JUNE 12, 2025

Gyromagnetic zero-index metamaterials enable stable light vortices for advanced optical control

by Hong Kong University of Science and Technology edited by Lisa Lock, reviewed by Robert Egan

Comparing the characteristics of gyromagnetic and ordinary DZIMs. (a–d) Comparison between conventional double-zero-index metamaterials and gyromagnetic double-zero-index metamaterials (GDZIMs). (e) The schematic of generating optical spatiotemporal vortices with GDZIMs. Credit: *Nature* (2025). DOI: 10.1038/s41586-025-08948-6
The Hong Kong University of Science and Technology (HKUST)-led research team has adopted gyromagnetic double-zero-index metamaterials (GDZIMs)—a new optical extreme-parameter material—and developed a new method to control light using GDZIMs. This discovery could revolutionize fields like optical communications, biomedical imaging, and nanotechnology, enabling advances in integrated photonic chips, high-fidelity optical communication, and quantum light sources.

The study published in *Nature* was co-led by Prof. Chan Che-Ting, Interim Director of the HKUST Jockey Club Institute for Advanced Study and Chair Professor in the Department of Physics, and Dr. Zhang Ruoyang, Visiting Scholar in the Department of Physics at HKUST.

Unlocking the potential of GDZIMs and optical vortices

GDZIMs are a unique type of optical metamaterial with properties that reside precisely at the critical transition point between two different photonic topological phases and can manipulate light in ways previously thought impossible.

Unlike conventional materials, GDZIMs exhibit zero electric permittivity and a unique magneto-optic property that allows stable generation of optical spatiotemporal vortices—patterns of light that swirl in space and time. This makes them exceptionally effective for controlling light propagation, which is crucial for many advanced technologies.

Not only can they help create small integrated photonic chips that improve communication by minimizing interference, but they can also lead to novel handedness-selective light sources for advanced technologies. Moreover, their unique mechanism for generating light vortices presents a promising approach to long-distance, high-capacity spatial optical information transmission, potentially advancing both the speed and security of optical network communications.

Generation and observation of STVPs. (a) Time-sliced optical field distributions illustrating the evolution of optical spatiotemporal vortices. (b) Schematic of the experimental setup for generating and detecting spatiotemporal vortices. (c) Experimentally measured and numerically simulated optical spatiotemporal vortices. Credit: *Nature* (2025). DOI: 10.1038/s41586-025-08948-6

By constructing a magnetic photonic crystal and tuning the parameters to the critical phase transition point, the researchers realized this metamaterial for the first time. Using microwave real-time field-scanning systems, they further demonstrated that when a light pulse hits a GDZIM slab, it reflects as a spatiotemporal vortex—an exotic type of light wave-packet exhibiting a simultaneous swirling structure in space and time and carrying transverse orbital angular momentum.

Their investigation revealed that the generation of this light vortex stems from GDZIM's intrinsic topological properties, thereby ensuring exceptional stability regardless of the material's size or surrounding environment. This breakthrough could lead to significant improvements in optical technologies, such as faster and more secure communication systems.

Prof. Chan explained, "This research bridges three important areas of physics: metamaterials, topological physics, and structured light fields. It establishes a conceptually new mechanism for manipulating light structures in space-time based on the nontrivial topological properties of metamaterials. These findings open doors to high-precision optical devices with a wide range of applications that we have only begun to explore."

Dr. Zhang added, "The stability of these light vortices is remarkable. It provides a solid foundation for developing advanced materials and technologies that could transform industries like telecommunications and high-performance optical circuits."

More information: Ruo-Yang Zhang et al, Bulk–spatiotemporal vortex correspondence in gyromagnetic zero-index media, *Nature* (2025). DOI: 10.1038/s41586-025-08948-6
Journal information: Nature
Provided by Hong Kong University

IBM will build monster 10,000-qubit quantum computer by 2029 after 'solving science' behind fault tolerance — the biggest bottleneck to scaling up June 10, 2025

The quantum computer, called Starling, will use 200 logical qubits — and IBM plans to follow this up with a 2,000-logical-qubit machine in 2033

IBM has unveiled its plans to build Starling, the world's first fault-tolerant quantum computer, by 2029. (Image credit: IBM)

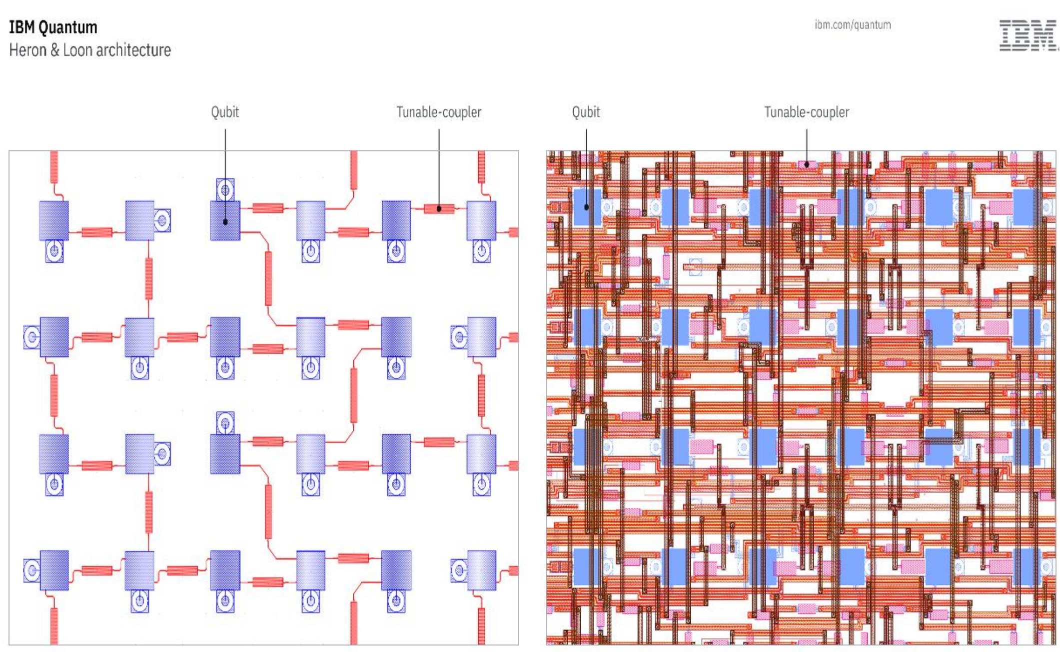
IBM scientists say they have solved the biggest bottleneck in quantum computing and plan to launch the world's first large-scale, fault-tolerant machine by 2029. The new research demonstrates new error-correction techniques that the scientists say will lead to a system 20,000 times more powerful than any quantum computer in existence today.In two new studies uploaded June 2 and June 3 to the preprint arXiv server, the researchers revealed new error mitigation and correction techniques that sufficiently handle these errors and allow for the scaling of hardware nine times more efficiently than previously possible.
The new system, called "Starling," will use 200 logical qubits — made up of roughly 10,000 physical qubits. This will be followed by a machine called "Blue Jay," which will use 2,000 logical qubits, in 2033.The new research, which has not yet been peer-reviewed, describes

IBM's quantum low-density parity check (LDPC) codes — a novel fault-tolerance paradigm that researchers say will allow quantum computer hardware to scale beyond previous limitations.

"The science has been solved" for expanded fault-tolerant quantum computing, Jay Gambetta, IBM vice president of quantum operations, told Live Science. This means that scaling up quantum computers is now just an engineering challenge, rather than a scientific hurdle, Gambetta added. While quantum computers exist today, they're only capable of outpacing classical computer systems (those using binary calculations) on bespoke problems that are designed only to test their potential.

One of the largest hurdles to quantum supremacy, or quantum advantage, has been in scaling up quantum processing units (QPUs). As scientists add more qubits to processors, the errors in calculations performed by QPUs add up. This is because qubits are inherently "noisy" and errors occur more frequently than in classical bits. For this reason, research in the field has largely centered on quantum error-correction (QEC).

Error correction is a foundational challenge for all computing systems. In classical computers, binary bits can accidentally flip from a one to a zero and vice versa. These errors can compound and render calculations incomplete or cause them to fail entirely. The qubits used to conduct quantum calculations are far more susceptible to errors than their classical counterparts due to the added complexity of quantum mechanics. Unlike binary bits, qubits carry extra "phase information."While this enables them to perform



Heron architecture

Above is a schematic of IBM's lattice for connecting qubits within its IBM Quantum Heron processor, in which the blue boxes represent qubits and the red lines and boxes represent connectors, or couplers.

Loon architecture

Above is a schematic of IBM's forthcoming quantum processor architecture, beginning to be developed in 2025 with the IBM Quantum Loon processor, which depicts a more complex lattice to allow a vastly increased number of connections between the qubits.

computations using quantum information, it also makes the task of error correction much more difficult.

IBM's current Heron QPU architecture will pale in comparison to the potential of its next-generation Loon architecture. (Image credit: A comparison of IBM's current Hex architecture and future Loom architecture.)

Until now, scientists were unsure exactly how to scale quantum computers from the few hundred qubits used by today's models to the hundreds of millions they theoretically need to make them generally useful.

But the development of LDPC and its successful application across existing systems is the catalyst for change, Gambetta said.

LDPC codes use a set of checks to detect and correct errors. This results in individual qubits being involved in fewer checks and each check involving fewer qubits than previous paradigms.

The key advantage of this approach is a significantly improved "encoding rate," which is the ratio of logical qubits to the physical qubits needed to protect them. By using LDPC codes, IBM aims to dramatically reduce the number of physical qubits required to scale up systems.

The new method is about 90% faster at conducting error-mitigation than all previous techniques, based on IBM research. IBM will incorporate this technology into its Loon QPU architecture, which is the successor to the Heron architecture used by its current quantum computers.

Moving from error-mitigation to error-correction

Starling is expected to be capable of 100 million quantum operations using 200 logical qubits. IBM representatives said this was roughly equivalent to 10,000 physical qubits. Blue Jay will theoretically be capable of 1 billion quantum operations using its 2,000 logical qubits.

Current models have about 5,000 gates (analogous to 5,000 quantum operations) using 156 logical qubits. The leap from 5,000 operations to 100 million will only be possible through technologies like LDPC, IBM representatives said in a statement. Other technologies, including those used by companies like Google, will not scale to the larger sizes needed to reach fault tolerance, they added.

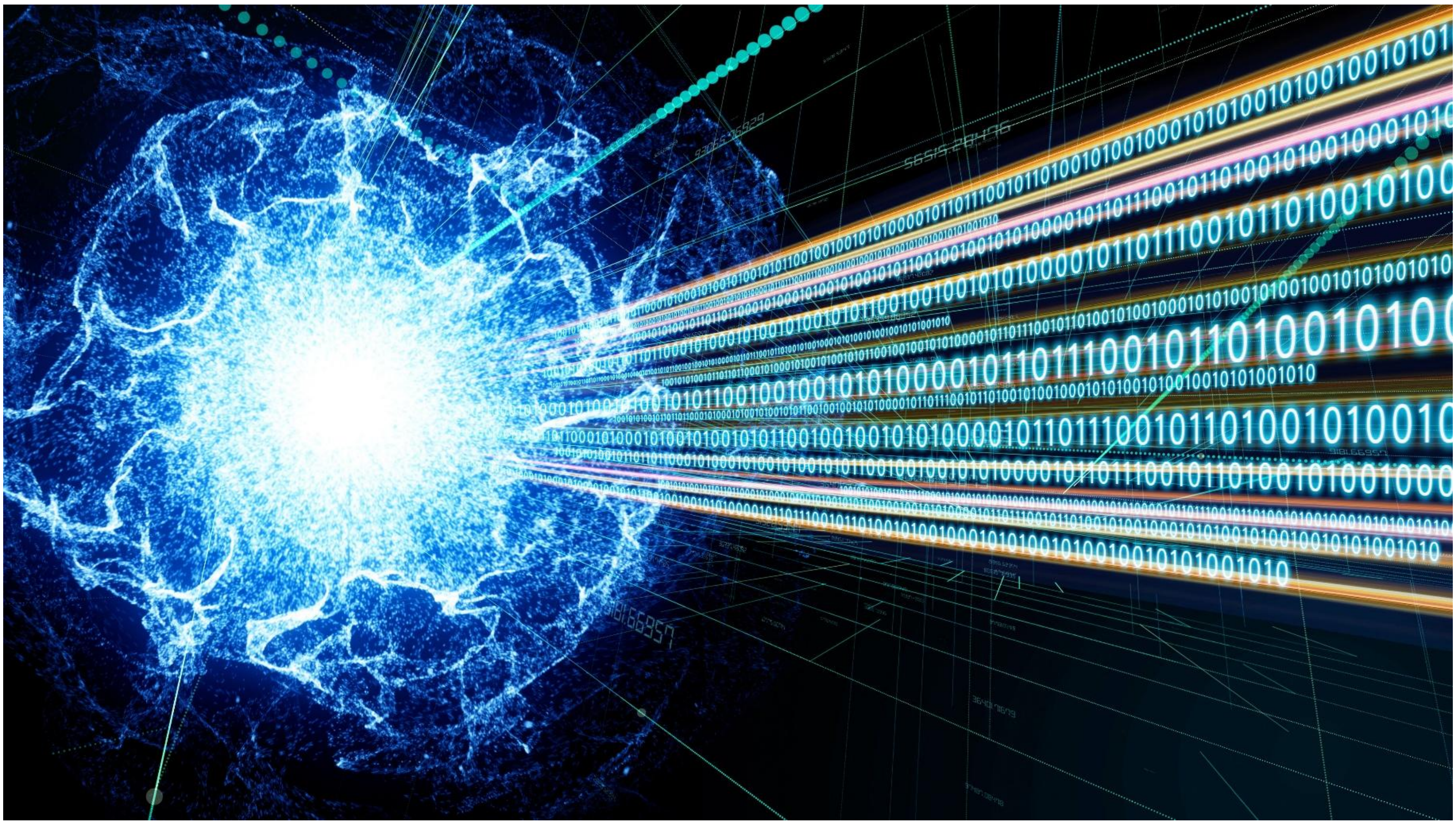
To take full advantage of Starling in 2029 and Blue Jay in 2033, IBM needs algorithms and programs built for quantum computers, Gambetta said. To help researchers prepare for future systems, IBM recently launched Qiskit 2.0, an open-source development kit for running quantum circuits using IBM's hardware.

"The goal is to move from error mitigation to error correction," Blake Johnson, IBM's quantum engine lead, told Live Science, adding that "quantum computing has grown from a field where researchers are exploring a playground of quantum hardware to a place where we have these utility-scale quantum computing tools available."

Quantum computing breakthrough could make 'noise' — forces that disrupt calculations — a thing of the past

News By Ben Turner published April 9, 2025

Useful quantum networks are hobbled by the problem of decoherence

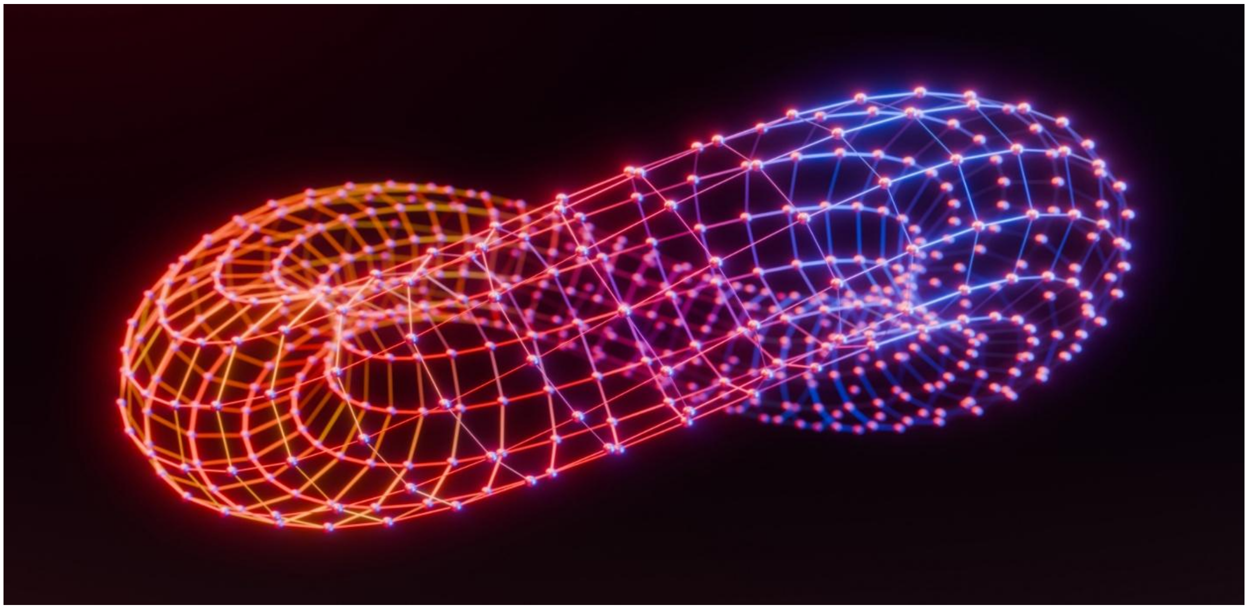


from environmental "noise." But a new breakthrough could change that.

An artist's illustration of an entangled qubit inside a quantum computer. (Image credit: Getty Images)

Scientists have discovered a groundbreaking method to shield quantum information from "noise" — and it could finally let us build practical quantum computers.
Quantum computers rely on quantum entanglement, the connection between the quantum properties of two particles that are shared instantaneously across time and space. This enables quantum computers to perform faster calculations than their traditional counterparts because they can process information in parallel rather than in sequence.

But maintaining this "coherence" is difficult due to "noise" from the outside world, as interactions with loose particles, rays of light and even minute changes in temperature can break the entanglement and disperse the information within. That's why the error rate in qubits is much higher than in conventional bits in classical computing.



"Basically even though companies claim [they have] 1,000 qubits, very few of them are useful. Noise is the reason," study co-author Andrew Forbes, a professor of physics at the University of Witwatersrand in Johannesburg, South Africa told Live Science. "Everyone agrees that there is no point in pushing for more qubits unless we can make them less noisy."

Now, by encoding the information in the topology (or the properties that stem from the shape) of two entangled photons, a team of physicists has found a way to preserve quantum information, even amid a storm of noise. The researchers published their findings on March 26 in the journal Nature Communications.

In much the same way that traditional computer bits are the basic units of digital information, qubits encode quantum information. Like bits, qubits can exist as a 1 or a 0, representing the two possible positions in a two-state system.

Thanks to the bizarre rules of the quantum world, qubits can also exist in theoretically infinite superpositions of the two classical states. And when they're entangled inside quantum computers, their ability to crunch numbers grows exponentially.

But this quantum daisy chain is fragile: Even when housed inside extremely cold and highly insulated cryostats, current quantum computers are still infiltrated by tiny disturbances that rapidly disrupt the delicate processes within.

Quantum noise-cancelation

The typical strategy for preventing quantum decoherence is to preserve entanglement, but this has so far only enjoyed relative success. To look for a way around this, the researchers behind the new study sought to preserve information even in systems that had already been partially decohered.
"We decided to let the entanglement decay — it is always fragile so let it be so — and instead preserve information even with very little entanglement," Forbes said.

For their solution, Forbes and his colleagues turned to a type of qubit known as a "topological qubit" that encodes information in the shape made by two entangled particles. They settled on a quasiparticle known as an optical skyrmion, a wave-like field formed between two entangled photons.

After exposing the skyrmions to varying levels of noise, the researchers found that the patterns and information coded within remained resilient far beyond the point where non-topological systems would decohere.

"It turns out that so long as some entanglement remains, no matter how little, the topology stays intact," Forbes said. "The topology only disappears when the entanglement vanishes."

The scientists believe their approach could play a key role in making quantum computers and networks that can overcome noise in any environment. Their next step will be to create a "topological toolkit" that can encode practical information into a skyrmion and get it out again.

"Once we have this, we can start to think about using topology in practical situations, like communication networks and in computing," Forbes said.

Scientists observe new quantum phase that could have major implications for quantum computing

News By Alan Bradley published April 17, 2025

The exotic quantum phase, predicted over half a century ago, could lead to advances in quantum computing, sensors and communication technology.

Researchers have observed an elusive quantum phenomenon that was first predicted more than 50 years ago. This process, which forms a new state of matter, may have ramifications for future quantum computing.

The phase, called a superradiant phase transition (SRPT), is the result of two independent groups of quantum particles beginning to fluctuate in a way that's both coordinated and collective, the scientists said in a new study published April 4 in the journal Science Advances.

In this case, the two groups of particles were iron ions and erbium ions inside a crystal. Researchers were able to induce the phenomenon by applying a magnetic field — over 100,000 times stronger than the Earth's — to a crystal made of erbium, iron and oxygen after cooling it to -457 °F (-271.67 °C), temperatures nearing absolute zero.

Under those conditions, the team was able to observe unmistakable signatures of an SRPT within the crystal. Their observations exactly matched predictions of what an SRPT would look like according to a famous model formulated by Robert H. Dicke in 1954.
The so-called Dicke model was the first to describe the phenomenon of superradiance — where excited atoms emit light faster than normal atoms — and laid the groundwork for understanding the superradiant phase transition as a distinct state of matter arising from strong interactions between light and matter. It was further elaborated on by Klaus Hepp and Elliot H. Lieb in 1973 who formally demonstrated the existence of this phase transition.
Related: Government scientists discover new state of matter that's 'half ice, half fire'
"Originally, the SRPT was proposed as arising from interactions between quantum vacuum fluctuations — quantum light fields naturally existing even in completely empty space — and matter fluctuations," said co-lead author Dasom Kim, a doctoral student in applied physics at Rice University, in a statement. "However, in our work, we realized this transition by coupling two distinct magnetic subsystems — the spin fluctuations of iron ions and of erbium ions within the crystal."

Spin describes the angular momentum of an elementary particle or atom. It dictates the behavior in magnetic fields and is important for determining the statistical properties of collections of particles, which, in turn, influence the structure of matter and the nature of fundamental forces. When excitation created by thermal fluctuations, alternating magnetic fields or other sources causes a wave-like disturbance across a pattern of spins in a material, it's called a magnon.

In the past, SRPT was branded a "no-go theorem" because it violated a fundamental limitation of light-based systems. But creating a magnonic version of the phenomenon allowed the team to bypass this restriction. In their experiment, the iron ions' magnons play the role normally occupied by vacuum fluctuations, and the erbium ions' spins fill in for matter fluctuations.
Researchers were able to clearly observe the disappearance of one spin mode's energy signal and a shift in the other — unmistakable evidence of an SRPT.

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

The unique characteristics of an SRPT could have important implications for a diverse number of quantum technologies. This is due to a phenomenon called quantum squeezing, where fluctuations are reduced in one measurable property of a quantum system below the standard quantum limit (though fluctuations increase in another property).

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

There are further advantages beyond the precision of quantum measurements and computations due to an SRPT stabilizing quantum squeezed states, as well. Because SRPT arises from the collective behavior of many quantum particles, it could provide a form of built-in protection against individual qubit errors and decoherence, which are major hurdles in current quantum computing. The synchronized behavior could lead to more robust and stable qubits with longer coherence times. It's also possible that the strong, coherent interactions within an SRPT could lead to faster gates (the building blocks of quantum algorithms).

TOPICS

What are neural processing units (NPUs) and why are they so important to modern computing?

Features

By Tim Danton published May 12, 2025

Neural processing unts (NPUs) are the latest chips you might find in smartphones and laptops — but what are they ard why are they so important?

(Image credit: Dragon Claws via Getty Images)

Ever since the dawn of computing, people have compared machines to brains. This includes two founding fathers of computing — John von Neumann wrote a book called "The Computer and the Brain" while Alan Turing was quoted in 1949 saying: "Eventually I do not see why [a computer] may not compete on equal terms with the human intellect in most fields."
The only problem with this comparison is that the traditional processor — the central processing unit (CPU) — doesn't mimic the brain at all. CPUs are far too mathematical and logical. The neural processing unit (NPU), on the other hand, takes an entirely different approach: simulating the structure of the human brain in its very circuitry.

Yet mimicking the workings of the human brain electronically is far from a new idea.

Literal electronic brains date back to the birth of modern-day computing in the mid-1940s, specifically to a "neural network" of circuitry created by neurophysiologist Warren McCulloch and logician Walter Pitts. McCulloch's pioneering work spurred further research during the 1950s and 1960s, only for the idea to fall out of fashion — perhaps due to a lack of progress compared to the rising number-crunching power of classical computers.
"There were a few isolated people in Japan and Germany [working on neural networks] but it was not a field," Yann LeCun, a French-American computer scientist widely considered one of 'godfathers' of AI, said of his time working with Geoffrey Hinton, another of the field's pioneers, on neural networks in the early 1980s. "It started being a field again in 1986."
Yet for neural networks to regain their foothold as a respected part of computer science, it took the success of speech recognition in the early 2000s., Even then, LeCun said: "We didn't want to use the word neuron nets because it had a bad reputation, so we changed the name to deep learning."

Related: Light-powered computer chip can train AI much faster than components powered by electricity

The term NPUs would come in the late 1990s, but it has taken the deep pockets of Apple, IBM and Google to move it from university labs and into the mainstream. These tech companies invested billions of dollars into the development of silicon, crystallizing all the past work into a product that fits inside our phones and laptops: a processor that takes inspiration from the human brain. LeCun's fortunes have also improved for the better: he is now chief AI scientist at Meta.

How do NPUs work?

In some ways, the NPUs of today aren't that different from those created by McCulloch and Pitts: their structure mimics the brain through a parallel architecture. This means that rather than tackling a problem in sequence, an NPU will simultaneously run millions, even trillions, of mini computations simultaneously. This is what the term "tera operations per second," or TOPS, refers to.

But here's where things get complicated. NPUs rely on deep learning instruction sets, which have already been trained on vast amounts of existing data. Take the example of edge detection in photos, which usually relies on convolutional neural networks (CNNs).
In a CNN, the convolution layer runs a filter (called a "kernel") over every area of the image, which will hunt for patterns that it suspects — thanks to its training — are edges. Each mathematical operation the NPU performs is called a convolution, which creates a feature

map over the image. The software will repeat this process until it reaches the point where it is confident it has found edges.

NPUs are outstanding at performing convolutionary operations, being able to execute them at great speed and with low power demands. This is especially true when compared to CPUs. However, graphics processing units (GPUs), which also use parallel processing, are less optimized for this task and therefore less efficient. This drop in efficiency makes a big difference when it comes to the battery life of our devices.

What are NPUs now used for?

Perhaps surprisingly, the first phones to include an NPU date back to 2017. That's when Huawei released the Mate 10 and Apple debuted its A11 Bionic chipset in the iPhone X. But neither of these NPUs was very powerful — each having less than 1 TOPS compared to the 45 TOPS NPUs in a modern-day Qualcomm Snapdragon X chipset, fitted into our best laptops. It has also taken several years for applications to appear that can take advantage of the chips' unique structure.

Yet just eight years later, AI applications are everywhere. For example, if you own a recent phone that includes the option to remove people from photos — that almost certainly uses an NPU. Likewise, Google's "Circle to Search" feature, or "Add Me" uses a NPU-powered form of augmented reality (AR) to place you in the photo after you've already taken the original shot.

NPUs have now spread to laptops too. Last year, Microsoft announced "a new category of Windows PCs designed for AI, Copilot+ PCs." These required NPUs with at least 40 TOPS, which unfortunately for AMD and Intel (whose early NPUs only ran at 15 TOPS), ruled them out of the race. But their loss was Qualcomm's gain, as all of its Snapdragon X processors exceeded that threshold with NPUs rated at 45 TOPS. Models that take advantage of these new chips include the Microsoft Surface Laptop and Snapdragon versions of the Acer Swift AI series.

Both AMD and Intel have now released chips that meet Microsoft's minimum requirements, meaning far more laptops are on the market with the "Copilot+ PC" branding. Yet there's a sting in this tail: more affordable laptops (less than $800) are now likely to still use lesser processors that don't meet the Copilot+ PC criteria.

What are the best Copilot+ PC features?

But why should you pay more for a Copilot+ PC? Microsoft hopes to tempt you with a number of exclusive features, and frankly, the most impressive one is also the most controversial. Called Recall, this promises a "photographic memory" that enables you to rediscover something you've previously seen in Windows 11.

Each snapshot taken by Recall is analysed by the NPU, using context, optical character recognition (OCR) and sentiment analysis to create an index that you can then search — at which point Recall will take you back in time through a visual timeline. After a shaky launch, where it was attacked for the lack of security or user control over what snapshots were stored, Microsoft said it spent more time reworking the feature to be more secure.

Other features build upon what has come before. Image Creator uses the NPU to turn text into images, an enhanced version of Windows Studio Effects adds creative filters to your video calls and Live Captions deploys the NPU to translate any video you're watching.

Companies like Acer, HP and Lenovo have released their own local AI tools that can analyse documents stored on your PC and provide summaries and sentiment analysis. Such tools are only likely to improve over time.

Recall instantly with Recall on Copilot+ PC - YouTube
Watch On

What's likely to happen next with NPUs?

For the next few years, some AI experts contend that NPUs will follow a similar path to CPUs in their early days — something close to Moore's Law, with a doubling of TOPS every year or two. With that power will come far greater abilities, to the point where you can create realistic AI artwork locally on your computer rather than resorting to programs such as Midjourney.
Over time, as software matures along with the hardware, and more developers take advantage of it, we expect to see the emergence of personal AI agents that understand us because they have been "living" inside our computers as we work. They won't just serve as memory joggers but perform actions on our behalf.

NPUs will also likely find a home in more devices than our phones and laptops. TVs will produce personalized news services using your favourite avatar presenter; your fitness tracker will recommend workouts based on your mood and the time until your next meeting. Who knows, your best friend may one day be a humanoid robot who understands you better than any human.

JULY 4, 2025

Improving randomness may be the key to more powerful quantum computers

by Paul Arnold, Phys.org edited by Andrew Zinin

The circuit construction used to prove the paper's main result. Each block represents a quantum circuit acting on a small patch of the entire system. Credit: Thomas Schuster, Jonas Haferkamp, Hsin-Yuan Huang
Understanding randomness is crucial in many fields. From computer science and engineering to cryptography and weather forecasting, studying and interpreting randomness

helps us simulate real-world phenomena, design algorithms and predict outcomes in uncertain situations.

Randomness is also important in quantum computing, but generating it typically involves a large number of operations. However, Thomas Schuster and colleagues at the California Institute of Technology have demonstrated that quantum computers can produce randomness much more easily than previously thought.

And that's good news because the research could pave the way for faster and more efficient quantum computers.

Shuffling in the quantum world

Unlike classical computers that encode information in "bits" (either zeros or ones), the basic unit of information in quantum computing is the quantum bit or qubit. Arranging or shuffling these qubits in random configurations is one way scientists have demonstrated how quantum computers can outperform classical ones. It's known as the quantum advantage.

Shuffling qubits is a bit like shuffling a pack of playing cards. The more you add, the harder it becomes and the longer the process takes.

Also, the more you shuffle in the quantum world, the greater the chance of ruining the delicate quantum state of each qubit. For this reason, it was thought that only small quantum computers could handle applications that relied on randomness.

An overview of the main result of our paper. We show that short time i.e. low depth quantum circuits can rapidly become indistinguishable from exponential time random unitary operations. Credit: Thomas Schuster, Jonas Haferkamp, Hsin-Yuan Huang
What the team at the California Institute of Technology has done is show that these random qubit configurations can be produced with fewer shuffles. So, how did they do it?

They imagined splitting a group of qubits into smaller blocks and then proved mathematically that each block could generate randomness.

Describing their research in a paper in *Science*, the team showed how these smaller qubit blocks could be "glued" together to create a well-shuffled version of the original qubit sequence.

As a result, it may be possible to use randomly arranged qubit sequences on larger quantum systems. That means it could be easier to build more powerful quantum computers for tasks such as cryptography, simulations and a host of other real-world applications.

An illustration of several applications of our results. (Left) We show that a popular protocol for benchmarking quantum devices, classical shadow tomography, can be implemented with many fewer resources than previously thought. (Middle) Our results also have surprising implications for the complexity of recognizing quantum phases of matter such as topological order. We prove that the topological order of a quantum state cannot be efficiently recognized by any quantum or classical computation. (Right) Our results also show that quantum experiments with the ability to reverse time can detect properties of quantum dynamics that require exponential resources to detect without time-reversal. Credit: Thomas Schuster, Jonas Haferkamp, Hsin-Yuan Huang

Deeper implications

The researchers also believe their findings point to something even deeper. Namely, there may be fundamental limits to what we can observe in nature because quantum systems hide information incredibly quickly.

"Our results show that several fundamental physical properties—evolution time, phases of matter, and causal structure— are probably hard to learn through conventional quantum experiments. This raises profound questions about the nature of physical observation itself."

Written for you by our author Paul Arnold, edited by Andrew Zinin—this article is the result of careful human work. We rely on readers like you to keep independent science journalism alive. If this reporting matters to you, please consider a donation (especially monthly). You'll get an **ad-free** account as a thank-you.

More information: Thomas Schuster et al, Random unitaries in extremely low depth, *Science* (2025). DOI: 10.1126/science.adv8590

Naoki Yamamoto et al, Shrinking quantum randomization, *Science* (2025). DOI: 10.1126/science.adz0147
Journal information: Science

JULY 3, 2025

Quantum machine learning improves semiconductor manufacturing for first time

by Paul Arnold, Phys.org edited by Gaby Clark, reviewed by Robert Egan

Schematic representation of the quantum machine learning-based modeling process for the Ohmic contact formation in GaN HEMTs. Credit: *Advanced Science* (2025). DOI: 10.1002/advs.202506213

Semiconductor processing is notoriously challenging. It is one of the most intricate feats of modern engineering due to the extreme precision required and the hundreds of steps involved, such as etching and layering, to make even a single chip.

However, in a world first, researchers at the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia´s national research agency, have utilized quantum machine learning to fabricate semiconductors. Their research could revolutionize the way chips are made.

The team's study, published in the journal *Advanced Science*, shows for the first time that semiconductor fabrication can be improved by applying quantum methodology to real experimental data.

They focused their attention on a critical step in the semiconductor design process—modeling the Ohmic contact resistance of the semiconductor material. This is a measure of the electrical resistance that occurs when a semiconductor comes into contact with metal, which affects how easily current can flow.

Modeling problems

One sticking point until now is that Ohmic contact resistance is very difficult to model. A current approach uses classical machine learning (CML) algorithms, but they require large datasets, and their performance degrades in small-sample, nonlinear settings.

The Australian researchers, led by Muhammad Usman, a professor and head of quantum systems at CSIRO, went a different way.

They employed a quantum machine learning (QML) approach on data from 159 experimental samples of GaN HEMT (gallium nitride high-electron-mobility transistor) semiconductors. This clever method blends classical and quantum techniques.

Quantum ablation study for optimizing the performance of QKAR. Credit: *Advanced Science* (2025). DOI: 10.1002/advs.202506213
First, they narrowed down the many fabrication variables to just those that have a key impact on performance.

Then, they developed a Quantum Kernel-Aligned Regressor (QKAR) architecture to translate classical data into quantum states to begin the machine learning process. Once all the features had been extracted from the data, a classical algorithm retrieved the information, which was then trained to guide the fabrication process.

The QKAR technique outperformed seven different CML algorithms developed for the same problem.

"These findings demonstrate the potential of QML for effectively handling high-dimensional, small-sample regression tasks in semiconductor domains and point to promising avenues for its deployment in future real-world applications as quantum hardware continues to mature," wrote the researchers.

In addition to potentially reducing manufacturing costs and improving device performance in the semiconductor industry, this research may have other far-reaching consequences. As quantum technologies continue to evolve, they may help solve complex problems that are beyond the capabilities of classical computers.

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More information: Zeheng Wang et al, Quantum Kernel Learning for Small Dataset Modeling in Semiconductor Fabrication: Application to Ohmic Contact, *Advanced Science* (2025). DOI: 10.1002/advs.202506213
Journal information: Advanced Science

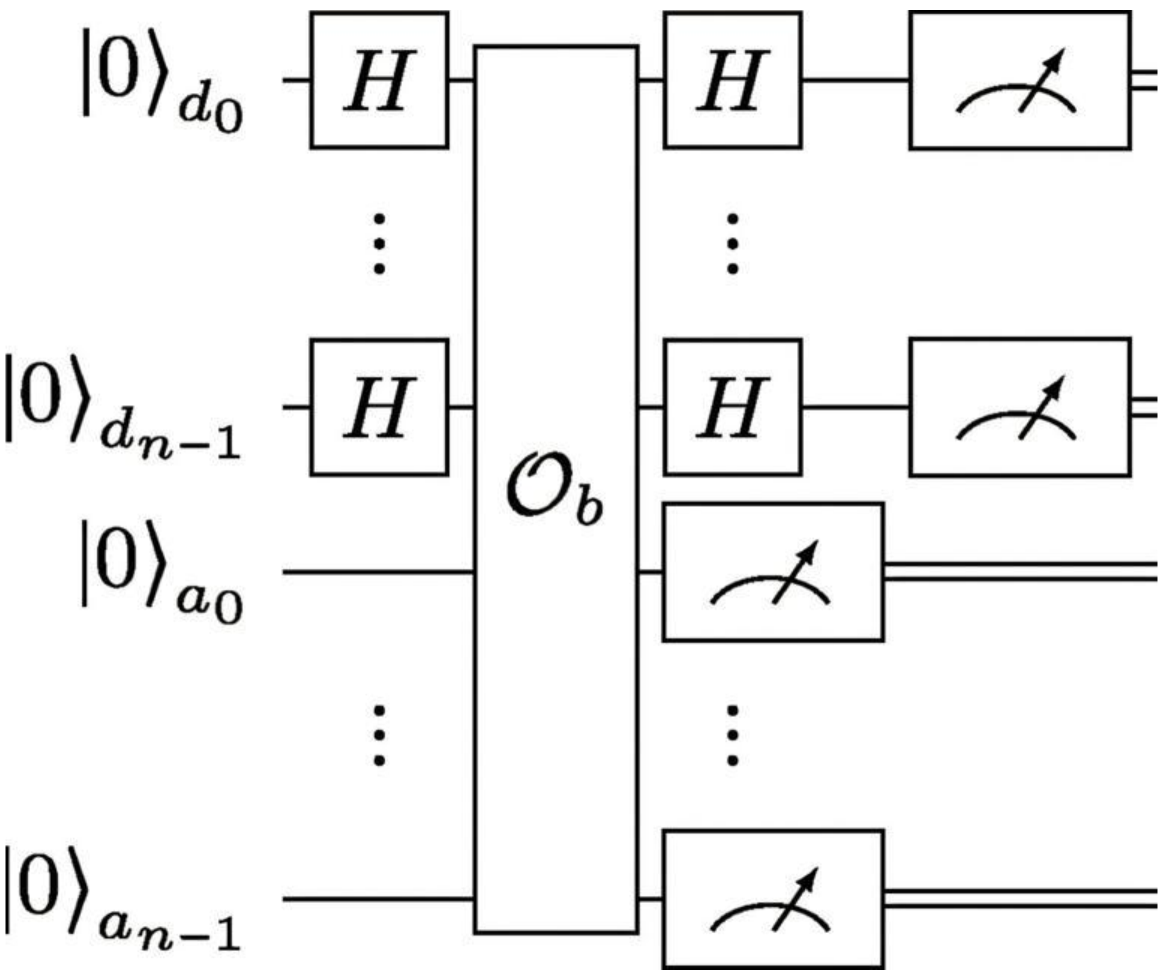
Scientists demonstrate unconditional exponential quantum scaling advantage using two 127-qubit computers

Interior shot of a quantum computer with an IBM Eagle processor. Credit: IBM

Quantum computers have the potential to speed up computation, help design new medicines, break codes, and discover exotic new materials—but that's only when they are truly functional.

One key thing that gets in the way: noise or the errors that are produced during computations on a quantum machine—which in fact makes them less powerful than classical computers—until recently.

Daniel Lidar, holder of the Viterbi Professorship in Engineering and Professor of Electrical & Computer Engineering at the USC Viterbi School of Engineering, has been iterating on quantum error correction, and in a new study along with collaborators at USC and Johns Hopkins, has been able to demonstrate a quantum exponential scaling advantage, using two 127-qubit IBM Quantum Eagle processor-powered quantum computers, over the cloud.



Quantum circuit for solving Simon's problem with a length- n hidden bitstring b. The structure of the oracle $\mathcal{O}b$ is not visible to the player who wishes to guess b. The top n measurement results form the bitstring z, and the bottom n measurement results are discarded in the algorithm. Credit: Physical Review X (2025). DOI: 10.1103/PhysRevX.15.021082

The paper, "Demonstration of Algorithmic Quantum Speedup for an Abelian Hidden Subgroup Problem," is published in the journal *Physical Review X*.

"There have previously been demonstrations of more modest types of speedups like a polynomial speedup, says Lidar, who is also the cofounder of Quantum Elements, Inc. "But an exponential speedup is the most dramatic type of speed up that we expect to see from quantum computers."

The key milestone for quantum computing, Lidar says, has always been to demonstrate that we can execute entire algorithms with a scaling speedup relative to ordinary "classical" computers.

He clarifies that a scaling speedup doesn't mean that you can do things, say, 100 times faster. "Rather, it's that as you increase a problem's size by including more variables, the gap between the quantum and the classical performance keeps growing. And an exponential speedup means that the performance gap roughly doubles for every additional variable. Moreover, the speedup we demonstrated is unconditional."

What makes a speedup "unconditional," Lidar explains, is that it doesn't rely on any unproven assumptions. Prior speedup claims required the assumption that there is no better classical algorithm against which to benchmark the quantum algorithm.

Here, the team led by Lidar used an algorithm they modified for the quantum computer to solve a variation of "Simon's problem," an early example of quantum algorithms that can, in theory, solve a task exponentially faster than any classical counterpart, unconditionally.

Simon's problem involves finding a hidden repeating pattern in a mathematical function and is considered the precursor to what's known as Shor's factoring algorithm, which can be used to break codes and launched the entire field of quantum computing. Simon's problem is like a guessing game, where the players try to guess a secret number known only to the game host (the "oracle").

Once a player guesses two numbers for which the answers returned by the oracle are identical, the secret number is revealed, and that player wins. Quantum players can win this game exponentially faster than classical players.

So, how did the team achieve their exponential speedup? Phattharaporn Singkanipa, USC doctoral researcher and first author, says, "The key was squeezing every ounce of performance from the hardware: shorter circuits, smarter pulse sequences, and statistical error mitigation."

The researchers achieved this in four different ways:

First, they limited the data input by restricting how many secret numbers would be allowed (technically, by limiting the number of 1's in the binary representation of the set of secret numbers). This resulted in fewer quantum logic operations than would be needed otherwise, which reduced the opportunity for error buildup.

Second, they compressed the number of required quantum logic operations as much as possible using a method known as transpilation.

Third, and most crucially, the researchers applied a method called "dynamical decoupling," which means applying sequences of carefully designed pulses to detach the behavior of qubits within the quantum computer from their noisy environment and keep the quantum processing on track. Dynamical decoupling had the most dramatic impact on their ability to demonstrate a quantum speedup.

Finally, they applied "measurement error mitigation," a method that finds and corrects certain errors that are left over after dynamical decoupling due to imperfections in measuring the qubits' state at the end of the algorithm.

Lidar, who is also a professor of Chemistry and Physics at the USC Dornsife College of Letters, Arts and Science, says, "The quantum computing community is showing how quantum processors are beginning to outperform their classical counterparts in targeted tasks, and are stepping into a territory classical computing simply can't reach., Our result shows that already today's quantum computers firmly lie on the side of a scaling quantum advantage."

He adds that with this new research, "The performance separation cannot be reversed because the exponential speedup we've demonstrated is, for the first time, unconditional." In other words, the quantum performance advantage is becoming increasingly difficult to dispute.

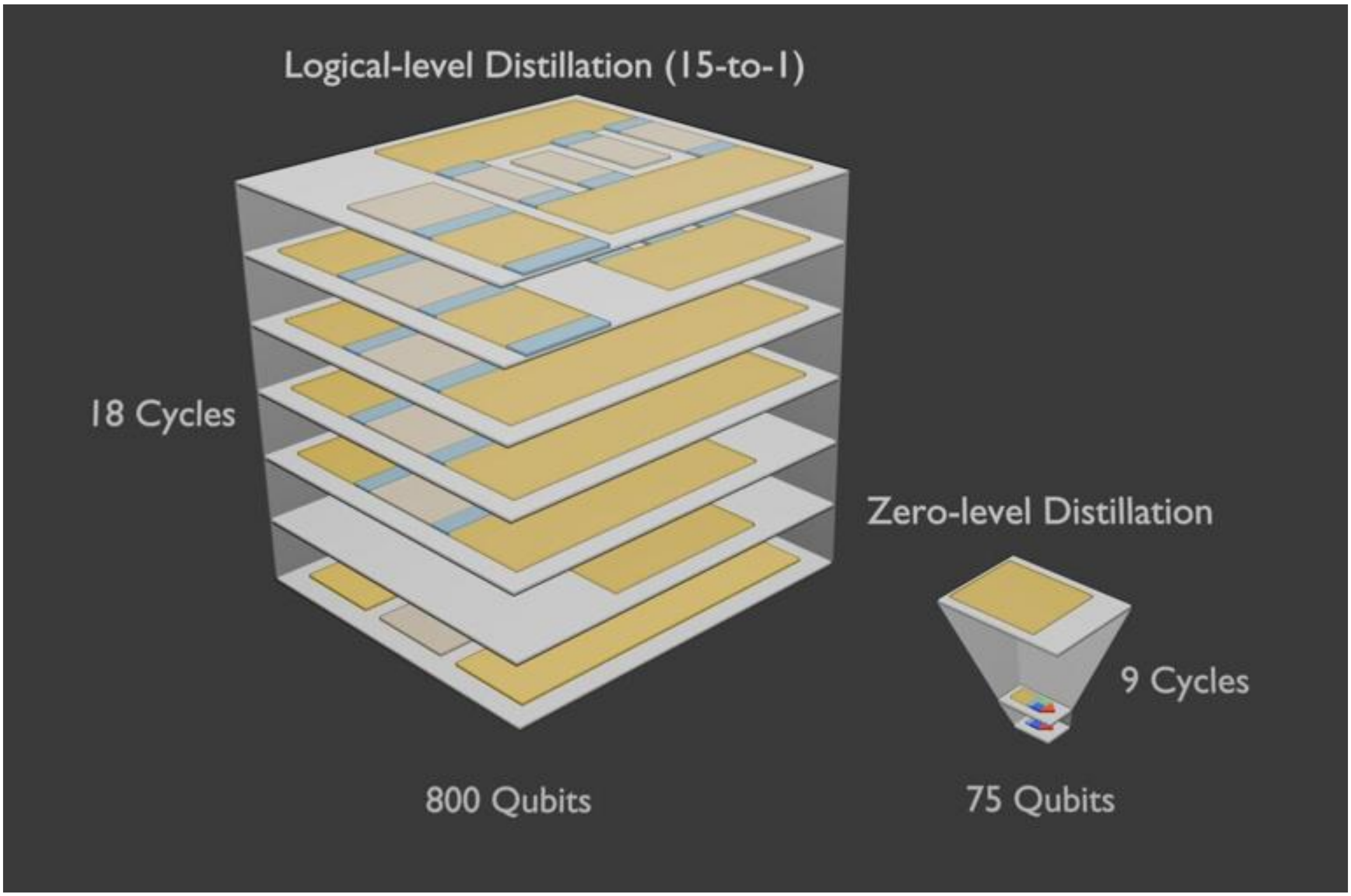
Lidar cautions that "this result doesn't have practical applications beyond winning guessing games, and much more work remains to be done before quantum computers can be claimed to have solved a practical real-world problem."

This will require demonstrating speedups that don't rely on "oracles" that know the answer in advance and making significant advances in methods for further reducing noise and decoherence in ever larger quantum computers. Nevertheless, quantum computers' previously "on-paper promise" to provide exponential speedups has now been firmly demonstrated.

More information: Phattharaporn Singkanipa et al, Demonstration of Algorithmic Quantum Speedup for an Abelian Hidden Subgroup Problem, *Physical Review X* (2025). DOI: 10.1103/PhysRevX.15.021082

Provided by University of Southern California

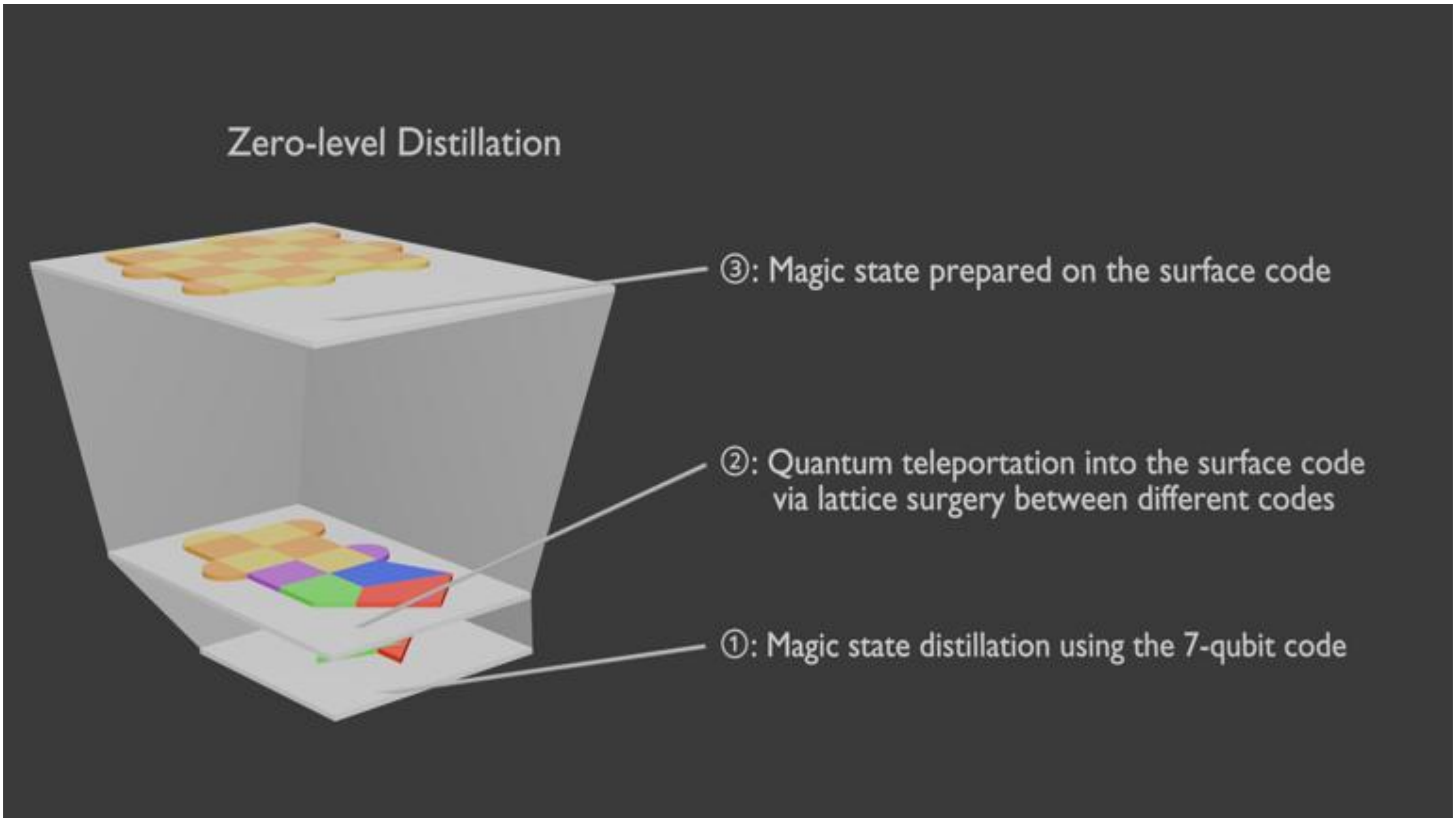
Magically reducing errors in quantum computers: Researchers invent technique to decrease overhead



Comparison of zero-level distillation (right) and logical-level distillation (left). Credit: PRX Quantum (2025). DOI: 10.1103/thxx-njr6

For decades, quantum computers that perform calculations millions of times faster than conventional computers have remained a tantalizing yet distant goal. However, a new breakthrough in quantum physics may have just sped up the timeline.

In an article titled "Efficient Magic State Distillation by Zero-Level Distillation" published in *PRX Quantum*, researchers from the Graduate School of Engineering Science and the Center for Quantum Information and Quantum Biology at the University of Osaka devised a method that can be used to prepare high-fidelity "magic states" for use in quantum computers with dramatically less overhead and unprecedented accuracy.



Detail of zero-level distillation. Credit: PRX Quantum (2025). DOI: 10.1103/thxx-njr6

Quantum computers harness the fantastic properties of quantum mechanics such as entanglement and superposition to perform calculations much more efficiently than classical computers can. Such machines could catalyze innovations in fields as diverse as engineering, finance, and biotechnology. But before this can happen, there is a significant obstacle that must be overcome.

"Quantum systems have always been extremely susceptible to noise," says lead researcher Tomohiro Itogawa. "Even the slightest perturbation in temperature or a single wayward photon from an external source can easily ruin a quantum computer setup, making it useless. Noise is absolutely the number one enemy of quantum computers."

Thus, scientists have become very interested in building so-called fault-tolerant quantum computers, which are robust enough to continue computing accurately even when subject to noise. Magic state distillation, in which a single high-fidelity quantum state is prepared from many noisy ones, is a popular method for creating such systems. But there is a catch.

"The distillation of magic states is traditionally a very computationally expensive process because it requires many qubits," explains Keisuke Fujii, senior author. "We wanted to explore if there was any way of expediting the preparation of the high-fidelity states necessary for quantum computation."

Following this line of inquiry, the team was inspired to create a "level-zero" version of magic state distillation, in which a fault-tolerant circuit is developed at the physical qubit or "zeroth" level as opposed to higher, more abstract levels. In addition to requiring far fewer qubits, this new method led to a roughly several dozen times decrease in spatial and temporal overhead compared with that of the traditional version in numerical simulations.

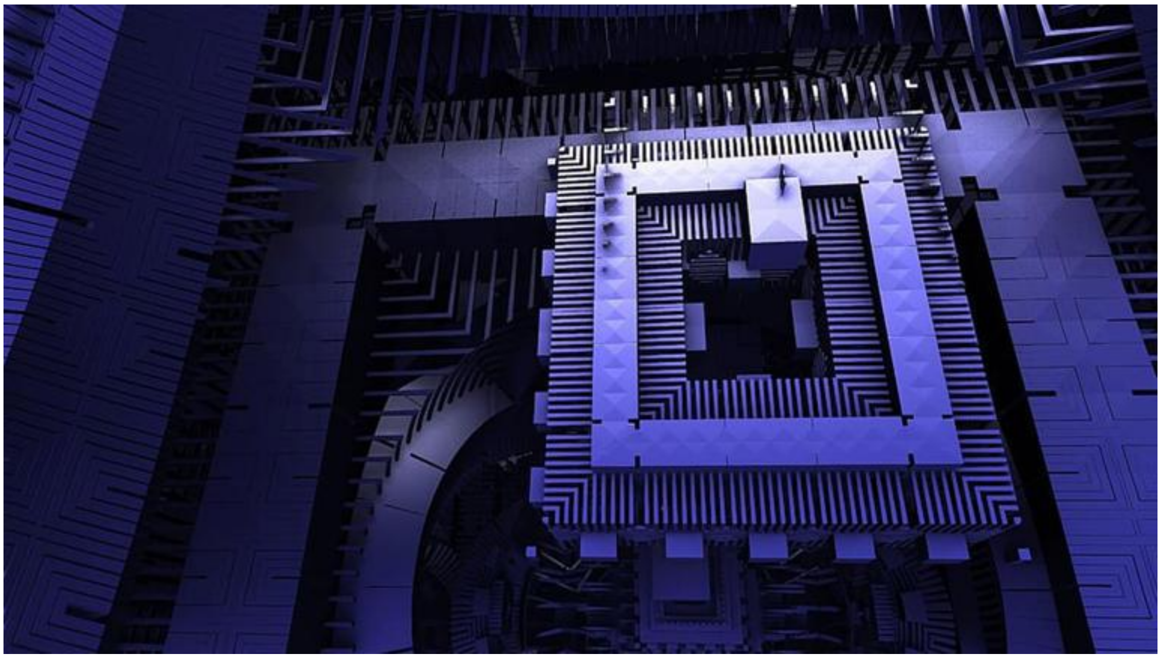
Itogawa and Fujii are optimistic that the era of quantum computing is not as far off as we imagine. Whether one calls it magic or physics, this technique certainly marks an important step toward the development of larger-scale quantum computers that can withstand noise.

More information: Tomohiro Itogawa et al, Efficient Magic State Distillation by Zero-level Distillation, *PRX Quantum* (2025). DOI: 10.1103/thxx-njr6.
On *arXiv*: DOI: 10.48550/arxiv.2403.03991

Provided by University of Osaka

This story was originally published on Phys.org.

Physicists double qubit coherence, opening door to faster quantum computing



Physicists double qubit coherence, opening door to faster quantum computing

Finnish researchers at Aalto University have made a significant advancement in quantum computing. The team achieved a new scientific record for transmon qubit coherence time, a key performance metric in quantum computing.

Specifically, they achieved an echo coherence time of 1 millisecond for a transmon qubit, with a median of 0.5 milliseconds. This crushes previous records of around 0.6 milliseconds.

For those who are not aware, coherence time refers to the duration during which a qubit can maintain its quantum state without errors due to environmental noise. In other words, the qubits can remain in a fragile quantum state (also known as superposition) for longer before decohering.

When this happens, the qubit loses all its quantum information. Therefore, longer coherence times equate to more time to perform complex operations without losing fidelity.

Longer coherence = better quantum computing

It also reduces the need for heavy quantum error correction, which is crucial for scaling up to practical, fault-tolerant quantum computers. Simply put, the longer this time, in theory at least, the more usable a quantum computer becomes.

“Quantum computers are [on] the verge of becoming useful with the increasing qubit coherence and fidelity. The first applications seem to lie in solving hard but short mathematical problems, such as high-order binary optimization problems,” Mikko Möttönen, Professor of Quantum Technology at Aalto University, told *IE*.

To achieve this incredible feat, the team built high-quality transmon qubits in cleanroom facilities at Aalto University. The required superconducting materials came from VTT, Finland’s national research institute.

They utilized Micronova cleanrooms, a component of Finland’s OtaNano infrastructure. The setup was led by Ph.D. student Mikko Tuokkola and supervised by Dr. Yoshiki Sunada (now at Stanford).

“At the moment, quantum error correction is only moderately improving qubit coherence because of still too frequent errors on the physical qubits. Thus, several factor-of-two improvements are required for efficient quantum error correction, and these first ones provide the most advantage in terms of the required number of physical qubits,” Möttönen explained to *IE*.

The achievement is not just a significant win for the team, but also for Finland as a whole. It can, in part, help Finland position itself as a global leader in quantum technology.

Quantum computers within five years?

The work is also supported by major initiatives, including the Finnish Quantum Flagship (FQF) and the Academy of Finland’s Centre of Excellence in Quantum Technology. Aalto’s Quantum Computing and Devices group is opening new positions to accelerate future breakthroughs.

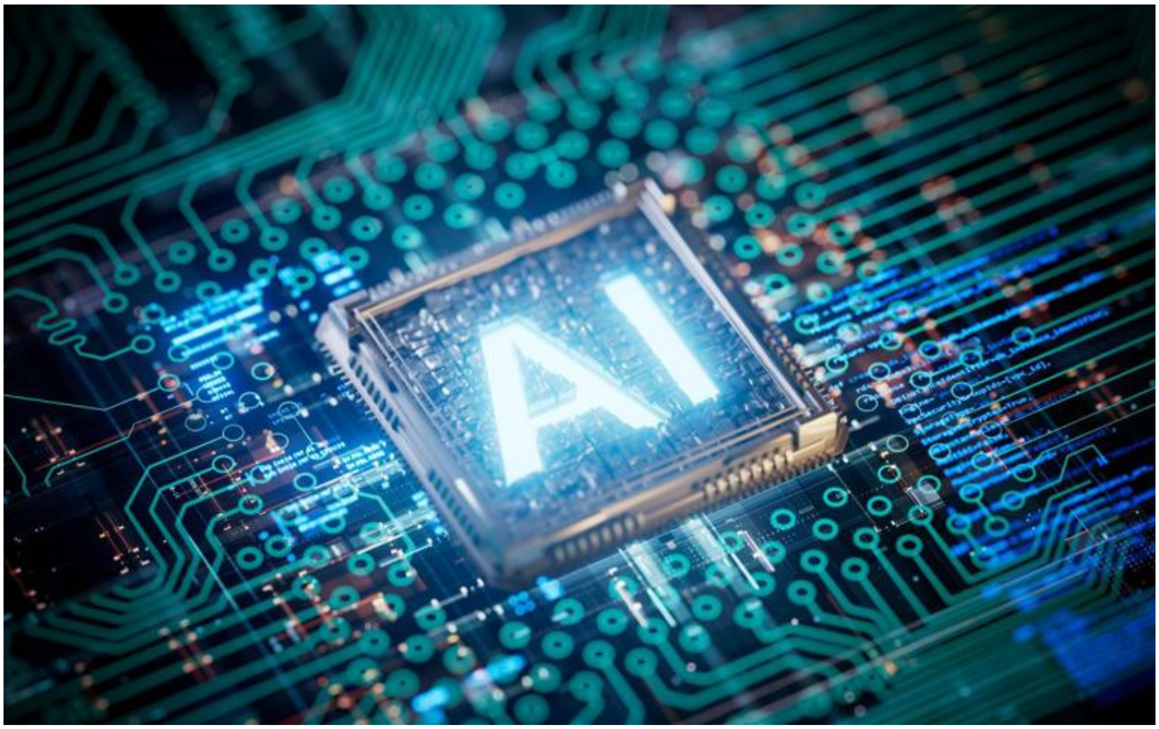
“This landmark achievement has strengthened Finland’s standing as a global leader in the field, moving the needle forward on what can be made possible with the quantum computers of the future,” Möttönen explained.

Looking ahead, achievements like this are edging us closer to real-world applications of quantum computers, perhaps even within the next five to ten years.

“It appears to me that industrial and commercial use of this technology is likely within the next five years, first in the form of early NISQ algorithms and then in the lightly error-corrected machines,” he said.

You can view their study for yourself in the journal *Nature Communications.*

Marché Du Film's Innovation Exec Predicts Fully AI-Generated Feature Films Within Five Years - Karlovy Vary



Marché Du Film's Innovation Exec Predicts Fully AI-Generated Feature Films Within Five Years - Karlovy Vary

Sten Saluveer, Strategic Advisor and Head of the Cannes Next Innovation Summit, the Marché Du Film's tech-focused think tank, made a startling prediction about the future relationship between Artificial Intelligence and film production during a presentation at the Karlovy Vary Film Festival's International Industry Insights Forum on Monday.

"What we’re estimating is that in about a maximum of 5 years, we will be able to generate full-quality Multimodal, which means video, audio, text, and feature films," Saluveer told the audience in Karlovy Vary. "So we are in a situation where, roughly, in about 5 years, perhaps at Karlovy Vary and elsewhere, you will see a fully automatically generated feature film.”

Saluveer: "This is the direction we are heading in."

While AI tools have been used in the feature film post-production process for many years, there is no widely recognized narrative feature that has been produced using only AI tools. Turkish filmmaker Alkan Avcioglu has claimed his 2025 documentary feature, *Post Truth,* is the first documentary film to be produced entirely using AI tools. Filmmaker Hooroo Jackson has also claimed to have created the first fully AI-produced animated feature with the 2024 flick *DreadClub: Vampire's Verdict*.

Hollywood filmmakers have been embracing AI research to varying degrees. In March, Darren Aronofsky's AI-focused studio Primordial Soup announced a strategic partnership with Google's DeepMind research lab to explore the role artificial intelligence coudl play in the filmmaking process. Last year, *Avatar* filmmaker James Cameron, widely considered one of the industry's most tech-forward filmmakers, joined the board of directors of artificial intelligence (AI) firm StabilityAI. However, the *Terminator* filmmaker has routinely stated his skepticism about the technology's potential to produce serviceable narrative works.

"I just don't personally believe that a disembodied mind that's just regurgitating what other embodied minds have said - about the life that they've had, about love, about lying, about fear, about mortality - and just put it all together into a word salad and then regurgitate it ... I don't believe that have something that's going to move an audience," Cameron told the *Boz to the Future* podcast in April.

"Let's wait 20 years, and if an AI wins an Oscar for Best Screenplay, I think we've got to take them seriously."

Karlovy Vary runs until July 12.

JULY 8, 2025

The GIST

New quantum record: Transmon qubit coherence reaches millisecond threshold

by Aalto University edited by Lisa Lock, reviewed by Robert Egan

Artistic image of a high-coherence transmon qubit on a quantum processor. Credit: Alexandr Käkinen

On July 8, 2025, physicists from Aalto University in Finland published a transmon qubit coherence measurement in *Nature Communications* that dramatically surpasses previous scientifically published records. The millisecond coherence measurement marks a quantum leap in computational technology, with the previous maximum echo coherence measurements approaching 0.6 milliseconds.

Longer qubit coherence allows for an extended window of time in which quantum computers can execute error-free operations, enabling more complex quantum computations and more quantum logic operations before errors occur. Not only does this allow for more calculations with noisy quantum computers, but it also decreases the resources needed for quantum error correction, which is a path to noiseless quantum computing.

"We have just measured an echo coherence time for a transmon qubit that landed at a millisecond at maximum with a median of half a millisecond," says Mikko Tuokkola, the Ph.D. student who conducted and analyzed the measurements. The median reading is particularly significant, as it also surpasses current recorded readings.

The researchers report their approach as thoroughly as possible, with the aim of making it reproducible for research groups around the world.

Finland cements position at forefront of quantum

Tuokkola was supervised at Aalto University by postdoctoral researcher Dr. Yoshiki Sunada, who fabricated the chip and built the measurement setup.

"We have been able to reproducibly fabricate high-quality transmon qubits. The fact that this can be achieved in a cleanroom which is accessible for academic research is a testament to Finland's leading position in quantum science and technology," adds Sunada who is currently working at Stanford University, U.S.

The work is a result of the Quantum Computing and Devices (QCD) research group, which is a part of Aalto University's Department of Applied Physics, Academy of Finland Center of Excellence in Quantum Technology (QTF), and the Finnish Quantum Flagship (FQF).

The qubit was fabricated by the QCD group at Aalto using high-quality superconducting film supplied by the Technical Research Center of Finland (VTT). The success reflects the high quality of Micronova cleanrooms at OtaNano, Finland's national research infrastructure for micro-, nano-, and quantum technologies.

"This landmark achievement has strengthened Finland's standing as a global leader in the field, moving the needle forward on what can be made possible with the quantum computers of the future," says Professor of Quantum Technology Mikko Möttönen, who heads the QCD group.

More information: Mikko Tuokkola et al, Methods to achieve near-millisecond energy relaxation and dephasing times for a superconducting transmon qubit, *Nature Communications* (2025). DOI: 10.1038/s41467-025-61126-0. On *arXiv*: DOI: 10.48550/arxiv.2407.18778
Journal information: Nature Communications , arXiv
Provided by Aalto University