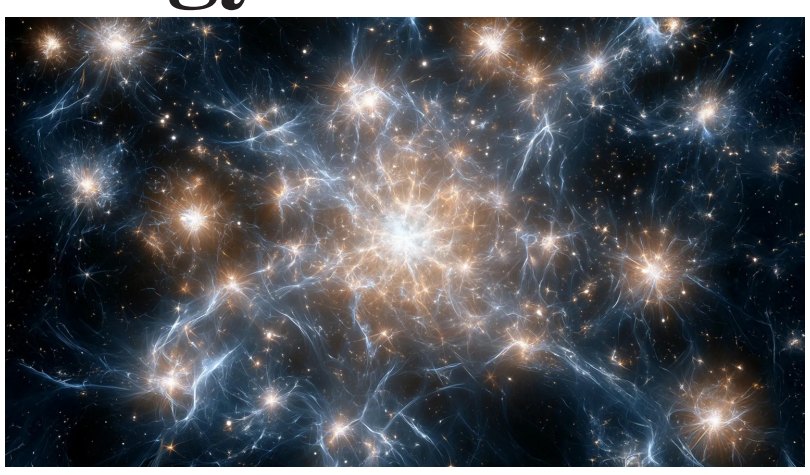
Exploding stars to reveal dark energy's secrets



Researchers led by the Institute of Cosmos Sciences of the University of Barcelona (ICCUB) have developed a new technique that could greatly improve how scientists study the expansion of the Universe and investigate the mysterious force known as dark energy.Published recently, the research introduces a framework called CIGaRS that can extract far more information from Type Ia supernovae, the powerful stellar explosions used to measure vast cosmic distances. Unlike many current approaches, the method relies mainly on imaging data rather than expensive spectroscopic observations. The advance is expected to help astronomers take full advantage of the enormous datasets that will soon arrive from next generation sky surveys, particularly those conducted by the Vera C. Rubin Observatory.

Type Ia supernovae occur when white dwarf stars explode. Because these explosions reach nearly the same intrinsic brightness, astronomers use them as "standard candles": by comparing their actual brightness with how bright they appear from Earth, researchers can calculate their distance.

These measurements played a crucial role in the discovery that the Universe is expanding at an accelerating rate. Scientists attribute that acceleration to dark energy, one of the most significant unsolved questions in modern physics.

However, there is an important complication. Type Ia supernovae are not perfectly identical. Over the past 20 years, astronomers have found that a supernova's observed brightness is influenced by the galaxy where it occurs. Supernovae found in older or more massive galaxies can appear slightly different from those occurring in younger or less massive galaxies.

Researchers have typically accounted for these differences using relatively simple correction methods. While useful, these approximations can limit the accuracy of distance measurements and, in turn, the precision of cosmological studies.

The new framework addresses this challenge by modeling multiple factors simultaneously. Rather than treating each component independently, the researchers built a single, integrated model that includes the supernova explosions themselves, their host galaxies, the dust that alters their light, changes in supernova rates throughout cosmic history, and even the expansion of the Universe.

By connecting all of these ingredients within one statistical and physical framework, the team can capture relationships that are often overlooked when the pieces are analyzed separately.

"A powerful way of modelling the Universe is to simulate it ab initio in the computer using Bayesian inference," says Raúl Jiménez (ICREA-ICCUB), co-author of the study. "This provides a way to vary all possible parameters at the same time to predict what Universe we live in. Furthermore, by having this capacity, one can look into possible 'unknown unknown' systematics to understand their effect. The impact of these systematics in our inference is arguably the most important missing ingredient in current approaches to model the Universe."

Building such a comprehensive model would normally require enormous computing power. To make the approach practical, the researchers turned to a modern technique called simulation-based inference.

The process begins with scientists generating large numbers of simulated universes based on physical models. A neural network (a type of artificial intelligence) then learns how the simulated observations relate to the physical properties that produced them. Once trained, the system can compare real astronomical observations with its simulations and determine the most likely underlying parameters.

This strategy makes it possible to analyze tens of thousands of supernovae simultaneously, a task that would be impractical using traditional techniques.

One of the study's most significant findings is that the framework can determine galaxy distances (redshifts) with high accuracy using only imaging data.

Redshift measures how much a galaxy's light has been stretched as the Universe expands. It provides information about both the galaxy's distance and how far back in time we are observing it.

According to the researchers, the new method delivers redshift estimates with precision comparable to spectroscopic measurements, but without requiring spectra. This capability is especially important because upcoming surveys are expected to identify millions of supernova candidates, while only a small percentage can realistically receive spectroscopic follow-up observations.

SpaceX mulls data centres on outer space

Imagine if one company could become the railroad, electric utility and cloud-computing provider of the emerging space economy. That potential fuelled excitement around the long-anticipated initial public offering of SpaceX. Investors are not simply betting on rockets anymore. They are betting on an entire orbital ecosystem.

Among the most ambitious and challenging ideas riding this wave of enthusiasm is something that sounds almost like science fiction: orbital data centers. SpaceX may be one of the most well-known companies seeking to build them, but it is not the only one.

The logic is seductive: Launch the data centres into orbit, where solar energy is abundant and land, water and local power grids are no longer constraints. As artificial intelligence drives an explosion in computing demand, companies are pitching orbital data centers as a way to escape the growing environmental and infrastructure pressures of earth-based computing. Data centres often also face backlash from the public at having these centers located in their communities.

But there is a vast difference between launching satellites and operating an industrial-scale computing infrastructure in orbit. Space is unforgiving. Radiation damages electronics. The electronics generate enormous amounts of heat, and getting rid of that heat is surprisingly difficult in space. Repairs are extraordinarily expensive, and every pound launched into orbit still carries a significant cost.

We are engineering professors who study data center design and space systems engineering. Building a space-based data center will involve considerations from both sides.What goes into a data centre on earth? First off, consider what goes into an earth-based data centre, like those that you've probably begun to see pop up everywhere. These facilities power cloud computing, video streaming, online banking, scientific computing and, increasingly, artificial intelligence. But a data center is much more than a room full of servers.

A data centre needs several things to operate reliably. The first is electric power. Servers, networking equipment and storage devices consume large amounts of electricity, and that power demand is growing rapidly with AI.

The second is cooling. Almost all the electricity consumed by servers eventually becomes heat. If that heat is not removed quickly and reliably, equipment performance drops, failures increase and the data center can shut down. Cooling systems often include air handling units, chillers, cooling towers, pumps and increasingly, liquid-cooling equipment. In many facilities, cooling is the largest energy consumer after the computing equipment itself.

The third is physical infrastructure, including the necessary land, buildings, structural support, backup power, water systems, communication networks and maintenance access. Data centers also need to be close enough to users and network backbones to provide fast digital services.

Another potential advantage found in space is cooling. The cold background of space (near minus 455 degrees Fahrenheit, or minus 270 degrees Celsius) creates an opportunity: waste heat from the data center could escape into space through radiators, keeping the electronics cool.

In principle, that design could eliminate some of the bulky and water-intensive cooling infrastructure used on Earth. However, those thermal radiators would require a large amount of surface area, and that would be in addition to the area required by the solar panels.

In space, there is no air to blow across hot equipment and help heat escape. The heat has to leave as infrared radiation, which is a relatively slow process. As a result, removing 10 megawatts of waste heat can require radiator surfaces comparable to the size of two football fields.

Quantum mechanics changing world

For much of the early 20th century, quantum mechanics was one of the most puzzling ideas in science. The theory challenged conventional thinking and left even leading physicists struggling to make sense of its implications. A century later, it has become the foundation of technologies that influence daily life, including lasers, microchips, secure communications, and emerging quantum computers.

In a new perspective article published in Science, Dr. Marlan Scully of Texas A&M University reflects on the remarkable evolution of quantum mechanics, from an abstract theory about tiny particles to a powerful framework helping researchers tackle some of the most difficult questions in science.

"Quantum mechanics started as a way to explain the behavior of tiny particles," said Scully, who is also affiliated with Princeton University. "Now it's driving innovations that were unimaginable just a generation ago."

Scully has played a major role in advancing the field. He co-authored the influential textbook Quantum Optics, a resource that has educated generations of physicists. His research in coherent nanoscale laser spectroscopy helped make it possible to study molecules with atomic-scale precision. He has also developed groundbreaking concepts involving quantum heat engines, which challenge traditional assumptions about thermodynamic efficiency and may one day lead to new energy technologies.

One of the most famous illustrations of quantum mechanics came in 1935, when Erwin Schrödinger proposed his cat paradox. The thought experiment suggested that a cat could exist in a state that is both alive and dead until it is observed. Schrödinger introduced the idea to highlight how strange quantum theory appeared.

Today, those once-bizarre concepts have moved far beyond philosophical debates.

"That 'quantum weirdness' is no longer just a philosophical puzzle," said Scully. "It's the foundation of quantum computing, quantum cryptography and even gravitational wave detection."

The foundations of quantum mechanics were built by pioneers including Schrödinger and Werner Heisenberg. They developed two different mathematical approaches, wave mechanics and matrix mechanics, to describe quantum systems. Over time, these approaches were unified and contributed to the development of quantum field theory, which explains how particles interact through electromagnetic and nuclear forces.

Their work expanded on Niels Bohr's early atomic model, which pictured electrons orbiting the nucleus much like planets orbit the sun. While later discoveries refined that picture, Bohr's model helped pave the way for modern quantum theory.

Among the most important concepts in quantum mechanics is quantum coherence. This phenomenon allows particles such as atoms and photons to remain linked in a coordinated state, even across significant distances.

Quantum coherence led directly to the development of the laser, a technology that many once believed could never work. Today, lasers are used throughout modern society, from supermarket barcode scanners to vision correction procedures and advanced scientific instruments.

Coherence is also closely tied to quantum entanglement, the phenomenon that prompted Albert Einstein to describe it as "spooky action at a distance."

Entanglement enables particles to share information through uniquely quantum properties. These effects form the basis of quantum encryption systems and improve the sensitivity of sophisticated instruments such as the Laser Interferometer Gravitational-Wave Observatory (LIGO), which detects tiny ripples in spacetime.

One of the more surprising applications of quantum physics involves quantum heat engines.

Traditional engines are constrained by the Carnot Limit, which defines the maximum efficiency allowed by classical thermodynamics. Researchers have found that by exploiting quantum coherence, it may be possible to create engines that exceed those classical limits."It's a striking example of how quantum principles can rewrite the rules of classical physics," Scully said.

Laptop solves complex quantum problem

Physicists have used an ordinary computer, advanced mathematics, and specialised software to solve a difficult quantum physics problem that had been described as beyond the reach of classical machines.

The work was carried out by researchers at the Centre for Computational Quantum Physics (CCQ) at the Simons Foundation's Flatiron Institute, together with collaborators at Boston University. Their method proved efficient enough for some of the calculations to run on a personal laptop.

By extracting more computing power from conventional hardware, the approach could expand the range of quantum dynamics problems scientists can study. It may also offer a useful strategy for optimisation problems in which researchers must identify the best answer among many possible solutions.

The challenge involved modelling hundreds of interacting 'qubits', the quantum counterparts of the bits used by traditional computers. The qubits were arranged in square, cubic, or diamond shaped lattices.

A conventional bit stores either a 0 or a 1. A qubit, however, can exist in a superposition of multiple states. This feature gives quantum systems their unusual capabilities, but it also makes their behavior extremely difficult to reproduce on a classical computer.

In a March 2025 article, also published in Science, another research team reported using a quantum computer to calculate the dynamics of an especially complex qubit system. That team argued that a classical computer could not match the achievement.

"Whenever we [at the CCQ] see these kinds of claims, we're always a bit skeptical," says Joseph Tindall, an associate research scientist at the CCQ and first author on the new Science paper. "Like, 'Did you try this? Did you try that?'"

AI's new take on superconductors

Machine learning is giving scientists a powerful new way to search for superconductors, materials that conduct electricity with zero resistance. An international team has demonstrated that AI can rapidly narrow an almost limitless number of possible material combinations to identify the most promising candidates. According to Aalto University Professor Päivi Törmä, who leads the SuperC consortium, the approach could dramatically speed the discovery of new superconductors.

Superconductors allow electric current to flow without losing energy, but only when cooled to extremely low temperatures where quantum effects emerge. These remarkable materials are already used in technologies ranging from quantum computers and medical neuroimaging systems to fusion reactors and maglev trains.

Despite their enormous potential, superconductors remain exceptionally difficult to discover. There are virtually endless combinations of chemical elements that could form new materials, yet only a tiny fraction turn out to be superconductors. Those that have already been identified generally require costly cooling systems that bring them close to absolute zero before they exhibit their unique properties.

Scientists around the world are searching for a practical superconductor that can operate at room temperature.

"Superconductive materials that can operate at room temperature would forever change the way we consume energy. If such a material could replace regular conductors in applications like computers and data centers, global energy consumption could be slashed and the heat footprint of the ICT sector vastly reduced," explains Törmä.

The SuperC consortium was established in 2023 by Professor Törmä and an international group of leading physicists who share the goal of using quantum physics to help address climate change. It is the first coordinated global collaboration dedicated to discovering new superconductors, with the ambitious objective of finding a room temperature superconductor by 2033.