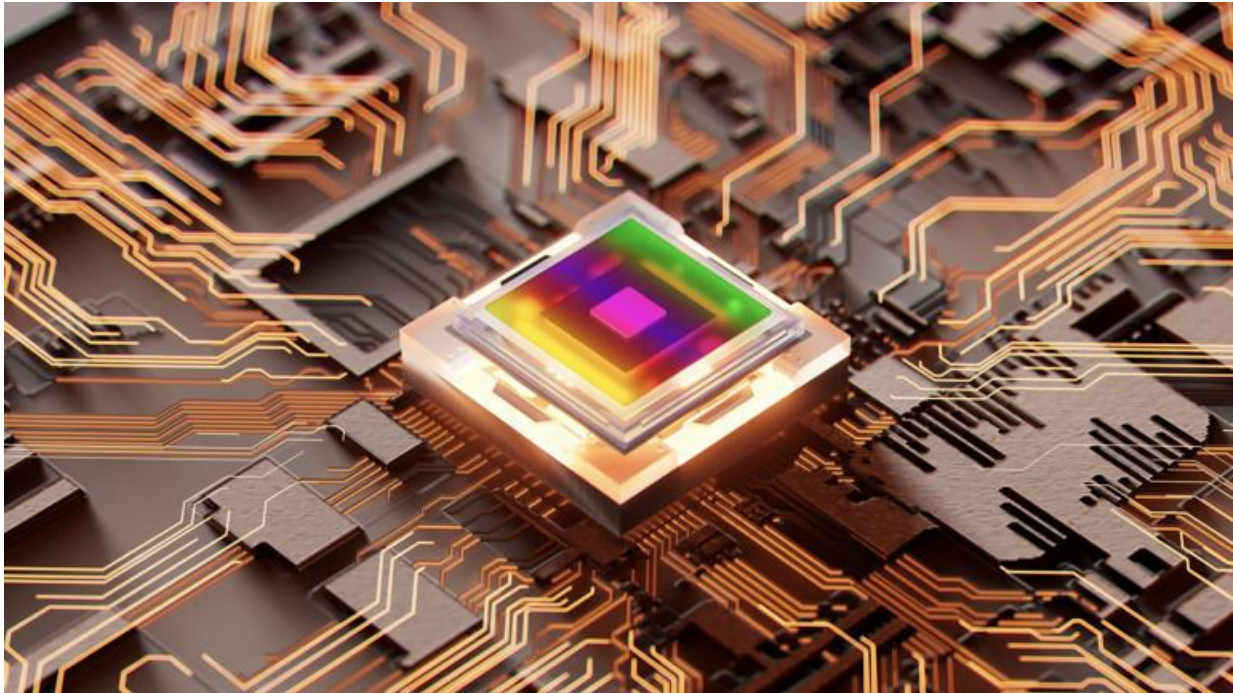


QUANTUM TECH VOL 2



What is a quantum processing unit (QPU)? © Getty Images/luchezar

One of the core components of a [quantum computer](#) is the quantum processing unit (QPU) or quantum processor. Instead of binary bits used in classical computing, quantum computers use [quantum bits](#) – or qubits for short. These qubits are subatomic particles that can use the properties of [quantum mechanics](#) to represent and process vast amounts of data.

A quantum processor manipulates qubits in order to complete tasks. It is akin to a conventional computer's central processing unit (CPU), which performs calculations using the information held in binary bits – the 1s and 0s of data.

Unlike classical processors, quantum processors use quantum logic gates (or quantum gates) to manipulate qubits and perform calculations. Quantum gates are inherently different from binary logic gates, as they are designed to take advantage of the weird properties of quantum physics. The bizarre rules of the quantum world enable quantum computers to carry out calculations in a mere fraction of the time that it would take normal binary computers.

As the technology is still in its infancy, there is currently no standard architecture or approach to developing a quantum processor, and one quantum processor may operate in a completely different way from another. Because of these differing architectures, it can be hard to compare the capabilities of different types of quantum processors.

How do quantum processors work?

The development of quantum processors still faces significant practical challenges. To be effective and accurate, quantum processors must also maintain qubit stability and have viable error correction systems in place. Both elements are essential for developing quantum computers capable of performing large-scale calculations accurately.

Part of the problem, however, is that qubits are inherently fragile and can be affected by a variety of external environmental conditions. A stable qubit state, which is essential for accuracy, is often (but not exclusively) achieved by using high-powered magnetic fields or by freezing the qubits to near [absolute zero](#).

There are also ongoing investigations into a variety of technologies that can detect unwanted changes in the qubit states, alongside those that correct or compensate for external interferences.

These technical challenges make quantum processors incredibly delicate technologies that are sensitive to the slightest external interference. Even tiny vibrations can disrupt a quantum processor from successfully completing task, meaning they are not yet suitable for applications outside of a laboratory environment.

Classical algorithms can't be used in quantum physics, so quantum processors use quantum algorithms that enable them to execute code differently. The unique nature of quantum algorithms allows them to take advantage of the quantum properties and process data at a faster rate.

Although quantum processors are able to perform computations too complex for today's [most powerful supercomputers](#), they are not able to solve undecidable problems such as anything that is fundamentally unsolvable.

The development of quantum processing units is akin to the early evolution of conventional CPUs. Although there are a variety of quantum processor unit architectures, these are likely to become unified into a single standard design as the technology is refined and improved in the coming years.

negative time discovery.jpg© iStock/ Getty Images

Scientists claim to have found evidence of “negative time” after observing photons exiting a material before entering it.

A team of quantum physicists from the University of Toronto in Canada made the discovery after studying the behaviour of photons – the wave particles of light – for seven years in order to better understand a phenomenon known as atomic excitation.

This is where photons absorbed by a material experience a time delay – also known as a group delay – before exiting the material due to their interactions with atoms within it.

To better understand this process, the researchers came up with an experiment to shoot photons through a cloud of ultracold atoms and observe the atomic excitation.

To their surprise, the transit time of some of the photons through the atoms concluded before the atomic excitation had finished, giving it a negative value and making it appear as though the photons exited the material before entering it.

“These results suggest that negative values taken by times such as the group delay have more physical significance than has generally been appreciated,” the researchers noted.

The results were detailed in [a study](#), titled ‘Experimental evidence that a photon can spend a negative amount of time in an atom cloud’, which is currently awaiting peer review.

“It took a positive amount of time, but our experiment observing that photons can make atoms seem to spend a *negative* amount of time in the excited state

is up!" Aeprhaim Steinberg, an experimental quantum physicist at the University of Toronto, [wrote on X](#). "It sounds crazy, I know."

Speaking to *Scientific American*, Josiah Sinclair from the University of Toronto said that his team was "completely surprised" by the results.

"A negative time delay may seem paradoxical, but what it means is that if you built a 'quantum' clock to measure how much time atoms are spending in the excited state, the clock hand would, under certain circumstances, move backward rather than forward," he said.

The findings have no practical impact on our understanding of time, however it does raise questions about previous studies relating to photons and optics, while also demonstrating the mysterious nature of the quantum realm.



Scientists found quantum edge states in ultracold sodium atoms, possibly leading to highly efficient energy systems with minimal loss. © hepjam - Getty Images

- Studying quantum phenomena—such as the quantum Hall effect and 'edge state' electrons—is incredibly difficult because they occur at such small scales.

- Now, scientists at MIT have created an experimental set-up that recreates the quantum Hall effect, but uses ultracold cloud of sodium atoms instead of electrons.
- With interactions occurring over milliseconds (instead of femtoseconds), this experimental stand-in can help scientists further study this fascinating mystery of the quantum world.

One of the hardest things about exploring the [quantum](#) world is that many of the phenomena in this “invisible” realm occur at mind-bogglingly small scales.

Take, for example, what is known as the [quantum Hall effect](#). First discovered in 1980 by German physicist Klaus von Klitzing, this effect describes the behavior of electrons (under the influence of a magnetic field and approaching absolute zero temperatures) as they pass through 2D materials, such as graphene. Usually, you’d expect the [electrons](#) to experience resistance and scatter, but under these conditions, they formed lossless energy states locked along the material’s boundary.

This quantization of [electrical](#) resistance, known as an “edge state,” is particularly useful if you want to create exotic materials free of electrical resistance. But there’s just one problem.

“These states occur over femtoseconds, and across fractions of a nanometer, which is incredibly difficult to capture,” Richard Fletcher, an assistant professor at MIT, [said in a press statement](#). A femtosecond is one quadrillionth of a [second](#). “The beauty is seeing with your own eyes physics which is absolutely incredible but usually hidden away in materials and unable to be viewed directly.”

To actually study this quantum interaction on a more reasonable scale, Fletcher—along with his colleagues at MIT’s Research Laboratory of Electronics and the MIT-Harvard Center for Ultracold Atoms—decided on a novel method to essentially scale up this phenomenon using a cloud of ultracold sodium [atoms](#) instead of electrons.

According to the researchers, this allowed the team to watch these edge states form “over milliseconds and microns,” which are much more manageable

experimental parameters. The results of the study were published last week in the [journal *Nature Physics*](#).

To create this quantum interaction on a bigger scale took a large amount of experimental ingenuity. The team used one million ultracold sodium atoms and essentially trapped them in a complex set-up of [lasers](#). However, to simulate the experience of living in a flat space, the researchers also spun them like “riders on an amusement park Gravitron.”

“The trap is trying to pull the atoms inward, but there’s centrifugal force that tries to pull them outward,” Fletcher said. “The two forces balance each other, so if you’re an atom, you think you’re living in a flat space, even though your world is [spinning](#). There’s also a third force, the Coriolis effect, such that if they try to move in a line, they get deflected. So these massive atoms now behave as if they were electrons living in a magnetic field.”

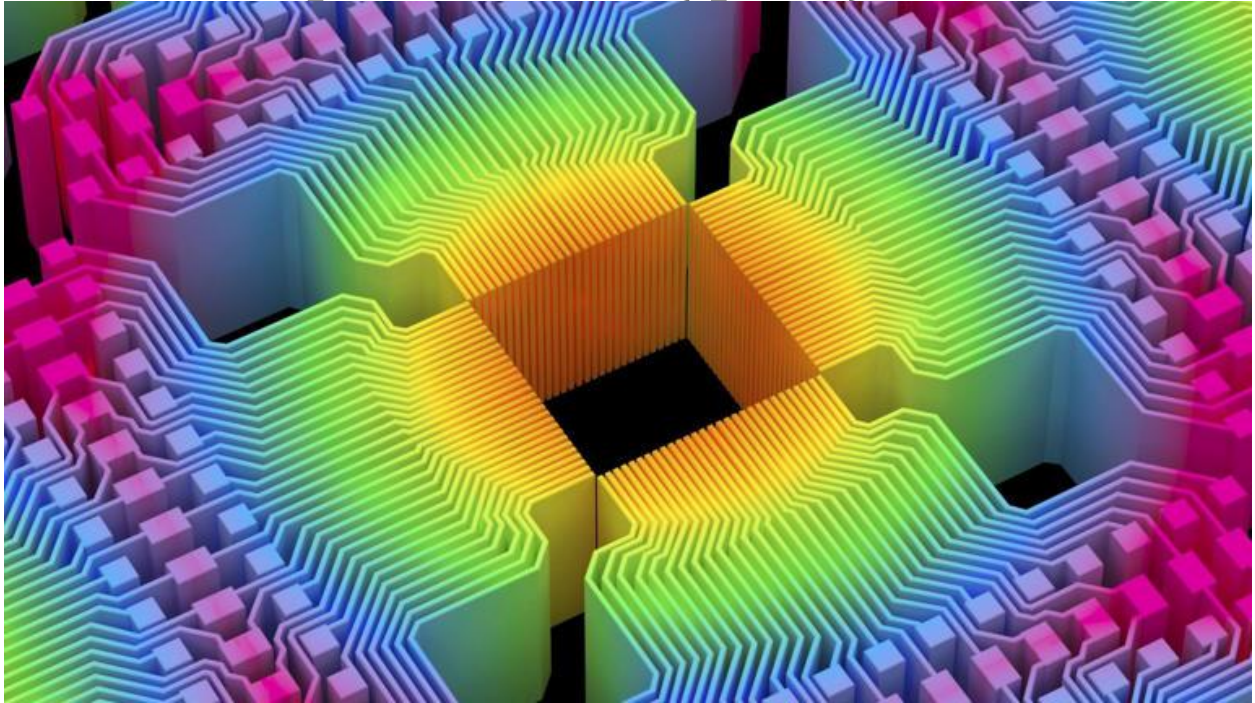
Scientists then defined the “edge” of this gaseous material by introducing a laser, which formed a wall around the atoms. Once atoms encountered this [light](#), they flowed in just one direction—much like electrons at ultra-small quantum scales.

“You can imagine these are like marbles that you’ve spun up really fast in a bowl, and they just keep going around and around the rim of the bowl,” Martin Zwierlein, a co-author of the study, said in a press statement. “There is no [friction](#). There is no slowing down, and no atoms leaking or scattering into the rest of the system. There is just beautiful, coherent flow.”

To test these atoms’ resistances, the team then placed obstacles—such as a point of light—in their paths, and the atoms passed by without any [measurable](#) resistance.

Now that scientists have a reliable stand-in for this quantum process, future experiments can push these interactions to the “edge” and begin to explore unknown frontiers of this fascinating piece of quantum [physics](#).

What is a quantum bit (qubit)?



What is a quantum bit (qubit)? © ALFRED PASIEKA/SCIENCE PHOTO LIBRARY via Getty Images

A quantum bit, otherwise known as a qubit, is the basic unit of data in quantum computing. Like a binary bit in classical computers, as it can store information, but behaves very differently thanks to [quantum mechanics](#).

[Quantum computers](#) normally use subatomic particles, such as photons (packets of light) or electrons, as qubits. In qubits, properties such as charge, photonic polarization or spin represent the 1s and 0s in binary computing. However, qubits are also subject to phenomena known as [superposition](#) and [entanglement](#), due to their quantum nature, which is where things start to get weird.

Bits vs qubits: What's the difference?

As well as being either 0 or 1, like a bit, qubits can occupy both states at the same time — or a superposition of 1 and 0. The qubit will remain in superposition until it is directly observed or disrupted by external environmental factors, such as heat. Because this quantum state is so delicate, qubits have to be kept free from interference, which requires very cold temperatures.

Superposition allows the qubits of a quantum computer to be in multiple states (0, 1 or both) and the number of possible states available grows exponentially the more qubits there are. If you have two classical bits, for example, at any given time they could take the values of either 0,0; 0,1; 1,0; or 1,1.

With two qubits, you can encode data in all four states at once. As such, quantum computers potentially have far greater processing power than conventional computers using binary bits. The more qubits you have, the more calculations you can process in parallel — and this rises exponentially if you add more to the system. However, to see exponential growth in processing power, you must also entangle the qubits.

How does entanglement work?

In quantum entanglement, the states of subatomic particles are linked, regardless of how far apart they may be. Gaining information about a qubit will automatically provide information about its entangled particle.

Entangled particles are always in a correlated state. Consequently, if a property (such as spin) of one particle is measured, thus bringing it out of superposition, the same thing will also instantaneously happen to the entangled particle. Since the states of the two entangled particles are always correlated, knowing the state of one entangled particle means the state of the other can be inferred.

Related: Prototype quantum processor boasts record 99.9% qubit fidelity

Rather than directly measuring the qubit, and thereby causing it to lose its superposition state, scientists are investigating whether there might be a way of indirectly inferring information about a qubit from its interaction with the surrounding environment.

Quantum entanglement of qubits also allows them to interact with each other simultaneously, regardless of their distance from each other. When combined with superposition, quantum entanglement theoretically enables qubits to greatly enhance the computing power of quantum computers, allowing them to perform complex calculations that powerful binary computers would struggle to resolve.

This is currently possible at a small scale, but the challenge is to scale it up. For instance, some calculations, such as breaking encryption algorithms, would take classical computers millions of years to perform. However, if we could build a quantum computer with millions of qubits, those same algorithms could be cracked within seconds.

Why are qubits so fragile and prone to decoherence?

So why haven't we simply stacked up more and more qubits to build such a machine? Unfortunately, qubits are short-lived, and the superposition can collapse with the very faintest of external environmental influences, like heat or movement. For that reason they are deemed "noisy" and error-prone.

For that reason, many qubits need to be chilled to near [absolute zero](#) and maintained using specialized equipment. They also have incredibly short "coherence times" — which is the measure of how long they retain the desired state needed to process quantum calculations. Coherence times usually only last [fractions of a second](#). (The world record is [10 minutes for a single qubit](#) — but experts think it's unlikely to be translated to a real quantum computer.) This factor also makes qubits unsuitable for long-term data storage.

Although many quantum computers exist today, we still need to apply "error correction" techniques to qubits to trust their results. One major error correction method under investigation today is building a "[logical qubit](#)." A logical qubit is actually a group of entangled, error-prone qubits that store the same information in different places. This spreads out the possible points of failure while a calculation is underway, thereby correcting the errors. Should qubits be stabilized sufficiently, with the superposition and quantum entanglement of qubits in place, quantum computers can one day perform calculations in a fraction of the time that a binary computer would need, as well as solve complex equations that are impossible for even today's [most powerful supercomputers](#).

The Quantum Revolution & Its Implications for Society & Beyond

Quantum mechanics, once confined to the realms of theoretical physics, is poised to revolutionize society in ways that are only beginning to be understood.

The implications of this quantum leap extend far beyond the confines of academia and into everyday life, promising to reshape industries, enhance technological capabilities, and introduce novel applications that were once the stuff of science fiction.

So, what exactly does this quantum revolution entail, and how will it impact all aspects of society?

The Quantum Advantage: More Than Just Computing

At the heart of the quantum revolution is the quantum computer, a device that leverages the principles of quantum mechanics to process information in ways that classical computers cannot.

Unlike classical bits, which represent either a 0 or a 1, quantum bits (qubits) can represent both simultaneously thanks to a property known as superposition.

Additionally, qubits can be entangled, allowing for instantaneous correlation between them regardless of distance, exponentially increasing computational power.

This capability has profound implications. Quantum computers can solve complex problems in seconds, which would take classical computers millennia to complete. This includes everything from optimizing large-scale systems, such as traffic flows or financial portfolios, to simulating molecular interactions for drug discovery and new materials development.

Quantum Sensing: Precision Redefined

Quantum sensors are another game-changer. These devices exploit the extreme sensitivity of quantum states to environmental changes, enabling measurements with unprecedented precision.

For instance, quantum sensors can detect minute variations in magnetic fields, temperature, and pressure, which classical sensors would miss. This could revolutionize fields such as medical imaging, navigation, and even geology.^(ref)

For example, researchers are developing quantum sensors that can measure the forces between individual cells, providing insights into cellular interactions that are critical for understanding diseases and developing new treatments.

Similarly, quantum sensors could enhance navigational systems, leading to more accurate and reliable GPS technology.

Quantum Communication: Securing the Future

Quantum cryptography promises unbreakable encryption by leveraging the principle that measuring a quantum state disturbs it, thus revealing any eavesdropping attempts. Quantum communication networks employing quantum repeaters to extend the range of communication could lead to a new era of secure data transmission.

This technology is already being tested for secure governmental and financial communications, promising a future where data breaches and hacking could become relics of the past.

Ethical & Societal Implications

As with any revolutionary technology, the rise of quantum computing and related technologies brings ethical and societal challenges. Quantum computers' ability to break current encryption standards poses significant risks to data security, necessitating the development of quantum-resistant encryption methods.

My new article, "Quantum Entanglement of Optical Photons: The First

Experiment, 1964–67," is intended to convey the spirit of a small research project that reaches into uncharted territory. The article breaks with tradition, as it offers a first-person account of the strategy and challenges of the experiment, as well as an interpretation of the final result and its significance. In this guest editorial, I will introduce the subject and also attempt to illuminate the question "What is a paradox?"

Let's begin with the gyroscope that I bought when I was eight, from a store that sold novelties and magic tricks. The spinning disk, supported at one end of its shaft, did not fall, but moved slowly around in a horizontal plane. This behavior seems mysterious or paradoxical in the context of common experience that excludes gyroscopes, but makes complete sense in the context of Newtonian mechanics, which resolves the paradox by predicting precisely how gyroscopes will behave.

Quantum theory, conceived in the mid-1920s, has been impressively successful in accounting for the properties and interactions of atoms and molecules. In 1935, Einstein, Podolsky, and Rosen stirred controversy with a thought experiment in which two particles of common origin move apart, noting that quantum theory predicts correlations in subsequent measurements of their spins. The correlation may seem quite puzzling, as a measurement on one of the particles appears to influence a subsequent measurement on the other, even if the particles do not interact.

In current terminology, these correlations are an example of entanglement, and the correlation phenomenon is known as the EPR paradox. The puzzle has become a subject for much discussion and analysis, especially because there was (and is) no known mechanism for measurements to communicate with each other.

Disentangling entanglement

In 1964, I was intrigued by this unfamiliar effect and began to think of a way to actually perform the EPR experiment—or at least a version of it—by observing

the correlation and entanglement. It would be a low-energy experiment that could be set up in a small laboratory.

For the experiment outlined here, the particles of interest are visible-light photons, which are noninteracting, emitted by excited calcium atoms in a two-stage spontaneous emission process. The polarization states of the photons, which are related to their spins, can be measured simply, with ordinary linear polarizers. Photomultiplier detectors count the individual photons, #1 (green) and #2 (violet), and timing circuits enable the identification of photon pairs from the same atom. A rotatable linear polarizer is mounted in front of each detector.

In the simplest terms, the experiment involves counting the rate at which photon pairs are detected, as a function of the orientation of the polarizers. A photon pair detected from the same atom is recorded as a "coincidence count."

Quantum theory makes the following predictions:

1. Each photon, taken separately, has a 50% chance of being transmitted by its polarizer, regardless of its angle of orientation.
2. If the polarizer axes are parallel, both photons from the same atom can pass through their polarizers and be counted. Coincidence counts will be observed.
3. If the polarizer axes are perpendicular, it never happens that both photons pass through their polarizers. Therefore, no coincidence counts will be observed.

Predictions #1 and #2 are not surprising, as the green and violet beams of light are unpolarized.

Prediction #3, discussed further in my article, is a quantum entanglement effect with no analog in classical (non-quantum) physics. It is especially interesting because it can be tested experimentally. I designed the experiment specifically for this purpose.

The results of the experiment, after nearly three years of effort in the laboratory, clearly demonstrate that coincidence counts are recorded if the polarizer axes are

parallel, and that no coincidences are recorded if the polarizers are perpendicular. The agreement between theory and experiment is unequivocal and striking.

So, is there a paradox?

In our brief discussion of the gyroscope, no paradox was acknowledged because Newton's theory (classical dynamics) fully explains how a gyroscope moves. Furthermore, both the theory and the observed gyroscopic behavior are compatible with our life experience and intuitive ability to grasp natural processes in the classical realm.

In the entanglement case, quantum theory accounts for the observed correlation of the photon polarizations. But even when a theory predicts experimental results, a paradox may remain if the intuition cannot reach out to connect with it.

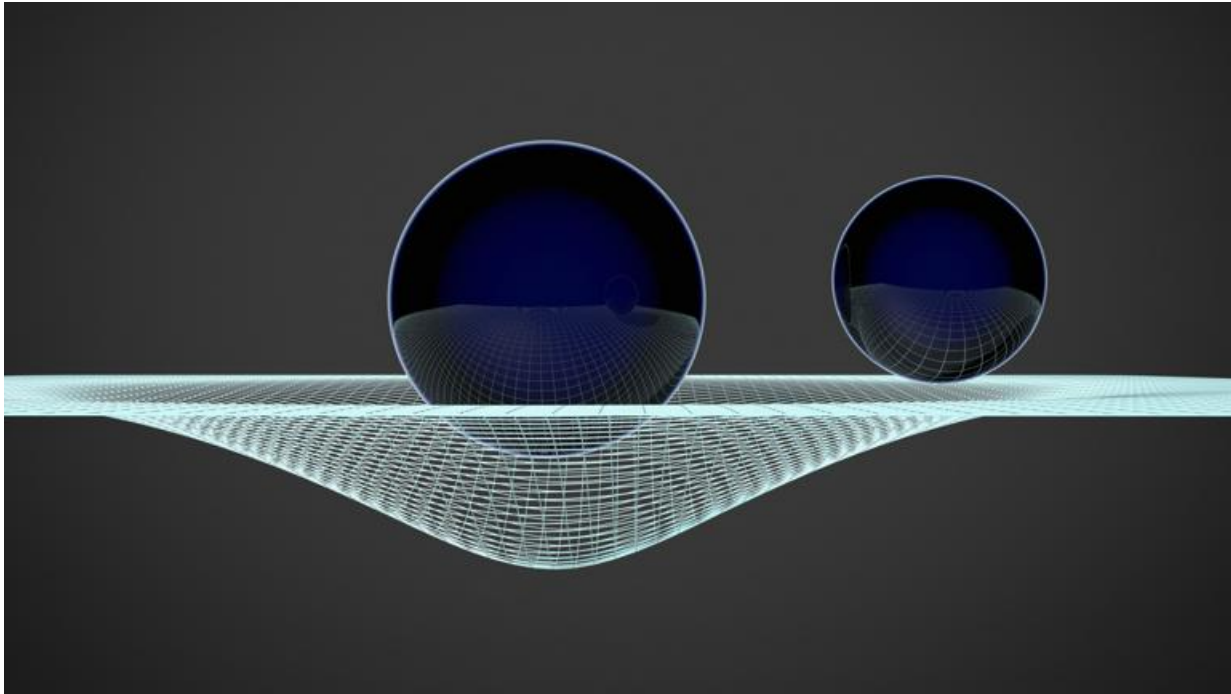
Take another look at predictions #1 and #3 above. If we draw on our experience of life in a non-quantum world, we may notice something very strange when the polarizers are "crossed" at 90 degrees. If each photon has a 50% chance of transmission through its polarizer, why don't we get coincidences 25% of the time? Instead, we observe none at all.

On first consideration, this does seem to qualify as a paradox. One possible explanation could involve a missing component of quantum theory—perhaps a causal mechanism that could allow one photon, or one measurement, to communicate with the other. However, despite extensive research, no evidence has been found for such a mechanism.

As we do not live in an overtly quantum world, classical phenomena may influence our thought processes—even when we venture into the quantum realm. It may therefore remain a challenge to assimilate entanglement into the intuition. I believe that the paradox can be at least partially resolved when further thought and experience, such as the experiment considered here, 'stretch the mind' to more fully embrace entanglement and other quantum phenomena.

I have come to view these aspects of nature as "strangely wonderful."

More information: Quantum Entanglement of Optical Photons: The First Experiment, 1964-67, *Frontiers in Quantum Science and Technology* (2024). DOI: [10.3389/frqst.2024.1451239](https://doi.org/10.3389/frqst.2024.1451239)



Magical equation unites quantum physics, Einstein's general relativity in a first

For the first time, a mathematical framework proves that Einstein's theory of general relativity, which explains the relationship between space, time, and gravity, is in alignment with quantum physics — the branch of science that describes the behavior of electrons, photons, and other fundamental particles.

"We proved that the Einstein field equation from general relativity is actually a relativistic quantum mechanical equation," the researchers note in their study.

In simple words, this new framework [connects the science](#) that governs the macroscopic world with that of the microscopic world.

Therefore, it has the potential to explain every physical phenomenon known to humanity ranging from the [mysterious dark matter](#) in space to the photons emitted by your phone's flashlight.

"To date, no globally accepted theory has been proposed to explain all physical observations," the [researchers](#) added. They claim that their theory can challenge the foundations of physics and change our understanding of the universe.

The disconnect between relativity and the quantum world

Einstein's [theory of general relativity](#) explains how gravity works. It says that massive objects like planets, stars, or galaxies bend the fabric of space and time around them, like a heavy ball on a trampoline. This bending creates what we feel as gravity.

So, instead of thinking of gravity as an invisible force pulling objects together, general relativity shows that objects move along curves in the warped space around them. The more massive the object, the more it bends space, and the stronger the gravitational effect.

Quantum physics, on the other side, is concerned with the study of the [unusual behavior](#) of the tiniest particles in the universe.

For instance, it investigates how particles such as electrons can exist in multiple states or locations at once (superposition) until we measure them. This type of strange behavior is not found in the objects we deal with regularly.

Until now, scientists have failed to reconcile general relativity and quantum physics because the two theories describe the universe in fundamentally different ways. When attempts were made to apply both theories together—such as in the case of black holes, they produced contradictory results, making it difficult to unify them into a single framework.

For example, general relativity predicts a black hole's core is [infinitely dense](#), while quantum physics suggests such infinities can't exist.

Bridging the gap between relativity and quantum physics

General relativity works well for large-scale objects, while quantum physics accurately describes microscopic phenomena, but what's the need to unite them?

Well, there are two big reasons for that. First, combining these would provide a complete understanding of the universe across all scales.

This is important because many concepts such as black holes or the Big Bang are probably results of the conditions where both quantum physics and general relativity [played a role](#). Understanding them requires a theory that integrates both.

Second, one can not fully understand the science behind quantum gravity, Hawking radiation, [string theory](#), and various other phenomena without connecting the dots between the theory of general relativity and quantum physics.

To link them, the researchers developed a mathematical framework that "Redefined the mass and charge of leptons (fundamental particles) in terms of the interactions between the energy of the field and the curvature of the spacetime."

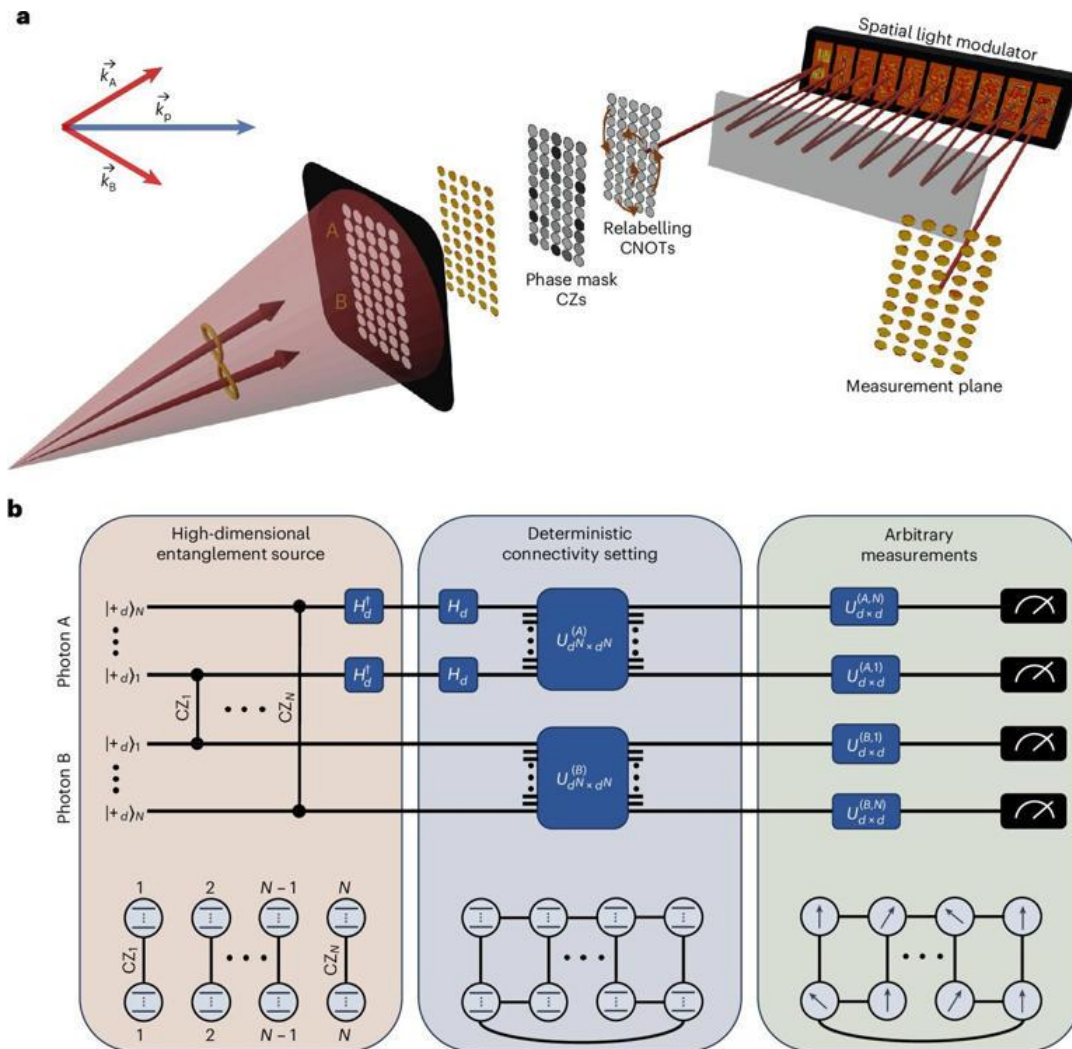
"The obtained equation is covariant in space-time and invariant with respect to any Planck scale. Therefore, the constants of the universe can be reduced to only two quantities: Planck length and Planck time," the researchers note.

This equation mathematically proved that the [Einstein Field Equation](#) related to the theory of relativity is equal to the quantum equation. The study authors claim it can provide answers to various questions that have been a mystery.

For instance, it might explain why black holes don't collapse, what were the conditions during the Big Bang, and how space-time entanglement works.

Moreover, "In recent years, the James Webb Space Telescope (JWST) has observed several phenomena, including galaxies that had already existed 300 Myr after the big bang, which have never been thought to exist. Our proposed theory suitably explains this phenomenon," said the researchers.

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



High-dimensional spatially encoded cluster states. Credit: Nature Photonics (2024). DOI: 10.1038/s41566-024-01524-w

A recent study, [published](#) in *Nature Photonics*, by Prof. Yaron Bromberg and Dr. Ohad Lib from the Racah Institute of Physics at the Hebrew University of Jerusalem has made significant strides in advancing quantum computing through their research on photonic-measurement-based quantum computation.

This method holds the potential to overcome some of the challenging obstacles in quantum computation, offering a more scalable and resource-efficient solution by using high-dimensional spatial encoding to generate large cluster states.

Quantum computers are facing a major roadblock in producing large cluster states necessary for computations. The standard approach sees detection probabilities decreasing exponentially as the number of photons increases.

Prof. Bromberg and Dr. Lib's study addresses this issue by encoding multiple qubits within each photon through spatial encoding. This innovative approach has successfully generated cluster states with over nine qubits at a frequency of 100 Hz, a remarkable achievement in the field.

Additionally, the researchers demonstrated that this method substantially reduces computation time by enabling instantaneous feedforward between qubits encoded within the same photon. This breakthrough opens the door to more resource-efficient quantum computations, potentially leading to faster, fault-tolerant quantum computers capable of handling complex problems.

Prof. Bromberg commented, "Our results show that using high-dimensional encoding not only overcomes previous scalability barriers but also offers a practical and efficient approach to quantum computing. This represents a major leap forward."

Dr. Lib added, "By tackling both scalability and computation duration issues, we've paved a new way forward for measurement-based quantum computation. The future of quantum technology just became a little closer."

This study marks an important milestone in the ongoing pursuit of realizing the full potential of quantum computing through photonics.

More information: Ohad Lib et al, Resource-efficient photonic quantum computation with high-dimensional cluster states, *Nature Photonics* (2024). DOI: [10.1038/s41566-024-01524-w](https://doi.org/10.1038/s41566-024-01524-w)

Provided by Hebrew University of Jerusalem



Google's Sycamore quantum computer chip can now outperform the fastest supercomputers, new study suggests© Peter Hansen/Getty Images

[Quantum computers](#) can outpace our fastest classical computers in very specific areas, a groundbreaking experiment suggests.

Google Quantum AI researchers have discovered a "stable computationally complex phase" that can be achieved with existing [quantum processing units](#) (QPUs), also known as quantum processors.

This means that when quantum computers enter this specific "weak noise phase," they can perform computationally complex calculations that outpace the performance of the [fastest supercomputers](#). The research — which was led by [Alexis Morvan](#), a quantum computing researcher at Google — was published Oct. 9 in the journal [Nature](#).

"We are focused on developing practical applications for quantum computers that cannot be done on a classical computer," Google Quantum AI representatives told Live Science in an email. "This research is a significant step in that direction. Our next challenge is to demonstrate a 'beyond classical' application with real-world impact."

However, the data produced by quantum computers is still noisy, meaning they still need to do fairly intensive quantum "error correction" as the number of qubits rises in order for the qubits to remain in the "weak noise phase," they added.

Related: [History of quantum computing: 12 key moments that shaped the future of computers](#)

[Qubits](#), which are embedded in QPUs, rely on the principles of [quantum mechanics](#) to run calculations in parallel, whereas classical computing bits can only process data in sequence. The more qubits are on a QPU, the more exponentially powerful a machine becomes. Due to these parallel processing capabilities, calculations that would take a classical computer thousands of years to perform could be accomplished by a quantum computer in seconds.

But qubits are "noisy," meaning they are highly sensitive and prone to failure due to interference; approximately [1 in 100 qubits fails](#), versus [1 in 1 billion, billion bits](#). Examples include environmental disturbances such as temperature changes, magnetic fields or even radiation from space.

This high error rate means that to achieve "quantum supremacy," you would need extremely proficient error-correction technologies — which do not yet exist — or a quantum computer with millions of qubits. Scaling quantum computers isn't easy, with the most qubits in a [single machine today standing at approximately 1,000](#).

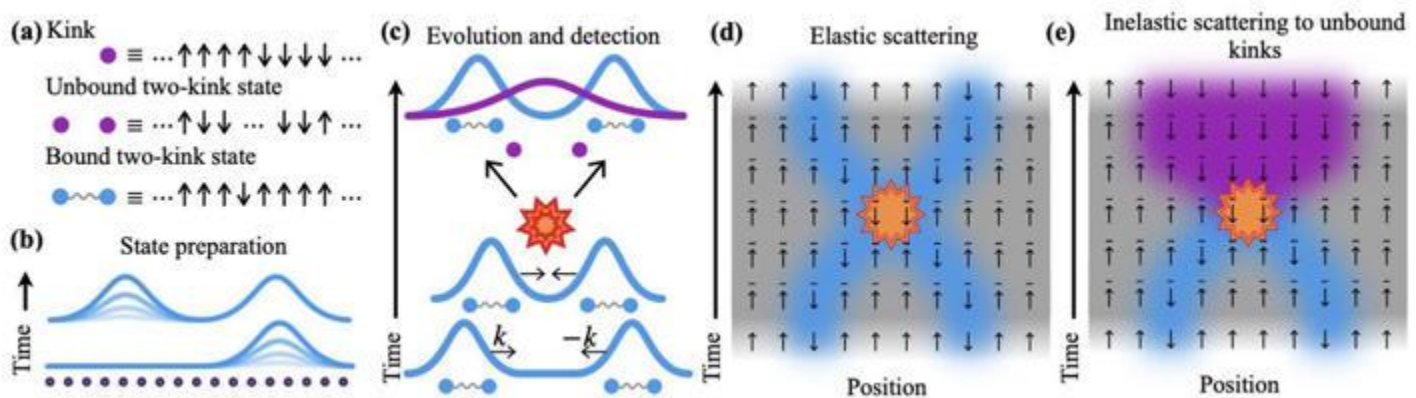
But the new experiment run by Google scientists suggests that quantum computers can withstand the current levels of noise and outperform classical computers in specific calculations. However, error correction may still be required when machines scale up.

The scientists used a method known as random circuit sampling (RCS) to test the fidelity of a 2D grid of superconducting qubits, which are one of the most common types of qubits and made from a superconducting metal suspended in temperatures close to [absolute zero](#). RCS is a benchmark that measures the performance of a quantum computer compared with that of a classical supercomputer, and it's the hardest benchmark to perform on a quantum computer, the scientists said.

The experiments revealed that working qubits can transition between a first phase and a second phase, called a "weak noise phase," by triggering certain conditions. In the experiments, the scientists artificially increased the noise or slowed the spread of [quantum correlations](#). In this second, "weak noise phase," the computation was complex enough that they concluded a quantum computer could outperform a classical computer. They demonstrated this on Google's 67-qubit Sycamore chip.

"This is a waypoint on the journey to get to real-world applications, or beyond classical commercial applications," Google Quantum AI representatives said.

"Those applications should not be replicable on a classical computer. Our results within this research is a significant step in that direction. If you cannot win on the RCS benchmark, you cannot win on anything else."



Scattering of meson wave packets on spin quantum simulators. Credit: Elizabeth R. Bennewitz / University of Maryland

Physicists share a common interest in understanding how the physical world works. For example, when a particle physicist breaks apart a particle into smaller pieces, they ask themselves: are those the smallest pieces we can find in nature?

For years, theoretical physicists have been limited to using classical computers, that is, computers that process information in 1s and 0s, as they explore the

interactions between these small particles. Thanks to the power of quantum computers, which can encode numerous possible combinations of 1 and 0 simultaneously, physicists can create larger models that will potentially solve some of the most compelling puzzles in theoretical physics.

However, theoretical researchers need access to novel computing technologies and a strong expert network for this new scientific endeavor. That's where the [Quantum Systems Accelerator](#)'s catalyzing energy comes in.

Since 2020, the Quantum Systems Accelerator (QSA), a U.S. Department of Energy (DOE) National Quantum Information Science (QIS) Research Center, has developed advanced quantum prototypes across major technologies to facilitate groundbreaking research in fundamental physics into the quantum world.

Led by Lawrence Berkeley National Laboratory (Berkeley Lab) with Sandia National Laboratories as the lead partner, QSA brings together an ecosystem of 15 institutions in North America. With over 60 principal investigators, 130 staff, 91 postdocs, and 139 students, QSA advances national particle physics research by co-designing across institutions.

Two teams of QSA researchers across partner institutions have recently made headway toward understanding more about the framework of the subatomic quantum world with quantum devices.

One collaboration between Berkeley Lab and UC Berkeley, led by researchers Anthony Ciavarella and Christian W. Bauer, examined the dynamics between quarks and gluons, the tiny particles that comprise every atom's core.

Their [published results](#) build on previous studies supported by the QSA. The work is published on the *arXiv* preprint server.

They created a model to understand how these particles were held together (their nuclear force). They also wondered if a quantum computer could help them understand what would happen if quarks and gluons collided and broke into more pairs of particles.

Using a theoretical understanding of these subatomic relationships, researchers built a model that mapped gluons onto a lattice for a quantum computer, marking the first time that anyone in this field has created such a model.

Ciavarella and Bauer's model will allow experimentalists to run simulations and compare these results to their experimental data. It will also help theorists take experimental results and, working backward, create a more robust theoretical underpinning for nuclear models.

"If you want to search for new physics events where you produce Higgs bosons," Ciavarella explains, "what you measure in [a particle accelerator] looks very similar to an event where you just have quarks and gluons radiating."

One day, simulations of Ciavarella and Bauer's model can be used by experimentalists to reduce the size of background noise in their experiments and interpret results more clearly.

Thanks to QSA, Ciavarella and Bauer can soon run their model on a quantum computer. While the researchers worked on their paper, QSA staff helped them connect with researchers at Harvard University and Massachusetts Institute of Technology's Center for Ultracold Atoms. The Harvard group has been building the type of hardware capable of running Ciavarella and Bauer's proposed simulations.

Ciavarella and Bauer are currently working with their colleagues to start running simulations this fall. "Once we can start doing these full simulations," Ciavarella explains, "that should open up a whole new set of experimental observables that we've never really worked with because we've never been able to make predictions for them."

Another multi-institutional QSA team has been investigating how one might use quantum processors to investigate models inspired by quantum chromodynamics (QCD). Using quantum processors to study the theories of the Standard Model in particle physics is a long-term goal of quantum simulation.

While current quantum processors have not yet reached this capability, researchers have begun considering the required steps. Elizabeth Bennewitz, a researcher and graduate student at the University of Maryland, worked with other team members to develop a protocol for understanding the interactions between two mesons composed of tightly bound quarks.

Bennewitz, the lead author of a second article, released as a [preprint](#) on the *arXiv* server, is a DOE Computing Sciences Graduate (CSGF) Fellow and was

formerly a Berkeley Lab intern. As a theorist, Bennewitz is interested in exploring what happens when mesons collide.

However, running her simulations on a classical computer limits the number of interacting particles that theorists can study in a model. She worked with her collaborators to create a protocol that lists the necessary steps to build a model that would simulate the movement of mesons and what happens when those mesons collide.

Their protocol will help experimentalists fill in the gaps as they try to create working models they can implement on quantum devices. Their work showed the types of meson scattering that might show up in a quantum device. By recognizing the byproducts of meson scattering, experimentalists can better interpret their results, distinguishing between irrelevant data (noise) and essential data (signal).

This study represents one step towards using quantum processors as powerful tools to study quantum phenomena in particle physics and potentially extend the standard model of physics.

"Probing physics in these new ways will hopefully lead to discoveries in the physics side of things but can also influence other areas like material sciences and chemistry," said Bennewitz.

Like Ciavarella and Bauer, Bennewitz's team benefited from QSA's support. Bennewitz has been struck by the interdisciplinary nature of QSA's partners and its ability to connect researchers across different areas with relevant collaborators.

"Being able to work really closely with experts in quantum simulation, high-energy and nuclear physics, and experimental quantum devices was one of the reasons this work was possible," said Bennewitz.

Both QSA teams voiced how working with new colleagues helped them consider new dimensions of planning an experiment.

"Something that might be obvious to them when they're just looking at the experiments up in the lab might not be obvious to me because I've never worked directly in the lab on a device myself and vice versa, with how to map problems

on their computers. It's a way to learn a lot about interesting things," said Ciavarella.

The work of these QSA researchers has underscored the importance of quantum simulators as a tool for investigating the almost invisible subatomic world of particle physics.

By bringing together experimentalists and theorists, QSA continues to facilitate research by streamlining the design of quantum devices and engineering solutions. Moreover, QSA provides early career researchers like Ciavarella and Bennewitz with the infrastructure and support to conduct their studies.

"There's a lot of evidence that studying these models on quantum computers and quantum simulators should be more powerful for certain types of problems. With quantum simulations, we can unveil and probe particle physics in ways that we haven't been able to before and hopefully find new physics," said Bennewitz.

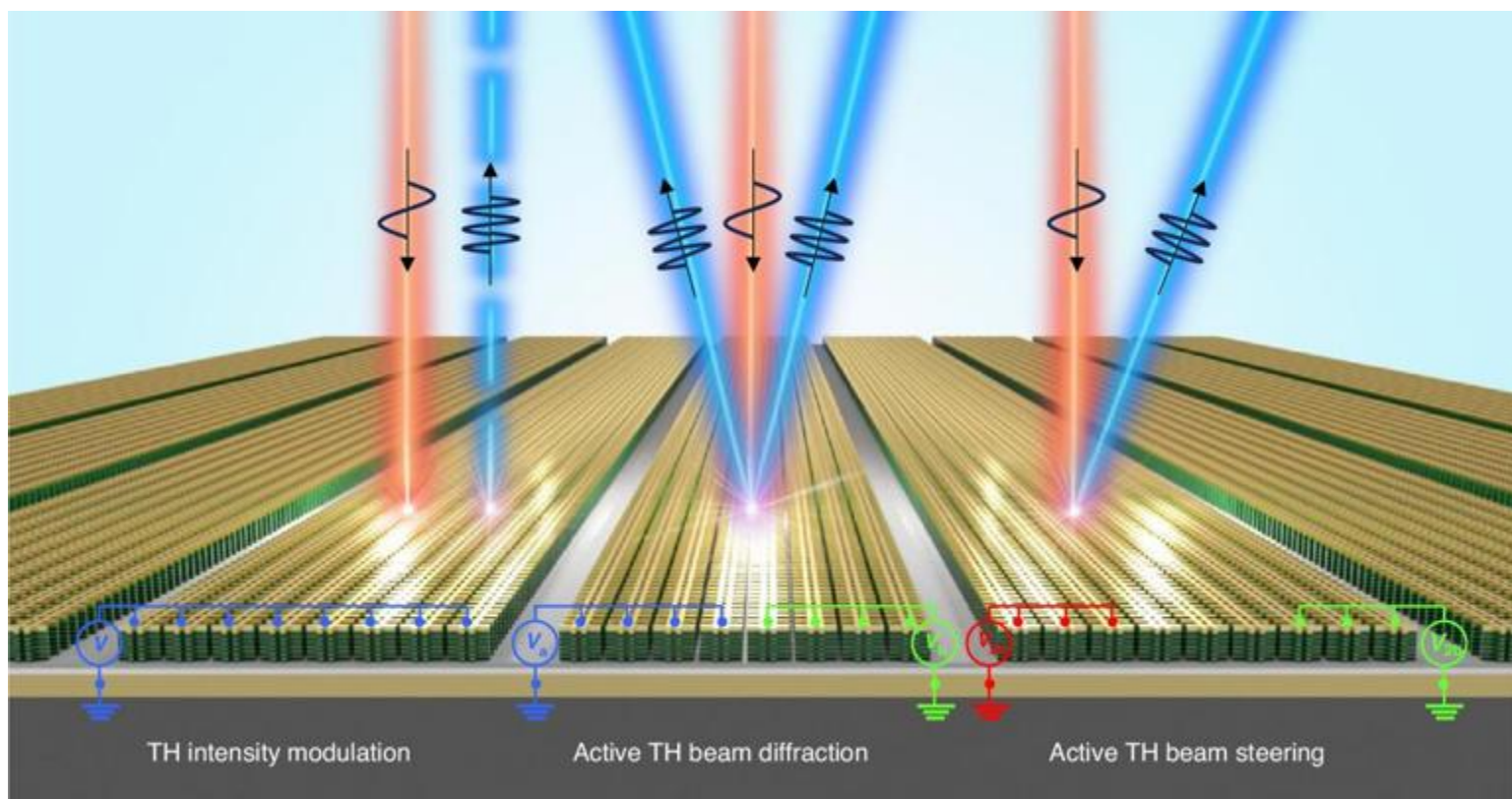
QSA director Bert de Jong believes that, in the coming decade, even more researchers like Bennewitz will embrace quantum computers as an investigative tool.

"We have a high-energy physics team in the QSA team that would like to build better theories to understand the foundational building blocks of the universe," concluded de Jong.

More information: Anthony N. Ciavarella et al, Quantum Simulation of SU(3) Lattice Yang Mills Theory at Leading Order in Large N, *arXiv* (2024). DOI: [10.48550/arxiv.2402.10265](https://doi.org/10.48550/arxiv.2402.10265)

Elizabeth R. Bennewitz et al, Simulating Meson Scattering on Spin Quantum Simulators, *arXiv* (2024). DOI: arxiv.org/abs/2403.07061

Provided by Lawrence Berkeley National Laboratory



Electrically tunable nonlinear polaritonic metasurface for THG. Credit: Light: Science & Applications (2024). DOI: 10.1038/s41377-024-01517-y

A recent study has unveiled a transformative nonlinear optical metasurface technology. This new technology, characterized by structures smaller than the wavelength of light, paves the way for significant advancements in next-generation communication technologies, including quantum light sources and medical diagnostic devices.

The innovative nonlinear optical metasurface created by Professor Lee's team allows for the development of compact and lightweight optical instruments, with laser devices possibly as thin as paper and utilizing materials even thinner than a human hair. While prior methods struggled with electrical control, this new metasurface can be easily modulated, making it a game changer in the field.

Notably, the team has introduced the world's first technology that allows for voltage control of second-harmonic generation (SHG) and achieved independent modulation of the intensity and phase of THG, enabling the metasurface to control not only the wavelength but also the intensity and phase of light.

"This advancement allows for unprecedented control of light," said Professor Lee. "By adjusting the intensity and phase of nonlinear THG through electrical means, we open new avenues for applications in light modulation for cryptography, dynamic holography, next-generation quantum sensors, and quantum communication light sources."

Chinese researchers have reportedly claimed to have successfully breached the encryption algorithms used in banking and crypto using a quantum computer.

Shanghai University researchers led by Wang Chao claimed they used a quantum computer produced by Canada's D-Wave Systems to breach the algorithms through quantum annealing, which involves searching for the lowest energy state, the South China Morning Post (SCMP) [reported](#) on Oct. 11.

They noted that further developments could yield more robust quantum attacks in the future and reveal potential new vulnerabilities in existing cryptographic systems.

The findings were recorded in a peer-reviewed paper published on Sept. 30 in the academic journal, the China Computer Federation (CCF) Chinese Journal of Computers.

Related: [What 'far-fetched' scenarios could still send Bitcoin price to \\$0?](#)

Ethereum co-founder Vitalik Buterin has [already proposed a way to mitigate](#) the risk of quantum computing in the future, explaining in a March X post that a simple hard fork could subvert the issue.

Buterin says the blockchain would have to hard fork and users would have to download new [wallet software](#), but few would lose their funds.

He also thinks the infrastructure needed to implement the hard fork on the Ethereum blockchain could, in theory, “start to be built tomorrow.”

Qunova Computing, a Daejeon, South Korea-based quantum computing firm, is the first to have achieved ‘chemical accuracy’ on a commercial quantum computing device using its platform-agnostic algorithm.

‘Chemical accuracy’ is the threshold of 1.6 millihartrees below, which results from quantum computing platforms that must remain considered solutions for real-world chemistry applications.

Achieving ‘Chemical Accuracy’

At the Quantum Korea 2024 Event, Qunova demonstrated chemical accuracy on a series of quantum computers, irrespective of their platform technology.

In the first demonstration, Qunova used an IQM 20-qubit machine and demonstrated its algorithm by producing energy estimations of three different geometries of Lithium Sulfide (Li₂S) live at the event.

Before this, Qunova achieved an accuracy of 0.1 millihartrees using IBM’s Quantum Eagle processor, which uses 24 qubits. The company also achieved similar accuracy using the IBEX Q1 quantum computer, which uses 20 qubits and is built by Alpine Quantum Technologies (AQT), based in the European Union.

IQM and [IBM](#) use transmon superconducting architecture, while AQT uses trapped ions for its quantum computing platform. This also demonstrates that Qunova’s algorithm is platform agnostic.

“Quantum algorithms are platform agnostic if the algorithm performance is subject to quantum noise which can be unique for certain platforms. HiVQE is designed not to use the information associated with quantum noise,” explained Rhee in the email.



Kevin Rhee, CEO and Founder of Qunova Computing, speaks with attendees at Quantum Korea in Seoul. Image credit: Qunova Computing

How does Qunova's algorithm work?

Simulations used on conventional computers use Variational Quantum Eigensolvers (VQEs) to carry out complex computations. However, this approach could be more scalable and achieve chemical accuracy on quantum computers.

Qunova's innovation lies in using a simplified version of VQE, which it refers to as Handover Iteration VQE or HiQVE.

"An analogy to explain this is like our algorithm takes information of what happened only, ignoring how many times it happened," added Rhee in the email to IE. "The quantum noise often alters the information of how many times it happened, so Qunova is using only information that is unaltered."

Its approach focused on not carrying over errors from [quantum computations](#) and excluded “Pauli word measurements,” usually used to measure the spin of qubits along different axes.

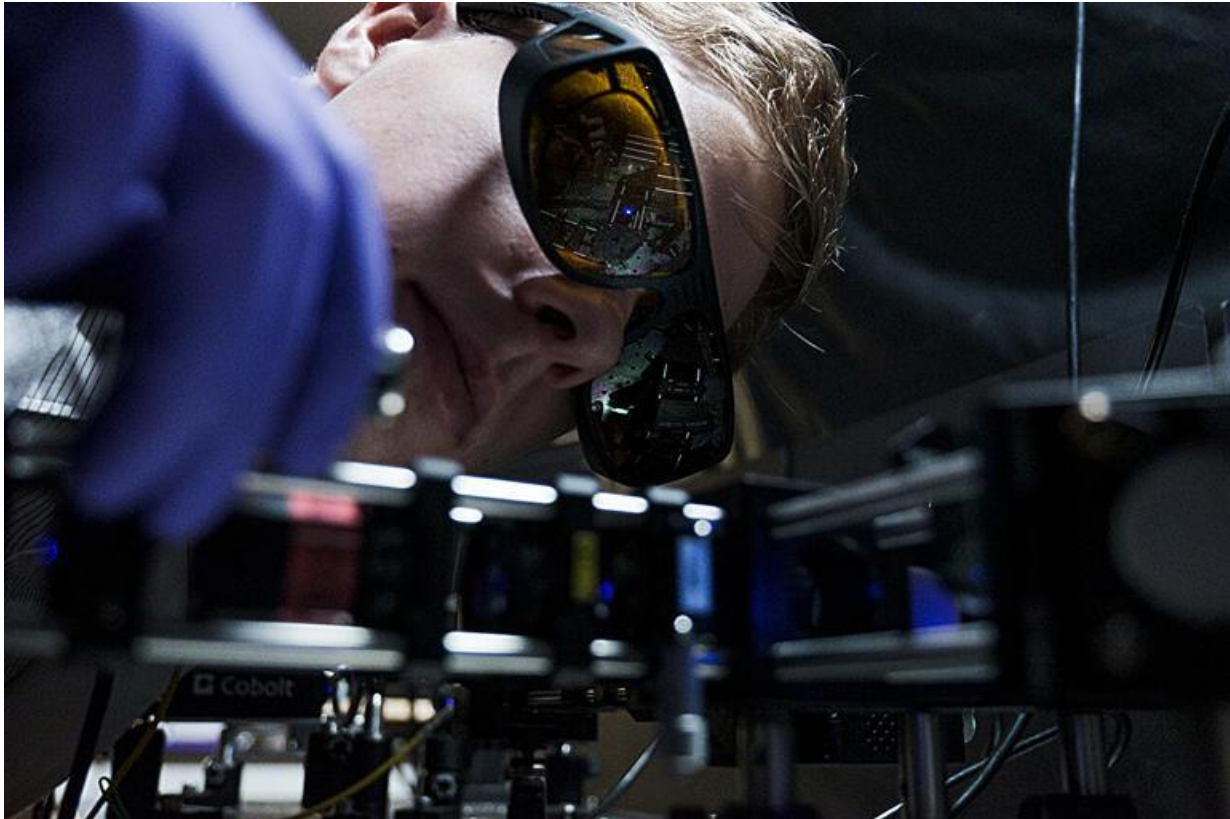
This allowed the team only to extract essential data related to the orbitals of each qubit, which were then fed into a classic computer to calculate the result quickly and with a higher level of accuracy.

Overall, the computations also ran 1,000x more efficiently. “This is a very exciting result for our team, and indeed for the quantum computing community more broadly,” said Rhee in a [press release](#).

“These results show that we can meet the requirements of industrial users on existing NISQ machines. We anticipate that running a similar demonstration on a NISQ machine with as few as 40-qubits could provide industrial users with a real quantum advantage.”

The team will spend the next few months demonstrating this.

Quantum computing and photonics discovery potentially shrinks critical parts by 1,000 times



PhD student Leevi Kallioniemi from NTU Singapore's School of Physical & Mathematical Sciences with a blue laser set-up for generating entangled photon pairs. Credit: NTU Singapore

Researchers have made a discovery that could make quantum computing more compact, potentially shrinking essential components 1,000 times while also requiring less equipment. The research is published in *Nature Photonics*.

A class of quantum computers being developed now relies on light particles, or photons, created in pairs linked or "entangled" in quantum physics parlance. One way to produce these photons is to shine a laser on millimeter-thick crystals and use optical equipment to ensure the photons become linked. A drawback to this approach is that it is too big to integrate into a computer chip.

Now, Nanyang Technological University, Singapore (NTU Singapore) scientists have found a way to address this approach's problem by producing linked pairs of photons using much thinner materials that are just 1.2 micrometers thick, or

about 80 times thinner than a strand of hair. And they did so without needing additional optical gear to maintain the link between the photon pairs, making the overall set-up simpler.

"Our novel method to create entangled photon pairs paves the way for making quantum optical entanglement sources much smaller, which will be critical for applications in quantum information and photonic quantum computing," said NTU's Prof Gao Weibo, who led the researchers.

He added that the method could scale down the size of devices for quantum applications because many of these devices currently need large and bulky optical equipment, which are cumbersome to align, before they can work.

Thinner materials

Quantum computers are expected to revolutionize the approach to many challenges, from helping us better understand climate change to finding new drugs faster by completing complex computations and quickly finding patterns in large data sets. For instance, calculations that would take supercomputers today millions of years to resolve could be done within minutes by quantum computers.

This is expected to happen because quantum computers perform many computations simultaneously instead of doing them one at a time like standard computers.

Quantum computers can do so as they perform calculations using tiny switches called quantum bits, or qubits, that can be in both the on and off position simultaneously. It is akin to flipping a coin in the air, with the spinning coin in a state between heads and tails. In contrast, standard computers use switches that can be on or off at any time, but not both.

Photons can be used as qubits for quantum computers to perform faster calculations as they can have on and off states at the same time. But being in two states simultaneously only happens if the photons are produced in a pair, with one photon linked, or entangled, to the other. An important condition for entanglement is that the paired photons need to vibrate in sync.

One advantage of using photons as qubits is that they can be produced and entangled at room temperature. Relying on photons can thus be easier, cheaper and more practical than using other particles like electrons that need ultra-low temperatures close to the coldness of outer space before they can be used for quantum computing.

Researchers have been trying to find thinner materials to produce linked pairs of photons so that they can be worked into computer chips. However, one challenge is that when materials get thinner, they produce photons at a much lower rate, which is impractical for computing.

Recent advances showed that a promising new crystalline material called niobium oxide dichloride, which has unique optical and electronic properties, can produce pairs of photons efficiently despite its thinness. But these photon pairs are useless for quantum computers because they are not entangled when produced.

A solution was found by NTU scientists led by Prof Gao, from the University's School of Electrical & Electronic Engineering and School of Physical & Mathematical Sciences, in collaboration with Prof Liu Zheng from the School of Materials Science & Engineering.

Sparked by tradition

Prof Gao's solution was inspired by an established method to create entangled pairs of photons with thicker and bulkier crystalline materials, which was published in 1999. It involves stacking two flakes of thick crystals together and positioning the crystalline grains of each flake perpendicularly to each other.

However, the vibrations of photons produced in a pair can still be out of sync due to how they travel within the thick crystals after they are created. Additional optical equipment is therefore needed to synchronize the photon pairs to maintain the link between the light particles.

Prof Gao theorized that a similar two-crystal set-up could be used with two thin crystal flakes of niobium oxide dichloride, with a combined thickness of 1.2 micrometers, to produce the linked photons without requiring extra optical instruments.

He expected this to happen because the flakes used are much thinner than the bulkier crystals from earlier studies. As a result, the pairs of photons produced travel a smaller distance within the niobium oxide dichloride flakes, so the light particles remain in sync with each other. Experiments by the NTU Singapore team proved that his hunch was correct.

Prof Sun Zhipei from Finland's Aalto University, who specializes in photonics and was not involved in NTU's research, said that entangled photons are like synchronized clocks that show the same time no matter how far apart they are and can thus enable instant communication.

He added the NTU team's method to generate quantum entangled photons "is a major advancement, potentially enabling the miniaturization and integration of quantum technologies."

"This development has potential in advancing quantum computing and secure communication, as it allows for more compact, scalable and efficient quantum systems," said Prof Sun, a co-principal investigator at the Research Council of Finland's Center of Excellence in Quantum Technology.

The NTU team plans to further optimize the design of their set-up to generate even more linked pairs of photons than possible now.

Some ideas include exploring whether introducing tiny patterns and grooves on the surface of niobium oxide dichloride flakes can increase the number of photon pairs produced. Another one will examine whether stacking the niobium oxide dichloride flakes with other materials can boost photon production.

More information: Van der Waals engineering for quantum-entangled photon generation, *Nature Photonics* (2024) DOI: [10.1038/s41566-024-01545-5](https://doi.org/10.1038/s41566-024-01545-5)

Provided by Nanyang Technological University

Study explores the physical origin of errors in a spin qubit processor

To achieve remarkable performances, quantum computing systems based on multiple qubits must attain high-fidelity entanglement between their underlying qubits. Past studies have shown that solid-state quantum platforms—quantum

computing systems based on solid materials—are highly prone to errors, which can adversely impact the coherence between qubits and their overall performance.

Researchers at Diraq, a Sydney-based quantum hardware technology company, and UNSW recently set out to investigate the errors emerging in a spin qubit processor composed of high-fidelity two-qubit gates in silicon quantum dots.

Their findings, [published](#) in *Nature Physics*, provide new insight into the possibilities and challenges associated with the up-scaling of silicon spin-based qubits.

"The 21st century has revolved around computerization thanks to the semiconducting silicon chip," Andrew Dzurak and Tuomo Tantt, co-authors of the paper, told Phys.org.

"The humble silicon chip is critical to the digitalization and interconnectivity of our daily lives—from the phones we use, the computers we rely on and the systems we operate for accessing information, sharing data, and effectively managing the infrastructure and decision-making tools needed for interconnected modern thriving economies.

"This demand has underpinned the growth of the complementary metal-oxide semiconductor (CMOS) manufacturing industry."

In recent years, some engineers and quantum physicists have been exploring the possibility of developing quantum technologies using well-established silicon-based transistors. This is because the processes for manufacturing these transistors are well-established and highly controlled.

"State-of-the-art fabrication processes are central to the Diraq vision of building the world's first fault tolerant quantum computer based on silicon quantum dots," said Dzurak, CEO and Founder of Diraq. "Our foundational IP is in the design and operation of silicon spin qubits compatible with CMOS foundry manufacturing."

Dzurak, Tantt and their colleagues at Diraq have been exploring ways to leverage lithographic techniques used to manufacture silicon transistors to fabricate quantum technologies. The researchers have recently been specifically

exploring the potential of advanced techniques for encoding qubits in semiconductor spin carriers that could be manufactured and integrated on a large scale.

"Quantum computation requires many qubits that can be coherently controlled and coupled to each other," said Dzurak. "We set ourselves the challenge to understand whether it is possible to execute high-fidelity (above 99%) entangling gates between qubits in the same silicon platform that is used for silicon transistors. The research expanded to also understand what noise sources degrade the fidelity of the entangling gate."

By exploring the physical origin of errors in silicon-based quantum processors, Dzurak, Tanttú and their colleagues plan to contribute to the development of quantum computers built on widely available materials. As part of their study, they used three key diagnostic techniques to benchmark and characterize quantum states and logic gates in a silicon-based spin qubit device.

"We wanted a comprehensive methodology, so we chose three different robust techniques to support our investigation into the control and measurement of sustained performance," explained Tanttú. "The three measurement techniques we used are Interleaved Randomized Benchmarking (IRB), Gate Set Tomography (GST) and Fast Bayesian Tomography (FBT)."

All of the techniques employed by the researchers entail running a set of specific logical circuits in a quantum processor. By applying them to their processor, they gathered information about the physics underlying its functioning and thus any errors produced.

"These diagnostic tools are essential to the development of quantum devices as they are critical to improving system reliability and quantum logic operations, also known as logic gates," said Tanttú.

"For example, with GST, the findings inform how to prevent errors instead of correcting them. Both tomography methods yielded a detailed picture on the noise channels. In contrast, the more traditional IRB method yielded a single fidelity number with no additional physical information."

Dzurak, Tanttú and colleagues also identified a promising method for extracting rich information from data connected using IRB. Specifically, they reanalyzed the IRB data by running an FBT analysis on the exact same dataset.

"This yielded information on the noise channels and how they evolved over time," explained Tanttú. "In summary, the combination of these different techniques allowed us to build a more complete physical picture of our system and enabled us to better benchmark the performance of our qubit."

The tests carried out by this research team led to two important findings. First, they demonstrated the possibility of attaining high operational fidelities of above 99% for the entangling gates in their platform.

Second, they were able to identify sources of noise in their entangling gates. This in turn allowed them to devise strategies to improve the fidelity of their gates.

"Our results do imply the viability of using the silicon transistor technology as the core building block for making future utility-scale quantum computers," said Dzurak. "In practice, this also means that we can focus more on scaling up the platform."

The team at Diraq is now working on further improving and testing their spin qubit processor. For instance, they are planning to repeat their experiment beyond the university laboratory devices, using spin processors manufactured in a semiconductor foundry.

"Additionally, we think there is strong merit in exploring whether the understanding of the underlying errors can be utilized to further improve the fidelity of the operation with enhanced materials or different control methods," added Dzurak.

"With our operational fidelities in close alignment to other solid-state platforms, what we are looking forward to now are further advances, in particular by increasing the number of qubits in a single chip."

More information: Tuomo Tanttú et al, Assessment of the errors of high-fidelity two-qubit gates in silicon quantum dots, *Nature Physics* (2024). DOI: [10.1038/s41567-024-02614-w](https://doi.org/10.1038/s41567-024-02614-w)

Enhanced wavelength conversion paves the way for more efficient quantum information transfer

Advancements in quantum information technology are paving the way for faster and more efficient data transfer. A key challenge has been ensuring that qubits, the fundamental units of quantum information, can be transferred between different wavelengths without losing their essential properties, such as coherence and entanglement.

As [reported](#) in *Advanced Photonics*, researchers from Shanghai Jiao Tong University (SJTU) recently made significant strides in this area by developing a novel method for broadband frequency conversion, a crucial step for future quantum networks.

The SJTU team focused on a technique using X-cut thin film lithium niobate (TFLN), a material known for its nonlinear optical properties. They achieved broadband second-harmonic generation—an important process for converting light from one wavelength to another—with a remarkable bandwidth of up to 13 nanometers. This was accomplished through a process called mode hybridization, which allows for precise control over the frequency conversion in a micro-racetrack resonator.

According to corresponding author Professor Yuping Chen, "An efficient second-order nonlinear process with widely-tunable pump bandwidth has been a long-pursued goal, owing to the extensive applications in wavelength division multiplexing networks, ultrashort pulse nonlinearity, quantum key distribution, and broadband single-photon source generation.

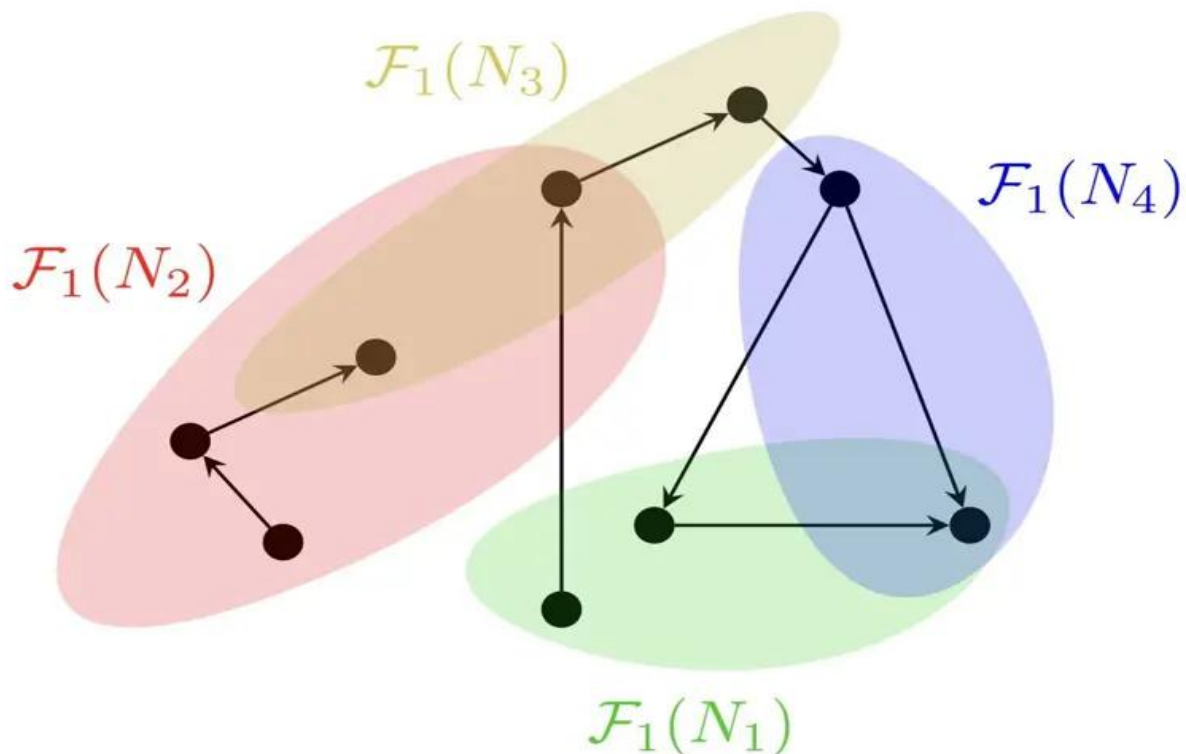
"Thanks to the great progress in fabrication technology on the TFLN platform, this work will pave the way to chip-scale nonlinear frequency conversion between the ultrashort optical pulses and even the quantum states."

This breakthrough could have wide-ranging implications for integrated photonic systems. By enabling on-chip tunable frequency conversion, it opens the door to enhanced quantum light sources, larger capacity multiplexing, and more effective multichannel optical information processing. As researchers continue to explore these technologies, the potential for expanding quantum information networks grows, bringing us closer to realizing their full capabilities in various applications.

More information: Tingge Yuan et al, Chip-scale nonlinear bandwidth enhancement via birefringent mode hybridization, *Advanced Photonics* (2024). DOI: [10.1117/1.AP.6.5.056012](https://doi.org/10.1117/1.AP.6.5.056012)

Provided by SPIE

New theoretical framework sets limits for the realization of quantum processes in spacetime



Bell's theorem, the well-known theoretical framework introduced by John Bell decades ago, delineates the limits of classical physical processes arising from

relativistic causality principles. These are principles rooted in Einstein's theory of relativity, which dictate how cause and effect operate in the universe. Researchers at Inria, Université Grenoble Alpes and ETH Zurich recently set out to investigate whether similar types of limits also apply to quantum processes. Their paper, [published](#) in *Physical Review Letters* (PRL), introduces new theorems that outline fundamental limits that could constrain the realization of quantum experiments in classical background spacetimes.

"Causality is central to how we make sense of the world, but it takes on different forms within two of our key physical theories: quantum theory and general relativity," V. Vilasini, co-author of the paper, told Phys.org.

"In quantum theory, causality concerns how information flows between systems and operations, while in general relativity, it's tied to the structure of spacetime itself. Surprisingly, quantum theory permits processes with '[indefinite causal order](#)' (ICO) where the sequence of events can exist in a superposition."

To understand whether ICO processes, quantum processes in which a causal relationship between sequential events does not exist, can physically occur, researchers first need to connect these processes to the well-established relativistic notion of causality in spacetime. This was the primary motivation behind the recent paper by Vilasini and her colleague Renato Renner.

"We developed a theoretical framework that links the two concepts of causality in a clear and consistent way, aiming to use minimal physical assumptions," said Vilasini. "This allowed us to derive general no-go theorems for any quantum experiment performed in classical spacetime."

"Interestingly, several sophisticated experiments have already been performed, that suggest an ICO process, [the 'quantum switch'](#) in Minkowski spacetime. The physical interpretation of these experiments has been a subject of longstanding discussions."

"Our framework and no-go results apply to these experiments as well, and yield a new fine-grained perspective on their interpretation, and how quantum and relativistic causality can be reconciled in these experiments."

Along with their recent paper in *PRL*, Vilasini and Renner [published](#) a longer manuscript in *Physical Review A*. In this longer paper, they outline their formalism in greater detail, including additional results they collected.

"Our *PRL* paper introduces two no-go theorems that outline fundamental limits on spacetime configurations and possible causal explanations for quantum experiments in classical spacetimes, which respect relativistic causality (implying no faster-than-light signaling)," explained Vilasini.

The first theorem presented by the researchers essentially shows that any experiment aimed at successfully realizing ICO processes in classical spacetime would require that input and output agent systems be non-localized or "spread out" in spacetime.

Their second theorem, on the other hand, theoretically demonstrates that even if an ICO process is realized under the conditions outlined by the first theorem, "zooming in" at a finer level would unveil a well-defined and acyclic causal order.

"To give an analogy: imagine a situation where the demand and price of a commodity seem to influence each other in a loop," said Vilasini. "Upon closer inspection, we would realize that the demand at one time influences the price at a later time, which then affects demand at an even later time, and so on.

"Similarly, in quantum experiments in classical spacetimes, while ICO might appear at a 'coarse' level, a closer examination would reveal a quantum process with a definite information-theoretic causal order that fits within spacetime causality."

Typically, experimental physics research builds on previously introduced theories and are aimed at testing their predictions. In contrast, the aforementioned quantum switch experiments were already performed years ago, and have fueled the search for better theoretical frameworks to fully interpret and understand them.

"Despite our no-go results, the ICO experiments already performed remain fascinating," said Vilasini. "Even though these experiments can unravel into a definite causal order, there's hope that they involve a distinct quantum resource not present in classical scenarios, where spatial and temporal degrees of freedom both play a role."

The recent papers by this team of researchers propose a unified framework that could be used to relate different notions of causality across quantum and relativistic theories, potentially enabling a reconciliation between these distinct physical theories.

Vilasini and Renner hope that their theoretical framework will foster new causality-focused interdisciplinary collaborations between physicists specialized in the study of quantum mechanics and general relativity.

"The idea of fine-graining causal structures introduced in our work is versatile—it can be applied whether or not there is a classical background spacetime—this could offer new techniques for exploring the physical realization of quantum processes in more exotic scenarios, such as when quantum clocks or rods are involved, or in quantum gravitational regimes where spacetime geometry is subject to quantum uncertainty," said Vilasini.

In their next studies, Vilasini and her collaborators plan to continue building on their framework. First, they hope to tackle the open question of which classes of ICO processes can be physically realized in spacetime.

"In a [follow-up project with Matthias Salzger](#) (now based at the International Center for Theory of Quantum Technologies, Gdansk), we have extended our framework to provide a characterization of these processes, suggesting that more counter-intuitive ICO processes, such as those violating causal inequalities, cannot be faithfully realized in classical spacetimes," said Vilasini.

"In our next studies, it would be intriguing to investigate whether our no-go theorems still hold in these new (possibly quantum gravitational) regimes, and to determine whether a broader class of ICO processes can be realized there. For instance, is there a way to operationally certify the non-classicality of spacetime geometry, similar to how violations of Bell inequalities certify non-classicality in correlations?

"Even more fundamentally, is there a way to understand how spacetime or familiar aspects of it may emerge from basic properties of quantum information-theoretic causal structures?"

In the future, Vilasini also plans to investigate the possible applications of her framework with Renner, for realizing information processing within a fixed

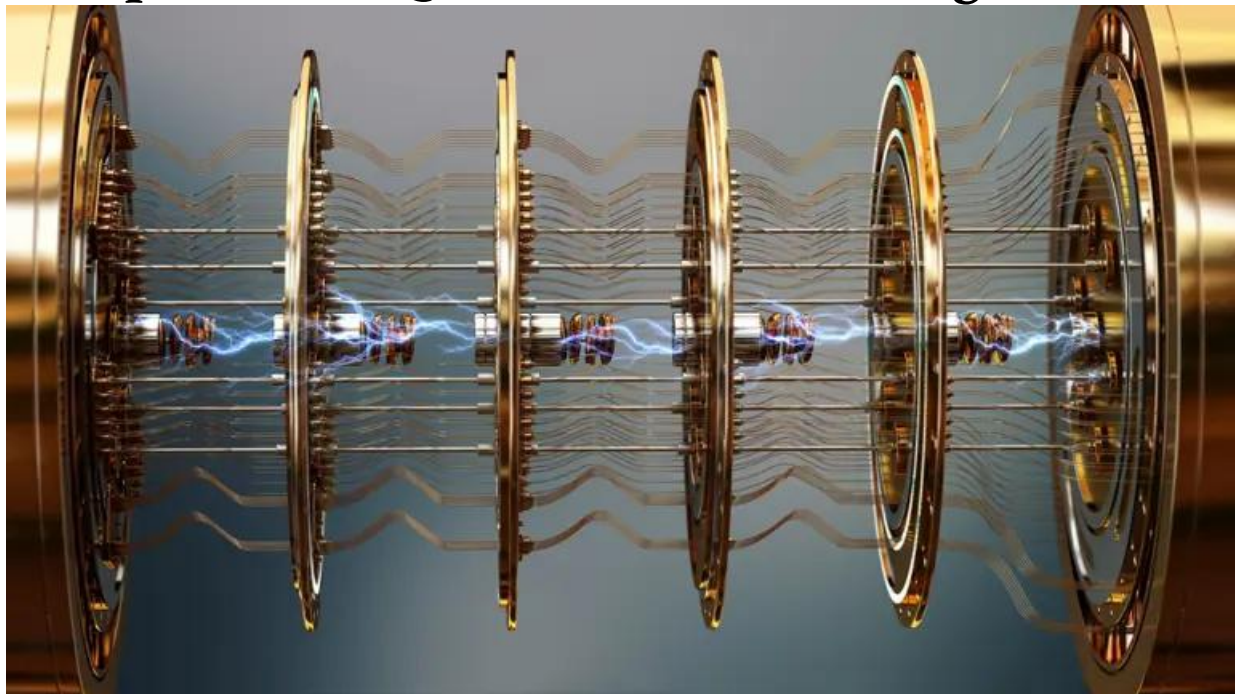
spacetime. In other words, she would like to determine if the "quantumness" in the localization of systems could be leveraged to realize or enhance quantum communication, computation and cryptography.

More information: V. Vilasini et al, Fundamental Limits for Realizing Quantum Processes in Spacetime, *Physical Review Letters* (2024). DOI: [10.1103/PhysRevLett.133.080201](https://doi.org/10.1103/PhysRevLett.133.080201). On arXiv: arxiv.org/html/2408.13387v1

V. Vilasini et al, Embedding cyclic information-theoretic structures in acyclic space-times: No-go results for indefinite causality, *Physical Review A* (2024). DOI: [10.1103/PhysRevA.110.022227](https://doi.org/10.1103/PhysRevA.110.022227)

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Superconducting qubit ditches magnetic field for speed in a Quantum breakthrough



Japanese researchers have developed the world's first superconducting flux qubit that functions in a zero magnetic field.

Conventional superconducting flux qubits need external magnetic fields from large coils or flux lines. The new qubit, using a ferromagnetic Josephson junction (π -junction), works without a magnetic field.

A team led by researchers from Japan's National Institute of Information and Communications Technology (NICT) and Tohoku University claims the new π -junction qubit has the longest lifetime among its type, and future improvements could make it key to high-performance quantum computers.

"Our results pave the way for developing quantum coherent devices, including qubits and sensors, that utilize the interplay between ferromagnetism and superconductivity," said the team, in the study [abstract](#).

Magnetic-free qubit

Quantum computers are expected to play a key role in future technology, benefiting fields like material science, pharmaceuticals, and information security. Superconducting qubits stand out due to their easier control of quantum states. A crucial part of these qubits is the Josephson junction, which helps control qubit operations.

Due to their low anharmonicity, transmon qubits—which are frequently seen in modern quantum computers—can result in problems like frequency crowding when numerous qubits are added.

Flux qubits, which employ three Josephson junctions and have higher anharmonicity, can lessen this problem. However, flux qubits are difficult to scale up because they require external coils to deliver a magnetic flux to the circuit, which can result in issues like noise and the requirement for additional control lines.

To address this, Tohoku University researchers used a ferromagnetic Josephson junction to create a π -junction. Without requiring external magnetic forces, this π -junction produces a 180-degree phase shift, enabling the qubit to function at its best independently.

According to the team, the innovation reduces noise, simplifies the circuit, and makes qubit integration easier. fields, reducing noise and enabling easier large-scale integration.

Enhanced qubit coherence

In the study, researchers combined NICT's nitride superconducting qubit technology, based on niobium nitride (NbN) grown on [silicon](#), with ferromagnetic Josephson devices to create a flux qubit with a π -junction.

The team claims the qubit operates optimally without an external magnetic field, and its coherence properties were successfully demonstrated. Unlike earlier studies, which did not achieve quantum coherent operation with a flux qubit, this new qubit showed a significant improvement.

The scientists improved on earlier experiments using CuNi by using a stable material, PdNi, to generate the π -junction. A device that verified an ideal working point at zero magnetic fields was used to measure the qubit, which was created using sophisticated design procedures. Its coherence time was 1.45 microseconds, 360 times better than that of earlier phase qubits.

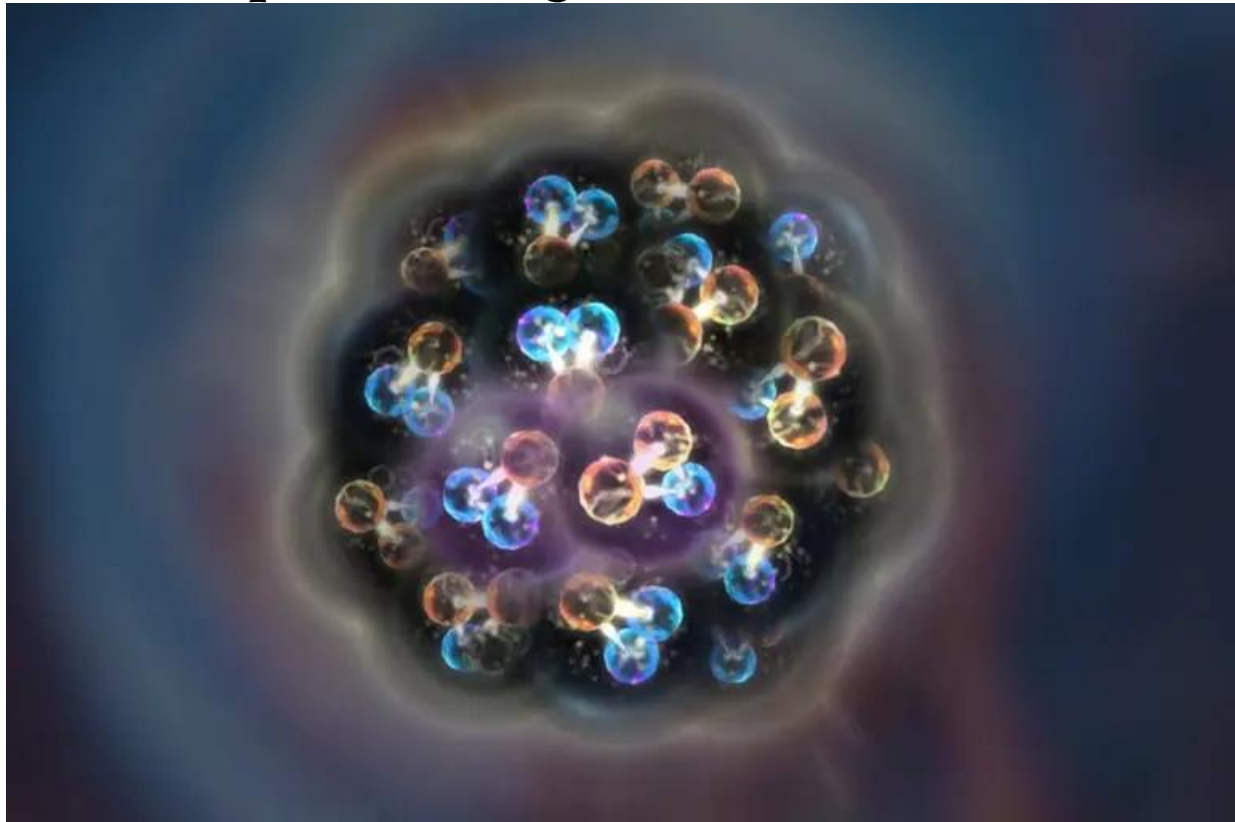
According to researchers, while the coherence time is still shorter than conventional flux qubits without a π -junction, this breakthrough is a critical step toward simplifying and integrating quantum circuits. It could lead to more energy-efficient, cost-effective [quantum technologies](#) by removing the need for external magnetic fields.

With an eye toward large-scale integration, the team now intends to improve device uniformity and prolong coherence time by optimizing the circuit topology and fabrication method. Their goal is to create a new quantum hardware platform that performs better than traditional aluminum qubits.

Researchers hope to develop a π -junction flux [qubit](#) with a longer coherence time that can function in zero magnetic fields by enhancing materials and the ferromagnetic junction structure. This qubit could be a crucial part of future quantum technologies, such as quantum computer chips.

The details of the team's [research](#) were published in the journal *Communications Materials*.

First coherent picture of an atomic nucleus made of quarks and gluons



The atomic nucleus is made up of protons and neutrons, particles that exist through the interaction of quarks bonded by gluons. It would seem, therefore, that it should not be difficult to reproduce all the properties of atomic nuclei hitherto observed in nuclear experiments using only quarks and gluons. However, it is only now that physicists, including those from the Institute of Nuclear Physics of the Polish Academy of Sciences in Cracow, have succeeded in doing this. It's been almost a century since the discovery of the main components of atomic nuclei: protons and neutrons. Initially, the new particles were considered indivisible. In the 1960s, however, there was a suggestion that, at sufficiently high energies, protons and neutrons would reveal their internal structure—the presence of quarks constantly held together by gluons.

Soon afterwards, the existence of quarks was confirmed experimentally. It may therefore seem surprising that, despite the passage of many decades, no one has been able to reproduce with quark-gluon models the results of nuclear experiments at low energies when only protons and neutrons are visible in atomic nuclei.

This long-standing deadlock has only now been broken, in a paper [published](#) in *Physical Review Letters*. Its main authors are scientists from the international nCTEQ collaboration on quark-gluon distributions, including those from the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Cracow.

"Until now, there have been two parallel descriptions of atomic nuclei, one based on protons and neutrons which we can see at low energies, and another, for high energies, based on quarks and gluons. In our work, we have managed to bring these two so far separated worlds together," says Dr. Aleksander Kusina, one of the three theoreticians from IFJ PAN participating in the research.

Humans see their surroundings because they use innate detectors (eyes) to register scattered photons that have previously interacted with the atoms and molecules that make up the objects of our environment. Physicists gain knowledge of atomic nuclei in a similar way: they collide them with smaller particles and meticulously analyze the results of the collisions.

For practical reasons, however, they use not electrically neutral photons, but elementary particles carrying a charge, usually electrons. Experiments then show that when electrons have relatively low energies, atomic nuclei behave as if they were made of nucleons (i.e. protons and neutrons), whereas at high energies, partons (i.e. quarks and gluons) are "visible" inside the atomic nuclei.

The results of colliding atomic nuclei with electrons have been reproduced quite well using models assuming the existence of nucleons alone to describe low-energy collisions, and partons alone for high-energy collisions. However, so far these two descriptions have not been able to be combined into a coherent picture.

In their work, physicists from the IFJ PAN used data on high-energy collisions, including those collected at the LHC accelerator at CERN laboratory in Geneva.

The main objective was to study the partonic structure of atomic nuclei at high energies, currently described by parton distribution functions (PDFs).

These functions are used to map how quarks and gluons are distributed inside protons and neutrons and throughout the atomic nucleus. With PDF functions for the atomic nucleus, it is possible to determine experimentally measurable parameters, such as the probability of a specific particle being created in an electron or proton collision with the nucleus.

From the theoretical point of view, the essence of the innovation proposed in this paper was the skillful extension of parton distribution functions, inspired by those nuclear models used to describe low-energy collisions, where protons and neutrons were assumed to combine into strongly interacting pairs of nucleons: proton-neutron, proton-proton and neutron-neutron.

The novel approach allowed the researchers to determine, for the 18 atomic nuclei studied, parton distribution functions in atomic nuclei, parton distributions in correlated nucleon pairs and even the numbers of such correlated pairs.

The results confirmed the observation known from low-energy experiments that most correlated pairs are proton-neutron pairs (this result is particularly interesting for heavy nuclei, e.g. gold or lead). Another advantage of the approach proposed in this paper is that it provides a better description of the experimental data than the traditional methods used to determine parton distributions in atomic nuclei.

"In our model, we made improvements to simulate the phenomenon of pairing of certain nucleons. This is because we recognized that this effect could also be relevant at the parton level. Interestingly, this allowed for a conceptual simplification of the theoretical description, which should in future enable us to study parton distributions for individual atomic nuclei more precisely," explains Dr. Kusina.

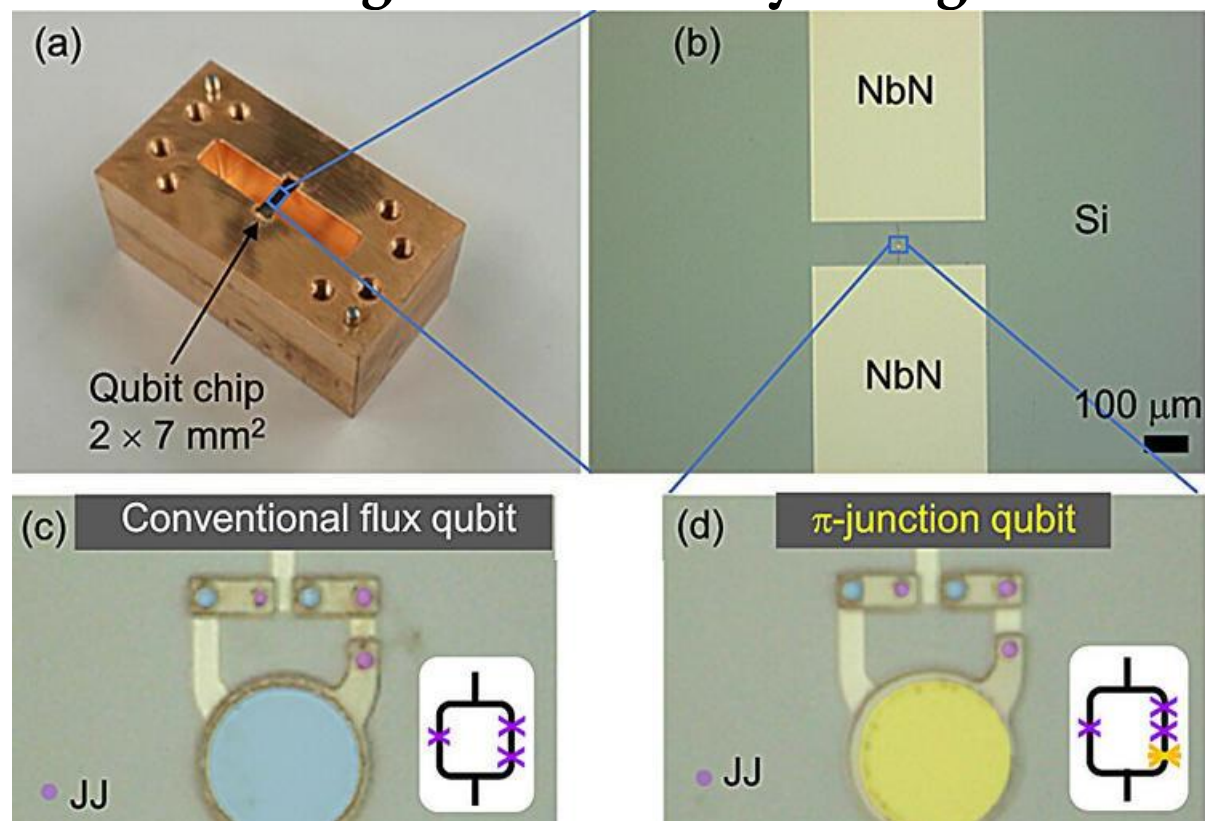
The agreement between theoretical predictions and experimental data means that, using the parton model and data from the high-energy region, it has been possible for the first time to reproduce the behavior of atomic nuclei so far explained solely by nucleonic description and data from low-energy collisions. The results of the described studies open up new perspectives for a better

understanding of the structure of the atomic nucleus, unifying its high- and low-energy aspects.

More information: A. W. Denniston et al, Modification of Quark-Gluon Distributions in Nuclei by Correlated Nucleon Pairs, *Physical Review Letters* (2024). DOI: [10.1103/PhysRevLett.133.152502](https://doi.org/10.1103/PhysRevLett.133.152502)

Provided by Polish Academy of Sciences

Novel superconducting flux qubit can operate without being surrounded by a magnetic field



NbN-based flux qubits and 3D cavity. Credit: Communications Materials (2024). DOI: 10.1038/s43246-024-00659-1

A team of computer engineers from the National Institute of Information and Communications Technology, NTT Corporation and Nagoya University have

developed what they claim is the world's first superconducting flux qubit that can operate without the need for a surrounding magnetic field.

In their paper [published](#) in the journal *Communications Materials*, the group describes how they used a ferromagnetic Josephson junction to create the flux qubit and how well it performed.

A flux qubit is made using an extremely tiny loop made of a superconductor that allows electrical current to flow either clockwise or counterclockwise, or in a quantum superposition of both directions. Such qubits are used in quantum computer designs via nonlinear inductance of a Josephson junction. Until now, all such flux qubits could only be run when enveloped in a magnetic field.

In this new effort, the research team introduced the use of a ferromagnetic Josephson junction (π -junction) when creating their flux qubit—a move, the team claims, that allows the flux qubit to operate independently. They also claim it allows for the longest lifetime yet for flux qubits. Together, they suggest the improvements could lead to the development of a truly high-performance quantum computer.

Flux qubits were developed after transmon qubits proved problematic due to frequency crowding, resulting in low anharmonicity. Using Josephson junctions resulted in higher anharmonicity but has also been difficult to scale to a usable size because of the big coils needed to induce the magnetic field. The coils also tend to make noise, which has to be muted to prevent introducing errors into the system.

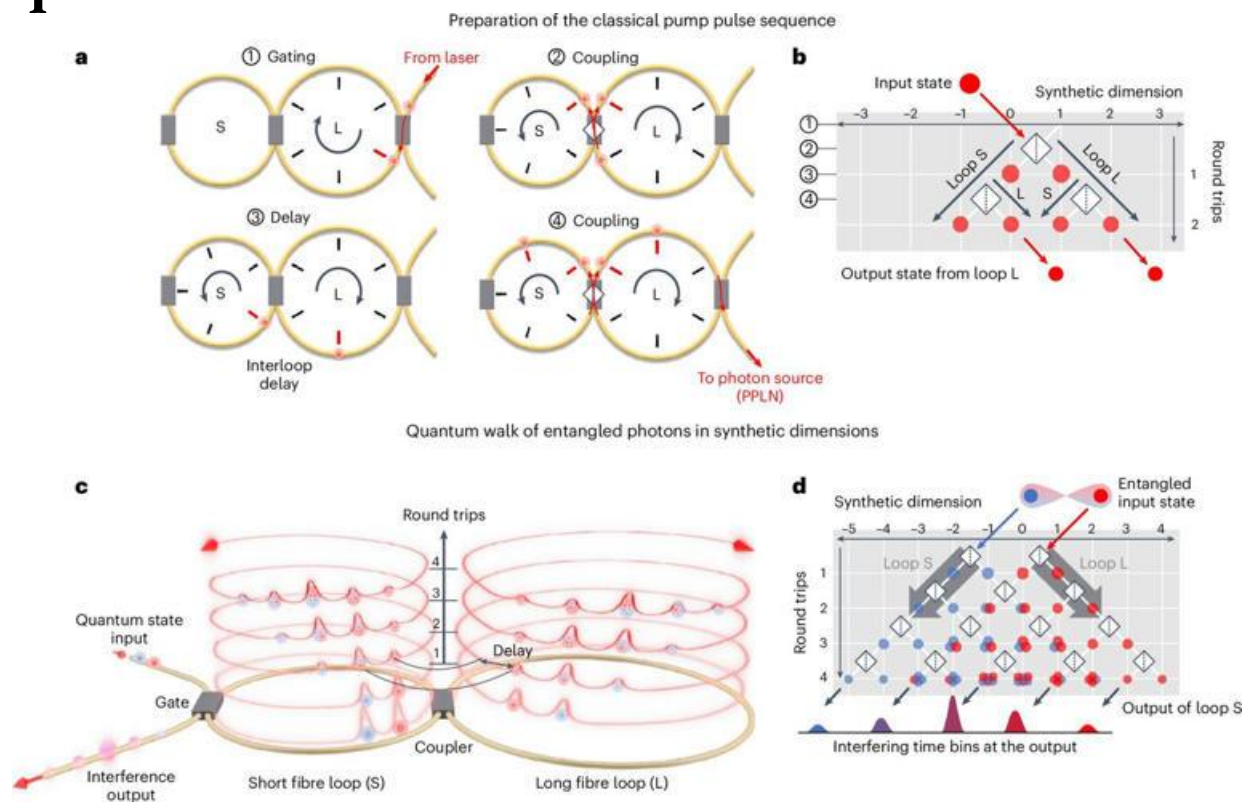
The team found that using a π -junction removed the need for the coils and the noise they produced. It also allows for 180° phase shifting, which the researchers note, allows the qubit to function independently, where it performs at its best. To create their π -junction, the researchers combined a ferromagnetic Josephson device with previously developed NICT nitride superconducting qubit technology.

Testing so far has shown the new type of qubit was able to demonstrate coherence properties though they were still a little shorter than non- π -junction designs.

More information: Sunmi Kim et al, Superconducting flux qubit with ferromagnetic Josephson π -junction operating at zero magnetic field, *Communications Materials* (2024). DOI: [10.1038/s43246-024-00659-1](https://doi.org/10.1038/s43246-024-00659-1)

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Quantum research breakthrough uses synthetic dimensions to efficiently process quantum information



A new study opens the door to cutting-edge solutions that could contribute to the realization of a system capable of processing quantum information in a simple yet powerful way.

Their work, just [published](#) in the journal *Nature Photonics*, presents a method for manipulating the photonic states of light in a never-before-seen way, offering greater control over the evolution of photon propagation. This control makes it possible to improve the detection and number of photon coincidences, as well as the efficiency of the system.

The study was co-directed by Professor Roberto Morandotti of Institut national de la recherche scientifique (INRS) in collaboration with teams from Germany, Italy, and Japan.

Unsuspected properties

Central to the research team's experiments is the concept of quantum walks. "The development of the field of quantum computing, which began some twenty years ago, has benefited greatly from the notion of quantum walks, which are known to increase the speed and complexity of computer algorithms," explains Professor Morandotti, whose laboratory is based at the INRS Énergie Matériaux Télécommunications Research Centre.

Recently, the scientific community developed another concept: synthetic photonic networks. "This work enables us to use the concept of synthetic photonics dimensions to explore many quantum phenomena at the fundamental level, and to apply them to quantum technologies," explains Stefania Sciara, a post-doc on Morandotti's team and co-author of the study.

The potential of this type of lattice was already known, for example to simulate effects such as parity-time symmetry, superfluidity of light and topological structures, but using conventional technology.

"But despite their potential," she adds, "a synthetic photonic lattice capable of handling quantum states had never been demonstrated."

This is precisely what Morandotti and his team have done. They have discovered a temporal synthetic photonic lattice capable of generating and manipulating quantum states of light (photons), using the concept of quantum walks in simple fiber systems.

"Our team has discovered how to use synthetic photonic lattices to process quantum information, based on the quantum walks of high-dimensional photons entangled in their temporal states," reports Morandotti. "The system doesn't require a lot of resources, as it consists of fiber devices, which are compatible with standard telecom infrastructures."

An innovative technique with wide-ranging applications

This breakthrough opens the door to the use of synthetic photonic lattices simplified by the use of quantum walks for quantum information processing.

"Our approach is unprecedented for two reasons," says Morandotti. "It allows better control of the evolution of quantum walks in the time domain, and it makes possible the simultaneous manipulation of classical light and entangled photons. This discovery paves the way for a variety of advanced quantum computing and information protocols on telecom-ready architectures compatible with microprocessor chips."

Several fields of fundamental physics linked to quantum information processing can benefit from the researchers' results, including quantum computing, quantum metrology, and secure quantum communications.

"Our system is entirely based on fiber-optic devices used in the telecommunications field and can be combined with current and future telecommunications infrastructures," says Sciara. "This discovery is proof that it is possible to realize high-performance quantum systems using devices, techniques, and infrastructures that are within reach. It also demonstrates that it is possible to use quantum networks to transmit personal data securely."

The article study was co-authored by Monika Monika, Farzam Nosrati, Agnes George, Stefania Sciara, Riza Fazili, André Luiz Marques Muniz, Arstan Bisianov, Rosario Lo Franco, William J. Munro, Mario Chemnitz, Ulf Peschel, and Roberto Morandotti.

More information: Monika Monika et al, Quantum state processing through controllable synthetic temporal photonic lattices, *Nature Photonics* (2024). DOI: [10.1038/s41566-024-01546-4](https://doi.org/10.1038/s41566-024-01546-4)

Provided by INRS

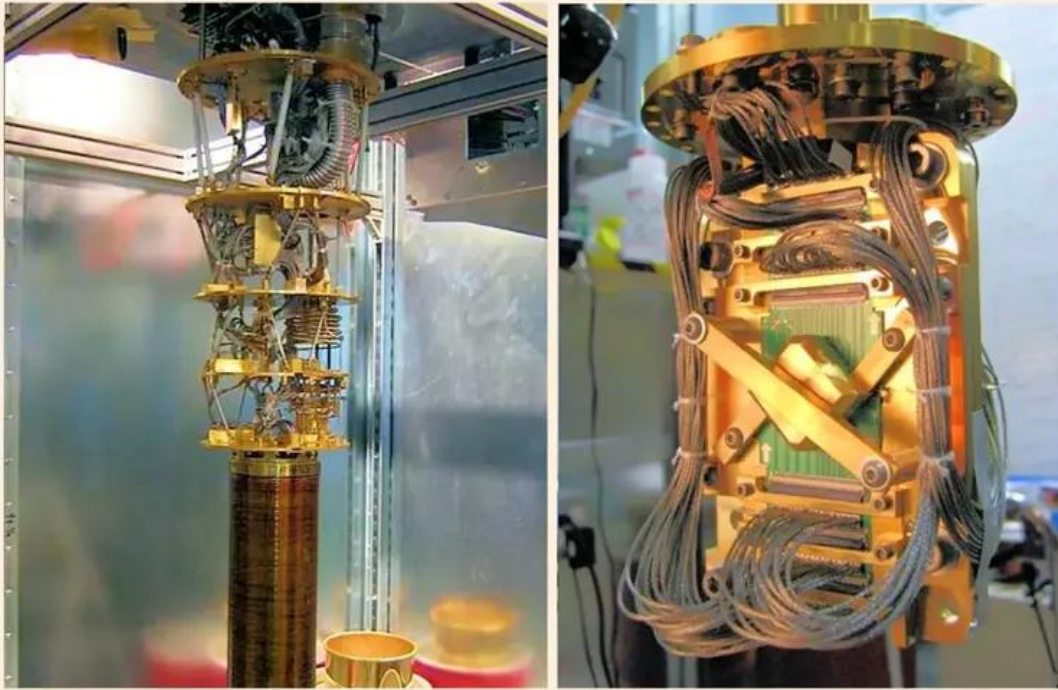
In a global first, quantum computers crack RSA and AES data encryption

Recent developments in quantum computing have sent shockwaves through the cybersecurity community, revealing the potential of quantum systems to undermine modern encryption.

A team of Chinese researchers, led by Wang Chao from [Shanghai University](#), has demonstrated that D-Wave's quantum annealing computers can crack encryption methods that safeguard sensitive global data.

This breakthrough, published in the [Chinese Journal of Computers](#), emphasizes that quantum machines are closer than expected to threatening widely used cryptographic systems, including RSA and Advanced Encryption Standard (AES).

The research team's experiments focused on leveraging [D-Wave's quantum technology](#) to solve cryptographic problems. In their paper, titled "Quantum Annealing Public Key Cryptographic Attack Algorithm Based on D-Wave Advantage," the researchers explained how quantum annealing could transform cryptographic attacks into combinatorial optimization problems, making them more manageable for quantum systems.



They reported using the D-Wave Advantage system to factor a 50-bit RSA integer, showcasing the potential of [quantum machines](#) to disrupt encryption practices that have been considered secure for decades.

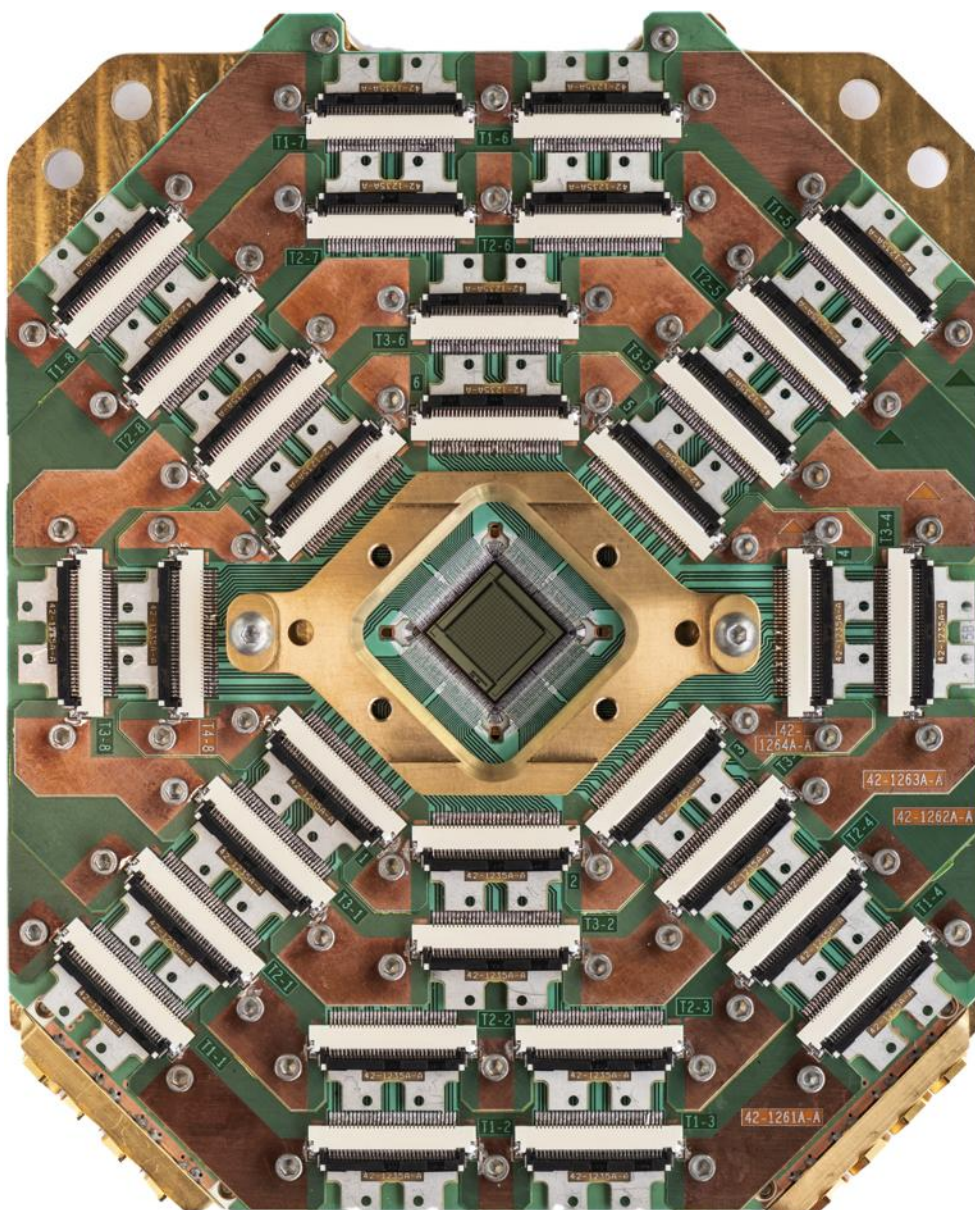
This marks a turning point, with quantum computers now posing a substantial threat to classical encryption systems, particularly those based on the Substitution-Permutation Network (SPN) structure, which underpins many of today's cryptographic methods.

The research didn't just target RSA; it also demonstrated the vulnerability of algorithms essential to AES, such as the Present, Rectangle, and Gift-64 block ciphers. These [encryption standards](#), used by major organizations and governments worldwide, could be compromised as quantum computing continues to evolve.

Prabhjyot Kaur, a senior analyst at Everest Group, weighed in on the potential implications of this breakthrough: “Many cryptographic algorithms that enterprises rely on today, such as RSA and ECC, are based on mathematical problems that are computationally difficult for classical computers to solve efficiently. However, the advent of quantum computing threatens the security of these algorithms. The need for robust quantum-safe or post-quantum cryptographic solutions becomes increasingly evident as quantum computing advances.”

For years, experts have predicted that quantum computing could eventually break today's encryption, but the timeline for these threats was thought to be several decades away. Wang Chao's team challenges this assumption. Their findings suggest that quantum computers are already making significant strides in attacking [cryptographic systems](#), potentially accelerating the timeline for when these machines could become a significant threat.

Even though [AES-256](#) is considered one of the safest encryption methods, researchers warn that quantum computers could soon become a real threat. If a breakthrough occurs, it could seriously undermine the password protection that keeps our online information secure. Wang's research describes quantum annealing as similar to artificial intelligence, capable of optimizing solutions on a global scale.



The implications for cybersecurity are profound. Data encrypted today might be safe for now, but adversaries could be intercepting and storing that data, waiting for the day when quantum computers become powerful enough to decrypt it. This threat, known as "Harvest Now, Decrypt Later," is a growing concern for organizations and governments alike. It underscores the urgent need for [quantum-safe encryption](#) methods.

Many companies are already racing to develop post-quantum cryptographic solutions to mitigate the risk posed by quantum attacks. Yet, the research from Shanghai University highlights the need for immediate action. Organizations that rely on cryptographic systems like RSA and AES must reassess their security measures in light of these advancements.

Kaur stressed the urgency of this issue: "The advancement of quantum computers can seriously threaten [data security](#) and privacy for various enterprises, affecting fundamental principles such as confidentiality, integrity, and authentication. This makes it essential to reassess the security of these cryptographic methods."

While efforts to develop quantum-safe encryption are underway, experts warn that the time to act is now. "The growing threat from quantum computers requires immediate attention to ensure the security of our digital future," the researchers cautioned in their paper. If quantum systems continue to develop at their current pace, they could enable cyberattacks far more sophisticated than anything seen today, making it critical to implement quantum-resistant encryption measures.

The risks are not hypothetical. D-Wave's quantum systems, which the Chinese team used in their research, are accessible through cloud services for around \$2,000 an hour. In 2017, a D-Wave quantum computer cost roughly \$15 million, but today, these machines are increasingly within reach for those with the resources. With over [5,000 qubits](#), the D-Wave Advantage system is among the most advanced quantum computers available, capable of solving problems classical computers struggle with.

This rise in quantum computing capability has prompted responses from global organizations. Apple, for instance, introduced its PQ3 security protocol earlier this year to bolster the encryption of its iMessage app, aiming to protect users' data from future quantum decryption attempts.

Apple researchers warned in February of the "Harvest Now, Decrypt Later" scenario, where data encrypted today could be stored and decrypted in the future once [quantum computers](#) become powerful enough.

The Global Risk Institute (GRI), a Canadian organization that assesses financial risks related to global events, has also highlighted the dangers of quantum computing.

A 2023 survey conducted by GRI found that the majority of cryptography experts believe quantum computers will be able to break RSA-2048 encryption within 30 years. They urged the [cybersecurity community](#) to prioritize "crypto-agility" and develop layered defenses to counteract the quantum threat.

In 2022, Chinese researchers proposed a method to break RSA-2048 encryption, though it required "millions of qubits"—a capability far beyond current quantum systems. However, with D-Wave's Advantage system already equipped with over 5,000 qubits, the gap between theory and reality is closing.

Wang Chao's team has sent a clear message: the [quantum computing era](#) is not a distant future—it is fast approaching. The cybersecurity community must act now to protect data and systems from the emerging quantum threat.

New benchmark helps solve the hardest quantum problems

From subatomic particles to complex molecules, quantum systems hold the key to understanding how the universe works. But there's a catch: when you try to model these systems, that complexity quickly spirals out of control—just imagine trying to predict the behavior of a massive crowd of people where everyone is constantly influencing everyone else. Turn those people into quantum particles, and you are now facing a "quantum many-body problem."

Quantum many-body problems are efforts to predict the behavior of a large number of interacting quantum particles. Solving them can unlock huge advances in fields like chemistry and materials science, and even push the development of new tech like quantum computers.

But the more particles you throw into the mix, the harder it gets to model their behavior, especially when you're looking for the ground state, or lowest energy state, of the system. This matters because the ground state tells scientists which materials will be stable and could even reveal exotic phases like superconductivity.

For every problem, a solution: But which one?

For years, scientists have relied on a mix of methods like quantum Monte Carlo simulations and tensor networks (variational wave functions) to approximate solutions to these problems. Each method has its strengths and weaknesses, but

it's hard to know which one works best for which problem. And until now, there hasn't been a universal way to compare their accuracy.

A large collaboration of scientists, led by Giuseppe Carleo at EPFL has now developed a new benchmark called the "V-score" to tackle this issue. The V-score ("V" for "Variational Accuracy") offers a consistent way to compare how well different quantum methods perform on the same problem. The V-score can be used to identify the hardest-to-solve quantum systems, where current computational methods struggle, and where future methods—such as quantum computing—might offer an advantage.

The breakthrough method is [published](#) in *Science*.

How the V-score works

The V-score is calculated using two key pieces of information: the energy of a quantum system and how much that energy fluctuates. Ideally, the lower the energy and the smaller the fluctuations, the more accurate the solution. The V-score combines these two factors into a single number, making it easier to rank different methods based on how close they come to the exact solution.

To create the V-score, the team compiled the most extensive dataset of quantum many-body problems to date. They ran simulations on a range of quantum systems, from simple chains of particles to complex, frustrated systems, which are notorious for their difficulty. The benchmark not only showed which methods worked best for specific problems, but also highlighted areas where quantum computing might make the biggest impact.

Solving the hardest quantum problems

Testing the V-score, the scientists found that some quantum systems are much easier to solve than others. For example, one-dimensional systems, such as chains of particles, can be tackled relatively easily using existing methods like tensor networks. But more complex, high-dimensional systems like frustrated quantum

lattices, have significantly higher V-scores, suggesting that these problems are much harder to solve with today's classical computing methods.

The researchers also found that methods relying on neural networks and quantum circuits—two promising techniques for the future—performed quite well even when compared to established techniques. What this means is that, as quantum computing technology improves, we may be able to solve some of the hardest quantum problems out there.

The V-score gives researchers a powerful tool to measure progress in solving quantum problems, especially as quantum computing continues to develop. By pinpointing the hardest problems and the limitations of classical methods, the V-score could help direct future research efforts. For instance, industries that rely on quantum simulations, such as pharmaceuticals or energy, could use these insights to focus on problems where quantum computing could give them a competitive edge.

More information: Dian Wu et al, Variational benchmarks for quantum many-body problems, *Science* (2024). DOI: [10.1126/science.adg9774](https://doi.org/10.1126/science.adg9774). www.science.org/doi/10.1126/science.adg9774

Provided by Ecole Polytechnique Federale de Lausanne

A physical qubit with built-in error correction

There has been significant progress in the field of quantum computing. Big global players, such as Google and IBM, are already offering cloud-based quantum computing services. However, quantum computers cannot yet help with problems that occur when standard computers reach the limits of their capacities because the availability of qubits or quantum bits, i.e., the basic units of quantum information, is still insufficient.

One of the reasons for this is that bare qubits are not of immediate use for running a quantum algorithm. While the binary bits of customary computers store information in the form of fixed values of either 0 or 1, qubits can represent

0 and 1 at one and the same time, bringing probability as to their value into play. This is known as quantum superposition.

This makes them very susceptible to external influences, which means that the information they store can readily be lost. In order to ensure that quantum computers supply reliable results, it is necessary to generate a genuine entanglement to join together several physical qubits to form a logical qubit. Should one of these physical qubits fail, the other qubits will retain the information. However, one of the main difficulties preventing the development of functional quantum computers is the large number of physical qubits required.

Advantages of a photon-based approach

Many different concepts are being employed to make quantum computing viable. Large corporations currently rely on superconducting solid-state systems, for example, but these have the disadvantage that they only function at temperatures close to absolute zero. Photonic concepts, on the other hand, work at room temperature.

Single photons usually serve as physical qubits here. These photons, which are, in a sense, tiny particles of light, inherently operate more rapidly than solid-state qubits but, at the same time, are more easily lost. To avoid qubit losses and other errors, it is necessary to couple several single-photon light pulses together to construct a logical qubit—as in the case of the superconductor-based approach.

A qubit with the inherent capacity for error correction

Researchers of the University of Tokyo together with colleagues from Johannes Gutenberg University Mainz (JGU) in Germany and Palacký University Olomouc in the Czech Republic have recently demonstrated a new means of constructing a photonic quantum computer. Rather than using a single photon, the team employed a laser-generated light pulse that can consist of several photons. The research is [published](#) in the journal *Science*.

"Our laser pulse was converted to a quantum optical state that gives us an inherent capacity to correct errors," stated Professor Peter van Loock of Mainz University. "Although the system consists only of a laser pulse and is thus very small, it can—in principle—eradicate errors immediately." Thus, there is no need to generate individual photons as qubits via numerous light pulses and then have them interact as logical qubits.

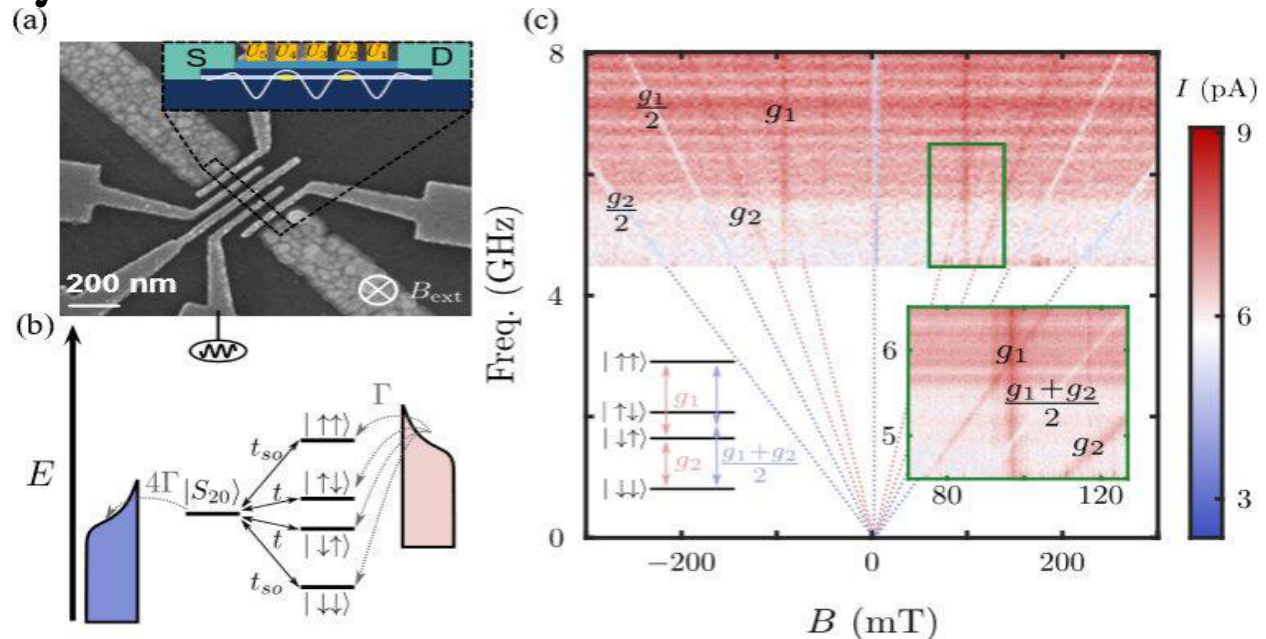
"We need just a single light pulse to obtain a robust logical qubit," added van Loock. To put it in other words, a physical qubit is already equivalent to a logical qubit in this system—a remarkable and unique concept. However, the logical qubit experimentally produced at the University of Tokyo was not yet of a sufficient quality to provide the necessary level of error tolerance. Nonetheless, the researchers have clearly demonstrated that it is possible to transform non-universally correctable qubits into correctable qubits using the most innovative quantum optical methods.

More information: Shunya Konno et al, Logical states for fault-tolerant quantum computation with propagating light, *Science* (2024). DOI: [10.1126/science.adk7560](https://doi.org/10.1126/science.adk7560)

Olivier Pfister, Qubits without qubits, *Science* (2024). DOI: [10.1126/science.adm9946](https://doi.org/10.1126/science.adm9946)

Provided by Johannes Gutenberg University Mainz

Researchers achieve tunable coherent population trapping in a double quantum dot system



Spectroscopy, energy levels and odd-even effect of DQD system. Credit: Prof. Guo Guangcan's team

A research team has achieved coherent population trapping (CPT) in a semiconductor double quantum dot (DQD) system.

CPT is an important phenomenon of quantum interference, which was first observed in a three-level atom in an optical experiment. In such a three-level system, two states are coupled to a third intermediate state. When the frequency and phase of the driving field are properly tuned, the first two states form a superposition state that decouples from the intermediate state. This superposition state is known as the "dark state" as it does not respond to the probe field, giving rise to intriguing phenomena such as electromagnetically induced transparency.

The dark state has important applications in quantum information processing, but hasn't been well implemented in DQD systems. Unlike the traditional three-level atomic system, the internal structure and dynamics of DQD can realize intrinsic CPT without an external driving field, making it a promising platform for quantum computing.

To implement CPT in the DQD system, the team leveraged the intrinsic properties of the energy levels in Ge and Si systems. Without any driving field, they measured the leakage current through the DQD in the Pauli Spin Blockade (PSB) and observed a significant dip in the current at zero bias, indicating the formation of dark states and the occurrence of CPT. Furthermore, the team demonstrated the ability to selectively create a dark state and the related CPT process by applying a longitudinal drive to the DQD system.

The team also delved deeply into the odd-even effect induced by a longitudinal driving field. Researchers observed that when the driving frequency meets certain conditions, the current exhibits enhancement or suppression corresponding to odd or even orders of harmonics.

This phenomenon offers a fresh perspective for understanding and utilizing CPT. Additionally, the team found that the signal intensity and width of CPT can be effectively modulated by adjusting the longitudinal driving field.

The realization of CPT in the DQD system shows that the semiconductor quantum dot system is not only an ideal platform for understanding quantum interference but also a powerful tool for high-precision quantum information processing. This work clearly demonstrates the potential tunability of the longitudinally driven DQD system, paving the way for practical application of semiconductor quantum dot systems in quantum computing.

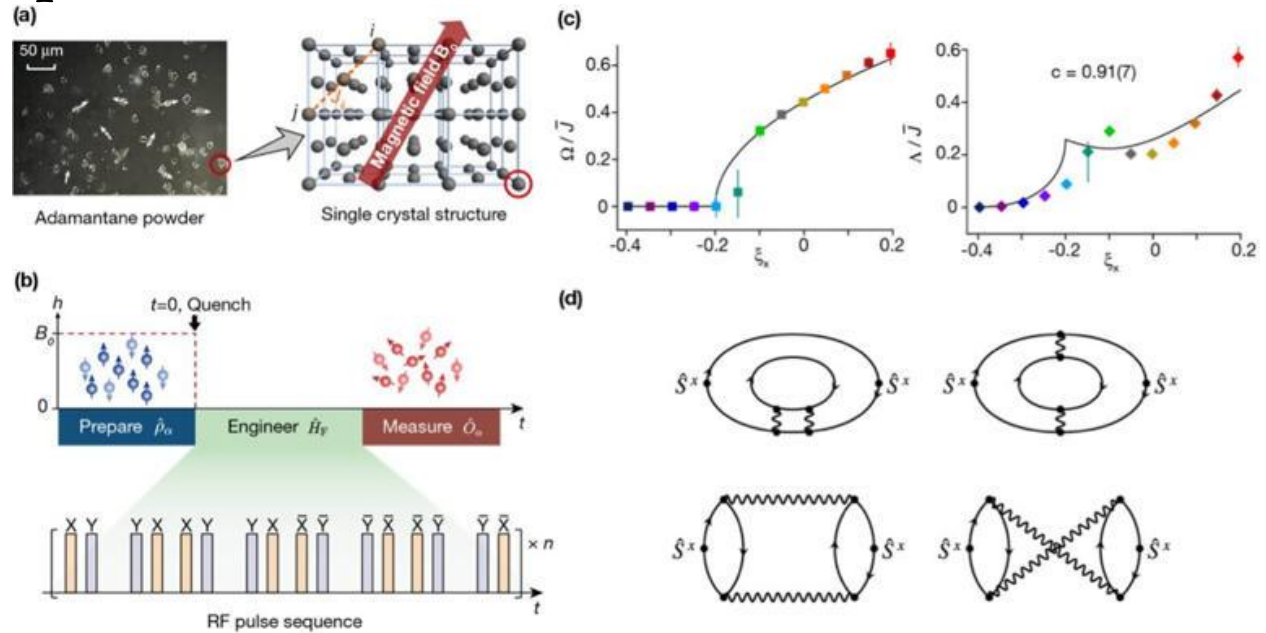
The findings are [published](#) in the journal *Nano Letters*.

The team was led by Guo Guangcan, Prof. Guo Guoping and Prof. Li Haiou from the University of Science and Technology of China (USTC), collaborating with Researcher Zhang Jianjun from the Institute of Physics of the Chinese Academy of Sciences (CAS).

More information: Yuan Zhou et al, Quantum Interference and Coherent Population Trapping in a Double Quantum Dot, *Nano Letters* (2024). DOI: [10.1021/acs.nanolett.4c01781](https://doi.org/10.1021/acs.nanolett.4c01781)

Provided by University of Science and Technology of China

Physicists uncover universal non-equilibrium quantum dynamics in randomly interacting spin models



a. Powder sample of adamantane (C₁₀H₁₆) and its lattice structure. b. Experimental protocol and pulse sequence. c. Observed universality in the spin depolarization dynamics. d. Dominating interaction processes behind the spin depolarization dynamics. Credit: Prof. Du's team

A new study has uncovered the universal dynamics far from equilibrium in randomly interacting spin models, thereby complementing the well-established universality in low-energy equilibrium physics. The study, recently published in *Nature Physics*, was the result of a collaborative effort involving the research group led by Prof. Du Jiangfeng and Prof. Peng Xinhua at the University of Science and Technology of China (USTC), along with the theoretical groups of Prof. Zhai Hui from Tsinghua University and Dr. Zhang Pengfei from Fudan University.

Non-equilibrium dynamics in quantum many-body systems lies at the heart of the current development of modern quantum science and technology, where rich phenomena have been found during recent years, especially in synthetic

quantum platforms such as ultracold atoms, superconducting qubits, trapped ions, NV centers, and NMR systems.

However, despite its rich phenomena, simple and universal rules behind quantum non-equilibrium dynamics are still lacking. Non-equilibrium dynamics usually involve highly excited states beyond the conventional low-energy universality.

Whether universal behavior can also emerge in non-equilibrium dynamics, is a cutting-edge question in the field of quantum many-body physics. The main difficulties arise from the strongly correlating nature and the complexity of non-equilibrium many-body systems, as well as the experimental challenges associated with high-precision quantum control of these systems.

Solid-state nuclear spin systems are naturally complex many-body quantum systems that can be precisely controlled through quantum control technologies, thereby enabling the implementation of various many-body spin models. This provides a natural and adjustable experimental platform for studying the non-equilibrium dynamics of quantum many-body systems.

Leveraging years of expertise in quantum control and quantum simulation of nuclear spin systems, the researchers designed the pulse sequences to high-precisely control the ^1H nuclear spins in adamantane ($\text{C}_{10}\text{H}_{16}$) powder (each grain containing approximately 10^9 to 10^{12} molecules), and realized randomly interacting spin models with adjustable anisotropic parameters. The randomness arises from the random orientations between the lattice axes in different grains and the static magnetic field.

Then the researchers observed a new phenomenon: The spin depolarization dynamics showed a clear transition from monotonic to oscillatory decay as the anisotropic parameter changed. They found that the behavior of the spin depolarization dynamics can be universally described by two parameters. By comparing the experimental observations with several different theoretical approaches, the researchers offered a comprehensive theoretical explanation of this non-equilibrium quantum many-body dynamics.

This study has identified a new type of universality in non-equilibrium dynamics of quantum many-body systems that are challenging to simulate on classical computers. It serves as an excellent example of how quantum information technology can be used to discover new physical laws.

Additionally, the methods and techniques used in the experiments provide new insights into other physical systems, such as ultracold atoms or molecules and NV center ensembles. The research significantly enhances the understanding of such complex systems, potentially sparking widespread interest across various fields of physics.

More information: Yuchen Li et al, Emergent universal quench dynamics in randomly interacting spin models, *Nature Physics* (2024). DOI: [10.1038/s41567-024-02664-0](https://doi.org/10.1038/s41567-024-02664-0)

Provided by University of Science and Technology of China

Breakthrough Tachyon discovery

The concept of the tachyon, a theoretical particle that travels [faster than light](#), has fascinated physicists and sparked decades of theoretical exploration. Originally conceived as a solution to certain quantum and relativity puzzles, tachyons remain hypothetical.

Yet, a new study by an international research team has reignited interest by proposing that tachyons are indeed possible within the framework of Einstein's special theory of relativity—a finding that could significantly reshape our understanding of causality, time, and even the structure of reality.

The Origins of the Tachyon

Physicist Gerald Feinberg introduced the idea of tachyons in 1962 as particles that could potentially [travel faster than light](#), always maintaining speeds beyond that limit. This groundbreaking suggestion was rooted in his study of imaginary mass, a concept involving the square root of a negative number.

The blue glow of Cherenkov radiation in a nuclear reactor, one of the ways hypothetical tachyons can be detected. (CREDIT: Argonne National Laboratory)© The Brighter Side of News

Imaginary mass, he proposed, could permit particles to exceed the speed of light without conflicting with Einstein's theory of relativity, which prohibits massive

particles from accelerating to that speed. Feinberg's tachyon hypothesis ignited curiosity about faster-than-light communication, time travel, and other extreme physical phenomena.

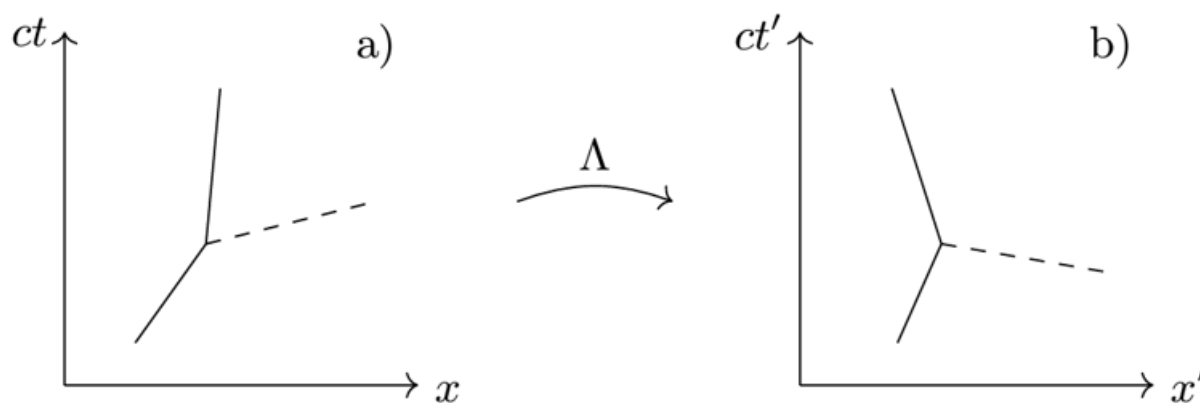
However, integrating tachyons into existing theories posed challenges. For one, their [faster-than-light nature](#) seemed to violate causality, a core principle in physics requiring causes to precede effects. Moreover, calculations around tachyons frequently produced "infinite energy," a mathematical impossibility that cast doubt on their physical relevance.

Additionally, theoretical models indicated that the number of observed tachyons would vary depending on the observer's frame of reference, a contradiction to established physical laws. Despite these hurdles, tachyons continued to be studied within quantum field theory and theoretical frameworks like string theory.

A New Study: Tachyons Within Relativity

Recent research led by physicists from the [University of Warsaw](#) and the [University of Oxford](#), including Andrzej Dragan and Artur Ekert, has introduced a framework that reconciles tachyons with Einstein's special relativity.

Published in [Physical Review D](#), the study challenges past assumptions and proposes a new approach where tachyons not only exist within relativity but could theoretically travel through time. According to Dragan, this framework allows superluminal particles to carry information backward in time, thereby opening new possibilities in how we understand causality.



An emission of a positive-energy tachyon (a) in one reference frame is Lorentz-transformed by a boost Λ into an emission of a negative-energy tachyon (b) backward in time, which can be reinterpreted as a regular absorption of a

positive-energy antitachyon forward in time, in the boosted reference frame. The worldlines of tachyons are shown as dashed lines. (CREDIT: Physical Review D)© The Brighter Side of News

Dragan explains, “The idea that the future can influence the present rather than the present determining the future is not new in physics. However, until now, this kind of view has been at best an unorthodox interpretation of certain [quantum phenomena](#), and this time we were forced to this conclusion by the theory itself.”

Dragan’s explanation illustrates this with a “movie” analogy, where knowing both the beginning and the end simultaneously allows one to understand the entire plot in full—suggesting a model where future events influence current behaviors.

Resolving Tachyon Paradoxes: A New Mathematical Framework

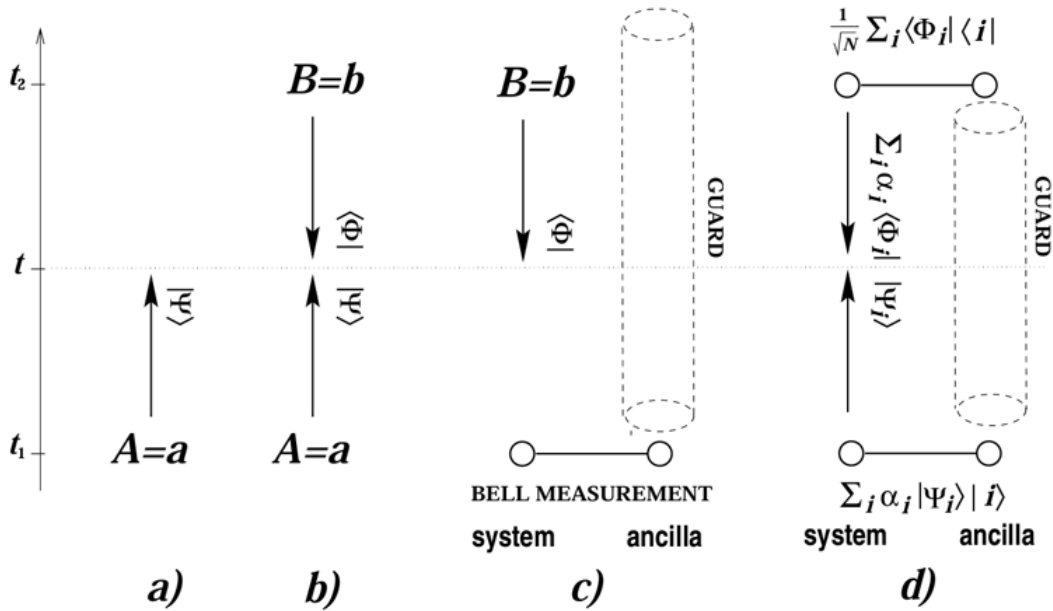
The study by Dragan and his colleagues, including researchers Jerzy Paczos, Kacper Dębski, Szymon Cedrowski, Szymon Charzyński, and Krzysztof Turzyński, addresses some of the primary issues that made tachyons mathematically implausible.

Traditional calculations involving tachyons have resulted in unlimited energy and unstable vacuum states, and models have varied based on the observer’s perspective, challenging physical principles. To overcome these problems, the team used an extended mathematical approach, incorporating both initial and final states of the system in a way that allows tachyons to exist stably within the [relativity framework](#).

This new framework has significant implications. By resolving issues such as infinite energy and observer dependency, the researchers created a consistent model for tachyons within special relativity. The study suggests that tachyons, long thought impossible due to mathematical paradoxes, might indeed fit into our current understanding of physics.

The Influence of Quantum Mechanics: Two-State Formalism

One of the study’s breakthroughs is in its use of two-state formalism, a concept in [quantum mechanics](#) that supports time-reversible processes. This formalism, originally proposed by physicists Aharonov, Bergmann, and Lebowitz, has typically been seen as an exotic interpretation within quantum mechanics.



Single forward-evolving quantum state. Description of quantum systems: (a) pre-selected, (b) pre- and post-selected, (c) post-selected, and (d) generalized pre- and post-selected. (CREDIT: arxiv Quantum Physics)© The Brighter Side of News

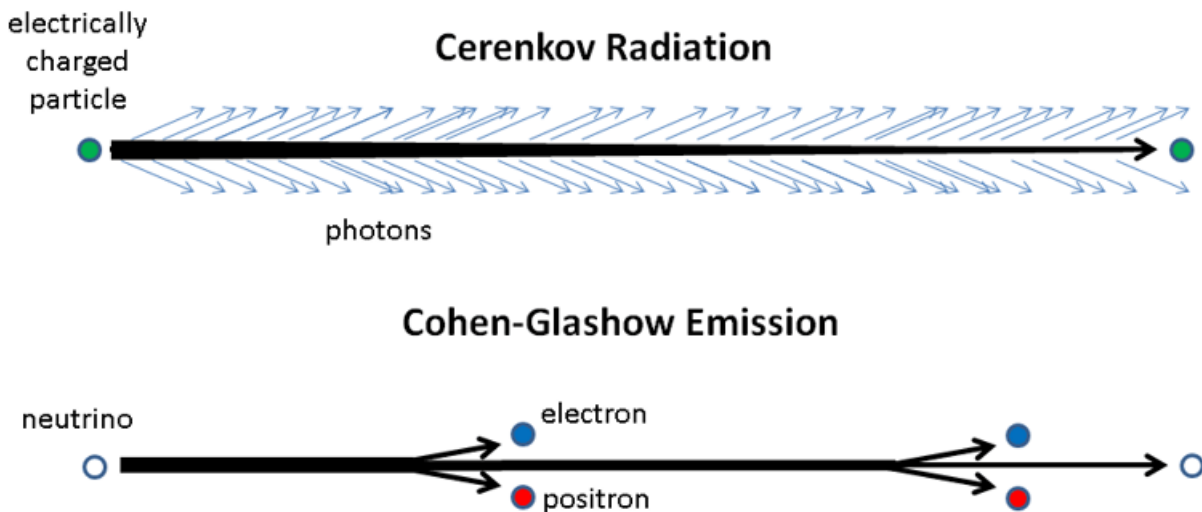
However, the team applied it to their tachyon model to guarantee time-reversibility, suggesting that the processes involving tachyons could operate backward in time without violating causality. Dragan and Ekert further argue that superluminal particles, contrary to prior assumptions, do not create paradoxes but only introduce causal “disturbances” akin to those observed in [quantum mechanics](#).

This two-state formalism provides a stable, relativistic framework that may redefine the tachyon’s place in physics. If validated, this approach could transform theories of time and quantum processes, possibly offering new explanations for complex phenomena such as how particles gain mass or how matter itself forms within the universe.

Previous Research and Experimental Constraints

Over the years, physicists have explored various theories and conducted experiments, albeit inconclusively, in search of tachyons. Notably, Sheldon Glashow and Andrew Cohen from Harvard University [published a study](#) on potential faster-than-light neutrinos, a phenomenon resembling tachyons, but later findings disproved this hypothesis. CERN's OPERA experiment also

examined superluminal neutrinos, sparking brief excitement, though subsequent tests revealed measurement errors rather than new physics.



M. Strassler 2011

Cerenkov radiation involves the nearly continuous emission of photons by a charged particle moving faster than the speed of light in its vicinity. The charged particle gradually radiates away its energy. Cohen-Glashow emission involves the occasional creation, near a speeding neutrino, of an electron-positron pair, in which the neutrino loses a large fraction of its energy in one step. (CREDIT: Matt Strassler)© The Brighter Side of News

Beyond particle experiments, tachyonic fields have been studied in other theoretical contexts, including cosmology and the Casimir effect. In cosmology, tachyonic fields are theorized as potential drivers for dark energy and cosmic expansion.

Researchers like Dr. Shinji Tsujikawa from [Waseda University](#) have examined tachyonic fields to explore the accelerating universe's mysteries. Although still speculative, this research could eventually link tachyonic fields with observable cosmological phenomena, helping scientists explain why the universe's expansion rate appears to be increasing.

Broader Implications: Changing Our Understanding of Time and Reality

The Dragan team's study may have far-reaching consequences. With a mathematically sound framework for tachyons, physicists now have the opportunity to explore questions around time's nature and quantum reality more deeply. The tachyon framework could reveal hidden aspects of [time symmetry](#) and causality, possibly linking it to symmetry-breaking events, such as those theorized to explain mass in the Higgs field.

<https://www.youtube.com/watch?v=R7dsACYTTXE>

While tachyons remain hypothetical, the Dragan and Ekert study demonstrates that such particles may indeed have a place in physics, free of past contradictions. This advancement reminds us of science's role in challenging assumptions and stretching the boundaries of what we know.

The new framework could redefine [quantum theory](#) and time's nature, reshaping how we understand the universe at its most fundamental level.

Scientists Discovered a Secret World Where Particles Turn Chaos Into Order



MIT scientists discovered particles transition from chaos to order due to entropy. This breakthrough reveals hidden dynamics of collective motion in systems. © Yuichiro Chino - Getty Images

- In new research, scientists find that flocks of birds may become ordered after a disordered start.
- The way flocks and other “collective motions” form has eluded scientists for a long time.

- Understanding physics this way could help us understand trends in the human body's cells.

Particles, in many senses, are one of the most vibrant parts of popular and academic culture in 2024. Our video games and movies are marked by how many particles are represented in order to mimic reality. Our science is moved forward by supercomputer models that can sledgehammer through billions of individual points in a simulation. These models allow scientists to combine models from different disciplines and calculate likelihoods rather than certainties.

Real life is also crammed with “particles”—and things that act a surprising amount like particles—that we’re coming to understand more and more. For instance, [new research](#) published in the Institute of Physics’ peer-reviewed *Journal of Statistical Mechanics: Theory and Experiment* lays out why the “transition to collective motion”—the catalyst moment where discrete (separate) things with individual directions all turn together and act as one thing—is so hard to pin down.

Collective motion is a well-known phenomenon of particle physics, but it’s not exclusive to the micro-realm. Fish, for example, are icons of collective motion, and scientists believe that their sophisticated ability to change direction is a result of [better sensory organs](#) and sharper senses than we previously thought. But that doesn’t completely explain the physics of how the groups stay orderly, respond in shockingly fast ways, and group up in the first place.

Is a flock of birds the same as the plasma inside a nuclear fusion tokamak reactor in some ways? The answer, fascinatingly, is yes. And both show qualities shared by fluids like water and wind. It’s the why behind these similarities that’s still contested. How can it be that “self-propelled” things—like fish, birds, individual cells, and even magnets—model the same physical ideas as particles?

In a [statement from the SISSA Lab](#) in Italy, Julien Tailleur of the Massachusetts Institute of Technology (MIT) said that his professional curiosity about this topic dates back to an observation made by fellow scientist Hugues Chaté 20 years ago—that group responses of magnetic particles are dependent on pressure and

temperature. As scientists observed fish and birds, they thought something like this property of magnetism could explain how *those* groups form as well. Within the right parameters, the magnetized particles behave in an orderly way, and animals certainly look orderly as they change, group, and regroup.

But in this new experiment, the scientists found that, instead, these groups pivoted based on fluctuations.

In statistical mechanics—a field that studies large groups, like bodies of water molecules, using methods from probability and statistics—fluctuation is a specific formula that shows the rise of entropy (propensity for disorder) in a system like a flock of birds or a bloodstream. This entropy comes in forms like “noise,” which (in this case) is just a variable for what affects one part of a flock or system in order to create change. In their experimental setup, even magnets responded to the noise in a discontinuous, or less orderly, way that led to an orderly grouping. Despite the outcome of a neat flock or grouping, the catalyst to move into those groups was disordered.

The finding was not true of all the models that the scientists tested. But it did end up applying even to what seem like much more complex scenarios—like pigeons that group based on what they can see and mentally compute, rather than through their other senses.

By creating their own novel model in order to calculate findings similar to what is already known about collective motion, the scientists hope they can encourage future work using this or other novel models to move our knowledge forward. “To illustrate the usefulness of our approach,” they explain, “we highlight that it has been successfully applied to the case of active particles experiencing nematic torques.”

Nematic torques are a response in the unusual phase of matter known as [time crystals](#), when atoms line up neatly in parallel and can be synced up (torque in this case is torsion, or turning, of those atoms as a collective motion). The scientists found that fluctuations make the particles more responsive to one another and, in a way, more persistent in that response. This means that this

collective behavior could explain the formation of time crystals themselves, as atoms are able to slow and sync up. And this is just one step toward the long road of understanding these phenomena.

As Tailleir said in the statement, "We are making progress!"

'It's ultimately about predicting everything'— theory could be a map in the hunt for quantum materials

A breakthrough in theoretical physics is an important step toward predicting the behavior of the fundamental matter of which our world is built. It can be used to calculate systems of enormous quantities of quantum particles, a feat thought impossible before.

The new University of Copenhagen research may prove of great importance for the design of quantum computers and could even be a map to superconductors that function at room temperature. The paper is [published](#) in the journal *Physical Review X*.

On the fringes of theoretical physics, Berislav Buca investigates the nearly impossible by way of "exotic" mathematics. His latest theory is no exception. By making it possible to calculate the dynamics, i.e., movements and interactions, of systems with enormous quantities of quantum particles, it has delivered something that had been written off in physics. An impossibility made possible.

The unexpected presence of a white cat adorns the illustrations of Buca's research. Pulci the cat is his eye-catching muse. Arrows through the cat's body illustrate the quantum mechanical origin of the playful cat's movements—and this is precisely the relationship that Buca is trying to understand by making it possible to calculate the dynamics of the very smallest particles.

The breakthrough has reinvigorated an old and fundamental scientific question: Theoretically, if all behavior in the universe can be calculated by way of the laws of physics, can we then predict everything by calculating its smallest particles?

"Many physics disciplines are ultimately about explaining and predicting the world by understanding the laws of physics and calculating the behavior of the smallest particles. In principle, we would be able to answer any possible question about how all sorts of things behave if we were able to," says Buca of the University of Copenhagen's Niels Bohr Institute.

"In principle, the behavior of everything in the universe can be understood from the microscopic laws that govern particle dynamics," he says, while quickly appealing for caution.

"Of course I can't do that," says the theorist.

A theoretical shortcut avoids the devil in the details

The interactions and movements of quantum particles in their systems are so complex, the researcher explains, that even the world's most powerful supercomputer today is only able to perform calculations on a dozen of these particles at a time.

At the same time, a single atom consists of at least two quantum particles, and a single grain of sand of about 50 billion times a billion atoms—not to mention a cat or anything else one would want to understand in our universe.

"So in practice, it isn't possible. Not currently. However, my theory is a significant step in the right direction. This is because it takes a kind of mathematical shortcut to understanding the dynamics of the whole, without computing power being lost in the details for a broad class of systems with many quantum particles. That is, without the need to calculate all of the individual particles in a system," explains Buca.

The theory has already made a name for itself by providing the first mathematical proof of a long-held hypothesis in theoretical physics.

Up until now, the so-called eigenstate-thermalization hypothesis has been an assumption—an educated guess—in physics that had yet to be explained mathematically. It concerns the ability of mathematics to describe the motions of quantum systems as wholes.

Thus, Buca's theory has already demonstrated its value as basic theoretical research, and accomplished what theorists had long considered impossible. While the results mainly interest the bright minds of physics for now, the consequences could eventually be great for us all.

A compass for the quantum-mechanical treasure map

This knowledge could end up showing the way to sought for quantum materials with properties so unique that they could transform our world.

These quantum materials are a prerequisite for digging our claws into some of the greatest scientific "birds on the bush"—such as stable quantum computers or even superconductors that work at room temperature.

"We are looking for a material for quantum computers that can withstand entropy—a law of nature that causes complex systems—e.g., materials—to decay into less complex forms. Entropy destroys the coherence needed for quantum computers to be stable and keep working," Buca explains.

The exotic math systems that initially inspired him and made his research breakthrough possible may be just what a quantum computer needs to be truly useful.

"The so-called qubits that a quantum computer theoretically works with must be in a state of superposition to function, meaning that they are simultaneously turned on and off—in common phrasing. This requires them to be in a stable quantum state. However, thermodynamics does not like the structures required by the current materials. My theory may be able to inform us whether these exotic systems can be a way of structuring things so this quantum state could be more permanent," says Buca.

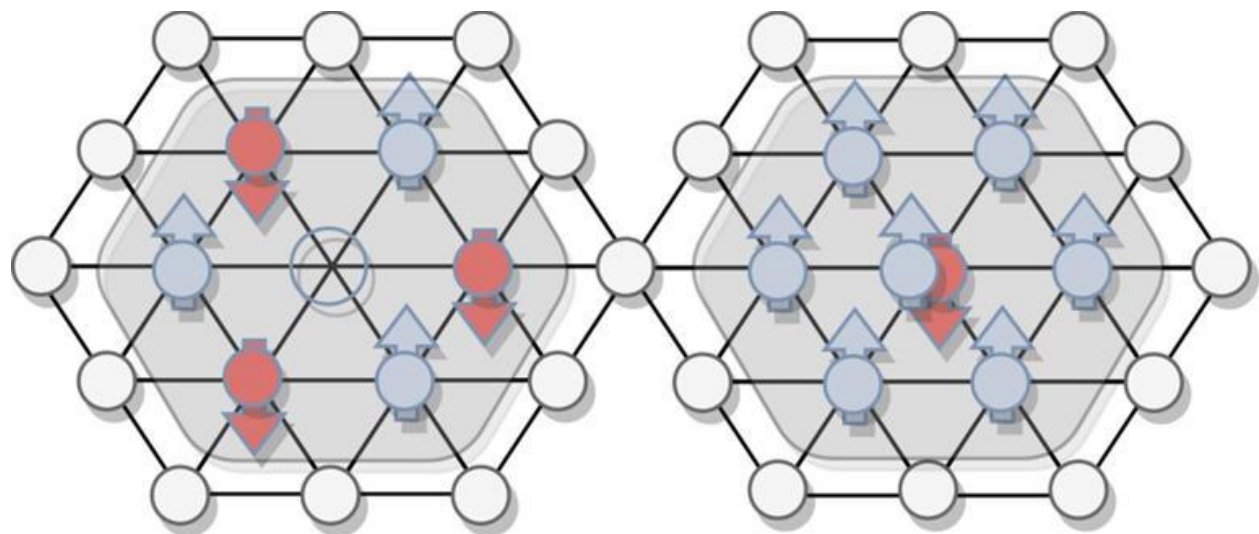
The method is a bit like a road map that can guide researchers across a vast landscape of possible materials by allowing for predictions of how these materials would behave under experimental conditions. For the first time, this gives researchers a way to target their search for quantum materials equipped with special properties.

"Until now, the hunt for these materials has been governed by chance. But my results can, for the first time, provide a guiding principle to navigate by when searching for unique properties in materials," says Buča.

More information: Berislav Buča, Unified Theory of Local Quantum Many-Body Dynamics: Eigenoperator Thermalization Theorems, *Physical Review X* (2023). DOI: [10.1103/PhysRevX.13.031013](https://doi.org/10.1103/PhysRevX.13.031013)

Provided by University of Copenhagen

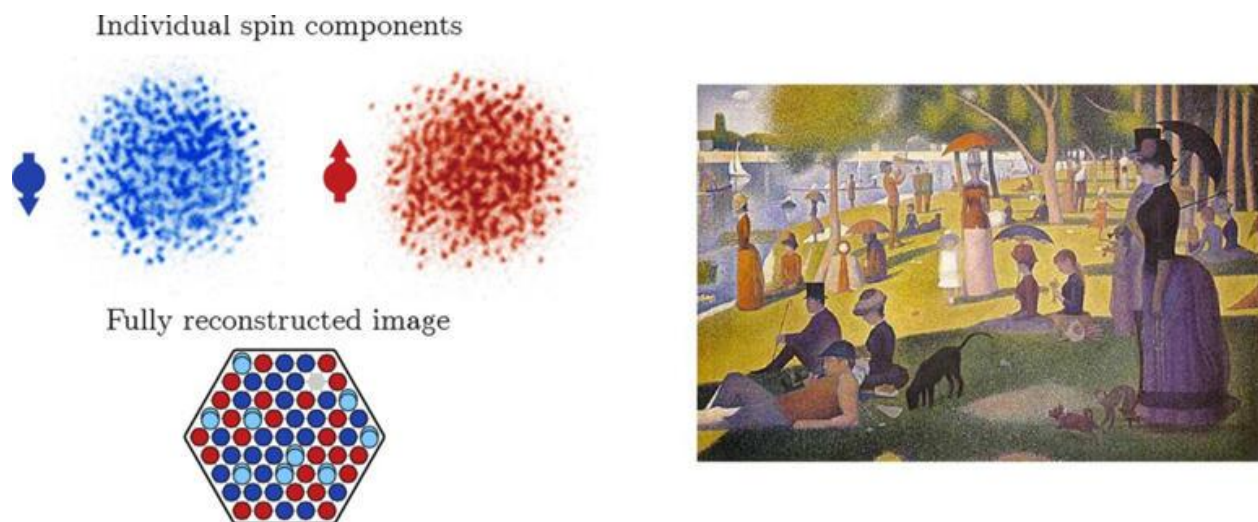
Quantum simulators solve physics puzzles with colored dots



In kinetic magnetism, an extra electron paired up to form a doublon can lead to ferromagnetic order of the spins in its vicinity (right), whereas a missing electron or hole causes antiferromagnetic order (left). Credit: Morera, I. et al. High-temperature kinetic magnetism in triangular lattices. *Phys. Rev. Res.* 5, L022048 (2023)© Provided by Phys.org

By analyzing images made of colored dots created by quantum simulators, ETH researchers have studied a special kind of magnetism. In the future this method could also be used to solve other physics puzzles, for instance in superconductivity.

Up close it looks like lots of colored dots, but from a distance one sees a complex picture rich in detail: Using the technique of pointillism, in 1886 George Seurat created the masterpiece "A Sunday afternoon on the island of La Grande Jatte." In a similar way, Eugene Demler and his coworkers at ETH Zurich study complex quantum systems made of many interacting particles. In their case, the dots are not created by dabbing a paintbrush, but rather by making individual atoms visible in the laboratory.

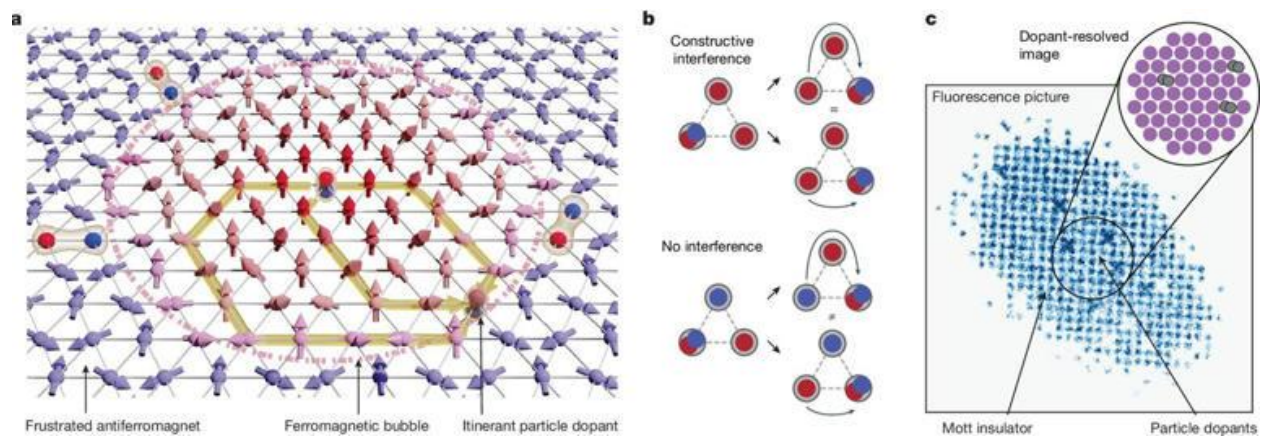


Similarly to George Seurat's pointillism ("A Sunday afternoon on the island of La Grande Jatte", right), in quantum pointillism complex pictures are created from colored points (left). From these pictures, the researchers can draw conclusions about the processes in the quantum system using theoretical calculations. Credit: Left : Prichard et al., 2024; Right: Keystone-SDA)© Provided by Phys.org

Together with colleagues in Harvard and Princeton, Demler's group has now used the new method—which they call "quantum pointillism"—to take a closer look at a special kind of magnetism.

The researchers have just published their results in two papers in the journal *Nature* with titles "[Observation of Nagaoka polarons in a Fermi–Hubbard](#)

quantum simulator" and "Directly imaging spin polarons in a kinetically frustrated Hubbard system."



Nagaoka polarons in a Fermi-Hubbard quantum simulator. Credit: Nature (2024). DOI: 10.1038/s41586-024-07272-9© Provided by Phys.org

Paradigm shift in understanding

"These studies represent a paradigm shift in our understanding of such magnetic quantum phenomena. Until now, we were not able to study them in detail," says Demler. It all started around two years ago at ETH. The group of Ataç Imamoğlu experimentally investigated special materials with a triangular crystal lattice (moiré materials made of transition metal dichalcogenides).

When Demler and his postdoc Ivan Morera analyzed Imamoğlu's data, they encountered a peculiarity that suggested a kind of magnetism that had previously only been predicted theoretically.

"In this kinetic magnetism, a few electrons moving inside the crystal lattice can magnetize the material," Morera explains.

In Imamoğlu's experiment this effect, known as Nagaoka mechanism among experts, could be detected for the first time in a solid by measuring, among other things, the magnetic susceptibility—that is, how strongly the material reacts to an external magnetic field.

"That detection was based on very strong evidence. For a direct proof, however, one would have to measure the state of the electrons—their position and spin direction—simultaneously in several places inside the material," says Demler.

Complex processes made visible

In a solid, however, this is not possible with conventional methods. At most, researchers can use X-ray or neutron diffraction to find out how the spins of the electrons relate to each other at two positions—the so-called spin correlation. Correlations between complex spin arrangements and additional or missing electrons cannot be measured in this way.

To still make the complex processes of the Nagaoka mechanism visible, which Demler and Morera had calculated using a model, they turned to colleagues in Harvard and Princeton. There, research teams led by Markus Greiner and Waseem Bakr have developed quantum simulators that can be used to precisely recreate the conditions inside a solid.

Instead of electrons moving inside a lattice made of atoms, in such simulators the U.S. researchers use extremely cold atoms trapped inside an optical lattice made of light beams. The mathematical equations describing the electrons inside the solid and the atoms inside the optical lattice, however, are almost identical.

Colored snapshots of the quantum system

Using a strongly magnifying microscope, Greiner's and Bakr's groups were able not only to resolve the positions of the individual atoms, but also their spin directions. They translated the information obtained from these snapshots of the quantum system into colored graphics that could be compared to the theoretical pointillist pictures.

Demler and his coworkers had theoretically calculated, for instance, how a single extra electron in the Nagaoka mechanism forms a pair with another electron of opposite spin and then moves through the triangular lattice of the material as a doublon.

According to the prediction of Demler and Morera, that doublon should be surrounded by a cloud of electrons whose spin directions are parallel, or ferromagnetic. Such a cloud is also known as a magnetic polaron.

That is exactly what the American researchers saw in their experiments. Moreover, if there was an atom missing in the crystal optical lattice of the quantum simulator—which corresponds to a missing electron or "hole" in the real crystal—then the cloud forming around that hole consisted of pairs of atoms whose spins pointed in opposite directions, just as Demler and Morera had predicted.

This antiferromagnetic order (or, more precisely: antiferromagnetic correlations) had also previously been indirectly detected in a solid state experiment at Cornell University in the U.S. In the quantum simulator, it now became directly visible.

"For the first time, we have solved a physics puzzle using experiments both on the 'real' solid as well as in the quantum simulator. Our theoretical work is the glue that holds everything together," says Demler. He is confident that in the future his method will also be useful for solving other tricky problems.

For instance, the mechanism that causes the magnetic polaron cloud to form could also play an important role in high temperature superconductors.

More information: Martin Lebrat et al, Observation of Nagaoka polarons in a Fermi–Hubbard quantum simulator, *Nature* (2024). DOI: [10.1038/s41586-024-07272-9](https://doi.org/10.1038/s41586-024-07272-9)

Max L. Prichard et al, Directly imaging spin polarons in a kinetically frustrated Hubbard system, *Nature* (2024). DOI: [10.1038/s41586-024-07356-6](https://doi.org/10.1038/s41586-024-07356-6)

Provided by ETH Zurich

A new paradigm for control of quantum emitters—modulating and encoding quantum photonic info on a single light stream

A U.S. Naval Research Laboratory (NRL) multi-disciplinary team developed a new paradigm for the control of quantum emitters, providing a new method for

modulating and encoding quantum photonic information on a single photon light stream.

Quantum photonics is expected to offer functionality not possible with classical light and promises significant advances in secure communications, metrology, sensing and quantum information processing and computation.

These applications impose many requirements on quantum emitter (QE) candidates, including deterministic creation and placement of the emitter, a high degree of single photon purity ranging from 90–100%, and a mechanism to control or modulate such emission.

The ability to modulate the character of the light emitted from these discrete emitters offers a mechanism for encoding information on a single photon stream, with applications in secure communications and quantum encryption schemes based upon single photon sources. This work was recently [published](#) in *ACS Nano*.

Quantum photonics is a science and technology that uses quantum optics for certain applications where quantum effects play an essential role. It involves generating, manipulating and detecting light in regimes where it is possible to coherently control individual quanta of the light field. QEs, also known as single photon emitters, are key components in this technology.

"Two dimensional materials such as monolayer tungsten disulfide and tungsten diselenide serve as hosts for QEs, and their planar, atomic layered structure offers many advantages as material platforms for quantum photonic circuits," said Berend Jonker, Ph.D., NRL senior scientist and principal investigator. "They can be readily integrated with other materials and substrates, and the proximity of the QE to the surface facilitates both extraction of the light as well as control of the emission by external effects."

The NRL team developed a nonvolatile and reversible procedure to control single photon emission purity in monolayer tungsten disulfide (WS_2) by integrating it with a ferroelectric material. They create an emitter in the WS_2 and are able to toggle the emission between high purity quantum light and semi-classical light by switching the ferroelectric polarization with a bias voltage. Localized emitters in the monolayer WS_2 over "up-domains" in the ferroelectric film emit high purity quantum light, while those over "down-domains" emit semi-classical light.

"This novel heterostructure introduces a new paradigm for control of quantum emitters by combining the nonvolatile ferroic properties of a ferroelectric with the radiative properties of the zero-dimensional atomic scale emitters embedded in the two-dimensional WS₂ semiconductor monolayer," Jonker said.

The samples studied consist of monolayer films of WS₂ grown by chemical vapor deposition and mechanically transferred onto a 260-nanometer film of an organic ferroelectric polymer, which had been previously transferred onto a highly doped silicon substrate. The scientists deterministically create and place quantum emitters within the WS₂ using the atomic force microscope (AFM) nanoindentation technique developed and patented by NRL.

"Achieving intimate contact between WS₂ and the ferroelectric film is crucial, and requires an ultra-smooth ferroelectric film surface," said Sungjoon Lee, Ph.D., an American Society for Engineering Education (ASEE) postdoctoral fellow working with Jonker. "Therefore, a spin-coating and flip-over process was used for the film."

"The organic ferroelectric polymer serves as a deformable polymer," said Ben Chuang, Ph.D. research physicist with NRL Materials Science and Technology Division. "When the AFM tip is removed, the WS₂ conforms to the contour of the nanoindent, and the local strain field activates single photon emission from atomic scale defect states in the WS₂."

For the top electrical contact, graphite was then transferred and partially covered the WS₂, and a conductive piezo force microscopy tip was used to apply a bias voltage to switch the polarization of the ferroelectric polymer beneath the WS₂.

The NRL research team consisted of Sungjoon Lee, Ph.D., a postdoctoral fellow; Hsun-jen Chuang, Ph.D., research physicist; Kathy McCreary, Ph.D., research physicist; Dante O'Hara, Ph.D., materials engineer; Berend Jonker, Ph.D., senior scientist; all of the NRL Materials S&T Division; and Andrew Yeats, Ph.D., research physicist with NRL Electronic S&T Division.

More information: Sung-Joon Lee et al, Ferroelectric Modulation of Quantum Emitters in Monolayer WS₂, *ACS Nano* (2024). DOI: [10.1021/acsnano.4c10528](https://doi.org/10.1021/acsnano.4c10528)

Provided by Naval Research Laboratory

Gravitational waves and the geometry of spacetime

When speaking of our universe, it's often said that "matter tells spacetime how to curve, and curved spacetime tells matter how to move." This is the essence of Albert Einstein's famous general theory of relativity, and describes how planets, stars, and galaxies move and influence the space around them. While general relativity captures much of the big in our universe, it's at odds with the small in physics as described by quantum mechanics.

For his [Ph.D. research](#), Sjors Heefer has explored gravity in our universe, with his research having implications for the exciting field of gravitational waves, and perhaps influencing how the big and small of physics can be reconciled in the future.

A little over a hundred years ago, Albert Einstein revolutionized our understanding of gravity with his general theory of relativity.

"According to Einstein's theory, gravity is not a force but emerges due to the geometry of the four-dimensional spacetime continuum, or spacetime for short," says Heefer. "And it's central to the emergence of fascinating phenomena in our universe such as gravitational waves."

Massive objects, such as the sun or galaxies, warp spacetime around them, and other objects then move along the straightest possible paths—otherwise known as geodesics—through this curved spacetime.

Due to the curvature, however, these geodesics are not straight in the usual sense at all. In the case of the planets in the solar system, for instance, they describe elliptical orbits around the sun. In this way, general relativity elegantly explains the movement of the planets as well as numerous other gravitational phenomena, ranging from everyday situations to black holes and the Big Bang. As such, it remains a cornerstone of modern physics.

Clash of the theories

While general relativity describes a host of astrophysical phenomena, it clashes with another fundamental theory of physics—quantum mechanics.

"Quantum mechanics suggests that particles (like electrons or muons) exist in multiple states at the same time until they are measured or observed," says Heefer. "Once measured, they randomly select a state due to a mysterious effect referred to as the 'collapse of the wave function.'"

In quantum mechanics, a wave function is a mathematical expression that describes the position and state of a particle, such as an electron. And the square of the wave function leads to a collection of probabilities of where the particle might be located. The larger the square of the wave function at a particular location, the higher the probability that a particle will be located at that location once it is observed.

"All matter in our universe appears to be subject to the strange probabilistic laws of quantum mechanics," Heefer notes. "And the same is true for all forces of nature—except for gravity. This discrepancy leads to deep philosophical and mathematical paradoxes, and resolving these is one of the primary challenges in fundamental physics today."

Is expansion the solution?

One approach to resolving the clash of general relativity and quantum mechanics is to expand the mathematical framework behind general relativity.

In terms of mathematics, general relativity is based on pseudo-Riemannian geometry, which is a mathematical language capable of describing most of the typical shapes that spacetime can take.

"Recent discoveries indicate, however, that our universe's spacetime might be outside the scope of pseudo-Riemannian geometry and can only be described by Finsler geometry, a more advanced mathematical language," says Heefer.

Field equations

To explore the possibilities of Finsler gravity, Heefer needed to analyze and solve a certain field equation.

Physicists like to describe everything in nature in terms of fields. In physics, a field is simply something that has a value at each point in space and time.

A simple example would be temperature, for instance; at any given point in time, each point in space has a certain temperature associated with it.

A slightly more complex example is that of the electromagnetic field. At any given point in time, the value of the electromagnetic field at a certain point in space tells us the direction and magnitude of the electromagnetic force that a charged particle, like an electron, would experience if it were located at that point.

When it comes to the geometry of spacetime itself, that is also described by a field, namely the gravitational field. The value of this field at a point in spacetime tells us the curvature of spacetime at that point, and it is this curvature that manifests itself as gravity.

Heefer turned to the Christian Pfeifer and Mattias N. R. Wohlfarth's vacuum field equation, which is the equation that governs this gravitational field in empty space. In other words, this equation describes the possible shapes that the geometry of spacetime could take in the absence of matter.

Heefer explains, "To good approximation, this includes all interstellar space between stars and galaxies, as well as the empty space surrounding objects such as the sun and the Earth. By carefully analyzing the field equation, several new types of spacetime geometries have been identified."

Gravitational waves confirmation

One particularly exciting discovery from Heefer's work involves a class of spacetime geometries that represent gravitational waves—ripples in the fabric of

spacetime that propagate at the speed of light and can be caused by the collision of neutron stars or black holes, for example.

The first direct detection of gravitational waves on September 14, 2015, marked the dawn of a new era in astronomy, allowing scientists to explore the universe in an entirely new way.

Since then, many observations of gravitational waves have been made. Heefer's research indicates that these are all consistent with the hypothesis that our spacetime has a Finslerian nature.

Scratching the surface

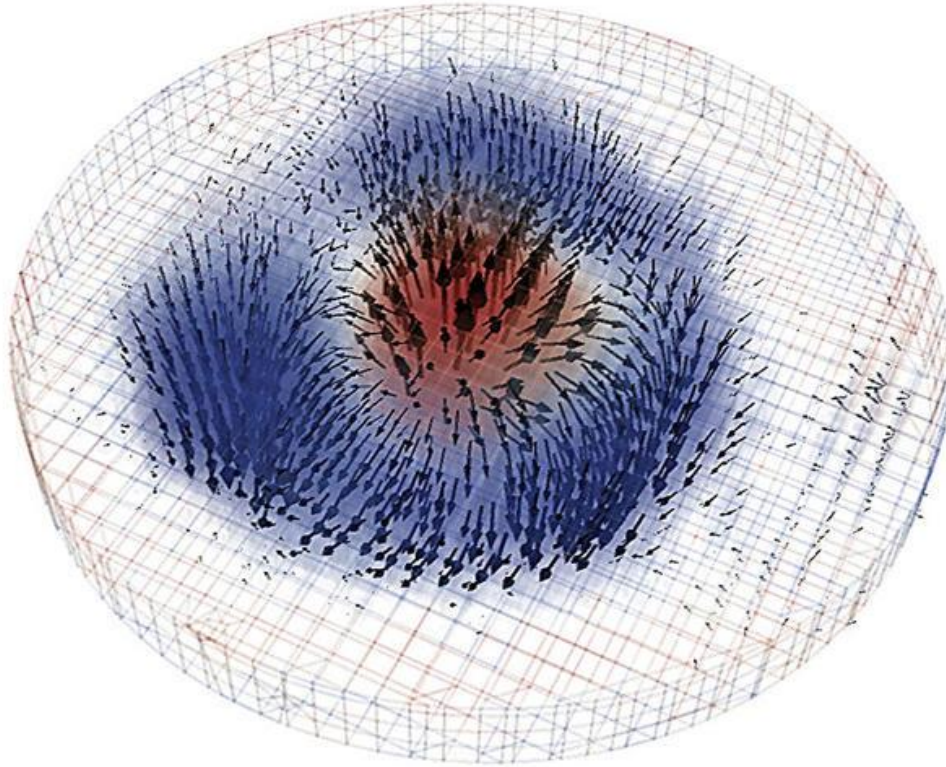
While Heefer's results are promising, they only scratch the surface of the implications of the field equation of Finsler gravity.

"The field is still young and further research in this direction is actively ongoing," says Heefer. "I'm optimistic that our results will prove instrumental in deepening our understanding of gravity and I hope that, eventually, they may even shine light on the reconciliation of gravity with quantum mechanics."

More information: S.J. Heefer, [Finsler Geometry, Spacetime & Gravity](#) (2024)

Provided by Eindhoven University of Technology

Researchers succeed in taking 3D X-ray images of a skyrmion



A difficult-to-describe nanoscale object called the magnetic skyrmion might one day yield new microelectronic devices that can do much more—for example, massive data storage—all while consuming much less power.

But researchers need a more detailed understanding of skyrmions if they are ever to be used reliably in computational devices, including quantum computers. Peter Fischer, a senior researcher at the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab), led a project to make 3D X-ray images of skyrmions that can characterize or measure the orientations of spins inside the whole object.

"Our results provide a foundation for nanoscale metrology for spintronics devices," Fischer said. The work was recently [published](#) in *Science Advances*.

Magnetic skyrmions can be thought of as spinning circles of magnetism, explains David Raftrey, a student researcher in Fischer's team who was the lead author of this study. At the center, the magnetic spin is pointing upward, while moving out from the center, the magnetism twists and pulls in a downward direction. What's more, skyrmions are stable, small, fast, and not easily unfolded, a trait materials scientists dub "topological."

These spin directions are part of the appeal of skyrmions because they might be used to carry and store information in much the same way that electrons carry and store information in current devices. "However, relying on the charge of the electron, as it is done today, comes with inevitable energy losses. Using spins, the losses will be significantly lower," Fischer said.

But theoretical knowledge of skyrmions has been based on descriptions of them as 2D objects. In the real world of electronics and silicon wafers—no matter how thin—skyrmions have to be dealt with as 3D objects. To put skyrmions to work, or perhaps to one day synthesize custom skyrmions, researchers must be able to examine and understand their spin characteristics throughout the whole 3D object.

If you are looking at a skyrmion magnetic whirlpool from the top and start slicing off layers, you might think that each successive layer would be the same. "But that's not the case," Raftrey said. "And we said, okay, how can we get our arms around this? How do we actually demonstrate this?"

Raftrey took a thin magnetic layer, which was synthesized by colleagues from Western Digital, and patterned a nanodisk using the Molecular Foundry's nanofabrication facility. To obtain 3D tomographic images, he traveled to Switzerland to use a novel imaging technique called magnetic X-ray laminography at a microscopy beamline at the Swiss Light Source.

With X-ray laminography, "You can basically reconfigure and reconstruct [the skyrmion] from these many, many images and data," Raftrey said. It was a process that took months, finally yielding a better understanding of skyrmion spin structures.

A full understanding of skyrmions' 3D spin texture "opens opportunities to explore and tailor 3D topological spintronic devices with enhanced functionalities that cannot be achieved in two dimensions," Fischer said.

More information: David Raftrey et al, Quantifying the topology of magnetic skyrmions in three dimensions, *Science Advances* (2024). DOI: [10.1126/sciadv.adp8615](https://doi.org/10.1126/sciadv.adp8615)

Provided by Lawrence Berkeley National Laboratory

Theoretical physicists develop method to model a central theory of quantum gravity in the laboratory

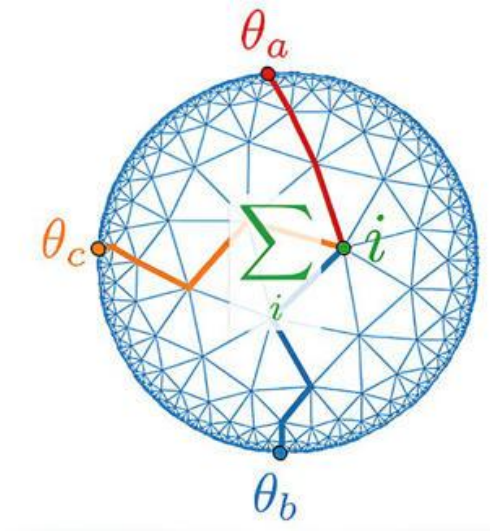


Illustration of the theory used to model quantum gravity: The lattice simulates a curved space-time—near the boundary, the lattice is denser due to the curvature. The interacting electrical signals (yellow, red and blue lines) in the bulk simulate the gravitational dynamics. The dynamics in the bulk and at the outer boundary correspond to each other. They are consistent with the AdS/CFT correspondence. Credit: Erdmenger/JMU, Böttcher/Alberta

Gravity is no longer a mystery to physicists—at least when it comes to large distances. Thanks to science, we can calculate the orbits of planets, predict tides, and send rockets into space with precision. However, the theoretical description of gravity reaches its limits at the level of the smallest particles, the so-called quantum level.

"To explain the Big Bang or the interior of black holes, we have to understand the quantum properties of gravity," explains Professor Johanna Erdmenger, Chair of Theoretical Physics III at the University of Würzburg (JMU) in Bavaria, Germany.

"At very high energies, the classical laws of gravity fail. Therefore, our goal is to contribute to the development of new theories that can explain gravity at all scales, including at the quantum level."

The central theory of quantum gravity

The AdS/CFT correspondence, a central theory of quantum gravity, plays an important role in the development of new models. It states that complex gravitational theories in a high-dimensional space can be described by simpler quantum theories at the boundary of that space.

AdS stands for Anti-de-Sitter, a special type of spacetime that is curved inward, like a hyperbola. CFT stands for conformal field theory, which describes quantum physical systems whose properties are the same at all spatial distances.

"This sounds very complicated at first, but it's easy to explain," says Erdmenger.

"The AdS/CFT correspondence allows us to understand difficult gravitational processes, such as those that exist in the quantum world, using simpler mathematical models. At its heart is a curved spacetime, which can be thought of as a funnel.

"The correspondence states that the quantum dynamics at the edge of the funnel must correspond to the more complex dynamics inside—similar to a hologram on a banknote, which generates a three-dimensional image even though it is only two-dimensional itself.

Proof of concept for realizing gravitational dynamics in the laboratory

Together with her team, Erdmenger has now developed a method to experimentally test the predictions of the previously unconfirmed AdS/CFT correspondence. A branched electrical circuit is used to mimic curved space-time—the electrical signals at the individual branch points of the circuit correspond to the gravitational dynamics that would be found at different points in space-time.

The study is [published](#) in the journal *Physical Review Letters*.

The theoretical calculations of the research team show that in the proposed circuit, the dynamics at the edge of the mimicked spacetime also correspond to those inside—and thus a central prediction of the AdS/CFT correspondence can be realized by the circuit.

As a next step, the Würzburg research team now plans to put the experimental setup described in the study into practice. In addition to significant advances in gravitational research, this could also lead to technical innovations.

"Our circuits also open up new technological applications," explains Erdmenger. "Based on quantum technology, they are expected to transmit electrical signals with reduced loss, since the simulated curvature of space bundles and stabilizes the signals. This would be a breakthrough for signal transmission in neural networks used for artificial intelligence, for example."

More information: Santanu Dey et al, Simulating Holographic Conformal Field Theories on Hyperbolic Lattices, *Physical Review Letters* (2024). DOI: [10.1103/PhysRevLett.133.061603](https://doi.org/10.1103/PhysRevLett.133.061603). On *arXiv*: DOI: [10.48550/arxiv.2404.03062](https://doi.org/10.48550/arxiv.2404.03062)

Provided by Julius-Maximilians-Universität Würzburg

A mathematical bridge between the huge and the tiny

A mathematical link between two key equations—one that deals with the very big and the other, the very small—has been developed by a young mathematician in China.

The mathematical discipline known as differential geometry is concerned with the geometry of smooth shapes and spaces. With roots going back to antiquity, the field flourished in the early 20th century, enabling Einstein to develop his general theory of relativity and other physicists to develop quantum field theory and the Standard Model of particle physics.

Gao Chen, a 29-year-old mathematician at the University of Science and Technology of China in Hefei, specializes in a branch known as complex differential geometry. Its complexity is not in dealing with complicated structures, but rather because it is based on complex numbers—a system of numbers that extends everyday numbers by including the square root of -1 .

This area appeals to Chen because of its connections with other fields. "Complex differential geometry lies at the intersection of analysis, algebra, and mathematical physics," he says. "Many tools can be used to study this area."

Chen has now found a new link between two important equations in the field: the Kähler–Einstein equation, which describes how mass causes curvature in space–time in general relativity, and the Hermitian–Yang–Mills equation, which underpins the Standard Model of particle physics.

Chen was inspired by his Ph.D. supervisor Xiuxiong Chen of New York's Stony Brook University, to take on the problem. "Finding solutions to the Hermitian–Yang–Mills and the Kähler–Einstein equations are considered the most important

advances in complex differential geometry in previous decades," says Gao Chen. "My results provide a connection between these two key results."

"The Kähler–Einstein equation describes very large things, as large as the universe, whereas the Hermitian–Yang–Mills equation describes tiny things, as small as quantum phenomena," explains Gao Chen. "I've built a bridge between these two equations." Gao Chen notes that other bridges existed previously, but that he has found a new one.

"This bridge provides a new key, a new tool for theoretical research in this field," Gao Chen adds. His paper describing this bridge was [published](#) in the journal *Inventiones mathematicae* in 2021.

In particular, the finding could find use in string theory—the leading contender of theories that researchers are developing in their quest to unite quantum physics and relativity. "The deformed Hermitian–Yang–Mills equation that I studied plays an important role in the study of string theory," notes Gao Chen.

Gao Chen now has his eyes set on other important problems, including one of the seven Millennium Prize Problems. These are considered the most challenging in the field by mathematicians and carry a \$1 million prize for a correct solution. "In the future, I hope to tackle a generalization of the Kähler–Einstein equation," he says. "I also hope to work on other Millennium Prize problems, including the Hodge conjecture."

Provided by University of Science and Technology of China

Quantum vortices confirm superfluidity in supersolid

Simulation of quantum vortices superimposed with experimental data. Credit: University of Innsbruck, Austria

Supersolids are a new form of quantum matter that has only recently been demonstrated. The state of matter can be produced artificially in ultracold, dipolar quantum gases. A team led by Innsbruck physicist Francesca Ferlaino has now demonstrated a missing hallmark of superfluidity, namely the existence of quantized vortices as a system's response to rotation. They have observed tiny quantum vortices in the supersolid, which also behave differently than previously assumed.

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

Matter that behaves like both a solid and a superfluid at the same time seems impossible. Yet, more than 50 years ago, physicists predicted that quantum mechanics allows such a state, where a collection of indistinguishable particles can simultaneously exhibit seemingly contradictory properties.

"It is a bit like Schrödinger's cat, which is both alive and dead, a supersolid is both rigid and liquid," explains Francesca Ferlaino from the Department of Experimental Physics at the University of Innsbruck and the Institute of Quantum Optics and Quantum Information (IQOQI) of the Austrian Academy of Sciences (ÖAW).

While the crystalline arrangement giving rise to the "solid" nature of supersolids has been directly imaged, the superfluid properties are much more elusive. While researchers have probed various aspects of superfluid behavior, such as phase coherence and gapless Goldstone modes, direct evidence of one of superfluidity's defining features—quantized vortices—has remained elusive.

Now, in a major breakthrough, quantized vortices have finally been observed in a rotating two-dimensional supersolid, providing the long-awaited confirmation of irrotational superfluid flow into a supersolid and marking a critical step forward in the study of modulated quantum matter.

Challenging experiment

In this new study, scientists combined theoretical models with cutting-edge experiments to create and observe vortices in dipolar supersolids—a feat that proved extraordinarily challenging. The Innsbruck team had previously achieved a breakthrough in 2021 by creating the first long-lived two-dimensional supersolid in an ultracold gas of erbium atoms, which was a difficult task in itself.

"The next step—developing a way to stir the supersolid without destroying its fragile state—required even greater precision," explains lead author Eva Casotti.

Using high-precision techniques guided by theory, the researchers employed magnetic fields to carefully rotate the supersolid. Because liquids do not rotate rigidly, this stirring caused the formation of quantized vortices, which are the hydrodynamic fingerprint of superfluidity.

"This work is a significant step forward in understanding the unique behavior of supersolids and their potential applications in the field of quantum matter," adds Francesca Ferlaino.

Moreover, the experiment took nearly a year, revealing significant differences between the dynamics of vortices in supersolids and unmodulated quantum fluids, and offering fresh insight into how the superfluid and solid characteristics coexist and interact in these exotic quantum states.

Exploring new physics

The implications of this discovery reach far beyond the laboratory, potentially impacting fields ranging from condensed matter physics to astrophysics, where similar quantum phases may exist under extreme conditions.

"Our findings open the door to studying the hydrodynamic properties of exotic quantum systems with multiple broken symmetries, such as quantum crystals and even neutron stars," said Thomas Bland, who guided the theoretical development of the project.

"For instance, it is assumed that the change in rotational speed observed in neutron stars—so-called glitches—are caused by superfluid vortices trapped inside neutron stars. Our platform offers the opportunity to simulate such phenomena right here on Earth. Superfluid vortices are also believed to exist in superconductors, which can conduct electricity without loss. "

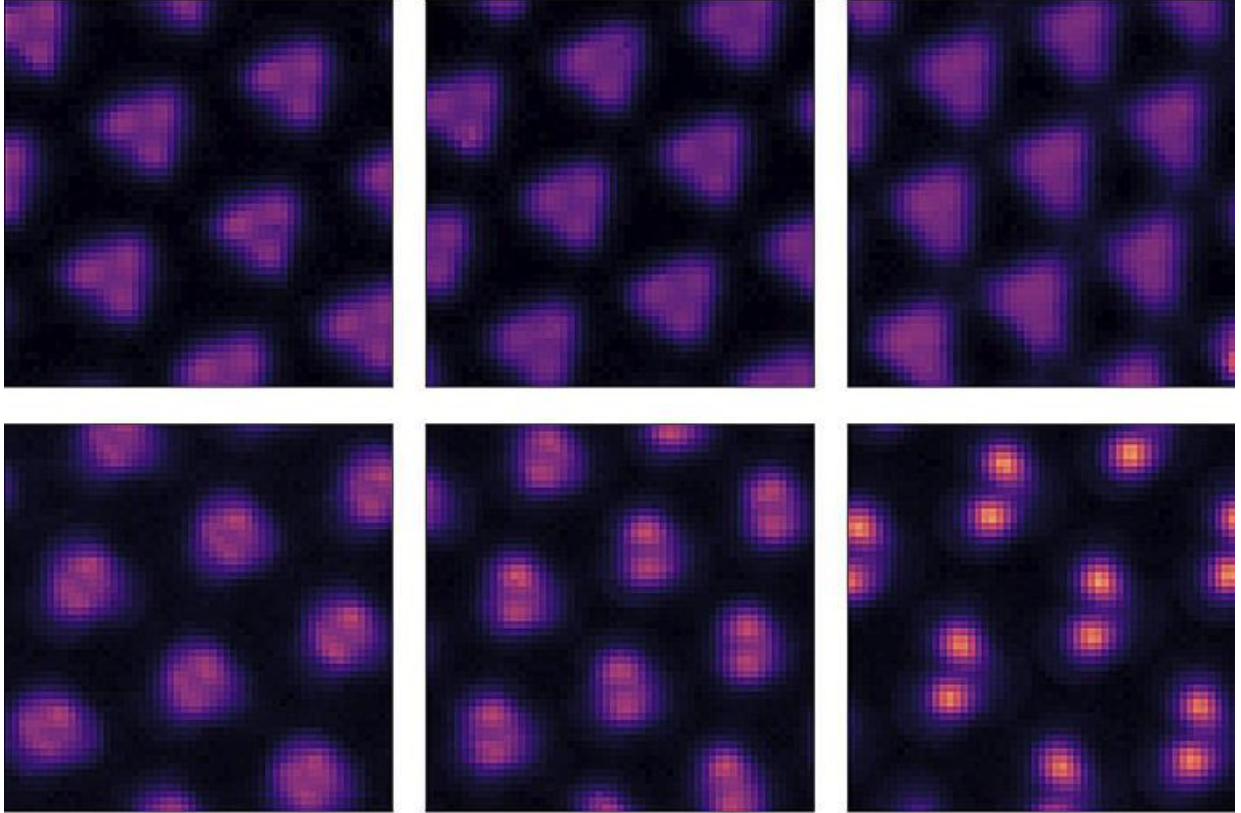
Our work is an important milestone on the way to investigating new physics," says Francesca Ferlaino.

"We can observe physical phenomena here in the lab that occur in nature only under very extreme conditions, such as in neutron stars."

More information: Eva Casotti et al, Observation of vortices in a dipolar supersolid, *Nature* (2024). DOI: [10.1038/s41586-024-08149-7](https://doi.org/10.1038/s41586-024-08149-7).
www.nature.com/articles/s41586-024-08149-7.
On *arXiv*: arxiv.org/abs/2403.18510

Provided by University of Innsbruck

Scientists capture images of a new quantum phase in electron molecular crystals



From top left: Scanning tunneling microscope images of electrons evolving into a single Wigner molecule (bottom right). Credit: Berkeley Lab

Electrons typically travel at high speeds, zipping through matter unbound. In the 1930s, physicist Eugene Wigner predicted that electrons could be coaxed into stillness at low densities and cold temperatures, forming an electron ice that would later be called the Wigner crystal.

Ninety years later, in 2021, a team led by Feng Wang and Michael Crommie, Berkeley Lab senior faculty scientists in the Materials Sciences Division and UC Berkeley physics professors, provided direct evidence that these electron crystals exist.

Now Wang, Crommie, and their teams have captured direct images of a new quantum phase of an electron solid—the Wigner molecular crystal.

Their [findings](#) were reported in the journal *Science*.

Whereas Wigner crystals or electron ice are characterized by a honeycomb arrangement of electrons, Wigner molecular crystals have a highly ordered pattern of artificial "molecules" made of two or more electrons.

"We are the first to directly observe this new quantum phase, which was quite unexpected," Wang said. "It's pretty exciting."

For many years, scientists have tried to capture direct images of the Wigner molecular crystal, but their progress has been hindered by the tendency of the STM tip to destroy the material's electron configuration.

In the new study, the Berkeley Lab researchers overcame this hurdle by minimizing the electric field from the STM tip, an advance that allowed them to see the Wigner molecular crystal's delicate electronic structure.

During experiments at Wang's lab, they formed a nanomaterial called a "twisted tungsten disulfide (tWS_2) moiré superlattice" by placing an atomically thin bilayer of tungsten disulfide (WS_2) on top of a 49-nanometer-thick layer of hBN (hexagonal boron nitride) and a graphite back gate. The WS_2 layers are stacked on top of each other at a 58-degree twist angle.

Using their STM technique, they found that doping the tWS_2 moiré superlattice with electrons filled each 10-nanometer-wide unit cell of the material with just two or three electrons. And in a surprising result, these filled unit cells formed an array of moiré electron molecules throughout the superlattice—resulting in a Wigner molecular crystal.

"Low temperatures along with the energy potential created by the tWS_2 moiré superlattice confine the electrons locally," Wang explained, adding that "the interplay between quantum mechanics and the electron-electron interaction drives the localized electrons into Wigner molecule states."

In future experiments, Wang, Crommie, and team hope to use their new STM technique to gain a better understanding of this new quantum phase and see what potential applications it could lead to.

More information: Hongyuan Li et al, Wigner molecular crystals from multielectron moiré artificial atoms, *Science* (2024). DOI: [10.1126/science.adk1348](https://doi.org/10.1126/science.adk1348). On *arXiv*: DOI: [10.48550/arxiv.2312.07607](https://doi.org/10.48550/arxiv.2312.07607)

Provided by Lawrence Berkeley National Laboratory

Historic breakthrough in quantum mechanics and gravity research

Physicists at [Purdue University](#) have achieved a significant breakthrough by creating a unique experimental setup involving levitated fluorescent nanodiamonds. These tiny diamonds are not just floating in a vacuum; they're spinning at incredibly high speeds, emitting and scattering multicolored lights as they rotate.

This research, led by Tongcang Li, a professor at Purdue, marks an exciting advancement in the study of rotating quantum systems and levitodynamics, with their results published in [Nature Communications](#). Reviewers have hailed the work as "arguably a groundbreaking moment" and "a new milestone for the levitated optomechanics community."

Li, who is also a member of the Purdue Quantum Science and Engineering Institute, explains the significance of their work. "Inside these floating diamonds, there are spin qubits that allow us to make precise measurements and explore the mysterious relationship between [quantum mechanics](#) and gravity.

Previous experiments faced challenges in preventing the diamonds' loss in vacuum and in reading out the spin qubits. However, in our work, we successfully levitated a diamond in a high vacuum using a special ion trap and, for the first time, observed and controlled the behavior of the spin qubits inside the levitated diamond."

Stable levitation of a nanodiamond in high vacuum. (CREDIT: Nature Communications)© The Brighter Side of News

By rotating these diamonds at speeds of up to 1.2 billion times per minute, the team could observe the unique effect of rotation on the spin qubits, known as the Berry phase. Li highlights that this achievement deepens our understanding of the [quantum world](#).

The nanodiamonds used in the experiment have an average diameter of about 750 nanometers. These diamonds were produced through a high-pressure, high-temperature synthesis process, followed by irradiation with [high-energy electrons](#) to create nitrogen-vacancy color centers, which host the electron spin qubits.

When illuminated by a green laser, the diamonds emit red light, which is used to read out their electron spin states. Additionally, an infrared laser is used to monitor the diamonds' rotation. As the nanodiamonds rotate, they scatter infrared light in different directions, similar to how a disco ball scatters light, which provides information about the rotation.

Related Stories

[Mercury has a 10-mile thick layer of diamonds hidden beneath its surface, NASA discovers](#)
[World's first diamond transistor paves the way towards high-speed computing](#)

The research team primarily consists of members from Li's research group at Purdue, including postdoc Yuanbin Jin, PhD students Kunhong Shen and Xingyu Gao, and recent PhD graduate Peng Ju. Jin, Shen, and Ju were instrumental in

conceiving and designing the project, while Jin and Shen built the experimental setup.

The team collectively discussed the results, with contributions from Alejandro Grine of Sandia National Laboratories and Chong Zu from [Washington University in St. Louis](#), who offered suggestions to improve the experiment and manuscript.

Jin explains the technical aspects of their work: "For the design of our integrated surface ion trap, we used commercial software to perform [3D simulations](#). We optimized the design by calculating the trapping position and microwave transmittance using different parameters. We also added extra electrodes to conveniently control the motion of a levitated diamond. The surface ion trap is fabricated on a sapphire wafer using photolithography, and a 300-nanometer-thick gold layer is deposited on the wafer to create the electrodes."

Fast rotation of a levitated nanodiamond. (CREDIT: Nature Communications)© The Brighter Side of News

Shen adds that they have the capability to adjust the [spinning direction](#) of the diamonds. "We can change the spinning direction by adjusting the driving voltage. The levitated diamond can rotate around the z-axis, either clockwise or counterclockwise, depending on our driving signal. Without the driving signal, the diamond spins in multiple directions, like a ball of yarn."

Levitated nanodiamonds with embedded spin qubits are promising for precision measurements and could help create large [quantum superpositions](#) to test the limits of quantum mechanics and gravity.

Li underscores the importance of this work: "General relativity and quantum mechanics are two of the most important scientific breakthroughs of the 20th century. However, we still do not know how gravity might be quantized. Studying quantum gravity experimentally would be a tremendous breakthrough. Rotating diamonds with embedded spin qubits provide a platform to explore the coupling between mechanical motion and quantum spins."

This discovery could have broader implications for industrial applications. Li mentions that levitated micro- and nano-scale particles in vacuum could serve as excellent accelerometers and electric field sensors. For instance, the US Air Force Research Laboratory is already using optically-levitated [nanoparticles](#) to address critical issues in navigation and communication.

Effects of the Berry phase generated by a rotating nanodiamond. (CREDIT: Nature Communications)© The Brighter Side of News

Li also notes that Purdue University is well-equipped for such research. "At Purdue, we have state-of-the-art facilities for our work in levitated optomechanics. We have two specialized, home-built systems dedicated to this area of study. Additionally, we have access to the Birck Nanotechnology Center, which enables us to fabricate and characterize the integrated surface ion trap on campus."

"We're fortunate to have talented students and postdocs capable of conducting cutting-edge research. My group has been working in this field for ten years, and our extensive experience has allowed us to make rapid progress," he continued.

This research is a part of Purdue's broader focus on quantum technologies, a key pillar of the Purdue Computes initiative, which emphasizes the university's commitment to advancing technological and computational research.

After a 50-Year Search, Scientists Have Discovered Fluidity in the Supersolid State



Scientists have officially spotted characteristics of superfluidity (a quantum fluid with zero viscosity) inside a two-dimensional supersolid for the first time. © Floriana - Getty Images

- Scientists have officially spotted characteristics of superfluidity (a quantum fluid with zero viscosity) inside a two-dimensional supersolid for the first time.
- In a new study, physicists from the University of Innsbruck in Austria used magnetic fields to carefully stir a supersolid of erbium atoms and spotted quantum vortices.
- This will help scientists study the characteristics of supersolids under extreme conditions while also examining certain aspects of celestial objects like neutron stars.

As a kid, you probably learned that there are three states of matter: solid, liquid, and gas. But like most things in life, it gets a bit more complicated as you get older. For example, super hot plasma powering the Sun (and, hopefully, future fusion reactors) is an important fourth state of matter, and the fifth—the super-

cold [Bose-Einstein Condensates](#)—helps scientists study the nature of the quantum world.

But it gets even more complicated. Within these states of matter reside other, potentially even more counterintuitive objects. Take, for example, the supersolid—a material that’s both a [superfluid](#) (exotic matter with zero viscosity) *and* a solid. The existence of this bizarre example of matter was first hypothesized more than half a century ago, but examining a supersolid’s free-flowing atoms through its crystalline lattice has been an extremely difficult undertaking. Now, scientists from University of Innsbruck in Austria state in a new paper (published [in the journal Nature](#)) that they’ve successfully stirred a two-dimensional supersolid and observed “quantum vortices”—a phenomenon that physicist Francesca Ferlaino [told AFP](#) is the “smoking gun of superfluidity.”

“It is a bit like Schrödinger’s cat, which is both alive and dead, a supersolid is both rigid and liquid,” Ferlaino said [in a press statement](#). “This work is a significant step forward in understanding the unique behavior of supersolids and their potential applications in the field of quantum [matter](#).”

The first stage of this remarkable breakthrough actually occurred back in 2021, when Ferlaino’s team developed the first long-lived, two-dimensional supersolid out of an ultracold gas of erbium atoms, a [rare-earth metal](#). At the time, supersolids had only been observed as a series of droplets in one dimension. The team hoped that this first breakthrough could allow for the study of vortices within the supersolid itself. While that hope wasn’t misplaced, observing those quantum tornadoes was far from simple.

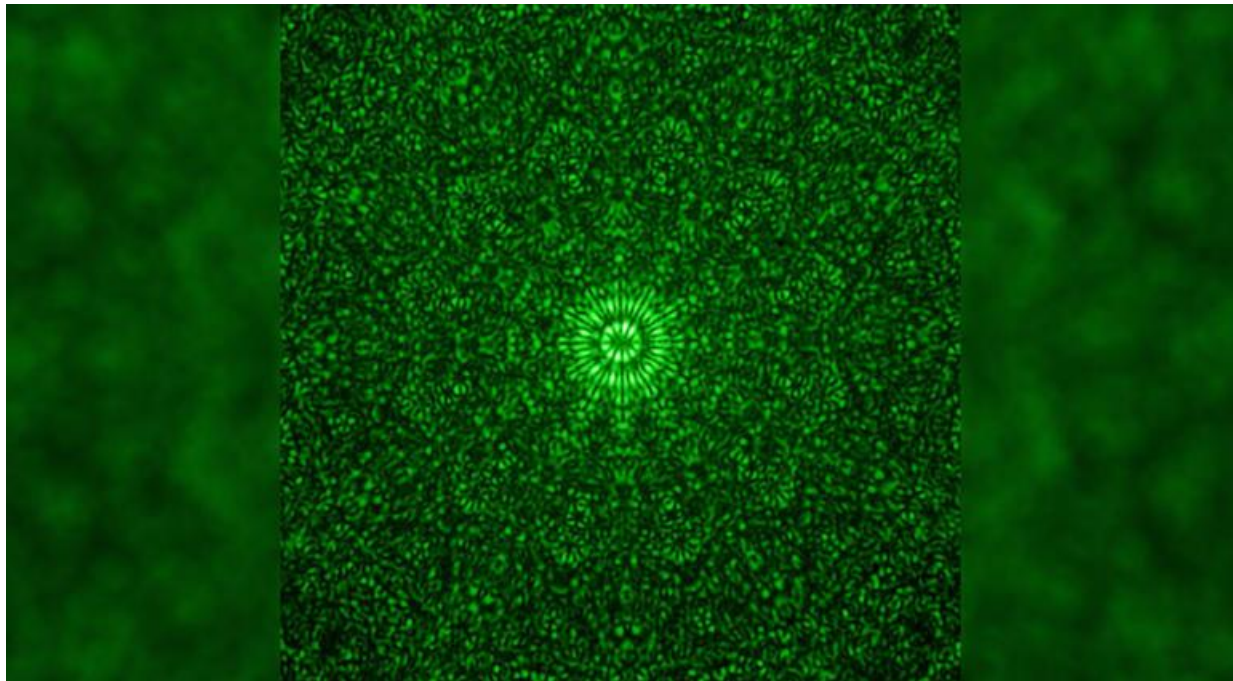
“The next step—developing a way to stir the [supersolid](#) without destroying its fragile state—required even greater precision,” Eva Casotti, lead author of the study, said in a press statement.

The team used magnetic fields to deftly rotate the supersolid, and because liquids within the lattice of the supersolid don’t rotate rigidly, this high-precision movement created quantum vortices that are a tell-tale sign of superfluidity. The discovery of this phenomenon has big implications for laboratory studies of supersolid dynamics in exotic conditions, but it could also help answer some questions about one of the most extreme celestial objects in the known universe: the [neutron star](#).

"It is assumed that the change in rotational speed observed in neutron stars—so-called glitches—are caused by superfluid vortices trapped inside neutron stars," Thomas Bland, co-author of the study, said in a press statement. "Our platform offers the opportunity to simulate such phenomena right here on [Earth](#)."

Considering that the [surface of a neutron star](#) would vaporize the [human body](#) immediately, studying their physical characteristics from afar seems like a good idea.

Physicists create tiny hurricanes of light that could transport huge amounts of data

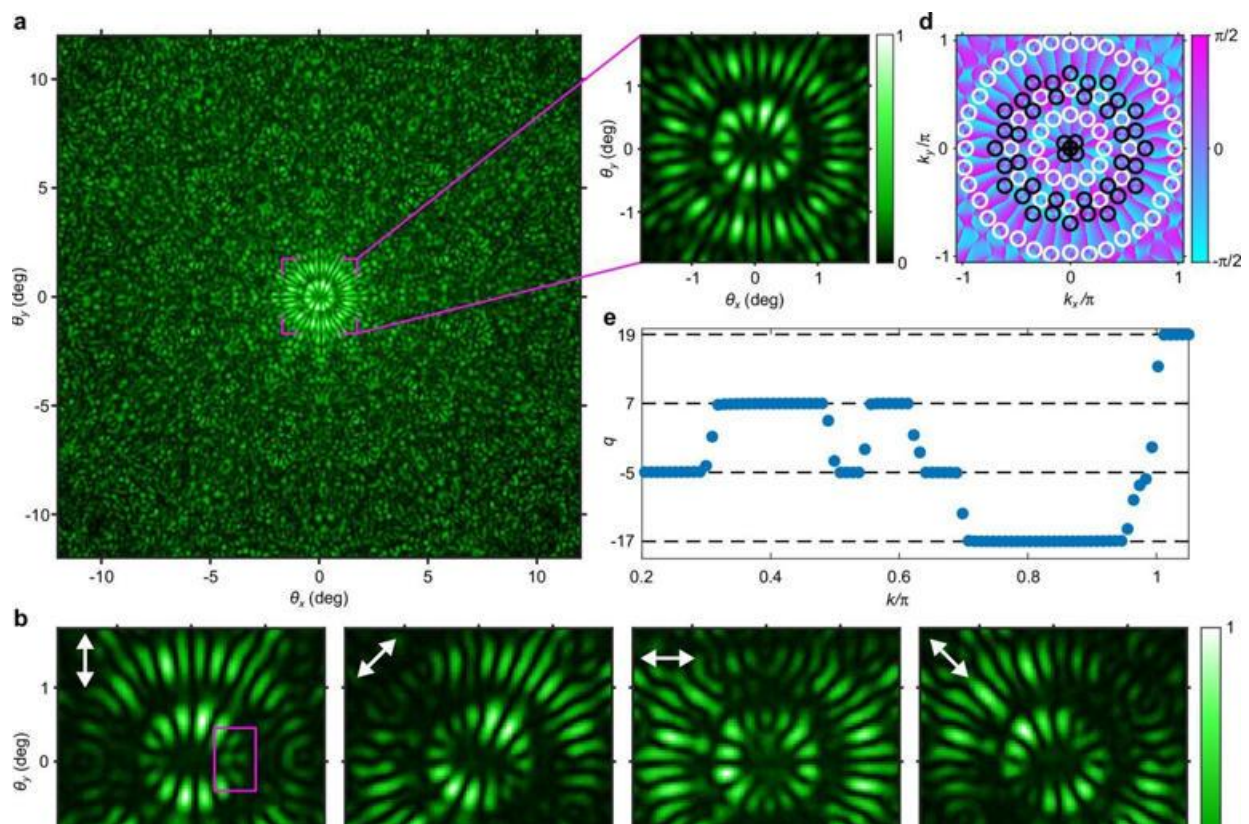


The new quasicrystal design method allows for theoretically any kind of vortex. Credit: Kristian Arjas/Aalto University.

Much of modern life depends on the coding of information into means of delivering it. A common method is to encode data in laser light and send it through optic cables. The increasing demand for more information capacity demands that we constantly find better ways of encoding it.

Researchers at Aalto University's Department of Applied Physics have found a new way to create tiny hurricanes of light—known to scientists as vortices—that can carry information. The method is based on manipulating metallic nanoparticles that interact with an electric field.

The design method, belonging to a class of geometries known as quasicrystals, was conceived by Doctoral Researcher Kristian Arjas and experimentally realized by Doctoral Researcher Jani Taskinen, both from Professor Päivi Törmä's Quantum Dynamics group. The discovery represents a fundamental step forward in physics and carries the potential for entirely new ways of transmitting information.



High topological charge lasing in plasmonic quasicrystal modes. Credit: Nature Communications (2024). DOI: 10.1038/s41467-024-53952-5

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

Half order and chaos

A vortex is—in this case—like a hurricane that occurs in a beam of light, where a calm and dark center is surrounded by a ring of bright light. Just like the eye of a hurricane is calm due to the winds around it blowing in different directions, the eye of the vortex is dark due to the electric field of bright light pointing to different directions on different sides of the beam.

Previous physics research has connected what kind of vortices can appear with how much symmetry there is in the structure that produces them. For example, if particles in the nanoscale are arranged in squares, the produced light has a single vortex; hexagons produce a double vortex and so on. More complex vortices require at least octagonal shapes.

Now Arjas, Taskinen and the team unlocked a method for creating geometric shapes that theoretically support any kind of vortex.

"This research is on the relationship between the symmetry and the rotationality of the vortex, i.e. what kinds of vortices can we generate with what kinds of symmetries. Our quasicrystal design is halfway between order and chaos," Törmä says.

Good vibrations

In their study, the group manipulated 100,000 metallic nanoparticles, each roughly the size of a hundredth of a single strand of human hair, to create their unique design. The key lay in finding where the particles interacted with the desired electric field the least instead of the most.

"An electrical field has hotspots of high vibration and spots where it is essentially dead. We introduced particles into the dead spots, which shut down everything else and allowed us to select the field with the most interesting properties for applications," Taskinen says.

The discovery opens a wealth of future research in the very active field of topological study of light. It also represents the early steps for a powerful way of

transmitting information in domains where light is needed to send encoded information, including telecommunications.

"We could, for example, send these vortices down optic fiber cables and unpack them at the destination. This would allow us to store our information in a much smaller space and transmit much more information at once. An optimistic guess for how much would be eight to sixteen times the information we can now deliver over optic fiber," Arjas says.

Practical applications and scalability of the team's design are likely to take years of engineering. The Quantum Dynamics group at Aalto, however, have their hands full with research into superconductivity and improving organic LEDs.

The group used the OtaNano research infrastructure for nano-, micro- and quantum technologies in their study.

More information: Kristian Arjas et al, High topological charge lasing in quasicrystals, *Nature Communications* (2024). DOI: [10.1038/s41467-024-53952-5](https://doi.org/10.1038/s41467-024-53952-5)

Provided by Aalto University

Quantum vortices confirm superfluidity in supersolid. First-ever observation of mini-tornadoes in supersolid quantum gas. The implications of this discovery reach far beyond the laboratory, potentially impacting fields ranging from condensed matter physics to astrophysics, where similar quantum phases may exist under extreme conditions. "Our findings open the door to studying the hydrodynamic properties of exotic quantum systems with multiple broken symmetries, such as quantum crystals and even neutron stars. For instance, it is assumed that the change in rotational speed observed in neutron stars - so-called glitches - are caused by superfluid vortices trapped inside neutron stars. Our platform offers the opportunity to simulate such phenomena right here on Earth." Superfluid vortices are also believed to exist in superconductors, which can conduct electricity without loss. quantamagazine.org/physicists-spo

Scientists stir bizarre "supersolid" matter for first time, proving dual nature

Scientists this week said that they have successfully stirred a strange matter called a "supersolid" – which is both rigid and fluid – for the first time, providing direct proof of the dual nature of this quantum oddity.

Physicist Francesca Ferlaino describes what would happen if you tried to stir a superfluid with a spoon like coffee. © Unsplash/Manki Kim

In everyday life, there are four states of matter – solid, liquid, gas, and the rarer plasma.

But physicists have long been investigating what are known as "exotic" states of matter, which are created at incredibly high energy levels or temperatures so cold they approach absolute zero (-273.15 degrees Celsius or -459.67 degrees Fahrenheit).

Under these extreme conditions, matter starts behaving very differently from what we are used to.

Fluids such as liquid or gas may get more or less resistance to flow, which is measured by viscosity. Honey, for example, is more viscous than water.

Superfluids, an extremely cold exotic matter, have zero viscosity – there is no resistance so they flow freely.

If a superfluid was stirred in a cup, it would flow around indefinitely without ever slowing down.

More than half a century ago, physicists predicted the existence of a "supersolid" state.

It is matter that has the properties of both a solid and a superfluid, in which a fraction of the atoms flow friction-free through the lattice – a regular arrangement of points or objects – of a rigid crystal structure.

New study proves the dual nature of supersolid state

But a direct observation of the bizarre manner in which this matter flows has remained elusive, said Francesca Ferlaino, a physicist at Austria's University of Innsbruck. © Unsplash/Manki Kim

Researchers had previously managed to observe these crystal structures inside supersolids in several ways.

But a direct observation of the bizarre manner in which this matter flows has remained elusive, said [Francesca Ferlaino](#), a physicist at Austria's University of Innsbruck.

Until [a new study](#) led by Ferlaino was published in the journal Nature on Wednesday.

"Our findings give us strong, direct proof of the dual nature of a supersolid state," Ferlaino said.

Using magnetic fields, the team managed to stir a supersolid to observe the tiny whirlpools – called quantized vortices – which are the "smoking gun of superfluidity," the scientist explained.

"Imagine you have a cup of coffee, and you give it a little swirl with a spoon... You'll see the coffee spinning around the center, and if you look closely, there might be a whirlpool in the middle where the liquid is swirling the fastest. This is a classic example of a vortex in a regular fluid."

Now imagine the coffee is replaced with a superfluid.

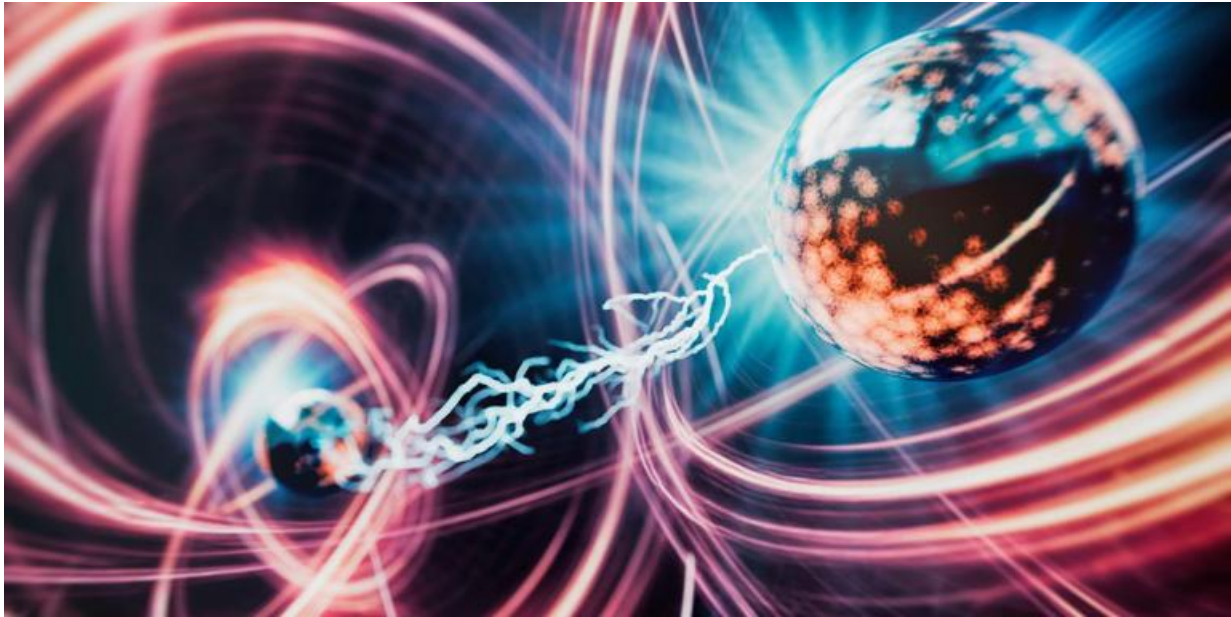
"If you swirl the spoon slowly, you'll be surprised to see that the superfluid doesn't rotate along with the spoon at all – it remains perfectly still, as if nothing disturbed it," Ferlaino said.

"However, if you swirl the spoon faster, instead of forming one large whirlpool in the center, something remarkable happens. A series of tiny whirlpools, or quantized vortices, begin to appear," she said.

"These are like small holes in the fluid, each rotating at a specific speed... they arrange themselves in beautiful, regular patterns across the surface of the

superfluid, almost like the holes in a piece of Gruyere cheese, but perfectly organized," the physicist added.

Scientists Think Gravity Might Be a Quantum Field



Scientists think gravity could be a quantum field, and they're getting closer to confirming it.© koto_feja - Getty Images

- Scientists have proposed a new test to hopefully help shed some light on quantum gravity.
- Gravity is the only major force in the universe that doesn't fit into our current quantum framework, driving the pursuit of a grand unified theory of physics.
- The new test would not be proof or a full understanding of quantum gravity, but it would be a huge step in the right direction—if we can pull it off.

Almost all we know about the universe boils down to the rules of quantum mechanics. Just about everything can be described as fields ([electromagnetism](#), the strong and weak nuclear forces) and matter, and we've slowly re-built our

fundamental understanding of the cosmos out of these fundamental building blocks.

That is, except for one big, neon-green brick in the uniform, rustic wall of physics—gravity. Gravity, as far as we have been able to prove, *isn't* quantum, even though it theoretically should be. The greatest scientific minds in the world still don't have a quantum description of gravity, usually just called "[quantum gravity](#)." The best way to describe it right now is through general relativity, and the disconnect between classical gravity and all of our known quantum fields is the reason people continue to feverishly search for a grand unified theory of physics. We watch gravity and quantum fields work together, so the rules should work together, too.

The search for the rules of quantum gravity has been a slog, but scientists keep at it regardless, as it would truly change our understanding of... well... [everything](#). And according to a recent study, published in the journal [Physical Review Letters](#), one group of researchers has an idea regarding how to test for the existence of gravity in the quantum realm.

The proposal stems from the idea that instead of trying to prove purely quantum gravity, we could at least *disprove* purely classical gravity by showing that the measurement of this force follows at least one quantum rule: [superposition](#). The scientists suggest creating a teeny-tiny crystal (we're talking only nanometers in size) and placing it into a state of superposition—a quantum state where an object (usually a particle) is in two places at once until it is measured.

Now, superposition [has been used to test for quantum gravity](#), but the authors of this new paper argue that observation of the phenomenon isn't enough. "As quantum mechanics is not defined by the superposition principle alone, but also requires the unitarity of evolution and the measurement postulate," the authors wrote. "Witnessing entanglement [...] will imply that gravity is described either by quantum mechanics, or by a (unknown) nonclassical theory that obeys superposition principle. To know whether gravity is indeed quantum, we need to test other quantum mechanical postulates for gravity."

So, they decided to go a step farther—but they still intend to start with superposition. Once the superposition state has been induced, two paths are to be followed. On the first path, to set up a kind of control group, the crystal in the superposition state is measured and its final state recorded. On the second path,

another nanocrystal is brought into the mix close enough to the first that there should be a very weak gravitational force between the two [crystals](#).

The gravity of that second crystal should (in theory) be felt by the first crystal in the superposition. According to a research highlight write-up in the journal [Nature](#), that behavior “would effectively ‘[measure](#)’ the mass of the first [crystal].” Then, the researchers would measure that first crystal again and see if its final state was different from when it was measured pre-second-crystal intervention—an effect caused by a phenomenon known as ‘quantum measurement-induced disturbance,’ which only happens if quantum effects are at play.

According to *Nature*, if the state is in fact different, it would be “a first proof that [gravity](#) does indeed have a quantum nature.” It’s complicated, it’s never been done, it’s incredibly cutting-edge, and it is (critically) *not* the full theory of quantum gravity that we eventually hope to decode. As the authors wrote in the paper, “adding this test to [existing tests of superposition’s effects on gravity] will take us towards a more *complete* demonstration of gravity as a quantum entity.”

But if it works, it would be an excellent next step. Let’s hope for [success](#).

Making quantum physics easier to digest in schools: Experts encourage focus on two-state systems

A team of physics educators from Italy, Hungary, Slovenia and Germany is focusing on a new approach to teaching quantum physics in schools. Traditional classroom teaching has tended to focus on presenting the history of the origins of quantum physics, which often poses problems for learners.

Using the quantum measurement process as an example, the researchers have now [published](#) their first empirical findings on learning [quantum physics](#)—based on two-state systems—in *Physical Review Physics Education Research*.

The researchers, including physics education specialist Professor Philipp Bitzenbauer from Leipzig University, concentrate on what are known as qubits. These are two-state systems, the simplest and at the same time most important quantum systems that can be used to describe

many situations. Controlling and manipulating these qubits plays a central role in modern quantum technologies.

According to Bitzenbauer, until now there have been no empirical studies of the effectiveness of these approaches using two-state systems in developing conceptual understanding in learners. There is also a lack of scientific research on the specific advantages and disadvantages for learning different teaching approaches based on two-state systems.

"Using the example of the quantum measurement process, one of the central problems of quantum physics, we show how to develop a survey method that can then be used in the field as part of intervention studies. Overall, teaching concepts that focus on two-state systems do indeed appear to be more conducive to learning than the traditional approach," says the Leipzig-based physics education specialist, who is the first author of the paper.

Much-discussed approach for the classroom

Making two-state systems the starting point for understanding quantum physics has been the subject of much discussion in recent years. According to Bitzenbauer, this approach opens the door to modern quantum technologies, be it quantum cryptography or quantum computing.

One of the aims of quantum cryptography is to make communication secure against eavesdropping. Quantum computers can be used to solve problems that even supercomputers can only solve after a very long time or not at all, such as breaking down large integers into prime factors.

"My team and I are working to make the ground-breaking potential of quantum technologies accessible to schoolchildren," says Bitzenbauer. The American Physical Society (APS) has invited him to present the results of the project at the [APS Global Physics Summit in Los Angeles in March 2025](#).

Bitzenbauer points out that 2025 will be the International Year of Quantum Science and Technology: the [scientific community](#) can look back on 100 years of quantum mechanics making world history. And it continues to do so today, albeit at a more advanced level. Scientists are talking about a second quantum revolution that will shape the new century in the same way that the first quantum revolution shaped the 20th century.

"Today, the focus is on the transition from many-body systems to the control and manipulation of single electrons, single photons or, more generally, single degrees of freedom in a quantum system. The simplest and most important quantum system has only two degrees of freedom—the two-state system. And this is the starting point for teaching quantum physics in schools," says the researcher.

More information: Philipp Bitzenbauer et al, Design and evaluation of a questionnaire to assess learners' understanding of quantum measurement in different two-state contexts: The context matters, *Physical Review Physics Education Research* (2024). DOI: [10.1103/PhysRevPhysEducRes.20.020136](https://doi.org/10.1103/PhysRevPhysEducRes.20.020136)

The quantum theory of gravitation, effective field theories and strings: Past and present

Gravity is one of four fundamental interactions. The most precise description of this force is still provided by Einstein's General Theory of Relativity, published in 1915, an entirely classical theory. This description sets gravity apart from the other three forces—strong, weak, and electromagnetism—all described by quantum fields. Therefore, any attempt to unify the four forces must depend on a description of gravity that uses the principles of quantum mechanics.

This has been an active area of theoretical physics since the 1930s. A historian and a physicist, Alessio Rocci from VUB in Brussels and Thomas Van Riet from KU Leuven in Belgium have set out a historical overview of the development of quantum theories of gravity to explain our current view on a future unified theory of the four forces. [This work](#) has been published in *The European Physical Journal H*.

Physicists began to investigate the quantum theory of gravitation in the 1930s, taking a perturbative approach, convinced that there should be no fundamental difference between the gravitational force and the other interactions. However, finding a description of the gravitational interaction according to the laws of quantum mechanics is still a very complex task.

Later in the century, Steven Weinberg, a pioneer of both effective field theory and the standard model of particle physics, began a process of cross-fertilization between these areas and the research area of quantum gravity that produced our current view on Einstein's theory. From the mid-1980s, string theory set up a possible framework to approach quantum gravity using a 'top-down' approach. The effective field theory approach to strong forces drove the development of the 'bottom-up' perspective, culminating in the mid-1990s.

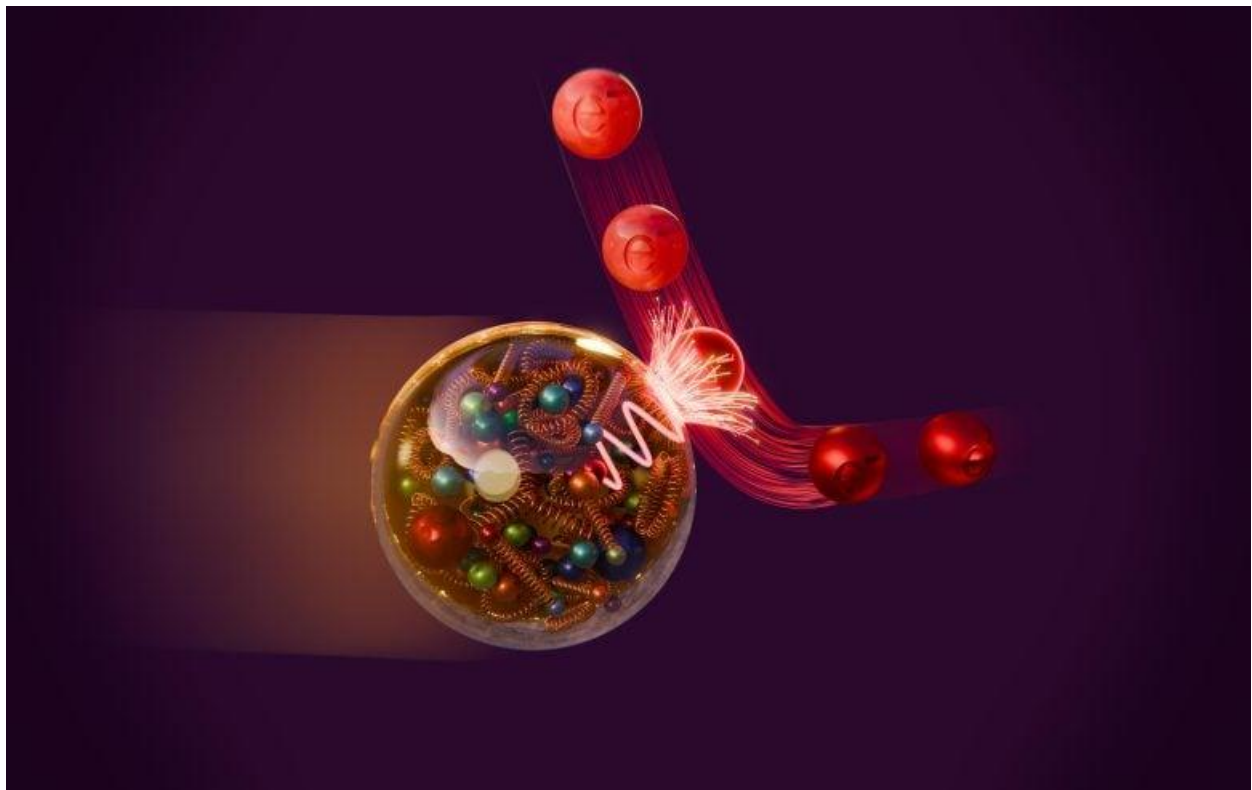
Recently, physicists have started a new program called Swampland to overcome the criticism of string theory that arose in the 2000s. Van Riet says, "The ultimate hope is that the Swampland program can lead to general patterns with observational consequences."

More information: Alessio Rocci et al, The quantum theory of gravitation, effective field theories, and strings: yesterday and today, *The European Physical Journal H* (2024). DOI: [10.1140/epjh/s13129-024-00069-4](https://doi.org/10.1140/epjh/s13129-024-00069-4)

Provided by SciencePOD

“Spooky Action” at Ultra-Short Distances: Unlocking the Quantum Core of Matter

BY BROOKHAVEN NATIONAL LABORATORY DECEMBER 5, 2024 [NO COMMENTS](#) [9 MINS READ](#)
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Data from past proton-electron collisions provide strong evidence of entanglement among the proton's sea of quarks (spheres) and gluons (squiggles), which may play an important

role in their strong-force interactions. Credit: Valerie Lentz/Brookhaven National Laboratory

Researchers at Brookhaven Lab discovered that quarks and gluons inside protons are entangled, reshaping the understanding of proton structure.

Using quantum information science, they validated theoretical predictions with collision data, paving the way for studies at the Electron-Ion Collider.

Peering Inside Protons With Quantum Science

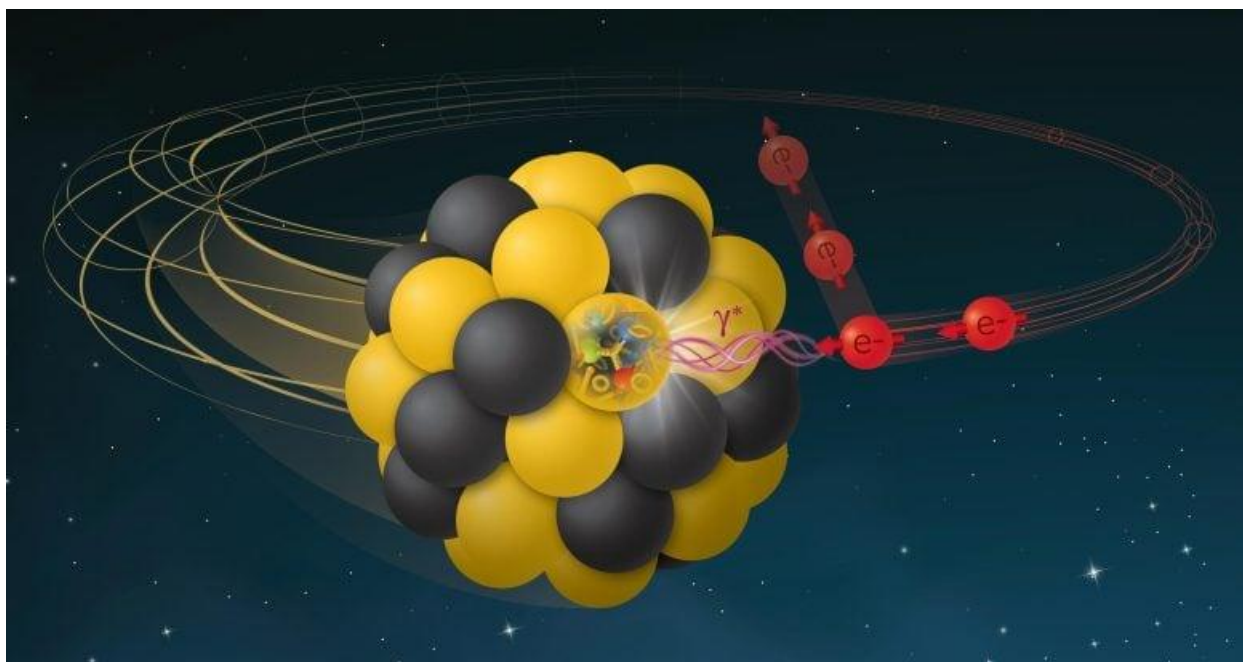
Scientists at the U.S. Department of Energy's Brookhaven National Laboratory, along with their collaborators, have developed a novel method to explore the inner workings of protons. Using quantum information science, they analyze data from high-energy electron-proton collisions to map how particle tracks are shaped by quantum entanglement within the proton.

Their findings reveal that [quarks and gluons](#)—the fundamental particles that form a proton's structure—experience quantum entanglement. This phenomenon, famously dubbed “spooky action at a distance” by Albert Einstein, allows particles to share information about their states, such as spin direction, even when separated. However, in protons, this entanglement happens at astonishingly small scales—less than one quadrillionth of a meter—and extends across the entire group of quarks and gluons within the proton.

Mapping the Impact of Entanglement

The team's latest paper, published on December 2 in the journal *Reports on Progress in Physics (RPP)*, summarizes the group's six-year research effort. It maps out precisely how entanglement affects the distribution of stable particles that emerge at various angles from the particle smashups after quarks and gluons liberated in the collisions coalesce to form these new composite particles.

This new view of entanglement among quarks and gluons adds a layer of complexity to an evolving picture of protons' inner structure. It may also offer insight into other areas of science where entanglement plays a role.



Future experiments at the Electron-Ion Collider (EIC) will reveal how being in a nucleus affects the quantum entanglement among quarks and gluons within a proton. Credit: Tiffany Bowman/Brookhaven National Laboratory

A Dynamic System of Proton Structure

“Before we did this work, no one had looked at entanglement inside of a proton in experimental high-energy collision data,” said physicist Zhoudunming (Kong) Tu, a co-author on the paper and collaborator on this exploration since joining Brookhaven Lab in 2018. “For decades, we’ve had a traditional view of the proton as a collection of quarks and gluons and we’ve been focused on understanding so-called single-particle properties, including how quarks and gluons are distributed inside the proton.

“Now, with evidence that quarks and gluons are entangled, this picture has changed. We have a much more complicated, dynamic system,” he said. “This latest paper refines our understanding of how entanglement impacts proton structure.”

Mapping out the entanglement among quarks and gluons inside protons could offer insight into other complex questions in nuclear physics, including how being part of a larger nucleus affects proton properties. This will be one focus of future experiments at the [Electron-Ion Collider](#) (EIC), a nuclear physics research facility expected to open at Brookhaven Lab in the 2030s. The tools these scientists are developing will enable predictions for EIC experiments.

Theoretical physicist Dmitri Kharzeev, a joint appointee of Brookhaven National Laboratory and Stony Brook University, developed equations based on quantum information science to predict how entanglement among quarks and gluons would impact

the entropy, or disorder, of particles emerging from electron-proton collisions. Credit: Kevin Coughlin/Brookhaven National Laboratory

Understanding Entropy and Particle Collisions

For this study, the scientists used the language and equations of quantum information science to predict how entanglement should impact particles streaming from electron-proton collisions. Such collisions are a common approach for probing proton structure, most recently at the Hadron-Electron Ring Accelerator (HERA) particle collider in Hamburg, Germany, from 1992 to 2007, and are planned for future EIC experiments.

This approach, [published](#) in 2017, was developed by Dmitri Kharzeev, a theorist affiliated with both Brookhaven Lab and Stony Brook University who is a co-author on the paper, and Eugene Levin of Tel Aviv University. The equations predict that if the quarks and gluons are entangled, that can be revealed from the collision's entropy, or disorder.

“Think of a kid’s messy bedroom, with laundry and other things all over the place. In that disorganized room, the entropy is very high,” Tu said, contrasting it with the low-entropy situation of his extremely neat garage, where every tool is in its place.

According to the calculations, protons with maximally entangled quarks and gluons — a high degree of “entanglement entropy” — should produce a lot of particles with a “messy” distribution — a high degree of entropy.

“For a maximally entangled state of quarks and gluons, there is a simple relation that allows us to predict the entropy of particles produced in a high energy collision,” Kharzeev said. “In our paper, we tested this relation using experimental data.”

Physicist Zhoudunming (Kong) Tu has been exploring the possibility of entanglement among a proton’s constituent quarks and gluons since joining Brookhaven National Laboratory as a Goldhaber Fellow in 2018. Credit: Kevin Coughlin/Brookhaven National Laboratory

Testing Predictions With Data Analysis

The scientists started by [analyzing data](#) from proton-proton collisions at Europe’s Large Hadron Collider, but they also wanted to look at the “cleaner” data produced by electron-proton collisions. Knowing it would be a while before the EIC turns on, Tu joined one of the HERA experiment collaborations, known as H1, which still has a crew of retired physicists meeting occasionally to discuss their experiment.

Tu worked with physicist Stefan Schmitt, the current co-spokesperson for H1 from the Deutsches Elektronen-Synchrotron ([DESY](#)), for three years to mine the old data. The pair cataloged detailed information from data recorded in 2006-2007, including how particle production and distributions varied and a wide range of other information about the collisions that produced these distributions. They [published](#) all the data for others to use.

When the physicists compared the HERA data with the entropy calculations, the results matched the predictions perfectly. These analyses, including the latest *ROPP* results on how particle distributions change at various angles from the collision point, provide strong evidence that quarks and gluons inside protons are maximally entangled.

The results and methods help to lay the groundwork for future experiments at the EIC.

Strong Force Interactions and Emergent Phenomena

The revelation of entanglement among quarks and gluons sheds light on the nature of their strong-force interactions, Kharzeev noted. It may offer additional insight into what keeps quarks and gluons confined within protons, which is one of the central questions in nuclear physics that will be explored at the EIC.

“Maximal entanglement inside the proton emerges as a consequence of strong interactions that produce a large number of quark-antiquark pairs and gluons,” he said.

Strong-force interactions — the exchange of one or more gluons among quarks — take place between individual particles. That may sound just like the simplest description of entanglement, where two individual particles can know about one another no matter how far apart they are. But entanglement, which is really an exchange of information, is a system-wide interaction.

“Entanglement doesn’t only happen between two particles but among all the particles,” Kharzeev said.

Statistical Models in Complex Physics

Now that scientists have a way of exploring this collective entanglement, the tools of quantum information science could make some problems in nuclear and particle physics easier to understand.

“Particle collisions can be extremely complex with many steps that influence the outcome,” Tu said. “But this study shows that some outcomes, like the entropy of the particles emerging, are determined by the entanglement within the protons before they collide. Entropy doesn’t ‘care’ about the complexity of all the in-between steps. So maybe we can use this approach to explore other complex nuclear physics phenomena without worrying about the details of what happens along the way.”

Thinking about the collective behavior of a whole system rather than individual particles is common in other areas of physics and even everyday life. For example, when you think about a pot of boiling water, you don’t really know about the vibrational motion of each individual water molecule. No single water molecule can burn you. It’s the statistical average of all the molecules vibrating — their collective combined behavior — that gives rise to the property of temperature and makes the water feel hot. In a similar way,

understanding how one quark and gluon behave doesn't immediately convey how a proton behaves as a whole.

"The physics perspective changes when you have so many particles together," Tu said, noting that quantum information science is a tool to describe the statistical or emergent behavior of the whole system. "This approach may offer insight into how the entanglement of the particles leads to the group behavior," Tu said.

Probing Proton Behavior in Nuclei

Now that the scientists have confirmed and validated their model, they want to use it in new ways. For example, they want to learn how being in a nucleus affects the proton.

"To answer this question, we need to collide electrons not just with individual protons but with nuclei — the ions of the EIC," Tu said. "It will be very helpful to use the same tools to see the entanglement in a proton embedded in a nucleus — to learn how it is impacted by the nuclear environment."

Will putting a proton in the very busy nuclear environment surrounded by lots of other interacting protons and neutrons wash out the individual proton's entanglement? Could this nuclear environment play a role in so-called quantum decoherence?

"Looking at entanglement in the nuclear environment will definitely tell us more about this quantum behavior — how it stays coherent or becomes decoherent — and learn more about how it connects to the traditional nuclear and particle physics phenomena that we are trying to solve," Tu said.

"The impact of the nuclear environment on protons and neutrons is at the center of the EIC science," said by Martin Hentschinski, a co-author on the paper from the Universidad de las Américas Puebla (UDLAP) in Mexico.

Co-author Krzysztof Kutak of the Polish Academy of Sciences added, "There are many other phenomena we want to use this tool to study to push our understanding of the structure of visible matter to a new frontier."

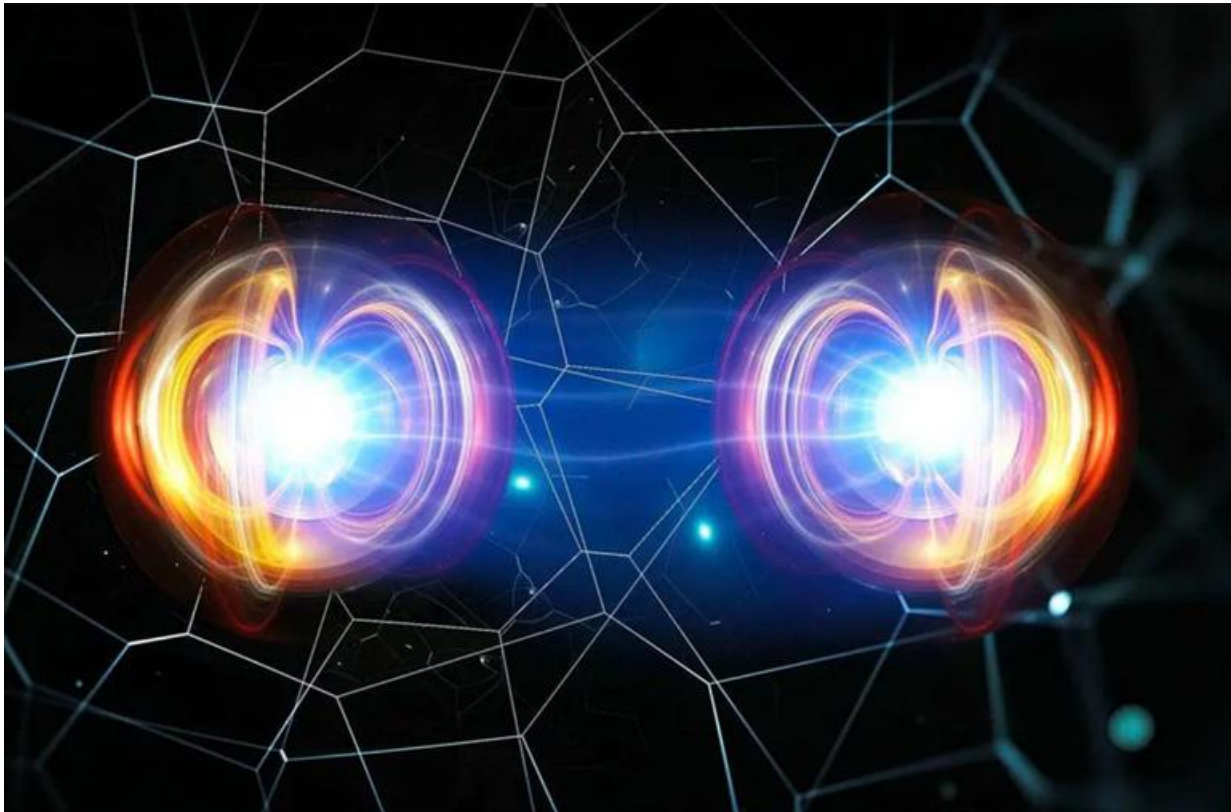
Reference: "QCD evolution of entanglement entropy" by Martin Hentschinski, Dmitri E Kharzeev, Krzysztof Kutak and Zhoudunming Tu, 2 December 2024, *Reports on Progress in Physics*.

DOI: [10.1088/1361-6633/ad910b](https://doi.org/10.1088/1361-6633/ad910b)

This research was funded by the DOE Office of Science, the European Union's Horizon 2020 research and innovation program, UDLAP Apoyos VAC 2024, and Brookhaven Lab's Laboratory Directed Research and Development program.

[Atomic Physics](#)[Brookhaven National Laboratory](#)[Nucl](#)

Scientists Measure the Speed of Quantum Entanglement in a Groundbreaking Experiment



Scientists Measure the Speed of Quantum Entanglement in a Groundbreaking Experiment© Daily Galaxy

Prof. Joachim Burgdörfer from the Institute of Theoretical Physics at TU Wien explains, “**Entangled particles possess no individual properties, only common ones.** Mathematically, they are inextricably linked, even when separated by vast distances.” This peculiar behavior defies classical physics and our everyday understanding of reality.

The implications of quantum entanglement extend far beyond theoretical physics. Its potential applications include :

- Quantum computing

- Ultra-secure communications
- Precision measurements in various scientific fields
- Advanced medical imaging techniques

As researchers delve deeper into the intricacies of quantum entanglement, they pave the way for technological breakthroughs that could revolutionize multiple industries. This research complements other recent advances in quantum physics, such as the [record-breaking 42.02-Tesla magnet developed in China](#), which promises to unlock new physical phenomena.

Peering into the quantum realm : Attosecond precision

The team's innovative approach employs **advanced computer simulations and laser experiments** to probe quantum processes occurring on attosecond timescales – a mind-boggling billionth of a billionth of a second. This unprecedented temporal resolution allows scientists to observe the birth of quantum entanglement with extraordinary detail.

Prof. Iva Březinová, a co-author of the study, emphasizes, "Our focus is on understanding how entanglement develops and which physical effects play a role on extremely short time scales." To achieve this, the researchers devised an ingenious experiment involving intense, high-frequency laser pulses interacting with atoms.

The experiment unfolds as follows :

- An atom is struck by an ultra-intense laser pulse
- One electron is excited to the point of breaking free
- A second electron within the atom is jolted to a higher energy state
- The two electrons become quantum entangled

This process reveals a fascinating aspect of quantum mechanics : the departing electron's exact moment of departure is inherently uncertain. Prof. Burgdörfer notes, "The electron itself doesn't know when it left the atom." This uncertainty is intrinsically linked to the energy state of the remaining electron, creating a complex interplay of quantum effects.

Measuring the unmeasurable : A quantum leap in precision

The research team's ability to measure these infinitesimal time differences represents a significant achievement in experimental physics. Their measurement protocol combines two distinct laser beams to capture the elusive timing of quantum entanglement formation.

To put the scale of these measurements into perspective, consider the following comparison :

The team's measurements revealed that the timing difference between high and low energy states of the remaining electron averages around 232 attoseconds. This level of precision is akin to **freezing time itself**, allowing researchers to peer into the quantum realm with unprecedented clarity.

These findings not only push the boundaries of quantum physics but also have potential applications in fields such as [static electricity research](#), where quantum effects play a crucial role at the atomic level.

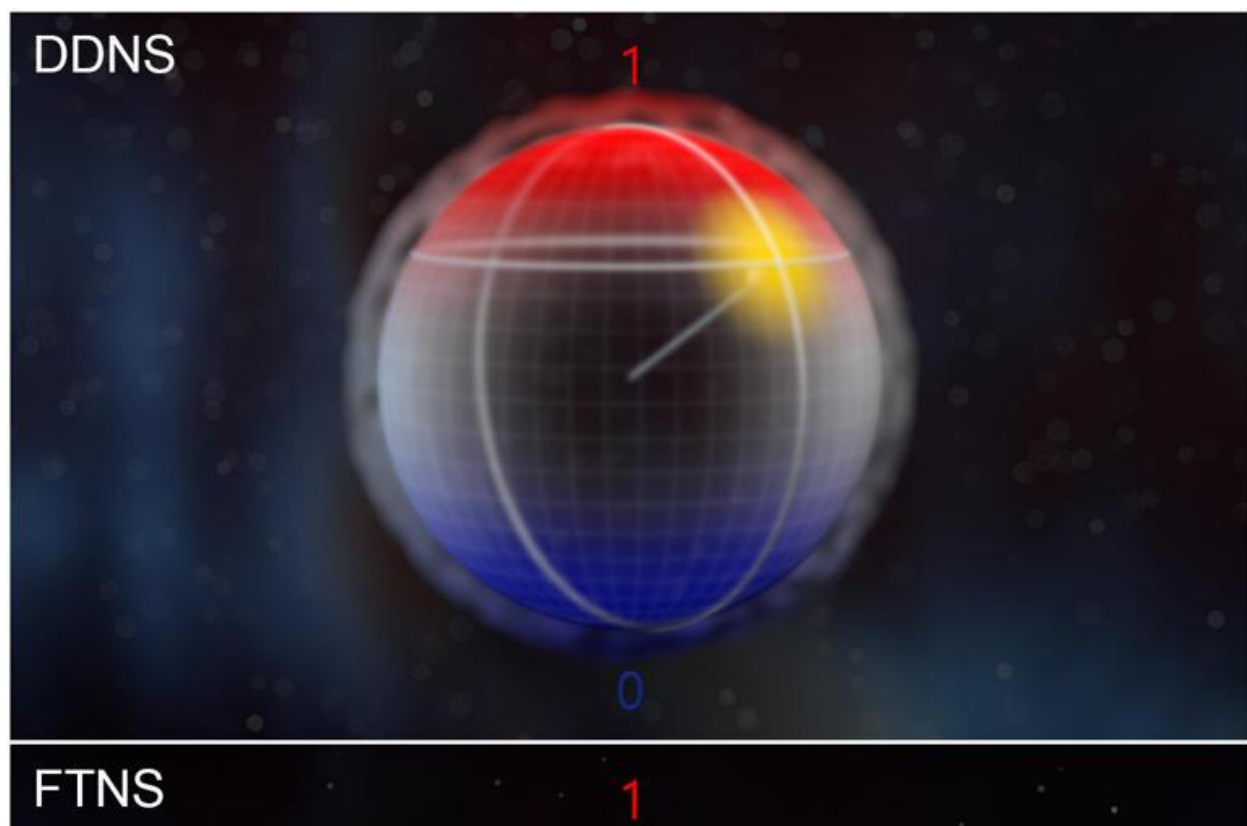
Implications for the future of quantum technologies

The ability to measure and understand the formation of quantum entanglement opens up new avenues for controlling quantum systems. This breakthrough could lead to significant advancements in quantum computing, cryptography, and communication technologies.

As Prof. Burgdörfer and his team continue their research, they are already collaborating with other scientists eager to test and observe these ultrafast entanglements in laboratory settings. The potential applications of this knowledge are vast, ranging from enhancing the security of quantum networks to developing more efficient quantum sensors.

In the quantum world, even the briefest moments hold a wealth of information. As researchers continue to push the boundaries of what can be measured and understood, we inch closer to harnessing the full potential of quantum mechanics. The journey of discovery in quantum physics is far from over, and each new insight brings us closer to unlocking the secrets of the universe at its most fundamental level.

Mapping noise to improve quantum measurements



Comparison of two noise spectroscopy methods of qubit environments. The Sun group's FTNS significantly outperforms current DDNS methods. Credit: Steven Burrows/Sun group© Provided by Phys.org

One of the biggest challenges in quantum technology and quantum sensing is "noise"—seemingly random environmental disturbances that can disrupt the delicate quantum states of qubits, the fundamental units of quantum information.

Looking deeper at this issue, JILA Associate Fellow and University of Colorado Boulder Physics Assistant Professor Shuo Sun collaborated with Andrés Montoya-Castillo, Assistant Professor of Chemistry, and his team to develop a new method for better understanding and controlling this noise, potentially paving the way for significant advancements in quantum computing, sensing, and control.

Breaking Physics: Inside the Strange World of Quantum Metals



New research reveals that quantum critical metals challenge traditional physics, offering insights that could enhance high-temperature superconductors. Credit: SciTechDaily.com

A new study examined how quantum critical metals, which behave unusually under low temperatures, challenge conventional physics theories.

The research reveals that these metals experience significant changes at quantum critical points, potentially informing the development of high-temperature superconductors.

Strange Metals and Quantum Fluctuations

A recent study led by Rice University physicist Qimiao Si sheds light on the mysterious behavior of quantum critical metals — materials that break the usual rules of physics at low temperatures. Published on December 9 in *Nature Physics*, the research explores quantum critical points (QCPs), where materials hover between two distinct states, such as being magnetic or nonmagnetic. These findings help explain the unique properties of these metals and offer new insights into high-temperature superconductors, which conduct electricity without resistance at relatively high temperatures.

At the heart of the study is quantum criticality, a state where materials become extremely sensitive to quantum fluctuations — tiny disruptions that change how electrons behave. While most metals follow well-established physical laws, quantum critical metals defy these expectations, displaying unusual and collective behaviors that have puzzled scientists for decades. Physicists refer to these systems as “strange metals.”

Role of Quasiparticles in Quantum Metals

“Our work dives into how quasiparticles lose their identity in strange metals at these quantum critical points, which leads to unique properties that defy traditional theories,” said Si, the Harry C. and Olga K. Wiess Professor of Physics and Astronomy and director of Rice’s Extreme Quantum Materials Alliance.

Quasiparticles, representing the collective behavior of electrons acting like individual particles, play a crucial role in energy and information transfer in materials. However, at QCPs, these quasiparticles vanish in a phenomenon known as Kondo destruction. Here magnetic moments in the material cease their usual interaction with electrons, dramatically transforming the metal’s electronic structure.

This change is evident in the Fermi surface, a map of possible electron states within the material. As the system crosses the QCP, the Fermi surface abruptly shifts, significantly altering the material’s properties.

Exploring Universal Behaviors

The study extends beyond heavy fermion metals — materials with unusually heavy electrons — to include copper oxides and certain organic compounds. All of these strange metals exhibit behaviors that defy traditional Fermi liquid theory, a framework used to describe electron motion in most metals. Instead, their properties align with fundamental constants such as Planck’s constant, governing the quantum relationship between energy and frequency.

Implications for Advanced Superconductors

The researchers identified a condition called dynamical Planckian scaling, where the temperature dependence of electronic properties mirrors universal phenomena like cosmic microwave background radiation and the radiation of the “black body” that approximates the behavior of stars. This discovery underscores a shared organizational pattern across various quantum critical materials, offering insights into creating advanced superconductors.

Quantum Transitions in New Materials

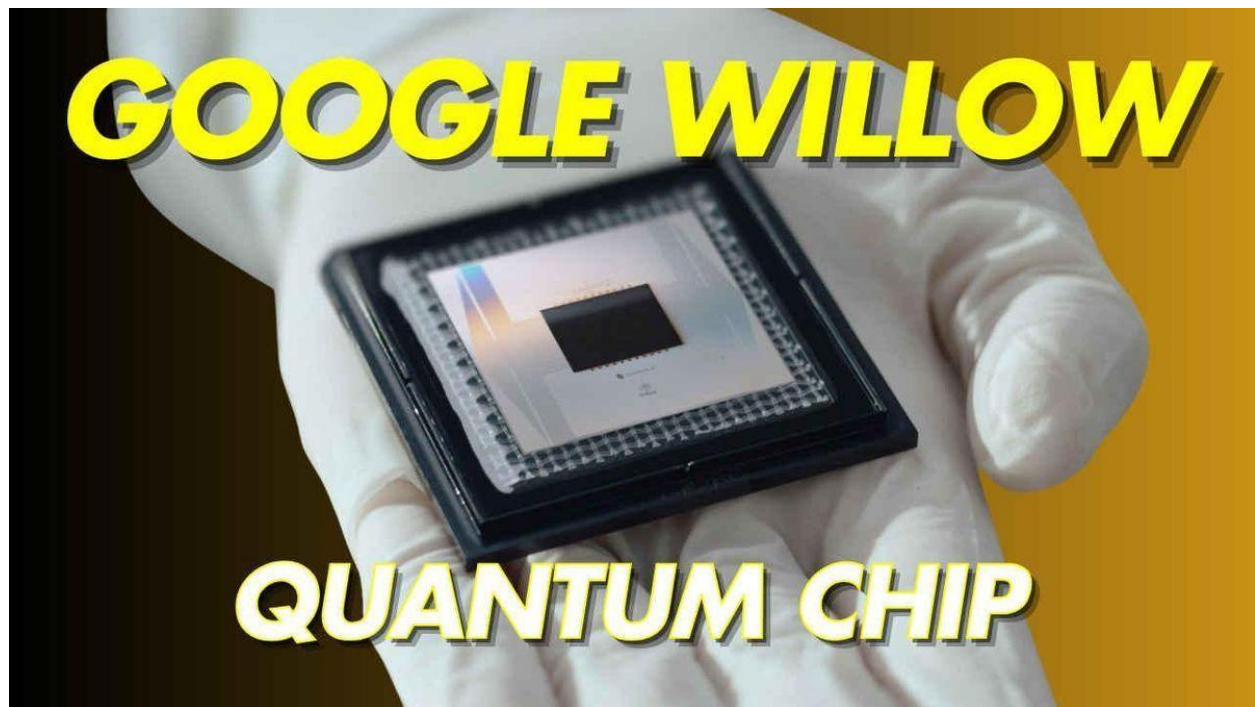
The research implications extend to other quantum materials, including iron-based superconductors and those with intricate lattice structures. One example is CePdAl, a compound where the interplay of two competing forces — the Kondo effect and RKKY interactions — determines its electronic behavior. By studying these transitions, scientists hope to decode similar phenomena in other correlated materials, where complex interelectronic relationships dominate.

Observing how these forces shape the material at QCPs could help scientists better understand transitions in other correlated materials or those with complex interelectronic relationships.

Reference: “Quantum critical metals and loss of quasiparticles” by Haoyu Hu, Lei Chen and Qimiao Si, 9 December 2024, *Nature Physics*.

DOI: [10.1038/s41567-024-02679-7](https://doi.org/10.1038/s41567-024-02679-7)

This research, co-authored by Haoyu Hu and Lei Chen from Rice’s Department of Physics and Astronomy, Extreme Quantum Materials Alliance and Smalley-Curl Institute, was supported by the National Science Foundation, Air Force Office of Scientific Research, Robert A. Welch Foundation, Vannevar Bush Faculty Fellowship and European Research Council.



Google's Quantum Chip Can Do in 5 Minutes What Would Take Other Computers 10 Septillion Years

Google's quantum computing division unveiled a new chip, dubbed Willow, that the tech giant says makes it infinitely faster and better than existing supercomputers.

The chip addresses two major problems with quantum computers as we know them today. First, Google claims Willow can reduce quantum computing errors "exponentially." Quantum computers, as Microsoft's Azure Quantum [explains](#), are more prone to errors than classical computers because they exist in fragile states.

And researchers believe that quantum computers need more qubits to be more powerful—but more qubits also means more errors. Tackling this error issue has long been one of the quantum computing sector's largest challenges—one Google may be able to tackle.

"The more qubits we use in Willow, the more we *reduce* errors, and the more quantum the system becomes," [writes](#) Google Quantum AI lead Hartmut Neven (a qubit is a basic unit of quantum information, and the building block for a quantum computer).

The Willow chip. (Credit: Google.)

"We tested ever-larger arrays of physical qubits, scaling up from a grid of 3x3 encoded qubits, to a grid of 5x5, to a grid of 7x7—and each time, using our latest advances in quantum error correction, we were able to cut the error rate in half. In other words, we achieved an exponential reduction in the error rate," Neven continued.

Google has been [working](#) on quantum chips for the past decade. Its latest Willow chip is so fast that it can complete a computation in less than five minutes that would take a leading supercomputer of today like the [Frontier](#) supercomputer in Tennessee 10 septillion years, or 10,000,000,000,000,000,000,000,000 years, which is technically older than the universe itself, according to the company.

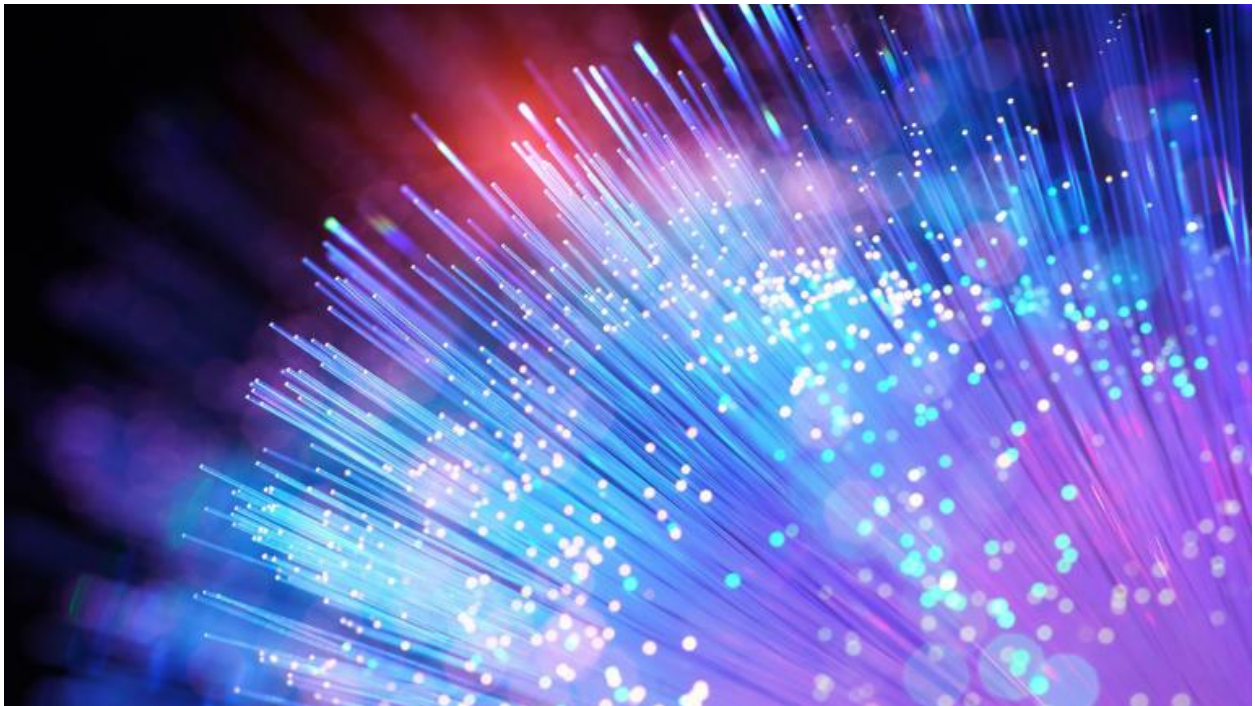
"It lends credence to the notion that quantum computation occurs in many parallel universes, in line with the idea that we live in a multiverse," Neven said, citing David Deutsch's prediction detailed in his 1997 book *The Fabric of Reality*.

In 2019, Google previously did a quantum computation in 200 seconds that would have taken the fastest supercomputer at that time 10,000 years. But IBM [dismissed](#) its claims, arguing that a classical computer could do the same calculation with greater "fidelity" in 2.5 days and argued that "quantum supremacy" had yet to be achieved.

While quantum computers are arguably still in their early stages, some researchers have already started to show how such machines might be able to disrupt our lives in the future—or potentially make them better. Chinese researchers have begun to [crack](#) military-grade with one machine, partly affirming a theory that quantum computers could eventually make present-day encryption methods obsolete.

But quantum computers could also help us better understand the universe, and could solve difficult computational problems. As the industry develops, some quantum firms are also looking to [establish manufacturing in North America](#) to ensure American and Canadian national security.

Engineers enable quantum communication over existing fiber optic cables — new research shows data transmission using quantum teleportation is possible in parallel with a classical network at specific wavelengths



Engineers at [Northwestern University](https://www.northwestern.edu) have successfully achieved quantum communication in parallel with classical channels by identifying specific wavelengths with minimal interference from classical signals (Source: [northwestern.edu](https://www.northwestern.edu)). This breakthrough lays the groundwork for quantum communication by leveraging existing infrastructure and sending quantum data alongside classical data. The researchers managed quantum teleportation over a 30.2km fiber optic cable carrying 400 Gbps of classical traffic.

Quantum computing seems to be all the hype these days. Google claims its new [quantum chip](#) can solve problems swiftly, which classical computers would otherwise take, and I quote 10 billion years to do; that's 10, followed by 24 zeroes. Quantum entanglement is a phenomenon wherein two particles are linked so that their quantum states (spin, polarization, energy levels, etc.) are connected, regardless of the physical distance. When measuring the state of one particle, the entanglement collapses, revealing the correlated state of the other particle. However, this does not allow for FTL (Faster Than Light) communication in line with the no communication theorem.

Enter Quantum teleportation. This concept combines entanglement with a classical channel, such as the Internet, and is the backbone of this research. It transfers one particle's quantum state to another located elsewhere.

Jordan Thomas, one of the research paper's authors, underlined the essence of quantum teleportation; "By performing a destructive measurement on two photons — one carrying a quantum state and one entangled with another photon — the quantum state is transferred onto the remaining photon, which can be very far away." A key point to understand here is that the photons aren't transmitted physically. Instead, information encoded within their quantum states is what is sent.

The primary concern with a worldwide network employing quantum teleportation is compatibility; will quantum communication work over classical channels? The likelihood of interference is exceptionally high among the billions of photons being sent concurrently in a fiber optic cable. The research discovered specific wavelengths where the density of classical photons was lower, making such wavelengths suitable for the photons in quantum teleportation. Bell state measurement, or simply state measurement, is performed at the mid-point of the cable. Coupled with other methods to reduce noise and interference, this method can potentially support multiple TB/s of classical data alongside quantum communication.

While it may take years or decades before quantum communication goes mainstream, Prem Kumar, the head of the research team, has high hopes for the future. Based on the current roadmap, the next major milestones are using two

pairs of entangled photons instead of one and scaling this experiment to real-world optical fiber networks.

Scientist says human consciousness comes from another dimension

A baffling new [theory to explain human consciousness](#) has suggested it comes from hidden dimensions and is not just brain activity.

A physicist claimed that we plug in to these invisible planes of the universe when making art, practicing science, pondering philosophy or dreaming, and this could explain the phenomenon that has evaded scientific understanding for centuries.

Michael Pravica, a professor of physics at the University of [Nevada, Las Vegas](#), has based the wild idea on hyperdimensionality, the idea that the universe is made up of more dimensions than just the four we perceive: height, length width and time. But his theory is highly controversial, with one scientist saying that the cornerstone of Pravica's theory 'borders on science fiction.'



Physicist Michael Pravica believes that human consciousness transcend the physical world and move between hidden dimensions

'The sheer fact that we can conceive of higher dimensions than four within our mind, within our mathematics, is a gift... it's something that transcends biology,'

Scientists have been attempting to explain human consciousness and its origins for hundreds of years - and the theories run the gamut.

One leading theory suggests that consciousness is related to how much information is integrated between the different parts of the brain. The more information is connected and integrated, the more conscious a being is thought to be.

Another posits that conscious mental states are driven by top-down signaling in the brain. Top-down signaling refers to the process by which higher-level brain regions send information, expectations or context to lower-level brain regions.

But Pravica's theory ventures outside the realm of neuroscience and into theoretical physics.

He suggested that in moments of heightened awareness, like when we enter a dream state or use our brains for deeply creative or intellectual tasks, our consciousness could transcend our physical dimension and enter a higher plane.

In these moments, our consciousness syncs with hidden dimensions and receives a flood of inspiration, Pravica said.

To better understand the controversial theory, consider the following scenario.

Imagine you're a two-dimensional being living in a two-dimensional world, like a character in a comic book. Now, imagine that a sphere passes through your plane of view.

The sphere would look like a dot that grows into a larger and larger circle as it comes closer, then gradually shrinks until it's out of view. You would have no way of knowing that it's actually a three-dimensional shape.

Pravica sees us as a version of these 2D characters. Although we exist in a four-dimensional world, we can only perceive matter and energy that is of those four dimensions, just like how beings in a 2D world cannot perceive a 3D object.

Thus, the limitations of our world prevent us from detecting higher dimensions that could, in theory, exist all around us.

This is the foundation of hyperdimensionality - the idea that the universe is made up of many dimensions, some of which are hidden because they are beyond the reach of our physical realm.

Hyperdimensionality ties into string theory, which states that reality is made up of infinitely small vibrating strings that are smaller than atoms, electrons or quarks.

As the strings vibrate, twist and fold, they produce effects in multiple unseen dimensions that give rise to all the particles and forces that we can observe, from particle physics to gravity.

'String theory is essentially a theory of hyperdimensionality,' Pravica said. 'It's looking at how the universe is put together on a sub-quantum scale.'



Pravica believes that our brains can tap into higher dimensions when in a dream state or performing deeply creating or intellectual tasks

Although we can observe the effects that these vibrating strings have on the physics of our dimension, we can't observe the hidden dimensions that they're vibrating in.

That is - we can't physically observe them.

But our consciousness may be able to tap into them, Pravica says.

Hyperdimensionality and string theory are widely accepted by physicists, but Pravica's idea of their relationship with consciousness is more controversial - especially because it blurs the lines between science and spirituality.

As an Orthodox Christian with a Ph.D. from Harvard, Pravica has found hyperdimensionality to be a way to bridge his scientific background with his religious beliefs.

For example, he believes Jesus may be a hyperdimensional being.

'According to the Bible, Jesus ascended into heaven 40 days after being on Earth. How do you ascend into heaven if you're a four-dimensional creature?' Pravica asked.

But being hyperdimensional could, theoretically, have allowed Jesus to move between our world and heaven - which may be a world of higher or infinite dimensions, he said.

Pravica's theory is based on a 'God of the gaps' perspective, where gaps in scientific knowledge are explained by divine intervention, said Stephen Holler, associate professor of physics at Fordham University.

He believes that this type of thinking is insufficient, and hampers the scientific inquiry needed to truly understand and explain ineffable phenomena like human consciousness.

'It's a poor explanation mechanism that arguably stifles the inquisitive nature required for good science and teaches that it's not okay to say, 'I don't know,'" Holler told Popular Mechanics.

He points out that our ability to mathematically manipulate higher dimensions is not proof that they actually exist, or that our consciousness can interact with them.

What's more, exploring these higher dimensions is impossible due to the limitations of our current technological capabilities.

Not even the most powerful particle accelerator in the world - the Large Hadron Collider (LHC) at CERN - can provide real proof that these dimensions exist.

The LHC smashes particles together at incredibly high speeds - up to the speed of light.

This allows physicists to study the fundamental building blocks of matter and energy and access infinitesimally small dimensions - even smaller than a single proton.

But even the LHC isn't able to reveal the high-dimensional strings that quantum physics predicts. To get that granular, physicists would need a much more powerful collider.

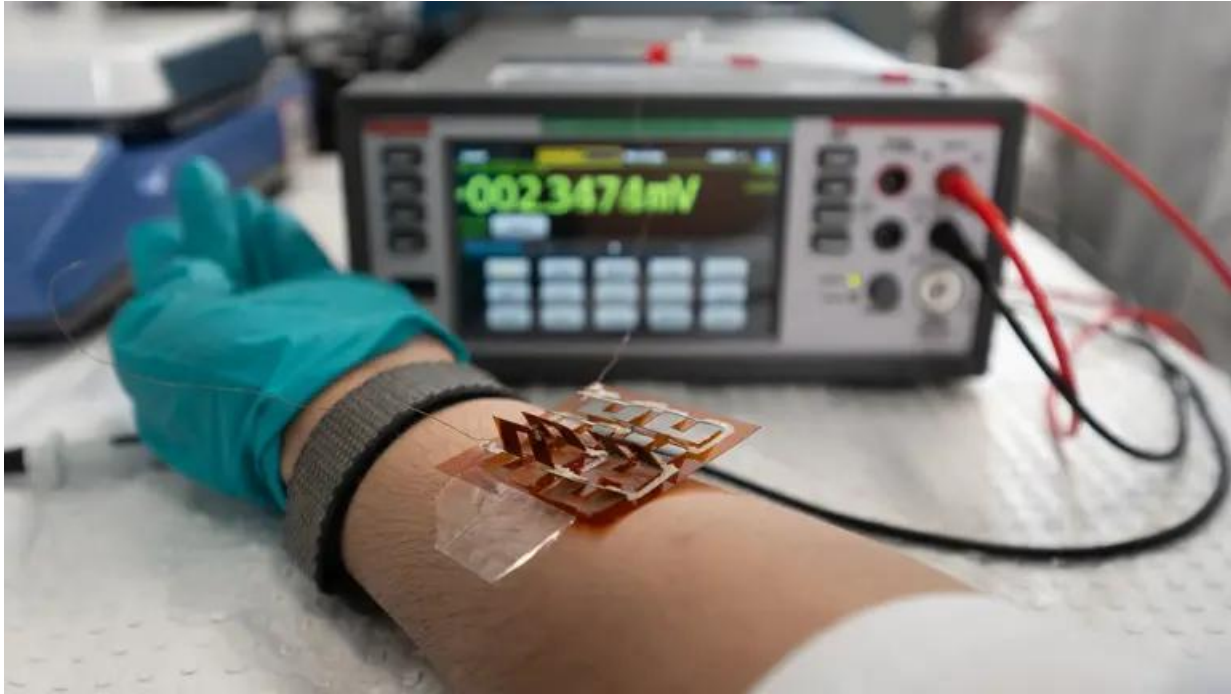
Without that concrete evidence, Holler says that hyperdimensionality 'borders on science fiction.'

But Pravica is optimistic that such technology could exist within his children's lifetime.

Until then, he will continue to support hyperdimensionality and his theory of how it relates to our consciousness.

'I see no point otherwise,' he said. 'Why study? Why live?'

Body Heat Could Power Next Generation of Wearable Devices, Marking New Battery Era



Body Heat Could Power Next Generation of Wearable Devices, Marking New Battery Era

Why it matters: Scientists have developed flexible thermoelectric devices that convert body heat into electricity, potentially eliminating the need for traditional batteries in wearable technology. As reported by [PopSci](#), this breakthrough comes as the global battery industry undergoes massive transformation to meet growing energy storage demands.

The Big Picture: According to [The Hustle](#), researchers at Queensland University of Technology and the [University of Washington](#) have created innovative materials that harness body heat:

- Uses nanobinder crystals and bismuth telluride sheets
- Generates enough power to run LED lights
- Enables battery-free medical devices
- Creates self-powered smart clothing

Healthcare Applications: The technology could revolutionize medical devices:

- Continuous glucose monitoring without battery changes
- Self-powered pacemakers
- Uninterrupted health tracking
- Enhanced patient comfort and safety

Broader Energy Transition: This development coincides with massive growth in battery technology:

- Lead-acid battery market projected to reach \$59 billion by 2032
- Electric car registrations hit 14 million globally in 2023
- Lithium-ion battery demand growing at 15.5% annually
- Battery costs declining through economies of scale

Looking Forward: The technology could expand beyond wearables to cool data centers and power virtual reality systems, marking a significant step toward sustainable electronics like the [best smart watches](#) and reduced environmental impact.

Can entangled particles communicate faster than light?

Entanglement is perhaps one of the most confusing aspects of quantum mechanics. On its surface, entanglement allows particles to communicate over vast distances instantly, apparently violating the speed of light. But while entangled particles are connected, they don't necessarily share information between them.

In quantum mechanics, a particle isn't really a particle. Instead of being a hard, solid, precise point, a particle is really a cloud of fuzzy probabilities, with those probabilities describing where we might find the particle when we go to actually look for it. But until we actually perform a measurement, we can't exactly know everything we'd like to know about the particle.

These fuzzy probabilities are known as quantum states. In certain circumstances, we can connect two particles in a quantum way, so that a single mathematical equation describes both sets of probabilities simultaneously. When this happens, we say that [the particles are entangled](#).

When particles share a quantum state, then measuring the properties of one can grant us automatic knowledge of the state of the other. For example, let's look at the case of quantum spin, a property of subatomic particles. For particles like electrons, the spin can be in one of two states, either up or down. Once we entangle two electrons, their spins are correlated. We can [prepare the entanglement](#) in a certain way so that the spins are always opposite of each other.

If we measure the first particle, we might randomly find the spin pointing up. What does this tell us about the second particle? Since we carefully arranged our entangled quantum state, we now know with 100% absolute certainty that the second particle must be pointing down. Its quantum state was entangled with the first particle, and as soon as one revelation is made, both revelations are made.

But what if the second particle was on the other side of the room? Or across the galaxy? According to quantum theory, as soon as one "choice" is made, the partner particle instantly "knows" what spin to be. It appears that communication can be achieved faster than light.

The resolution to this apparent paradox comes from scrutinizing what is happening when—and more importantly, who knows what when.

Let's say I'm the one making the measurement of particle A, while you are the one responsible for particle B. Once I make my measurement, I know for sure what spin your particle should have. But you don't! You only get to know once you make your own measurement, or after I tell you. But in either case, nothing is transmitted faster than light. Either you make your own local measurement, or you wait for my signal.

While the two particles are connected, nobody gets to know anything in advance. I know what your particle is doing, but I only get to inform you at a speed slower than light—or you just figure it out for yourself.

So, while the process of entanglement happens instantaneously, the revelation of it does not. We have to use good old-fashioned no-faster-than-light communication methods to piece together the correlations that quantum entanglement demand.

Provided by Universe Today

What Is Quantum AI? Everything to Know About This Far-Out Tech



A close-up view of an IBM quantum computer. The processor is in the silver-colored cylinder. Stephen Shankland/CNET

Artificial intelligence has been infiltrating our daily workflows and routine tasks for while now. It may be AI working in the background, as with [Gemini's](#) integration across Google products, or you may be engaging more directly with popular content generators such as OpenAI's ChatGPT and Dall-E. Looming in the not-too-distant future are amped-up [virtual assistants](#).

As if AI itself weren't futuristic enough, now there's a whole new leap forward on the horizon: quantum AI. It's a fusion of artificial intelligence with unconventional and still largely experimental quantum computing into a super-fast and highly efficient technology. Quantum computers will be the muscles, while AI will be the brains.

"My colleagues sometimes ask me why I left the burgeoning field of AI to focus on quantum computing," Hartmut Neven, founder of Google's Quantum AI lab, wrote in a December blog post [introducing the Willow quantum chip](#). "My answer is that both will prove to be the most transformational technologies of

our time, but advanced AI will significantly benefit from access to quantum computing."

Here's a quick breakdown of the basics to help you better understand quantum AI.

What are AI and generative AI?

Artificial intelligence is a technology that mimics human decision making and problem solving. It's software that can recognize patterns, learn from data and even "understand" language enough to interact with us, via chatbots, to recommend movies or to identify faces or things in photos.

One powerful type of AI is [generative AI](#), which goes beyond simple data analysis or predictions. Gen AI models create new content based on their training data -- like text, images and sounds. Think [ChatGPT](#), [Dall-E](#), [Midjourney](#), [Gemini](#), [Claude](#) and [Adobe Firefly](#), to name a few.

These tools are powered by [large language models](#) trained on tons of data, allowing them to produce realistic outputs. But behind the scenes, even the most advanced AI is still limited by classical computing -- the kind that happens in Windows and Mac computers, in the servers that populate data centers and even in supercomputers. But there's only so far that binary operations will get you.

And that's where quantum computing could change the game.

Quantum computing

Classical and quantum computing differ in several ways, one of which is processing. Classical computing uses linear processing (step-by-step calculations), while quantum uses parallel processing (multiple calculations at once).

Another difference is in the basic processing units they use. Classical computers use bits as the smallest data unit (either a 0 or a 1). Quantum computers use quantum bits, aka qubits, based on the laws of quantum mechanics. Qubits can

represent both 0 and 1 simultaneously thanks to a phenomenon called superposition.

Another property that quantum computers can leverage is entanglement. It's where two qubits are linked so that the state of one immediately influences the state of the other, no matter the distance.

Superposition and entanglement allow quantum computers to solve complex problems much faster than traditional computers. Where classical computing can take weeks or even years to solve some problems, quantum computing reduces the timeframe for achievement to merely hours. So [why aren't they mainstream?](#)

Quantum computers, running on purpose-built [quantum chips](#), are incredibly delicate and must be kept at amazingly low temperatures to work properly. They're massive and not practical for everyday use yet. Still, companies like [Intel](#), [Google](#), [IBM](#), [Amazon](#) and [Microsoft](#) are heavily invested in quantum computing, and the race is on to make it viable. While most companies don't have the funds or specialized teams to support their own quantum computers, cloud-based quantum computing services like [Amazon Braket](#) and Google's [Quantum AI](#) could be options.

While the potential is enormous, quantum AI faces challenges like hardware instability and a need for specialized algorithms. However, [improvements in error correction](#) and qubit stability are making it more reliable.

Current quantum computers, like [IBM's Quantum System Two](#) and [Google's quantum machinery](#), can handle some calculations but aren't yet ready to run large-scale AI models. Additionally, quantum computing requires highly controlled environments, so scaling up for widespread use will be a big challenge.

That's why most experts believe we're likely years away from fully realized quantum AI. As Lawrence Gasman, president of LDG Tech Advisors, wrote for [Forbes](#) at the start of 2024: "It is early days for quantum AI, and for many organizations, quantum AI right now might be overkill."

The what-if game

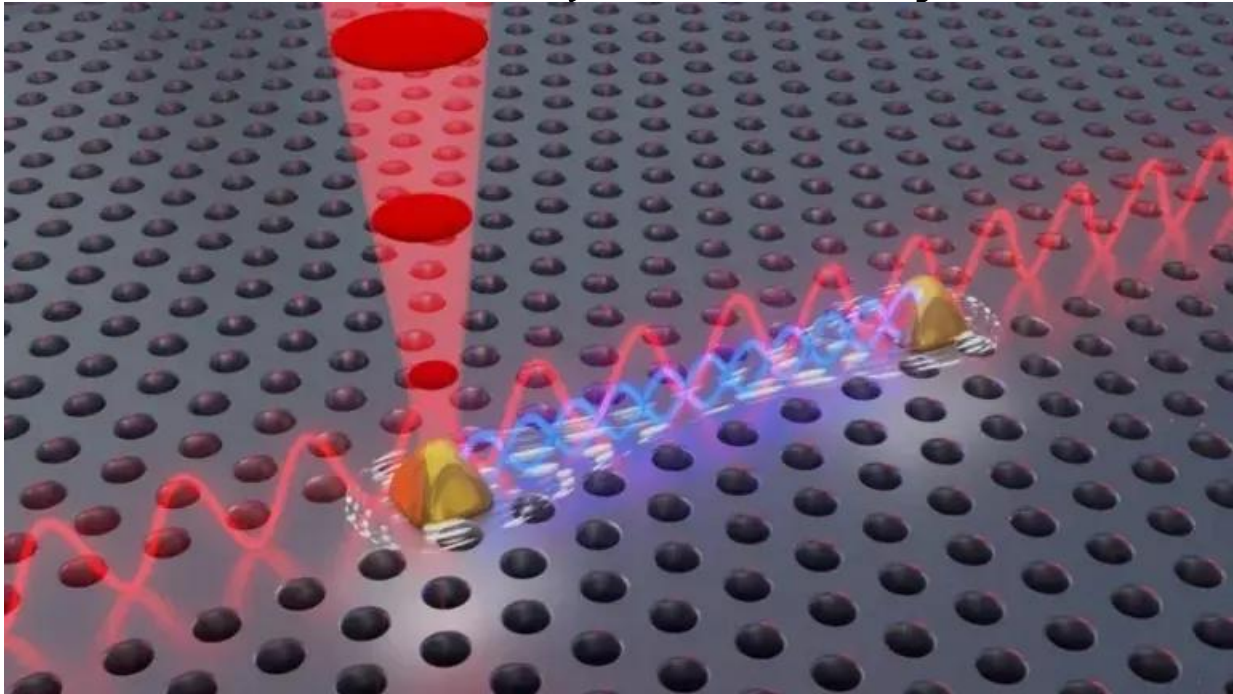
Quantum AI is still in the early trial stages, but it's a promising technology. Right now, AI models are limited by the power of classical computers, especially when processing big datasets or running complex simulations. Quantum computing could provide the necessary boost AI needs to process large, complex datasets at ultrafast speeds.

Although the future real-world applications are somewhat speculative, we can assume certain fields would benefit the most from this technological breakthrough, including [financial trading](#), natural language processing, image and speech recognition, health care diagnostics, [robotics](#), drug discovery, supply chain logistics, [cybersecurity](#) through quantum-resistant cryptography and [traffic management for autonomous vehicles](#).

Here are some other ways that quantum computing could enhance AI:

- Training large AI models, like LLMs, takes massive amounts of time and computing power. It's one reason AI companies need huge data centers to support their tools. Quantum computing could speed up this process, allowing models to learn faster and more efficiently. Instead of taking weeks or months to train, quantum AI models might be trained in days.
- AI thrives on pattern recognition, whether it's in images, text or numbers. Quantum computing's power to process many possibilities at once could lead to faster, more accurate pattern recognition. This would be particularly beneficial in fields where AI needs to consider many factors simultaneously, like financial forecasting for trading.
- Although impressive, generative AI tools still have limitations, especially when it comes to creating realistic, nuanced outputs. Quantum AI could enable generative AI models to process more data and create content that's even more realistic and sophisticated.
- In decision-making processes where multiple factors need to be balanced, like drug discovery or climate modeling, quantum computers could allow AI to test countless possible scenarios and outcomes simultaneously. This could help scientists find optimal solutions in a fraction of the time it takes them now.

Danish researchers redefine quantum mechanics with major discovery



A persistent challenge in quantum research has been overcome by scientists at the [University of Copenhagen](#) in collaboration with [Ruhr University Bochum](#). They have successfully achieved control over two quantum light sources simultaneously—a feat previously limited to just one.

This breakthrough might appear modest to those outside the realm of quantum mechanics, but it marks a pivotal moment in the field. By enabling the creation of [quantum mechanical entanglement](#), this advancement opens the door to transformative commercial technologies.

The ability to control two quantum light sources is a cornerstone of quantum physics. Stable quantum light sources and the realization of entanglement—where two light sources can influence each other instantaneously, even across vast distances—are critical for building quantum networks. Entanglement underpins the development of efficient quantum computers and next-generation encryption methods.

Part of the team behind the invention. From left: Peter Lodahl, Anders Sørensen, Vasiliki Angelopoulou, Ying Wang, Alexey Tiranov, Cornelis van Diepen. (CREDIT: Ola J. Joensen)© The Brighter Side of News

The findings, recently published in [journal Science](#) by researchers at the Niels Bohr Institute, highlight the significant implications of this advancement.

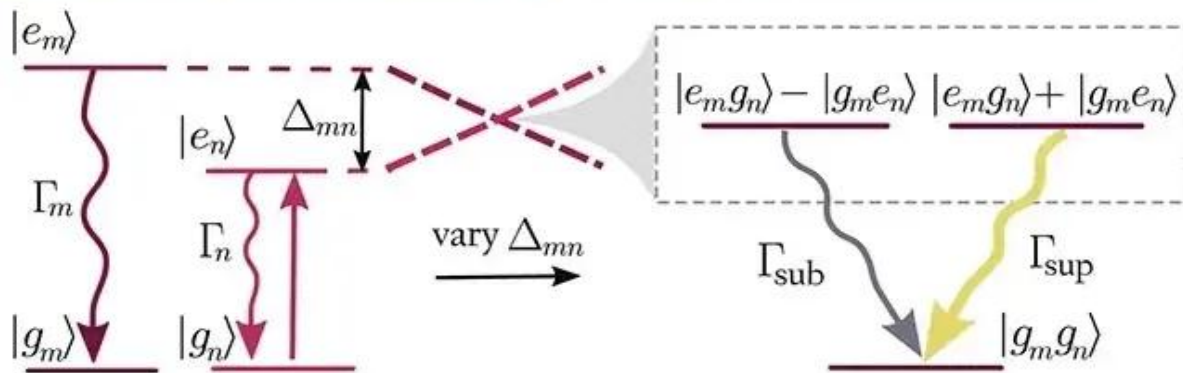
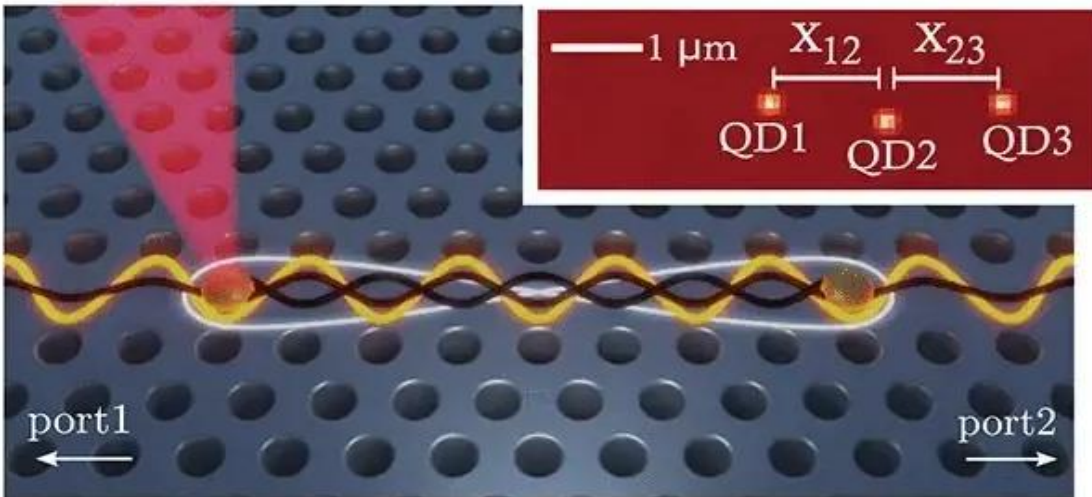
Professor Peter Lodahl, one of the lead researchers, emphasized that this achievement represents a major step toward the practical application of quantum technologies, including quantum computing, secure encryption, and an entirely new internet framework.

"We can now control two [quantum light sources](#) and connect them. It might not sound like much, but it's a major advancement and builds upon the past 20 years of work. By doing so, we've revealed the key to scaling up the technology, which is crucial for the most groundbreaking of quantum hardware applications," says Professor Lodahl, who has been researching in this area since 2001.

This innovation happens on a nanochip, barely larger than a human hair, developed by the researchers over recent years.

Professor Lodahl's group focuses on quantum technology using photons, light particles, to transport quantum information. Despite being a leader in this field, they could only control one light source at a time until now due to the sensitivity of these sources to external noise. The new research has succeeded in creating two identical [quantum light sources](#).

"Entanglement means that by controlling one light source, you immediately affect the other. This makes it possible to create a whole network of entangled quantum light sources, all of which interact with one another, and which you can get to perform [quantum bit operations](#) in the same way as bits in a regular computer, only much more powerfully," explains postdoc Alexey Tiranov, the lead author of the article.

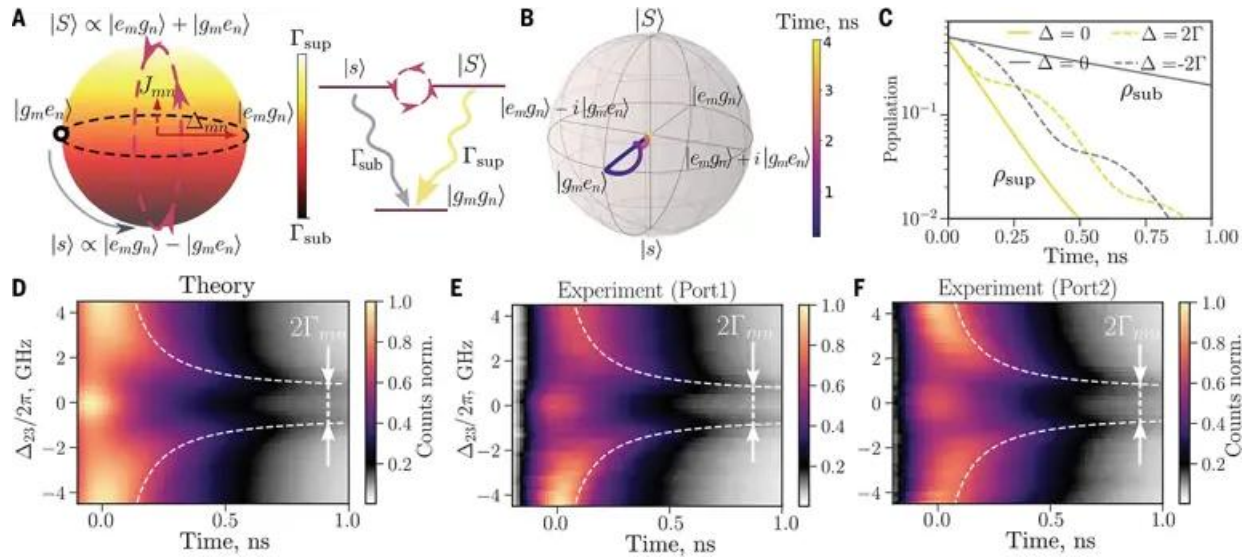


Collective super- and subradiant dynamics between distant optical quantum emitters. (CREDIT: Science)© The Brighter Side of News

A quantum bit can be both a 1 and 0 simultaneously, leading to processing power far beyond today's computer technology. According to Professor Lodahl, 100 photons from a single [quantum light source](#) contain more information than the world's largest supercomputer can process.

Using 20-30 entangled quantum light sources could potentially build a universal error-corrected quantum computer—the ultimate "holy grail" of quantum technology. Large IT companies are investing billions in this pursuit.

The biggest challenge was moving from controlling one to two quantum light sources, which required developing extremely quiet nanochips and precise control over each light source. Now, with this breakthrough, the fundamental [quantum physics research](#) is established. The task now is for other entities to build upon this work and apply quantum physics to technologies like computers, the internet, and encryption.



Photon emission is the hallmark of light-matter interaction and the foundation of photonic quantum science. (CREDIT: Science)

"It is too expensive for a university to build a setup where we control 15-20 quantum light sources. So, now that we have contributed to understanding the [fundamental quantum physics](#) and taken the first step along the way, scaling up further is very much a technological task," says Professor Lodahl.

The research was conducted at the Danish National Research Foundation's "Center of Excellence for Hybrid Quantum Networks (Hy-Q)" and is a collaboration between Ruhr University Bochum in Germany and the University of Copenhagen's Niels Bohr Institute.

Engineering quantum entanglement at the nanoscale

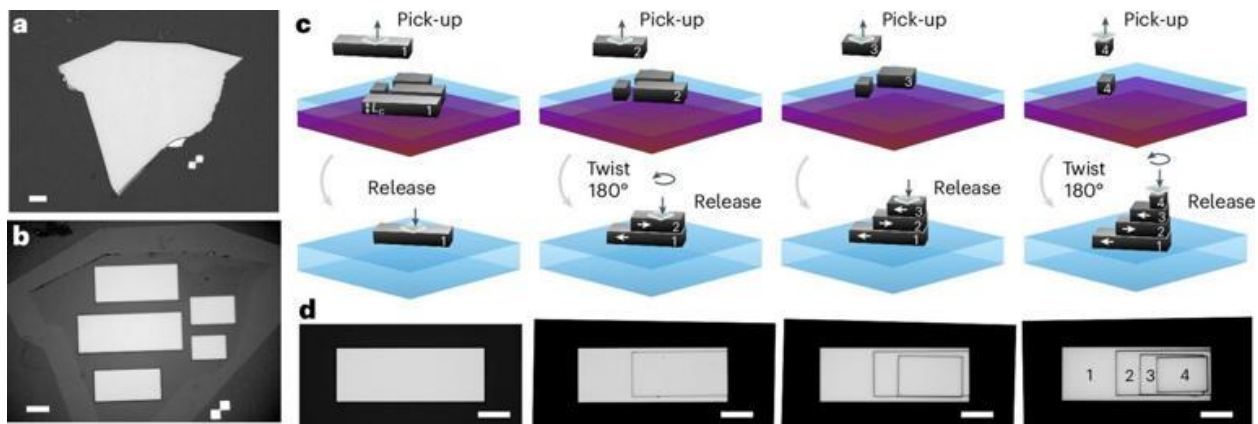
Physicists have spent more than a century measuring and making sense of the strange ways that photons, electrons, and other subatomic particles interact at extremely small scales. Engineers have spent decades figuring out how to take advantage of these phenomena to create new technologies.

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

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

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

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



PPTMDs. a,b, Micrograph of the 3R-MoS2 flake before (a) and after (b) patterning (electron beam lithography, etching). c, Stacking procedure. Slab 1 is first transferred on a 500- μm -thick SiO2 transparent substrate. Slab 2 is

twisted by 180° and released on top of slab 1. Slab 3 is transferred on top of slab 2. Finally, slab 4 is twisted by 180° and released on top of the 3 stacked portions. d, Micrographs of each stacking step. Scale bars, 10 μm . Credit: Nature Photonics (2025). DOI: 10.1038/s41566-024-01602-z

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

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

How it works

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

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

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

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

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

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

How it happened

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

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

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

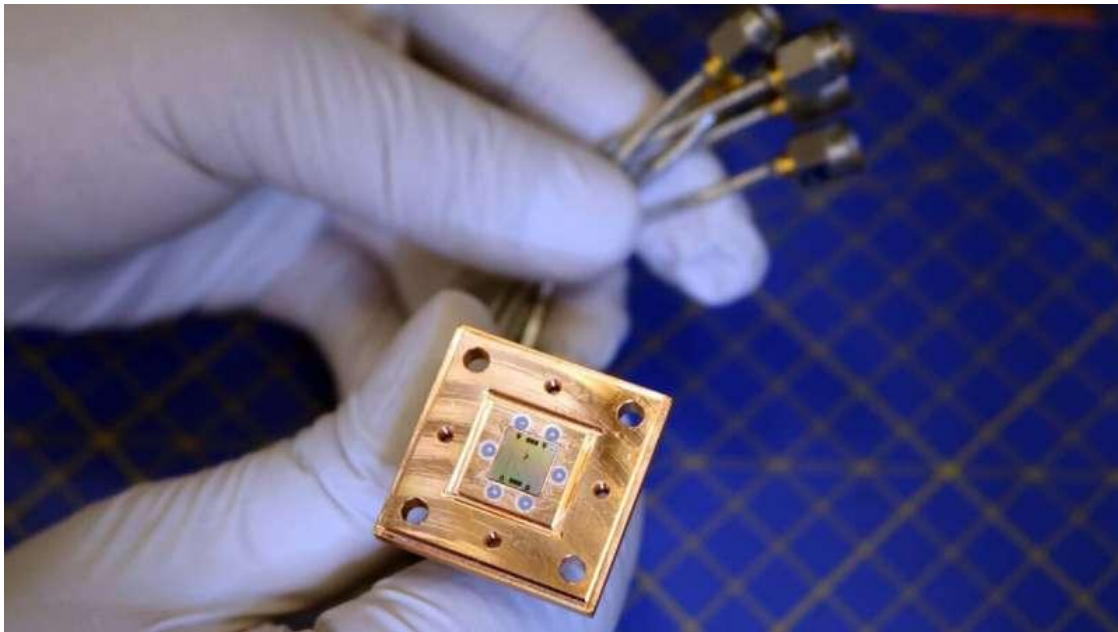
More information: Chiara Trovatello et al, Quasi-phase-matched up- and down-conversion in periodically poled layered semiconductors, *Nature Photonics* (2025). DOI: [10.1038/s41566-024-01602-z](https://doi.org/10.1038/s41566-024-01602-z)

Provided by Columbia University School of Engineering and Applied Science

JANUARY 9, 2025

Record cold quantum refrigerator paves way for reliable quantum computers

by [Chalmers University of Technology](#)



The new quantum refrigerator—the square object in the center of the qubit in the image—is based on superconducting circuits and powered by heat from the environment. It can autonomously cool qubits to record low temperatures, paving the way for more reliable quantum computers. The device was fabricated in the nanofabrication lab Myfab at Chalmers University of Technology in Sweden. Credit: Chalmers University of Technology | Lovisa Håkansson

Quantum computers require extreme cooling to perform reliable calculations. One of the challenges preventing quantum computers from entering society is the difficulty of freezing the qubits to temperatures close to absolute zero.

Now, researchers at Chalmers University of Technology, Sweden, and the University of Maryland, U.S., have engineered a new type of refrigerator that can autonomously cool superconducting qubits to record [low temperatures](#), paving the way for more reliable quantum computation.

Quantum computers have the potential to revolutionize fundamental technologies in various sectors of society, with applications in medicine, energy, encryption, AI, and logistics. While the building blocks of a classical computer—bits—can take a value of either 0 or 1, the most

common building blocks in quantum computers—qubits—can have a value of 0 and 1 simultaneously.

The phenomenon is called superposition and is one of the reasons why a quantum computer can perform parallel computations, resulting in enormous computational potential. However, the time a quantum computer can work on a calculation is still significantly constrained, because it spends a lot of time correcting errors.

"Qubits, the building blocks of a quantum computer, are hypersensitive to their environment. Even extremely weak electromagnetic interference leaking into the computer could flip the value of the qubit randomly, causing errors—and subsequently hindering quantum computation," says Aamir Ali, research specialist in quantum technology at Chalmers University of Technology.



A dilution

refrigerator is a cooling system that encloses a quantum computer and brings the qubits down to about 50 millikelvin, that is minus 273.1 degrees. When the cooling system is supplemented with a newly developed quantum refrigerator, which fits on a small chip, it is possible to reach record-low temperatures and bring the qubits down to about 22 millikelvin, which corresponds to minus 273.13 degrees. In the photo, the outer shells of the dilution refrigerator have been removed. Credit: Chalmers University of Technology

Demonstrates record low temperatures

Today, many quantum computers are based on superconducting electrical circuits that have zero resistance and therefore preserve information very well. For qubits to work without errors and for longer periods in such a system, they need to be cooled to a temperature

close to absolute zero, equivalent to minus 273.15 degrees Celsius or zero Kelvin, the scientific unit of temperature.

The [extreme cold](#) puts the qubits into their lowest-energy state, the [ground state](#), equivalent to value 0, a prerequisite for initiating a calculation.

The [cooling systems](#) used today, so-called dilution refrigerators, bring the qubits to about 50 millikelvin above absolute zero. The closer a system approaches to absolute zero, the more difficult further cooling is. In fact, according to the laws of thermodynamics, no finite process can cool any system to absolute zero.

Now, researchers at Chalmers University of Technology and the University of Maryland have constructed a new type of quantum refrigerator that can complement the dilution refrigerator and autonomously cool superconducting qubits to record-low temperatures.

The quantum refrigerator is described in [an article](#) titled "Thermally driven quantum refrigerator autonomously resets a superconducting qubit" in the journal *Nature Physics*.

"The quantum refrigerator is based on superconducting circuits and is powered by heat from the environment. It can cool the target qubit to 22 millikelvin, without external control. This paves the way for more reliable and error-free quantum computations that require less hardware overload," says Aamir Ali, lead author of the study and continues:

"With this method, we were able to increase the qubit's probability to be in the ground state before computation to 99.97%, which is significantly better than what previous techniques could achieve, that is, between 99.8 and 99.92%. This might seem like a small difference, but when performing multiple computations, it compounds into a major performance boost in the efficiency of quantum computers."

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Powered naturally by the environment

The refrigerator utilizes interactions between different qubits, specifically between the target qubit to be cooled and two quantum bits used for cooling. Next to one of the qubits, a warm environment is engineered to serve as a hot thermal bath. The hot thermal bath gives energy to one of the quantum refrigerator's superconducting qubits and powers the quantum refrigerator.

"Energy from the thermal environment, channeled through one of the quantum refrigerator's two [qubits](#), pumps heat from the target qubit into the quantum [refrigerator's](#) second qubit, which is cold. That cold qubit is thermalized to a cold environment, into which the target qubit's heat is ultimately dumped," says Nicole Yunger Halpern, NIST Physicist and Adjunct Assistant Professor of Physics and IPST at the University of Maryland, U.S..

The system is autonomous in that, once it is started, it operates without external control and is powered by the heat that naturally arises from the temperature difference between two thermal baths.

"Our work is arguably the first demonstration of an autonomous quantum thermal machine executing a practically useful task. We originally intended this experiment as a proof of concept, so we were pleasantly surprised when we found out that the performance of the machine surpasses all existing reset protocols in cooling down the qubit to record-low temperatures," says Simone Gasparinetti, Associate Professor at Chalmers University of Technology and lead author of the study.

The studied device was fabricated in Myfab, Chalmers University of Technology in Sweden, a nanofabrication laboratory.

More information: Thermally driven quantum refrigerator autonomously resets a superconducting qubit, *Nature Physics* (2025). DOI: [10.1038/s41567-024-02708-5](https://doi.org/10.1038/s41567-024-02708-5)

Journal information: [Nature Physics](#)

Provided by [Chalmers University of Technology](#)

Diamonds infused with boron: A breakthrough in quantum tech



Diamonds mixed with boron could revolutionize applications in electronics and quantum optics. Recent research shows that these types of semiconductors can be highly useful.

The latest studies published in Nature Communications highlight new possibilities for using diamond semiconductors. **Boron-doped diamonds** can generate plasmons, paving the way for their use in advanced biosensors and optical devices at the nanoscale.

Diamonds are also excellent heat conductors, known for their hardness and clarity. For this reason, they are used in thermal conductive pastes. With dopants like boron, diamonds can become semiconductors, making them attractive for high-power electronics and modern quantum optics. Scientists from Case Western Reserve University and the University of Illinois Urbana-Champaign have

discovered that boron-doped diamonds can generate plasmons—waves of electrons that move under the influence of light.

New possibilities for diamonds

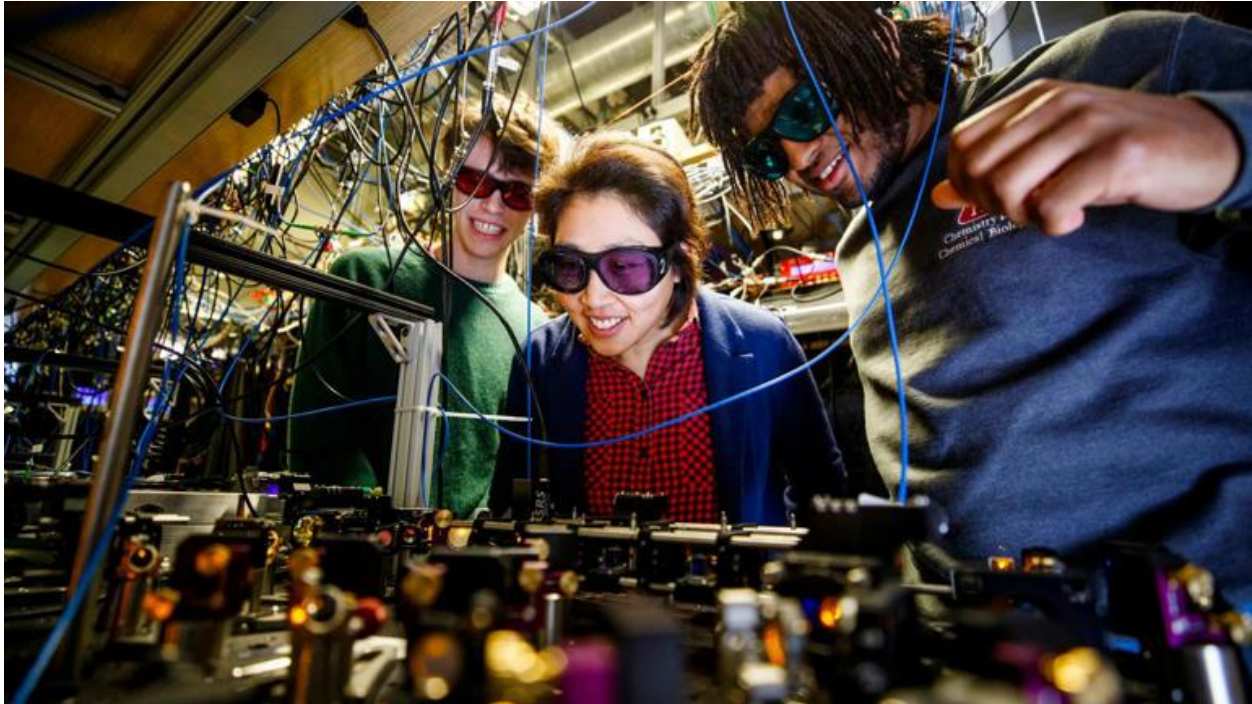
Plasmons in boron-doped diamonds allow for the control and enhancement of electric fields on the nanometer scale. This discovery could lead to developing new types of biomedical and quantum devices that are more efficient than current technologies. These diamonds may be used in medical imaging, high-sensitivity biochips, and molecular sensors.

"Understanding how doping affects the optical response of semiconductors like diamond changes our understanding of these materials," said Mohan Sankaran, professor of nuclear, plasma, and radiological engineering at the Illinois Grainger College of Engineering.

Plasmonic materials have been used for centuries, long before their scientific foundations were understood. Medieval stained glass owes its colors to metal nanoparticles that generate plasmons. Due to their transparency and chemical inertness, boron-doped diamonds can be used in applications where other materials fail.

These diamonds, despite doping, maintain transparency with a blue tint, making them unique among semiconductor materials.

Scientists trap molecules for quantum tasks, enabling ultra-fast tech advancements



Scientists trap molecules for quantum tasks, enabling ultra-fast tech advancements

In an exciting development for the field of quantum computing, a team of scientists from Harvard University has successfully trapped molecules to perform quantum operations, marking a significant leap forward in the technology.

This development leverages the complexities of ultra-cold polar molecules as qubits, the basic units of information in quantum systems, providing remarkable potential for fast processing and groundbreaking advancements across multiple sectors, including medicine, science, and finance.

Historically, molecules were overlooked in quantum computing due to their intricate structures, which were considered too complex and delicate for reliable manipulation.

Instead, researchers have largely relied on smaller particles like ions and atoms. However, the recent findings published in the journal *Nature* could change the landscape.

Quantum operations using trapped molecules

“As a field, we have been trying to do this for 20 years, and we’ve finally been able to do it!” exclaimed senior co-author Kang-Kuen Ni, Theodore William Richards Professor of Chemistry and professor of physics at Harvard.

Quantum computing, which exploits the properties of quantum mechanics to perform calculations exponentially faster than classical computers, holds the promise of solving problems previously deemed unsolvable.

“Our work represents the last critical piece needed to construct a molecular quantum computer,” stated co-author and postdoctoral fellow Annie Park.

While much of the research in quantum computing has centered on trapped ions, neutral atoms, and superconducting circuits, this new approach utilizing molecules opens up a range of possibilities.

The Harvard study specifically details the complex process involving the formation of an ISWAP gate, a crucial quantum circuit responsible for creating entangled states—one feature that makes quantum computing so powerful.

To conduct their experiment, the researchers successfully trapped sodium-cesium (NaCs) molecules using optical tweezers within a stabilizing and extremely cold environment.

The team achieved a significant quantum operation by exploiting the electric dipole-dipole interactions between the molecules.

They meticulously controlled the rotation of the molecules, resulting in the creation of a two-qubit Bell state with an impressive 94 percent accuracy—an essential milestone in demonstrating the feasibility of using molecular structures in quantum computations.

In classical computing, logic gates manipulate binary bits (0s and 1s), while quantum gates operate on qubits that can [exist](#) in multiple states simultaneously, thanks to superposition.

This unique capability allows quantum computers to perform computations that would be impossible for traditional systems. Quantum gates also retain their

reversibility and precision, which is crucial for maintaining the delicate nature of quantum states.

Computing

The ISWAP gate, utilized in this groundbreaking experiment, facilitates the swapping of states between two qubits while applying a phase shift—a critical procedure in generating entangled states.

As entanglement allows qubits to become correlated regardless of distance, this property is central to the formidable power of quantum computing.

While researchers have dreamed of leveraging molecular structures for quantum computations since the 1990s, earlier attempts faced challenges due to the instability of molecules, which often moved unpredictably and disrupted the coherence necessary for reliable operations.

The breakthrough achieved by the Harvard team lies in their ability to trap molecules in ultra-cold environments, significantly reducing their motion and allowing for greater control over their quantum states.

The advancement was made possible through the collaborative efforts of Ni's lab members—Lewis R.B. Picard, Annie J. Park, Gabriel E. Patenotte, and Samuel Gebretsadkan—as well as physicists from the University of Colorado's Center for Theory of Quantum Matter.

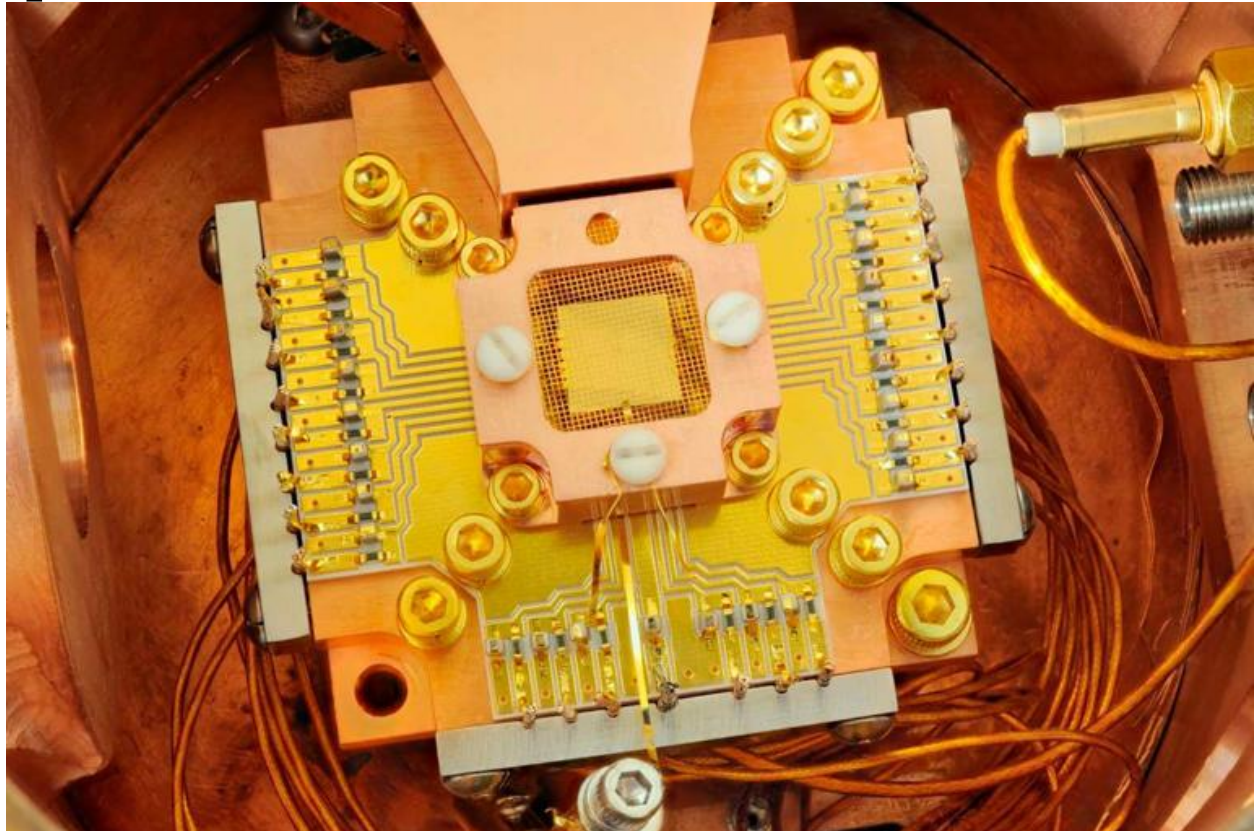
The research team conducted extensive evaluations of their operations by measuring the resulting two-qubit Bell state and assessing errors due to any residual motion, paving the way for improvements in the stability and accuracy of future experiments.

"There's a lot of room for innovations and new ideas [about](#) leveraging the advantages of the molecular platform," Ni noted, expressing excitement for these findings' potential for advancing quantum computing technologies.

With this breakthrough, the landscape of quantum computing could transform, steering researchers closer to realizing the dream of a molecular quantum

computer that capitalizes on the unique properties of molecules, thereby unlocking new horizons in computational capabilities.

Elusive phase change finally spotted in a quantum simulator



An ion trap can control atoms for quantum experiments Y. Colombe/NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY/SCIENCE PHOTO LIBRARY

After decades of looking, researchers have seen a string of atoms go through a 1D phase change so elusive that it could only happen inside a quantum simulator.

"One motivation [for our experiment] is really trying to understand fundamental physics. We're trying to understand just the basic states that matter can be in," says [Alexander Schuckert](#) at the University of Maryland.

Quantum computers are revealing an unexpected new theory of reality

He and his colleagues used electromagnetic fields to arrange 23 ions of the element ytterbium into a line, forming a nearly one-dimensional chain. This device can be used for quantum computing, but in this case, the researchers used the chain as a simulator instead.

Within it, they built a 1D ytterbium magnet one atom at a time. Previous calculations predicted this type of magnet would become unmagnetised when warmed, thanks to quantum effects. But no past experiment had achieved this phase transition.

One reason for the difficulty is that systems like quantum computers and simulators typically only work well when they are very cold. Warming them to make the phase transition occur can thus cause malfunctions, says Schuckert.

To avoid this, he and his colleagues tuned the initial quantum state of the atoms so that, as time went on, the 1D magnet's collective state changed as if its temperature had been increased. This revealed the never-before-seen phase transition.

The achievement is very exotic because chains of atoms generally shouldn't undergo phase transitions, says [Mohammad Maghrebi](#) at Michigan State University. The researchers were only able to engineer it because they could make each ion interact with others that were far from it, even though they weren't touching. This pushed the whole line into an unusual collective behaviour. Weird particle that remembers its past discovered by quantum computer

Because their simulator makes such exotic states of matter possible, it could be used to study theoretical systems that may be very rare – or even not exist – in nature, says Maghrebi.

Schuckert suggests quantum simulators could also help explain odd electric or magnetic behaviours that some materials show in the real world. But to do so, these devices must be able to reach higher temperatures than they can today. They can currently model extremely cold temperatures only, but he says higher-temperature simulations may be possible within five years.

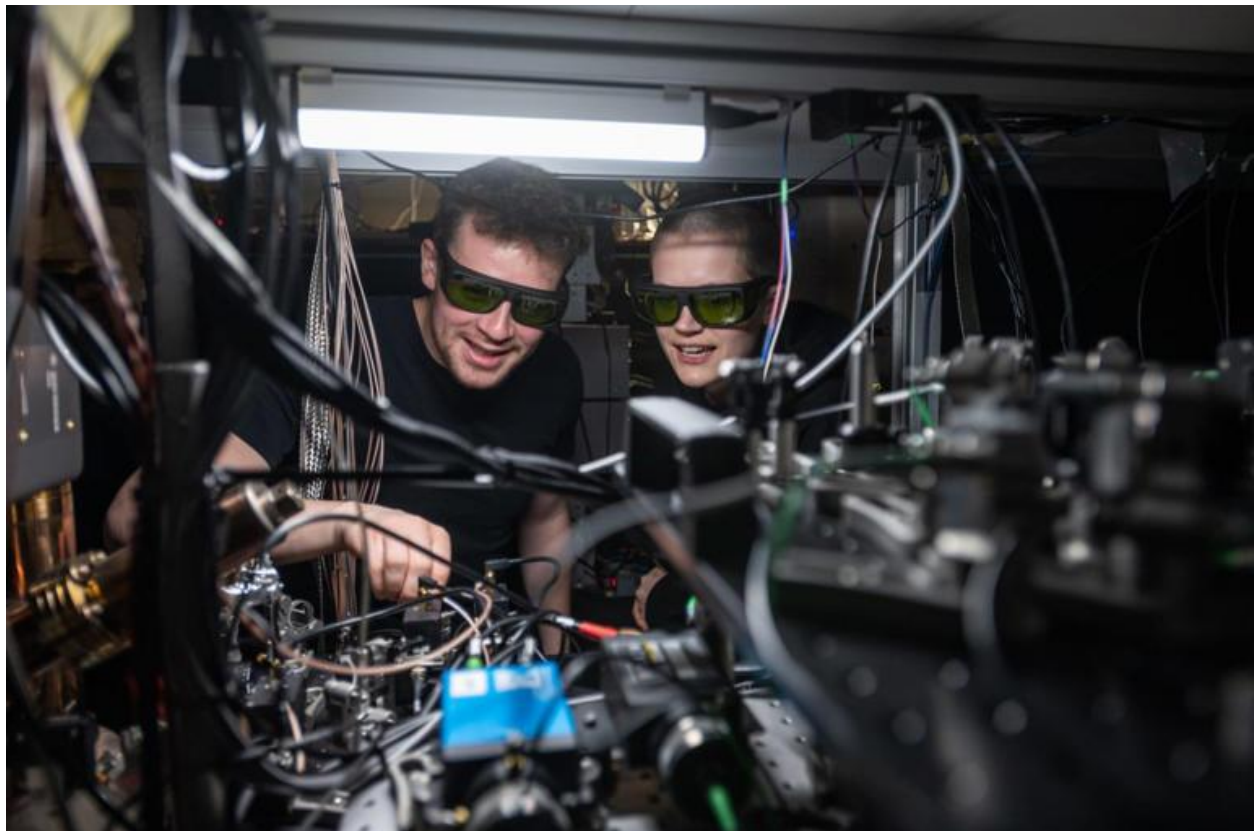
And even more existing and theoretical systems could be studied if the simulators can be made larger, for example by arranging the ions into two-

dimensional arrays, says [Andrea Trombettoni](#) at the University of Trieste in Italy. "This will suggest new physics to explore," he says.

Journal reference

Nature Physics DOI: [10.1038/s41567-024-02751-2](https://doi.org/10.1038/s41567-024-02751-2)

First-ever distributed quantum algorithm is a breakthrough for quantum supercomputers



Dougal Main and Beth Nichol working on the distributed quantum computer.(CREDIT: John Cairns)© The Brighter Side of News

Scientists have taken a major step toward building [large-scale quantum computers](#) by successfully linking two separate quantum processors into a single, fully connected system.

This breakthrough in distributed quantum computing offers a promising way to overcome the challenges of scaling up quantum computers and has the potential to revolutionize fields such as cryptography, drug discovery, and artificial intelligence.

A New Approach to Quantum Computing

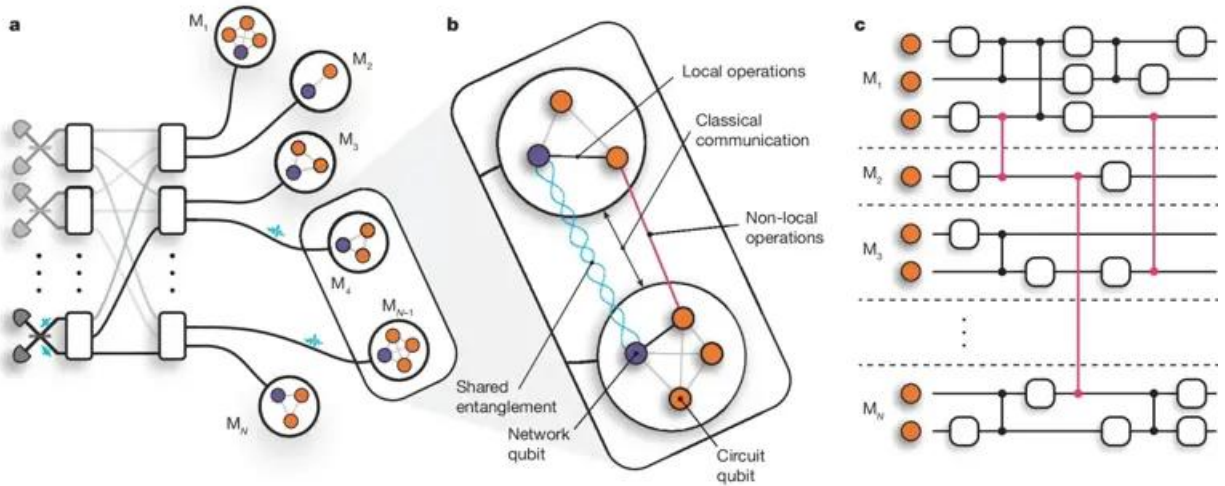
Quantum computers rely on qubits, which can exist in multiple states simultaneously due to [quantum superposition](#). This ability allows them to process complex problems much faster than classical computers. However, increasing the number of qubits within a single system while maintaining control and connectivity is an immense challenge.

Instead of cramming more qubits into a single machine, researchers at [Oxford University Physics](#) have demonstrated a distributed approach.

They connected two separate quantum modules using photonic links—fiber-optic cables that transmit quantum information using light instead of electrical signals. This method enables qubits in different modules to interact as if they were in the same processor.

The study 'Distributed Quantum Computing across an Optical Network Link,' is published in the journal [Nature](#).

Dougal Main, a lead researcher on the project, explains: "Previous demonstrations of quantum teleportation have focused on transferring quantum states between physically separated systems. In our study, we use quantum teleportation to create interactions between these distant systems. By carefully tailoring these interactions, we can perform logical quantum gates—the fundamental operations of quantum computing—between qubits housed in separate quantum computers."



Schematic of a DQC architecture comprising photonicallly interconnected modules. Entanglement is heralded between network qubits through the interference of photons on beam splitters. (CREDIT: Nature)© The Brighter Side of News

The Role of Quantum Teleportation

The key to this distributed system is [quantum teleportation](#), a process that allows information to be transferred between qubits without direct transmission. This is achieved through quantum entanglement, where two particles remain correlated even when separated by long distances.

When one qubit in a module is entangled with another in a separate module, performing an operation on one immediately affects the other. This enables the execution of quantum gate teleportation (QGT), a method that implements logical quantum operations across a network. Unlike direct data transfer, which risks information loss due to noise or interference, teleportation ensures that the quantum state remains intact.

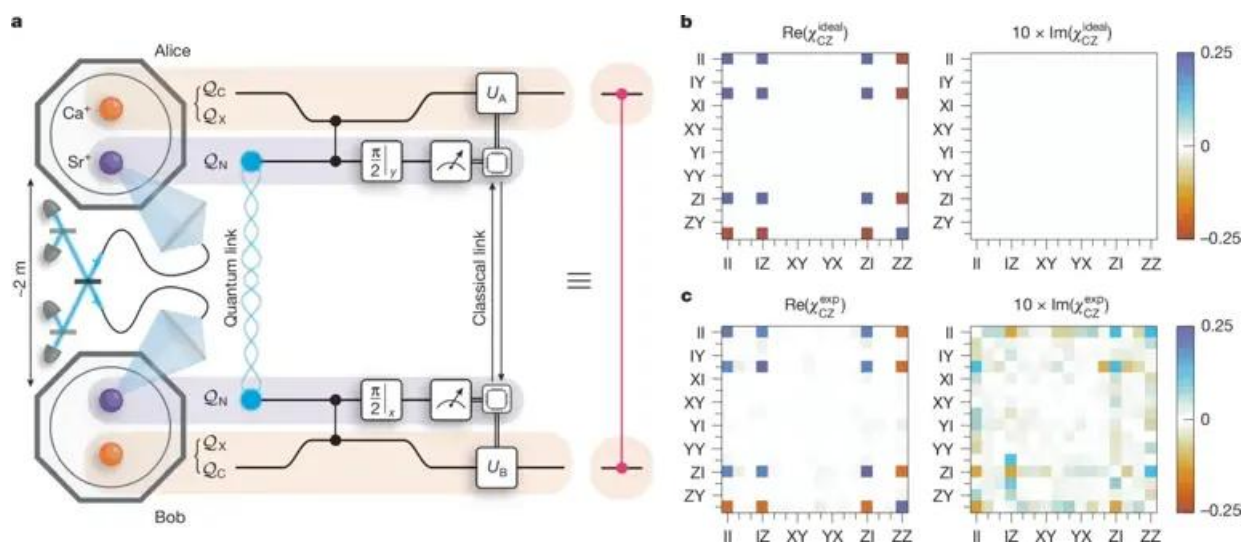
Professor David Lucas, lead scientist for the [UK Quantum Computing and Simulation Hub](#), says: "Our experiment demonstrates that network-distributed quantum information processing is feasible with current technology. Scaling up quantum computers remains a formidable technical challenge that will likely require new physics insights as well as intensive engineering effort over the coming years."

Breaking the Scalability Barrier

For quantum computers to reach their full potential, they must handle millions of qubits. Packing all those qubits into a single machine would create enormous technical challenges, from maintaining [quantum coherence](#) to managing complex interconnections. The distributed approach sidesteps these issues by linking smaller modules together.

In the Oxford experiment, the two quantum modules were separated by about two meters and contained dedicated network and circuit qubits. By generating entanglement between network qubits, researchers teleported a controlled-Z (CZ) gate—a key quantum logic operation—between circuit qubits in separate modules with 86% fidelity.

They then successfully executed Grover's search algorithm, a quantum algorithm designed to quickly find solutions within large datasets. The method achieved a 71% success rate, demonstrating the feasibility of distributed quantum computing.



Teleportation of a CZ gate between two trapped-ion modules. (CREDIT: Nature)© The Brighter Side of News

Quantum physicist Dougal Main describes the approach as similar to how traditional supercomputers function: "These are made up of [smaller computers](#) linked together to achieve capabilities that are greater than those of each separate unit.

This strategy circumvents many of the engineering obstacles associated with packing ever larger numbers of qubits into a single device, while preserving the delicate quantum properties needed for accurate and robust computations."

Toward a Quantum Internet

The success of this experiment suggests that [quantum processors](#) could eventually be networked across vast distances, forming a "quantum internet." This could enable ultra-secure communication, large-scale computational collaboration, and advances in quantum sensing.

Unlike traditional networks, where data is transmitted through classical signals, a quantum internet would rely on entanglement to instantly share information across different nodes. This could revolutionize industries requiring high levels of security, such as finance and national defense.

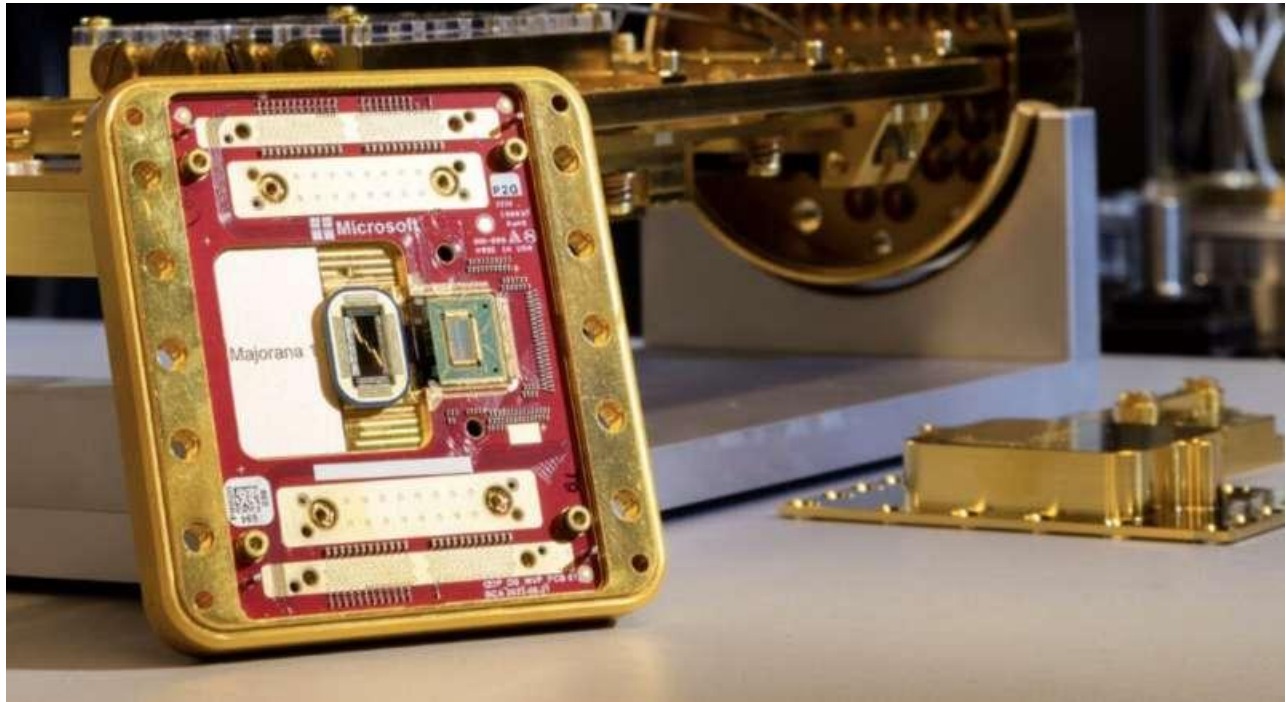
Additionally, the modular approach allows for system upgrades without disrupting the overall network. "By interconnecting the modules using [photonic links](#), the system gains valuable flexibility, allowing modules to be upgraded or swapped out without disrupting the entire architecture," says Main.

With ongoing advancements in quantum computing and networking, this breakthrough provides a crucial foundation for future scalable quantum systems. While many engineering challenges remain, the success of distributed quantum computing brings researchers one step closer to harnessing the full power of quantum mechanics.

FEBRUARY 20, 2025

Topological quantum processor uses Majorana zero modes for fault-tolerant computing

by [University of California - Santa Barbara](#)



Majorana 1, the eight-qubit topological quantum processor unveiled at Microsoft Station Q's 2025 conference. Credit: Microsoft

In a leap forward for quantum computing, a Microsoft team led by UC Santa Barbara physicists on Wednesday unveiled an eight-qubit topological quantum processor, the first of its kind. The chip, built as a proof-of-concept for the scientists' design, opens the door to the development of the long-awaited topological quantum computer.

"We've got a bunch of stuff that we've been keeping under wraps that we're dropping all at once now," said Microsoft Station Q Director Chetan Nayak, a professor of physics at UCSB and a Technical Fellow for Quantum Hardware at Microsoft. The chip was revealed at Station Q's annual conference in Santa Barbara, and accompanies a [paper published](#) in the journal *Nature*, authored by Station Q, their Microsoft teammates and a host of collaborators that presents the research team's measurements of these new qubits.

"We have created a new state of matter called a topological superconductor," Nayak explained. This phase of matter hosts exotic boundaries called Majorana zero modes (MZM) that are useful for [quantum computing](#), he explained. Results of rigorous simulation

and testing of their heterostructure devices are consistent with the observation of such states. "It shows that we can do it, do it fast and do it accurately," he said.

The researchers also followed up their *Nature* result with a [paper currently in preprint](#) on *arXiv*, outlining a roadmap for scaling up their technology into a fully functional topological quantum computer.

Majorana magic

The promise of quantum computing lies in the speed and power of its computations, expected to outperform even the most advanced classical supercomputer. All of this rests on the qubit, the quantum computing version of the bit, the fundamental unit of information for classical computers. While classical bits exist only in a state of either zero or one, qubits can represent zero, one and combinations in between.

Qubits can come in different forms, utilizing the quantum behaviors of trapped ions, for instance, or photons. Topological systems are based on a different type of particle called an anyon, a type of "quasiparticle" that emerges as the result of the correlated states of many interacting particles at the surface of a material, in this case a superconducting nanowire.

What makes topological quantum computing such a hot field of research is that it promises more stability and robustness to error than other quantum computing systems. Qubits can be prone to error, requiring quantum computer builders to account for it by, for instance, building more qubits to error-correct.

"A complementary approach is to build in error correction at the hardware level," Nayak said. Because [quantum information](#) is distributed and stored over a physical system rather than in individual particles or atoms, he explained, the information being handled by the topological qubits is less likely to lose its coherence, resulting in a more fault-tolerant system.

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But not just any quasiparticle will do. For topological quantum computing, Majorana particles—more specifically Majorana zero modes—are the tool of choice. Named for Italian physicist Ettore Majorana, who predicted them in 1937, these particles are special in that they are their own antiparticles, and are able to retain a "memory" of their relative positions over time. By "braiding" them—moving them physically around each other—it is possible to create a more robust quantum logic.

The researchers realized these particles through the placement of an indium arsenide semiconductor nanowire very close to an aluminum superconductor. Under the right conditions, the semiconducting wire becomes superconducting and enters a topological phase. MZMs emerge at the ends of the wire, while the rest of the wire has an energy gap.

"The larger this topological gap," Nayak pointed out, "the more robust the topological phase is. The surprising thing is, when you make the gap larger, not only does it become more robust, but you potentially go faster and maybe shrink everything a little bit so you're not paying for your fidelity with size."

At eight qubits, the researchers' topological processor is a mere embryo in the world of quantum computers, but marks a major milestone in the scientists' decades-long quest to develop a topological quantum computer. Along the way, Nayak said, there have been fruitful partnerships between Station Q and the university, especially in the realm of creating the materials that host topological quantum behaviors.

"Chris Palmstrom has been a collaborator at times, and he has made important advances in these kinds of materials," he said of the electronic materials expert, while materials scientist Susanne Stemmer contributed her expertise with fabrication processes. Station Q has also hired many students to its team, and importantly, Nayak added, the semiconductor heterostructure concept is born from the Nobel Prize-winning ideas of the late Herb Kroemer, who was a professor in the Department of Electrical and Computer Engineering.

"There's a long history of expertise and talent at UCSB in these kinds of material combinations, and in this really cutting-edge materials science, that opens up new types of physics we can do."

More information: David Aasen et al, Roadmap to fault tolerant quantum computation using topological qubit arrays, *arXiv* (2025). DOI: [10.48550/arxiv.2502.12252](https://doi.org/10.48550/arxiv.2502.12252)

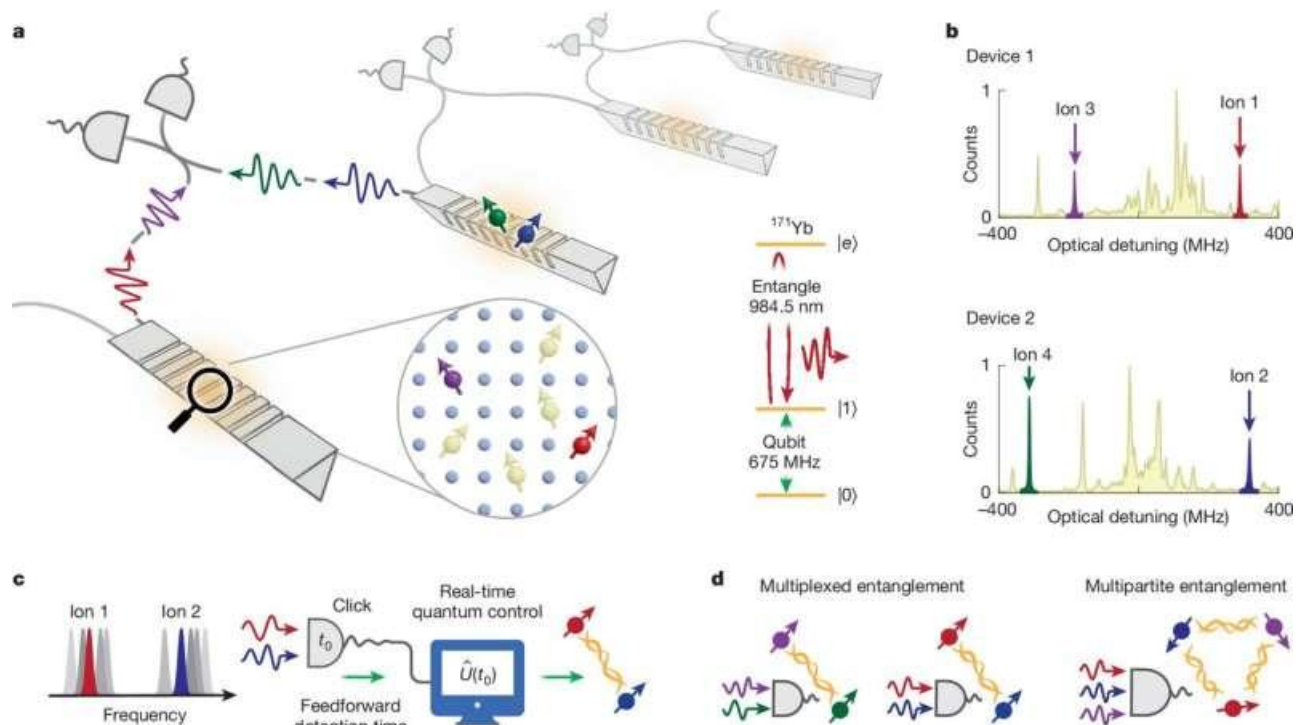
Journal information: [arXiv](#) , [Nature](#)

Provided by [University of California - Santa Barbara](#)

FEBRUARY 26, 2025

Engineers achieve multiplexing entanglement in quantum network

by [California Institute of Technology](#)



Schematic of a quantum network link based on multiple ^{171}Yb qubits in nanophotonic cavities. Credit: *Nature* (2025). DOI: 10.1038/s41586-024-08537-z

Laying the groundwork for quantum communication systems of the future, engineers at Caltech have demonstrated the successful operation of a quantum network of two nodes, each containing multiple quantum bits, or qubits—the fundamental information-storing building blocks of quantum computers.

To achieve this, the researchers developed a new protocol for distributing [quantum information](#) in a parallel manner, effectively creating multiple channels for sending data, or multiplexing. The work was accomplished by embedding ytterbium atoms inside crystals and coupling them to optical cavities—nanoscale structures that capture and guide light. This platform has unique properties that make it ideal for using multiple qubits to transmit quantum information-carrying photons in parallel.

"This is the first-ever demonstration of entanglement multiplexing in a quantum network of individual spin qubits," says Andrei Faraon (BS '04), the William L. Valentine Professor of Applied Physics and Electrical Engineering at Caltech. "This method significantly boosts quantum communication rates between nodes, representing a major leap in the field."

The work is described in a paper [published](#) on February 26 in the journal *Nature*. The lead authors of the paper are Andrei Ruskuc (Ph.D. '24), now a postdoctoral fellow at Harvard University, and Chun-Ju Wu, a graduate student at Caltech, who completed the work in Faraon's lab.

Just as the internet connects with the classical computers we are accustomed to using today, the quantum networks of the future will connect quantum computers that exist in different physical locations.

When working with the quantum realm, researchers are dealing with the miniscule scale of individual atoms and of photons, the basic particles of light. At this scale, matter does not behave according to classical physics; instead, quantum mechanics are at play.

One of the most important and bizarre concepts in quantum mechanics is that of entanglement, where two or more objects such as atoms or photons are inextricably linked regardless of their physical separation. This connection is so fundamental, that one particle cannot be fully described without reference to the other. As a result, measuring the [quantum state](#) of one also provides information about the other, which is key to quantum communication.

In quantum communication, the goal is to use entangled atoms as qubits to share, or teleport, quantum information. The key challenge that has thus far limited communication rates is the time it takes to prepare qubits and to transmit photons.

"Entanglement multiplexing overcomes this bottleneck by using multiple qubits per processor, or node. By preparing qubits and transmitting photons simultaneously, the entanglement rate can be scaled proportionally to the number of qubits," says Ruskuc.

In the new system, the two nodes are nanofabricated structures made from crystals of yttrium orthovanadate (YVO4). Lasers are used to excite ytterbium atoms (Yb³⁺), a rare-earth metal, within these crystals, causing each atom to emit a photon that remains entangled with it. Photons from atoms in two separate nodes then travel to a central location where they are detected. That detection process triggers a quantum processing protocol that leads to the creation of entangled states between pairs of ytterbium atoms.

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Each node has many ytterbium atoms within the YVO4 crystal, so there are plenty of available qubits. However, each of those atoms has a slightly different optical frequency caused by imperfections within the crystal.

"This is like a double-edged sword," Ruskuc says. On one hand, the differing frequencies allow the researchers to fine-tune their lasers to target specific atoms. On the other, scientists previously believed that the corresponding differences in photon frequencies would make it impossible to generate entangled [qubit](#) states.

"That's where our protocol comes in. It is an innovative way to generate entangled states of atoms even when their optical transitions are different," Ruskuc says.

In the new protocol, the atoms undergo a kind of tailored quantum processing in real time once the photons are detected at the central location. The researchers call this processing "quantum feed-forward control."

"Basically, our protocol takes this information that it received from the [photon](#) arrival time and applies a quantum circuit: a series of logic gates that are tailored to the two qubits. And after we've applied this circuit, we are left with an entangled state," Ruskuc explains.

The team's YVO4 platform can accommodate many qubits—in this work, each node contained approximately 20. "But it may be possible to increase that number by at least an order of magnitude," says co-author Wu.

"The unique properties of rare-earth ions combined with our demonstrated protocol pave the way for networks with hundreds of qubits per node," Faraon says. "We believe this work lays a robust foundation for high-performance quantum communication systems based on rare-earth ions."

Additional Caltech authors of the paper, "Multiplexed Entanglement of Multi-emitter Quantum Network Nodes," are graduate student Emanuel Green; AWS Quantum Postdoctoral Scholar Research Associate Sophie L. N. Hermans; graduate student William Pajak; and Joonhee Choi of Stanford University, a former postdoctoral scholar from Faraon's lab. Device nanofabrication was performed in the Kavli Nanoscience Institute at Caltech.

More information: A. Ruskuc et al, Multiplexed entanglement of multi-emitter quantum network nodes, *Nature* (2025). DOI: [10.1038/s41586-024-08537-z](https://doi.org/10.1038/s41586-024-08537-z)

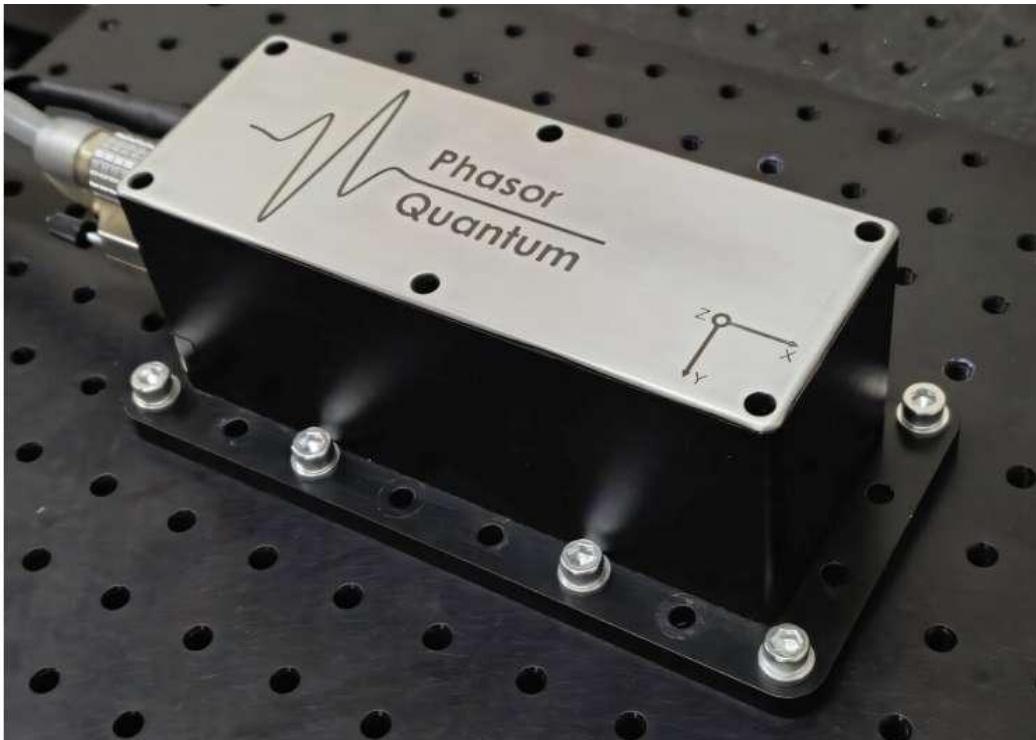
Journal information: [Nature](#)

Provided by [California Institute of Technology](#)

FEBRUARY 27, 2025

Quantum navigation could transform how we travel. So what is it, and how does it work?

by Allison Kealy, [The Conversation](#)



A quantum magnetometer used in our research. Credit: Swinburne University/RMIT/Phasor Quantum technology is no longer confined to the lab—it's making its way into our everyday lives. Now, it's about to transform something even more fundamental: how we navigate the world.

Imagine submarines traveling beneath the ocean, never needing to surface for location updates. Planes flying across continents with unshakeable precision, unaffected by signal disruptions.

Emergency responders could navigate smoke-filled buildings or underground tunnels with flawless accuracy, while autonomous vehicles chart perfect courses through dense urban environments.

These scenarios might sound like science fiction, but they can all be made possible with an emerging approach known as quantum navigation.

This game-changing tech will one day redefine movement, exploration and connectivity in ways we're only just beginning to imagine. So, what is it?

Satellite navigation is at the heart of many things

Global navigation satellite systems, like GPS, are deeply embedded in modern society. We use them daily for navigation, ordering deliveries and tagging photo locations. But their impact goes far beyond convenience.

Timing signals from satellites in Earth's orbit authenticate stock market trades and help balance the electricity grid. In agriculture, satellite navigation [guides autonomous tractors](#) and [helps muster cattle](#).

Emergency services rely on navigation satellite systems for rapid response, reducing the time it takes [to reach those in need](#).

Despite their benefits, systems like GPS are quite vulnerable. Satellite signals can be jammed or interfered with. This can be due to active warfare, terrorism or for legitimate (or illegitimate) privacy concerns. Maps [like GPSJAM](#) show real-time interference hotspots, such as those in the Middle East, areas around Russia and Ukraine, and Myanmar.

The environment of space isn't constant, either. The sun regularly ejects giant balls of plasma, causing what we know as solar storms. These emissions slam into Earth's magnetic field, disrupting satellites and GPS signals. Often these effects are temporary, but they can also cause significant damage, [depending on the severity of the storm](#).

An outage of global navigation satellite systems would be more than an inconvenience—it would disrupt our most critical infrastructure.

Estimates suggest a loss of GPS would cost just the United States economy [about US\\$1 billion per day](#) (A\$1.5 billion), causing cascading failures across interconnected systems.

Quantum navigation to the rescue

In some environments, navigation signals from satellites don't work very well. They don't penetrate water or underground spaces, for example.

If you've ever tried to use Google Maps in a built-up city with skyscrapers, you may have run into issues. Tall buildings cause signal reflections that degrade accuracy, and signals are weakened or completely unavailable inside buildings.

This is where quantum navigation could step in one day.

Quantum science describes the behavior of particles at scales smaller than an atom. It reveals mind-boggling effects like superposition—particles existing in multiple states simultaneously—and [entanglement](#) (when particles are connected through space and time in ways that defy classical understanding).

These effects are fragile and typically collapse under observation, which is why we don't notice them in everyday life. But the very fragility of quantum processes also lets them work as exquisite sensors.

A sensor is a device that detects changes in the world around it and turns that information into a signal we can measure or use. Think automatic doors that open when we walk near them, or phone screens that respond to our touch.

Quantum sensors are so sensitive because quantum particles react to *tiny* changes in their environment. Unlike normal sensors, which can miss weak signals, [quantum sensors](#) are extremely good at detecting even the smallest changes in things like time, gravity or magnetic fields.

Their sensitivity comes from how easily quantum states change when something in their surroundings shifts, allowing us to measure things with much greater accuracy than before.

This precision is critical for robust navigation systems.

Our team is researching new ways to use quantum sensors to measure Earth's magnetic field for navigation. By using [quantum effects](#) in diamonds, we can detect Earth's magnetic field in real time and compare the measurements to [pre-existing magnetic field maps](#), providing a resilient alternative to [satellite navigation](#) like GPS.

Since magnetic signals are unaffected by jamming and work underwater, they offer a promising backup system.

The future of navigation

The future of navigation will integrate quantum sensors to enhance location accuracy (via Earth's magnetic and gravitational fields), improve orientation (via quantum gyroscopes), and enable superior timing (through compact atomic clocks and interconnected timekeeping systems).

These technologies promise to complement and, in some cases, provide alternatives to traditional satellite-based navigation.

However, while the potential of quantum navigation is clear, making it a practical reality remains a significant challenge. Researchers and companies worldwide are working to refine these technologies, with major efforts underway in academia, government labs and industry.

Startups and established players are developing prototypes of [quantum accelerometers](#) (devices that measure movement) and gyroscopes, but most remain in early testing phases or specialized applications.

Key hurdles include reducing the size and power demands of quantum sensors, improving their stability outside of controlled laboratory settings, and integrating them into existing navigation systems.

Cost is another barrier—today's quantum devices are expensive and complex, meaning widespread adoption is still years away.

If these challenges can be overcome, quantum navigation could reshape everyday life in subtle but profound ways. While quantum navigation won't replace GPS overnight, it could become an essential part of the infrastructure that keeps the world moving.

Provided by [The Conversation](#)

MARCH 4, 2025

Scientists unravel spiraling secrets of magnetic materials for next-generation electronics

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

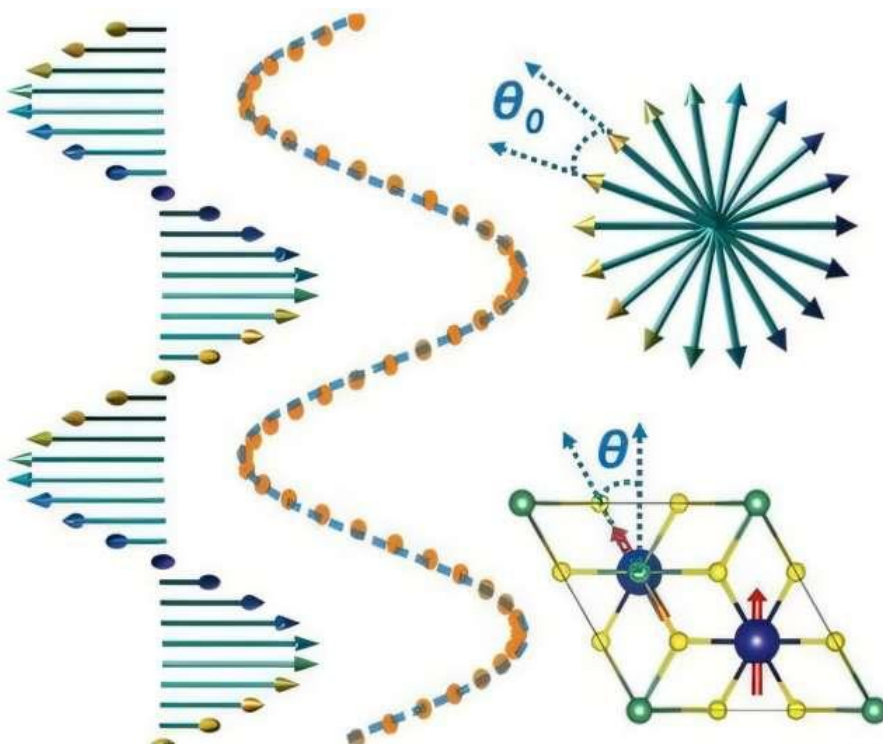


Illustration of how spin rotation changes the total energy of a helimagnetic system. Credit: Kesong Yang lab

Deep within certain magnetic molecules, atoms arrange their spins in a spiral pattern, forming structures called chiral helimagnets. These helical spin patterns have intrigued researchers for years due to their potential for powering next-generation electronics. But decoding their properties has remained a mystery—until now.

Researchers at the University of California San Diego have developed a [new computational approach](#) to accurately model and predict these complex spin structures using quantum mechanics calculations. Their work was [published](#) on Feb. 19 in *Advanced Functional Materials*.

"The helical spin structures in two-dimensional layered materials have been experimentally observed for over 40 years. It has been a longstanding challenge to predict them with precision," said Kesong Yang, professor in the Aiiso Yufeng Li Family Department of

Chemical and Nano Engineering at the UC San Diego Jacobs School of Engineering and senior author of the study. "The helical period in the layered compound extends up to 48 nanometers, making it extremely difficult to accurately calculate all the electron and spin interactions at this scale."

In this approach, researchers calculated how the total energy of a chiral helimagnet changes as the spin rotation shifts between successive layers of atoms. By applying first-principles quantum mechanics calculations, they were able to map out the critical features of these spiraling structures.

"Rather than modeling the entire system at a large length scale, we chose to focus on how spin rotation affects the total energy of the system," said study first author Yun Chen, a nanoengineering Ph.D. student in Yang's group. "By using a small supercell and designing optimized spin configurations, we were able to obtain highly accurate results."

They tested their approach on a group of chiral helimagnets containing chromium, a metal known for its [magnetic properties](#). The team successfully predicted three key parameters: the helix wavevector, which describes how tightly the spins spiral; the helix period, or the length of one complete spiral turn; and the critical magnetic field, the strength of an external field needed to alter the helimagnet's structure.

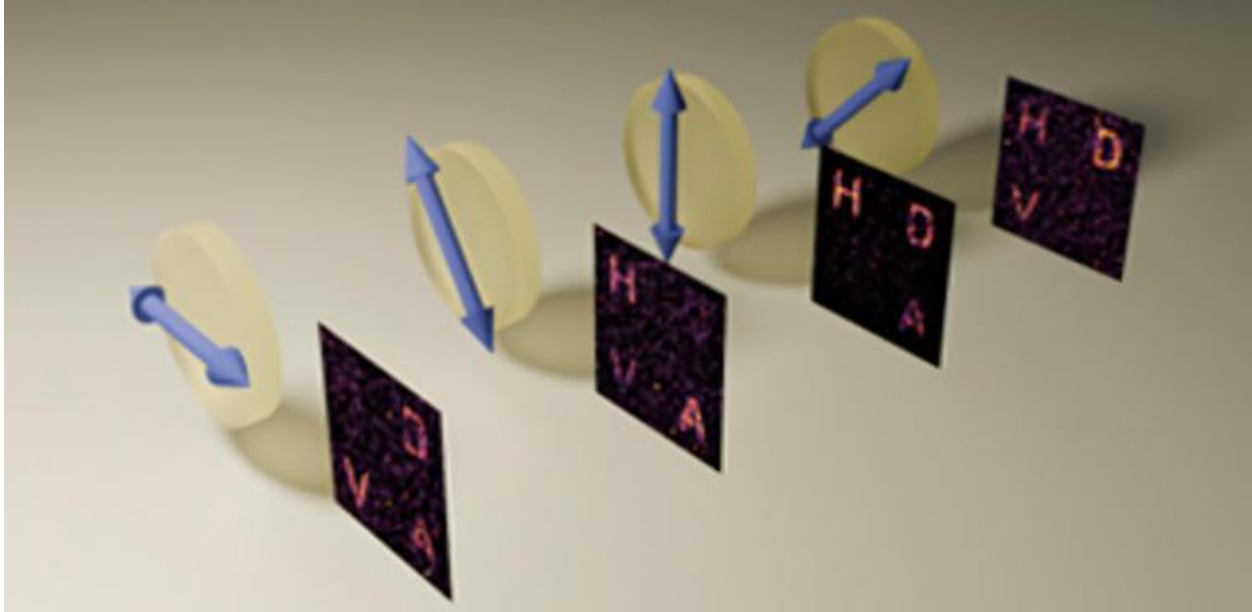
"This is exciting because we can now precisely model these complex spin structures using quantum mechanics calculations, opening new opportunities for designing better materials," said Yang.

More information: Yun Chen et al, First-Principles Approach for Predicting Chiral Helimagnetism, *Advanced Functional Materials* (2025). DOI: [10.1002/adfm.202501665](https://doi.org/10.1002/adfm.202501665)

Journal information: [Advanced Functional Materials](#)

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

Quantum holograms: Metasurfaces entangle light and information in new study



Polarization and holographic information become entangled in a quantum hologram. Holographic letters demonstrate entanglement through polarization of paired photons. By selecting different polarizer orientations for one photon, specific letters in the hologram could be selectively erased, demonstrating precise control over the entangled holographic information. Credit: Figure by J. Li (University of Exeter).

Quantum entanglement is a fundamental phenomenon in nature and one of the most intriguing aspects of quantum mechanics. It describes a correlation between two particles, such that measuring the properties of one instantly reveals those of the other, no matter how far apart they are. This unique property has been harnessed in applications such as quantum computing and quantum communication.

A common method for generating entanglement is through a nonlinear crystal, which produces photon pairs with entangled polarizations via spontaneous parametric down-conversion (SPDC): if one photon is measured to be horizontally polarized, the other will always be vertically polarized, and vice versa.

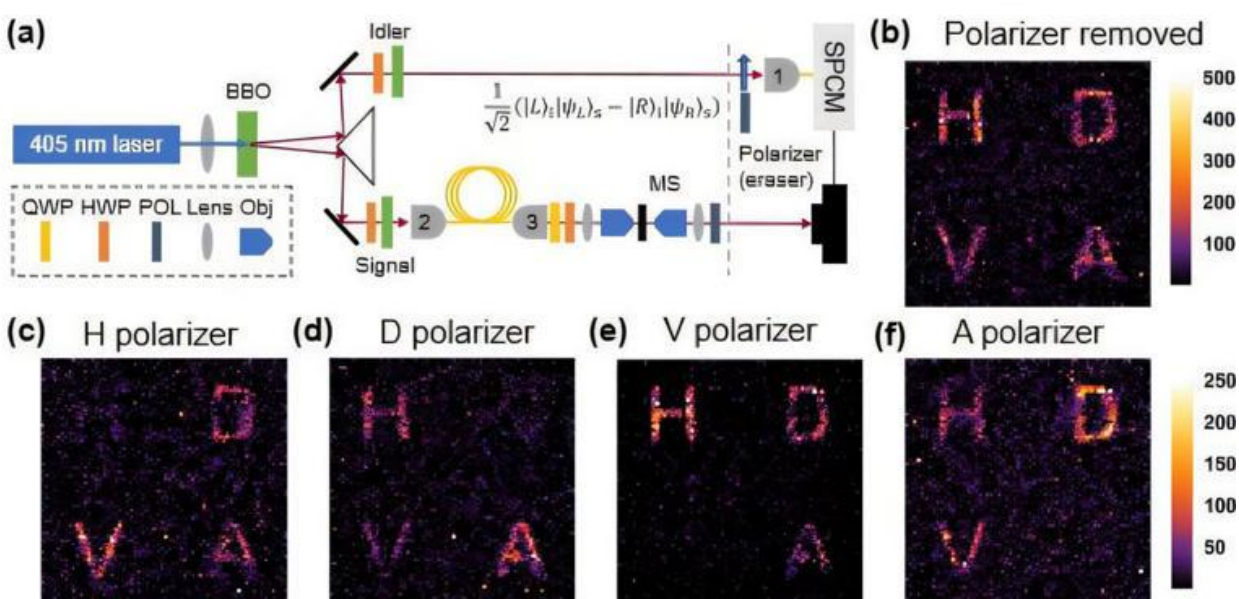
Meanwhile, metasurfaces—ultrathin optical devices—are known for their ability to encode vast amounts of information, allowing the creation of high-resolution holograms. By combining metasurfaces with nonlinear crystals, researchers can

explore a promising approach to enhancing the generation and control of entangled photon states.

In a recent study [published](#) in *Advanced Photonics*, researchers from Hong Kong and the UK introduced a novel approach to creating quantum holograms using metasurfaces. By carefully designing the orientations of nanostructures within the metasurface, they enabled the generation of a quantum hologram, where polarization and holographic information become entangled.

"We have demonstrated that metasurfaces serve as a versatile platform for generating quantum holograms. The entanglement property of these quantum holograms is further revealed by projecting one photon onto various polarization states corresponding to interference effects observed elsewhere," explained Jensen Li, professor of Computational Engineering and Metamaterials at the University of Exeter, and senior author of the report.

The approach offers a compact yet flexible method that is difficult to achieve with conventional materials. To demonstrate, the researchers successfully created four holographic letters—"H," "V," "D," and "A"—entangled with the polarization of the paired photons. By selecting different polarizer orientations for one photon, specific letters in the hologram could be selectively erased, demonstrating precise control over the entangled holographic information.



Experimental setup demonstrating entanglement between two photons. (a) The experimental setup: A 405 nm laser illuminates a β -barium borate (BBO) crystal to generate entangled photon pairs, with the idler photon in the upper arm and the signal photon in the lower arm. The metasurface (MS) encodes polarization information into holographic letters. (b) The signal photon's hologram observed without a polarizer (eraser) in the idler arm. (c-f) Holograms with different polarizer orientations in the idler arm. The polarizer set to horizontal (H), diagonal (D), vertical (V), and antidiagonal (A) orientations selectively erases the corresponding letter in the holographic output. Credit: H. Liang et al., doi 10.1117/1.AP.7.2.026006.

Beyond its fundamental significance, this research also holds promise for practical applications, such as quantum communication, by encoding information in both the letters and polarization states. "With more complex entanglement patterns, we may be able to increase the information capacity for quantum key distribution, which is a secure way to communicate," said Hong Liang, a co-author of the study. "We believe that metasurfaces can significantly reduce the size of quantum optical systems, making this technology much more practical for everyday use."

Additionally, the researchers suggest that metasurfaces can be used for anti-counterfeiting technology. Beyond the inherent difficulty of replicating the metasurface itself, the intricate relationship between the letters and polarization states and the relative phase profile between different holograms creates a unique pattern that is extremely challenging to reproduce, enhancing security against forgery.

"Our demonstration can also be interpreted as a quantum eraser at the holographic level. Compared to the traditional double-slit quantum eraser, our setup replaces two slits with two holograms and obtains 'which-hologram information' from the polarization of entangled photons. Erasing this information now has a concrete effect, as illustrated by erasing holographic letters," added Wai Chun Wong, another co-author of the paper.

This research highlights how modern nanofabrication technology can harness quantum effects for practical applications. Despite their ultrathin nature, metasurfaces enable complex quantum operations that would traditionally require intricate optical setups. This achievement not only deepens our collective understanding of quantum mechanics but also provides further general insight for quantum information processing.

More information: Hong Liang et al, Metasurface-enabled quantum holograms with hybrid entanglement, *Advanced Photonics* (2025). DOI: [10.1117/1.AP.7.2.026006](https://doi.org/10.1117/1.AP.7.2.026006) Provided by SPIE

- **EDITORIAL**
- 08 January 2025

Quantum mechanics 100 years on: an unfinished revolution

A century ago, physics had its Darwinian moment — a change in perspective that was as consequential for the physical sciences as the theory of evolution by natural selection was for biology.

Quantum theory helped to explain how the energy levels of an atom split in a magnetic field, a phenomenon known as the Zeeman effect. Credit: Harsh Vardhan Dewangan/Shutterstock

It is rare for a scientific idea or theory to fundamentally change our perspective on reality. One such revolutionary moment is being celebrated in 2025, which the United Nations has declared to be the [International Year of Quantum Science and Technology](#). This marks the centenary of the advent of quantum mechanics, which began in a flurry of papers 100 years ago. Just as it would be impossible to make sense of modern biology without Charles Darwin's theory of evolution, our fundamental understanding of the physical world is now rooted in quantum principles. Modern physics is quantum physics.

The word quantum refers to the way matter absorbs or releases energy — in discrete packets, or quanta. Its use in physics comes from the German word *quant*, which is derived from a Latin term meaning 'how much'. In around 1900, physicists such as Max Planck and Albert Einstein began to describe, in an ad hoc way, why several phenomena of the subatomic realm could not be explained using the classical mechanics developed by Isaac Newton and others some two centuries earlier. Then, in 1925, quantum came to be used to describe the fundamentals of an entirely new form of mechanics — the branch of physics that describes the relationship between forces and the motion of physical objects.

As science historian Kristian Camilleri describes in an [Essay on the startling developments of that year](#) and those that followed, the physicist Werner Heisenberg travelled to the German island of Heligoland in the North Sea in the summer of 1925 in search of relief from severe hay fever. Shortly after this, he submitted to the journal *Zeitschrift für Physik* a paper whose title translates as ‘On quantum-theoretical reinterpretation of kinematic and mechanical relationships’ ([W. Heisenberg Z. Physik 33, 879–893; 1925](#)). This prompted further studies in the following months by Heisenberg and his close collaborators, as well as work using an alternative approach by Erwin Schrödinger.

The revolution did not begin with physicists throwing away the laws of classical mechanics, but with their radically reinterpreting classical concepts such as energy and momentum. However, it did require its initiators to abandon dearly held common-sense ideas — for example, the expectation that subatomic objects such as particles have a well-defined position and momentum at any given time. Instead, the physicists found that natural phenomena had an inherently unknowable nature. Classical physics, in other words, is only an approximate representation of reality, and manifests itself only at the macroscopic level. A century on, this insight into the nature of the physical world still thrills and bamboozles in equal measures.

Many *Nature* readers will know about the philosophical quandaries raised by quantum cats that are simultaneously dead and alive, and about the industry that is [growing around quantum computing](#).

Others will know how quantum ideas gave rise to the lasers that beam information through the cables of the Internet, and the transistors that provide the processing power of electronic chips. But quantum ideas also shape our understanding of nature, at all levels, explaining why solid objects don’t fall apart and how stars shine and, ultimately, die.

A quantum year

Commemorative events are being planned all over the world for the coming 12 months. They include an [opening ceremony for the UN year](#) at the headquarters of the UN scientific organization UNESCO in Paris in February;

special events at a [meeting of the American Physical Society](#) in Anaheim, California, in March; and a [workshop for physicists on Heligoland](#) in June. The organizers' collective ambition is to celebrate not just the centenary of quantum mechanics, but also the science and applications that arose from it in the past century — and to explore how quantum physics might bring further change in the century to come.

In May, Ghana, the country that originally proposed that the UN proclaim 2025 the year of quantum science, is hosting an international conference on the topic in Kumasi. And in August, science historians will meet to celebrate the quantum century in Salvador de Bahia in Brazil.

This meeting will be the high point of a [20-year research programme](#) that set out to re-examine the development of quantum theory. One major aim of that work, says historian Michel Janssen at the University of Minnesota in Minneapolis, was to establish the contributions of a collective of scientists, many of whom — particularly women — have not been recognized in the history of the field.

These “hidden figures” include Lucy Mensing, who was a member of the same group as Heisenberg and worked out some of the first applications of his quantum-mechanical theory, says Daniela Monaldi, a historian at York University in Toronto, Canada. One of the most notable events of the year will be the publication of a biographical volume of essays on 16 of them, *Women in the History of Quantum Physics*.



German physicists Otto Stern (pictured) and Walther Gerlach demonstrated quantum spin in the famous Stern–Gerlach experiment of 1922. Credit: AIP Emilio Segrè Visual Archives, Segrè Collection

For all that it has already brought, the quantum revolution still has unfinished business. In the years in which researchers were laying the foundations of quantum mechanics, they also began to rebuild other branches of physics — such as the study of electromagnetism, and states of matter — from quantum foundations. They also looked to extend their theories to encompass objects that move at close to light speed, something that the original quantum theory did not. These efforts drastically expanded the scope of quantum science and led researchers to develop the standard model of particles and fields, a process that finally came together in the 1970s.

The standard model has been incredibly successful, culminating in the 2012 discovery of its linchpin elementary particle, the Higgs boson. But these extensions lie on less-solid theoretical ground than quantum mechanics does — and leave several phenomena unexplained, such as the nature of the ‘dark matter’ that seems to greatly outweigh conventional, visible matter in the

wider cosmos. Moreover, one important phenomenon, gravity, still resists being quantized.

Other conceptual problems of quantum physics remain open. In particular, researchers struggle to understand what exactly happens when experiments ‘collapse’ the fuzzy probabilities of quantum objects into one precise measurement, a key step in creating the — still remorselessly classical — macroscopic world we live in. Over the past few decades, researchers have been developing ways to turn these quirks of quantum reality into useful technologies. The resulting applications in computing, ultra-secure communications and innovative scientific instruments are still in their nascent stages.

Quantum theory keeps on giving. This year is an opportunity to celebrate and to make the broader public aware of the role that quantum physics has in their lives — and to inspire future generations, whoever they are and wherever they are in the world, to contribute to another quantum century.

Nature **637**, 251-252 (2025)

doi: <https://doi.org/10.1038/d41586-025-00014-5>

World's first quantum microsatellite demonstrates secure communication with multiple ground stations

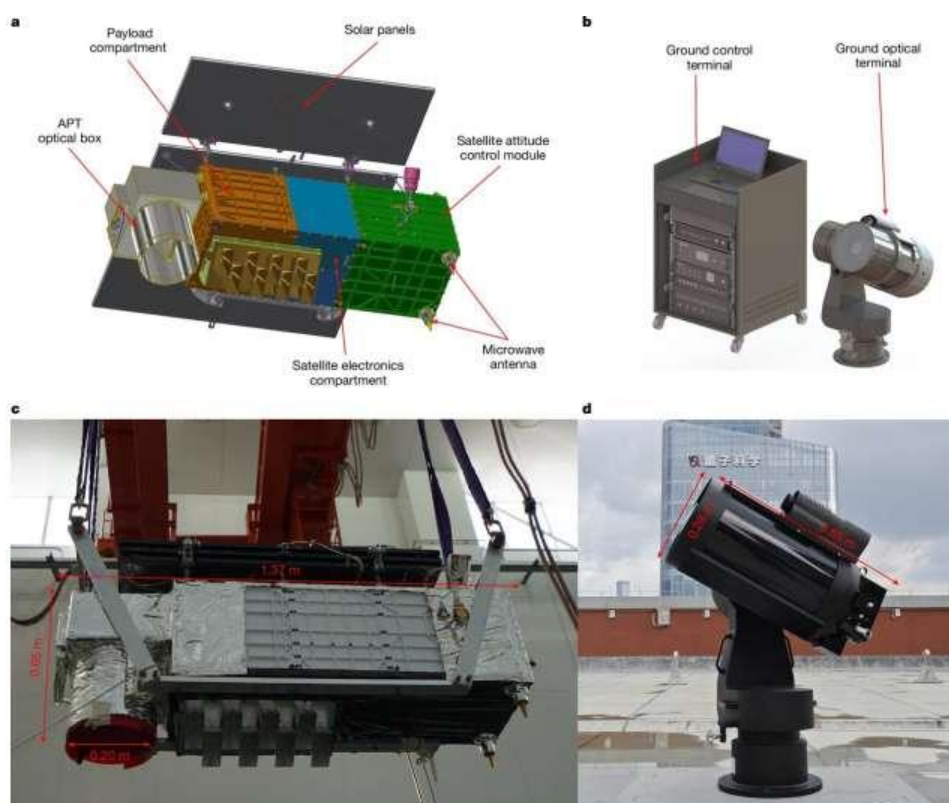
A research team has developed the world's first quantum microsatellite and demonstrated real-time quantum key distribution (QKD) between the satellite and multiple compact, mobile ground stations.

Quantum **secure communication** is fundamental to national information security and socioeconomic development. QKD, a communication method with proven unconditional security, significantly enhances data transmission security. While fiber-based QKD networks

have achieved regional implementation, their practical application over long distances remains constrained by signal loss and limited coverage. Satellite-based systems present a viable solution through free-space communication, potentially enabling QKD on a global scale.

USTC has pioneered groundbreaking research in [satellite](#)-based QKD. The launch of the Micius quantum satellite has achieved the world's first successful demonstration of space-to-ground QKD, which was subsequently integrated with the fiber-based Beijing-Shanghai backbone to create the space-ground quantum secure communication network.

Towards practical applications, however, compact payload and portable ground station are essential for widespread deployment and swift implementation. In particular, the small-size payload can be assembled on satellites of various sizes to compose a quantum satellite internet constellation for global services.



The microsatellite and the portable OGS. Credit: *Nature* (2025). DOI: 10.1038/s41586-025-08739-z

To achieve this, the team developed several key technologies, including miniaturized decoy-state QKD light sources for quantum state preparation, real-time key distillation and encrypted communication based on laser communication, and high-precision tracking based on satellite attitude control to maintain stable optical links.

Building on these advances, the team successfully launched Jinan-1, the world's first quantum microsatellite, on July 27, 2022. Additionally, the team developed compact optical ground stations, reducing the weight by two orders of magnitude to less than 100 kg. This

lightweight design allows for rapid deployment in different locations, significantly increasing the flexibility and practicality.

During the experiments, Jinan-1 established optical links with multiple optical ground stations in Jinan, Hefei, Nanshan, Wuhan, Beijing, Shanghai, in China, and Stellenbosch in South Africa. The satellite transmitted approximately 250 million quantum photons per second. For each satellite pass, the system generated up to 1 Mbits of secure keys. Using the satellite as a trusted relay, the team demonstrated successful secure key sharing and encrypted communication between Beijing and Stellenbosch—two cities separated by 12,900 km.

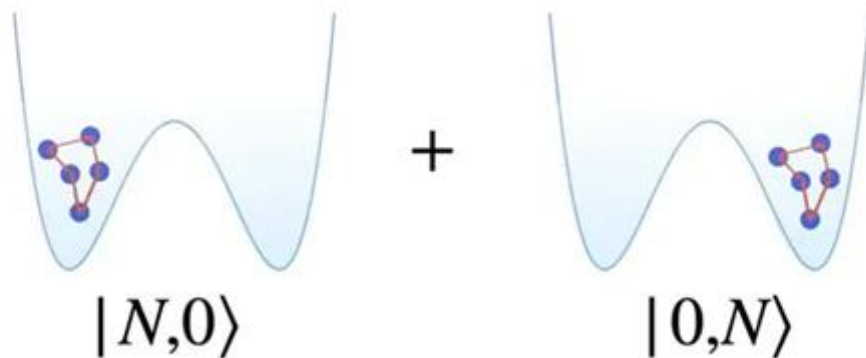
The team's work lays a solid foundation for the deployment of a constellation of quantum microsatellites, providing crucial technical support for large-scale quantum communication networks and holding immense promise for the global deployment of the quantum internet.

More information: Yang Li et al, Microsatellite-based real-time quantum key distribution, *Nature* (2025). DOI: [10.1038/s41586-025-08739-z](https://doi.org/10.1038/s41586-025-08739-z)

Journal information: [Nature](#)

Provided by [University of Science and Technology of China](#)

A quantum superhighway for ultrafast NOON states

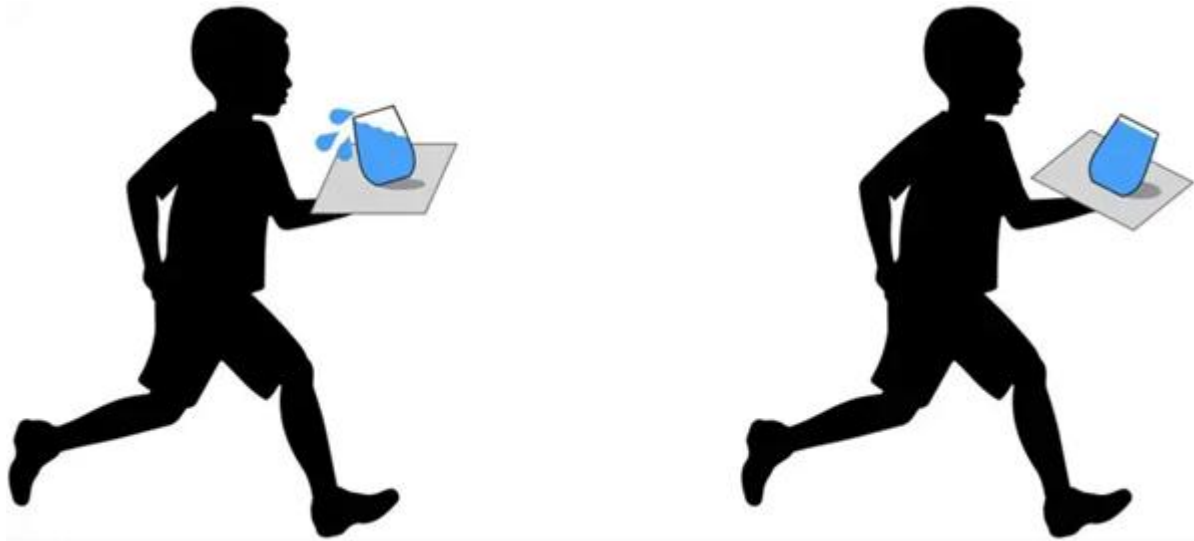


A NOON state is a superposed quantum state where N particles are in one state "at the same time" and in another "at the same time." Here, the particles are trapped in two wells, within a trap formed by lasers. The superimposed state therefore consists of a state in which all the particles are in the left-hand well, and a state in which they are trapped in the right-hand well. The particles interact with each other and stick together when they are in the same site, preventing an isolated particle from leaving the trap. Credit: University of Liège / S. Dengis

Until now, creating quantum superpositions of ultra-cold atoms has been a real headache, too slow to be realistic in the laboratory. Researchers at the University of Liège have now developed an innovative new approach combining geometry and "quantum control," which drastically speeds up the process, paving the way for practical applications in quantum technologies.

The paper is [published](#) in the journal *Physical Review A*.

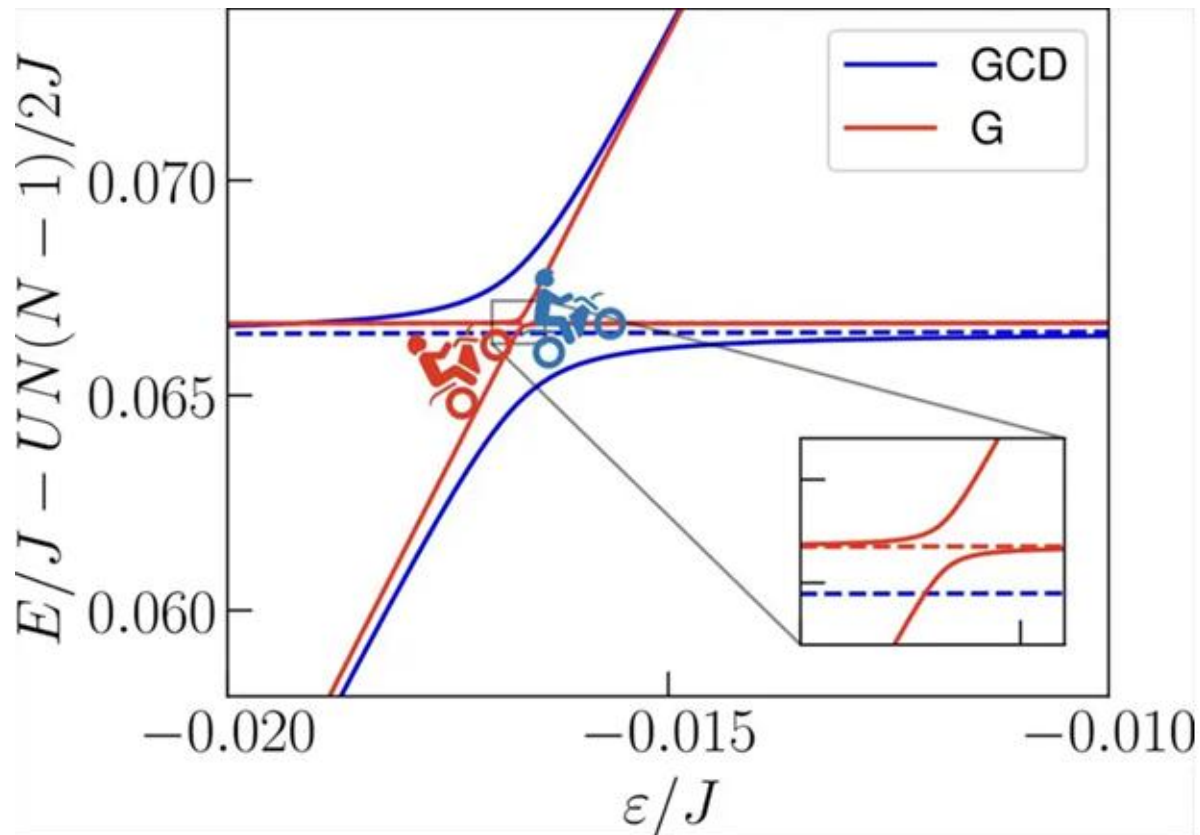
Imagine being in a supermarket with a cart filled to the brim. The challenge: get to the checkout before the others, without dropping your products on the corners. The solution? Choose a route with as few corners as possible to go faster without slowing down. That's exactly what Simon Dengis, a doctoral student at the University of Liège, has managed to do, but in the world of quantum physics.



Counter-diabatic control compensates for the inertia of a system by modifying it in a certain way. In this case, to compensate for the movement of the water caused by the movement of the waiter, the latter can tilt his tray to compensate for the inertia of the glass and prevent it from tipping over. Credit: University of Liège / S.Dengis

With his colleagues in the PQS (Quantum Statistical Physics) group, Dengis has developed a protocol for rapidly generating what are known as NOON states.

"These states, which look like miniature versions of Schrödinger's famous cat, are quantum superpositions," explains the physicist. "They are of major interest for technologies such as ultra-precise quantum sensors or quantum computers."



The proposed protocol (blue, GCD) makes it possible to widen the energy bottleneck (compared with the usual protocol in red, G) and therefore to have to brake less when approaching it. The image can be understood in the context of a motorbike race: the red motorbike will have to brake much more than the blue motorbike because the turn is less "smooth." The blue bike will therefore arrive at its destination before its opponent. Here, the change in the system's energies (and therefore its states) is less abrupt, allowing the process to be accelerated drastically. Credit: University of Liège / S.Dengis

The obstacle of time

The main challenge? Manufacturing these states normally takes far too long. We're talking tens of minutes or more, which often exceeds the lifetime of the experiment. The cause? An energy bottleneck, a "sharp bend" in the system's evolution that forces it to slow down.

This is where the ULiège team breaks new ground. By combining two powerful concepts—counterdiabatic driving and the optimal geodesic path—they have succeeded in "smoothing the road" for atoms. The result: the system can evolve faster without losing the trajectory of the desired state, just like a driver who anticipates a bend by tilting his tray.

"This strategy saves a considerable amount of time: in some cases, the process is accelerated by a factor of 10,000, while maintaining 99% fidelity, i.e. near-perfection of the result," says Peter Schlagheck, director of the laboratory. Where previously it would have taken around ten minutes to create such a state, the researchers have succeeded in considerably reducing this waiting time to 0.1 seconds.

Towards practical applications

With this breakthrough, it is finally possible to produce NOON states with ultra-cold atoms. This opens up prospects in quantum metrology (ultra-sensitive measurements of time, rotation or gravity) and quantum information technologies. Ultimately, these tools could improve instruments such as quantum gyroscopes or miniature gravity detectors.

This research shows how theory and experimentation can come together to make concrete advances in quantum physics. By combining mathematical concepts, fundamental physics and experimental feasibility, ULiège researchers have made a breakthrough that could well transform ideas that were once theoretical into tomorrow's technologies.

Quantum superposition and the NOON state

Quantum superposition is the idea that a quantum system (such as an atom, an electron or a photon) can exist in several states at the same time, as long as it is not observed. The example most often used to explain this concept is Schrödinger's cat: A cat is locked in a box. According to quantum mechanics, until the box is opened, the cat is both alive and dead.

This simultaneous combination of two states is called superposition. It is only by opening the box to observe it that we force nature to choose a state: alive or dead. The NOON states are an example of quantum superposition: all the atoms are in both the left-hand well and the right-hand well. It is only at the moment of measurement that they are found in one or the other.

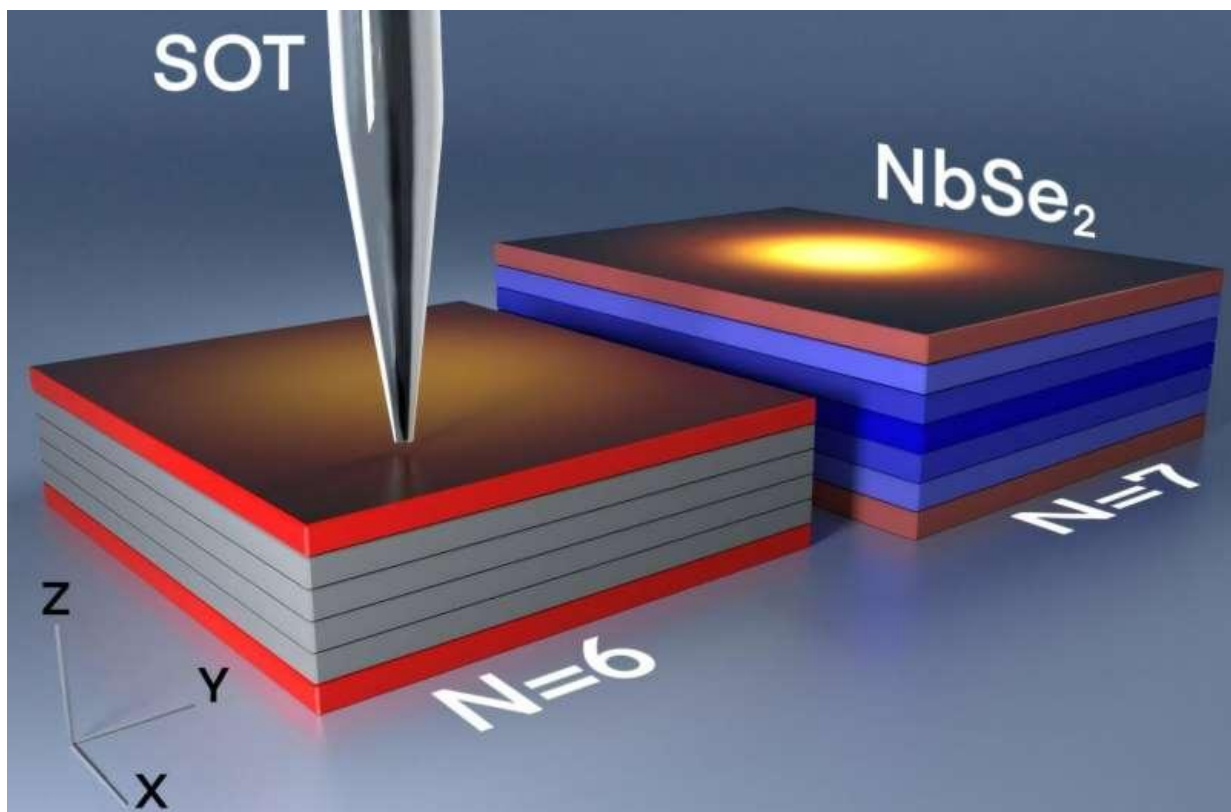
More information: Simon Dengis et al, Accelerated creation of NOON states with ultracold atoms via counterdiabatic driving, *Physical Review A* (2025). DOI: [10.1103/PhysRevA.111.L031301](https://doi.org/10.1103/PhysRevA.111.L031301). On *arXiv*: DOI: [10.48550/arxiv.2406.17545](https://doi.org/10.48550/arxiv.2406.17545)

Provided by University de Liege

MARCH 31, 2025

The hidden superconducting state in NbSe₂: Shedding layers and gaining insights

by [Hebrew University of Jerusalem](#)



A schematic illustration of the experimental setup shows a scanning magnetic microscope positioned above two different samples. One sample exhibits only surface superconductivity, while the other displays conventional superconductivity. Credit: Ori Lerman

Researchers have discovered an unexpected superconducting transition in extremely thin films of niobium diselenide (NbSe₂). Publishing in *Nature Communications*, they found that

when these films become thinner than six atomic layers, superconductivity no longer spreads evenly throughout the material, but instead becomes confined to its surface.

This discovery challenges previous assumptions and could have important implications for understanding [superconductivity](#) and developing advanced quantum technologies.

Researchers at the Hebrew University of Jerusalem have made a surprising discovery about how superconductivity behaves in extremely thin materials. Superconductors are materials that allow electric current to flow without resistance, which makes them incredibly valuable for technology. Usually, the properties of superconductors change predictably when the materials become thinner; however, this study found something unexpected.

The team, led by Ph.D. student Nofar Fridman, under the guidance of Prof. Yonathan Anahory from the Racah Institute of Physics and the Nano Center at Hebrew University looked closely at thin films made from niobium diselenide (NbSe_2), a special type of layered superconducting material, which can be assembled into structures where thickness is precisely controlled down to the few layer limit.

By using advanced magnetic imaging techniques, the researchers measured how these materials respond to magnetic fields as their thickness decreased.

Typically, scientists expect the ability of a superconducting material to expel magnetic fields to become stronger as the material becomes thicker. Here, this length is gauged by a physical property called the Pearl length. This study confirmed that rule for samples thicker than ten [atomic layers](#).

However, when the films became extremely thin—just three to six layers (2–4 nm)—the researchers observed something unexpected: the Pearl length sharply increased and became thickness independent, breaking the expected pattern.

"Our findings reveal something completely unexpected that could be ubiquitous in superconducting materials," explained Nofar Fridman, the Ph.D. student leading the study.

"In very thin samples, superconductivity behaves differently from what we've known. It seems that below a certain thickness, superconductors host current mostly at their top and bottom surfaces, rather than throughout their volume. This finding opens up exciting new questions about superconductivity in ultra-thin materials."

The team's supervisor, Prof. Yonathan Anahory emphasized the importance of their method, saying, "Our high-resolution magnetic imaging allowed us to see details that previous methods couldn't detect.

"By finding this unique surface superconductivity, we've expanded our understanding of how superconducting materials behave at extremely small scales. This could have significant implications for future research and technologies."

This discovery sheds new light on superconductivity in very thin films and challenges previously held theories. It also highlights how specialized measurement techniques can

uncover surprising new physical phenomena, potentially opening avenues for innovative applications in quantum technology.

More information: Anomalous Thickness Dependence of the Vortex Pearl Length in Few-Layer NbSe₂, *Nature Communications* (2025). DOI: [10.1038/s41467-025-57817-3](https://doi.org/10.1038/s41467-025-57817-3)

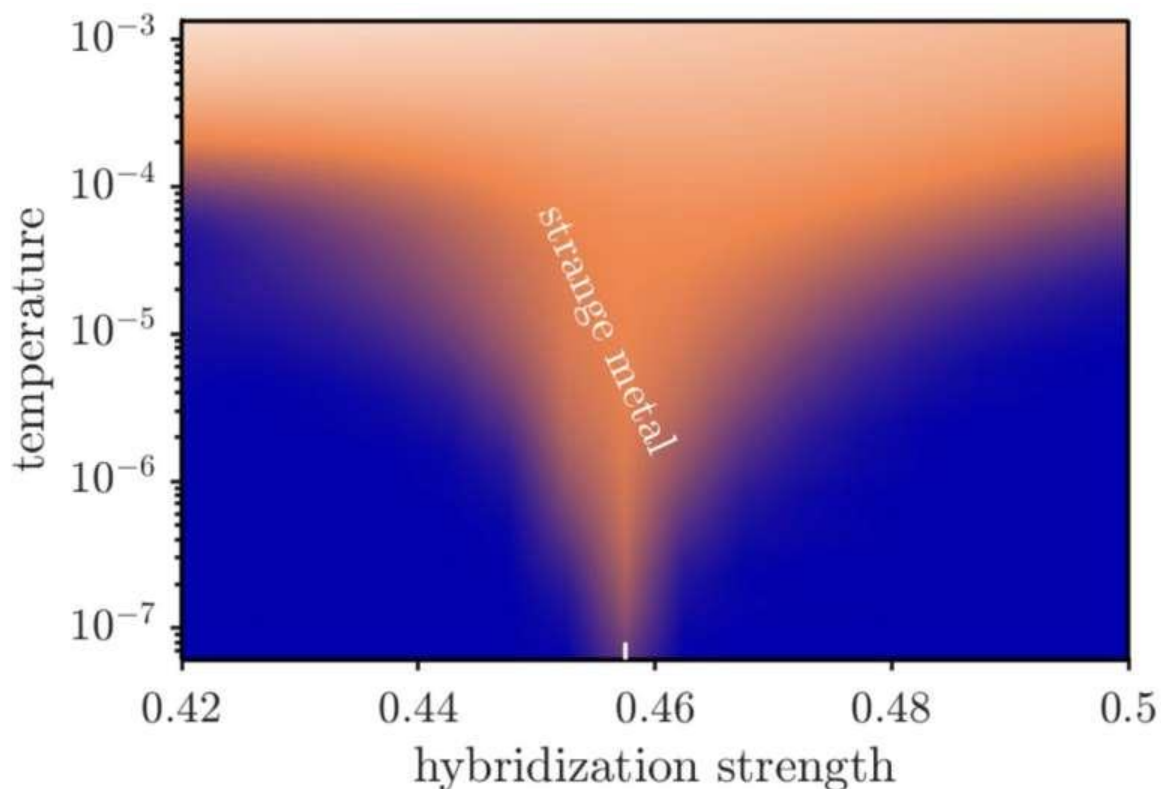
Journal information: [Nature Communications](#)

Provided by [Hebrew University of Jerusalem](#)

MARCH 30, 2025

Study proposes new mechanism underpinning intrinsic strange metal behavior

by Ingrid Fadelli , Phys.org



Theoretical phase diagram as a function of temperature and hybridization strength, which serve as our tuning parameters. The color indicates how correlations decay over time. In the blue regions, the decay is relatively fast, consistent with usual metals. In the orange region, correlations decay with a slow Planckian rate. This is where we find novel strange metal behavior. Credit: Gleis et al.

Quantum critical points are thresholds that mark the transition of materials between different electronic phases at absolute zero temperatures, around which they often exhibit exotic physical properties.

One of these critical points is the so-called Kondo-breakdown quantum critical point, which marks the collapse of the Kondo effect (i.e., [quantum phenomenon](#) that entails the localization of magnetic moments in metals), followed by new emergent physics.

Researchers at Ludwig-Maximilian University of Munich, Rutgers University, and Seoul National University set out to further study the dynamical scaling associated with the Kondo-breakdown quantum critical point, utilizing a [theoretical framework](#) describing heavy fermion materials known as the periodic Anderson model.

Their paper, [published](#) in *Physical Review Letters*, proposes a new mechanism that could underpin some of the unusual properties of the strange metal state of matter.

"Our initial incentive was to explore heavy fermion quantum criticality with modern, state-of-the-art [computational methods](#) that can resolve dynamics at much lower energies than previously studied," Andreas Gleis, first author of the paper, told Phys.org.

"The results on strange metal behavior in our *PRL* paper that came out of this study were more or less an unexpected surprise."

In their paper, Gleis and his colleagues introduce a new theory that describes the unusual dynamical response observed in many heavy fermion materials in proximity to their quantum critical points when they transition to the strange metal phase. Using computational methods, the researchers show that some fluctuations in these materials decay at a slow Planckian rate when they are in the quantum critical region governed by the quantum critical points.

"Interestingly, we find that critical collective short-ranged current fluctuations are also governed by this slow Planckian decay rate, which allows us to describe the unusual optical responses found in strange metals as an intrinsic property of the strange metal state," explained Gleis.

"How single-electron dynamics decay in the material, on the other hand, does not play a significant role. This is in stark contrast to the widespread 'marginal Fermi liquid' hypothesis, where single electron decay is at the heart of strange metal [optical properties](#)."

The researchers' paper suggests that the Kondo-breakdown quantum critical point considered in their study is an intrinsic (i.e., disorder-free) strange metal fixed point. Notably, their theoretical predictions are aligned with optical conductivity measurements collected as part of experiments focusing on the heavy-fermion compounds YbRh₂Si₂ and CeCoIn₅.

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This study also proposes a new mechanism that could underpin the intrinsic strange metal behavior reported in various heavy fermion materials. This mechanism, prompting the unusual optical properties that are intrinsic to strange metals, is rooted in critical short-ranged scattering (i.e., the strong and local electron-electron interactions observed close to a quantum [critical point](#)).

"In the near future, we plan to explore the mechanism and the properties of our newly found strange metal in more detail," added Gleis.

"We want to know under what precise conditions such strange metals arise, for instance, what kind of interactions are required and in what parameter regime they can be expected, and whether they also arise in other strongly correlated systems, such as cuprate superconductors.

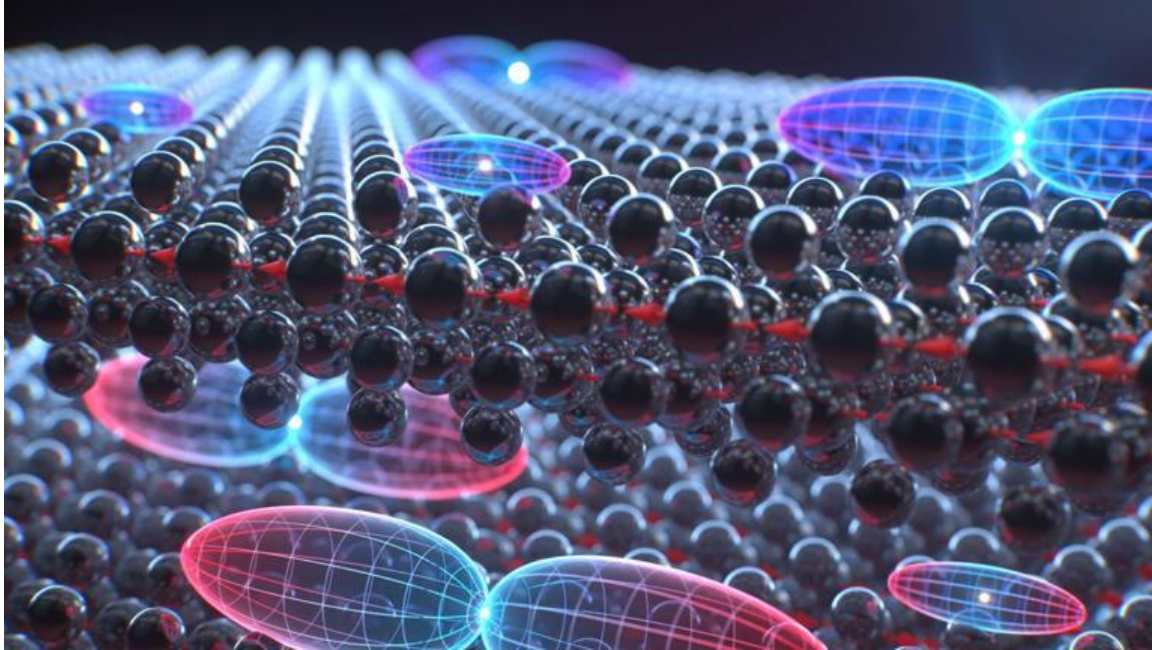
"Furthermore, we want to know whether and how the dynamics of the strange [metal](#) influence phenomena such as unconventional superconductivity."

More information: Andreas Gleis et al, Dynamical Scaling and Planckian Dissipation Due to Heavy-Fermion Quantum Criticality, *Physical Review Letters* (2025). DOI: [10.1103/PhysRevLett.134.106501](https://doi.org/10.1103/PhysRevLett.134.106501).

Journal information: [Physical Review Letters](#)

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Quantum 'miracle material' can store information in a single dimension thanks to newly discovered magnetic switching



Magnetic switch traps quantum information carriers in one dimension.© Brad Baxley, Part to Whole. For use reporting on this study, DOI: 10.1038/s41563-025-02120-1

Scientists have discovered how to use a quantum material to tap into the power of magnetism to store quantum information — thanks to its capacity to support magnetic switching (when the magnetic polarization switches direction). They say it can lead to more viable [quantum computing](#) and sensing, thanks to much longer-lasting quantum states.

[Chromium sulfide bromide](#) is an unusual material that has been likened to filo pastry (thin, folded layers of pastry) thanks to its structure of just a few layers of atoms. Scientists consider it extremely promising for quantum devices because many of its properties can be used for any type of information storage. It can be used to store information using an electric charge, as photons (as light), through magnetism (through the electronic spin) and even via phonons — like vibrations from sound. One of the many ways in which chromium sulfide bromide could be used to store information is through excitons — quasi-particles that form when

an electron and its hole become bound together. When a photon is moved from its grounded energy state, it effectively leaves behind a hole where it once was. Although they are separated, the photon and the hole remain paired together and become known as an exciton.

[Previous research](#) has highlighted how these excitons can sometimes form in a straight line in the material. But these excitons also exhibit unusual magnetic properties.

At temperatures less than 132 Kelvin (-222 degrees F or -141 degrees C), the material's layers are magnetized and the electrons are aligned, while the direction of the magnetic field switches for each layer in the material.

When chromium sulfide bromide is warmed to more than 132 K, the material loses its magnetization as the electrons can move in random directions. In this unmagnetized state, the excitons are no longer trapped and extend over multiple layers of the material.

However, when chromium sulfide bromide is only a single atom thick, the excitons are confined to a single dimension. When used in a quantum device, this restriction could allow quantum information in the excitons to be stored much longer than it would otherwise be, as the excitons are less likely to collide with each other and lose the information they carry through decoherence (the loss of quantum information due to interference).

Quantum information in one dimension

In the new study published Feb. 19 in the journal [Nature Materials](#), scientists reported that they had produced excitons in chromium sulfide bromide by firing pulses of infrared light in 20 bursts lasting only 20 quadrillionths of a second (20×10^{-15}). They then used a second infrared laser to nudge the excitons into a higher energy state, before finding they had created two different variations of exciton when they should otherwise have had identical states of energy.

When the less energetic pulses were shot by lasers from different axes, the researchers discovered that the direction-dependent excitons could be confined to a single line or expanded into three dimensions. The change from

unidimensional; to three-dimensional excitons accounted for how long the excitons could last without colliding with each other.

"The magnetic order is a new tuning knob for shaping excitons and their interactions. This could be a game changer for future electronics and information technology," said co-author of the study [Rupert Huber](#), professor of experimental and applied physics at the University of Regensburg, Germany.

One of the key areas the research team wants to pursue next is to investigate whether these excitons could be converted to magnetic excitations in the electronic spin of the material. Were they to achieve this, it could provide a useful method for converting quantum information between different subatomic particles (photons, excitons and electrons).

Switching between magnetized and non-magnetized states could provide a fast method for converting photon and spin-based quantum information. The hope with chromium sulfide bromide is to harness all of its properties for use in future devices.

"The long-term vision is, you could potentially build quantum machines or devices that use these three or even all four of these properties: photons to transfer information, electrons to process information through their interactions, magnetism to store information, and phonons to modulate and transduce information to new frequencies," said co-author of the study [Mackillo Kra](#), professor of electrical and computer engineering at the University of Michigan, in [a statement](#).

Quantum computer outperforms supercomputers in approximate optimization tasks



A quantum computer can solve optimization problems faster than classical supercomputers, a process known as "quantum advantage" and demonstrated by a USC researcher in a paper recently [published](#) in *Physical Review Letters*.

The study shows how quantum annealing, a specialized form of quantum computing, outperforms the best current classical algorithms when searching for near-optimal solutions to complex problems.

"The way quantum annealing works is by finding low-energy states in quantum systems, which correspond to optimal or near-optimal solutions to the problems being solved," said Daniel Lidar, corresponding author of the study and professor of electrical and computer engineering, chemistry, and physics and astronomy at the USC Viterbi School of Engineering and the USC Dornsife College of Letters, Arts and Sciences.

Approximate optimization

Scientists have been struggling to demonstrate quantum scaling advantage (where the quantum advantage grows as the problem size increases) through the use of a quantum annealer for years. Quantum annealing has long been theorized to offer computational advantages for optimization, but definitive evidence of scaling improvements over classical methods has been elusive. This study shifts the focus from exact optimization (where quantum advantage remains unproven) to approximate optimization, an area with broad applicability in industry and science.

Quantum annealing is a specific type of quantum computing that can use quantum physics principles to find high-quality solutions to difficult optimization problems. Rather than requiring exact optimal solutions, the study focused on finding solutions within a certain percentage ($\geq 1\%$) of the optimal value.

Many real-world problems don't require exact solutions, making this approach practically relevant. For example, in determining which stocks to put into a mutual fund, it is often good enough to just beat a leading market index rather than beating every other stock portfolio.

To demonstrate algorithmic quantum scaling advantage, the researchers used a D-Wave Advantage quantum annealing processor, a specialized type of quantum computing device installed at USC's Information Sciences Institute. Like with all current quantum computers, noise plays a major role in spoiling quantum advantage in quantum annealing.

To overcome this problem, the team implemented a technique called quantum annealing correction (QAC) on the D-Wave's processor, creating over 1,300 error-suppressed logical qubits. This error suppression was key to achieving the advantage over parallel tempering with isoenergetic cluster moves (PT-ICM), the most efficient current classical algorithm for comparable problems.

'Time-to-epsilon' performance

The study demonstrated quantum advantage by utilizing several research methods and focused on a family of two-dimensional spin-glass problems with high-precision interactions.

"Spin-glass problems are a class of complex optimization challenges that originate from statistical physics models of disordered magnetic systems," Lidar said.

Instead of seeking exact solutions, the researchers benchmarked "time-to-epsilon" performance, measuring how quickly each approach could find solutions within a specified percentage of the optimal answer.

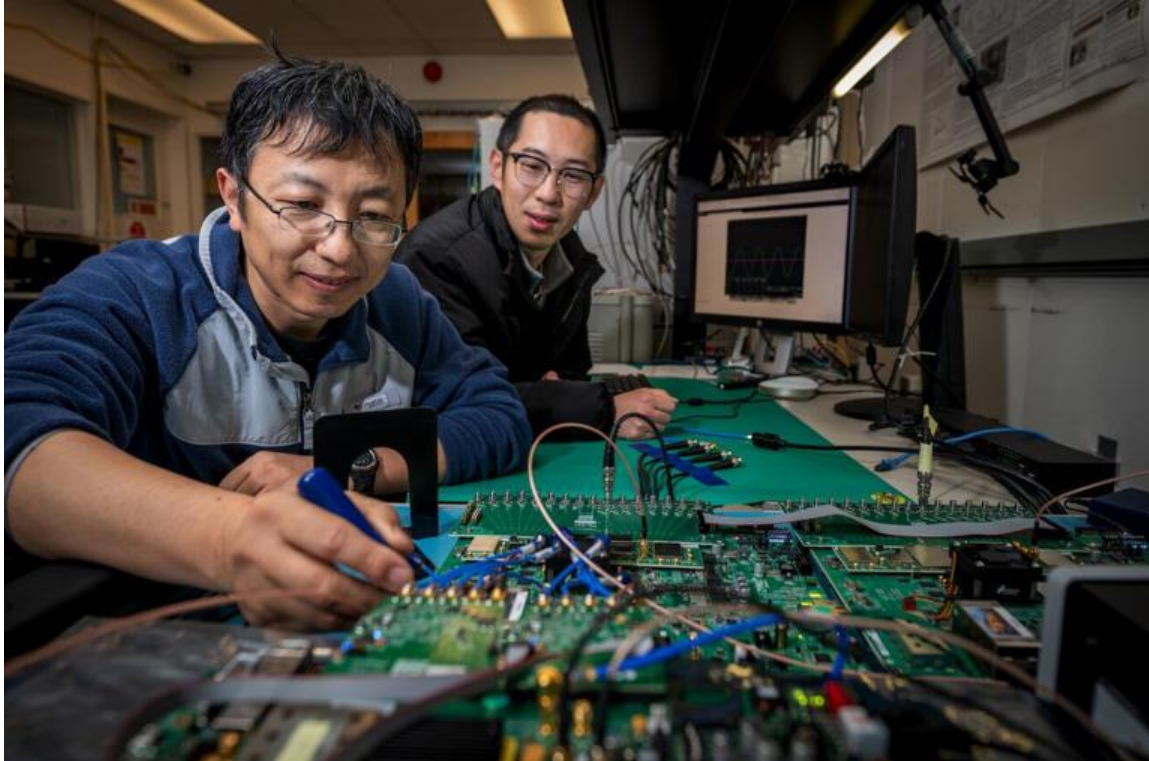
The researchers aim to extend their findings to denser, higher-dimensional problems and explore applications in real-world optimization. Lidar said further improvements in quantum hardware and error suppression could amplify the observed advantage.

"This opens new avenues for quantum algorithms in optimization tasks where near-optimal solutions are sufficient."

More information: Humberto Munoz-Bauza et al, Scaling Advantage in Approximate Optimization with Quantum Annealing, *Physical Review Letters* (2025). DOI: [10.1103/PhysRevLett.134.160601](https://doi.org/10.1103/PhysRevLett.134.160601)

Provided by University of Southern California

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°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 x 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)

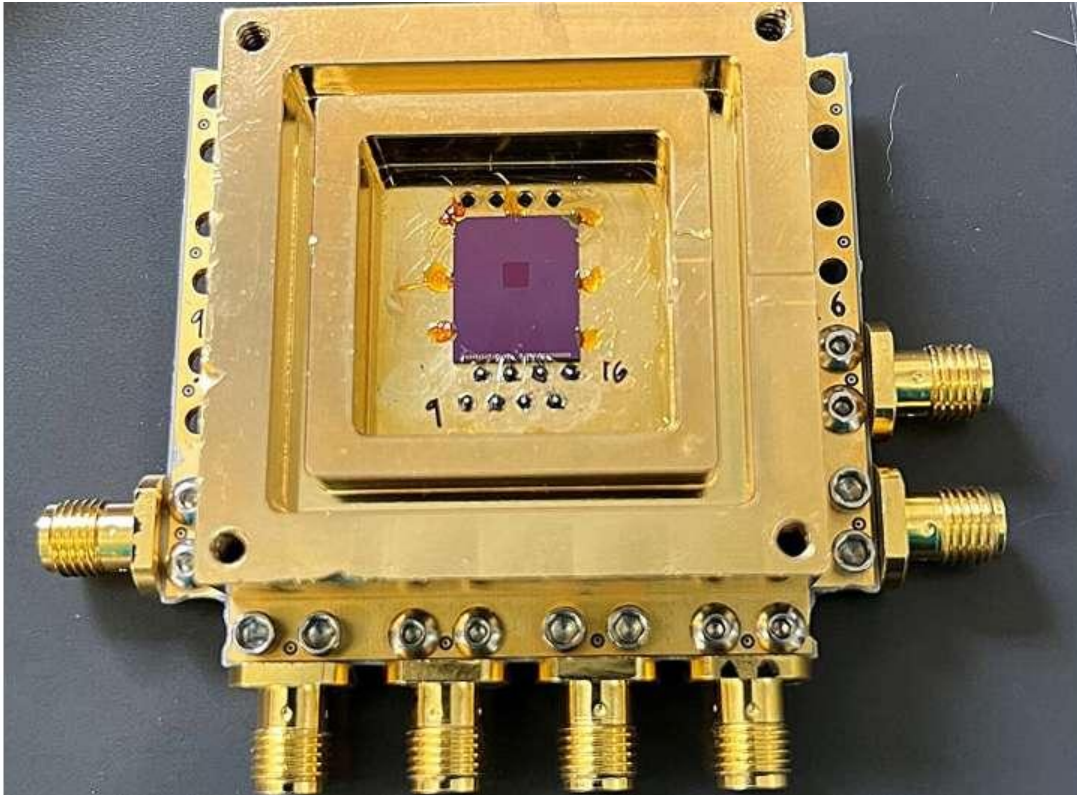
Yilun Xu et al, QubiC 2.0: An Extensible Open-Source Qubit Control System Capable of Mid-Circuit Measurement and Feed-Forward, *arXiv* (2023). DOI: [10.48550/arxiv.2309.10333](https://doi.org/10.48550/arxiv.2309.10333)

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

or next-generation particle physics experiments

by [California Institute of Technology](#)



The SMSPDs can precisely detect single particles at a time. The detectors were designed and fabricated at JPL and commissioned at the INQNET-Caltech labs. Credit: Cristián Peña, Fermilab

To learn more about the nature of matter, energy, space, and time, physicists smash high-energy particles together in large accelerator machines, creating sprays of millions of particles per second of a variety of masses and speeds. The collisions may also produce entirely new particles not predicted by the standard model, the prevailing theory of fundamental particles and forces in our universe. Plans are underway to create more powerful particle accelerators, whose collisions will unleash even larger subatomic storms. How will researchers sift through the chaos?

The answer may lie in [quantum sensors](#). Researchers from the U.S. Department of Energy's Fermi National Accelerator Laboratory (Fermilab), Caltech, NASA's Jet Propulsion Laboratory (which is managed by Caltech), and other collaborating institutions have developed a novel high-energy particle detection instrumentation approach that leverages the power of quantum sensors—devices capable of precisely detecting single particles.

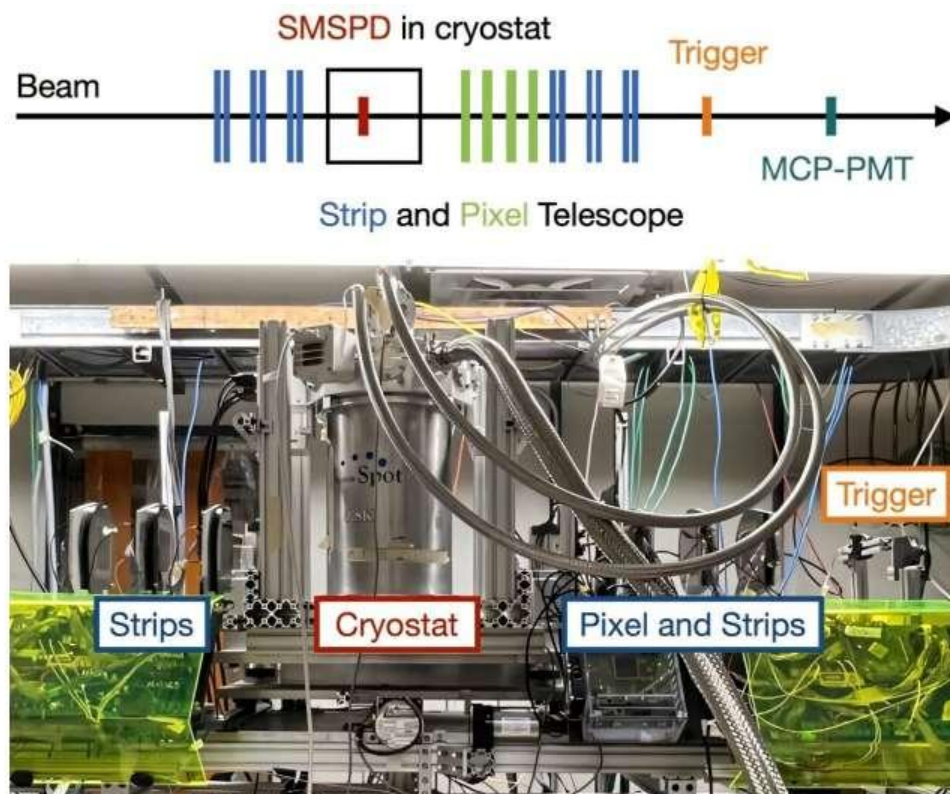
"In the next 20 to 30 years, we will see a [paradigm shift](#) in particle colliders as they become more powerful in energy and intensity," says Maria Spiropulu, the Shang-Yi Ch'en Professor of Physics at Caltech.

"And that means we need more precise detectors. This is why we are developing the quantum technology today. We want to include quantum sensing in our toolbox to optimize next-generation searches for [new particles](#) and dark matter, and to study the origins of space and time."

[Reporting](#) in the *Journal of Instrumentation*, the research team, which also includes collaborators at the University of Geneva and Universidad Santa María in Venezuela, tested its new technology, called superconducting microwire single-photon detectors (SMSPDs), for the first time at Fermilab near Chicago. They exposed the quantum sensors to high-energy beams of protons, electrons, and pions, and demonstrated that the sensors were highly efficient at detecting the particles with improved time and [spatial resolution](#) compared to traditional detectors.

This is a significant step toward developing advanced detectors for future particle physics experiments, says co-author Si Xie, a scientist at Fermilab who has a joint appointment at Caltech as a research scientist.

"This is just the beginning," he says. "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."



The experimental setup for studying SMSPDs at the Fermilab Test Beam Facility. A silicon

telescope tracks the position of each particle incident. The SMSPD is placed between the telescope's six strip modules on one side and four pixels plus an additional six strip modules on the other. The modules are placed as close to the cryostat as possible. Credit: Christina Wang, Fermilab

The quantum sensors used in the study are similar to a related family of sensors (called superconducting nanowire single-photon detectors, or SNSPDs), which have applications in [quantum networks](#) and astronomy experiments. For example, researchers at JPL—who are among the world's top experts at designing and fabricating these sensors—recently used them in the Deep Space Optical Communications experiment, a technology demonstration that used lasers to [transmit high-definition data from space to the ground](#).

Spiropulu, Xie, and other scientists from Fermilab, Caltech, and JPL have also used the SNSPD sensors in quantum networking experiments, in which they teleported information across long distances—an important step in developing a quantum internet in the future. That program, called Intelligent Quantum Networks and Technologies (INQNET), was jointly founded in 2017 by Caltech and AT&T.

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For the particle physics tests, the researchers used SMSPDs rather than the SNSPDs, because they have a larger surface area for collecting the sprays of particles. They used the sensors to detect charged particles for the first time, an ability that is not needed for quantum networks or astronomy applications but is essential for particle physics experiments. "The novelty of this study is that we proved the sensors can efficiently detect charged particles," Xie says.

The SMSPD sensors can also more precisely detect particles in both space and time. "We call them 4D sensors because they can achieve better spatial and time resolution all at once," Xie says. "Normally in particle physics experiments, you have to tune the sensors to have either more precise time or spatial resolution but not both simultaneously."

When researchers analyze the bunches of particles that fly out of high-speed collisions, they want to be able to precisely trace their paths in space and time.

As an analogy, imagine you want to use security images to track a suspicious person hiding in a crowd of people flooding into Grand Central Station from various trains. You would want the images to have enough spatial resolution to track individuals. But you would also want enough time resolution to make sure you catch your person of interest. If you can only obtain images taken every 10 seconds, you might miss the person, but if you have pictures captured every second, you will have better odds.

"In these collisions, you might want to track the performance of millions of events per second," Spiropulu says. "You are swamped with hundreds of interactions, and it can be hard to find the primary interactions with precision. Back in the 1980s, we thought having the spatial coordinates were enough, but now, as the particle collisions become more intense, producing more particles, we also need to track time."

"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 such as the planned Future Circular Collider or a muon collider," says Fermilab scientist and Caltech alumnus Cristián Peña (Ph.D. '17), who led the research. "And we are thrilled to have assembled a world-class team across several institutions to push this emerging research to the next level."

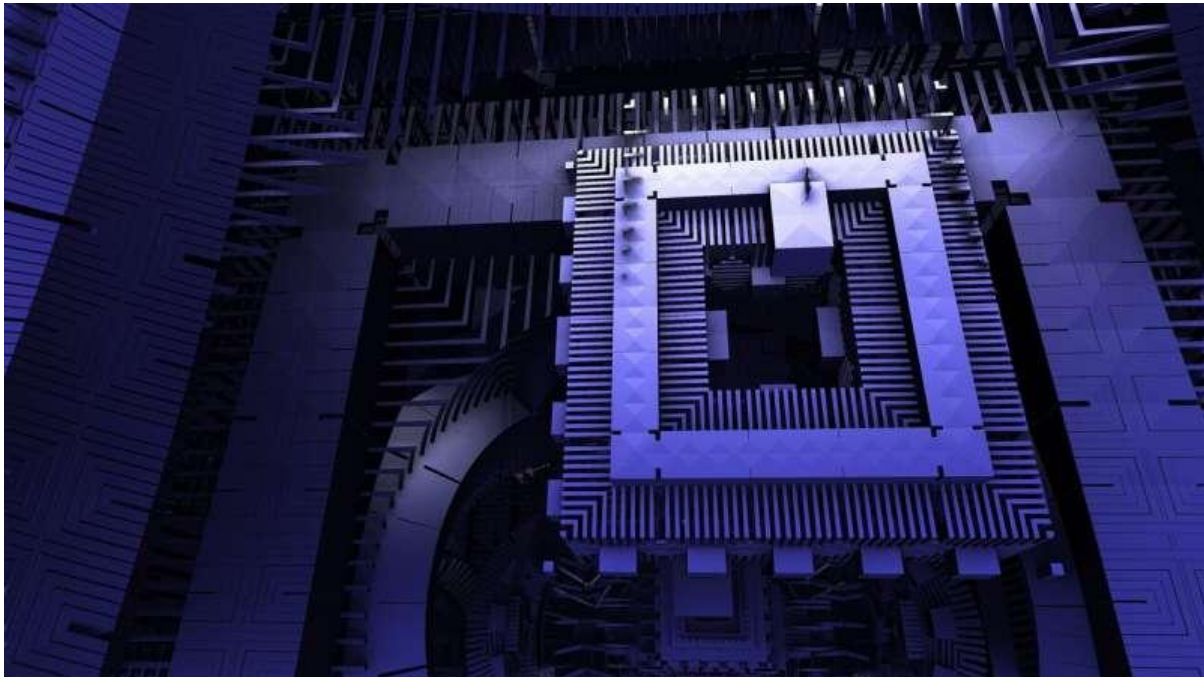
More information: Cristián Peña et al, High energy particle detection with large area superconducting microwire array, *Journal of Instrumentation* (2025). DOI: [10.1088/1748-0221/20/03/P03001](https://doi.org/10.1088/1748-0221/20/03/P03001)

Provided by [California Institute of Technology](#)

APRIL 30, 2025

Engineers advance toward a fault-tolerant quantum computer

by [Massachusetts Institute of Technology](#)



Credit: Pixabay/CC0 Public Domain

In the future, quantum computers could rapidly simulate new materials or help scientists develop faster machine-learning models, opening the door to many new possibilities.

But these applications will only be possible if quantum computers can perform operations extremely quickly, so scientists can make measurements and perform corrections before compounding error rates reduce their accuracy and reliability.

The efficiency of this measurement process, known as readout, relies on the strength of the coupling between photons, which are particles of light that carry [quantum information](#), and artificial atoms, units of matter that are often used to store information in a quantum computer.

Now, MIT researchers have demonstrated what they believe is the strongest nonlinear light-matter coupling ever achieved in a quantum system. Their experiment is a step toward realizing quantum operations and readout that could be performed in a few nanoseconds. The research appears in *Nature Communications*.

The researchers used a novel superconducting circuit architecture to show nonlinear light-matter coupling that is about an order of magnitude stronger than prior demonstrations, which could enable a quantum processor to run about 10 times faster.

There is still much work to be done before the architecture could be used in a real quantum computer, but demonstrating the fundamental physics behind the process is a major step in the right direction, says Yufeng "Bright" Ye Ph.D., lead author of a paper on this research.

"This would really eliminate one of the bottlenecks in quantum computing. Usually, you have to measure the results of your computations in between rounds of error correction. This could accelerate how quickly we can reach the fault-tolerant quantum computing stage and be able to get real-world applications and value out of our quantum computers," says Ye.

He is joined on the paper by senior author Kevin O'Brien, an associate professor and principal investigator in the Research Laboratory of Electronics at MIT who leads the Quantum Coherent Electronics Group in the Department of Electrical Engineering and Computer Science (EECS), as well as others at MIT, MIT Lincoln Laboratory, and Harvard University.

A new coupler

This physical demonstration builds on years of theoretical research in the O'Brien group.

After Ye joined the lab as a Ph.D. student in 2019, he began developing a specialized photon detector to enhance quantum information processing.

Through that work, he invented a new type of quantum coupler, which is a device that facilitates interactions between qubits. Qubits are the building blocks of a quantum computer. This so-called qarton coupler had so many potential applications in quantum operations and readout that it quickly became a focus of the lab.

This qarton coupler is a special type of superconducting circuit that has the potential to generate extremely strong nonlinear coupling, which is essential for running most quantum algorithms. As the researchers feed more current into the coupler, it creates an even stronger nonlinear interaction. In this sense, nonlinearity means a system behaves in a way that is greater than the sum of its parts, exhibiting more complex properties.

"Most of the useful interactions in quantum computing come from nonlinear coupling of light and matter. If you can get a more versatile range of different types of coupling, and increase the coupling strength, then you can essentially increase the processing speed of the quantum computer," Ye explains.

For quantum readout, researchers shine microwave light onto a qubit and then, depending on whether that qubit is in state 0 or 1, there is a frequency shift on its associated readout resonator. They measure this shift to determine the qubit's state.

Nonlinear light-matter coupling between the qubit and resonator enables this measurement process.

The MIT researchers designed an architecture with a qarton coupler connected to two superconducting qubits on a chip. They turn one qubit into a resonator and use the other qubit as an artificial atom which stores quantum information. This information is transferred in the form of microwave light particles called photons.

"The interaction between these superconducting artificial atoms and the microwave light that routes the signal is basically how an entire superconducting quantum computer is built," Ye explains.

Enabling faster readout

The qarton coupler creates nonlinear light-matter coupling between the qubit and resonator that's about an order of magnitude stronger than researchers had achieved before. This could enable a quantum system with lightning-fast readout.

"This work is not the end of the story. This is the [fundamental physics](#) demonstration, but there is work going on in the group now to realize really fast readout," O'Brien says.

That would involve adding additional electronic components, such as filters, to produce a readout circuit that could be incorporated into a larger quantum system.

The researchers also demonstrated extremely strong matter-matter coupling, another type of [qubit](#) interaction that is important for quantum operations. This is another area they plan to explore with future work.

Fast operations and readout are especially important for quantum computers because qubits have finite lifespans, a concept known as coherence time.

Stronger nonlinear coupling enables a quantum processor to run faster and with lower error, so the qubits can perform more operations in the same amount of time. This means the qubits can run more rounds of error correction during their lifespans.

"The more runs of error correction you can get in, the lower the error will be in the results," Ye says.

In the long run, this work could help scientists build a fault-tolerant quantum computer, which is essential for practical, large-scale quantum computation.

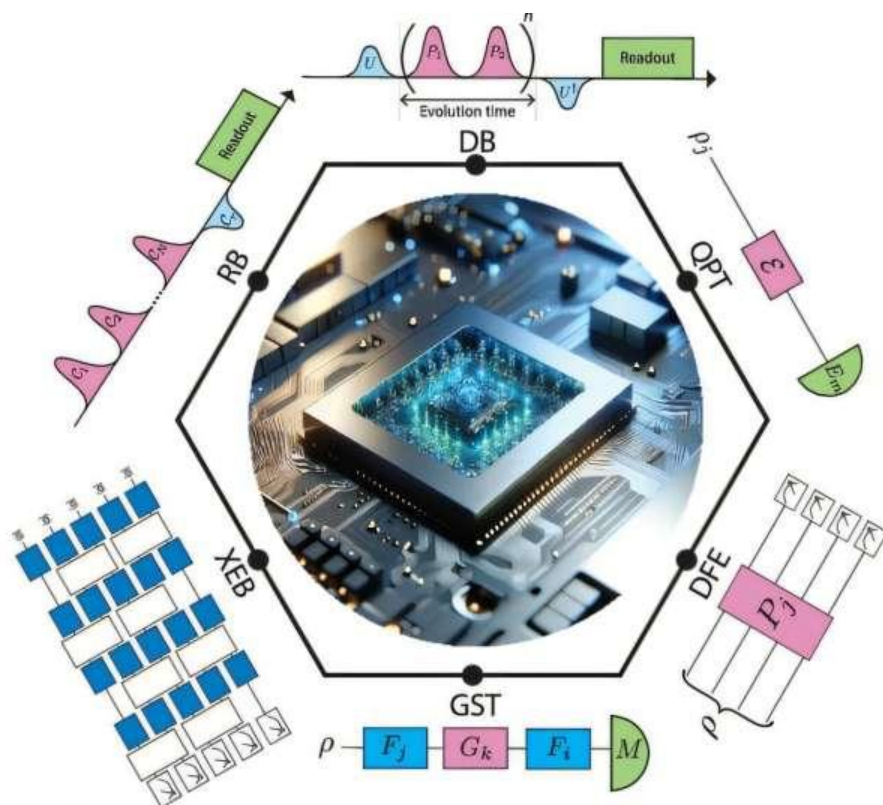
More information: Yufeng Ye et al, Near-ultrastrong nonlinear light-matter coupling in superconducting circuits, *Nature Communications* (2025). DOI: 10.1038/s41467-025-59152-Z

Journal information: [Nature Communications](#)
Provided by [Massachusetts Institute of Technology](#)

MAY 6, 2025

Benchmarking quantum gates: New protocol paves the way for fault-tolerant computing

by [University of Southern California](#)



Graphical abstract. Credit: *Chemical Reviews* (2025). DOI: 10.1021/acs.chemrev.4c00870
Researchers have developed a new protocol for benchmarking quantum gates, a critical step toward realizing the full potential of quantum computing and potentially accelerating progress toward fault-tolerant quantum computers.

The new protocol, called deterministic benchmarking (DB), provides a more detailed and efficient method for identifying specific types of quantum noise and errors compared to widely used existing techniques.

The work is [published](#) in the journal *Chemical Reviews*.

"Quantum computing is ultimately limited by how accurately we can implement gates—the basic operations of a quantum processor," said Daniel Lidar, co-corresponding author of the study and professor of electrical and computer engineering, chemistry, and physics and astronomy at the USC Viterbi School of Engineering and the USC Dornsife College of Letters, Arts and Sciences.

"Our new protocol can identify both coherent and incoherent error types using just a handful of simple experiments, making it much more efficient than current approaches."

Quantum gates and errors

Quantum computing may have the potential to solve complex problems that are beyond the reach of traditional, or classical, computers. However, the accuracy of quantum computations is highly dependent on the performance of quantum gates, which are prone to errors due to noise and miscalibration.

Quantum gates perform operations on qubits, which are the quantum equivalent of classical computer bits; they are essential for constructing quantum algorithms and are the fundamental building blocks of quantum circuits and quantum computations. They enable quantum computers to run algorithms that are exponentially faster than algorithms running on classical computers for certain tasks.

However, quantum gates are susceptible to noise and errors, which is why benchmarking and [error correction](#) are critical areas of research in [quantum computing](#).

The two main categories are coherent and incoherent errors. Coherent errors are deterministic and repeatable errors that preserve quantum state purity. Coherent errors accumulate as amplitudes (rather than probabilities), potentially leading to quadratically faster error accumulation than incoherent errors.

Incoherent errors are a category of errors that result from quantum systems' interaction with the environment; these errors rob quantum computers of their quantumness, leaving them performing no better than classical computers.

Physicists have recently realized the important role that coherent errors play in limiting the performance of quantum computers. Eli Levenson-Falk, co-corresponding author of the study and assistant professor of physics and astronomy and electrical and computer engineering at USC Dornsife, emphasizes the importance of accurate benchmarking of gate errors.

"What's unique about our approach is that it can clearly distinguish between different types of quantum errors," Levenson-Falk said. "This is crucial because certain error types, particularly coherent errors, can be more destructive to quantum algorithms and require different mitigation strategies."

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Deterministic benchmarking improves efficiency

Quantum benchmarks are a set of protocols and methods used to evaluate the performance of the overall quantum computer, which includes its gates, circuits, and processors. These protocols are crucial to the development and optimization of quantum computing technologies by providing quantitative measures of how well quantum operations are performed in the presence of noise and errors.

Lidar, who holds faculty positions at the USC Viterbi School of Engineering and USC Dornsife College of Letters, Arts, and Sciences, said deterministic benchmarking (DB) is a significant advancement in quantum computing because it is deterministic and efficient. Unlike other benchmarking methods, DB uses a small, fixed set of simple pulse-pair sequences rather than averaging over random circuits.

The researchers said the key to understanding the breakthrough of DB is to compare it to randomized benchmarking (RB), a widely used method for estimating the average error rate of quantum gates. Unlike RB, which averages many random gate sequences to provide a single error metric, DB uses designed sequences to detect specific error sources that go unnoticed when RB is used.

New method opens opportunities for advancements in quantum chemistry, materials science

The researchers demonstrated DB on a superconducting transmon qubit—a widely used type of superconducting qubit in quantum computing—to show its ability to detect small changes in qubit parameters that are invisible to standard benchmarking techniques.

"Through conducting several experiments, we demonstrated the variety of capabilities of DB," Lidar said. He said the standout capability of DB is that it provides detailed information about both coherent and incoherent errors, enabling better calibration of [quantum gates](#). DB also requires fewer experimental runs than RB, which improves resource-efficiency.

The research has significant implications for quantum chemistry and materials science applications, where precise gate operations are essential for achieving reliable simulations of molecular systems.

The researchers plan to explore ways to extend DB to two-qubit gates, which could lead to more complex quantum circuits. Additionally, they are investigating how DB can be adapted to other quantum computing platforms beyond superconducting qubits, such as trapped ions and photonic systems.

More information: Vinay Tripathi et al, Benchmarking Quantum Gates and Circuits, *Chemical Reviews* (2025). DOI: [10.1021/acs.chemrev.4c00870](https://doi.org/10.1021/acs.chemrev.4c00870)

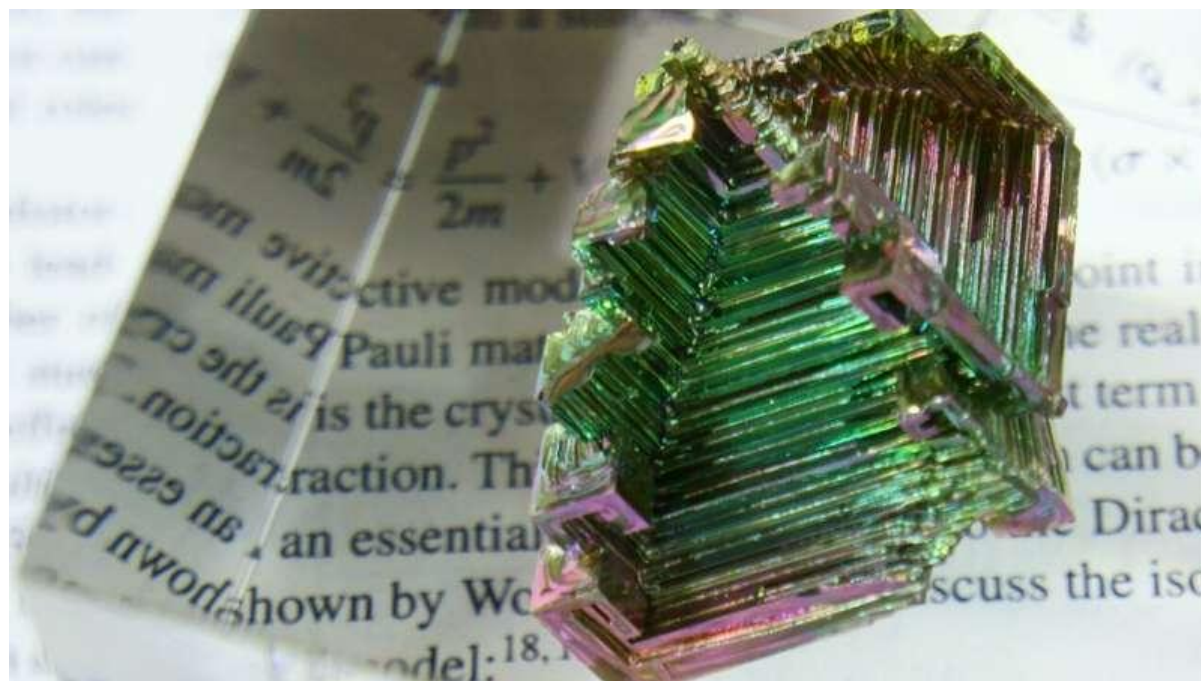
Journal information: [Chemical Reviews](#)

Provided by [University of Southern California](#)

MAY 15, 2025

Bismuth's mask uncovered: Implications for quantum computing and spintronics materials

by [Kobe University](#)



Kobe University quantum solid state physicist FUSEYA Yuki proved that the surface of bismuth masks the fact that the bulk material is not "topological," a property valuable for a material's use in quantum computers and spintronics. Credit: FUSEYA Yuki

Whether bismuth is part of a class of materials highly suitable for quantum computing and spintronics was a long-standing issue. Kobe University research has now revealed that the true nature of bismuth was masked by its surface, and in doing so uncovered a new phenomenon relevant to all such materials.

The team have published their results in a letter in the journal *Physical Review B*.

There is a class of materials that are insulators in their bulk, but robustly conductive at their surface. As this conductivity does not suffer from defects or impurities, such "topological materials," as they are called, are expected to be highly suitable for use in quantum computers, spintronics and other advanced electronic applications.

However, whether bismuth is a topological material or not has been under scientific debate for the past almost 20 years, with many calculations showing that it shouldn't be, but certain measurements indicating differently.

Kobe University quantum solid state physicist Fuseya Yuki says, "I have been fascinated by bismuth and have been conducting research with the desire to know everything there is to know about the element. As a bismuth lover, I could not overlook such a situation and delved into the debate, hoping to solve the mystery."

Fuseya's dedication to the material allowed him to consider phenomena others haven't.

He explains, "Among the many properties of bismuth I have studied, I was the first to discover that the [crystal structure](#) spontaneously changes due to relaxation near the surface of a crystal. This made me wonder whether this surface relaxation might affect the material's topological nature."

Thus, the Kobe University researcher and his team took to computer models of the behavior of electrons in the material and incorporated this change in crystal structure to investigate whether they can so contribute to the debate.

Their calculations could prove that the relaxation of the surface of bismuth crystals leads to the material appearing to be topological at the surface, masking that its bulk is non-topological.

"Until now, the topology of a material has been determined based on the principle of 'bulk-edge correspondence,' which holds that the characteristics at the surface represent those in the bulk. However, our study shows that this guiding principle can be broken," explains Fuseya.

"Our proposal that surface relaxation can lead to the breaking of bulk-edge correspondence is not limited to bismuth but can be broadly applied to other systems," the Kobe University team writes in their paper. Thus, the effect the researchers call "topological blocking" might be discovered in other materials, too.

"The most important thing in topological materials science is to get the topology of matter right," comments Fuseya, hinting at the wide implications his team's work has for the whole field.

For bismuth lover Fuseya, the discovery is personal, too.

He explains, "Bismuth has provided the setting for many discoveries and history has taught us that once a phenomenon is discovered there, similar phenomena are discovered in other

substances one after another. I am very happy to know that another phenomenon first discovered in [bismuth](#) has been added to that list."

More information: Kazuki Koie et al, Topological blocking at the Bi(111) surface due to surface relaxation, *Physical Review*

B (2025). link.aps.org/doi/10.1103/PhysRevB.111.L201303 , On arXiv: DOI: [10.48550/arxiv.2503.16819](https://arxiv.org/abs/10.48550/arxiv.2503.16819)

Journal information: *Physical Review B* , arXiv

Provided by [Kobe University](#)

QUANTUM ROADBLOCK: SCIENTISTS PROVE UNIVERSAL PURIFICATION OF ENTANGLEMENT NOISE IS IMPOSSIBLE

MAY 15, 2025

In the realm of quantum technologies, where strange and subtle phenomena like entanglement form the backbone of futuristic computing and secure communications, one pesky issue has loomed: noise.

In a new study, researchers from the University of Chicago and Microsoft have uncovered fundamental limits on how effectively environmental noise can be “cleaned” from quantum systems. This insight could help shape the future of practical [quantum networks](#).

The research, recently published in [Physical Review Letters](#), tackles a longstanding challenge: whether it’s possible to design a single, foolproof protocol capable of purifying entangled quantum states, regardless of the specific imperfections or noise those states may have picked up.

The findings revealed that, at a fundamental level, no universal protocol can eliminate noise from entangled states. Instead, noise-reduction strategies must be tailored to the specific characteristics of each [quantum system](#).

“In quantum information, we often hope for a protocol that works in all scenarios — a kind of cure-all,” study co-author and University of Chicago Professor of Molecular Engineering, Dr. Tian Zhong, said in a [press release](#). “This result shows that when it comes to purifying entanglement, that’s simply too good to be true.”

Quantum entanglement, famously described by Einstein as “spooky action at a distance,” underpins much of what scientists hope to achieve with quantum computing, quantum communication, and the quantum internet.

However, maintaining high-quality [entangled states](#) is notoriously tricky. Environmental interference and device imperfections degrade entanglement fidelity, jeopardizing the performance of quantum devices. Although methods such as quantum error correction exist, they are currently too resource-intensive for near-term technologies.

That’s where [entanglement purification](#) comes in. Purification protocols attempt to take several imperfect (noisy) entangled states and distill fewer but cleaner states from them with stronger correlations. Notably less demanding than full error correction, these methods are viewed as a practical path to creating high-fidelity entangled links across large-scale quantum networks.

However, until now, researchers have been unsure whether a universal purification method—one that works in every case, regardless of the specific errors—was even theoretically possible.

According to researchers at the University of Chicago and Microsoft, the answer is no.

The team demonstrated a definitive “no-go” theorem using sophisticated mathematical tools for so-called input-independent, universally monotonic quantum purification protocols.

Simply put, they showed that no local operation and classical communication (LOCC) protocol can simultaneously guarantee improvement for all possible two-qubit entangled states. This revelation closes a significant open question in quantum information theory.

Yet the findings weren't entirely pessimistic. The team found that if the purification toolkit is expanded beyond LOCC to include positive partial transpose-preserving (PPT) operations, universal purification becomes possible, albeit only for states with an entanglement fidelity greater than 50%.

These operations go beyond what is physically realizable with current technology but provide a theoretical blueprint for what could be engineered someday.

The study also cautions against relying on existing methods. The widely used DEJMPS purification protocol works well for certain structured noisy states, but as this paper reveals, even sophisticated bilocal Clifford entanglement purification (biCEP) circuits cannot achieve universality.

The researchers proved that even when the input states have been pre-ordered by fidelity or even when additional perfect Bell states are supplied to assist, bilocal Clifford circuits cannot outperform the trivial solution of discarding noisier states and keeping only the best available pair.

This work offers essential guidance for the next phase of quantum network engineering. As future technologies inch toward a global quantum internet—a vision [famously articulated](#) by quantum pioneers like H. J. Kimble and being aggressively pursued today—practical methods for dealing with non-identical, noisy, entangled states will be essential.

The findings imply that any architecture aiming to implement first-generation quantum repeaters or distributed [quantum computing](#) must plan for significant resource overhead, especially when error patterns vary unpredictably.

The authors suggest several different avenues for future directions. Could similar limits be mapped for more complex multi-partite entanglement states or higher-dimensional qudit systems?

Might there still be unknown universal purification techniques beyond bilocal Clifford circuits that circumvent the constraints found here?

It also remains unclear whether certain symmetry-based approaches might help bridge the operational gap between the achievable PPT schemes and what LOCC allows.

The team also noted that highly structured or biased noise models (common in certain hardware platforms, such as neutral atoms or cat qubits) remain more amenable to existing purification methods.

While universality may be out of reach, there remains hope that targeted purification tailored to specific noise landscapes could still offer near-optimal performance without demanding full-state characterization.

“Importantly, we’re not saying purification protocols don’t work,” co-author and Assoc. Professor of Electrical and Computer Engineering, Dr. Eric Chitambar, said. “But no single method works in all cases.”

“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,” co-author and Director of Product Management at Microsoft, Dr. Martin Suchara, added.

SMARTER, COLDER, FASTER: QUANTUM AMPLIFIER BREAKTHROUGH MAKES QUANTUM COMPUTING UP TO 10X MORE EFFICIENT

TIM MCMILLAN · JUNE 25, 2025

As quantum computing systems scale toward thousands—if not millions—of qubits, the role of the often overlooked quantum amplifier that listens to each qubit becomes increasingly critical. Researchers in Sweden have reported that the development of a smarter, ultra-low-power quantum amplifier could significantly alleviate one of [quantum computing](#)’s major engineering challenges.

Researchers in Sweden say they’ve engineered a smarter, ultra-low-power quantum amplifier that could dramatically ease one of quantum computing’s biggest engineering headaches.

A new study from Chalmers University of Technology, in collaboration with [Low Noise Factory AB](#), unveils a cryogenic amplifier that switches on only when needed. This reduces energy consumption and thermal noise that threaten the fragile state of quantum bits or qubits.

The breakthrough, detailed in [IEEE Transactions on Microwave Theory and Techniques](#), has the potential to pave the way for the realization of truly large-scale, fault-tolerant quantum computers, marking a significant advancement in the field.

“This is the most sensitive amplifier that can be built today using transistors,” lead author and doctoral student at Chalmers, Yin Zeng, said in the Chalmers [press release](#). “We’ve now managed to reduce its power consumption to just one-tenth of that required by today’s best amplifiers – without compromising performance. We hope and believe that this breakthrough will enable more accurate readout of qubits in the future.”

WHY QUANTUM AMPLIFIERS MATTER IN QUANTUM COMPUTERS

At the core of [quantum computing](#) lies a fundamental difference from conventional computers. Unlike classical bits, which are limited to values of either 1 or 0, quantum bits—or qubits—can exist simultaneously in a state of both 1 and 0. This unique property, known as superposition, enables a quantum computer to represent many states at once, a capability that underpins its potential to solve complex problems.

For instance, a 20-qubit system can theoretically encode over a million combinations simultaneously. This exponential information capacity is what enables quantum computers to tackle problems that are impossible for even the most powerful classical supercomputers.

Quantum processors use extremely weak microwave signals to read a qubit's state, which must be amplified before being processed. In superconducting systems, this task falls to high-electron-mobility transistor (HEMT) low-noise amplifiers (LNAs) that operate near absolute zero.

However, there's a trade-off. As more qubits are added to a system, more quantum amplifiers are required—each contributing heat and noise. This scaling problem threatens to overwhelm cooling systems and jeopardize qubit fidelity.

To combat this, Zeng's team took a novel approach, posing the question: What if you only turned on the amplifier when you were actually reading a qubit?

THE POWER OF PULSED OPERATION

The study introduces a novel “pulsed operation” mode for HEMT quantum amplifiers. Rather than operating continuously, the

amplifier is activated only when a qubit's state is read—a window typically lasting just hundreds of nanoseconds.

According to the team's measurements, synchronizing the amplifier to this pulse minimizes its impact on the qubit and reduces average power consumption by up to nearly 86%.

This could make large-scale [quantum systems](#) more efficient and help eliminate bulky cryogenic components like isolators and circulators, which are traditionally used to block amplifier back-action from disturbing qubits.

Nevertheless, the idea isn't as simple as just flipping a switch.

Qubits are highly sensitive, and any delay or noise introduced by turning the amplifier on and off could corrupt the measurement. To address this, the team modified a commercial HEMT amplifier—commonly used in quantum systems—to respond faster and cleaner.

GENETIC ALGORITHMS AND CRYOGENIC SPEED

One key innovation was optimizing how the quantum amplifier powers up. Instead of using a basic square waveform to toggle the quantum amplifier, the researchers developed a custom gate voltage waveform using a genetic algorithm (GA). This approach simulates evolution, testing thousands of waveform combinations to find one that produces the cleanest and fastest startup.

This resulted in a pulsed quantum amplifier that reaches full operating performance within just 35 nanoseconds—a fraction of typical qubit readout durations.

“This work presented pulsed operation of the cryogenic HEMT LNA aimed for qubit readout at very low-dc power in large-scale quantum computing systems,” researchers write. “We demonstrated that the LNA power dissipation can be significantly reduced without compromising critical performance by implementing pulsed operation.”

The team's custom-built cryogenic testbed achieved 5-nanosecond resolution and noise fluctuation under 0.3 Kelvin, allowing them to precisely monitor the amplifier's transient gain and noise behavior in real-time.

REAL-WORLD IMPACT ON QUANTUM AMPLIFIERS

When the optimized quantum amplifier was tested under realistic quantum operating conditions—with a readout pulse repeating every 5 microseconds—it consistently delivered stable, low-noise performance across cycles. More importantly, it cut average power consumption by more than 86%.

Multiply that level of energy efficiency across thousands of amplifiers in a quantum system, and the savings are dramatic—not only in electrical power but also in reduced cooling load and improved system reliability.

The work represents a crucial step toward scalable, modular quantum hardware that doesn't require exotic refrigeration solutions or compromise qubit quality.

As noted in previous coverage of quantum developments by [The Debrief—including](#) a new [magnetic material](#) that could reduce susceptibility to environmental disturbances or IBM's recent [quantum simulation](#) breakthrough—scaling up quantum computers will usher in an entirely new technological era. Reducing noise, improving fidelity, and managing thermal environments will be as critical as adding more qubits in new quantum systems.

The researchers see the potential for further improvements, including better power supply regulation and even more intelligent pulse shaping through advanced machine learning techniques. This ongoing research and development should inspire optimism about the future of [quantum computing](#).

This new pulsed amplifier technique isn't limited to superconducting qubits either. The researchers suggest that any quantum platform that

relies on sensitive microwave readouts—such as spin qubits or photonic qubits—could benefit from similar strategies.

“This is the first demonstration of low-noise semiconductor amplifiers for quantum readout in pulsed operation that does not affect performance and with drastically reduced power consumption compared to the current state of the art,” co-author and professor of Microtechnology and Nanoscience, Dr. Jan Grahm, explained. “This study offers a solution in future upscaling of quantum computers where the heat generated by these qubit amplifiers poses a major limiting factor.”

As researchers conclude in their paper, “This advancement is crucial for reducing power dissipation and minimizing qubit disturbance, both being key factors for scalable quantum computing.”