem and how it impacts modern life, and has been shortlisted for the prestigious 2024 Royal Society Trivedi Science Book Prize. Below is a short excerpt from the book's introduction, which explores to what extent we can predict the future.

Can you predict the future? Yes, of course you can.

You can predict with near-certain accuracy that in the next few seconds, you'll take a breath, and let it out again. Your heart will beat, somewhere between one and three times a second. Tomorrow morning, the sun will come up, at a particular time which depends upon your latitude and the time of year but which nonetheless you can find out with great accuracy. All of these events you can predict with confidence.

You can also predict that the train will arrive at a certain time, or that your friend will arrive on time at the restaurant at which you've arranged to meet her. Though, depending on the rail company, or your friend, you might be less confident in that.

And you can predict that the world's population will continue to grow until around the middle of the century, and then start to fall again. You can predict that global average surface temperatures in the year 2030 will be higher than they were in the year 1930.

The future isn't opaque. You can see into it. Some parts are more predictable than others – the Newtonian dance of the planets we can predict out for thousands of years; the Lorenzian chaos of the weather, really only a few days. But you can peer through the murk, after a fashion.

That's not what people normally mean when they say, "I can predict the future." They are referring to something mystical, some psychic or magical vision. We probably can't do that. (You'll read about a scientist in this book who thinks we can, and you'll also read about why he's almost certainly wrong.) But we don't need to. All that we do, all the time, is predict the future. We couldn't function if we couldn't. We make very basic predictions, like "the air will continue to be breathable," implicitly, with every breath we take. We make more complex predictions, like "The corner shop will have Alpen [a breakfast cereal] when I get there," each time we make a decision. We're not basing them on mystical visions, but on information we have gathered in the past.

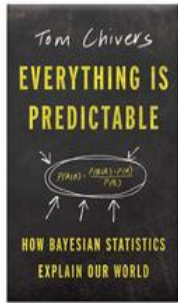
The thing with all these predictions is that they are *uncertain*. The universe may or may not be deterministic; perhaps if we had perfect, God-like knowledge of the position, movement and qualities of every particle in the universe, we could perfectly predict everything, the fall of every sparrow. But we don't. Instead, we have partial information. We can see bits of the universe, imperfectly, through our imperfect senses. We have best guesses for the way those bits move — we know the human-shaped bits tend to seek food and company; we

know the rock-shaped bits tend to sit still. We can make messy, imperfect predictions with that information.

Life isn't chess, a game of perfect information, one that can in theory be "solved." It's poker, a game where you're trying to make the best decisions using the limited information you have. This book is about the equation that lets you do that.

Excerpted from "[Everything is predictable: How Bayesian Statistics Explain our World.](#)" Copyright © 2024 by Tim Chivers.

---



**"Everything Is Predictable: How Bayesian Statistics Explain Our World" by Tom Chivers is available on Amazon for \$20.25**

"Everything Is Predictable" by award-winning science writer Tom Chivers gives a captivating tour of Bayes' theorem and its impact on modern life, from medical testing to artificial intelligence. While Bayes was an 18th-century Presbyterian minister and amateur mathematician who lived an obscure life, today Bayesian principles are widely used in modeling and forecasting.

## **This 180-year-old graffiti scribble was actually an equation that changed the history of mathematics**

By [Robyn Arianrhod](#) published October 19, 2024

In 1843, William Rowan Hamilton had a four-dimensional flash of insight that still shapes our three-dimensional world.



A photograph of the arched stone bridge that William Rowan Hamilton scratched his equation into. (Image credit: William Murphy via Flickr, [CC BY](#))

On October 16 1843, the Irish mathematician William Rowan Hamilton had an epiphany during a walk alongside Dublin's Royal Canal. He was so excited he took out his penknife and carved his discovery right then and there on Broome Bridge.

It is the most famous graffiti in mathematical history, but it looks rather unassuming:

$$i^2 = j^2 = k^2 = ijk = -1$$

Yet Hamilton's revelation changed the way mathematicians represent information. And this, in turn, made myriad technical applications simpler — from calculating forces when

designing a bridge, an [MRI](#) machine or a wind turbine, to programming search engines and orienting a rover on [Mars](#). So, what does this famous graffiti mean?

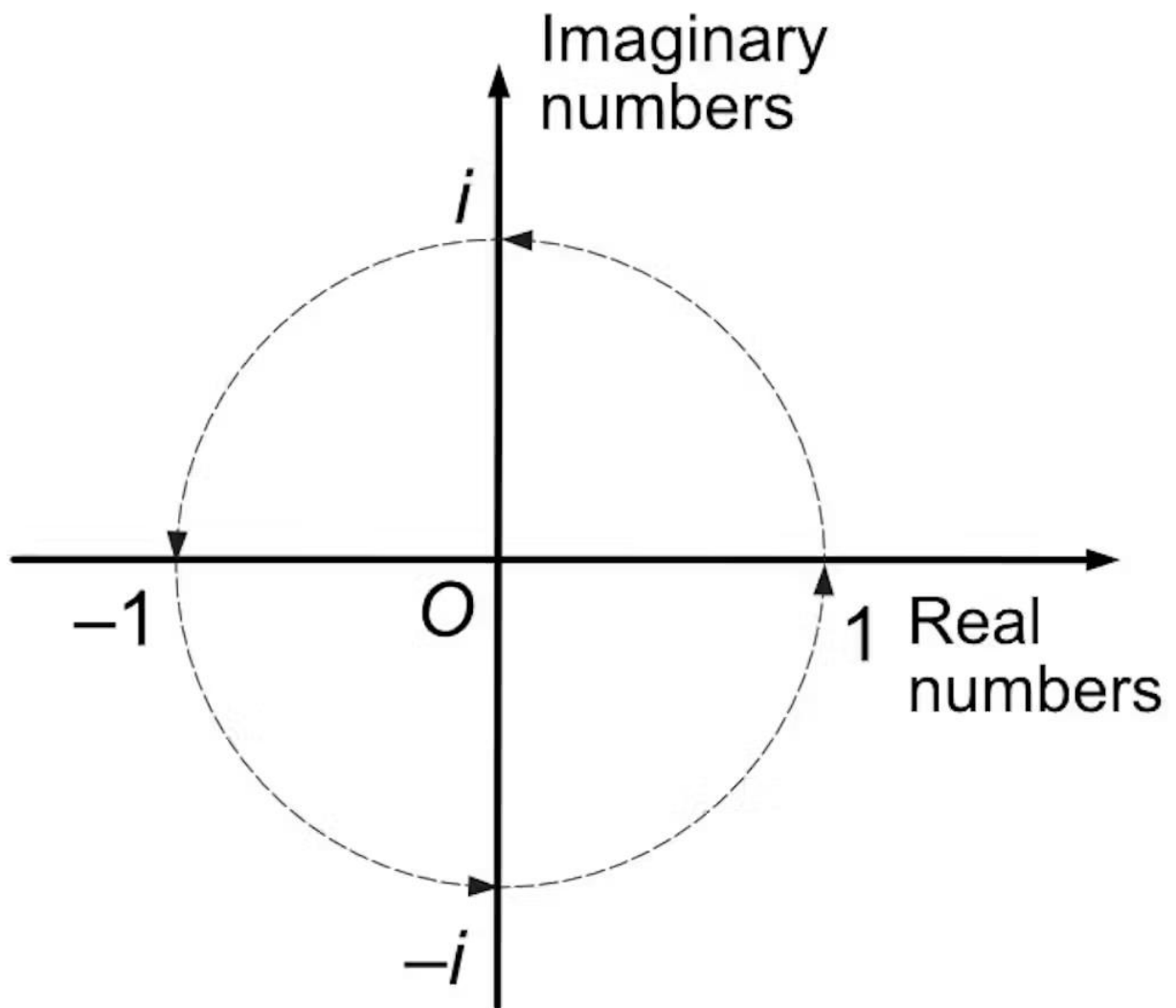
## Rotating objects

The mathematical problem Hamilton was trying to solve was how to represent the relationship between different directions in three-dimensional space. Direction is important in describing forces and velocities, but Hamilton was also interested in 3D rotations.

Mathematicians already knew how to represent the position of an object with coordinates such as  $x$ ,  $y$  and  $z$ , but figuring out what happened to these coordinates when you rotated the object required complicated spherical geometry. Hamilton wanted a simpler method. He was inspired by a remarkable way of representing two-dimensional rotations. The trick was to use what are called "[complex numbers](#)", which have a "real" part and an "[imaginary](#)" part. The imaginary part is a multiple of the number  $i$ , "the square root of minus one", which is defined by the equation  $i^2 = -1$ .

**Related: [Imaginary numbers could be needed to describe reality, new studies find](#)**

By the early 1800s several mathematicians, including Jean Argand and John Warren, had discovered that a complex number can be represented by a point on a plane. Warren had also shown it was mathematically quite simple to rotate a line through  $90^\circ$  in this new complex plane, like turning a clock hand back from 12.15pm to 12 noon. For this is what happens when you multiply a number by  $i$ .



When a complex number is represented as a point on a plane, multiplying the number by  $i$  amounts to rotating the corresponding line by  $90^\circ$  counterclockwise. (Image credit: The Conversation, [CC BY](#))

Hamilton was mightily impressed by this connection between complex numbers and geometry, and set about trying to do it in three dimensions. He imagined a 3D complex plane, with a second imaginary axis in the direction of a second imaginary number  $j$ , perpendicular to the other two axes.

It took him many arduous months to realize that if he wanted to extend the 2D rotational wizardry of multiplication by  $i$  he needed *four*-dimensional complex numbers, with a *third* imaginary number,  $k$ .

In this 4D mathematical space, the  $k$ -axis would be perpendicular to the other three. Not only would  $k$  be defined by  $k^2 = -1$ , its definition also needed  $k = ij = -ji$ . (Combining these two equations for  $k$  gives  $ijk = -1$ .)

Putting all this together gives  $i^2 = j^2 = k^2 = ijk = -1$ , the revelation that hit Hamilton like a bolt of lightning at Broome Bridge.

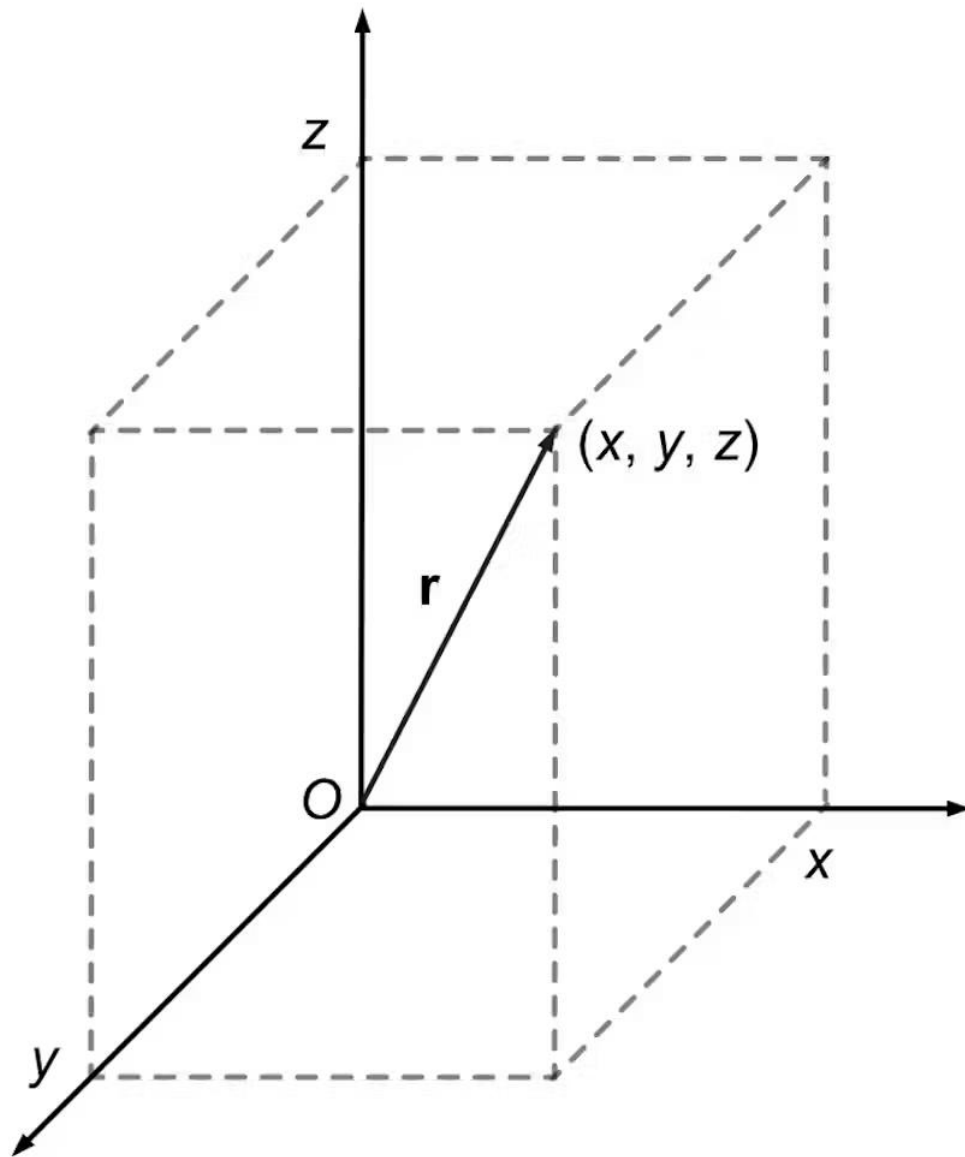
## Quaternions and vectors

Hamilton called his 4D numbers "quaternions", and he used them to calculate geometrical rotations in 3D space. This is the kind of rotation used today to move a robot, say, or orient a satellite.

But most of the practical magic comes into it when you consider just the imaginary part of a quaternion. For this is what Hamilton named a "vector".

A vector encodes two kinds of information at once, most famously the magnitude and direction of a spatial quantity such as force, velocity or relative position. For instance, to represent an object's position  $(x, y, z)$  relative to the "origin" (the zero point of the position axes), Hamilton visualised an arrow pointing from the origin to the object's location. The arrow represents the "position vector"  $x i + y j + z k$ .

This vector's "components" are the numbers  $x, y$  and  $z$  — the distance the arrow extends along each of the three axes. (Other vectors would have different components, depending on their magnitudes and units.)



A vector ( $\mathbf{r}$ ) is like an arrow from the point  $O$  to the point with coordinates  $(x, y, z)$ . (Image credit: The Conversation, [CC BY](#))

Half a century later, the eccentric English telegrapher Oliver Heaviside helped inaugurate modern vector analysis by replacing Hamilton's imaginary framework  $i, j, k$  with real unit

vectors, **i**, **j**, **k**. But either way, the vector's components stay the same — and therefore the arrow, and the basic rules for multiplying vectors, remain the same, too.

Hamilton defined two ways to multiply vectors together. One produces a number (this is today called the scalar or dot product), and the other produces a vector (known as the vector or cross product). These multiplications crop up today in a multitude of applications, such as the formula for the electromagnetic force that underpins all our electronic devices.

## A single mathematical object

Unbeknown to Hamilton, the French mathematician Olinde Rodrigues had come up with a version of these products just three years earlier, in his own work on rotations. But to call Rodrigues' multiplications the products of vectors is hindsight. It is Hamilton who linked the separate components into a single quantity, the vector.

Everyone else, from Isaac Newton to Rodrigues, had no concept of a single mathematical object unifying the components of a position or a force. (Actually, there was one person who had a similar idea: a self-taught German mathematician named Hermann Grassmann, who independently invented a less transparent vectorial system at the same time as Hamilton.)

Hamilton also developed a compact notation to make his equations concise and elegant. He used a Greek letter to denote a quaternion or vector, but today, following Heaviside, it is common to use a boldface Latin letter.

This compact notation changed the way mathematicians represent physical quantities in 3D space.

Take, for example, one of Maxwell's equations relating the electric and magnetic fields:

$$\nabla \times \mathbf{E} = -\partial \mathbf{B} / \partial t$$

With just a handful of symbols (we won't get into the physical meanings of  $\partial / \partial t$  and  $\nabla \times$ ), this shows how an electric field vector (**E**) spreads through space in response to changes in a magnetic field vector (**B**).

Without vector notation, this would be written as three separate equations (one for each component of **B** and **E**) — each one a tangle of coordinates, multiplications and subtractions.

$$\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} = -\frac{\partial B_x}{\partial t}$$

$$-\frac{\partial E_z}{\partial x} + \frac{\partial E_x}{\partial z} = -\frac{\partial B_y}{\partial t}$$

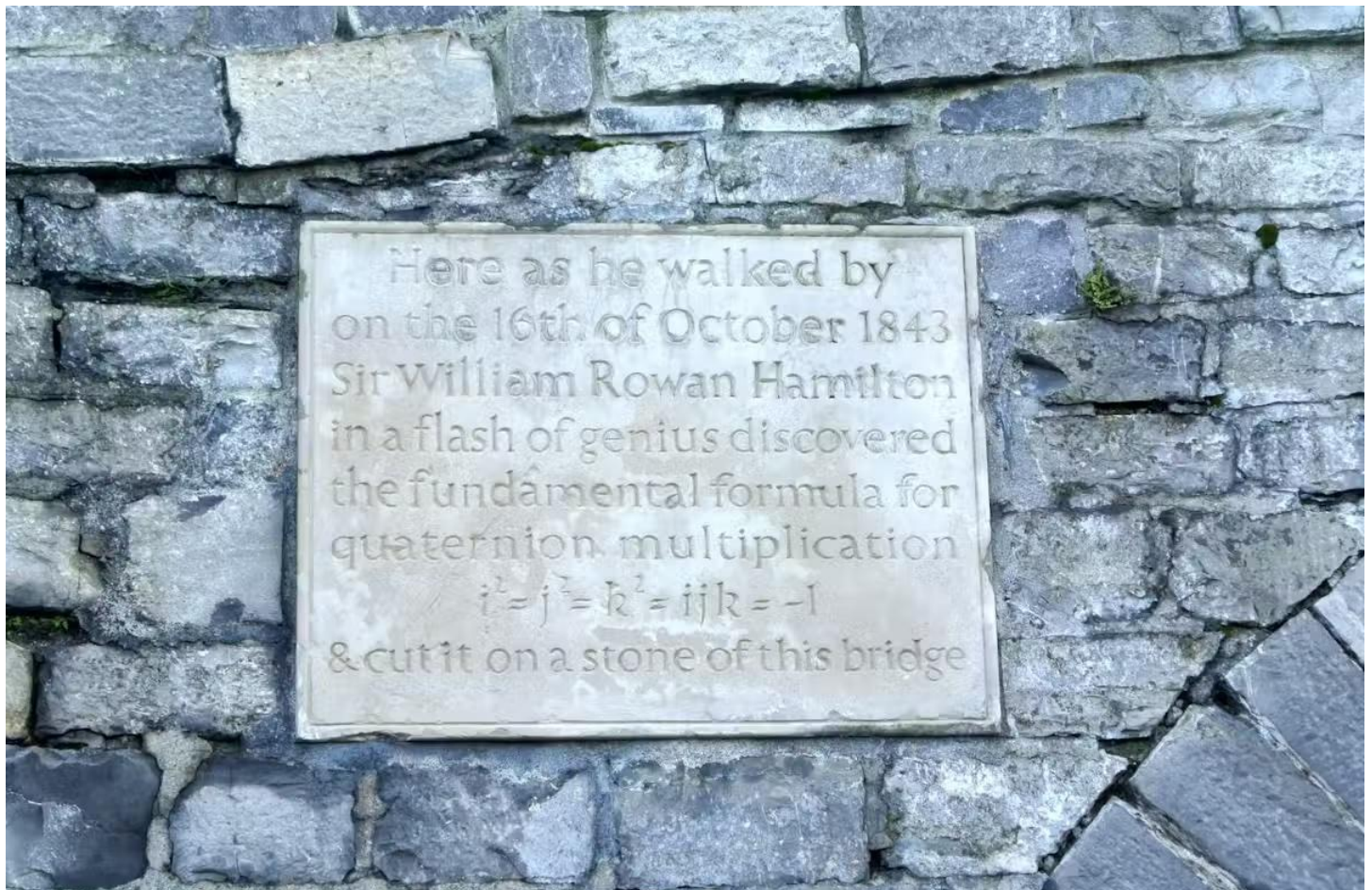
$$\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial z} = -\frac{\partial B_z}{\partial t}$$

The expanded form of the equation. As you can see, vector notation makes life much simpler. (Image credit: The Conversation, [CC BY](#))

## The power of perseverance

I chose one of Maxwell's equations as an example because the quirky Scot James Clerk Maxwell was the first major physicist to recognise the power of compact vector symbolism. Unfortunately, Hamilton didn't live to see Maxwell's endorsement. But he never gave up his belief in his new way of representing physical quantities.

Hamilton's perseverance in the face of mainstream rejection really moved me, when I was researching [my book on vectors](#). He hoped that one day — "never mind when" — he might be thanked for his discovery, but this was not vanity. It was excitement at the possible applications he envisaged.



A plaque on Dublin's Broome Bridge commemorates Hamilton's flash of insight. (Image credit: Cone83 via Wikimedia, [CC BY-SA](#))

He would be over the moon that vectors are so widely used today, and that they can represent digital as well as physical information. But he'd be especially pleased that in programming rotations, quaternions are still often the best choice — as [NASA](#) and computer graphics programmers know.

In recognition of Hamilton's achievements, maths buffs [retrace his famous walk](#) every October 16 to celebrate Hamilton Day. But we all use the technological fruits of that unassuming graffiti every single day.

# Can Quantum Physics Explain Consciousness? One Scientist Thinks It Might

Fellow scientists labeled him a crackpot. Now Stuart Hameroff's quantum consciousness theories are getting support from unlikely places.

By [Steve Volk](#)



Anesthesiologist Stuart Hameroff believes tiny structures in our cells called microtubules could explain consciousness. (Credit: Steve Craft)

Stuart Hameroff is an impish figure — short, round, with gray hair and a broad, gnomish face. His voice is smoke — deep and granular, rumbling with the weight of his 70 years. For more than two decades, he's run a scientific conference on consciousness

research. He turns up each day in rumpled jeans and short-sleeved shirts. The effect is casual bordering on slovenly. But up close, he is in charge, and to his critics, he comes off as pugnacious.

He may not care so much about how he's dressed. He cares a great deal about how he and his theories are addressed.

Hameroff is best known for serving as a kind of gadfly in the fields of neuroscience and philosophy. He emerged in 1994 from the windowless bowels of the Arizona hospital where he still works as an anesthesiologist to put forward what seemed — at the time — some of the more outlandish ideas about the human brain.

Most neuroscientists say thoughts are born from brain cells called neurons. Hameroff suggests the most meaningful action happens at the impossibly small quantum level, where subatomic particles like photons and electrons exhibit bizarre behavior. Quantum physics drives consciousness, he believes.

If Hameroff proposed these ideas himself, he might have been ignored, but his co-theorist was [Sir Roger Penrose](#), an esteemed figure in mathematical physics. Their theory, dubbed “orchestrated objective reduction,” or Orch-OR, suggests that structures called microtubules, which transport material inside cells, underlie our conscious thinking.

But the Penrose-Hameroff model of what you'd call [quantum consciousness](#) was a scientific non-starter. Leading experts dismissed the new model outright. Quantum effects, the criticism went, are notoriously difficult to maintain in the lab, requiring ultracold temperatures and shielding to protect against even the mildest interference. Critics said living things are simply too “warm, wet and noisy” to allow significant quantum effects to persist. What's more, neuroscientists argued, the Penrose-Hameroff model offered no testable hypotheses.



Mathematical physicist Sir Roger Penrose speaks at the 2017 Science of Consciousness conference. (Credit: Brad Buhr)

The pair disagreed unequivocally, churning out more papers over the years. But while Penrose's reputation is too towering to destroy, Hameroff seemed to find his firmest footing through pop culture. He embraced support from Deepak Chopra, an author and New Age guru of quantum consciousness theories. He was also featured in *What the Bleep Do We Know?*, a film that angered scientists for pushing a quantum mysticism that underlies our nuts-and-bolts existence.

Along the way in 2006, Hameroff gave a talk that encapsulated his relationship with the scientific community. At a conference called "Beyond Belief" that was packed with leading luminaries from many disciplines, he presented his theories on everything from consciousness to a quantum mechanics-based "spirituality." At the end, prominent physicist Lawrence Krauss spoke from his seat in the audience. "From a physics perspective," he said, "everything you said is nonsense."

Many regard Hameroff as nonsensical, a creature from a Lewis Carroll story calling out from under a toadstool that we've got it all wrong, that some kind of quantum magic undergirds our brain function.

But just four years later, a shift was underway. In 2010, Hameroff was invited to speak at a less public meeting, at Google's campus in Mountain View, California. His presentation suggested he might have a firmer view of reality than some may have thought.

Hameroff and several other scientists were invited by Hartmut Neven, a Google researcher in visual search technologies. By then, scientists were already trying to tap the laws of quantum physics to build **smaller, smarter computers**. And biologists had begun to suspect quantum physics could be important to processes like photosynthesis and migration using Earth's magnetic field. Neven says he was interested in Hameroff's research because understanding the brain's efficiencies could bring huge cost savings for Google.

"I think it is rather remarkable that the human brain is able to accomplish its tremendous feats on just a spoonful of sugar a day," Neven says.

A funny thing happened on Hameroff's trip through the weedy fields of scientific derision: Data appeared.

The data isn't enough to confirm Orch-OR, but the new findings suggest some of Hameroff's claims are more plausible than previously supposed. Furthermore, the microtubule — the tiny structures that Hameroff thinks house quantum operations in the brain — is suddenly a hot subject. And two researchers are finding that the old anesthesiologist might be right: Quantum physics might be vital to our awareness, cognition and even memory.

---

## The Hard Problem

Despite Hameroff's controversial standing in the scientific community, the conferences he hosts remain a good get for neuroscience researchers and philosophers. At his first consciousness conference in Tucson, Arizona, in 1994, a young philosopher named David Chalmers — a leather-jacketed Australian, then topped by the long, shaggy hair of a heavy metal fan — made waves with a new interpretation of an ancient question.

Chalmers argued that some problems associated with cognitive studies are relatively "easy" to solve. Most information processing, such as driving a car, is mere computation. And for this, firing neurons suffice. The "hard problem," he says, is the existence of **consciousness itself**. The same wiring in our brain lets us enjoy eating an

apple and also lets us imagine eating one when no actual apple is around. Science can't explain precisely how. Theories already abounded, and researchers like neuroscientist Christof Koch — partnered with Francis Crick, the co-discoverer of the DNA molecule — sought what he called the neural correlates of consciousness.

But where most stuck to orthodox understandings of physics and neuroscience, Hameroff came in touting his more out-there ideas.

During the 2016 Tucson Science of Consciousness Conference, Hameroff was treated with the respect accorded a conference organizer and also made the butt of occasional jokes. Audible groans could be heard in the audience, for instance, when Hameroff took the microphone and related whatever was just presented back to his own theory.

But over lunch, on a particularly hot day at the conference's midpoint, Hameroff sought a seat in the shade and argued that he merely gives as good as he gets: His critics may couch their judgments in academic niceties, he says, but essentially they're saying he wasted his career in a wrong-headed attempt to steer neuroscience into sheer speculation and quantum woo.

"Roger is still on board," he says of Penrose. "To be honest, we kind of feel like we're riding high."

Penrose remains committed to what the pair has co-published over the years — the theoretical science. They differ off the page. Penrose has been mostly mum on the philosophical implications of their theory. Hameroff has freely speculated on what it all means. For instance, he posited that near-death experiences might reflect something real: a potentially short-lived quantum afterlife.

The challenge, then, is to set aside Hameroff's speculations and look instead at what he and Penrose have published, and how this odd couple came to be partners in the first place.

Hameroff's biography, and at least some of his claims, are more firmly rooted in science than his critics normally allow.

## Carnival Barker's Son

Hameroff was born in 1947 in Buffalo, New York. His father, Harry, performed as a carnival barker and as a comedian in burlesque theater and vaudeville. His grandfather Abraham was a huge influence on him. He'd buy the young Stuart books on science

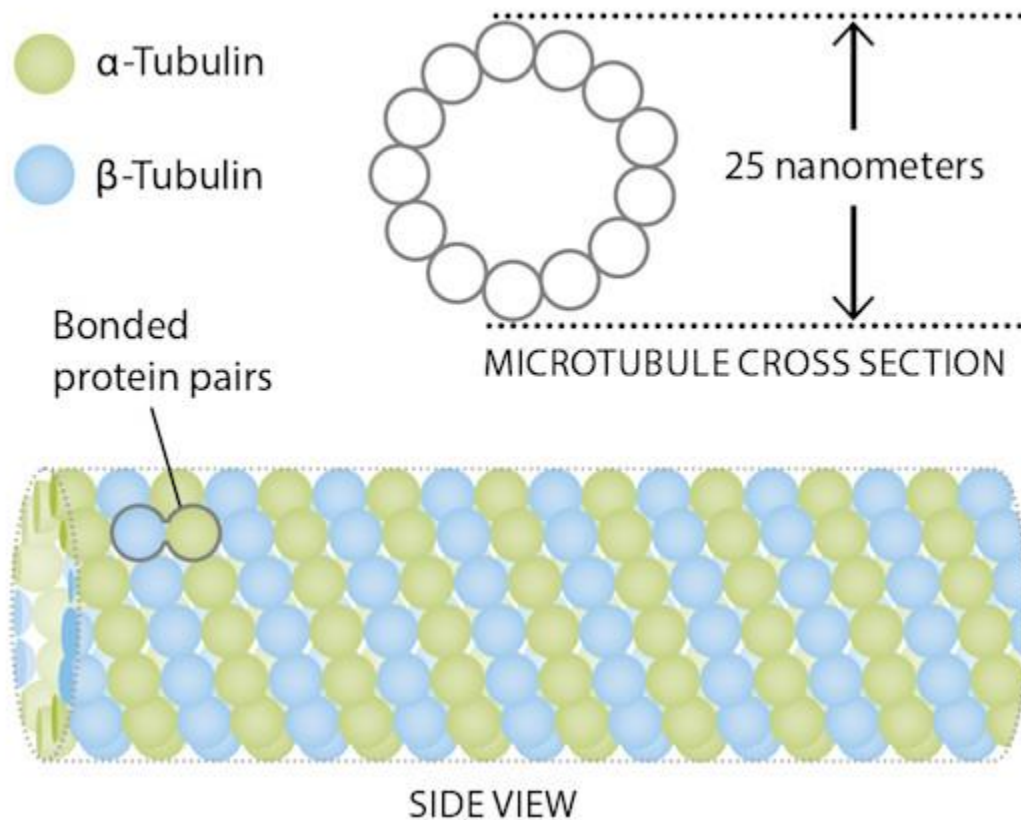
and teach him about Einstein. “He was kind of an intellectual dilettante,” says Hameroff. “He knew a lot about a lot.”

When it was time to pursue a higher education, Hameroff was already deeply interested in the “mind-body problem”— in essence, Chalmers’ “hard problem” before he coined the term.

Hameroff chose medical school, but finding a specialty eluded him. Neurology? Psychiatry? During an internship at the Tucson Medical Center, the chairman of the anesthesiology department told him that anesthesiology was key to understanding consciousness. So Hameroff investigated, and his career in anesthesiology quickly took shape.

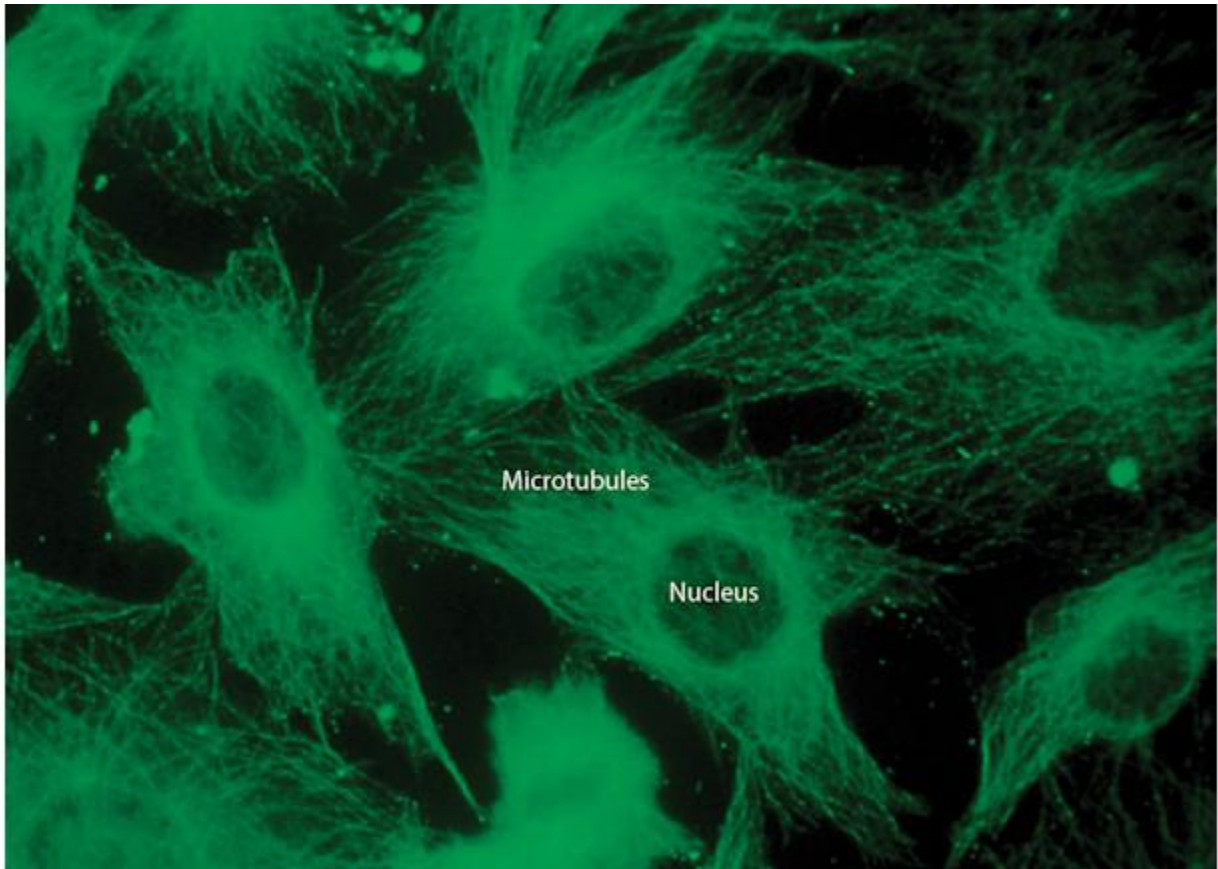
Hameroff says that a patient under anesthesia exhibits relatively normal brain function save one thing: consciousness. Neurons keep firing, and even pain signals travel their normal routes. But that pain is never felt, never experienced. The science of anesthesia sits right at the heart of the hard problem — allowing “easy” computational processes to continue while selectively eliminating subjective experience. But no one knows quite how.

Early on in his career, Hameroff suspected microtubules might provide an answer. Microtubules were discovered by accident in the 1960s. Over the coming decades, they proved to be among the most versatile biological structures in nature. Tubulin, a flexible protein, assembles into a long chain to create microtubules. These 25-nanometer-wide tubes — thousands of times smaller than a red blood cell — are found in every cell in plants and animals.



These hollow, cylindrical structures are made up of two types of tubulin protein — dubbed alpha and beta — which bond together into a single unit. These units assemble themselves into chains, forming the microtubule. Found in every plant and animal cell, microtubules serve a variety of purposes, from support structures to conveyor belts, and perhaps even the seat of consciousness. (Credit: Alison Mackey/Discover)

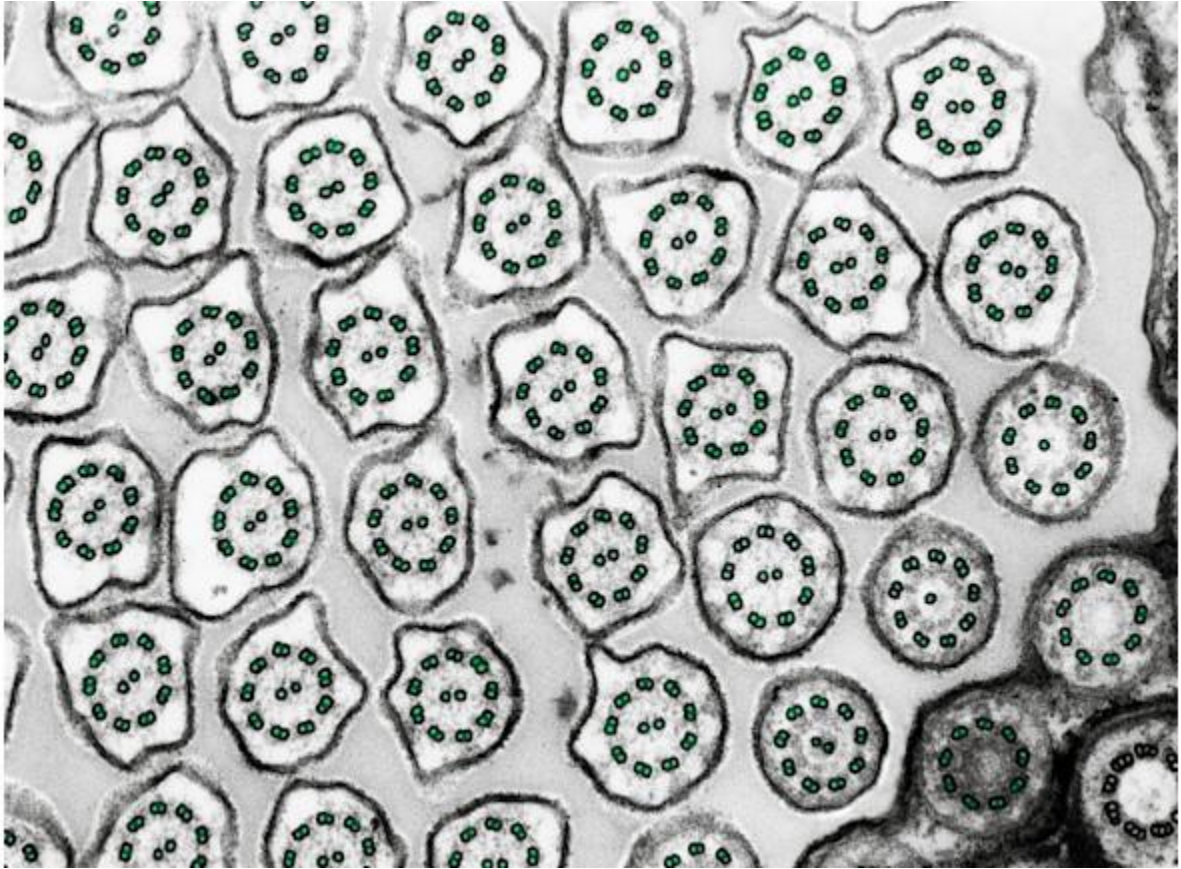
Microtubules act as the crucial cytoskeleton, supporting the structure of living cells; as conveyor belts, moving chemical components from one cell to another; and as movers themselves, taking on different formations and dividing chromosomes. During cell division, microtubules move chromosomes from one end of the cell to the other, then position the chromosomes in the new daughter cells. Microtubules even come into play on the outside of cells, forming into cilia and flagella that allow for cell movement. That makes these structures something like the Transformers of biology.



A special fluorescence microscope reveals the cytoskeletal structures that help give shape and mechanical support to cells. This cytoskeleton is largely made from the tubulin proteins that form microtubule filaments. (Credit: Gopal Murti/Science Source)

Hameroff came to believe the microtubule plays a defining role in anesthesia effects — in consciousness. He points to the single-celled paramecium as evidence. “The paramecium has no central nervous system,” he says. “No brain, no neurons, but it swims around, finds food, finds a mate and avoids danger. It seems to make choices, and it definitely seems to process information.”

How? Or more to Hameroff’s point, where? In what part of the paramecium does this crude kind of cognition take place? Hameroff believed he could find the answers in the paramecium’s only internal structure: microtubules, the paramecium’s cytoskeleton. And since these are nanoscale structures, he also began thinking that quantum physics might play a role. But throughout the 1980s, his research got nowhere in terms of public recognition. Then, one night in 1990, he sat down to read Penrose’s book *The Emperor’s New Mind*, a surprising best-seller that winds through physics, cosmology, mathematics and philosophy before marking a final, slam-bang stop at consciousness.



(Credit: Dennis Kunkel Microscopy/Science Source)

In his concluding pages, Penrose wonders how firing neurons generate experience. He opines that quantum physics might be necessary to understand consciousness.

But where in the body — an inhospitable place for delicate quantum perturbations — could such happenings take place? Hameroff felt an immediate connection to Penrose. And of course, he thought microtubules held the answer.

From afar, the two seemed like an odd pairing: Penrose is one of the more respected scientists of the last half-century, and his work in cosmology and general relativity has garnered him high honors. Hameroff was a relative unknown, shouting about an obscure biological structure. But within a few years, they were co-authoring papers together, and drawing the scorn of a generation of fellow scientists.



Single-celled organisms like this paramecium appear to process information even without a brain or neurons. Hameroff thinks microtubules might explain how. (Credit: Ted Kinsman/Science Source)

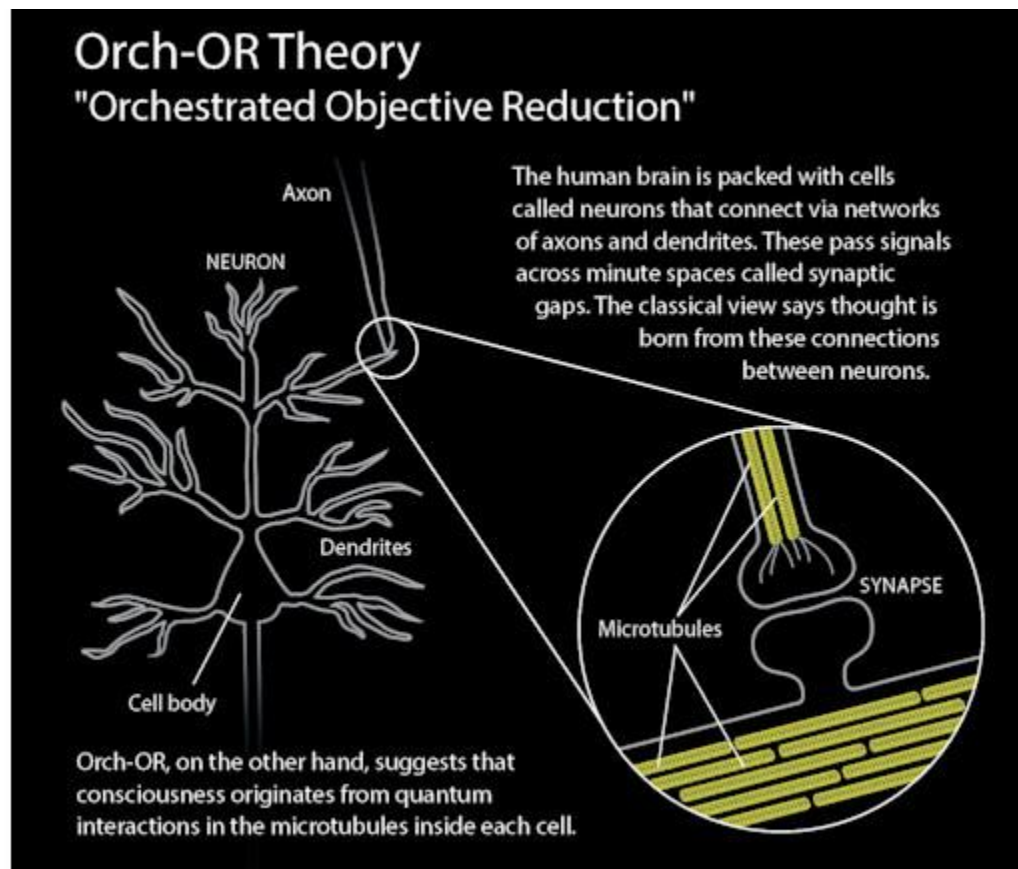
## Data Arrives

In sum, Orch-OR proposes that consciousness originates from microtubules and actions inside neurons, rather than the connections between neurons. Whack a tennis ball with a racket, and afterward you can use traditional physics to predict where it is at any particular point. But in the quantum realm, such expectations go out the window. Movements are unknown until they're observed, according to the traditional interpretation of quantum mechanics. Physicists refer to this final observation, which determines what happened, as a wave "collapsing" into a single state.

In quantum systems inside the neuron, Hameroff and Penrose argue that it's each collapse of the wave function that yields a conscious moment.

Hameroff and Penrose were guilty of invoking one mystery to solve another: We don't understand consciousness, and we don't understand quantum physics, so maybe they explain each other?

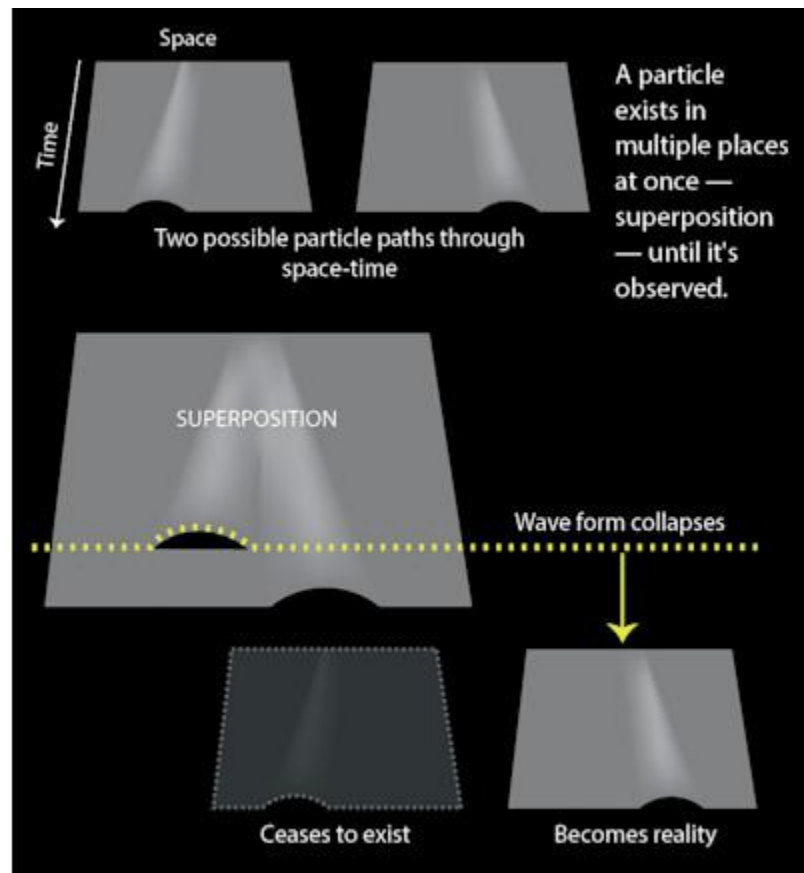
So Orch-OR was and remains vulnerable to attack — and many do so with tremendous gusto. Two decades ago, neurophilosopher Patricia Churchland and physicist Max Tegmark were among those who launched outright broadsides. Hameroff and Penrose responded, and Hameroff published a list of 20 testable predictions yielded by Orch-OR.



This theory of quantum consciousness developed by Stuart Hameroff and Sir Roger Penrose suggests that tiny cellular structures called microtubules underlie conscious thought. (Credit: Alison Mackey/Discover)

However, the greater theory serves as something of a distraction from some of Hameroff's ideas: that quantum physics might play a non-trivial role in human cognition and consciousness, and that microtubules — activity inside the neuron — could house these quantum happenings.

"If you would have speculated in this direction, say, 10 years ago, you would have been labeled a crackpot," says Google's Neven.



Traditional quantum mechanics says that a physical system doesn't have definite properties until it's observed — an act known as collapsing a wave function. For example, in Erwin Schrödinger's classic thought experiment, a cat in a box is both dead and alive — known as superposition — until observed as one or the other. So an observation, or consciousness itself, causes the wave to collapse. OR proposes the opposite: The collapse gives rise to consciousness. (Credit: Alison Mackey/Discover)

But researchers recently have found quantum effects are important for certain biological processes, like photosynthesis. When a photon strikes an electron in a leaf, the electron delivers it to another molecule dubbed the reaction center, which converts that light into chemical energy to feed the plant. Scientists always thought the process looked almost too efficient because very little excess energy is lost in the process.

Then in 2007, researchers started to suspect quantum physics was behind this efficiency. The electron could use the quantum effect of superposition, where a particle can be in two places at once, to test several routes to the reaction center where photosynthesis takes place, and take the most efficient one. The concept isn't yet proven, but it has gained traction. Neven says scientists are now careful not to dismiss such ideas outright.

For example, in a recent *Nature Physics* paper, physicist Neill Lambert of the Advanced Science Institute in Japan called out new photosynthesis research as remarkable just for suggesting quantum effects can happen in biological systems at room temperature.

And most recently, Rod Eckenhoff, a University of Pennsylvania researcher and Hameroff critic, gave tadpoles anesthetics to tease out what molecules they bind to. His team discovered that tubulin proteins were among them, and then found that if a kind of reverse agent were administered — a microtubule-stabilizing drug — so were the anesthetic effects. He remains a critic of Hameroff's "speculative" theories, but says his research suggests microtubules might play "some role" in consciousness.

Yet Hameroff remains controversial. Koch, the brain researcher and consciousness expert, declined to comment, saying he doesn't want to be the "eternal critic" everyone goes to for takedowns of the Hameroff-Penrose theory. But some are coming around.

"I was always quite skeptical of Stuart's claims about microtubules," says Anthony Hudetz, a neuroscientist in the anesthesiology department at the University of Michigan. "But now there is data. And I have to say, I think Stuart does have some momentum now."

Hudetz sees microtubules as a good potential mechanism for explaining anesthesia. "I have the feeling that this whole microtubule theory has matured actually quite nicely," he says. For Hudetz, the key going forward is testing whether molecular events inside microtubules actually relate to the quantum events as Hameroff proposes.

And now, two scientists working independently of one another, yet both openly inspired by Hameroff, are taking microtubule research to a whole new level.

## Inside The Neuron

Anirban Bandyopadhyay summarized his research in a talk at Hameroff's 2016 Science of Consciousness conference. Six feet tall and slim with dark, black hair and a broad, joyful smile, Bandyopadhyay enjoys a plum job for a scientist in his early 40s, leading his own research group at the National Institute for Materials Science (NIMS) in Japan. As a physicist, he's studied the inner workings of both natural and artificial brains. To understand brain function, Bandyopadhyay believes scientists must understand the workings inside the neuron, including the microtubule.

The conventional view is that neurons fire when a channel within the cell membrane opens, flooding the neuron with positively charged ions. Once a specific threshold is reached, an electrical signal travels down the axon — the nerve fibers within the neuron — and the neuron fires. Axons are long wires that connect neurons to other cells. And inside each axon is a bundle of nanowires, including the microtubule.

Bandyopadhyay found that he could apply one of these specific charges to the microtubule, causing activity to build up in the neuron. By allowing the current to continue, he could cause the neuron to fire, or — by cutting the signal off — stop it from firing altogether.

He says this bundle of nanowire resonates like a guitar string, firing thousands of times faster than normal activity in a neuron. The neuron, he thought, contrary to all current scientific understanding, wasn't the essential, or first cause of the human thought process.

"[Neuroscientists] need to go deeper — into the microtubule," he says.

To Bandyopadhyay, modern brain science's emphasis on the neuron is misguided. Brash at times, he refers to neuroscience as akin to dermatology.

"The neuron is the skin," he says. "It's important, yes, but not everything."

## Fringe or Frontier?

Bandyopadhyay's 2013 work on the microtubule required refitting a special microscope and contracting with an outside firm to create a needle with a 1-by-1-nanometer point — the smallest ever constructed, Bandyopadhyay says. His team used it to peer inside the microtubule with incredible precision.

Bandyopadhyay inserted the needle into a rat neuron to view the microtubule. As he did, monitors on one wall in the room flickered with images from the tiniest level of animal biology. The next set of experiments was to apply various electrical charges and watch the "skin" of the neuron as well as the inside of the microtubule. At first, nothing happened. But when he began applying specific energy charges to the microtubule, it responded, vibrating and conducting the electricity. This was curious, and exciting.



Anirban Bandyopadhyay, a physicist who studies both artificial and natural brains, has been applying currents to microtubules to see how they react. (Credit: Brad Buhr)

A microtubule is composed of many individual subunits. If they operated in a purely classical fashion, as insulators — like wood, glass and other common materials that stop electrical current from flowing freely — the amount of resistance across the microtubule should increase. But Bandyopadhyay found something very different when he applied specific charges of alternating current. Resistance levels jumped by a factor of 1 billion. The microtubule was acting something like a semiconductor, one of the most important developments in electronics. He stood there in wonder at his own results.

“When you get results like this,” he says, “you are scared. Am I wrong somehow?”

But he checked, even having colleagues outside his lab at NIMS look over his results. In subsequent experiments, he saw that this conducting activity in the microtubule preceded neuronal, or membrane-level, firing. His microtubules research appeared in the journal *Biosensors and Bioelectronics*. And he has another study still under peer review.

The findings still need to be replicated by other scientists. But those touting Bandyopadhyay's findings are philosophical about his standing.

"If you're looking for frontier science, you have to drive out to the edge of what's known," says David Sonntag, a toxicologist who formerly worked in Tokyo for the U.S. Air Force's research and development wing and helped fund some of Bandyopadhyay's research.

"If you take a wrong turn," he says, "you'll run into its crazy next-door neighbor, fringe science. The issue is understanding when you're at the bifurcation point. When does the fringe become the frontier?"

For now, Bandyopadhyay remains clearly on the fringe. But he has brought something new to the debate: an experiment that can be replicated, or not, and a different perspective on Hameroff.

He is careful to distance himself from Hameroff's larger theory of consciousness. "This is not my concern," he says. Still, he describes Hameroff as a father to his own research. "This man was talking about microtubules back in 1982," he says. "Just thinking about them, unable to study them as I have, he *knew*, and so far ahead of everyone else. I wondered, 'What kind of brain has he got?'"

## A Circuit's Missing Element

There is also another far more experienced scientist working the same vein of research and seeing dramatic results regarding the microtubule.

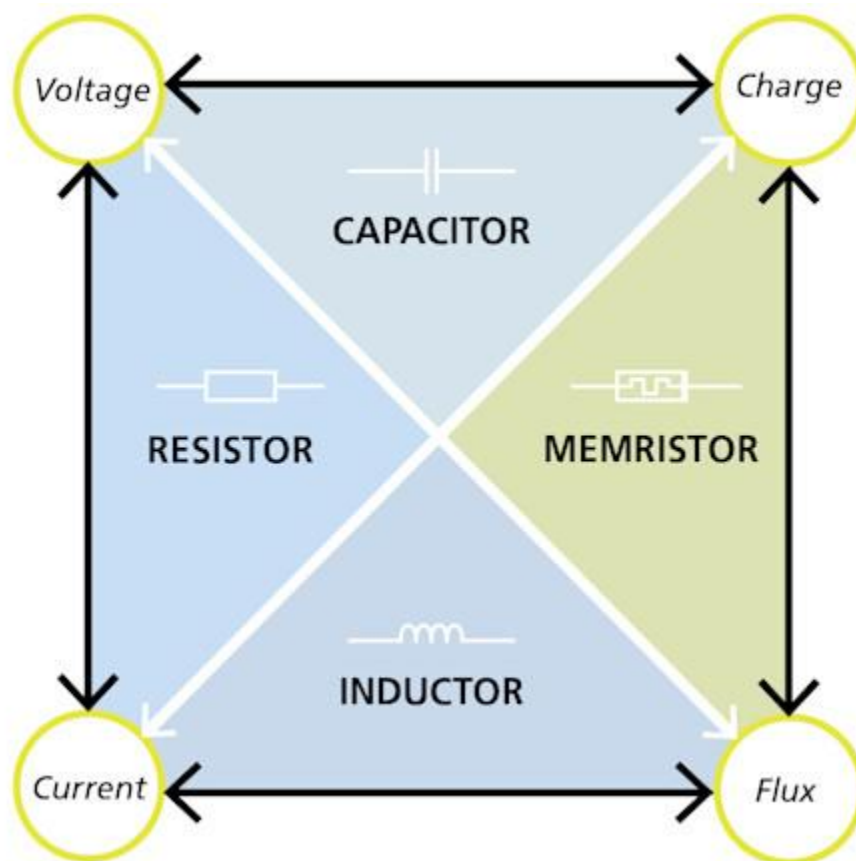
Jack Tuszynski, a biophysicist at the University of Alberta, is a longtime Hameroff collaborator who creates cancer drugs. His latest findings suggest microtubules have interesting conductive properties, but indicate they could also be what are called "memristors." The memristor is the much sought-after fourth element in an electrical circuit, first theorized by Leon Chua, an electrical engineer at the University of California, Berkeley.

Chua spotted something obvious. The three existing circuit elements — resistor, capacitor and inductor — depend on relationships between pairs that control how electricity flows, how it gets stored and how it changes as it moves through a circuit:

- resistor (voltage + current)

- capacitor (voltage + charge)
- inductor (magnetic flux + current)

By studying the pairs, Chua theorized there should be a fourth circuit element governing the relationship between the “missing” pair — charge and flux. Chua coined the term *memristor*, playing off the words *memory* and *resistor*, and from there his work was strictly mathematical. If such a circuit element existed, what would it do? Chua’s equations suggested that a memristor’s electrical resistance, or conductivity, would not be constant, like a lightbulb’s, but dynamic, and determined by the history of the current that had flowed through the device.



Electrical circuits use four fundamental variables — current, voltage, charge and magnetic flux-linkage. Relationships between these variables led to the classic components of a circuit — resistor, capacitor, inductor — with the exception of one pairing: charge + flux. The memristor fills this hole, creating a fourth circuit element that would operate like a resistor with memory. (Credit: Alison Mackey/Discover)

What's the big deal? In transistors, any interruption in the flow of electrons results in data loss. Memristors, however, incorporate both electron flow and ions — electrically charged atoms.

Because they remember the charge that previously passed through the material, information could be retained even when turned off. In computers, the innovation means no more rebooting. Computers would turn on like lightbulbs, and hard drives would become a thing of the past.

The race is on to build memristor chips at a cost scalable to consumer computers, and for good reason: Memristors require perhaps 1 percent of the energy of a standard chip. And while standard computer chips are limited to the binary code of 0s and 1s, memristors deal in fractional units of information — a development considered key in building computers that behave like the human brain.

Tuszynski wasn't familiar with memristors until he met Chua at a 2015 conference in India. "I think microtubules are memristors," Chua told him, revealing a longstanding interest in Hameroff's work. Chua was particularly struck, he says, when he once heard Hameroff point out that microtubules are ubiquitous in nature, while neurons are not. This insight — really, a simple statement of fact — struck Chua as crucial. "All of these biological systems engage in a kind of information processing," he says. "So how do they do it?"

He thought Hameroff had found the answer in microtubules.

Tuszynski is very different from Hameroff, his longtime research collaborator. Stolid and practical, he's published more than 400 papers in peer-reviewed publications, toiling in the earthy fields of precision medicine and computational biology. "Stuart, I think, is very prone to speculation," he says. "In many respects, he is his own worst enemy and would be better off if he limited himself a bit. But Stuart is a genius. His work on microtubules, prior even to ever getting involved with Penrose, is brilliant, and it is the reason I work on microtubules today."

To test the memristor theory, Tuszynski's team filled a dish with microtubules, tubulin proteins and a buffer solution, then added electricity. Over the course of many weeks, he found a fascinating result. The more he replaced the buffer solution with more microtubules, the better the conductance.

“The conductance increased by two- or threefold with the increased presence of microtubules,” says Tuszynski, suggesting the microtubules were better at conducting energy than the buffer solution.

Further, he found the signature memristor effect: When he reversed the flow of electricity, as in an alternating current, the efficiency of the conductance increased, as if the microtubule had remembered the current that previously passed through it.

Tuszynski’s lab published a paper last summer on the conductive properties of microtubules in *Nature Scientific Reports*, and it is preparing a paper on microtubules as memristors. If these results hold up, it could support Hameroff’s case.

## The Quantum Realm

The last morning of the conference in Tucson, Hameroff slowly rolls a suitcase out to the lobby and plops down in a lounge chair to handle a few more administrative duties.

“I think it went well,” he says. “People are telling me they enjoyed it. I organized this, so that could be bullshit. But I think they mean it.”

This being a Hameroff production, there was a fair amount of combat. Chalmers accused Hameroff of taking the conference too far into the quantum realm.

Hameroff has a ready response. He was able to include so many quantum-oriented conference sessions, he says, because quantum biology is a growing field.

Of course, none of this is to say that Hameroff wins this debate. He has yet to reframe fringe as frontier, and he may never. But in this moment, with scientific success being in part a simple function of math — is an idea gaining or losing adherents? — he is clearly on the way up, and that is perhaps never so apparent as when he gets up to leave.

With one hand on the handle to his luggage, he is immediately stopped. Hudetz, the anesthesiologist who was once dismissive of Hameroff, walks over to say hello. He tells his host, with seeming earnestness, “It was a very good conference, Stuart. I had a great time.”

Hameroff thanks him. They banter a bit, and Hudetz turns to walk away. “You know,” says Hameroff, stopping him, “you ought to do some research on microtubules.”

“It’s funny you should say that,” Hudetz replies. “Because we’re talking about it in my lab. There’s some interest. We might just do that.”

## **New theory challenges Big Bang, dark matter, and dark energy in the birth of the universe**



A physics professor has proposed a bold new idea: the universe didn't begin with one Big Bang. (CREDIT: Shutterstock)© The Brighter Side of News

In the search to understand how the universe came to be, a new theory is rewriting the script. Instead of one massive, fiery birth like the [Big Bang](#), this idea suggests the cosmos has been growing in sudden, powerful steps — invisible, lightning-fast bursts that shake the very foundation of physics.

These events, called temporal singularities, may hold the key to the mystery of how galaxies form and why the universe keeps expanding faster and faster. Most importantly, this theory dares to explain it all without relying on dark matter or dark energy — two invisible forces that scientists have been hunting for decades but have yet to find.

## A New Way to Picture the Universe

Dr. Richard Lieu, a physics professor at [The University of Alabama in Huntsville](#), believes that cosmic history is shaped not by one beginning but by many. In his recent paper published in [Classical and Quantum Gravity](#), Lieu offers a bold alternative: the universe unfolds through a sequence of energy spikes — rapid bursts in time that ripple across all of space. Each burst floods the universe with



matter and energy, kickstarting expansion and helping to build the vast structures we see today.

Dr. Richard Lieu, a physics professor at The University of Alabama in Huntsville. (CREDIT: The University of Alabama in Huntsville)© The Brighter Side of News

“The new model can account for both structure formation and stability, and the key observational properties of the expansion of the universe at large,” Lieu explains. These bursts, or singularities, “uniformly affect all space” and replace the need for the invisible stuff cosmologists have long assumed fills the cosmos.

This model builds on Lieu’s earlier work from 2024, which proposed that gravity might not always need mass to operate — an idea that sparked intense discussion and drew over 41,000 reads. That version also attempted to explain the way [galaxies stay together](#) without using dark matter.

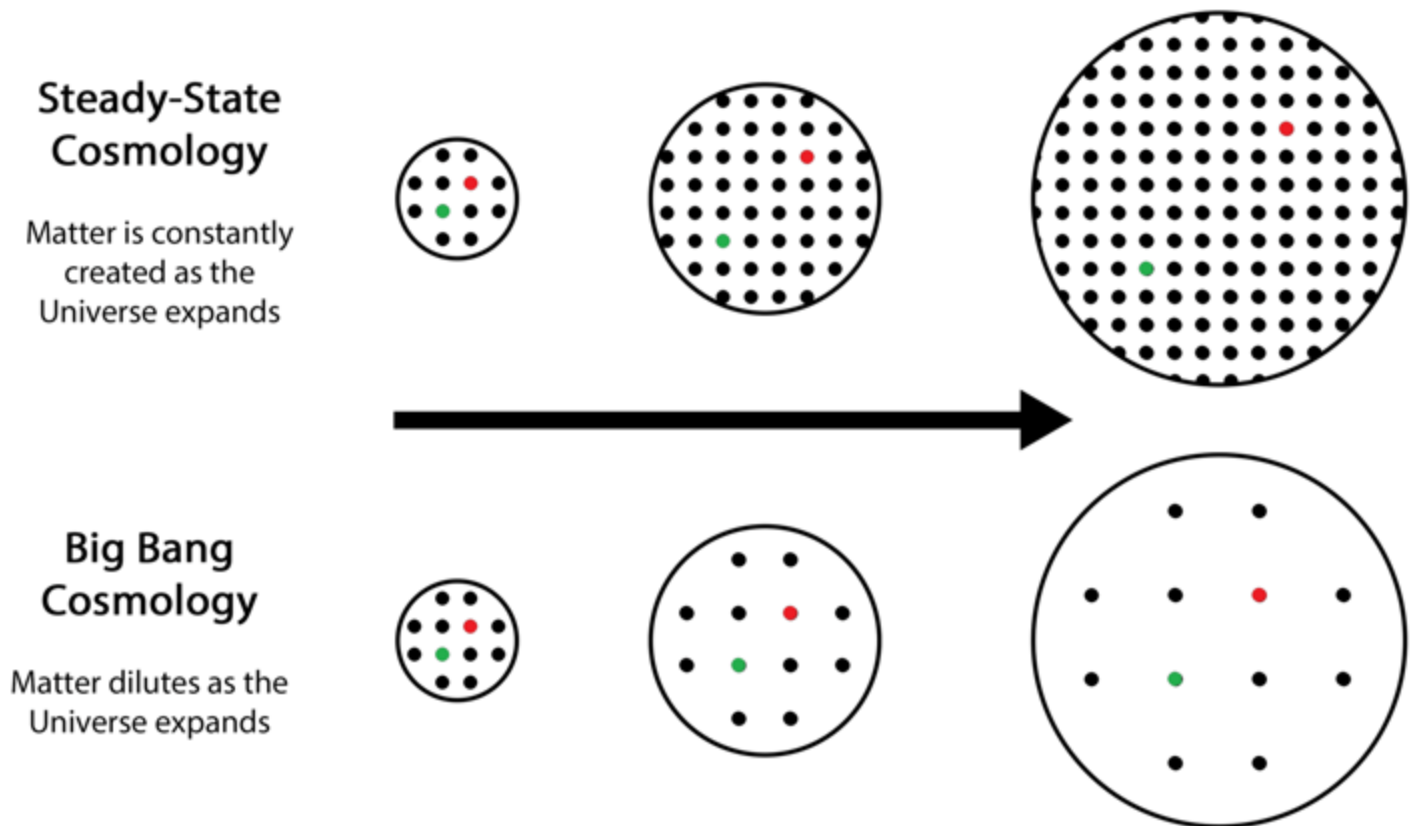
But the earlier model relied on a concept known as “negative density.” While mathematically useful, negative density remains hard to explain in real-world terms. The newer version drops that piece while still solving the same puzzles — and more.

## Unseen Bursts That Shape Space

These temporal singularities happen so quickly and so rarely that they’re impossible to detect with current tools. But their impact may be enormous. Like the spark of the Big Bang, they bring matter and energy into existence — but unlike the Big Bang, they don’t break the laws of physics.

Lieu points out that this is what separates his model from earlier alternatives. British astronomer Sir Fred Hoyle once argued against the Big Bang by proposing a [“steady-state” universe](#), where matter is continuously created as space expands. That idea was appealing but flawed — it violated the law of mass-energy conservation.

Lieu’s theory, in contrast, holds that matter and energy appear and disappear suddenly — but always in a way that follows the rules. “Interestingly enough, there is no violation of conservation laws,” he says. “These singularities are unobservable because they occur rarely in time and are unresolvedly fast.”



"Steady-state" universe, where matter is continuously created as space expands. (CREDIT: Artistosteles)© The Brighter Side of News

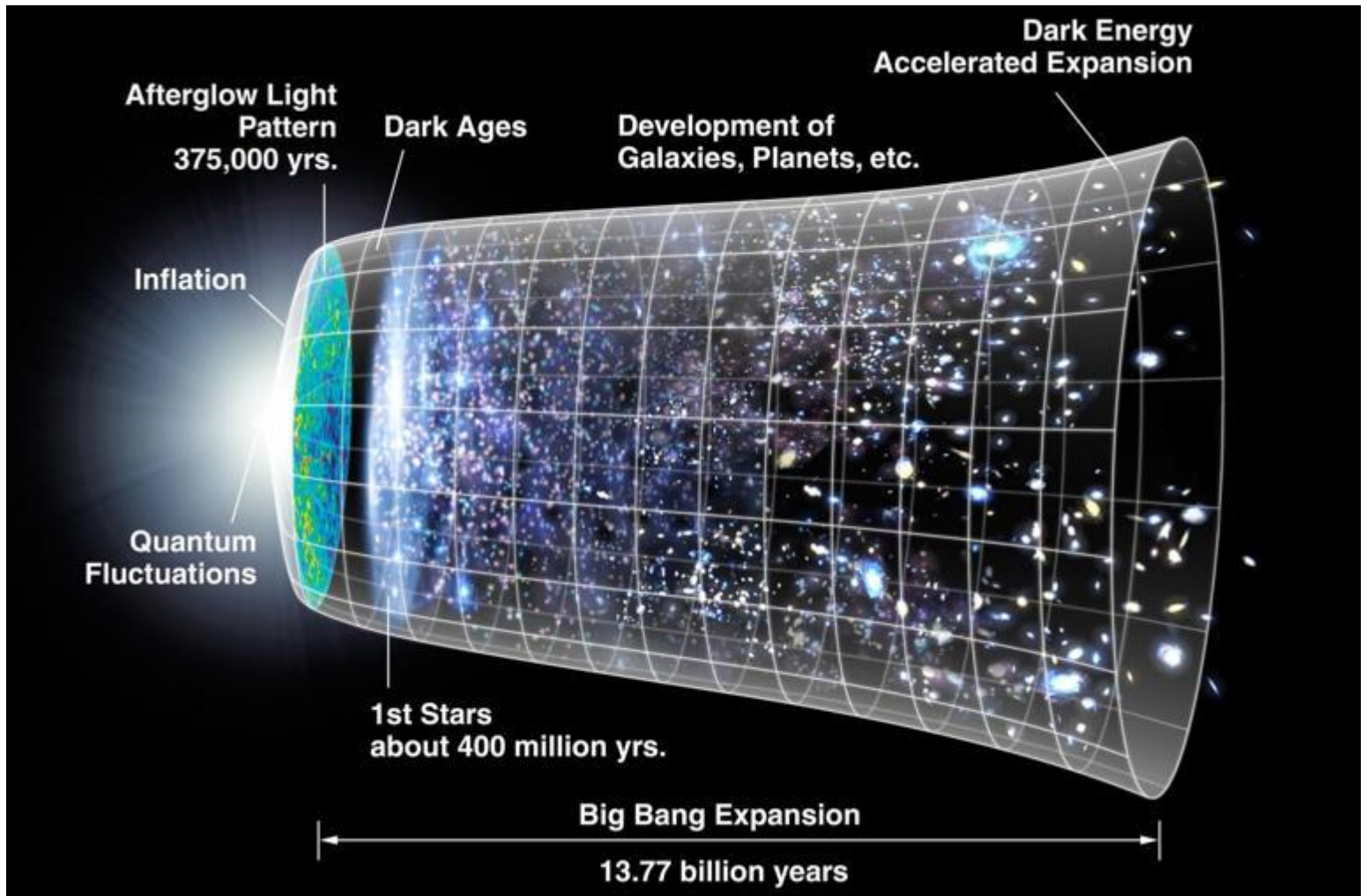
The origin of these bursts remains unknown, just like the exact cause of the Big Bang. But that uncertainty doesn't make the model weaker. In fact, it might make it more realistic.

## Pressure That Pushes the Universe

Lieu's model explains more than just how matter forms. It also tackles why the universe keeps expanding at an accelerating pace — a phenomenon usually blamed on [dark energy](#).

The answer lies in something called negative pressure. Unlike the kind of pressure you feel from a tire or water pipe, negative pressure has a strange effect in space. It pushes out instead of in. That makes it a perfect candidate to drive the universe's runaway expansion.

"An example is the negative pressure exerted by a [magnetic field](#) along a field line," Lieu says. He notes that even Albert Einstein considered negative pressure in his 1917 work on the Cosmological Constant — the first known attempt to explain why the universe doesn't collapse under gravity.



In cosmology, the cosmological constant (usually denoted by the Greek capital letter lambda:  $\Lambda$ ), alternatively called Einstein's cosmological constant, is a coefficient that Albert Einstein initially added to his field equations of general relativity. (CREDIT: NASA/WMAP Science Team) © The Brighter Side of News

When positive mass-energy is paired with negative pressure, it can drive expansion without breaking physics. The math still works. More importantly, Lieu's model avoids needing the controversial "negative density" idea from his earlier paper.

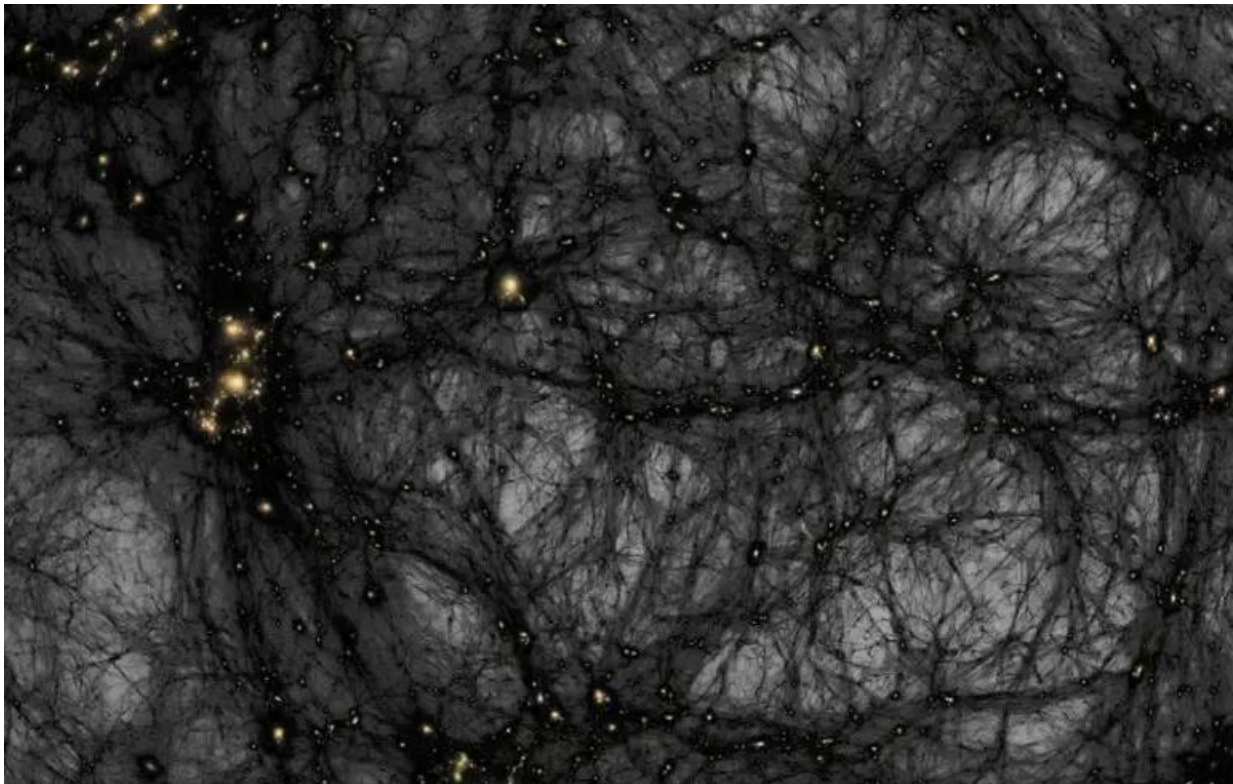
This balance also makes the universe's structure more stable. The singularities don't just create matter — they set the stage for [galaxies to grow](#) and hold

together, a role that has long been assigned to dark matter. But in this view, there's no need for dark matter at all.

## Fleeting Forces With Big Effects

The paper's title — *Are dark matter and dark energy omnipresent?* — gives away Lieu's key point. He believes they're not always there. In fact, he says, they only appear in rare, fleeting moments. The rest of the time, they're gone.

"They only appear in brief instances during which the matter and energy do fill the [entire universe](#) uniformly," he explains. Between those moments, they simply do not exist.



A simulation of the formation of dark matter structures from the early universe until today. (CREDIT: Ralf Kaehler/SLAC National Accelerator Laboratory, American Museum of Natural History)© The Brighter Side of News

This model shares one basic feature with the traditional view: a cosmic burst that shapes the universe. But while the standard model says that happened once — the Big Bang — Lieu argues that it happens over and over again.

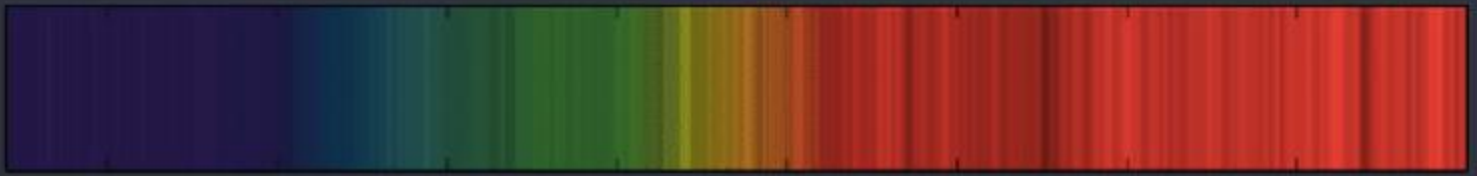
These repeated bursts could explain not just the beginning of the cosmos but also why it continues to expand and evolve. With each pulse, matter is distributed across space. That matter then clumps together under [gravity](#), forming galaxies, clusters, and other cosmic structures.

The sudden nature of these events may also explain why scientists have never directly seen dark matter or dark energy. “That could be the reason why dark matter and dark energy have not been found,” Lieu suggests.

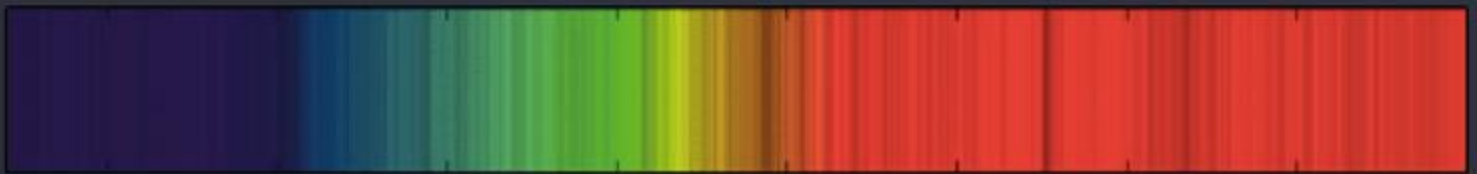
## **Testing the Theory From Earth**

The next step is proving the theory. While it sounds futuristic, Lieu says the answer might be surprisingly close — not in space, but on Earth.

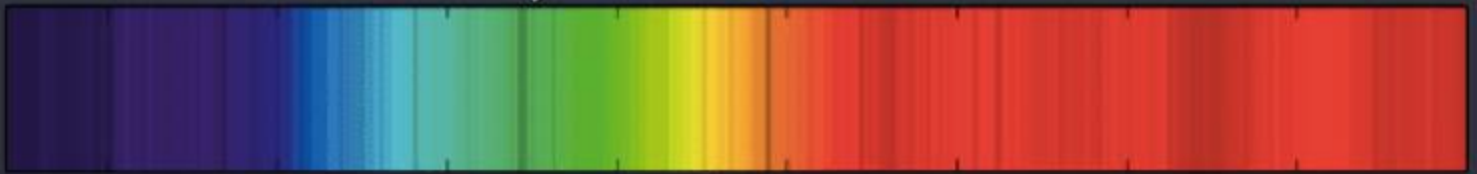
*Very distant galaxy*



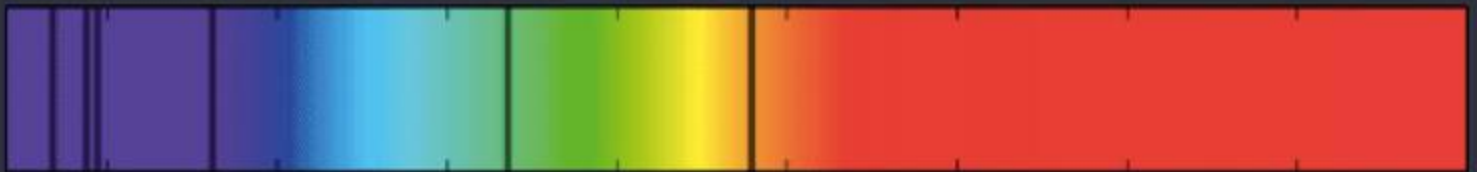
*Distant galaxy*



*Nearby galaxy*



*Spectrum laboratory reference*



400 450 500 550 600 650 700 750 800  
nm

Hubble eventually determined that the velocity at which galaxies were receding was proportional to how far away they were; the further away the galaxies were, the higher their redshift was. This equation, Hubble's Law, is written as  $v = H_0 d$ . (CREDIT: University of Iowa)© The Brighter Side of News

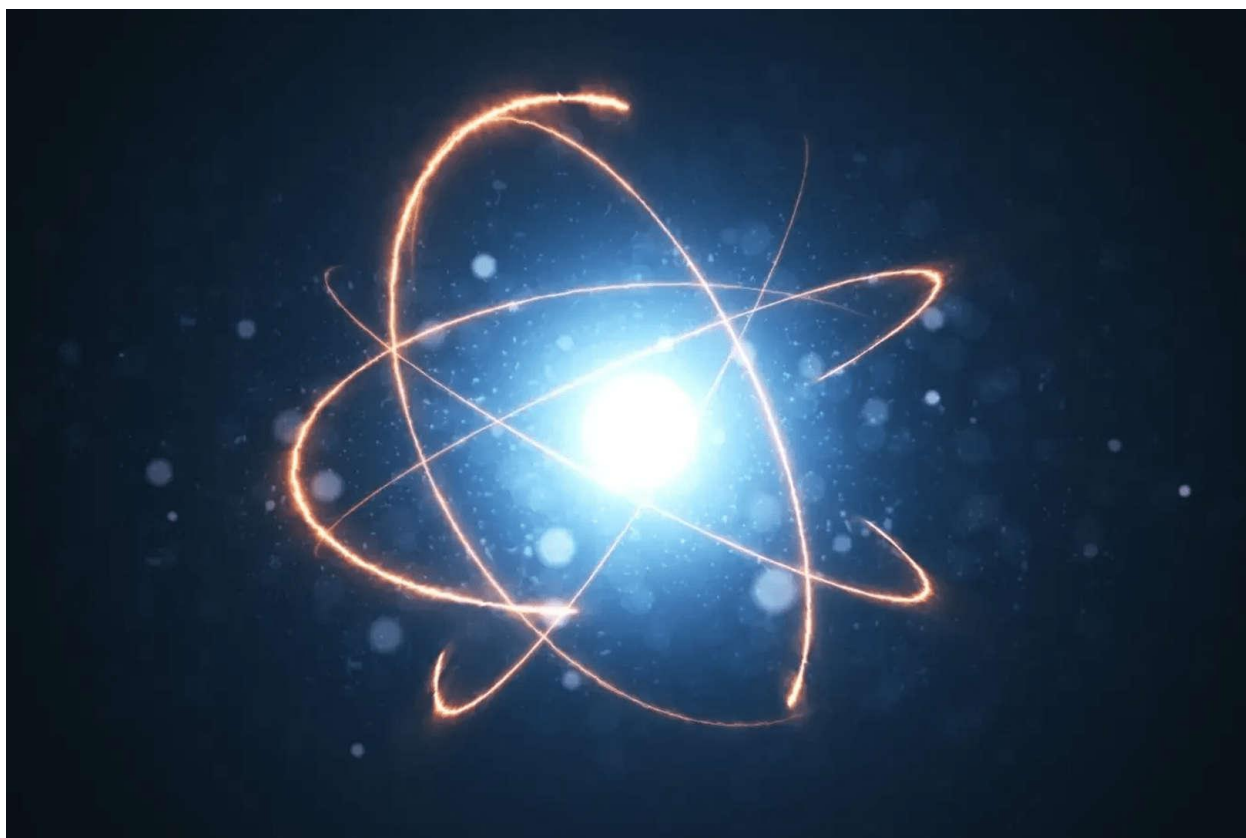
Rather than waiting for images from the [James Webb Space Telescope](#), researchers could use powerful ground-based telescopes like the Keck Observatory in Hawaii or the Isaac Newton Group of Telescopes in Spain. These tools can gather deep-field images of distant galaxies across a range of redshifts — a way of measuring how fast things in space are moving away.

By slicing that data by redshift, astronomers could look for sudden jumps in how far away galaxies appear. If found, those jumps might point to past singularities — evidence of a universe that grows in pulses rather than through smooth, continuous expansion.

“Given sufficient redshift resolution effected by the [redshift](#) slicing, one might just find that the Hubble diagram exhibits jumps,” Lieu says. That would be a powerful clue that something other than the Big Bang may be at work.

For now, Lieu’s model remains a theory — but one with powerful implications. If true, it could solve two of the biggest mysteries in cosmology: what dark matter and dark energy really are, and why we’ve never been able to find them.

Instead of hunting for invisible ingredients, scientists might start listening for the echoes of ancient, unstoppable bursts — the hidden rhythms of a universe still in motion.

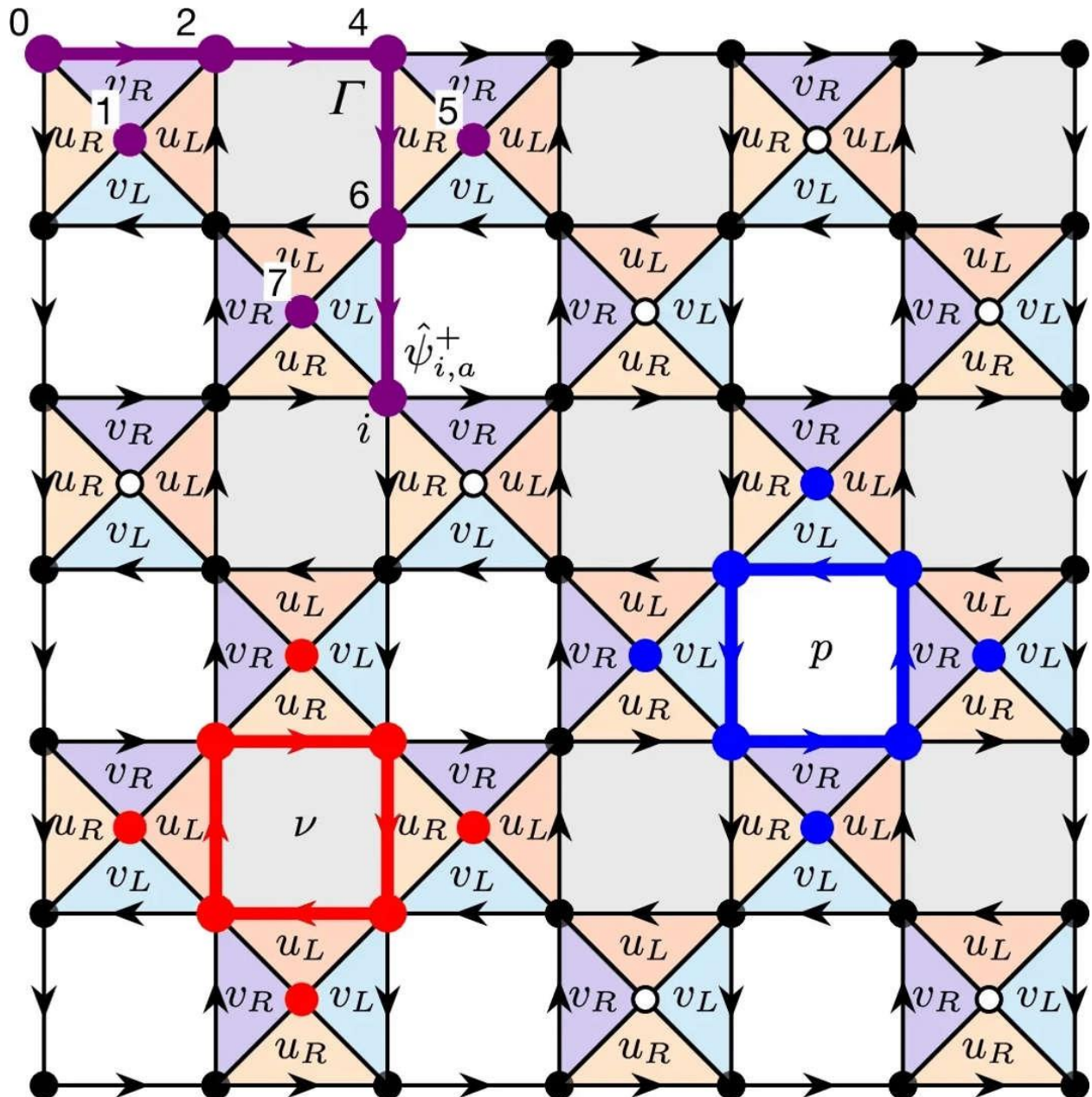


## Mathematical model hints at new quantum particles

In the strange and fascinating world of [quantum mechanics](#), particles have long been sorted into just two types: fermions and bosons. These labels help explain how matter forms and how forces work. Fermions, like electrons and quarks, make up the atoms in everything around you.

They follow a strict rule that keeps them from piling into the same spot, a rule called the Pauli exclusion principle. That's why your chair doesn't let you fall through it when you sit down. On the flip side, bosons are more generous. They can share space freely, acting like invisible bridges that carry forces between particles.

But now, a bold new idea is challenging this tidy system. Scientists at [Rice University](#) in Texas believe there may be a third kind of particle—one that doesn't follow the rules of fermions or bosons. They've developed a mathematical model showing how these unusual entities, called paraparticles, could exist in real materials without breaking the laws of physics.



Their work, published in [Nature](#), suggests that paraparticles might arise in special systems and act differently than anything scientists have seen before.

Their journey into this mystery started with a question: Are fermions and bosons really all there is? For decades, the answer seemed to be yes. Even when theorists invented models for paraparticles in the 1950s, deeper study in the 1970s seemed to show they were nothing new—just fermions or bosons wearing different masks.

Still, something didn't quite add up. In certain two-dimensional systems, researchers had found strange particles called anyons that didn't fit neatly into either category. These

oddballs behave in ways that seem to defy the usual laws. But because they only exist in flat systems, they've been seen more as clever tricks of math than signs of new types of matter.

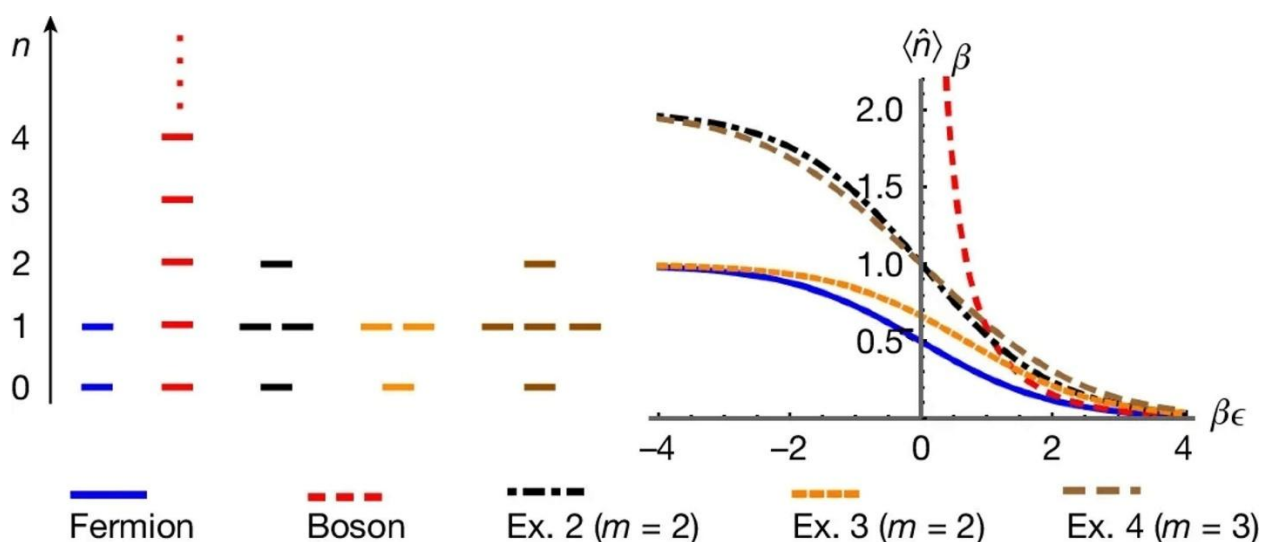
Hazzard and Wang wanted to know: Could something like anyons exist in our three-dimensional world?

## A New Twist on an Old Equation

To answer that, they turned to a set of powerful [mathematical tools](#), including something called the Yang-Baxter equation. This formula helps explain what happens when particles trade places. By applying it alongside theories like group theory and Lie algebra, the researchers crafted a new way to look at how particles behave.

Their fresh approach introduced what they called a “second step of quantization,” a method different from anything used before. It allowed them to model how collective actions in a material—tiny ripples or “excitations” that behave like particles—could act in bizarre new ways.

In their models, these excitations didn't stick to the fermion or boson playbook. Instead, they showed behaviors that could only be explained if something new—paraparticles—was in the mix. The key difference? When paraparticles switch places, their internal traits also change. This swap creates strange, complex results that existing [quantum theory](#) can't explain.



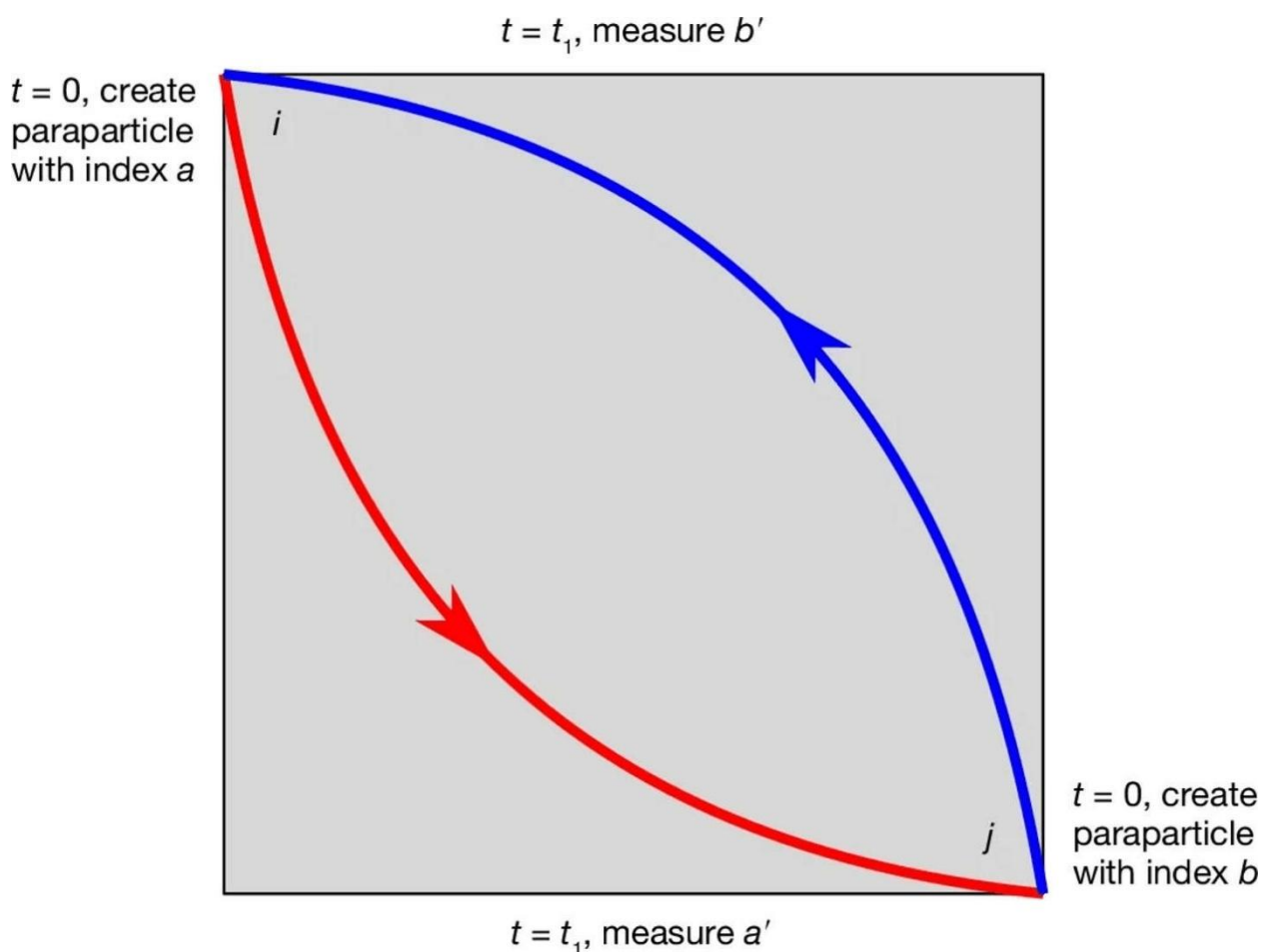
## Not Just a Thought Experiment

While the idea of paraparticles still lives in math, the materials that inspired this research are very real. Hazzard and Wang based their work on condensed matter systems, like magnets, which are often used to study quantum effects. “Particles aren’t just these fundamental things,” says Hazzard. “They’re also important in describing materials.”

In the real world, many particles we think of as “elementary” may not be building blocks at all. They might just be useful ways to describe how parts of a system act together. This means paraparticles might not be locked away in some far-off theory. They could be hiding in plain sight, waiting to be uncovered in [lab experiments](#).

Wang explains that this study brought together multiple branches of [physics](#) and mathematics to find something that had been missed for decades. “This is cross-disciplinary research,” he said. “It involves several areas of theoretical physics and mathematics.”

By combining abstract algebra and visual tools like tensor network diagrams, they built models that could point the way to finding paraparticles in real life. These ideas, once tested, could shift how scientists think about the smallest parts of nature.



## Looking Toward a Quantum Future

There's still a long way to go before paraparticles move from theory to reality. Hazzard and Wang know that experiments will need better, more practical designs to test these predictions. "To realize paraparticles in experiments, we need more realistic theoretical proposals," Wang says.

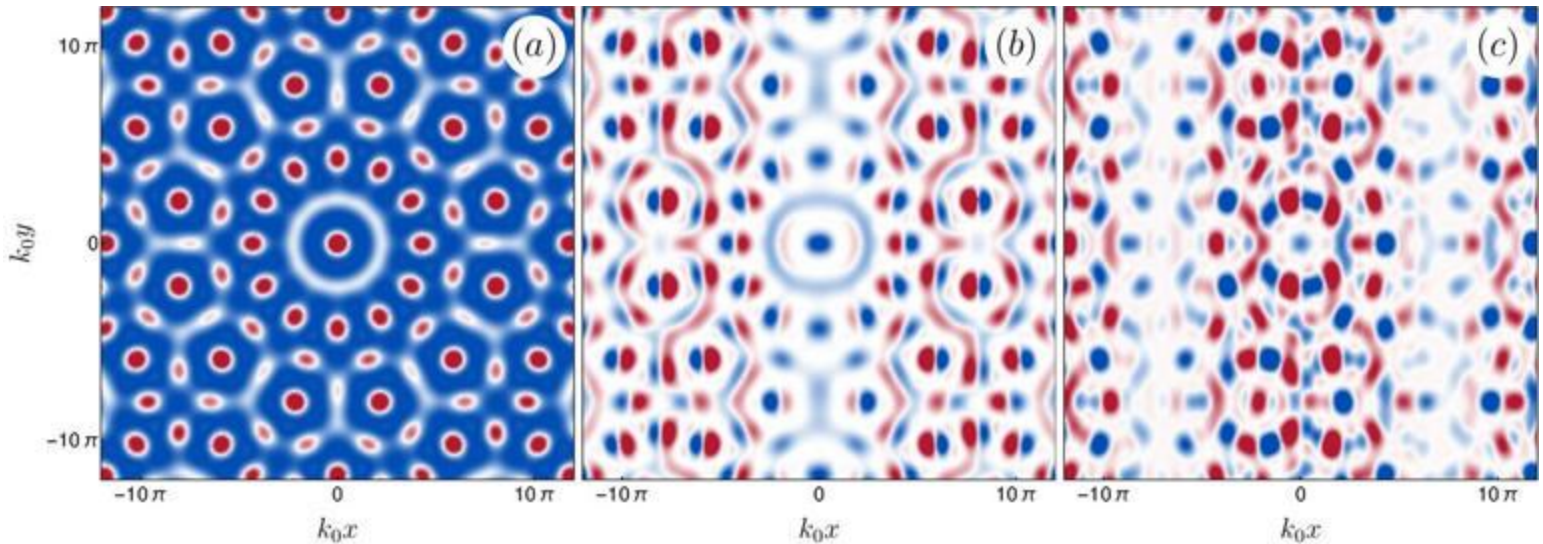
If paraparticles do exist, they could offer more than just a new chapter in physics textbooks. They might help solve big mysteries, like what [dark matter](#) is made of or how to unite quantum physics with the theory of gravity. These questions have puzzled scientists for decades.

In the short term, paraparticles could also lead to new ways to store and process information. Because their internal states change in unique ways, scientists might one day use them in quantum computers or in secure communication systems where information stays hidden inside the particles themselves.

These applications are still ideas on the horizon, but the possibilities are exciting. "I don't know where it will go," says Hazzard, "but I know it will be exciting to find out."

This new research may not rewrite physics overnight. But it opens a door that had seemed shut for years. Fermions and bosons have ruled the quantum world for nearly a century. Now, paraparticles are knocking, and the rules may never be the same.

# New physics theory to study low-energy excitations in quantum quasicrystals



By developing a microscopic quantum elasticity theory, this work describes the dynamics of deformations in a quasicrystalline lattice of bosonic particles at the lowest temperatures. Figure (a) illustrates an example of such a quasicrystalline structure. The study provides, for the first time, predictions about how standard lattice sound waves, as shown in Figure (b), interact with phason excitations—peculiar to non-periodic quasicrystal patterns, depicted in Figure (c). Additionally, these excitations couple to the modulation of the quantum phase of the macroscopic wavefunction, which governs the quantum behavior of low-temperature bosonic particles. These predictions shed light on the dynamics and thermodynamics of quantum quasicrystals and are experimentally verifiable, for instance, using ultracold atomic gases. Credit: Mendoza-Coto, Bonifacio & Piazza.

Quasicrystals, exotic states of matter characterized by an ordered structure with non-repeating spatial patterns, have been the focus of numerous recent physics studies due to their unique organization and resulting symmetries. Among the quasicrystals that have sparked significant interest among the physics community are so-called quantum quasicrystals, which are comprised of bosons (i.e., subatomic particles that have spin in integer values, such as 0, 1, 2, and so on, and can occupy the same quantum state simultaneously).

Researchers at the Max Planck Institute for the Physics of Complex Systems (MPIPKS) recently introduced a new theoretical framework that describes low-energy excitations in bosonic quantum quasicrystals. Their newly devised theory, outlined in a paper [published](#) in *Physical Review Letters*, is an extension of

conventional theories of elasticity, which also accounts for the unique symmetries of quantum quasicrystals.

"This paper is part of an ongoing collaboration with two colleagues, Prof. Francesco Piazza and Dr. Mariano Bonifacio, which began in 2022 when I was a guest scientist at MPIPKS in Dresden, Germany," Alejandro Mendoza-Coto, first author of the paper, told Phys.org.

"We were studying quantum self-assembled quasi-crystalline phases in cavity QED models, and at a certain point, we concluded that, considering future experimental verification of our results, the study of the low-energy excitations in these systems would be relevant.

"Another compelling reason to consider this problem was the existence in the literature of previous symmetry arguments predicting five gapless excitation modes for these systems, while a first-principles theory supporting this conclusion was still lacking."

Initially, Mendoza-Coto, Bonifacio and Piazza tried to study the entire excitation spectrum of quasicrystals numerically, but when this proved challenging, they started conducting theoretical analyses. As they progressed in their analyses, they realized that a first-principles elastic theory for bosonic quantum quasicrystals was still lacking, and they set out to develop one.

"We drew inspiration from several different papers focusing on the construction of a low energy effective theory for supersolids," said Mendoza-Coto.

"I believe that the main point to highlight here is the recognition that if we wanted to pursue a first-principles theory for modulated bosonic systems, we needed to include not only the expected fluctuations in the phases of the modulated pattern and the condensate itself but also the respective density field fluctuations conjugate to each phase fluctuation field introduced. This is a very important consideration that separates our work from others in the literature."

The main idea behind the team's theory is that to study low-energy fluctuations at the ground state of a quantum quasicrystal system, one needs to consider more than fluctuations in the phases of the density pattern and condensate wave functions that are already expected to occur. Specifically, they should also

account for other conjugate fluctuations (i.e., which are mathematically linked to expected fluctuations).

"In my view, this is the most important detail that we recognized in order to build a first-principles theory with the appropriate number of degrees of freedom, which at the same time is consistent with the symmetry properties already expected for this system," explained Mendoza-Coto.

"Once you know which kind of fluctuations need to be included and in which way they should be added to the ground state wave function, the calculations are quite straightforward, and our conclusions do not rely on further assumptions."

After the researchers obtained the low-energy action for the simplest possible quasicrystal structure (i.e., the dodecagonal quasicrystal), Piazza suggested extending their study to other possible quasi-crystalline structures. This allowed them to better understand the extent to which their theory could be generalized across different quantum quasicrystals and thus make predictions about the physics observed in these systems.

"This later proved valuable, as we found that different kinds of quasicrystal structures display different hybridization features between modes and even anisotropic properties, certainly a nice finding of our work," said Mendoza-Coto. "I believe that our results are, to a point, the analog for non-homogeneous phases of the well-known Bogoliubov excitation spectrum for homogeneous condensates.

"To obtain closed analytical expressions for the excitation energies at low momentum in quantum quasicrystals is, in my view, a very nice result, as the standard method to pursue this kind of calculation in the literature is a numerical one."

The recent work by Mendoza-Coto, Bonifacio, and Piazza could inform future studies to better understand bosonic quantum quasicrystals and their underlying physics. In the future, the theory they introduced could help to understand phase transitions in quantum quasicrystals and potentially also in supersolids (i.e., states of matter with a crystalline order that combine some properties of solids and superfluids).

"I think that this work will help us in the search for novel exotic phases in systems hosting superfluidity and topological defects, such as the proposed super-hexatic or super-nematic phases," added Mendoza-Coto. "I have several projects following up this research. We are already working on extending this work to one-dimensional quasicrystals in cavity QED conditions, as well as other projects related to the application of this formalism to supersolids."

**More information:** A. Mendoza-Coto et al, Low-Energy Excitations in Bosonic Quantum Quasicrystals, *Physical Review Letters* (2025). DOI: [10.1103/PhysRevLett.134.136003](https://doi.org/10.1103/PhysRevLett.134.136003).

© 2025 Science X Network

## New 4D quantum sensors may help physicists trace the birth of space and time

Smashing subatomic particles together at near-light speeds has long been the best way to understand the universe's fundamental building blocks.

These high-energy collisions, conducted inside massive particle accelerators, help physicists study matter, energy, space, and time.

As new accelerators promise even more powerful and chaotic collisions, scientists need tools far more advanced than those used before.

That's where quantum sensors come in.

A team from Fermilab, Caltech, NASA's Jet Propulsion Laboratory (JPL), and several international institutions has developed a new type of detector that could redefine how we study particle collisions.

These superconducting microwire single-photon detectors, or SMSPDs, were recently tested at Fermilab and showed exceptional precision in detecting particles produced during high-energy beams.

## Powerful collisions need precise detection

As future colliders reach greater energies and particle intensities, physicists expect to encounter a flood of data — sprays of particles flying out in all directions.

That makes detection more complex than ever.

According to Maria Spiropulu, the Shang-Yi Ch'en Professor of Physics at [Caltech](#), "In the next 20 to 30 years, we will see a paradigm shift in particle colliders as they become more powerful in energy and intensity.

And that means we need more precise detectors."

SMSPDs offer a breakthrough by detecting both time and spatial information at once, something traditional detectors can't do.

Fermilab scientist Si Xie, who also holds a joint appointment at Caltech, explains that these are essentially "4D sensors" because they combine spatial and time resolution, eliminating the need to compromise between the two.

## Quantum sensors put to the test

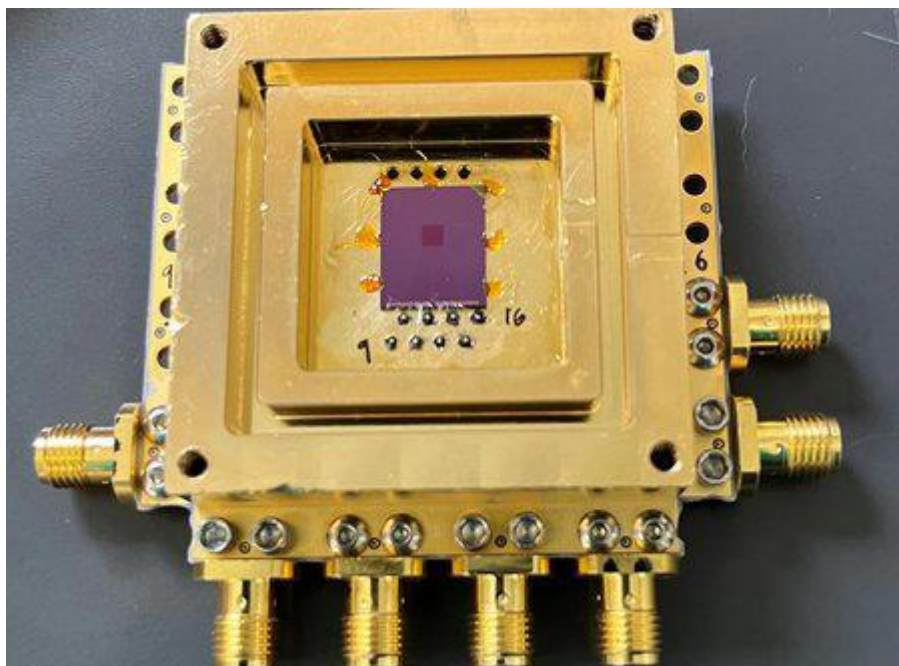
In their first major test, the SMSPDs were exposed to high-energy beams of protons, electrons, and pions at Fermilab.

The detectors outperformed conventional systems in both time precision and spatial tracking.

Determining exactly when and where particles travel is crucial when analyzing the millions of interactions that happen each second in particle collisions.

"The novelty of this study is that we proved the [sensors](#) can efficiently detect charged particles," says Xie.

Unlike their predecessors, superconducting nanowire single-photon detectors (SNSPDs), which are better suited for quantum networking or space-based optical communication, SMSPDs have a larger surface area and are capable of tracking particles that are key to high-energy physics experiments.



Quantum sensor for particle physics. – by Caltech

## Opening the door to dark matter

The detectors could make it possible to identify lower-mass particles or entirely new ones, such as those hypothesized to make up dark matter.

Xie sees this as just the beginning: “We have the potential to detect particles lower in mass than we could before as well as exotic particles like those that may constitute dark matter.”

Precision is vital in identifying such elusive targets.

As Spiropulu puts it, “Back in the 1980s, we thought having the spatial coordinates were enough, but now... we also need to track time.”

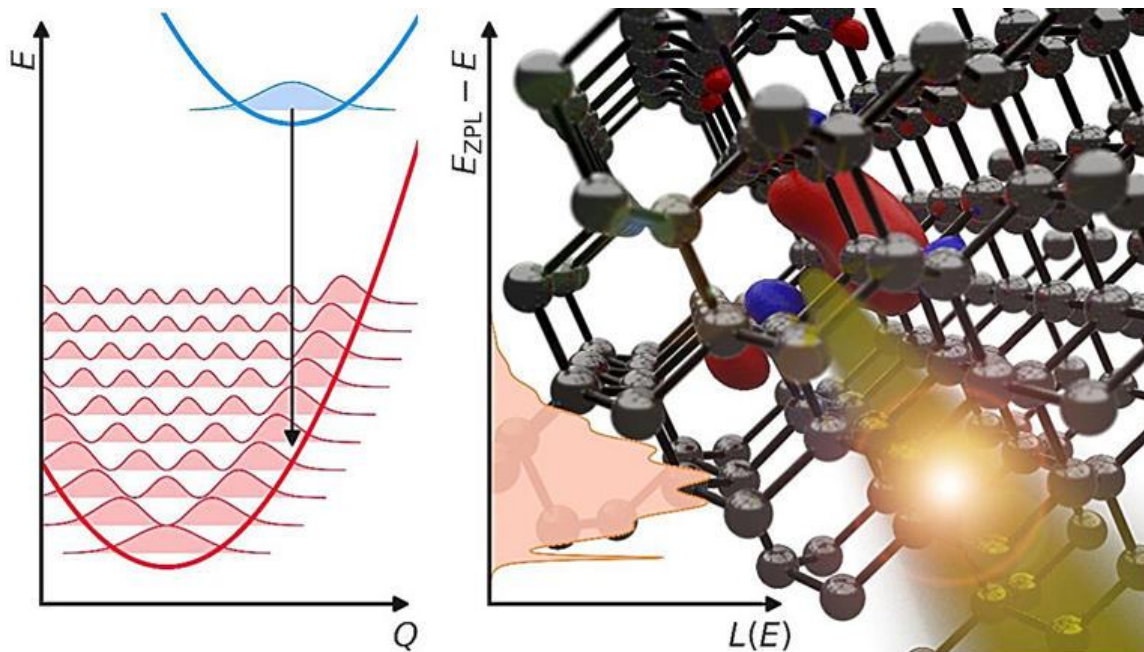
The SMSPDs help researchers trace particles in four dimensions, offering an edge in navigating the overwhelming complexity of modern collider environments.

These [quantum](#) detectors may become foundational to future colliders, including the proposed Future Circular Collider or a muon collider.

Fermilab scientist Cristián Peña, who led the research, sees the technology as a timely advancement.

"We are very excited to work on cutting-edge detector R&D like SMSPDs because they may play a vital role in capstone projects in the field," he says.

## Bright prospects for engineering quantum light



Concept illustration depicting a quantum defect emitting a single photon. Credit: Mark Turiansky© Provided by Phys.org

Computers benefit greatly from being connected to the internet, so we might ask: What good is a quantum computer without a quantum internet?

The secret to our modern internet is the ability for data to remain intact while traveling over long distances, and the best way to achieve that is by using photons.

Photons are single units ("quanta") of light. Unlike other quantum particles, photons interact very weakly with their environment. That stability also makes them extremely appealing for carrying quantum information over long distances, a process that requires maintaining a delicate state of entanglement for an extended period of time. Such photons can be generated in a variety of ways.

One possible method involves using atomic-scale imperfections (quantum defects) in crystals to generate single photons in a well-defined quantum state.

Decades of optimization have resulted in fiber-optic cables that can transmit photons with extremely low loss. However, this low-loss transmission works only for light in a narrow range of wavelengths, known as the "telecom wavelength band."

Identifying quantum defects that produce photons at these wavelengths has proven difficult. Researchers at the UC Santa Barbara College of Engineering conducted research to understand why that is and describe their findings in "[Rational Design of Efficient Defect-Based Quantum Emitters](#)," published in the journal *APL Photonics*.

"Atoms are constantly vibrating, and those vibrations can drain energy from a light emitter," says UCSB materials professor Chris Van de Walle. "As a result, rather than emitting a photon, a defect might instead cause the atoms to vibrate, reducing the light-emission efficiency."

Van de Walle's group developed theoretical models to capture the role of atomic vibrations in the photon-emission process and studied the role of various defect properties in determining the degree of efficiency.

Their work explains why the efficiency of single-photon emission drastically decreases when the emission wavelength increases beyond the wavelengths of visible light (violet to red) to the infrared wavelengths in the telecom band. The model also allows the researchers to identify techniques for engineering emitters that are brighter and more efficient.

"Choosing the host material carefully, and conducting atomic-level engineering of the vibrational properties are two promising ways to overcome low efficiency," said Mark Turiansky, a postdoctoral researcher in the Van de Walle lab, a fellow at the NSF UC Santa Barbara Quantum Foundry, and the lead researcher on the project.

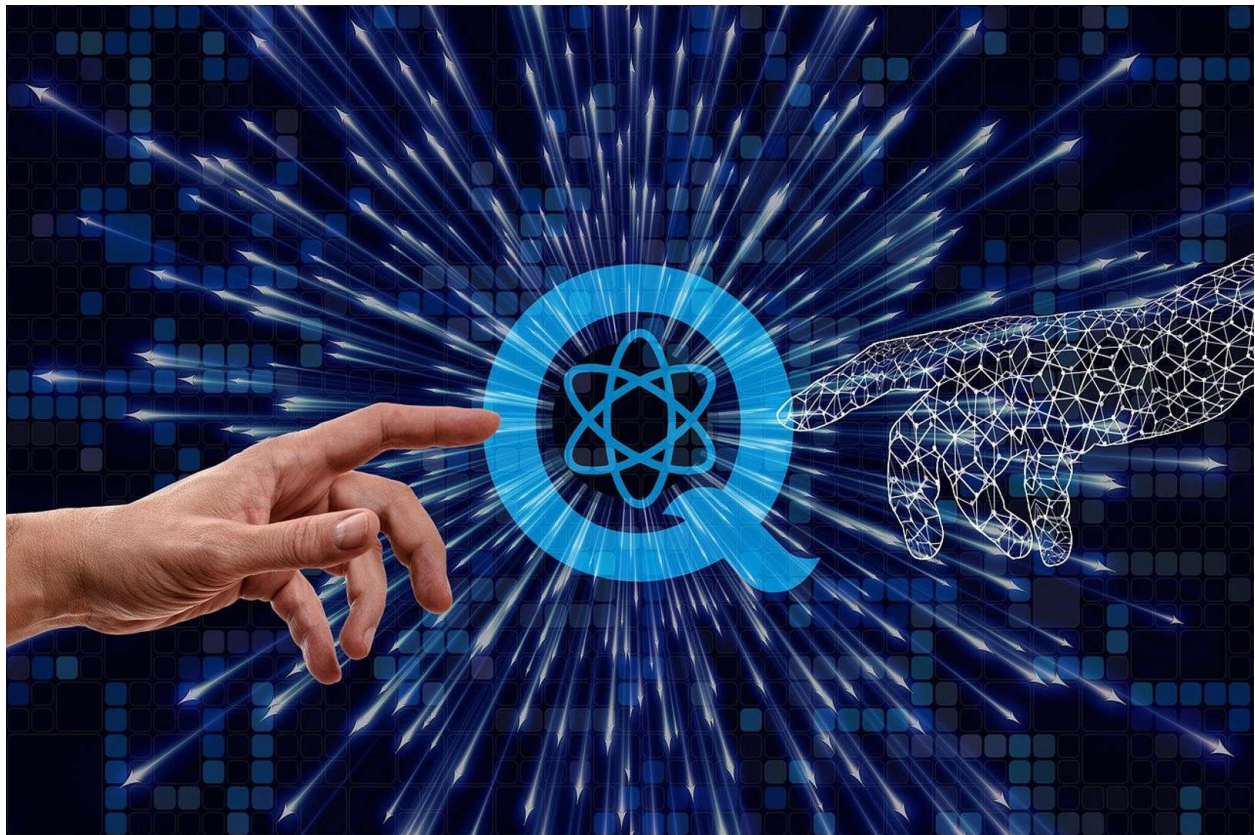
Another solution involves coupling to a photonic cavity, an approach that benefited from the expertise of two other Quantum Foundry affiliates: computer engineering professor Galan Moody and Kamyar Parto, a graduate student in the Moody lab.

The team hopes that their model and the insights it provides will prove useful in designing novel quantum emitters that will power the quantum networks of the future.

**More information:** Mark E. Turiensky et al, Rational design of efficient defect-based quantum emitters, *APL Photonics* (2024). DOI: [10.1063/5.0203366](https://doi.org/10.1063/5.0203366)

Provided by University of California - Santa Barbara

## The Strange Ways Reality Breaks Down at the Quantum Level



The universe is a mysterious place, and nowhere is this more evident than at the quantum level. Here, the familiar laws of physics seem to bend, twist, and sometimes outright break, creating a world that's more like a surreal dream than the structured reality we know. Imagine a place where particles can be in two places at once, where the mere act of observing changes what is observed, and where the fabric of reality itself is woven from probability rather than certainty. Welcome to the quantum realm, where the very rules of existence seem to warp and twist in the strangest ways.

## **The Uncertainty Principle: A Dance of Possibilities**

One of the most mind-bending aspects of quantum physics is Heisenberg's Uncertainty Principle. This principle tells us that the more precisely we know the position of a particle, the less precisely we can know its momentum, and vice versa. It's as if the universe is playing a cosmic game of hide and seek with us. Imagine trying to pin down a dancer's exact position while they're in the midst of a twirl; the more you focus on their position, the blurrier their movement becomes. This uncertainty isn't just a limitation of our measurement tools; it's a fundamental property of reality at the quantum level.

## **Quantum Entanglement: The Cosmic Connection**

Quantum entanglement is one of the most intriguing phenomena in the quantum world. It describes a situation where two or more particles become interconnected in such a way that the state of one particle instantly influences the state of the other, no matter how far apart they are. Albert Einstein famously referred to this as "spooky action at a distance." It's as if the universe has its own invisible threads, tying distant particles together in a cosmic web. This defies our classical understanding of space and time, hinting at a deeper level of interconnectedness in the universe.

## **Wave-Particle Duality: The Dual Nature of Reality**

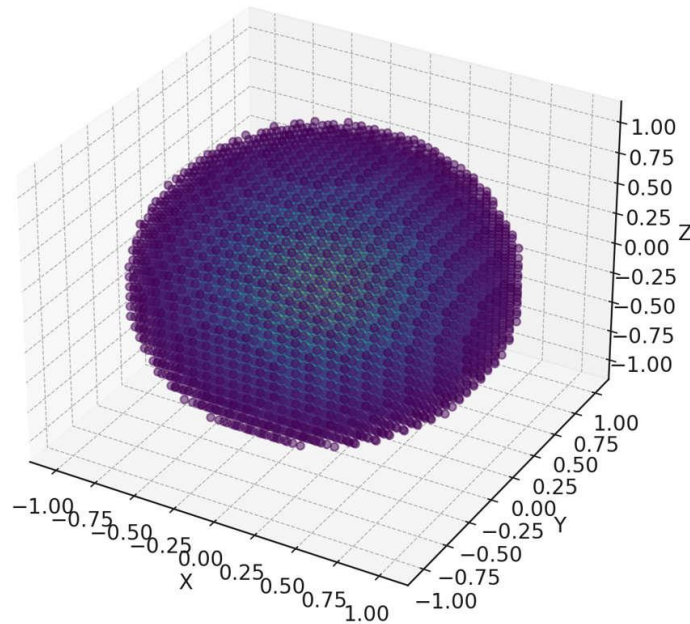
In the quantum realm, particles like electrons and photons exhibit a strange duality, behaving as both particles and waves. This wave-particle duality is like a cosmic masquerade ball where particles don different masks based on how we observe them. When not observed, these particles exist in a state of potential, like a ripple on a pond. However, when measured, they collapse into a definitive state, much like a wave crashing onto the shore. This duality challenges our intuitive notions of reality, suggesting that the act of observation plays a pivotal role in shaping the universe.

## **Quantum Superposition: The Art of Being Everywhere**

Quantum superposition is a concept that defies our everyday experience. It posits that particles can exist in multiple states or locations simultaneously until they are observed or measured. Consider Schrödinger's famous thought experiment with a cat that's simultaneously alive and dead until someone opens the box. This paradox illustrates the bizarre nature of superposition, where reality itself seems to hover in a liminal space of

possibilities. It's as if reality is a vast canvas, and every possibility is a brushstroke waiting to be observed into existence.

Probability Density of Quantum Particle



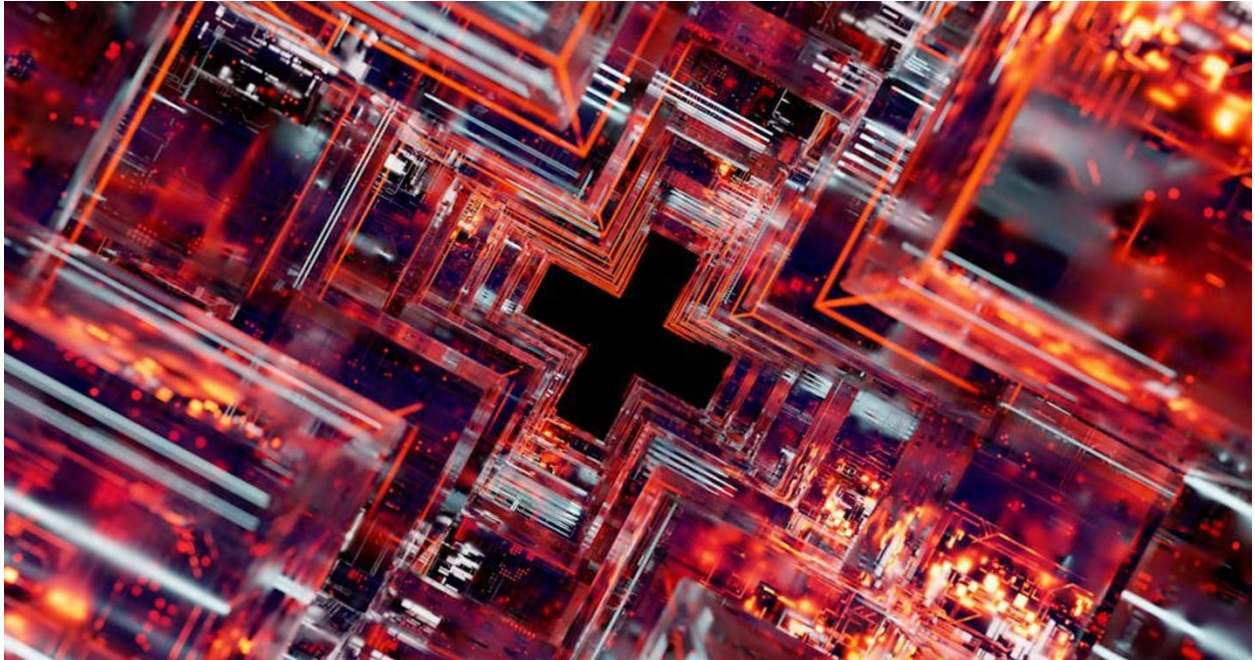
## Quantum Tunneling: The Great Escape

Quantum tunneling is another fascinating phenomenon where particles can pass through seemingly insurmountable barriers. Imagine a ghost effortlessly passing through walls. In the quantum world, particles can do something similar, appearing on the other side of an energy barrier that, under classical physics, they shouldn't be able to surmount. This ability to "tunnel" through obstacles has practical applications, such as in the workings of semiconductors and the sun's fusion process, where tunneling enables nuclear reactions that power our solar system.

## The Observer Effect: Reality's Shapeshifter

The observer effect suggests that the act of measurement or observation can alter the state of a quantum system. It's as if reality is a shape-shifting entity, responding to the gaze of an observer. When scientists try to measure certain properties of a particle, they

find that the very act of observing changes what they see. This idea challenges the traditional notion of an objective reality, suggesting instead that reality is, to some extent, a participatory phenomenon shaped by observers.



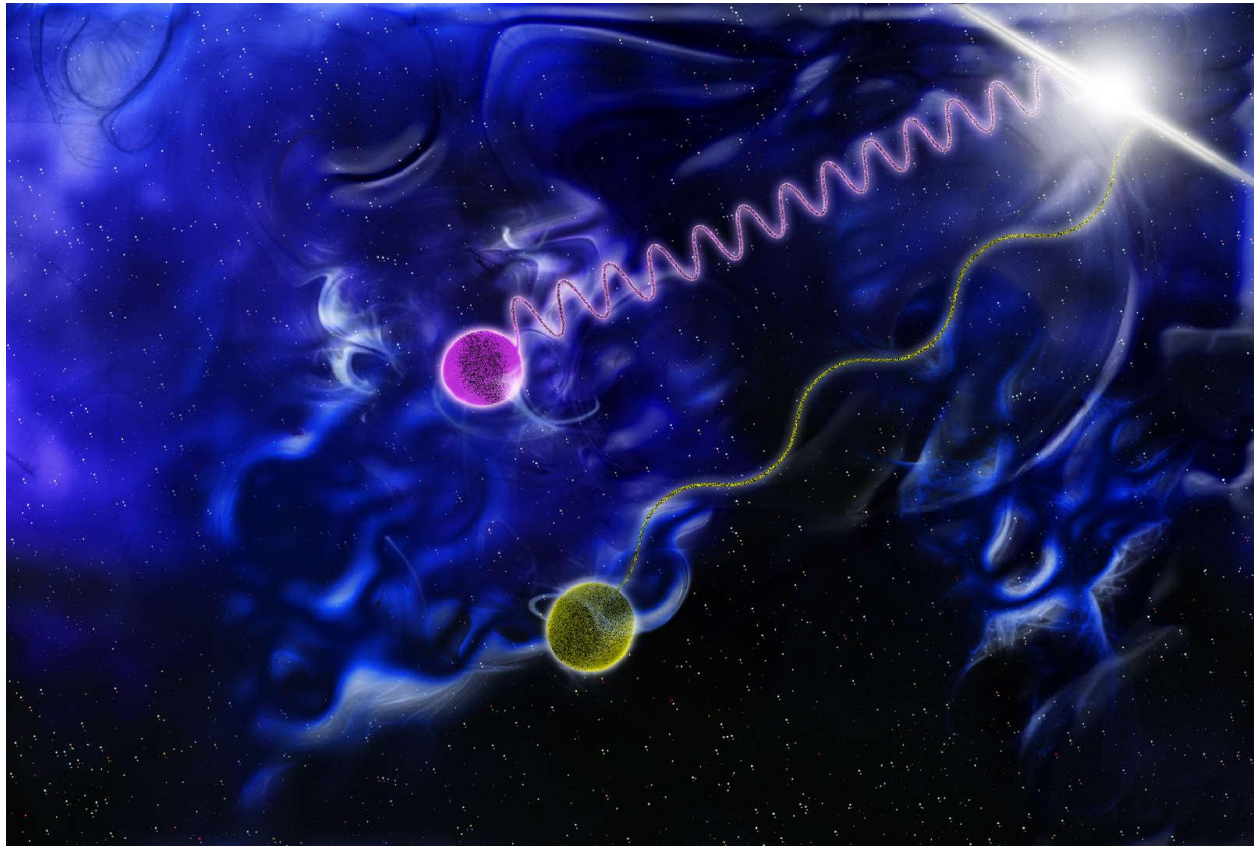
## **Quantum Decoherence: The Collapse of Possibilities**

Quantum decoherence is the process by which quantum systems lose their quantum behavior and transition into classical states. It's like a magician's trick being revealed, where the mystical possibilities of quantum superpositions collapse into the mundane reality we experience. Decoherence helps explain why we don't see superpositions in our daily lives, as it describes how the environment interacts with quantum systems, causing them to lose their quantum weirdness and behave in a predictable manner.

## **The Quantum Vacuum: A Sea of Virtual Particles**

Even in a perfect vacuum, the quantum world is teeming with activity. The quantum vacuum is a seething sea of virtual particles that pop in and out of existence in a fleeting dance of creation and annihilation. It's as if the universe is a restless ocean, with waves of energy constantly surging beneath the surface. These virtual particles, though ephemeral, have real effects,

contributing to phenomena like the Casimir effect and Hawking radiation, which in turn shape our understanding of the universe's fundamental nature.



## **Quantum Gravity: The Quest for Unification**

One of the greatest challenges in modern physics is the quest to unify quantum mechanics with general relativity, the theory of gravity. Quantum gravity seeks to reconcile these two seemingly incompatible frameworks, offering a cohesive understanding of the universe. It's like trying to merge two different languages into a single, harmonious dialogue. The pursuit of quantum gravity involves exploring concepts such as string theory and loop quantum gravity, which aim to uncover the underlying fabric of spacetime where gravity and quantum mechanics coexist.

## **The Many-Worlds Interpretation: Parallel Realities**

The many-worlds interpretation of quantum mechanics proposes that every quantum event spawns a multitude of parallel universes, each representing a different outcome. It's like a cosmic choose-your-own-adventure book, where every decision leads to a branching narrative. In this view, the universe is a vast multiverse, with countless realities

existing alongside our own. While this interpretation challenges our understanding of reality, it offers a tantalizing glimpse into the infinite possibilities that may lie beyond our perceptual horizon.

In conclusion, the quantum realm is a place where reality as we know it breaks down, giving rise to a world of paradoxes, possibilities, and profound mysteries. Each of these strange phenomena challenges our traditional understanding of the universe, urging us to rethink the very nature of reality. As we continue to explore the quantum frontier, we are reminded that the universe is far more mysterious and wondrous than we could ever imagine.

# The rotating universe, an elegant solution to this major astrophysical problem

Could the universe be rotating at an imperceptible speed? An extremely slow rotation, occurring once every 500 billion years, might explain discrepancies in measurements of its expansion. This hypothesis, proposed by a team of researchers, opens a new path for understanding cosmic evolution.

Scientists have long assumed the universe expands uniformly, without rotation. Yet, two main methods for measuring this expansion yield slightly different results. One uses light from distant supernovae, while the other analyzes the cosmic microwave background, a remnant of the Big Bang.



The rotating universe, an elegant solution to this major astrophysical problem 

István Szapudi's team introduced a minuscule rotation into their mathematical models of the universe. This adjustment, though tiny, helped reconcile conflicting measurements without violating known physical laws. Their model suggests a rotation so slow it remains undetectable with current instruments.

This innovative approach doesn't challenge cosmology's foundations. Instead, it offers an elegant solution to the 'Hubble tension problem,' a debate that has

divided astrophysicists for years. Universal rotation, however slight, would influence how space expands.

Next steps involve developing more precise simulations and searching for observational signatures of this rotation. Researchers hope finer data, particularly from the James Webb Space Telescope, may provide answers.

This theory, published in the *Monthly Notices of the Royal Astronomical Society*, relies on rigorous calculations. It shows how a simple idea can solve a complex problem without requiring exotic physics. The scientific community welcomes these results with a mix of skepticism and enthusiasm.

If confirmed, cosmic rotation could necessitate revising aspects of our understanding of the universe. For now, however, it remains one hypothesis among many in the quest to explain Hubble tension.

## What is Hubble tension?

Hubble tension refers to the discrepancy between two main methods for measuring the universe's expansion rate. The first relies on observations of supernovae—stellar explosions whose brightness helps calculate distances. The second analyzes the cosmic microwave background, the oldest light in the universe.

These approaches yield slightly different values for the Hubble constant, which describes the expansion rate. This divergence poses a major problem for cosmologists, as it might indicate a fundamental misunderstanding of the physical laws governing the universe.

Several theories have been proposed to solve this puzzle, including new physics or systematic measurement errors. The hypothesis of universal rotation now joins this list, offering a potential solution without resorting to exotic concepts.

Resolving Hubble tension is crucial for refining our cosmological model. It would improve our understanding of the universe's past and future, as well as the nature of dark energy, responsible for its accelerated expansion.

## How is the universe's rotation measured?

Detecting rotation as slow as Szapudi's team proposes presents a significant technical challenge. Current methods rely on meticulous observation of anisotropies in the cosmic microwave background and galaxy distribution.

Universal rotation would imprint specific patterns in this data, such as distortions in the cosmic microwave background's polarization. These signatures would be extremely faint, requiring unprecedented instrument sensitivity.

Future space missions and ground-based telescopes, like the Square Kilometer Array, may provide the necessary data. These tools will map the universe with unmatched precision, possibly offering proof of this rotation.

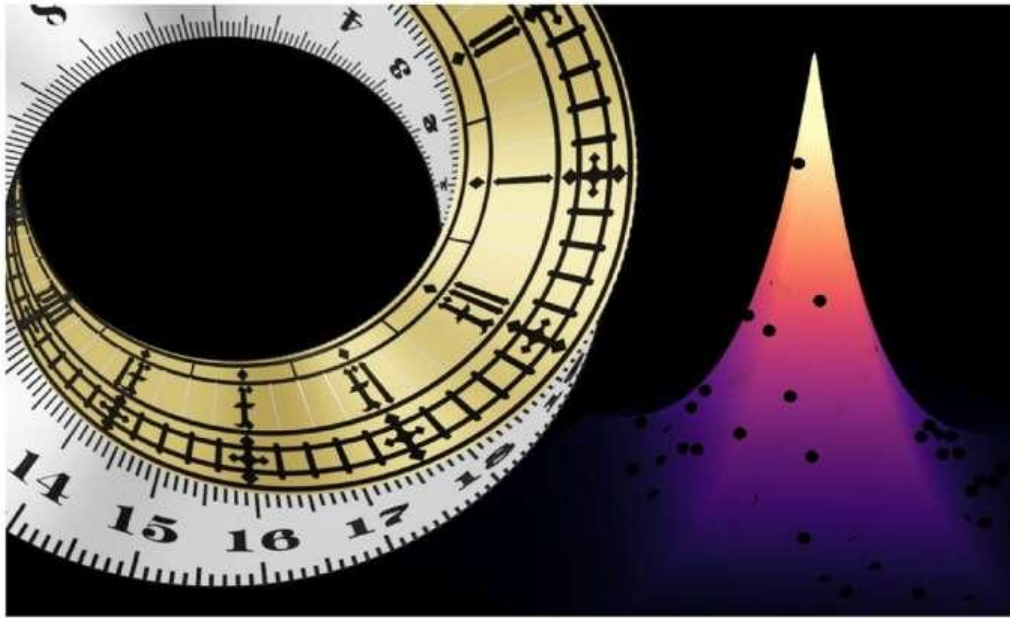
Confirming such rotation would open a new chapter in cosmology. It would imply the universe isn't as isotropic as thought, with profound consequences for our understanding of its origin and evolution.

---

APRIL 23, 2025

# It's about (space-)time: Scientists explore new dimension for light

by Kirstin Werner, [University of Rostock](#)



Time and space rethought: A new look at these old dimensions in physics opens doors to new phenomena, such as so-called space-time-topological events, and their technological applications. Credit: A. Szameit/ Universität Rostock

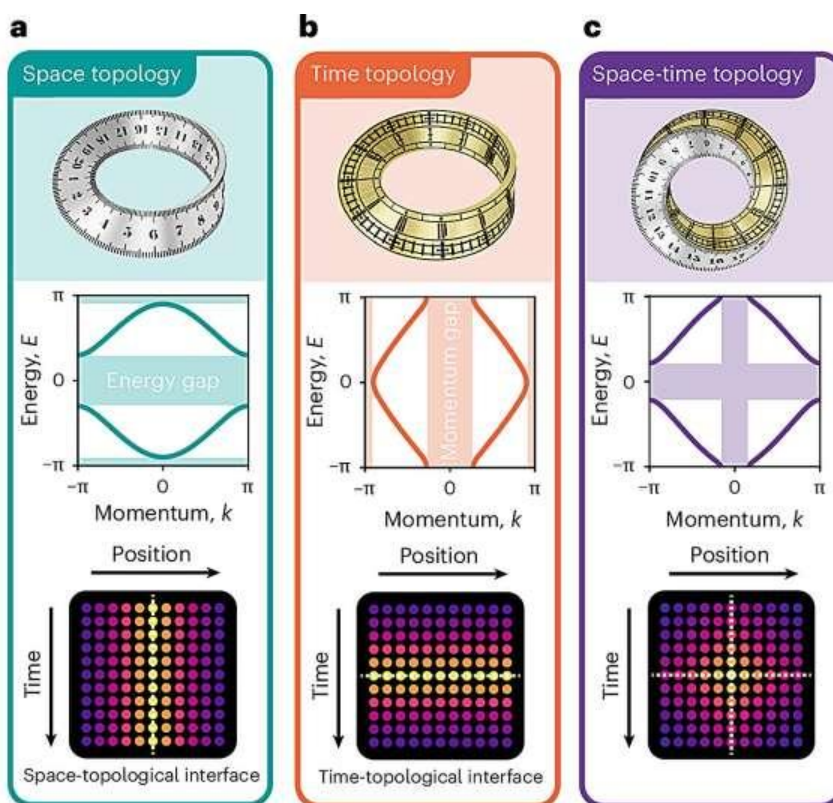
By breaking a decades-old paradigm and rethinking the role that the dimension of time plays in physics, researchers from the University of Rostock and the University of Birmingham have discovered novel flashes of light that come from and go into nothingness—like magic at first glance but with deep mathematical roots that protect against all kinds of outside perturbations. Their [findings](#) have now been published in the journal *Nature Photonics*.

Time is the strange dimension: Unlike its spatial siblings, it is a one-way street as the clock only ever ticks forward and never backward. Scientists have long been aware of time's quirks, with the British astrophysicist Sir Arthur Eddington musing about this "arrow of time" in his 1927 lectures. Nevertheless, whether it be because of or despite its uniqueness, time as a dimension for physics to play out in has long received far less attention than space.

Recently though, rapid progress in the research on so-called spatiotemporal crystals, objects with repeating patterns in time and space, has inspired a rethinking of the role time

should play in our understanding of physics. Additionally, this has spawned the question of whether the uniqueness of time can be more than a mere quirk and instead lead to new effects ultimately useful in applications.

Now, a team of researchers from the University of Rostock and the University of Birmingham has taken up this challenge and made a crucial discovery: In their experiments, light is brought to appear glued to a singular point in [space-time](#). "It's almost biblical: In the beginning, there is nothing. Then physics says, 'Let there be light!,' and there actually is light—at one precise moment in time and point in space," says Prof. Alexander Szameit of the University of Rostock.



Space, time and space-time topology. Credit: *Nature Photonics* (2025). DOI: 10.1038/s41566-025-01653-w

These fleeting flashes of light, however short, are no accident, but instead have deep mathematical roots, elaborates Prof. Hannah Price of the University of Birmingham: "Topology, a perhaps rather abstract but very fundamental and deeply consequential branch of mathematics, actually mandates certain physical behavior here."

Because of this and due to the one-way nature of time, such space-time-topological events, as they are called, also exhibit a unique robustness against outside perturbations: The researchers found that they come with an inherent protection against randomly messed-up experimental parameters as well as stray light.

"This is something seemingly all previously known states of light are susceptible to," Dr. Joshua Feis of the University of Rostock explains.

Dr. Sebastian Weidemann, also from the University of Rostock, adds, "Such protection is very desirable as it may allow the robust shaping of **light** waves in key applications such as imaging, communications or lasers."

These findings prove the potential that reconsidering the role of time in space-time, in physics in general as well as in its interplay with topology, has for both fundamental science as well as potential applications. Crucially, they open the door to a much wider field of potential discoveries enabled by directing research into this new-old dimension.

**More information:** Joshua Feis et al, Space-time-topological events in photonic quantum walks, *Nature Photonics* (2025). DOI: [10.1038/s41566-025-01653-w](https://doi.org/10.1038/s41566-025-01653-w)

**Journal information:** *Nature Photonics*

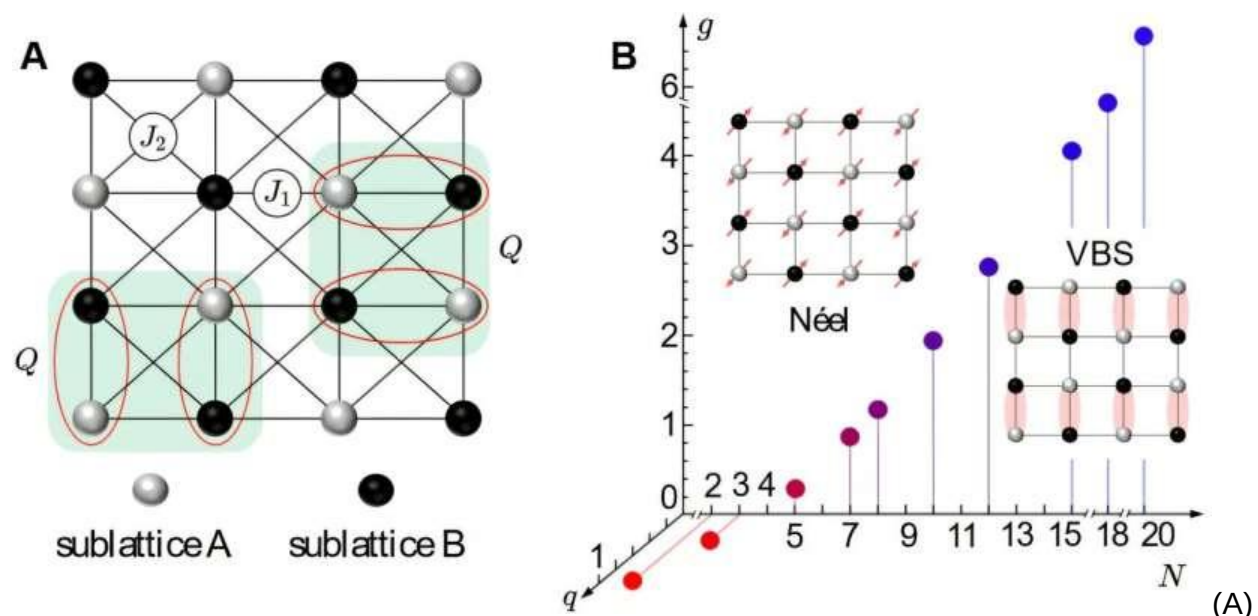
Provided by [University of Rostock](#)

---

APRIL 23, 2025

# Physicists uncover hidden order in the quantum world through deconfined quantum critical points

by [The University of Hong Kong](#)



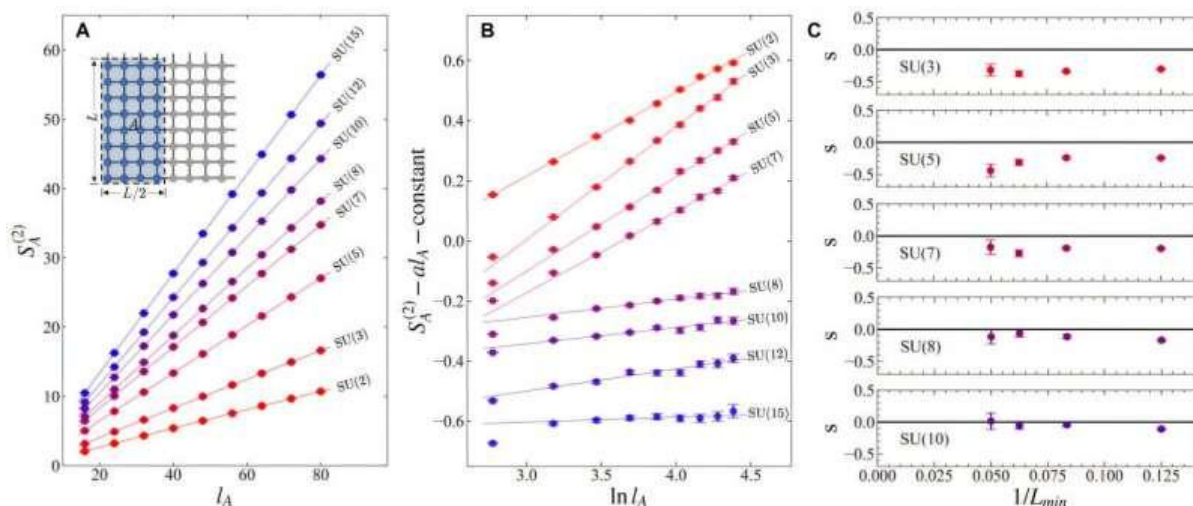
Lattice model for realizing the deconfined quantum phase transition. (B) The phase diagram for the square lattice  $SU(N)$  model. Dots represent the quantum phase transition points. Red points are those not compatible with a continuous phase transition and blues points are those consistent with conformal field theories, i.e., candidates for genuine DQCP.

Credit: *Science Advances* (2025). DOI: [10.1126/sciadv.adr0634](https://doi.org/10.1126/sciadv.adr0634)

In the intricate world of quantum physics, where particles interact in ways that seem to defy the standard rules of space and time, lies a profound mystery that continues to captivate scientists: the nature of deconfined quantum critical points (DQCPs). These elusive critical phenomena break away from the conventional framework of physics, offering a fascinating glimpse into a realm where quantum matter behaves in ways that challenge our classical understanding of the fundamental forces shaping the universe.

A recent study, led by Professor Zi Yang Meng and co-authored by his Ph.D. student Menghan Song of HKU Department of Physics, in collaboration with researchers from the Chinese University of Hong Kong, Yale University, University of California, Santa Barbara, Ruhr-University Bochum and TU Dresden, has unraveled some of the secrets concealed within the entangled web of [quantum systems](#).

Their findings, recently [published](#) in *Science Advances*, push the boundaries of modern physics and offer a fresh perspective on how [quantum matter](#) operates at these enigmatic junctures. The study not only deepens our understanding of quantum mechanics but also paves the way for future discoveries that could revolutionize technology, materials science, and even our understanding of the cosmos.



The scaling of entanglement entropy (EE) at SU(N) DQCPs. At NNc, the anomalous log-correction disappears and therefore the DQCPs are possibly continuous. Credit: *Science Advances* (2025). DOI: 10.1126/sciadv.adr0634

## What are deconfined quantum critical points?

In everyday life, we are familiar with [phase transitions](#), such as water freezing into ice or boiling into steam. These transitions are well-understood and explained by thermodynamics. However, in the realm of quantum physics, phase transitions can occur at absolute zero temperature (-273.15°C), driven not by thermal energy but by quantum fluctuations—tiny, unpredictable movements of particles at the smallest scales. These are known as quantum critical points.

Traditional quantum critical points act as boundaries between two distinct states: a symmetry-broken phase (ordered phase), where particles are neatly arranged, and a

disordered phase, where particles are jumbled and chaotic. This kind of transition is well-described by the Landau theory, a framework that has been the foundation of our understanding of phase transitions for decades.

But deconfined quantum critical points (DQCPs) break this mold. Instead of a sharp boundary separating an ordered phase from a disordered phase, DQCPs lie between two different ordered phases, each with its own unique symmetry-breaking pattern, meaning the way particles are arranged or interact in one phase is fundamentally different from the other.

This is unusual because, traditionally, phase transitions involve moving from an ordered state to a disordered one, not from one type of order to another. This distinction makes DQCPs fundamentally different and highly intriguing.

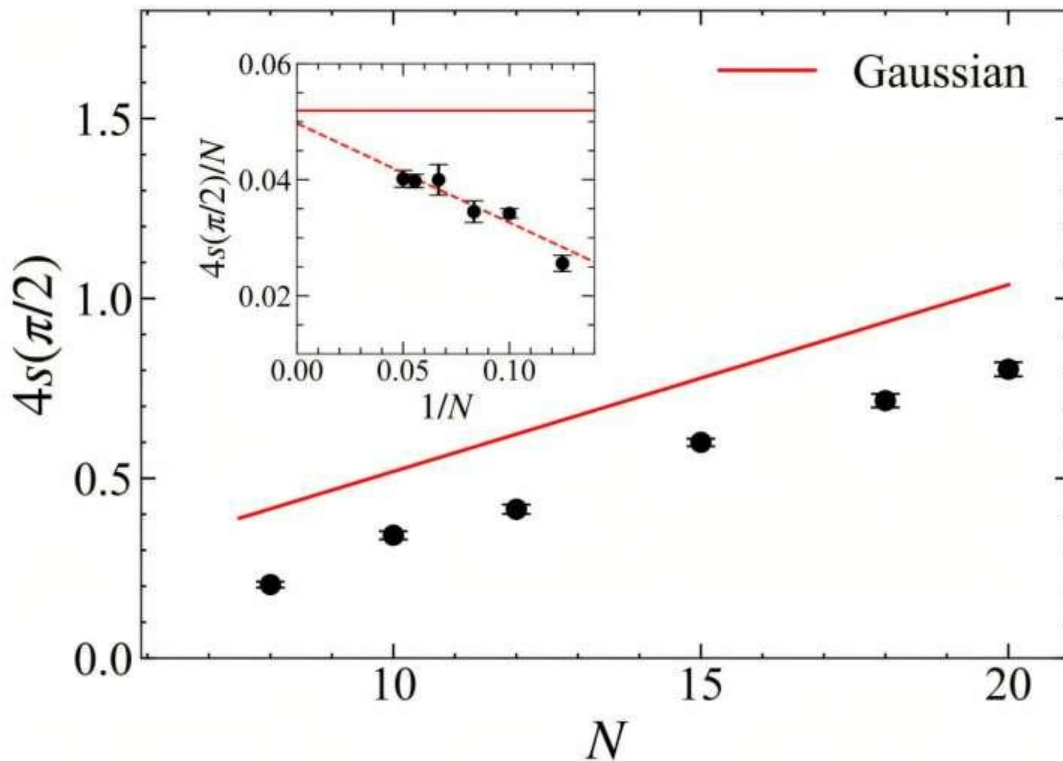
Scientists have debated for decades whether DQCPs represent continuous phase transitions (which are smooth and gradual) or first-order transitions (which are sudden and abrupt). Understanding DQCPs could provide new insights into how particles interact and how exotic states of matter emerge.

## **The key to the mystery: Entanglement entropy**

At the heart of this new study lies the concept of entanglement entropy, a measure of how particles in quantum systems are interrelated. It provides a way to quantify the amount of information shared between different parts of a system. Entanglement entropy offers a glimpse into the hidden structure of quantum systems, serving as a fundamental tool for probing quantum matter and understanding the nature of complex interactions that emerge at critical points.

Using advanced quantum Monte Carlo simulations (a computational method for modeling quantum systems) and rigorous theoretical analysis, researchers examine the behavior of entanglement entropy in square-lattice  $SU(N)$  spin models—a theoretical framework designed to capture the essence of DQCPs.

Their meticulous computations revealed something extraordinary: at small value  $N$  (a parameter that determines the symmetry of the system), the behavior of entanglement entropy deviated from expectations for smooth, continuous phase transitions. Instead, they found that DQCPs exhibit anomalous logarithmic behaviors, defying the theoretical constraints typically associated with continuous phase transitions.



The sub-leading log-coefficient from four  $\pi/2$  corners at large- $N$  and the red line indicating the corresponding Gaussian value. The inset shows  $4s(\pi/2)/N$  as a function of  $1/N$ , together with a linear fit which agrees with the Gaussian value (solid line) for  $N \rightarrow \infty$ . Credit: *Science Advances* (2025). DOI: 10.1126/sciadv.adr0634

## The breakthrough: A critical threshold and conformal fixed points

One of the most striking revelations of the study was the identification of a critical threshold value of  $N$ . When  $N$  exceeds this threshold, DQCPs exhibit behaviors consistent with conformal fixed points—a mathematical framework that describes smooth, continuous phase transitions.

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.  
Subscribe

This discovery is significant because it suggests that, under certain conditions, DQCPs can resemble continuous phase transitions. At these critical points, the system aligns with conformal fixed points, revealing a hidden structure in the quantum world where the boundaries between distinct phases dissolve, and matter exists in a state of extraordinary fluidity, defying the usual rules of physics.

The implications of these findings are profound. DQCPs provide a unique testing ground for exploring the interplay of quantum mechanics, symmetry, and critical phenomena. Understanding their nature could unlock new insights into:

1. Exotic States of Matter: DQCPs are believed to be connected to the emergence of exotic phases, such as quantum spin liquids, which have potential applications in [quantum computing](#) and other advanced technologies.
2. Fundamental Physics: By challenging the traditional Landau paradigm, DQCPs force us to rethink the principles that govern phase transitions, potentially leading to new theoretical frameworks.
3. Technological Innovation: Insights gained from studying DQCPs could inform the design of novel materials with unique quantum properties, such as high-temperature superconductors or quantum magnets.

The enigmatic world of deconfined quantum critical points stands at the frontier of modern physics, offering a glimpse into the uncharted territory of quantum mechanics. Through their meticulous investigation of entanglement entropy and  $SU(N)$  spin models, researchers have made significant strides in unraveling the mysteries of these critical phenomena.

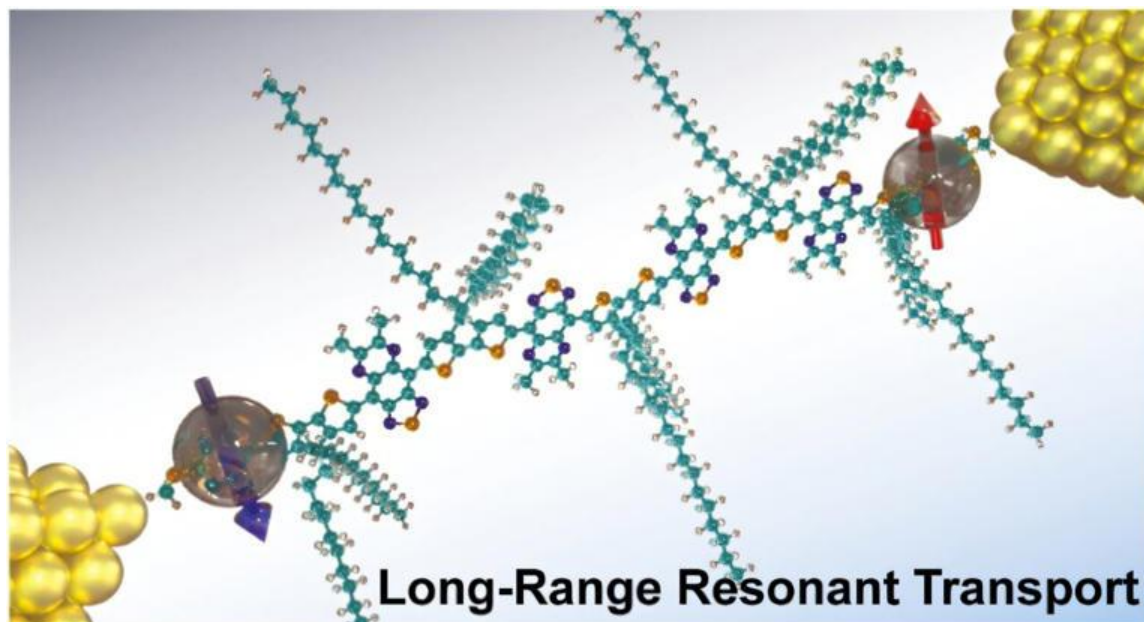
**More information:** Menghan Song et al, Evolution of entanglement entropy at  $SU(N)$  deconfined quantum critical points, *Science Advances* (2025). DOI: [10.1126/sciadv.adr0634](https://doi.org/10.1126/sciadv.adr0634)

**Journal information:** [Science Advances](#)

Provided by [The University of Hong Kong](#)

---

## Unique molecule may lead to smaller, more efficient computers



Graphical abstract. Credit: Journal of the American Chemical Society (2025). DOI: [10.1021/jacs.4c18150](https://doi.org/10.1021/jacs.4c18150)

Today, most of us carry a fairly powerful computer in our hand—a smartphone. But computers weren't always so portable. Since the 1980s, they have become smaller, lighter, and better equipped to store and process vast troves of data. Yet the silicon chips that power computers can only get so small.

"Over the past 50 years, the number of transistors we can put on a chip has doubled every two years," said Kun Wang, assistant professor of physics at the University of Miami College of Arts and Sciences. "But we are rapidly reaching the physical limits for silicon-based electronics, and it's more challenging to miniaturize electronic components using the we have been using for half a century."

It's a problem that Wang and many in his field of molecular electronics are hoping to solve. Specifically, they are looking for a way to conduct electricity without using silicon or metal, which are used to create computer chips today. Using tiny molecular materials for functional components, like transistors, sensors, and interconnects in electronic chips offers several advantages, especially as traditional silicon-based technologies approach their physical and performance limits.

But finding the ideal chemical makeup for this molecule has stumped scientists. Recently, Wang, along with his graduate students, Mehrdad Shiri and Shaocheng Shen, and collaborators Jason Azoulay, associate professor at Georgia Institute of Technology, and Ignacio Franco, professor at the University of Rochester, uncovered a promising solution.

This week, the team shared what they believe is the world's most electrically conductive organic molecule. Their discovery, [published](#) in the *Journal of the American Chemical Society*, opens up new possibilities for constructing smaller, more powerful computing devices at the molecular scale. Even better, the molecule is composed of chemical elements found in nature—mostly carbon, sulfur, and nitrogen.

"So far, there is no molecular material that allows electrons to go across it without significant loss of conductivity," Wang said. "This work is the first demonstration that organic molecules can allow electrons to migrate across it without any energy loss over several tens of nanometers."

The testing and validation of their unique new molecule took more than two years.

However, the work of this team reveals that their molecules are stable under everyday ambient conditions and offer the highest possible electrical conductance at unparalleled lengths. Therefore, it could pave the way for classical computing devices to become smaller, more energy-efficient, as well as cost-efficient, Wang added.

Currently, the ability of a molecule to conduct electrons decreases exponentially as the molecular size increases. These newly developed molecular "wires" are needed highways for information to be transferred, processed, and stored in future computing, Wang said.

"What's unique in our molecular system is that electrons travel across the molecule like a bullet without energy loss, so it is theoretically the most efficient way of electron transport in any material system," Wang noted. "Not only can it downsize future electronic devices, but its structure could also enable functions that were not even possible with silicon-based materials."

Wang means that the molecule's abilities might create new opportunities to revolutionize molecule-based quantum information science.

"The ultra-high electrical conductance observed in our molecules is a result of an intriguing interaction of electron spins at the two ends of the molecule," he added. "In the future, one could use this molecular system as a qubit, which is a fundamental unit for quantum computing."

The team was able to notice these abilities by studying their new molecule under a scanning tunneling microscope (STM). Using a technique called STM break-junction, the team was able to capture a single molecule and measure its conductance.

Shiri, the graduate student, added, "In terms of application, this molecule is a big leap toward real-world applications. Since it is chemically robust and air-stable, it could even be integrated with existing nanoelectronic components in a chip and work as an electronic wire or interconnects between chips."

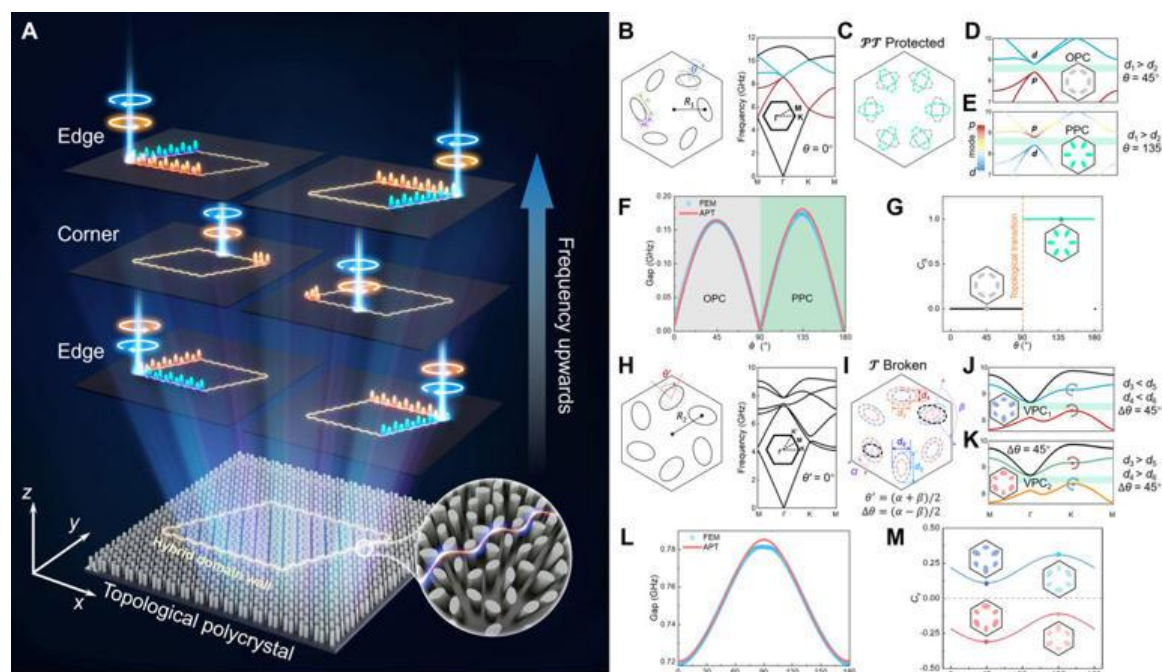
Beyond that, the materials needed to compose the molecule are inexpensive, and it can be created in a lab.

"This molecular system functions in a way that is not possible with current, conventional materials," Wang said. "These are new properties that would not add to the cost but could make (computing devices) more powerful and energy efficient."

**More information:** Shaocheng Shen et al, Long-Range Resonant Charge Transport through Open-Shell Donor–Acceptor Macromolecules, *Journal of the American Chemical Society* (2025). DOI: [10.1021/jacs.4c18150](https://doi.org/10.1021/jacs.4c18150)

Provided by University of Miami

## Topological polycrystal: A new approach to configurable, multiband topological photonic circuitry



Topological photonic polycrystal (TPPC) implemented in photonic integrated circuits (PIC) and its structural details. (A) Diagram of HTP-PIC displaying edge and corner states. Right/upper edges maintain TESs with identical spin-momentum locking at distinct frequencies, whereas left/lower edges sustain TESs with opposing spin-momentum locking at different frequencies. (B–E) Hexagonal lattice with  $C_6$  symmetry shows band degeneracies near 8 GHz at  $\Gamma$  points (B) and its modified versions with varying orientation angle  $\theta$  (increasing clockwise) (C), with  $\theta = 45^\circ$  (OPC) and

$\theta = 135^\circ$  (PPC) band structures displayed in D and E (blue/red lines indicate d/p modes respectively). (F) Correlation between frequency gap and rotation angle  $\theta$  from FEM simulations and APT computations. (G) CS values versus  $\theta$  from numerical calculations. (H–K) C6-symmetric hexagonal lattice demonstrates band degeneracies around 8 GHz at K points (H) and resulting C3-symmetric cells with broken parity symmetry P under angle variation (I), with band structures for two modified cells (VPC1 featuring larger top ellipse/VPC2 with smaller top ellipse) shown in J and K (circular arrows indicate valley-polarized states at K points). (L) Relationship between frequency gap and rotation angle  $\Delta\theta$  via FEM and APT analysis. (M) Computed CV values for both VPCs as a function of  $\Delta\theta$ . Credit: Tianyue Li

Molding the flow of light—whether confined to localized regions or propagating in free space—remains crucial for modern integrated photonics. The advancement of the multi-channel, programmable optical waveguide and coupler arrays has enabled us to develop photonic integrated circuits (PICs) as a viable alternative to electronic ones, overcoming limitations in processing speed, bandwidth, and efficiency across the optical-to-microwave spectrum.

However, as on-chip complexity grows, we face significant challenges regarding long-term stability and fabrication-induced defects, making operational reliability critical for practical applications.

The increasing demand for high-capacity information processing drives our need for more complex PICs with additional channels. In this context, topological photonics offers promising solutions due to its inherent robustness against defects.

Current PICs utilizing topologically protected domain-wall modes mainly rely on two-dimensional microstructures following the rule of bulk-edge correspondence, which typically supports only limited edge states and constrains channel capacity. To overcome this, we have focused on hybrid topological effects that combine multiple topological phenomena in a single system.

Recently, our research team has investigated hybrid artificial microstructured systems and their topological applications. By constructing a synthetic dimension combining momentum space and unit cell orientation space, we developed a configurable topological photonic polycrystal. This dielectric topological metasurface, composed of tunable elliptical elements, utilizes a novel coupling mechanism between pseudo-spin and the valley Hall effect, providing a versatile platform for multidimensional photonic control.

Our work, [published](#) in *National Science Review* under the title "Configurable Topological Photonic Polycrystal Based on Synthetic Hybrid Dimension," represents a significant advancement in the field.

We developed a perturbation theory based on structural orientation angles to enable rapid calculation and adjustment of photonic band gaps. Since both pseudo-spin and valley lattices are fundamentally linked to orientation angles, we observed that varying these angles induced delicate energy band shifts, effectively modulating the "mass term" of the system.

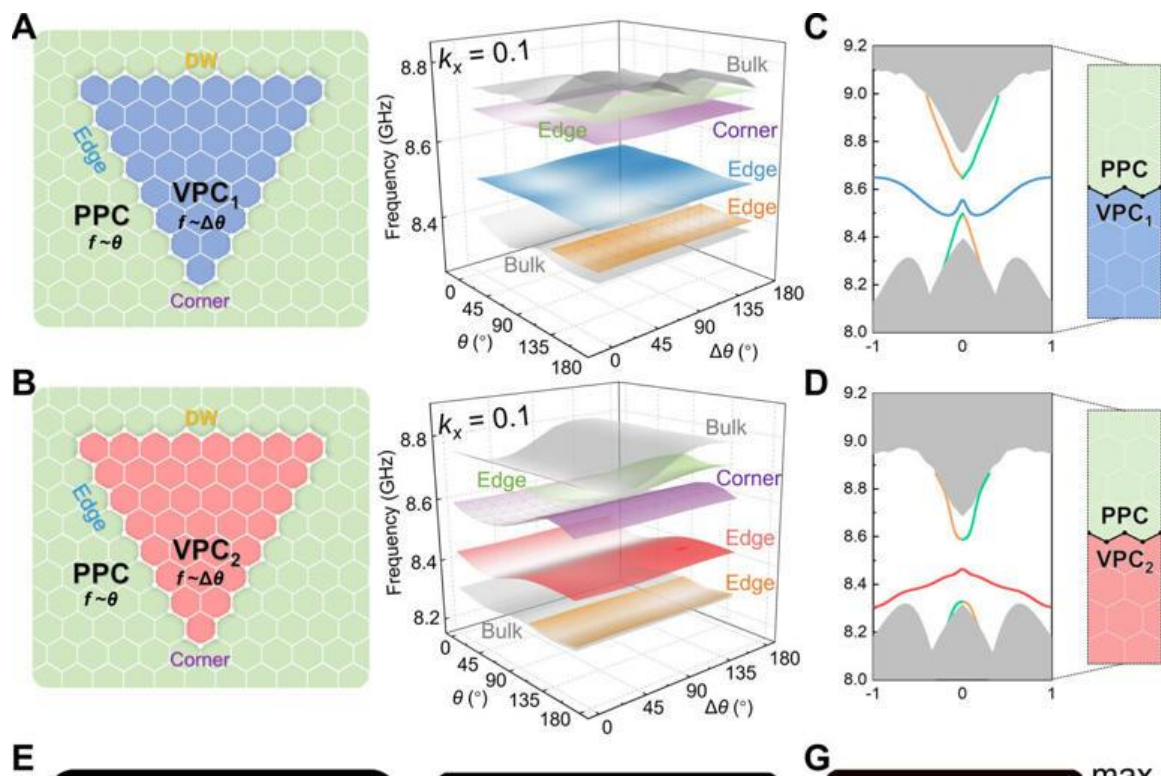
To fully characterize this phenomenon, we integrated our proposed scalar perturbation theory while treating orientation angles as synthetic dimension parameters. For any given photonic lattice, we successfully constructed a three-dimensional synthetic space by combining the two-dimensional Bloch momentum space and the one-dimensional orientation angle dimension.

This innovative approach allowed us to compute topological invariants as continuous functions of orientation angles, yielding a powerful theoretical framework for analyzing the system's topological properties. When coupling both topological effects, we found this hybrid-dimensional space depends on two independent orientation angles and the one-dimensional momentum space along domain walls.

Through detailed hybrid-dimensional analysis, we systematically tracked how bulk states, edge states, and corner states evolve with orientation angle variations. These insights fundamentally clarify how our hybrid topological polycrystal architecture achieves robust, dynamically reconfigurable photonic functionalities.

In addition, we introduced a novel local quality factor ( $Q^l$ ) specifically designed to characterize hybrid eigenmodes within band gaps. By integrating the local density of states at target frequencies, this quantitative metric provides an effective performance evaluation method for hybrid topological photonic devices.

As a validation, our team experimentally validated this approach by implementing a hybrid topological photonic integrated circuit that successfully demonstrated high-contrast multi-band edge states and higher-order corner states along the interface. This method enables on-chip logic gates, couplers, and high-density optical communication through multi-band chiral edge channels, while simultaneously supporting the development of multi-band lasers featuring ultra-small mode volumes and diverse corner states.



**E** **G** Hybrid topological states in superlattice-based HTP-PIC. (A–B) Schematic of TPPC consisting of VPC1 (A) and VPC2 (B) embedded in PPC, with right panels showing band dispersion of corresponding configurations at  $k_x = 0.1$  versus  $(\theta, \Delta\theta)$ . (C–D) Projected band structures for supercells combining VPC1 (C) or VPC2 (D) with PPC at  $\Delta\theta = 45^\circ$ , where gray areas indicate bulk states and gap-spanning solid lines represent TES dispersion. (E–F) Unidirectional light propagation simulations at 8.482 GHz (E) and 8.705 GHz (F) under LCP/RCP excitation for configuration C. (G–H) Field distributions of corner states (G) and localized quality factor QL (H) in VPC2-embedded PPC HTP-PIC. Credit: Tianyue Li

Furthermore, our orientation-dependent photonic lattice concept opens new possibilities for reconfigurable and programmable active topological devices. Looking ahead, we aim to explore nonlinear effects in hybrid topological polycrystals to enhance their multimodal and multi-band capabilities, paving the way for both classical and quantum photonic applications.

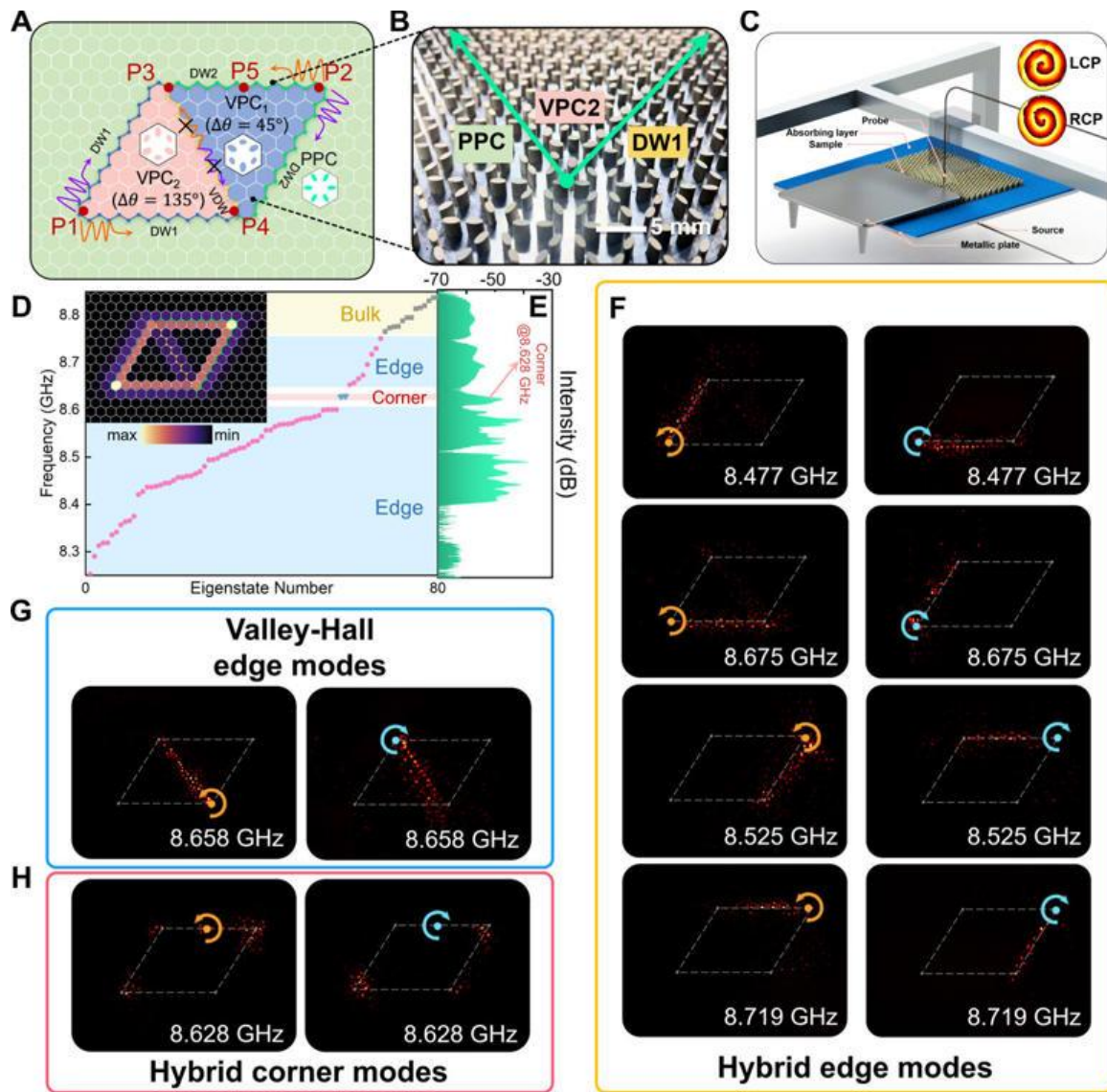
**More information:** Tianyue Li et al, Configurable Topological Photonic Polycrystal Based on a Synthetic Hybrid Dimension, *National Science Review* (2025). DOI: [10.1093/nsr/nwaf107](https://doi.org/10.1093/nsr/nwaf107)

## Bio:

Tianyue Li is currently a Research Fellow in the Department of Physics at the Institute of Advanced Study, Hong Kong University of Science and Technology (HKUST). His research focuses on nanophotonics, particularly investigating the

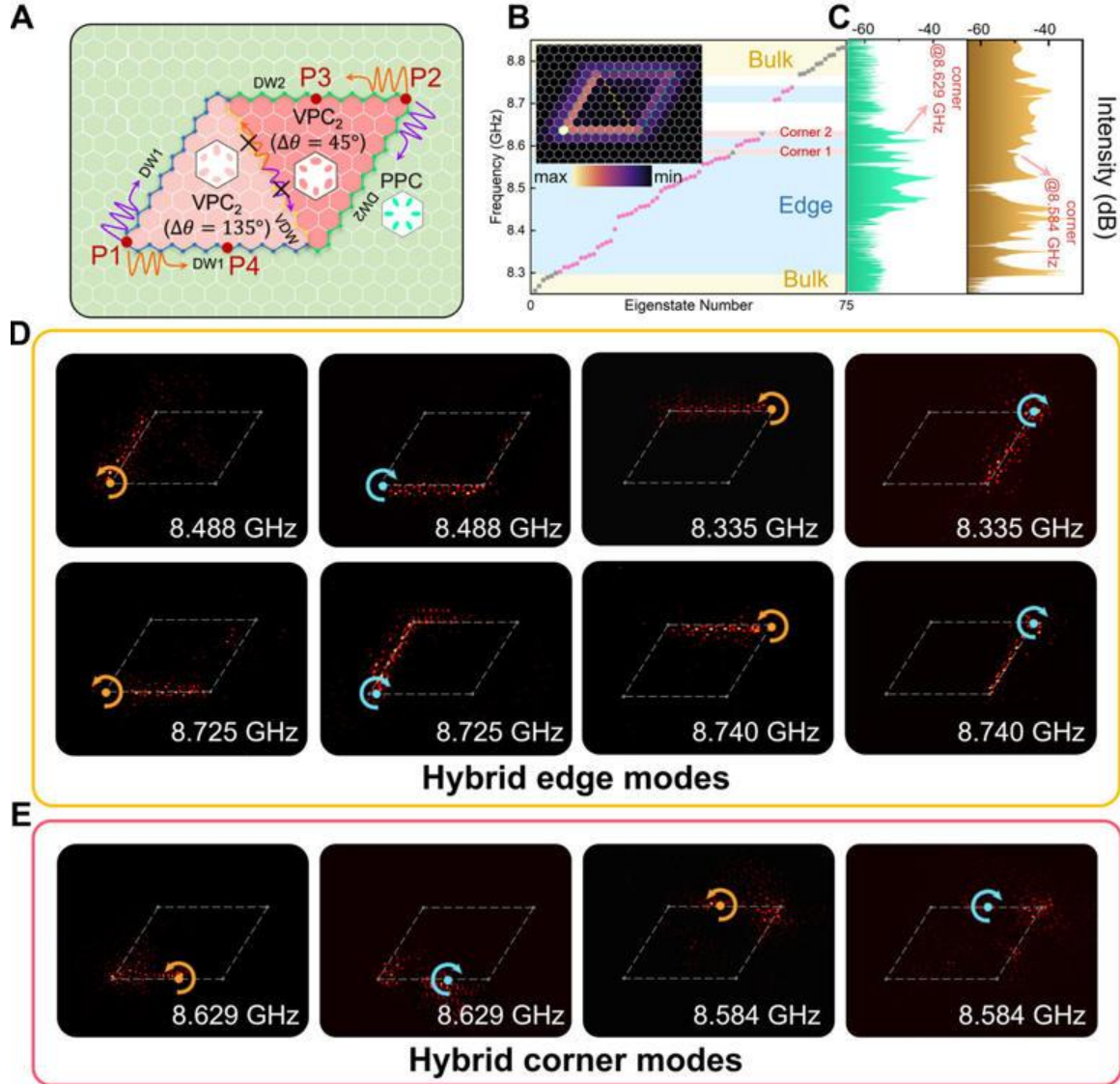
physical mechanisms and optical singularities in light-matter interactions. He strives to advance this field through explorations in light-field manipulation, topological photonics, and optomechanics. Additionally, he develops versatile nano-devices for on-chip and fiber-based platforms, including applications in optical tweezers, communication, photonic circuits, and imaging.

He has published more than 10 SCI papers and co-authored 10 additional papers. He has delivered four invited talks and more than 10 oral presentations. His work has received more than 600 citations, with an h-index of 12, and includes an Editors' Pick selection in *Optics Letters* and a cover article in another journal.



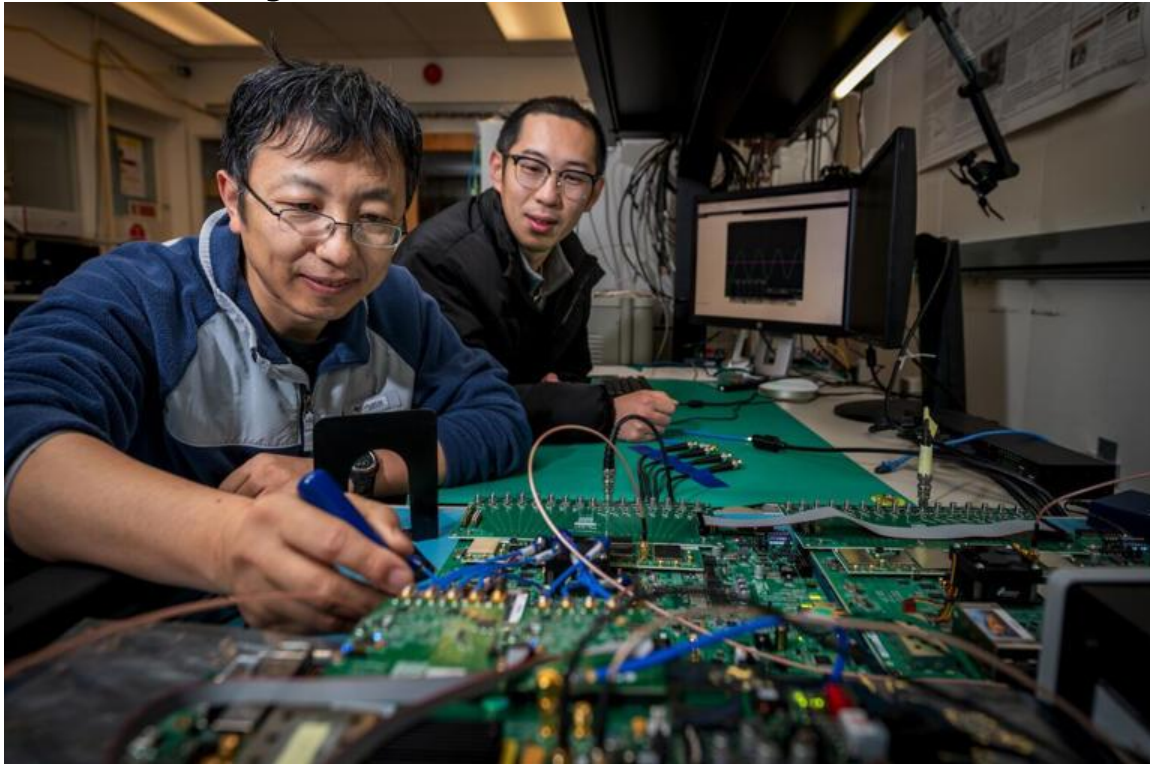
Experimental observation of hybrid TESs and TCSs in symmetry-maintained HTP-PIC. (A) Schematic design of HTP-PIC composed of VPC1 ( $\Delta\theta = 45^\circ$ ) and VPC2 ( $\Delta\theta = 135^\circ$ ) embedded in PPC. (B) Microscopy image showing partial view of DW1 in fabricated HTP-PIC sample. (C) Diagram of near-field measurement setup for sample characterization. (D)

Numerically computed eigenmodes of symmetric HTP-PIC: bulk (grey squares), edge (pink dots), and corner states (blue triangles), with inset showing QL distribution. (E) Experimentally obtained transmission spectrum. (F–H) Measured hybrid TESs at VPC/PPC interfaces (F), valley-polarized TESs at VPC1/VPC2 junction (G), and two hybrid TCSs (H) excited by LCP (orange arrows) and RCP (blue arrows) sources. Credit: Tianyue Li



Experimental characterization of hybrid TESs and TCSs in symmetric-antisymmetric HTP-PIC. (A) Structural design of HTP-PIC comprising VPC2 with varying  $\Delta\theta$  embedded in PPC. (B) Numerical eigenfrequency analysis of antisymmetric HTP-PIC, with green and blue triangles denoting distinct corner state frequencies, and inset displaying QL spatial profile. (C) Measured transmission spectra under localized excitation at positions P1 versus P2. (D) Experimental verification of eight hybrid TESs along VPC-PPC boundaries. (E) Dual-frequency hybrid TCSs detected when stimulating the system at locations P3 and P4 separately. Credit: Tianyue Li

# Superconducting qubits enable new quantum simulations and advanced control systems



Co-leads of the QubiC 2.0 and QubiC design from Berkeley Lab's Accelerator Technology & Applied Physics (ATAP) Division. Credit: Berkeley Lab

Interdisciplinary teams across the Quantum Systems Accelerator (QSA) are using innovative approaches to push the boundaries of superconducting qubit technology, bridging the gap between today's NISQ (Noisy Intermediate-Scale Quantum) systems and future fault-tolerant systems capable of impactful science applications.

QSA is one of the five United States Department of Energy National Quantum Information Science (QIS) Research Centers, bringing together leading pioneers in quantum information science (QIS) and engineering across 15 partner institutions.

A superconducting qubit is made from superconducting materials such as aluminum or niobium, which exhibit quantum effects when cooled to very low

temperatures (typically around 20 millikelvins, or  $-273.13^{\circ}\text{C}$ ). Numerous technology companies and research teams across universities and national laboratories are leveraging superconducting qubits for prototype scientific computing in this rapidly growing field.

However, many challenges in controlling, calibrating, and operating superconducting quantum processors currently hinder qubit performance and restrict the kinds of simulations possible, particularly for investigating complex material systems.

## Advancing quantum simulation

The QSA teams at the Massachusetts Institute of Technology and MIT Lincoln Laboratory simulated how charged particles behave under synthetic electromagnetic fields using superconducting qubits.

Publishing their results in fall 2024 in *Nature Physics*, the team [developed a two-dimensional array](#) of 16 superconducting transmon qubits arranged in a  $4 \times 4$  grid. They modified the qubits' properties with continuous signals using independent electrical control lines for each qubit. The resulting behavior of the qubit grid emulates a magnetic vector potential, a key concept in electromagnetism that impacts how charged particles move in materials.

"Now we can dial in any electromagnetic field we want—even fields beyond what is practically feasible in a laboratory environment—and watch how the motion of quantum particles changes in the field. Our work allows quantum computers to simulate much more of the rich behavior of quantum materials," said MIT's Ilan Rosen, who is the paper's lead author.

The team validated their approach to generating synthetic electromagnetic fields by observing the Hall effect, where a charged particle deflects sideways as it moves through a material under a perpendicular magnetic field. In real materials, the Hall effect leads to a voltage across the material, so their experiment demonstrated how precise control and engineering expand the capabilities of quantum simulators.

Expanding on their previous work leveraging the programmability of superconducting qubit arrays, the QSA teams at MIT and MIT Lincoln Laboratory

devised another unique approach to studying particle behavior and localization. They selected ten qubits from the 4×4 grid to form a one-dimensional rhombic lattice. This qubit configuration enabled researchers to flexibly manipulate particle transport and group velocity, shedding light on complex phenomena in condensed matter physics.

The results were [published](#) on the *arXiv* preprint server in 2024.

The team was able to tweak this lattice using the synthetic electromagnetic field. Without the field, particles move freely (dispersive band regime), but when the magnetic field increases, the particles slow down and eventually get stuck in the lattice (flat-band regime). The introduction of disorder (random energy variations) is also used to study the distinctive transport responses arising from the adjustably flat band structure.

"Our study demonstrates that adding new capabilities to quantum simulators—like electromagnetic fields—allows us to study impactful physical systems—like materials with flat-band structures. These techniques are readily extensible to larger lattices, where we can study exotic quantum phases predicted by condensed matter physics theories," added Rosen.

## Pioneering control systems

As programmable superconducting qubit platforms advance fundamental research, there is a growing need in the field for robust control systems. Researchers need to control and direct quantum information systems, performing real-time qubit measurements. A QSA team at Lawrence Berkeley National Laboratory (Berkeley Lab) built a modular field-programmable gate array (FPGA)-based electronics control system called QubiC 2.0, publishing [their results](#) on the *arXiv* preprint server, (after building its predecessor, QubiC).

QubiC 2.0 is uniquely tailored for superconducting quantum systems and is fully open-source, making it available to the broader community. It operates with room-temperature electronics hardware, FPGA gateware, and engineering software to realize the desired radio frequency pulses to control and measure qubits. The fully open-sourced QubiC 2.0 gateware also provides exquisite low-level access for researchers to all control layers, enabling others to participate in the product's evolution and provide feedback.

"QubiC 2.0 (and its predecessor QubiC) provides a modular, scalable, and cost-effective qubit control hardware system and customized engineering solution for nascent platforms being developed in the field. Community feedback makes it potentially compatible with other quantum computing prototypes and technologies, which QSA is advancing," explained Gang Huang, who co-led the QubiC design from the Accelerator Technology & Applied Physics (ATAP) Division at Berkeley Lab.

QubiC 2.0 also leverages the latest advances in artificial intelligence (AI) and machine learning. It integrates a multilayer custom neural network directly on the FPGA chip. According to the team's experimental results, the AI-powered FPGA only takes 54 ns inference time for state discrimination, improving the quantum readout fidelity from 92% to 98%.

"With QubiC 2.0's capabilities, mid-circuit measurement and feed-forward techniques are achievable, enabling the realization of advanced quantum algorithms and a broader class of experiments. This control system meets the growing demands for scalability and open-source systems, fostering co-design in quantum research at QSA and the broader ecosystem," said Yilun Xu, QubiC co-lead at Berkeley Lab's ATAP Division.

## Assessing performance

Another example of novel approaches using superconducting qubits was led by a team of researchers at the University of California, Berkeley, in collaboration with Berkeley Lab and Sandia National Laboratories. Researchers introduced a new technique to assess the performance of quantum logic gates called mirror randomized benchmarking (MRB), which can scale to thousands of qubits. Many widely used methods, like randomized benchmarking, become impractical beyond a small number of qubits.

Their results, [published](#) in *Physical Review X*, demonstrate that the method is highly adaptable, creating a way to study the performance of certain gates or even algorithms without costly computations.

"MRB's scalability allows it to accurately capture multi-qubit crosstalk errors missed by standard one- and two-qubit benchmarks. These crosstalk errors can be highly detrimental to performance. Our MRB results reveal that they constitute

a significant fraction of the error in some of today's quantum processors," said lead author Jordan Hines.

QSA teams focusing on superconducting qubit platforms are pushing the boundaries of the nascent quantum technologies and opening new possibilities for advanced computing and the exploration of complex phenomena. From simulating synthetic electromagnetic fields and particle behavior to developing scalable control systems and advanced benchmarking techniques, they're paving the way for versatile quantum systems.

The seamless collaboration across QSA will continue accelerating progress toward fault-tolerant quantum computing and creating new opportunities for exchanging lessons about qubit technologies.

**More information:** Ilan T. Rosen et al, A synthetic magnetic vector potential in a 2D superconducting qubit array, *Nature Physics* (2024). DOI: [10.1038/s41567-024-02661-3](https://doi.org/10.1038/s41567-024-02661-3)

Ilan T. Rosen et al, Flat-band (de)localization emulated with a superconducting qubit array, *arXiv* (2024). DOI: [10.48550/arxiv.2410.07878](https://doi.org/10.48550/arxiv.2410.07878)

Yilun Xu et al, QubiC 2.0: An Extensible Open-Source Qubit Control System Capable of Mid-Circuit Measurement and Feed-Forward, *arXiv* (2023). DOI: [10.48550/arxiv.2309.10333](https://doi.org/10.48550/arxiv.2309.10333)

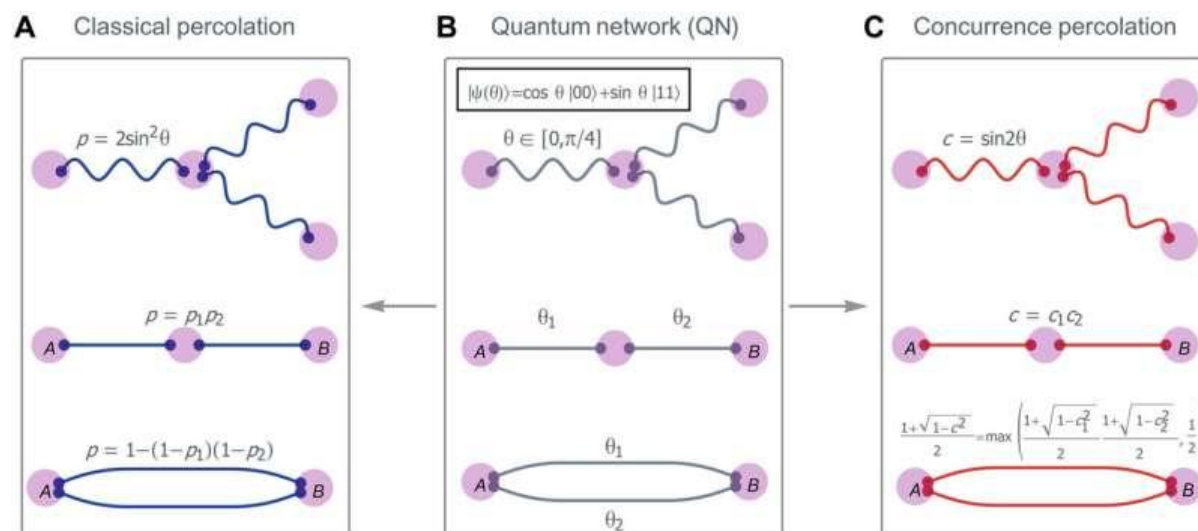
Jordan Hines et al, Demonstrating Scalable Randomized Benchmarking of Universal Gate Sets, *Physical Review X* (2023). DOI: [10.1103/PhysRevX.13.041030](https://doi.org/10.1103/PhysRevX.13.041030)

Provided by Lawrence Berkeley National Laboratory

MAY 2, 2025

# Novel strategy keeps quantum networks stable by replenishing entanglement

by [Rensselaer Polytechnic Institute](#)



Percolation mappings of a quantum network (QN). Credit: *Science Advances* (2025). DOI: 10.1126/sciadv.adt2404

Researchers at Rensselaer Polytechnic Institute (RPI) are tackling one of the most complex challenges in the world of quantum information—how to create reliable, scalable networks that can connect quantum systems over distances.

Their work has resulted in two publications in [Physical Review A](#) and [Science Advances](#), bringing us one step closer to realizing large-scale networked [quantum systems](#), or even the quantum internet.

The research team, which includes faculty members from the RPI Department of Physics, Applied Physics, and Astronomy, and the Department of Computer Science, is led by Assistant Professor Xiangyi Meng, Ph.D. Their research focuses on designing [quantum networks](#) that use entanglement—a phenomenon where quantum particles become mysteriously correlated.

These entangled particles are the foundation of quantum communication, allowing for fast, secure transfer of quantum data without the risk of eavesdropping. But the challenge is that once a pair of entangled particles are used for communication, the entanglement disappears, leaving the network unusable for future tasks.

That's where the RPI team's breakthrough comes in. Their research demonstrates a new strategy that could solve this issue, ensuring that quantum networks remain functional by replenishing new entanglement. By using a clever "bridging" approach that adds

redundancy to the network, they've shown that it's possible to maintain stable communication without overburdening the system.

One of the most exciting aspects of their work is the introduction of a "multiplexing" strategy. Rather than relying on a single entangled path to transmit information, multiple paths are used simultaneously. This redundancy combats the noise and imperfections inherent in quantum communication, ensuring that entanglement can be reliably established even under less-than-ideal conditions.

What's more, this strategy may prove even more effective in quantum networks than it does in classical systems, offering a distinct advantage for future quantum communication.

"By ensuring quantum networks can function reliably as they grow in complexity, our research opens up new possibilities for the future of quantum information," said Meng.

"This is a crucial step toward realizing large-scale quantum systems, where quantum information can be processed and shared securely, unlocking more sophisticated network functionalities. The opportunities at RPI allow us to take bold steps in this field, where we can not only push the boundaries of quantum science but also train the next generation of researchers to shape the future of technology."

This work has far-reaching implications, especially as major companies like IBM advance their quantum computing efforts. As quantum technologies become more powerful, a network of interconnected chips that can handle massive amounts of quantum data will be essential.

RPI's research is laying the groundwork for these future quantum systems, which could eventually lead to faster, more secure communication between quantum processing units.

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.

Subscribe

In addition to this theoretical work, Meng is dedicated to training the next generation of quantum scientists. He is part of a team that has submitted a proposal for a National Science Foundation Research Traineeship to educate students about quantum computing.

Meng is also part of the Co-design Center for Quantum Advantage (C2QA) between Brookhaven National Laboratory and RPI, which is a major Department of Energy initiative focused on developing the tools needed to build fault-tolerant quantum systems.

As part of his commitment to hands-on learning, he leads a research lab at RPI where undergraduates have the opportunity to work directly with quantum computers, gaining practical experience in the field.

This new research represents a critical step in the development of quantum [communication](#) and computational systems. It's a small but powerful piece of the

puzzle that could one day unlock the path to large-scale quantum architectures and enable the next generation of quantum technologies.

**More information:** Xinqi Hu et al, Unveiling the importance of nonshortest paths in quantum networks, *Science Advances* (2025). DOI: [10.1126/sciadv.adt2404](https://doi.org/10.1126/sciadv.adt2404)

Yaqi Zhao et al, Nonconvex entanglement monotone determining the characteristic length of entanglement distribution in continuous-variable quantum networks, *Physical Review A* (2025). DOI: [10.1103/PhysRevA.111.042429](https://doi.org/10.1103/PhysRevA.111.042429)

**Journal information:** [Physical Review Letters](#) , [Science Advances](#) , [Physical Review A](#)  
Provided by [Rensselaer Polytechnic Institute](#)

---

## New theory of gravity brings long-sought Theory of Everything closer

Researchers at Aalto University develop a quantum gravity theory that's compatible with the Standard Model of particle physics.

From Aalto University 13/05/25 (first released 05/05/25)

The gravity quantum field is calculated in flat spacetime. The curved classical metric is calculated using the expectation value of the gravity quantum field. Credit: Mikko Partanen and Jukka Tulkki / Aalto University.

At long last, a unified theory combining gravity with the other fundamental forces—electromagnetism and the strong and weak nuclear forces—is within reach.

Bringing gravity into the fold has been the goal of generations of physicists, who have struggled to reconcile the incompatibility of two cornerstones of modern physics: quantum field theory and Einstein's theory of gravity.

Researchers at Aalto University have developed a new quantum theory of gravity which describes gravity in a way that's compatible with the Standard Model of particle physics, opening the door to an improved understanding of how the universe began.

While the world of theoretical physics may seem remote from applicable tech, the findings are remarkable.

Modern technology is built on such fundamental advances — for example, the GPS in your smartphone works thanks to Einstein's theory of gravity.

Mikko Partanen and Jukka Tulkki describe their new theory in a paper just published in [Reports on Progress in Physics](#). Lead author Partanen expects that within a few years, the findings will have unlocked critical understanding.

‘If this turns out to lead to a complete quantum field theory of gravity, then eventually it will give answers to the very difficult problems of understanding singularities in black holes and the Big Bang,’ he says.

‘A theory that coherently describes all fundamental forces of nature is often called the Theory of Everything,’ says Partanen, although he doesn’t like to use the term himself. ‘Some fundamental questions of physics still remain unanswered.

For example, the present theories do not yet explain why there is more matter than antimatter in the observable universe.’

### **Reconciling the irreconcilable**

The key was finding a way to describe gravity in a suitable gauge theory — a kind of theory in which particles interact with each other through a field. ‘The most familiar gauge field is the electromagnetic field.

When electrically charged particles interact with each other, they interact through the electromagnetic field, which is the pertinent gauge field,’ explains Tulkki.

‘So when we have particles which have energy, the interactions they have just because they have energy would happen through the gravitational field.’

A challenge long facing physicists is finding a gauge theory of gravity that is compatible with the gauge theories of the other three fundamental forces — the electromagnetic force, the weak nuclear force and the strong nuclear force.

The Standard Model of particle physics is a gauge theory which describes those three forces, and it has certain symmetries.

‘The main idea is to have a gravity gauge theory with a symmetry that is similar to the Standard Model symmetries, instead of basing the theory on the very different kind of spacetime symmetry of general relativity,’ says Partanen, the study’s lead author.

Without such a theory, physicists cannot reconcile our two most powerful theories, quantum field theory and general relativity.

Quantum theory describes the world of the very small—tiny particles interacting in probabilistic ways—while general relativity describes the chunkier world of familiar objects and their gravitational interaction.

They are descriptions of our universe from different perspectives, and both theories have been confirmed to extraordinary precision—yet they are incompatible with each other.

Furthermore, because gravitational interactions are weak, more precision is needed to study true quantum gravity effects beyond general relativity, which is a classical theory.

‘A quantum theory of gravity is needed to understand what kind of phenomena there are in cases where there’s a gravitational field and high energies,’ says Partanen.

Those are the conditions around black holes and in the very early universe, just after the Big Bang—areas where existing theories in physics stop working.

Always fascinated with the very big questions of physics, he discovered a new symmetry-based approach to the theory of gravity and began to develop the idea further with Tulkki.

The resulting work has great potential to unlock a whole new era of scientific understanding, in much the same way as understanding gravity paved the way to eventually creating GPS.

### **Open invite to the scientific community**

Although the theory is promising, the duo point out that they have not yet completed its proof.

The theory uses a technical procedure known as renormalization, a mathematical way of dealing with infinities that show up in the calculations.

So far Partanen and Tulkki have shown that this works up to a certain point—for so-called ‘first order’ terms—but they need to make sure the infinities can be eliminated throughout the entire calculation.

‘If renormalization doesn’t work for higher order terms, you’ll get infinite results.

So it’s vital to show that this renormalization continues to work,’ explains Tulkki. ‘We still have to make a complete proof, but we believe it’s very likely we’ll succeed.’

Partanen concurs. There are still challenges ahead, he says, but with time and effort he expects they’ll be overcome.

‘I can’t say when, but I can say we’ll know much more about that in a few years.’

For now, they’ve published [the theory](#) as it stands, so that the rest of the scientific community can become familiar with it, check its results, help develop it further, and build on it.

‘Like quantum mechanics and the theory of relativity before it, we hope our theory will open countless avenues for scientists to explore,’ Partanen concludes.

Aalto University researchers Mikko Partanen and Jukka Tulkki hope their work will open new and exciting avenues for scientists to explore. Credit: Matti Ahlgren / Aalto University

# Mathematician solves algebra's oldest problem using intriguing new number sequences

A UNSW Sydney mathematician discovers innovative sequences, providing fresh insights into solving complex higher polynomial equations.

From University of New South Wales 13/05/25 (first released 01/05/25)

Norman Wildberger at his laptop. Credit: UNSW Sydney

A UNSW Sydney mathematician has discovered a new method to tackle algebra's oldest challenge – solving higher polynomial equations.

Polynomials are equations involving a variable raised to powers, such as the degree two polynomial:  $1 + 4x - 3x^2 = 0$ .

The equations are fundamental to maths as well as science, where they have broad applications, like helping describe the movement of planets or writing computer programs.

However, a general method for solving 'higher order' polynomial equations, where  $x$  is raised to the power of five or higher, has historically proven elusive.

Now, UNSW Honorary Professor [Norman Wildberger](#) has revealed a new approach using novel number sequences, outlined in a [recent publication](#) with computer scientist Dr. Dean Rubine.

"Our solution reopens a previously closed book in mathematics history," Prof. Wildberger says.

## The polynomial problem

Solutions to degree-two polynomials have been around since 1800 BC, thanks to the Babylonians' 'method of completing the square', which evolved into the quadratic formula familiar to many high school math students.

This approach, using roots of numbers called 'radicals', was later extended to solve three- and four-degree polynomials in the 16th century.

Then, in 1832, French mathematician Évariste Galois showed how the mathematical symmetry behind the methods used to resolve lower-order polynomials became impossible for degree five and higher polynomials.

Therefore, he figured, no general formula could solve them.

Approximate solutions for higher-degree polynomials have since been developed and are widely used in applications but, Prof.

Wildberger says, these don't belong to pure algebra.

### **Radical rejection behind new method**

The issue, he says, lies in the classical formula's use of third or fourth roots, which are radicals.

The radicals generally represent irrational numbers, which are decimals that extend to infinity without repeating and can't be written as simple fractions.

For instance, the answer to the cubed root of seven,  $\sqrt[3]{7} = 1.9129118\dots$  extends forever.

Prof. Wildberger says this means that the real answer can never be completely calculated because "you would need an infinite amount of work and a hard drive larger than the universe".

So, when we assume  $\sqrt[3]{7}$  'exists' in a formula, we're assuming that this infinite, never-ending decimal is somehow a complete object.

This is why, Prof. Wildberger says, he "doesn't believe in irrational numbers."

Irrational numbers, he says, rely on an imprecise concept of infinity and lead to logical problems in mathematics.

Prof. Wildberger's rejection of radicals inspired his best-known contributions to mathematics, rational trigonometry and universal hyperbolic geometry.

Both approaches rely on mathematical functions like squaring, adding, or multiplying, rather than irrational numbers, radicals, or functions like sine and cosine.

His new method to solve polynomials also avoids radicals and irrational numbers, relying instead on special extensions of polynomials called 'power series', which can have an infinite number of terms with the powers of  $x$ .

By truncating the power series, Prof. Wildberger says, they were able to extract approximate numerical answers to check that the method worked.

"One of the equations we tested was a famous cubic equation used by Wallis in the 17th century to demonstrate Newton's method.

Our solution worked beautifully," he said.

### **New geometry for a general solution**

However, Prof. Wildberger says the proof for the method is, ultimately, based on mathematical logic.

His method uses novel sequences of numbers that represent complex geometric relationships.

These sequences belong to combinatorics, a branch of mathematics that deals with number patterns in sets of elements.

The most famous combinatorics sequence, called the Catalan numbers, describes the number of ways you can dissect a polygon, which is any shape with three or more sides, into triangles.

The numbers have important practical applications, including in computer algorithms, data structure designs, and game theory.

They even appear in biology, where they're used to help count the possible folding patterns of RNA molecules.

And they can be calculated using a simple two-degree polynomial.

“The Catalan numbers are understood to be intimately connected with the quadratic equation.

Our innovation lies in the idea that if we want to solve higher equations, we should look for higher analogues of the Catalan numbers.”

Prof. Wildberger's work extends these Catalan numbers from a one-dimensional to multi-dimensional array based on the number of ways a polygon can be divided using non-intersecting lines.

“We've found these extensions, and shown how, logically, they lead to a general solution to polynomial equations.

“This is a dramatic revision of a basic chapter in algebra.”

Even quintics – a degree five polynomial – now have solutions, he says.

Aside from theoretical interest, he says, the method holds practical promise for creating computer programs that can solve equations using the algebraic series rather than radicals.

“This is a core computation for much of applied mathematics, so this is an opportunity for improving algorithms across a wide range of areas.”

### **Geode's unexplored facets**

Prof Wildberger says the novel array of numbers, which he and Dr. Rubine called the “Geode”, also holds vast potential for further research.

“We introduce this fundamentally new array of numbers, the Geode, which extends the classical Catalan numbers and seem to underlie them.

“We expect that the study of this new Geode array will raise many new questions and keep combinatorialists busy for years.

“Really, there are so many other possibilities. This is only the start.”

## TOPOLOGY

# Dimension 126 Contains Strangely Twisted Shapes, Mathematicians Prove

*A new proof represents the culmination of a 65-year-old story about anomalous shapes in special dimensions.*

## Introduction

May 5, 2025

It can be tempting to assume that your intuitions about three-dimensional space carry over to higher-dimensional realms. After all, adding another dimension simply creates a new direction to move around in. It doesn't change the defining features of space: its endlessness and its uniformity.

But different dimensions have decidedly different personalities. In dimensions 8 and 24, it's possible to [pack balls together](#) especially tightly. In other dimensions, there are “exotic” spheres that look irremediably crumpled. And dimension 3 is the only one that can contain knots — in any higher dimension, you can untangle a knot even while holding its ends fast.

Now, mathematicians have put the finishing touches on a story of dimensional weirdness that has been 65 years in the making. For many decades, researchers have wanted to know which dimensions can host particularly strange shapes — ones so twisted that they cannot be converted into a sphere through a simple procedure called surgery. The existence of these shapes, mathematicians have shown, is intimately intertwined with fundamental

questions in topology about the relationships between spheres of different dimensions.

Over the years, mathematicians found that the twisted shapes exist in dimensions 2, 6, 14, 30 and 62. They also showed that such shapes could not possibly exist in any other dimension — save one. No one could determine the status of dimension 126.

Three mathematicians have now settled this final problem. In a [paper posted online](#) last December, [Weinan Lin](#)() and [Guozhen Wang](#)() of Fudan University in Shanghai, along with [Zhouli Xu](#)() of the University of California, Los Angeles, proved that 126 is indeed one of the rare dimensions that can host these strangely twisted shapes.

It's "a very long program, finally finished," said [Ulrike Tillmann](#)(), a mathematician at the University of Oxford and the director of the Isaac Newton Institute for Mathematical Sciences.

The proof, which uses a combination of computer calculations and theoretical insights, is "like a monumental engineering project," said [Michael Hopkins](#)() of Harvard University. "It's just jaw-dropping how they did it."

## The Doomsday Hypothesis

In the 1950s, the mathematician [John Milnor](#)() astonished the mathematical world by showing that dimension 7 is [home to "exotic" spheres](#)(). An exotic sphere looks exactly like an ordinary sphere from the perspective of topology, which only considers the features of a shape that don't change when it is stretched or deformed. But the two spheres have incompatible definitions of smoothness — a curve that's smooth on an ordinary sphere might not be considered smooth on an exotic sphere. Milnor was eager to explore and classify these exotic spheres, which in some dimensions turned out to be rare and in others numbered in the thousands.

To do this, he [introduced a technique](#)() called surgery, a controlled way to simplify a mathematical shape, or manifold, and potentially convert it into an exotic sphere. The method would become essential to the study of manifolds more generally.

As its name suggests, surgery involves slicing out a piece of a manifold and then sewing in one or more new pieces along the boundary of the cut. You must sew in these new pieces smoothly, without creating sharp corners or edges. (When it comes to questions about twisted shapes, mathematicians also

require the surgery to respect the manifold's "framing," a technical attribute of how the manifold sits in space.)

To see this process in action, let's surgically transform a torus (the two-dimensional surface of a doughnut) into a sphere (the two-dimensional surface of a ball):

The result is an ordinary sphere — in fact, there are no 2D exotic spheres. But in certain dimensions, surgery converts some manifolds into ordinary spheres and others into exotic spheres. And sometimes, there's yet another possibility: manifolds that can't be converted into a sphere at all.

To visualize this last scenario, we can again look at a torus, only this time we'll give it some special twists to obstruct surgeries.

Mathematicians have proved that there is no surgery that can transform this twisted torus into a sphere, whether regular or exotic. It's an entirely different class of manifold.

In 1960, the French mathematician Michel Kervaire came up with an [invariant](#)() — a number you can calculate for a given smooth manifold — that equals zero when the manifold can be surgically converted into a sphere, and 1 when it cannot. So the ordinary torus has a Kervaire invariant of zero, while the twisted torus has a Kervaire invariant of 1.

Kervaire used his invariant to explore the menagerie of possible manifolds in different dimensions. He even used it to come up with a 10-dimensional manifold that has no Kervaire invariant, either zero or 1 — meaning that this manifold must be so crooked that it can have no sensible notion of smoothness at all.

No one had imagined that such a manifold could exist. Faced with the power of the new invariant, mathematicians rushed to determine the Kervaire invariants of manifolds in different dimensions.

Within a few years, they'd proved that twisted manifolds of Kervaire invariant 1 exist in dimensions 2, 6, 14 and 30. These dimensions fit a pattern: Each number is 2 less than a power of 2 (for example, 30 is  $2^5 - 2$ ). In 1969, the

mathematician William Browder [proved that dimensions of this form\(\)](#) are the only ones that might host shapes with a Kervaire invariant of 1.

It was natural to assume that twisted manifolds would exist in all dimensions of this form: 62, 126, 254 and so forth. Based on this assumption, one mathematician even built an entire edifice of conjectures about exotic spheres and other shapes. But the possibility that the original assumption might be false still loomed. It came to be known as the doomsday hypothesis, since it would falsify all these other conjectures.

Zhouli Xu was warned against trying to resolve the Kervaire conjecture while in graduate school. But the problem remained “a constant source of fascination,” he said.

Archives of the Mathematisches Forschungsinstitut Oberwolfach

And indeed, while mathematicians showed in 1984 that [twisted manifolds exist in dimension 62\(\)](#), no one could prove that such manifolds exist in any of the remaining dimensions. As search after search came up dry, mathematicians eventually ran out of steam, and the problem became a backwater.

In 2009, “to stem the tide of oblivion,” the mathematician [Victor Snaith\(\)](#) wrote a book exploring the implications of having manifolds with Kervaire invariant 1 in all the dimensions on Browder’s list. But, Snaith warned in the preface, “this might turn out to be a book about things which do not exist.”

If Snaith had published his book a year later, it might have read very differently. For within weeks of the book’s publication, Hopkins and two other researchers confounded mathematicians by announcing that Snaith’s warning to readers had been all too apt: The doomsday hypothesis was true. Manifolds of Kervaire invariant 1, [they had proved\(\)](#), cannot exist in dimensions 254 and higher.

The result left mathematicians in a curious position. Out of the entire infinitude of possible shapes in possible dimensions, the shapes in precisely one dimension still resisted classification. In the words of [Douglas Ravenel\(\)](#), a mathematician at the University of Rochester and one of the co-authors of the doomsday-hypothesis proof, there was “a big loose end.” It took the form of dimension 126.

## Surviving to Infinity

In 2011, Zhouli Xu arrived at the University of Chicago as a new graduate student planning to study computational aspects of manifolds. His

adviser, [Peter May\(\)](#), proposed the problem of dimension 126, which mathematicians thought was likely to involve massive computations. May sent Xu to Mark Mahowald of Northwestern University, an expert on the Kervaire invariant problem who had even named his sailboat after one of its key symbols —  $\theta_{11}$ , or “Thetajay.”

But Mahowald, who died in 2013, immediately vetoed the proposal. The dimension 126 problem was too hard, he told Xu — “a lifelong problem.” Instead, he guided the young mathematician toward related problems [in lower dimensions\(\)](#).

But for Xu, the dimension 126 problem remained “a constant source of fascination,” he said.

Guozhen Wang studies complicated objects to gain insights into high-dimensional shapes that defy imagination.

Courtesy of Guozhen Wang

The potential strategy to settle the problem was no mystery. Mathematicians had long known that crucial secrets about exotic spheres and other manifolds are encoded in objects known as [stable homotopy groups](#) of spheres. These are collections of functions, or “mappings,” that send points from a high-dimensional sphere to a lower-dimensional one.

Imagine, for instance, a mapping that sends every point in a 44-dimensional sphere to a point in a 33-dimensional sphere. This mapping essentially crushes down 11 dimensions’ worth of the bigger sphere. If you choose some point on the smaller sphere and find all the points on the bigger sphere that got mapped to it, these points will typically form an 11-dimensional manifold.

Now consider all the different points on your smaller sphere. Roughly speaking, each point gives you another 11-dimensional manifold. So your mapping doesn’t just create a single 11-dimensional manifold. It creates a bucket of 11-dimensional manifolds.

A stable homotopy group is a set in which each element is a collection of mappings like this one.

Mathematicians knew that to settle the Kervaire invariant question in a given dimension, they only needed to understand the [stable homotopy group\(\)](#) for

that dimension. There's just one difficulty: Understanding stable homotopy groups is one of the most challenging and foundational problems in topology. "I do not expect it to be solved within the lifetime of my granddaughters," Ravenel said.

So instead, mathematicians approach this problem by degrees. Since 1958, they've been organizing information about the structure of stable homotopy groups into an enormous but unfinished atlas of dots called the [Adams spectral sequence](#)().

Weinan Lin wrote a computer program that helped him and his colleagues resolve a decades-old conjecture about the strange properties of shapes in high dimensions.

Zhonglin Wu

Imagine a book with an infinite number of pages, each of which consists of infinitely many columns of dots. Let's open the book and examine a single page. Each column on this page represents a dimension. Each dot in a given column represents a different potential "flavor" for sphere mappings in that dimension. The flavor always comes in two types, like "regular" or "extra-crispy" (or, say, Kervaire invariant zero or 1).

In some ways, the book is exceedingly repetitive — each page has the same list of columns, and many of the same dots in each column. But as you turn the pages, you'll notice a key difference: Each page captures successively finer details of sphere mappings and manifolds. The atlas's early pages are only approximations of the truth. The approximations get better as you turn the pages, until on the final page of the atlas — known as the "infinity" page — the representation is perfect.

Navigating the atlas is like exploring the universe of manifolds with increasingly powerful telescopes. On page 1, the details of each manifold are hazy, and many manifolds that don't really belong have been erroneously included. But if you make a better telescope, you may be able to detect that a manifold has some "flaw" that would exclude it from the atlas. In that case, you would delete the relevant dot on all subsequent pages of the atlas. If your telescope doesn't find any flaws, then the dot survives to the next page, where you might hope to turn an even stronger telescope on it.

## [T O P O L O G Y](#)

### [An Old Conjecture Falls, Making Spheres a Lot More Complicated](#)

AUGUST 22, 2023

In 1969, Browder showed that [one specific dot\(\)](#) in the 126th column of the atlas holds the key to the Kervaire invariant problem in that dimension. If this dot survives to the infinity page, then buckets of 126-dimensional manifolds must come in both flavors: Half of the buckets will consist of manifolds with Kervaire invariant zero, and half will consist of manifolds with Kervaire invariant 1. If the dot doesn't survive, then 126-dimensional manifolds come in just one flavor, Kervaire invariant zero.

For the special dot in column 126, there were 105 different hypothetical ways that it might vanish before the infinity page. To get a handle on these possibilities, Xu partnered with Guozhen Wang, his longtime collaborator and former college roommate. As they developed new computational techniques, they passed them along to Weinan Lin, a mathematician Xu had known since graduate school. Lin wrote a program that was able to rule out 101 of the possibilities. Then, over the course of another year, the researchers painstakingly developed new methods to rule out the last four. Browder's special dot, they concluded, does survive to the infinity page — meaning that dimension 126 has manifolds with Kervaire invariant 1.

Prior to the team's announcement, mathematicians thought such a computation was way out of reach, Hopkins said. The new work is "heroically computational," he added. Its methods may eventually help mathematicians chart even more of the giant atlas.

While the new paper proves that strangely twisted shapes exist in dimension 126, it gives no hint of how to construct them. Researchers have identified specific twisted shapes in the first four special Kervaire dimensions: 2, 6, 14 and 30. But no one has found one yet in dimension 62 or 126, even though in each dimension where these shapes exist, they make up fully half of all possible shapes. Despite their abundance, "we can't actually point to one," Tillmann said.

If mathematicians do figure out how to construct twisted shapes in dimensions 62 and 126, it might give them some clue about what makes these six dimensions special — why it's possible to build such twisty shapes in those and only those dimensions. "Usually when [something like] that happens, there's some very beautiful construction," Hopkins said. "It's very ephemeral,

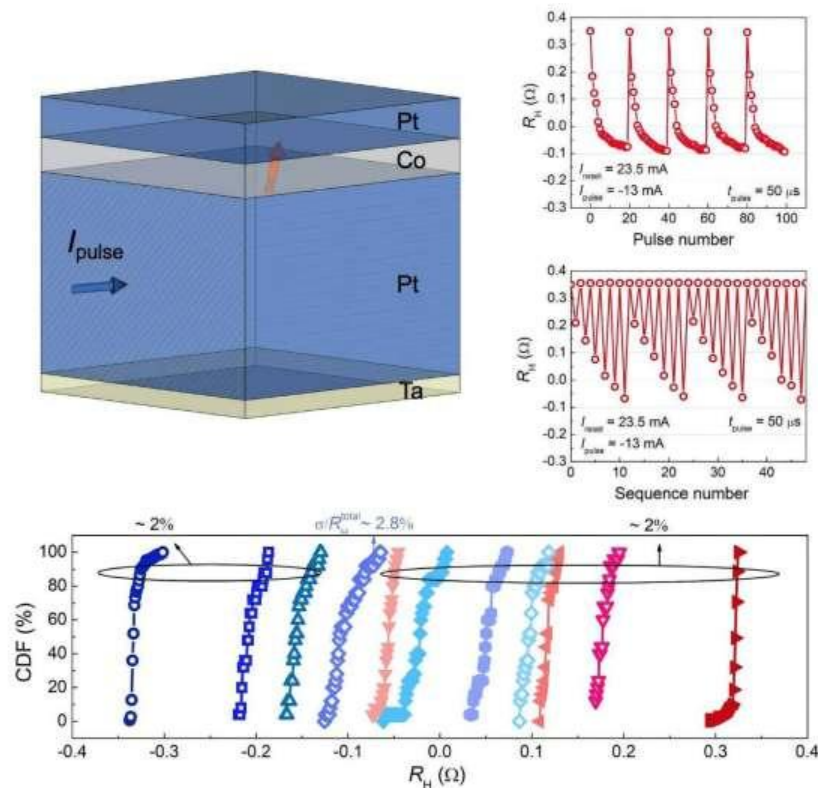
because it's got to only work five or six times, and not infinitely many times." The new work "makes it more inspiring to really try to find the special construction of these six things."

And the Kervaire problem is just one type of dimensional weirdness encoded in the Adams spectral sequence. The special Kervaire dimensions correspond to six special dots in the second row of the atlas. Recently, Xu and [Robert Burklund](#)() of the University of Copenhagen [figured out](#)() that a handful of special dimensions seem to exhibit another kind of oddball behavior in the third row of the atlas. No one knows yet what kind of strange manifolds correspond to the special dots in these dimensions — but mathematicians hope to find out.

Discoveries about subsequent rows will likely also be forthcoming, Xu said. "There should be a lot more stories later on, waiting for us to explore."

# Spin-based memory advance brings brain-like computing closer to reality

by [National Taiwan University](#)



The optimized spintronic device enables stable 11-state memory switching for brain-inspired AI systems. Credit: National Taiwan University

Researchers at National Taiwan University have developed a new type of spintronic device that mimics how synapses work in the brain—offering a path to more energy-efficient and accurate artificial intelligence systems.

In a study [published](#) in *Advanced Science*, the team introduced three novel memory [device](#) designs, all controlled purely by electric current and without any need for an [external magnetic field](#).

Among the devices, the one based on "tilted anisotropy" stood out. This optimized structure was able to achieve 11 stable memory states with highly consistent switching behavior.

Unlike conventional memory devices that often rely on unstable physical processes, this device demonstrated excellent reliability with a cycle-to-cycle variation of just 2%. This

makes it ideal for simulating how [synapses](#) in the brain strengthen or weaken connections over time—critical for [machine learning](#).

The team went a step further by simulating how this multi-state memory could be used in real neural networks. They applied the device's memory states to a convolutional neural network model (ResNet-18) for image classification. Using a process called post-training quantization, they matched the physical [memory](#) states to digital weights in the AI model.

The results were impressive: with the 11-state device, classification accuracy reached up to 81.51%—nearly the same as the original uncompressed software model.

These findings show that spintronic synapses could power future neuromorphic chips that are not only faster and more compact but also far more energy-efficient.

"Our work paves the way for reliable, scalable neuromorphic computing using purely electrical control," said Prof. Chi-Feng Pai.

**More information:** Tzu-Chuan Hsin et al, All-Electrical Control of Spin Synapses for Neuromorphic Computing: Bridging Multi-State Memory with Quantization for Efficient Neural Networks, *Advanced Science* (2025). DOI: [10.1002/advs.202417735](https://doi.org/10.1002/advs.202417735)

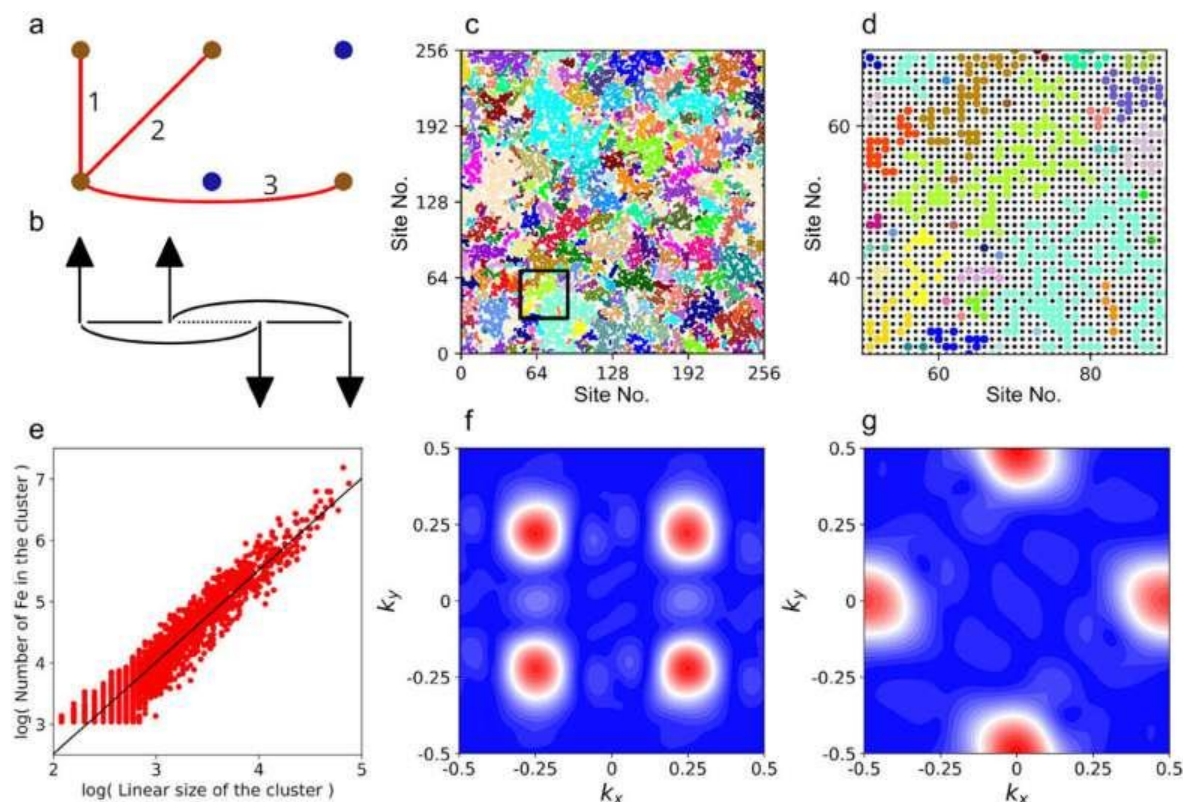
**Journal information:** [Advanced Science](#)

Provided by [National Taiwan University](#)

MAY 14, 2025

# Superconductors: Amazingly orderly disorder in murunskite

by [Vienna University of Technology](#)



Magnetic and Structural Analysis of Murunskite. Credit: *Advanced Functional Materials* (2025). DOI: 10.1002/adfm.202500099

A surprising effect was discovered through a collaborative [study](#) by researchers from TU Wien and institutions in Croatia, France, Poland, Singapore, Switzerland, and the US during the investigation of a special material: the atoms are arranged in a completely disordered manner but produce magnetic order.

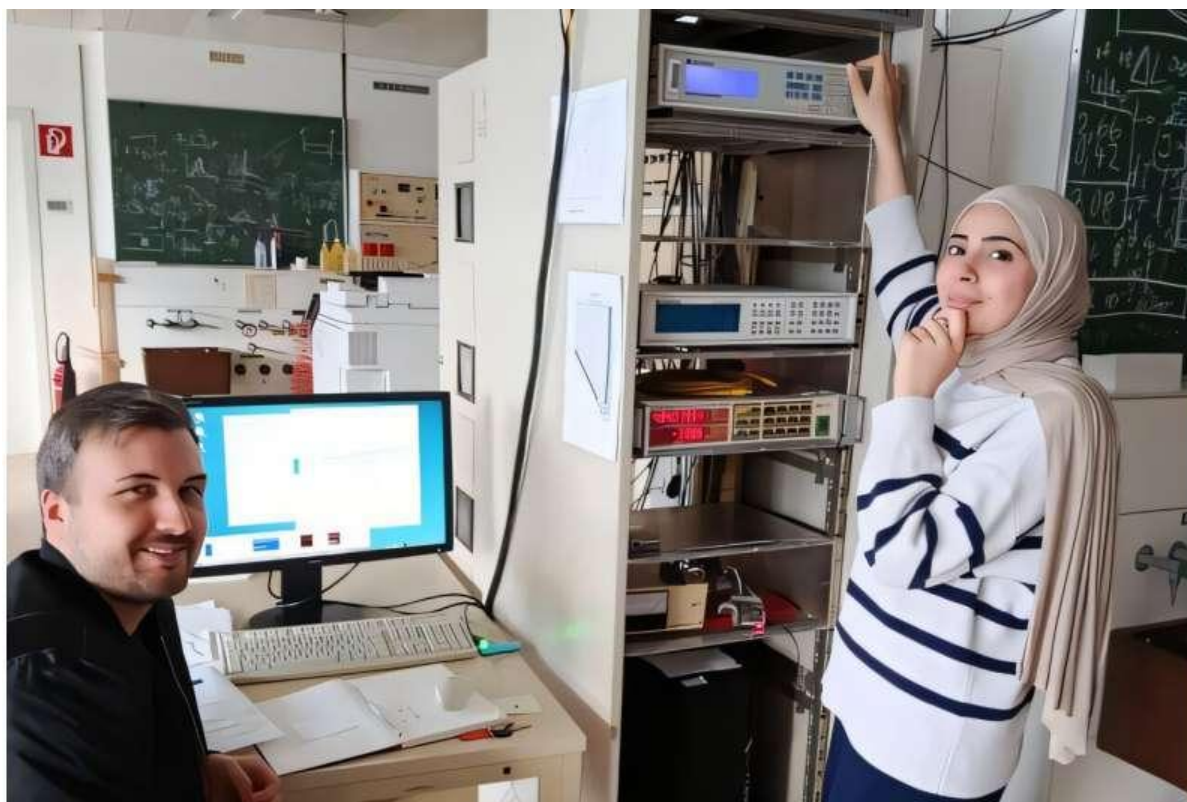
The study is published in the journal *Advanced Functional Materials*.

Superconductivity is one of the central topics in modern materials science: certain materials can conduct electrical current without any resistance—at least below a certain temperature. However, how to produce materials that still exhibit this property at higher temperatures remains an unsolved problem.

Now, researchers at TU Wien have discovered a surprising connection between two actually quite different classes of superconductors—the so-called "cuprates" and "pnictides": the material murunskite combines properties of both in unexpected ways.

The amazing thing is that even though the crucial atoms in murunskite are arranged completely randomly and irregularly, the [magnetic properties](#) are neatly ordered, even at surprisingly high temperatures, and resemble those of iron-pnictides.

Analogously, in the cuprates, a particular kind of metallicity—one that might be associated only with exceptionally clean systems—emerges despite a lot of local disorder, along with [high-temperature superconductivity](#). The "culprits" in cuprates and murunskite are open ligand orbitals.



Luka Akšamović and Priyanka Reddy, researchers in Neven Barišić's team. Credit: Vienna University of Technology

## Two worlds—and one in between

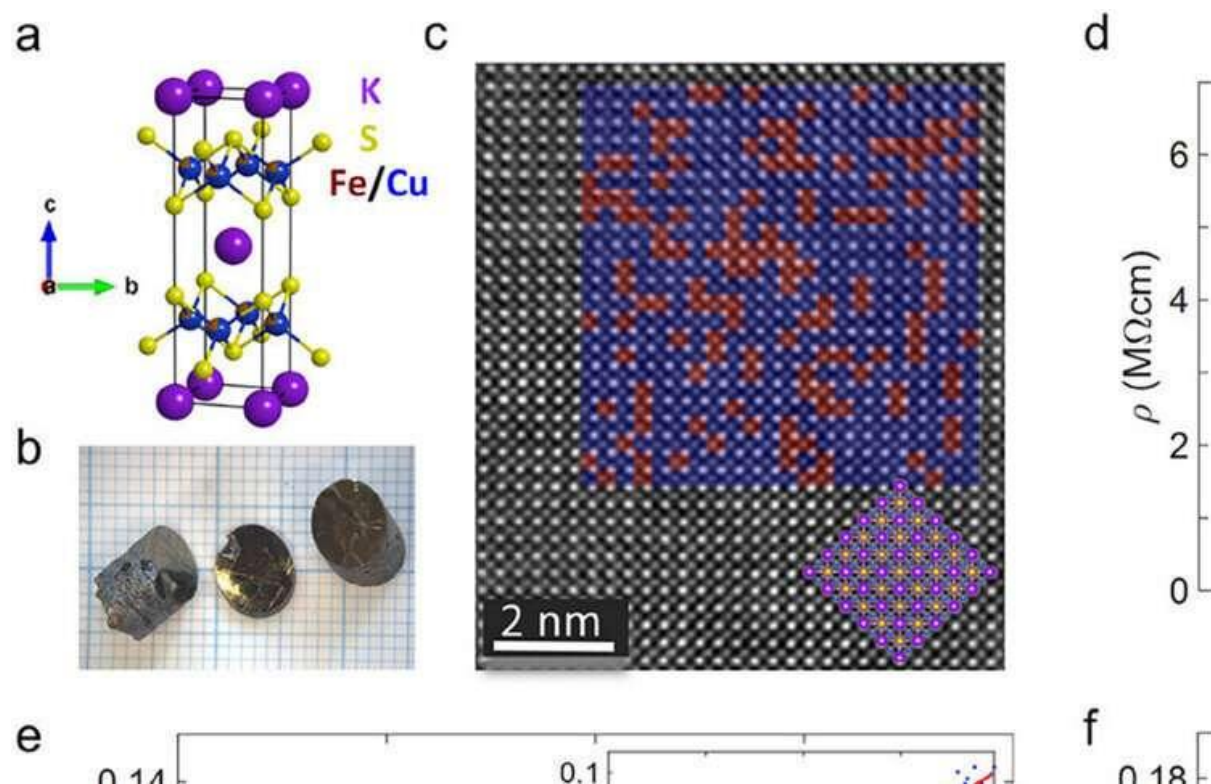
Materials that exhibit superconducting properties even at relatively high temperatures—known as [high-temperature superconductors](#)—normally owe this property to the complex quantum physical interaction between different types of atoms. It takes a great deal of effort to simulate the effects in such materials on a computer and understand them theoretically.

However, in recent decades, various classes of materials have been found that have proven promising for superconductivity research, such as the class of cuprates. These are ceramic compounds that contain [copper atoms](#) in which superconductivity emerges from an

insulating state upon doping with charge carriers. A completely different class of superconductors are pnictides—metallic materials with mobile electrons.

Researchers at TU Wien have now taken a closer look at another material: murunskite, a crystal composed of potassium, iron, copper and sulfur. Although it is not a superconductor itself, it is closely related to superconducting materials.

"Murunskite is, in a sense, the missing link between these two classes of materials," says Prof. Neven Barišić from the Institute of Solid State Physics at TU Wien. "It has a [crystal structure](#) like pnictides, but electronic properties similar to cuprates. Its magnetic properties are novel and surprising, though reminiscent of both cuprates and pnictides."



Structure and key microscopic properties of murunskite. Credit: *Advanced Functional Materials* (2025). DOI: 10.1002/adfm.202500099

## Geometric disorder, magnetic order

There are many materials that exhibit magnetic effects. This means that the atoms align magnetically in the same way—like many small compass needles all pointing in the same direction. Normally, the atoms must also be arranged geometrically in a regular manner. This is the universally accepted way to ensure that they all influence each other in the same way, so that magnetic order can develop over long distances.

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.  
Subscribe

Surprisingly, however, this is not the case with murunskite. "In this material, the atoms are not arranged regularly," says Priyanka Reddy. "At certain points in the crystal lattice, there can be either a copper atom or an iron atom. The copper atoms have no magnetic effect, but the iron atoms do."

There is no geometric pattern according to which copper and iron atoms arrange themselves; they are completely mixed up at random. And yet, as the research team has now been able to show, magnetic order emerges at a temperature of minus 176 degrees Celsius (97K): the iron atoms align themselves magnetically in the same patterns, even though they are at different distances from each other.

"In this case, we speak of emergent order," explains Davor Tolj.

"Even though the atoms do not follow any geometric rules, they form magnetically ordered clusters—ordered islands in a sea of disordered atoms that, in a sense, agree on a common magnetic direction." These clusters network with other clusters, so that, despite the lack of geometric order, a magnetic order emerges that pervades the entire crystal.

The result shows that [magnetic order](#) does not necessarily have to be based on perfect atomic order. This opens up new avenues in materials and device research, in relation to superconductors and beyond.

**More information:** Davor Tolj et al, High-Entropy Magnetism of Murunskite, *Advanced Functional Materials* (2025). DOI: [10.1002/adfm.202500099](https://doi.org/10.1002/adfm.202500099)

**Journal information:** [Advanced Functional Materials](#)

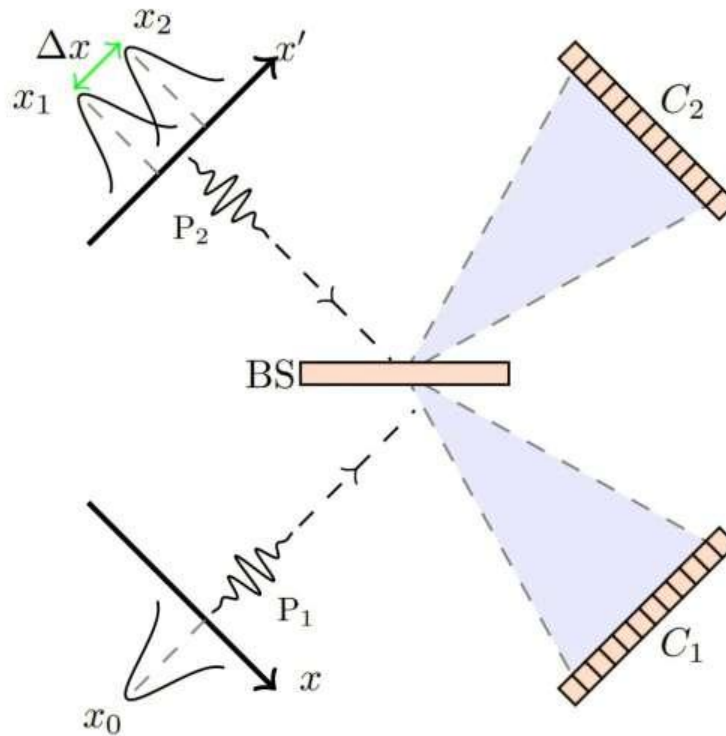
Provided by [Vienna University of Technology](#)

---

MAY 14, 2025

# A proposed new route to sharper imaging using quantum interference

by [University of Portsmouth](#)



Two-photon interferometer. A single photon  $P_2$  coming from two thermal sources with relative transverse displacement  $\Delta x$  interferes on a balanced beam splitter with a photon  $P_1$  produced by a reference source. Two cameras  $C_1$  and  $C_2$  in the far field resolve the transverse momenta of the two photons, while simultaneously recording whether the photons hit the same camera or opposite cameras. By collecting a relatively small number of sampling events at the output it is possible to optimally retrieve information on the separation also when  $\Delta x \approx 0$ . Credit: Salvatore Muratore et al

A new study from the University of Portsmouth has outlined a possible way to improve how we distinguish between two closely spaced light sources, an issue that has long challenged classical imaging systems.

The approach, [published](#) in *Physical Review Applied*, uses principles from [quantum physics](#) to estimate small separations between light-emitting objects, with potential future applications in fields like microscopy, astronomy, and remote sensing.

The research suggests that a relatively simple quantum set-up could be used to extract [spatial information](#) that is traditionally limited by the so-called Rayleigh criterion—a rule dating back over a century that defines the limits of classical resolution.

Study Principal Investigator and co-author Professor Vincenzo Tamma, Director of the University of Portsmouth's Quantum Science and Technology Hub, said, "This study shows that it is theoretically possible to achieve super-resolution in estimating the transverse distance between two faint distant thermal sources by measuring the interference at a beam splitter between a photon emitted by either one of them and a reference photon prepared in the laboratory.

"While the idea is not yet tested experimentally, our results show it could be implemented efficiently with current technologies without the need of complex optics."

The method relies on observing the two-photon interference with two cameras at the output channels of the [beam splitter](#) which resolve the detection position in the far field. By analyzing how they are registered—either in the same or different camera and at which position—scientists can measure the distance between two unresolved sources of light. According to the team, this works even when the separation between the sources is too small for traditional imaging methods to resolve.

The precision claims are based on simulations and theoretical modeling. The research assumes ideal conditions and does not yet account for practical sources of noise, photon losses, or imperfections that would be encountered in a lab or field setting.

However, the simplicity of the proposed set-up, which avoids the need for complex optical components, makes it a promising candidate for experiments.

"This could lead to an efficient way to enhance resolution in imaging objects beyond the classical limit" said Professor Tamma.

"This could be a simpler way to get sharper images, if it works out in practice," said Professor Tamma. "But we still need to test how well the method holds up outside of ideal lab conditions."

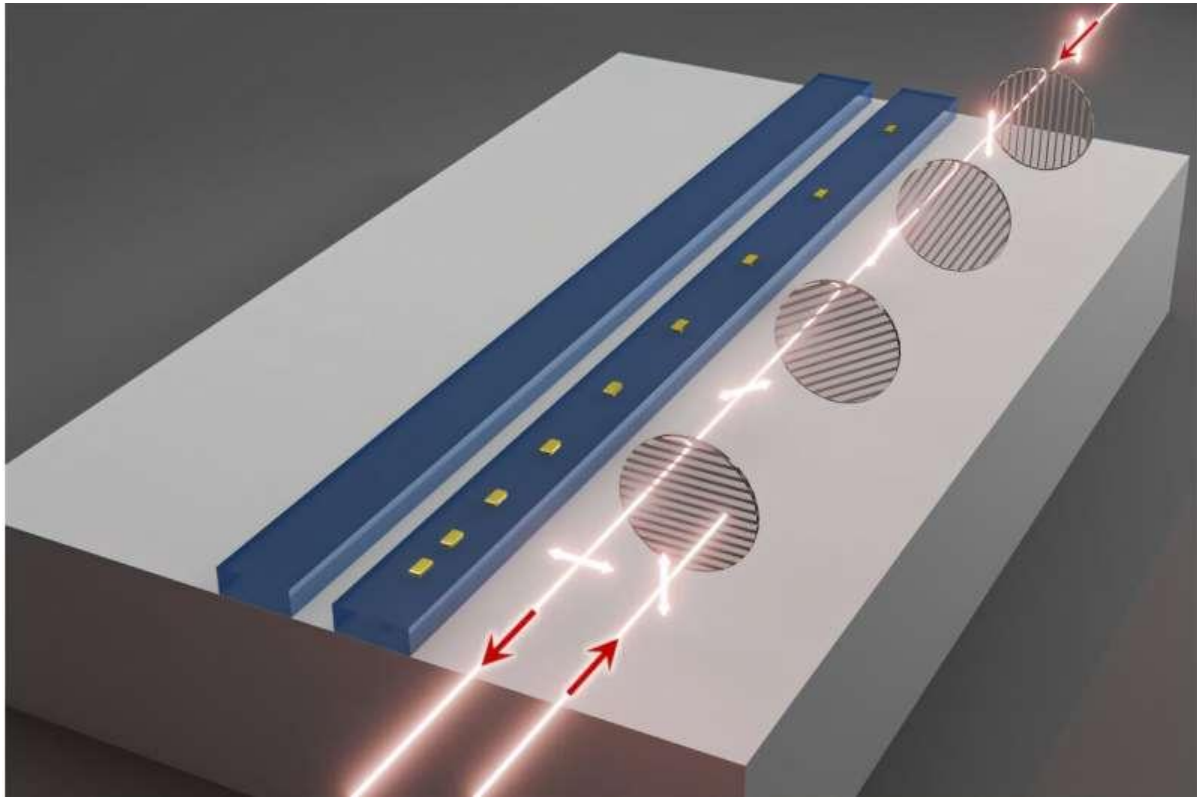
**More information:** Salvatore Muratore et al, Superresolution imaging of two incoherent sources via two-photon-interference sampling measurements of the transverse momenta, *Physical Review Applied* (2025). DOI: [10.1103/PhysRevApplied.23.054033](https://doi.org/10.1103/PhysRevApplied.23.054033). On arXiv: DOI: [10.48550/arxiv.2412.10057](https://doi.org/10.48550/arxiv.2412.10057)

**Journal information:** [Physical Review Applied](#) , [arXiv](#)  
Provided by [University of Portsmouth](#)

MAY 14, 2025

# Photonic chip design offers simpler solution for one-way light flow in optical circuits

by Leah Shaffer , [Washington University in St. Louis](#)



A

A new method developed by WashU researchers can reconfigure transmission directions of light in a way that will lower expenses and simplify photonic circuits. Credit: Micro/Nano Photonics Lab

To improve photonic and electronic circuitry used in semiconductor chips and fiber optic systems, researchers at the McKelvey School of Engineering at Washington University in St. Louis tinkered with the rules of physics that govern the movement of light over time and space. They have introduced a new way to manipulate light transmission, opening possibilities for advanced optical devices.

Their method causes a "mirror-flip of the system," said Lan Yang, the Edwin H. & Florence G. Skinner Professor of electrical and [systems engineering](#) and senior author of the research, now [published](#) in *Science Advances*.

Using parity-time (PT) symmetric photonic waveguides, they can manipulate the light waves to "reverse time" so the system behaves the same as before, Yang added.

"PT symmetry enables new ways to control light which are especially useful for applications in optical communications, lasers and sensors," she said.

Postdoctoral researchers Wenbo Mao and Fu Li, co-first authors of the study, described their systems as enabling "reconfigurable transmission."

Mao uses an optical polarizer as an analogy to explain this system. "Think of a polarizer as a door that is slightly open—it only allows light with a specific polarization direction, aligned with the slit, to pass through, while light polarized perpendicular to the slit is blocked," Mao said.

"Then, imagine a series of polarizers. The first one is aligned with the initial polarization of the light, while each subsequent polarizer gradually rotates until the last one is completely perpendicular to the original polarization. If light first encounters the properly aligned polarizer, the gradual rotation allows it to pass through the entire system. However, if light first encounters the final polarizer, which is perpendicular to its polarization, it gets blocked right away."

This effect enables light to travel through the system in only one direction. This "asymmetric transmission" is one of the key outcomes of this work because it can simplify telecommunication systems.

Telecom systems contain components designed to ensure that data flows in only one direction, such as from a server to a client. When someone is streaming a movie, for instance, they want that stream of data to move steadily toward their device; the user doesn't want their home data to move back to the source. Asymmetric transmission is how they address that.

In optical communication, isolators are typically used to direct light by applying magnetic fields, ensuring it travels in one direction and preventing interference. The system demonstrated in this study uses carefully designed waveguides to control light transmission, eliminating the need for complex and bulky isolator components and providing a simpler, more efficient solution for one-way light propagation.

In the work, the researchers carefully designed photonic chips to construct a periodical system, so-called Floquet non-Hermitian physics, to mimic that rotated polarizers effect as described by Mao. The system allows the light propagation in one way when it experiences non-Hermitian phase transitions.

Li described the light like "a dancer twirling across a room filled with carefully placed traps."

When the dancer moves forward (left to right), each step is precisely guided to avoid the traps. However, when the dancer tries to move backward, every step lands directly into a trap, preventing smooth movement in that direction. In the experiment, light acts as the dancer, while tiny pieces of metal along the waveguides serve as traps, ensuring light moves efficiently only in one direction.

"Our structure is very simple but delivers great performance which can be used to reduce the cross-talking between different optical components," said Li, who added that this mechanism has potential application for many telecommunication devices.

"We simply adjust the design of the device itself," Yang said. "This allows us to actively achieve asymmetrical [light transmission](#) that will carry information in the preferred direction."

**More information:** Wenbo Mao et al, On-chip reconfigurable transmission in spatially chirped Floquet parity-time symmetric photonics, *Science Advances* (2025). DOI: [10.1126/sciadv.adu4653](https://doi.org/10.1126/sciadv.adu4653)

**Journal information:** [Science Advances](#)

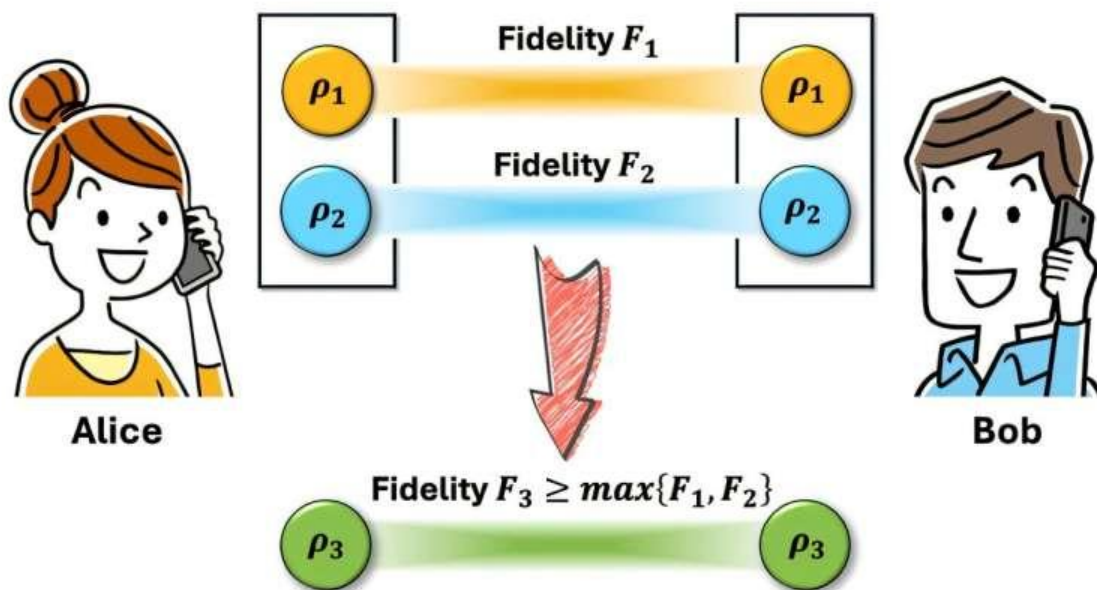
Provided by [Washington University in St. Louis](#)

---

MAY 14, 2025

## A new study provides insights into cleaning up noise in quantum entanglement

by Sarah C.P. Williams , [University of Chicago](#)



Researchers found that no universal entanglement purification protocol is guaranteed to improve fidelity of entangled states in all possible quantum systems. Credit: Zhong Lab

Quantum entanglement—a connection between particles that produces correlations beyond what is classically possible—will be the backbone of future quantum technologies, including secure communication, cloud quantum computing, and distributed sensing. But entanglement is fragile; noise from the environment degrades entangled states over time, leaving scientists searching for methods to improve the fidelity of noisy entangled states.

Now, researchers at the University of Chicago Pritzker School of Molecular Engineering (UChicago PME), University of Illinois Urbana-Champaign, and Microsoft have shown that it is fundamentally impossible to design a single one-size-fits-all protocol to counteract that noise.

"In [quantum information](#), we often hope for a protocol that works in all scenarios—a kind of cure-all," said Asst. Prof. Tian Zhong, senior author of the new work [published](#) in *Physical Review Letters*. "This result shows that when it comes to purifying entanglement, that's simply too good to be true."

The findings, he said, instead highlight the importance of tailoring noise-minimizing solutions to specific quantum systems.

## Searching for solutions

To counteract the degradation of entangled states due to noise, scientists often use entanglement purification protocols (EPPs), which combine multiple imperfect entangled pairs to try to extract fewer pairs with less noise. But the team knew that certain systems are hard to cleanse of noise—often because the input states of EPPs are almost never identical in reality. Entanglement states vary based on how and when they are created, stored, and processed.

Graduate student Allen Zang from UChicago PME, and Xinan Chen from UIUC are the co-first authors of this paper.

"We knew that existing input-independent protocols are not guaranteed to improve the fidelity of the entangled states," said Zang.

"We wondered whether there was any possible protocol that could always guarantee improvements, a property we call universality," said Chen.

Zang, Chen and their colleagues began by tackling the question within a set of broadly-used EPPs, applying the protocols to known quantum operations. However, the idea of "universality" failed. Surprised, they broadened their analysis to all mathematically possible purification methods allowed under the rules of quantum mechanics.

Still, the result held: No universal EPP is guaranteed to improve fidelity of entangled states in all possible quantum systems.

"Importantly, we're not saying purification protocols don't work," said Eric Chitambar, Assoc. Professor of Electrical and Computer Engineering at UIUC. "But no single method works in all cases."

## A fundamental limit

The work carries real implications for the design of quantum communication networks, where entangled states must be generated, stored, and transmitted over long distances. In these systems, blindly applying a purification protocol—without knowing the exact state of the system—can backfire.

Instead, the authors say, the results offer guidance: rather than seeking a universal solution, researchers should focus on tailoring error management strategies to the specific systems and error models they're working with.

"This result tells us not to waste time searching for a protocol that doesn't exist, and instead put more emphasis on understanding the unique characteristics of specific quantum systems," said Martin Suchara, Director of Product Management at Microsoft, one of the co-authors.

The team is now exploring how this kind of theoretical boundary might apply to other quantum resources. They're also investigating whether customized purification methods could still be developed for systems with well-understood errors—or whether a nearly universal method might exist under stricter constraints.

**More information:** Allen Zang et al, No-Go Theorems for Universal Entanglement Purification, *Physical Review Letters* (2025). DOI: [10.1103/PhysRevLett.134.190803](https://doi.org/10.1103/PhysRevLett.134.190803). On *arXiv*: DOI: [10.48550/arxiv.2407.21760](https://doi.org/10.48550/arxiv.2407.21760)

**Journal information:** [Physical Review Letters](#) , [arXiv](#)  
Provided by [University of Chicago](#)

---

---

MAY 14, 2025

# Light is the science of the future: The Africans using it to solve local challenges

by Andrew Forbes and Patience Mthunzi-Kufa , [The Conversation](#)



Credit: CC0 Public Domain

Light is all around us, essential for one of our primary senses (sight) as well as life on Earth itself. It underpins many technologies that affect our daily lives, including energy harvesting with solar cells, light-emitting-diode (LED) displays and telecommunications through fiber optic networks.

The smartphone is a great example of the power of light. Inside the box, its electronic functionality works because of [quantum mechanics](#). The front screen is an entirely photonic device: liquid crystals controlling light. The back too: white light-emitting diodes for a flash, and lenses to capture images.

We use the word photonics, and sometimes optics, to capture the harnessing of light for [new applications](#) and technologies. Their importance in [modern life](#) is celebrated every year on 16 May with the [International Day of Light](#).

Scientists on the African continent, despite the resource constraints they work under, have made notable contributions to photonics research. Some of these have been captured in a recent special issue of the journal [Applied Optics](#). Along with colleagues in this field from Morocco and Senegal, we [introduced this collection of papers](#), which aims to celebrate excellence and show the impact of studies that address continental issues.

## A spotlight on photonics in Africa

[Africa's history in formal optics](#) stems back thousands of years, with references to lens design already [recorded](#) in ancient Egyptian writings.

In more recent times, Africa has contributed to two Nobel prizes based on optics. [Ahmed Zewail](#) (Egyptian born) watched the ultrafast processes in chemistry with lasers (1999, Nobel Prize for Chemistry) and [Serge Harouche](#) (Moroccan born) studied the behavior of individual particles of light, photons (2012, Nobel Prize for Physics).

Unfortunately, the African optics story is one of pockets of excellence. The highlights are as good as anywhere else, but there are too few of them to put the continent on the global optics map. According to a 2020 calculation done for me by the [Optical Society of America](#), based on their journals, Africa contributes less than 1% to worldwide journal publications with optics or photonics as a theme.

Yet there are great opportunities for meeting continental challenges using optics. Examples of areas where Africans can innovate are:

- bridging the [digital divide](#) with modern communications infrastructure
- optical imaging and spectroscopy for improvements in agriculture and monitoring climate changes
- harnessing the sun with optical materials for clean energy
- bio-photonics to solve health issues
- quantum technologies for novel forms of communicating, sensing, imaging and computing.

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.  
Subscribe

The papers in the special journal issue touch on a diversity of continent-relevant topics.

One is on using optics to [communicate across free-space \(air\) even in bad weather conditions](#). This light-based solution was tested using weather data from two African cities, Alexandria in Egypt and Setif in Algeria.

Another paper is about [tiny quantum sources of quantum entanglement for sensing](#). The authors used diamond, a gem found in South Africa and more commonly associated with jewelry. Diamond has many flaws, one of which can produce single photons as an output when excited. The single photon output was split into two paths, as if the particle went both

left and right at the same time. This is the quirky notion of entanglement, in this case, created with diamonds. If an object is placed in any one path, the entanglement can detect it. Strangely, sometimes the photons take the left-path but the object is in the right-path, yet still it can be detected.

One contributor proposes a cost-effective [method to detect and classify harmful bacteria in water](#).

New approaches in [spectroscopy](#) (studying color) for detecting [cell health](#); [biosensors](#) to monitor salt and [glucose levels](#) in blood; and optical tools for [food security](#) all play their part in optical applications on the continent.

Another area of African optics research that has important applications is the use of [optical fibers for sensing the quality of soil and its structural integrity](#). Optical fibers are usually associated with communication, but a modern trend is to use the existing optical fiber already laid to sense for small changes in the environment, for instance, as early warning systems for earthquakes. The research shows that conventional fiber can also be used to tell if soil is degrading, either from lack of moisture or some physical shift in structure (weakness or movement). It is an immediately useful tool for agriculture, building on many decades of research.

The diverse range of topics in the collection shows how creative researchers on the continent are in using limited resources for maximum impact. The high orientation towards applications is probably also a sign that African governments want their scientists to work on solutions to real problems rather than purely academic questions. A case in point is South Africa, which has a funded national strategy ([SA QuTI](#)) to turn quantum science into quantum technology and train the workforce for a new economy.

## Toward a brighter future

For young science students wishing to enter the field, the opportunities are endless. While photonics has no discipline boundaries, most students enter through the fields of physics, engineering, chemistry or the life sciences. Its power lies in the combination of skills, blending theoretical, computational and experimental, that are brought to bear on problems. At a typical photonics conference there are likely to be many more industry participants than academics. That's a testament to its universal impact in new technologies, and the employment opportunities for students.

The last century was based on electronics and controlling electrons. This century will be dominated by photonics, controlling photons.

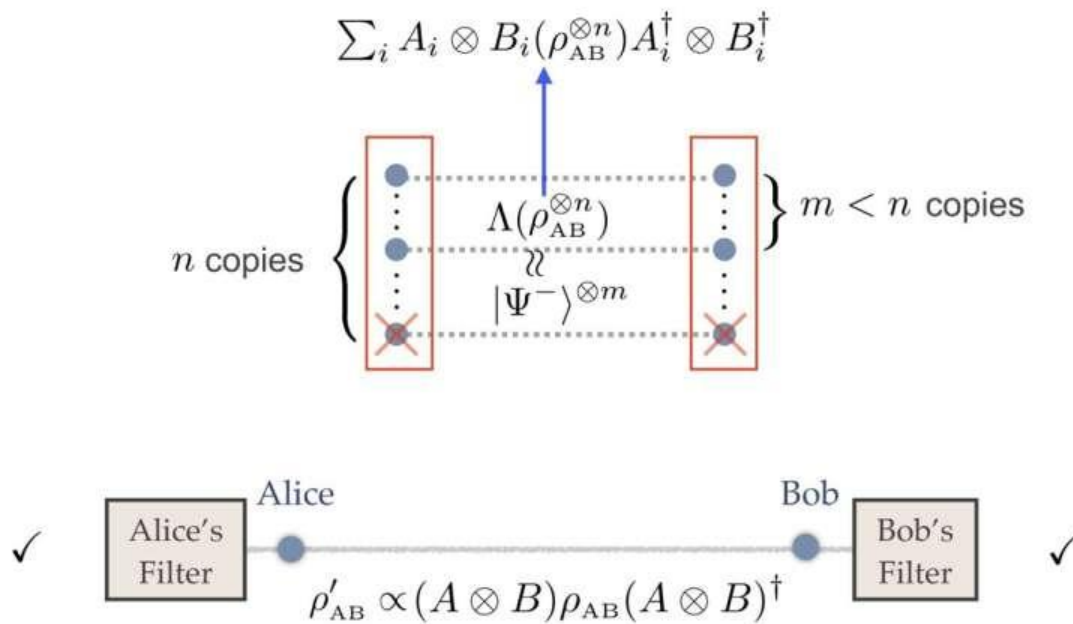
Provided by [The Conversation](#)

This article is republished from [The Conversation](#) under a Creative Commons license. Read the [original article](#).

MAY 8, 2025

# A scalable approach to distill quantum features from higher-dimensional entanglement

by [Ingrid Fadelli](#) , Phys.org



Credit: Fang et al.

The operation of quantum technologies relies on the reliable realization and control of quantum states, particularly entanglement. In the context of quantum physics, entanglement entails a connection between particles, whereby measuring one determines the result of measuring the other even when they are distant from each other, and in a way that defies any intuitive explanation.

A key challenge in the development of reliable quantum technologies is that entanglement is highly susceptible to noise (i.e., random interactions with the environment). These interactions with noise can adversely impact this desired quantum state of affairs and, in turn, reduce the performance of quantum technologies.

Researchers at Shandong University in China and National Cheng Kung University in Taiwan recently implemented a key step to experimentally recover hidden quantum correlations from higher-dimensional entangled states.

This method, outlined in [a paper](#) published in *Physical Review Letters*, entails the implementation of so-called single-copy local filtering (ScLF) operations.

"The preparation and manipulation of quantum entanglement are always imperfect, compromising their performance in quantum processing information tasks," He Lu, co-senior author of the paper, told Phys.org.

"Although conventional [distillation](#) protocols promise to return at least one copy of maximal entanglement over multi-copy noisy states, it is not 'friendly' for photonic systems as the strong photon-photon interactions required for collective manipulation remain challenging."

While physicists have developed various protocols for distilling entanglement over the past decades, most existing ones are difficult to implement on [quantum systems](#) comprised of photons (i.e., particles of light). The development of distillation approaches that are easier to implement on photonic systems could thus be highly advantageous, as it could inform quantum physics research and improve quantum technologies.

"The idea of single-copy distillation came out when I visited Liang in 2019, when he shared the thought of 'activating the teleportation power with ScLF operation,'" said Lu. "I quickly realized this was the easy-to-implement distillation protocol I sought, naturally leading to our collaboration."

The first objective of the recent study by Lu and his colleagues was to use ScLF to observe quantum features that were initially absent in a class of mixed quantum states known as Werner states, particularly nonlocality (i.e., the feature underpinning correlations between the behavior of entangled particles).

In addition, the researchers wanted to show that this technique is scalable and easier to implement on optical systems than existing entanglement distillation schemes.

"Our work is a natural continuation of our previous collaboration, aiming to recover teleportation power by ScLF," Yeong-Cherng Liang, co-senior author of the paper, told Phys.org.

"A question left open there was why one should favor a qubit projection over other ScLFs. This led us to higher-dimensional Werner states—a widely discussed family of quantum states in quantum foundations and entanglement distillation—but whose nonlocality has never been demonstrated. We decided to take up this challenge, and there we go!"

To demonstrate the potential of their ScLFs-based approach for the distillation of quantumness, the researchers carried out a series of experiments utilizing a two-qutrit photonic system, in which each quantum unit (qutrit) can exist in a superposition of three states. They specifically prepared the three-dimensional Werner states, which were encoded in the degrees of freedom (DoF) of photon pairs.

Discover the latest in science, tech, and space with over **100,000 subscribers** who rely on Phys.org for daily insights. Sign up for our [free newsletter](#) and get updates on breakthroughs, innovations, and research that matter—**daily or weekly**.

Subscribe

"To this end, we first prepared a two-qubit Werner state encoded in the polarization DoF, then used an array of beam displacers and waveplates to transform the quantum information to the path DoF," explained Lu. "The ScLF is quite simple—it only requires the blocking of one of the three paths."

Lu, Liang and their colleagues also used theoretical frameworks to confirm that their technique was effective in distilling quantum correlations in their experiments. Their analyses demonstrated that despite imperfections in their experiments, the ScLF implemented did transform the states they prepared in the way they anticipated, allowing them to observe quantum features that were previously hidden.

"To this end, we checked the experimentally 'reconstructed' states against various criteria and, in some cases, also performed numerical optimizations to strengthen our claims," said Liang.

The recent work by this team of researchers could significantly reduce the experimental complexity required to distill useful quantum features from noisy interactions. Notably, their experiments and theoretical analyses demonstrated that their proposed distillation approach is scalable and can also be applied to higher-dimensional quantum systems.

"To me, one of the most exciting moments is our rediscovery of the qubit decomposition of Werner states—implicitly given in the work of [Popescu](#)," said Liang.

"Not only has this shed light on a question that has led us to this work—namely, why one should favor qubit projection over other ScLFs—but it has also facilitated the possibility for us to perform our experimental demonstration. As for achievement, I would pick the first proof-of-principle experimental validation of the nonlocality of higher-dimensional Werner states, 30 years after Popescu first noticed it."

The new take on distillation advocated by He, Liang and their colleagues could soon be used to distill the quantumness in other higher-dimensional quantum systems, to further validate its potential. The team's findings could also have interesting theoretical implications, as it challenges previous views suggesting that entanglement can only become useful when it is heavily "purified" from noise.

In his next studies, Liang, who is a [theoretical physicist](#) working at National Cheng Kung University and Deputy Director of the Center for Quantum Frontiers of Technology (QFort), plans to devise an even more efficient single-copy distillation-based protocol to extract genuine quantum features from Werner states or prove that the current protocol is already optimal.

Lu and his colleagues at Shandong University, on the other hand, hope to soon demonstrate the implementation of the new distillation protocol on quantum states with more dimensions.

"In this work, we have demonstrated the single-copy distillation on three-dimensional quantum states," added Lu.

"I would like to explore even higher-dimensional states, although implementing our scheme using bulk optics in such cases seems quite challenging. However, the rapid development of integrated optics offers a promising platform for such demonstrations."

**More information:** Xiao-Xu Fang et al, Experimental Single-Copy Distillation of Quantumness from Higher-Dimensional Entanglement, *Physical Review Letters* (2025). DOI: [10.1103/PhysRevLett.134.150201](https://doi.org/10.1103/PhysRevLett.134.150201). On arXiv: DOI: [10.48550/arxiv.2410.06610](https://arxiv.org/abs/10.48550/arxiv.2410.06610)

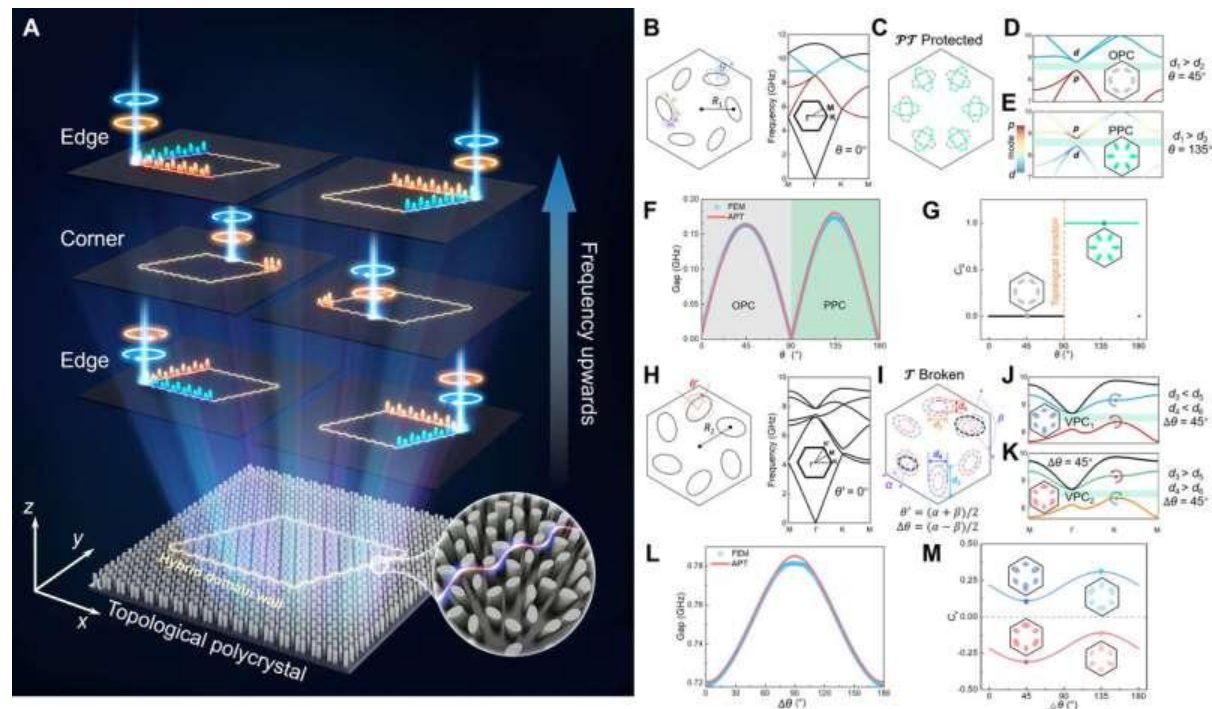
**Journal information:** [Physical Review Letters](#) , [arXiv](#)

© 2025 Science X Network

MAY 8, 2025

# Topological polycrystal: A new approach to configurable, multiband topological photonic circuitry

by Tianyue Li



Topological photonic polycrystal (TPPC) implemented in photonic integrated circuits (PIC) and its structural details. (A) Diagram of HTP-PIC displaying edge and corner states. Right/upper edges maintain TEs with identical spin-momentum locking at distinct

frequencies, whereas left/lower edges sustain TEs with opposing spin-momentum locking at different frequencies. (B–E) Hexagonal lattice with  $C_6$  symmetry shows band degeneracies near 8 GHz at  $\Gamma$  points (B) and its modified versions with varying orientation angle  $\theta$  (increasing clockwise) (C), with  $\theta = 45^\circ$  (OPC) and  $\theta = 135^\circ$  (PPC) band structures displayed in D and E (blue/red lines indicate d/p modes respectively). (F) Correlation between frequency gap and rotation angle  $\theta$  from FEM simulations and APT computations. (G)  $C_s$  values versus  $\theta$  from numerical calculations. (H–K)  $C_6$ -symmetric hexagonal lattice demonstrates band degeneracies around 8 GHz at K points (H) and resulting  $C_3$ -symmetric cells with broken parity symmetry P under angle variation (I), with band structures for two modified cells (VPC<sub>1</sub> featuring larger top ellipse/VPC<sub>2</sub> with smaller top ellipse) shown in J and K (circular arrows indicate valley-polarized states at K points). (L) Relationship between frequency gap and rotation angle  $\Delta\theta$  via FEM and APT analysis. (M) Computed  $C_v$  values for both VPCs as a function of  $\Delta\theta$ . Credit: Tianyue Li

Molding the flow of light—whether confined to localized regions or propagating in free space—remains crucial for modern integrated photonics. The advancement of the multi-channel, programmable optical waveguide and coupler arrays has enabled us to develop photonic integrated circuits (PICs) as a viable alternative to electronic ones, overcoming limitations in processing speed, bandwidth, and efficiency across the optical-to-microwave spectrum.

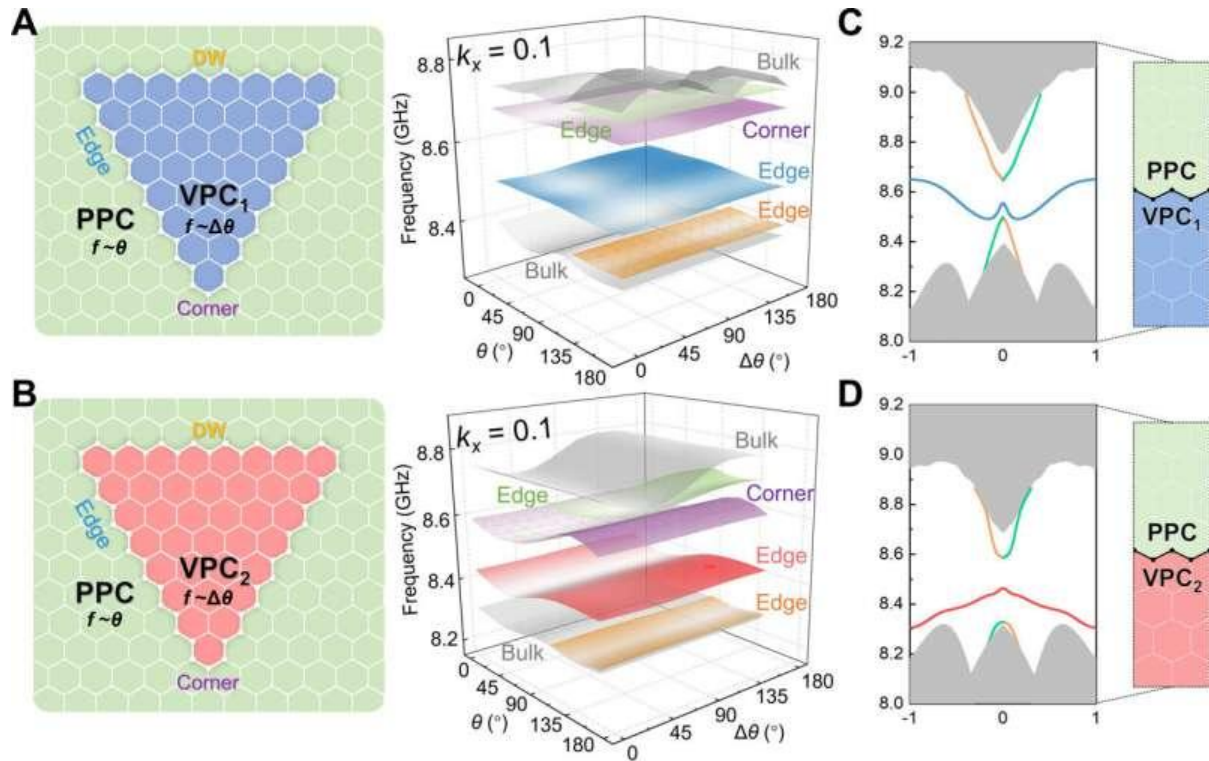
However, as on-chip complexity grows, we face significant challenges regarding long-term stability and fabrication-induced defects, making operational reliability critical for practical applications.

The increasing demand for high-capacity information processing drives our need for more complex PICs with additional channels. In this context, topological photonics offers promising solutions due to its inherent robustness against defects.

Current PICs utilizing topologically protected domain-wall modes mainly rely on two-dimensional microstructures following the rule of bulk-edge correspondence, which typically supports only limited edge states and constrains channel capacity. To overcome this, we have focused on hybrid topological effects that combine multiple topological phenomena in a single system.

Recently, our research team has investigated hybrid artificial microstructured systems and their topological applications. By constructing a synthetic dimension combining momentum space and unit cell orientation space, we developed a configurable topological photonic polycrystal. This dielectric topological metasurface, composed of tunable elliptical elements, utilizes a novel coupling mechanism between pseudo-spin and the valley Hall effect, providing a versatile platform for multidimensional photonic control.

Our work, [published](#) in *National Science Review* under the title "Configurable Topological Photonic Polycrystal Based on Synthetic Hybrid Dimension," represents a significant advancement in the field.

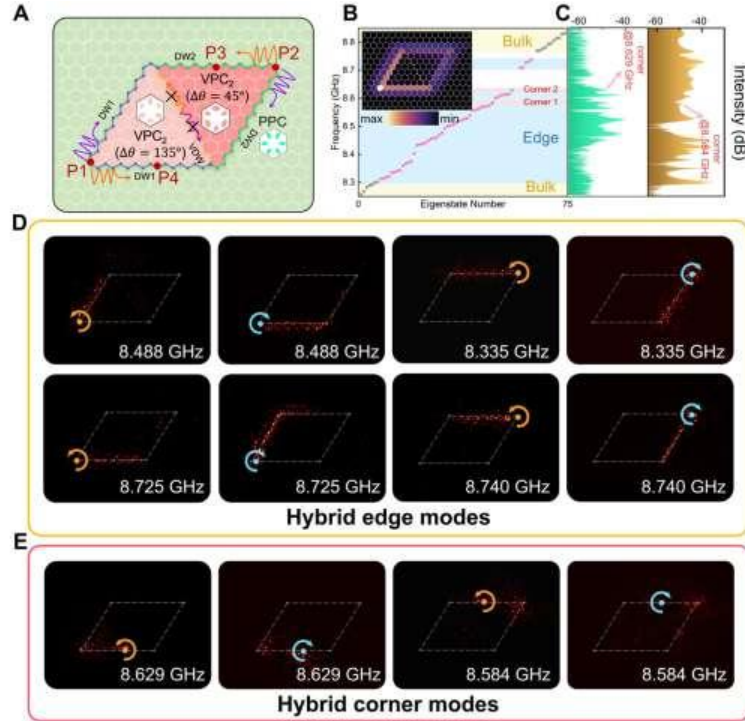


**E** **G** **H** **max**  
 Hybrid topological states in superlattice-based HTP-PIC. (A–B) Schematic of TPPC consisting of VPC<sub>1</sub> (A) and VPC<sub>2</sub> (B) embedded in PPC, with right panels showing band dispersion of corresponding configurations at  $k_x = 0.1$  versus  $(\theta, \Delta\theta)$ . (C–D) Projected band structures for supercells combining VPC<sub>1</sub> (C) or VPC<sub>2</sub> (D) with PPC at  $\Delta\theta = 45^\circ$ , where gray areas indicate bulk states and gap-spanning solid lines represent TES dispersion. (E–F) Unidirectional light propagation simulations at 8.482 GHz (E) and 8.705 GHz (F) under LCP/RCP excitation for configuration C. (G–H) Field distributions of corner states (G) and localized quality factor  $Q^L$  (H) in VPC<sub>2</sub>-embedded PPC HTP-PIC. Credit: Tianyue Li  
 We developed a perturbation theory based on structural orientation angles to enable rapid calculation and adjustment of photonic band gaps. Since both pseudo-spin and valley lattices are fundamentally linked to orientation angles, we observed that varying these angles induced delicate energy band shifts, effectively modulating the "mass term" of the system.

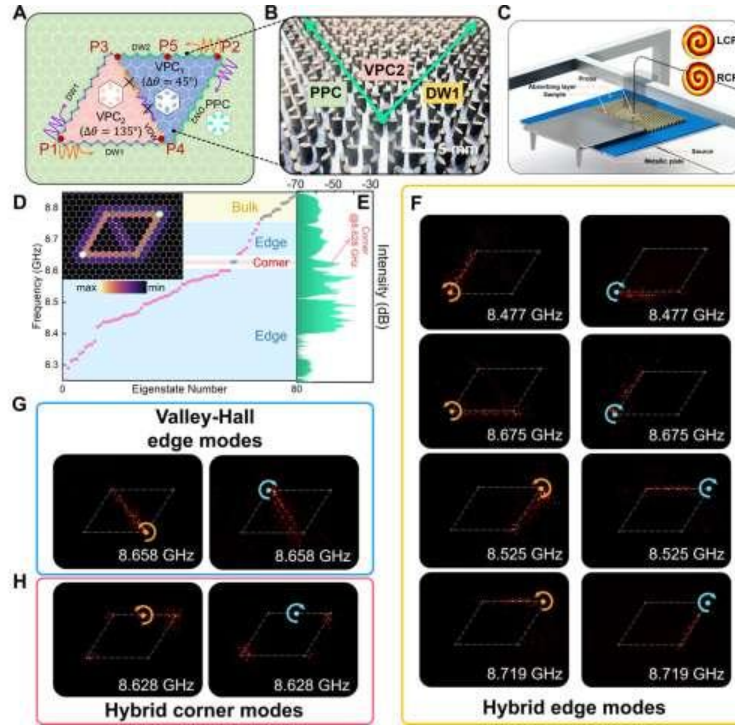
To fully characterize this phenomenon, we integrated our proposed scalar [perturbation theory](#) while treating orientation angles as synthetic dimension parameters. For any given photonic lattice, we successfully constructed a three-dimensional synthetic space by combining the two-dimensional Bloch momentum space and the one-dimensional orientation [angle](#) dimension.

This innovative approach allowed us to compute topological invariants as continuous functions of orientation angles, yielding a powerful theoretical framework for analyzing the system's topological properties. When coupling both topological effects, we found this hybrid-dimensional space depends on two independent orientation angles and the one-dimensional momentum space along domain walls.

Through detailed hybrid-dimensional analysis, we systematically tracked how bulk states, edge states, and corner states evolve with orientation angle variations. These insights fundamentally clarify how our hybrid topological polycrystal architecture achieves robust, dynamically reconfigurable photonic functionalities.



Experimental characterization of hybrid TESSs and TCSs in symmetric-antisymmetric HTP-PIC. (A) Structural design of HTP-PIC comprising VPC<sub>2</sub> with varying  $\Delta\theta$  embedded in PPC. (B) Numerical eigenfrequency analysis of antisymmetric HTP-PIC, with green and blue triangles denoting distinct corner state frequencies, and inset displaying  $Q^{\perp}$  spatial profile. (C) Measured transmission spectra under localized excitation at positions P1 versus P2. (D) Experimental verification of eight hybrid TESSs along VPC-PPC boundaries. (E) Dual-frequency hybrid TCSs detected when stimulating the system at locations P3 and P4 separately. Credit: Tianyue Li



- Experimental observation of hybrid TESSs and TCSs in symmetry-maintained HTP-PIC. (A) Schematic design of HTP-PIC composed of  $VPC_1$  ( $\Delta\theta = 45^\circ$ ) and  $VPC_2$  ( $\Delta\theta = 135^\circ$ ) embedded in PPC. (B) Microscopy image showing partial view of DW1 in fabricated HTP-PIC sample. (C) Diagram of near-field measurement setup for sample characterization. (D) Numerically computed eigenmodes of symmetric HTP-PIC: bulk (grey squares), edge (pink dots), and corner states (blue triangles), with inset showing  $Q^L$  distribution. (E) Experimentally obtained transmission spectrum. (F–H) Measured hybrid TESSs at VPC/PPC interfaces (F), valley-polarized TESSs at  $VPC_1/VPC_2$  junction (G), and two hybrid TCSs (H) excited by LCP (orange arrows) and RCP (blue arrows) sources. Credit: Tianyue Li
- In addition, we introduced a novel local quality factor ( $Q^L$ ) specifically designed to characterize hybrid eigenmodes within band gaps. By integrating the local density of states at target frequencies, this quantitative metric provides an effective performance evaluation method for hybrid topological photonic devices.

As a validation, our team experimentally validated this approach by implementing a hybrid topological photonic integrated circuit that successfully demonstrated high-contrast multi-band edge states and higher-order corner states along the interface. This method enables on-chip logic gates, couplers, and high-density optical communication through multi-band chiral edge channels, while simultaneously supporting the development of multi-band lasers featuring ultra-small mode volumes and diverse corner states.

Furthermore, our orientation-dependent photonic lattice concept opens new possibilities for reconfigurable and programmable active topological devices. Looking ahead, we aim to explore nonlinear effects in hybrid topological polycrystals to enhance their multimodal and multi-band capabilities, paving the way for both classical and quantum photonic applications.

**More information:** Tianyue Li et al, Configurable Topological Photonic Polycrystal Based on a Synthetic Hybrid Dimension, *National Science Review* (2025). DOI: [10.1093/nsr/nwaf107](https://doi.org/10.1093/nsr/nwaf107)

## Bio:

Tianyue Li is currently a Research Fellow in the Department of Physics at the Institute of Advanced Study, Hong Kong University of Science and Technology (HKUST). His research focuses on nanophotonics, particularly investigating the physical mechanisms and optical singularities in light-matter interactions. He strives to advance this field through explorations in light-field manipulation, topological photonics, and optomechanics. Additionally, he develops versatile nano-devices for on-chip and fiber-based platforms, including applications in optical tweezers, communication, photonic circuits, and imaging. He has published more than 10 SCI papers and co-authored 10 additional papers. He has delivered four invited talks and more than 10 oral presentations. His work has received more than 600 citations, with an h-index of 12, and includes an Editors' Pick selection in *Optics Letters* and a cover article in another journal. (Homepage: [tobeyleonard.github.io/](https://tobeyleonard.github.io/))

**Journal information:** [Optics Letters](#)

---