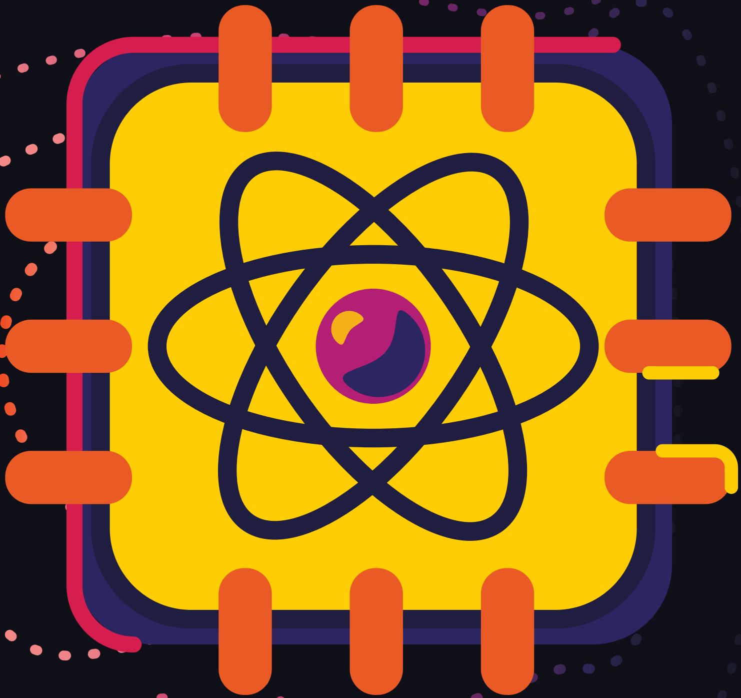
USC Dornsife



THE POWER AND PROMISE OF QUANTUM INFORMATION SCIENCE

HACK THE UNIVERSE

Picture this: The year is 2035. The unprecedented power and speed of quantum computers is revolutionizing the way we live and work.

They're discovering life-saving drugs, fortifying cybersecurity, and supercharging artificial intelligence. They're even helping us unravel the fundamental physical properties of the universe that had never been fully understood.

Built on technology entirely distinct from the computers we use every day, these systems are solving complex problems in seconds that today's best supercomputers would take thousands of years to crack.

It's a future where quantum information science redefines what's possible.

At USC Dornsife, that future starts now.

FRONTIERS OF COMPUTING

Central to the university's ambitious $1 billion Frontiers of Computing Initiative, Quantum Information Science brings together USC Dornsife's distinguished scholars in physics, math, chemistry, and the computational sciences, with renowned engineering experts at the USC Viterbi School of Engineering.

Working together, USC is uniquely positioned to solve some of the most fundamental — and fundamentally difficult — challenges to harnessing the full potential of quantum computing.

TECHNICALLY SPEAKING

You don’t have to be an expert to wrap your head around the potential for quantum information science to change the world. But, it doesn’t hurt to speak some of the basic language.

Quantum Information Science (QIS)

This emerging field engages experts across physics, math, chemistry, and engineering to explore how to harness and manipulate quantum properties of tiny particles like atoms and photons to enable the processing of information.

Quantum Computers

Don’t mistake these systems for a new version of traditional computers. While both process information, they are entirely different technologies — like a flashlight is to a candle. With exponentially increased computing power, quantum computers hold vast potential for solving extraordinarily complex problems.

Superposition

A quantum phenomenon in which a quantum particle can be in multiple states or places at once; they exist as a waveform that cannot be definitively located at any fixed position in space.

Decoherence

When a quantum system in a superposition state is affected by forces in the environment, it loses the ability to act like a wave and collapses into a single definite state. Decoherence leads to the loss of quantum information and introduces errors into quantum calculations.

Quantum Entanglement

A mysterious link where two particles become so deeply connected that the actions performed on one instantly have an effect on the other — regardless of the distance separating them. This behavior allows qubits in a quantum computer to be interconnected, boosting the ability to perform multiple calculations at once.

Qubit (Quantum Bit)

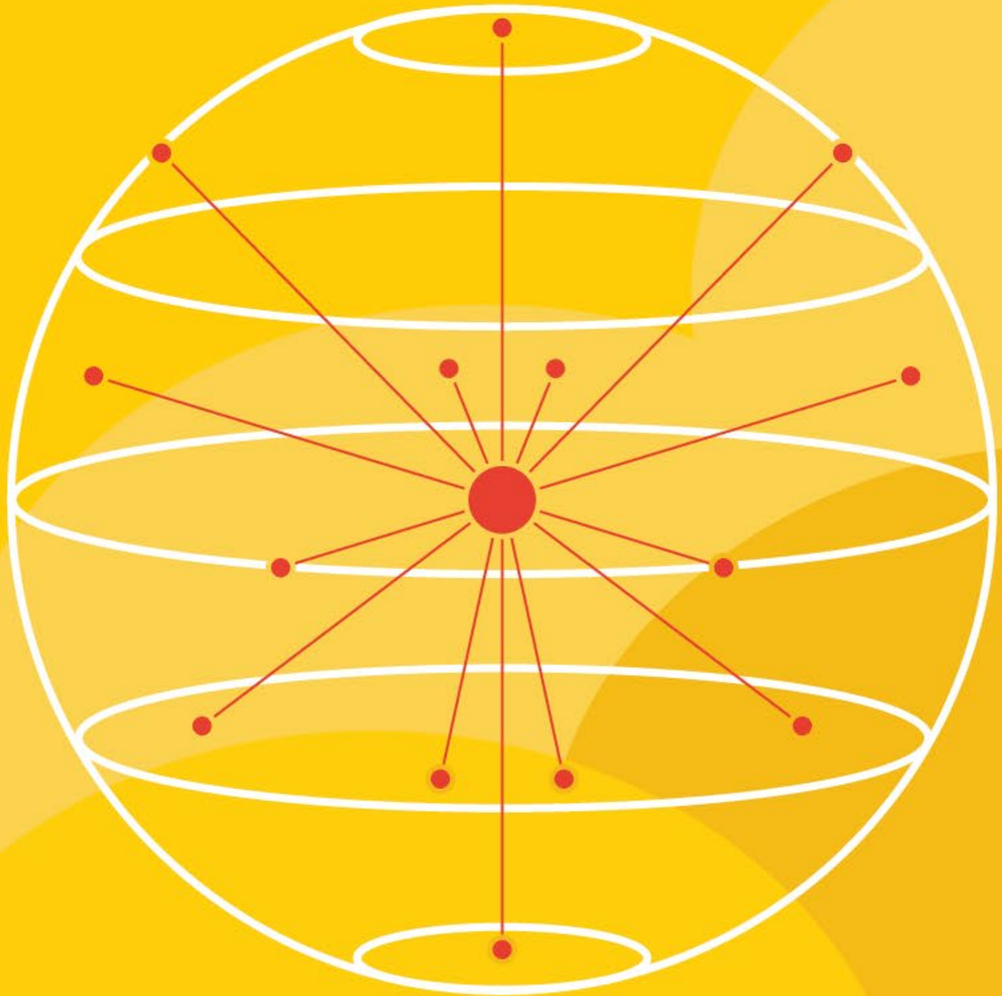
A qubit is like a regular bit, but it can be both 0 and 1 simultaneously, enabling quantum computers to perform certain calculations exponentially faster.

QUBITS: THE BUILDING BLOCKS OF QUANTUM TECH

Traditional computers process data using transistors (“bits”) that, like a light switch, must be in one of two states: “off” (0) or “on” (1). When processing information, electronic signals test each pathway one by one, like somebody finding their way through a maze.

In quantum computing, the star player is a quantum bit — a “qubit.” Qubits can be in a state of 0, 1, or both simultaneously, thanks to the phenomena of superposition. This allows them to test every path at the exact same time!

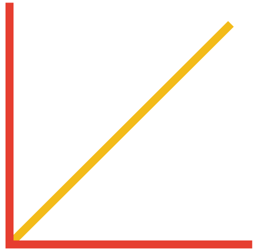
Quantum computers house qubits in highly controlled environments. This is necessary to minimize interactions with external forces that could cause decoherence and destroy the information the qubits hold.



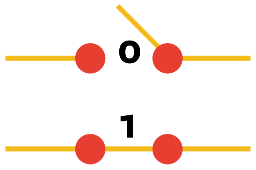
Power Surge

While each additional binary bit doubles processing power, each additional qubit increases power exponentially. This allows quantum computers to solve certain types of complex problems much more efficiently.

Classical Computing

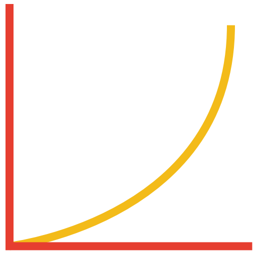


Power increases in a 1:1 relationship with the number of transistors

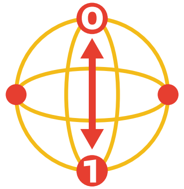


Calculates with transistors, which can represent either 0 or 1

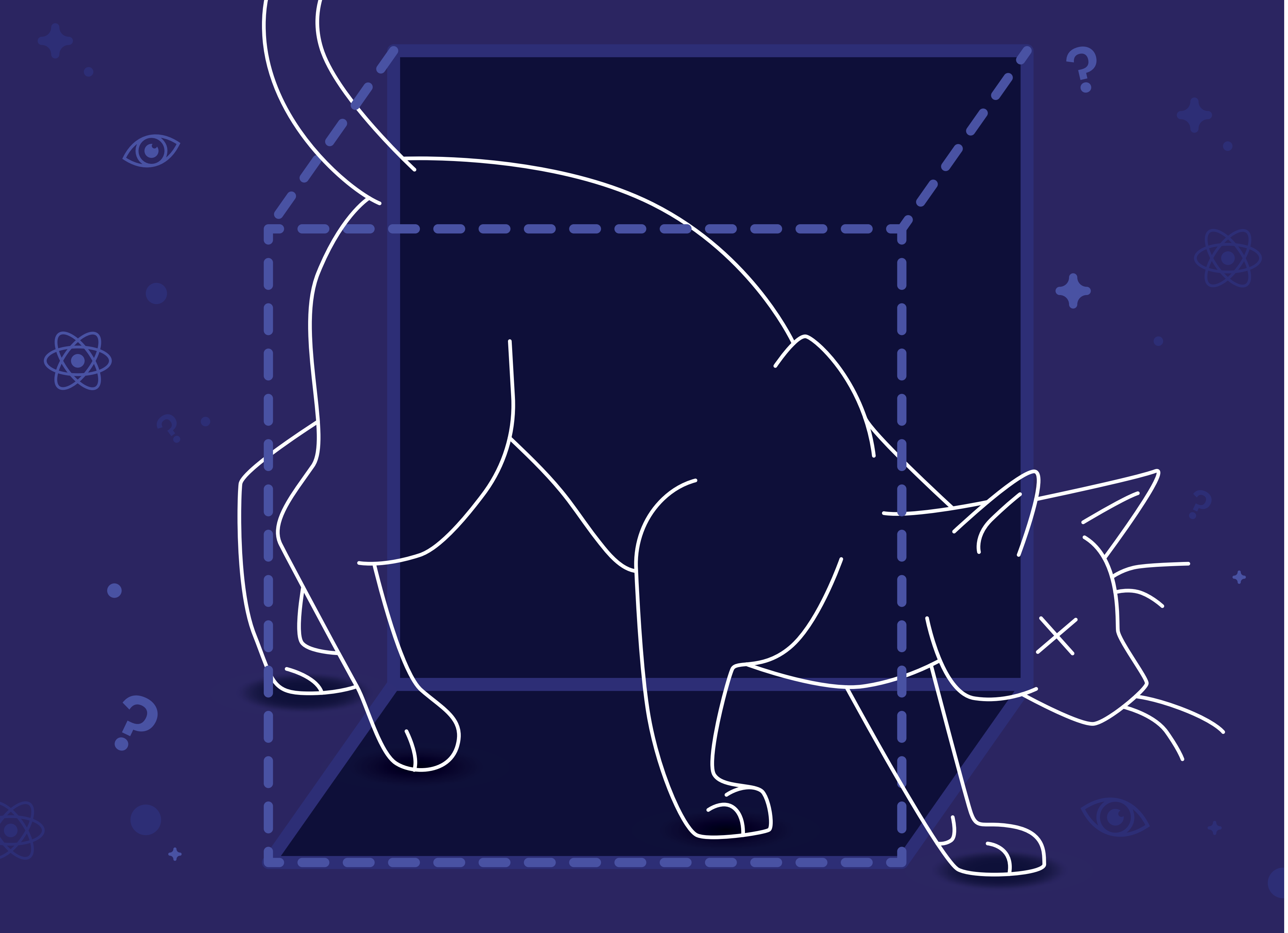
Quantum Computing



Power increase exponentially in proportion to the number of qubits



Calculates with qubits, which can represent 0 and 1 at the same time



SCHRÖDINGER'S CAT

Imagine a cat trapped inside a sealed box containing a vial of poison that could be released at any random moment. You can't see inside the box or communicate with the fated feline.

So … Is the cat alive or dead?

Until the box is opened, nobody knows. In fact, one could argue the cat is simultaneously alive *and* dead!

This well-known thought experiment by physicist Erwin Schrödinger can help us understand one of the more bizarre principles of quantum mechanics: superposition. Quantum particles act like waves that exist in a combination of different states at the same time. Only when we observe (i.e. measure) the particle does this wave function "collapse," revealing a distinct state and position.

THE USC DORNSIFE DIFFERENCE

While many research universities around the world are only starting to think about their role in the quantum revolution, USC has been building leadership in the field for nearly two decades. Through forward-looking research in and unmatched access to state-of-the-art quantum computing systems, our experts continue to be ahead of the game.

2011

1st university quantum computer

USC Lockheed Martin Quantum Computing Center established at the USC Viterbi Information Sciences Institute, providing access to USC Dornsife researchers; becomes the first academic institution to house an operational quantum computer.

2017

Intelligence Advanced Research Projects Activity (IARPA) contract

USC is selected to lead a consortium supported by the Office of the Director of National Intelligence to **build quantum computers that are at least 10,000x faster** than the best classical computers.

2020

MSQIS master's program

USC Dornsife and Viterbi jointly **launch a master's program in quantum information science** (MSQIS) to help develop the quantum workforce.

2022

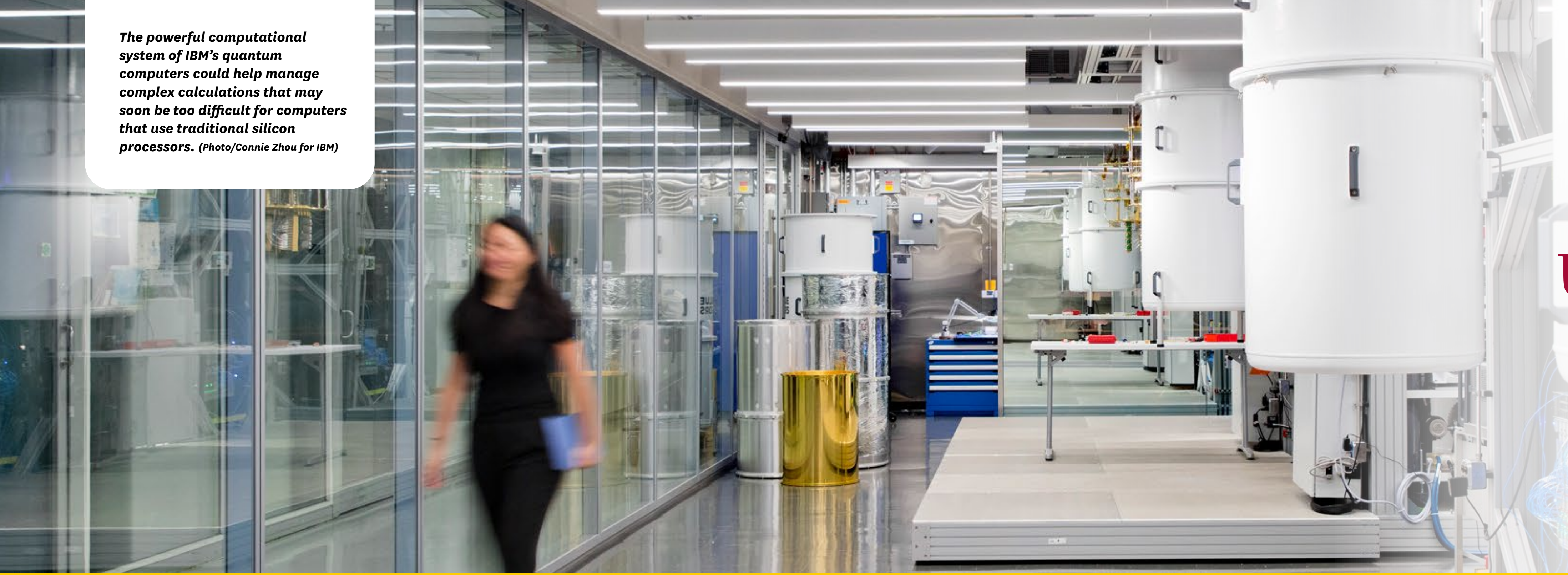
DARPA contract and D-Wave Advantage

USC **secures a DARPA contract** for quantum benchmarking to test for the best applications of quantum computers.
USC and quantum computing company D-Wave launch the first **cloud-accessible 5,000+ qubit quantum computing system** located in the U.S.

2024

Frontiers of Computing Quantum Initiative

USC became home to **the first IBM Quantum Innovation Center on the West Coast,** providing access to 20+ of the most advanced quantum computers, priority queue time, educational resources, branding, and technology leadership opportunities for USC and its academic and industry partners.



The powerful computational system of IBM's quantum computers could help manage complex calculations that may soon be too difficult for computers that use traditional silicon processors. (Photo/Connie Zhou for IBM)

IBM x USC Dornsife x USC Viterbi

USC-IBM QUANTUM INNOVATION CENTER

In partnership with IBM, USC recently established the USC-IBM Quantum Innovation Center — the first West Coast hub for faculty, students, and industry collaborators to work with some of the most powerful quantum computers and software on the planet.

Combining USC's academic excellence with IBM's industry-leading technology creates a research powerhouse with the potential to yield remarkable breakthroughs in areas like cryptography, materials science, finance, healthcare, and sustainability. It also positions USC as a premier destination for quantum computing education, attracting top talent from around the world and solidifying its role as a driving force in the quantum revolution.

“Our faculty experts were ahead of their time in applying emerging quantum computers to address grand challenges in health and energy. The USC-IBM Quantum Innovation Center now positions USC as a hub for industry partnerships that benefit from this expertise and prioritized access to quantum hardware”

– USC Dornsife Dean's Professor of Physics and Astronomy Moh El-Naggar

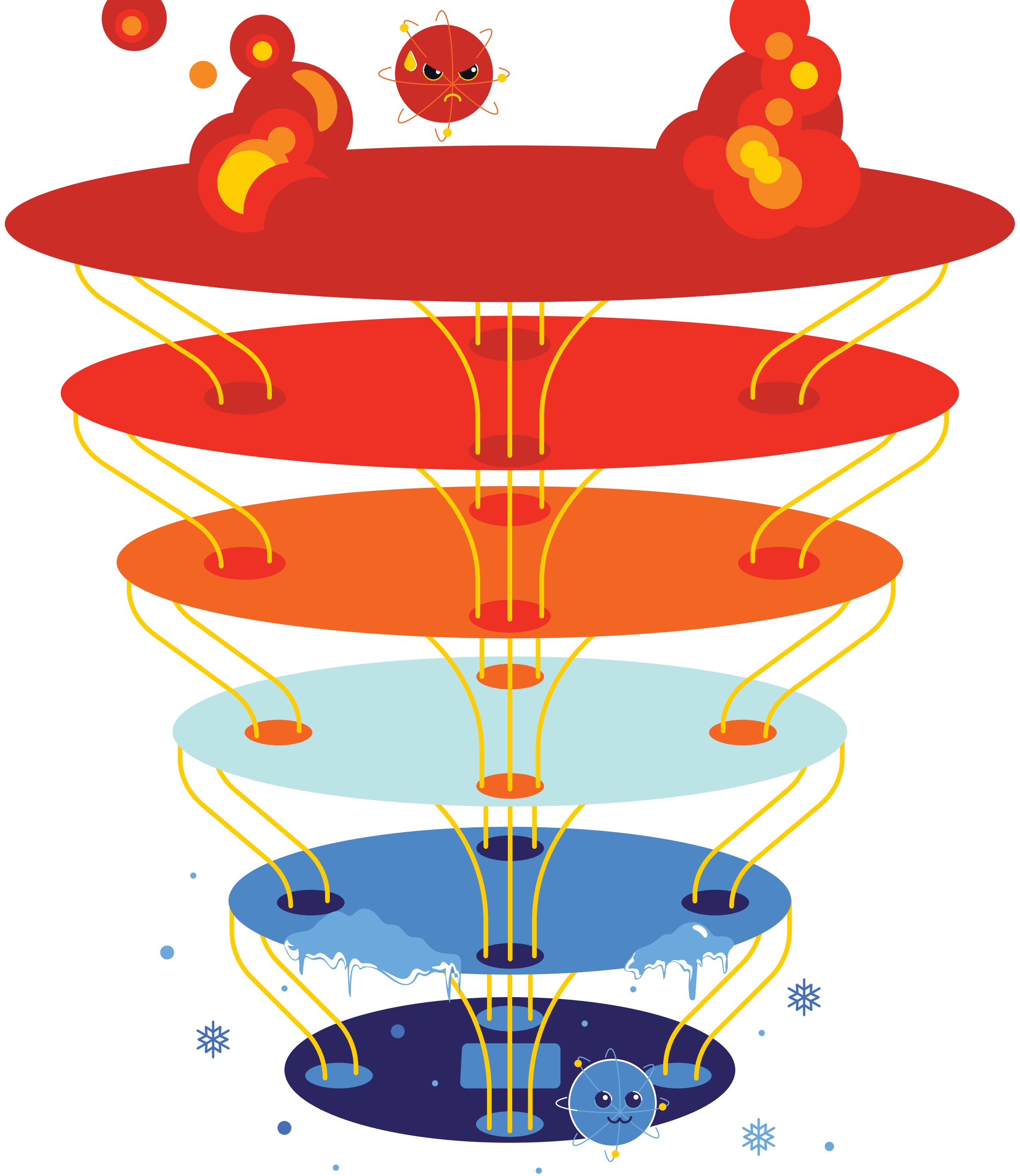
DON'T GET ME WRONG

Leading Research in Quantum Error Correction and Mitigation

Qubits are like toddlers having a tantrum — anxious, sensitive, and hard to rein in. This makes the current quantum technology prone to errors.

For a quantum computer to work correctly, qubits must typically operate at temperatures close to absolute zero and remain unaffected by minuscule changes to their environment. Figuring out how to maintain these "Goldilocks" conditions and preserve the qubits' quantum properties is a tremendous challenge. But USC experts are taking the problem head-on.

As world leaders in error correction, suppression, and mitigation, our researchers develop novel methods to create more reliable and scalable quantum systems, potentially unlocking the technology's full potential.



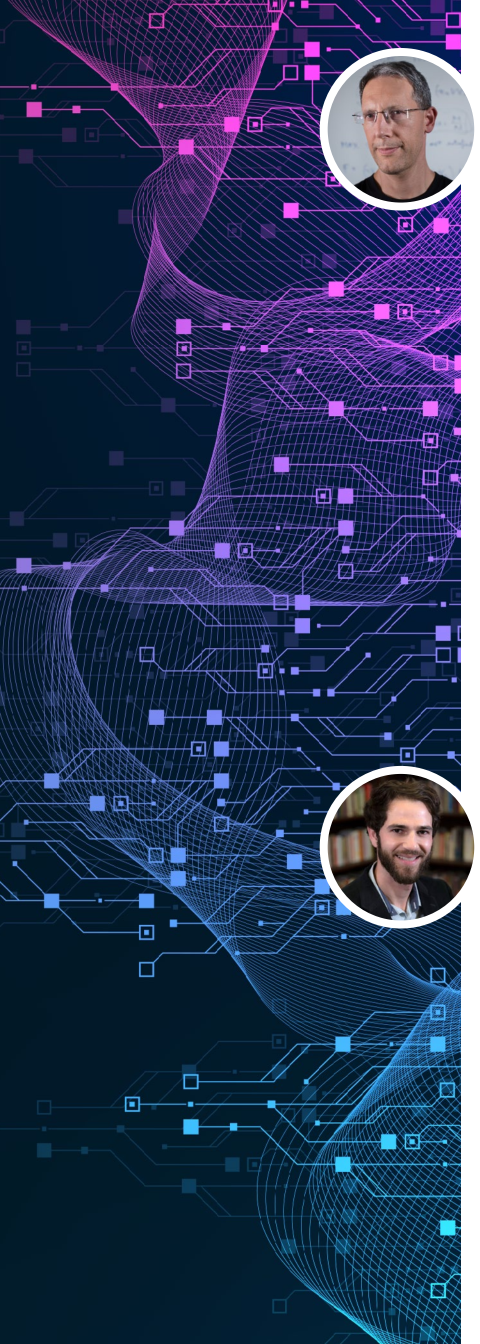
Big Little Errors

You might not know it, but classical computer processors frequently make mistakes. But they have reliable systems in place that check and correct for errors. So why can't we do the same thing with quantum computers?

The answer is: We're working on it. But it's a lot more complicated.

Because qubits can be entangled, a single error can quickly snowball. And as computational power grows, so does the potential problem.

We can use qubits themselves to fight back. But it currently takes between 1,000 to 10,000 qubits to correct a single error. It's a real conundrum, considering that the most powerful quantum computers at the moment contain just over 1,000 superconducting qubits. Hope isn't lost, however — because even if we can't correct errors, experts are making great strides in holding them back for as long as possible.



Dynamical Decoupling

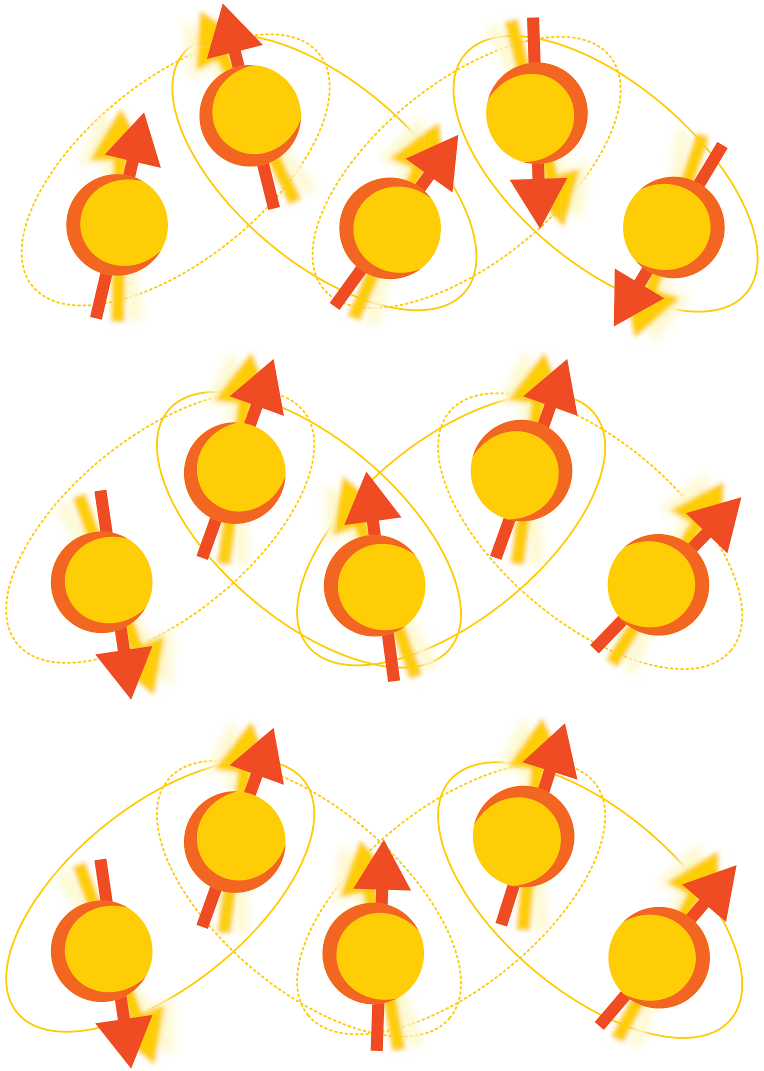
It can be frustrating to try to read a book in a noisy room. To focus better, you might put on noise-canceling headphones that detect ambient noise and generate an opposite sound wave to cancel it out. USC professor **Daniel Lidar**, director of the USC-IBM Quantum Innovation Center, explores a similar approach known as “dynamical decoupling” for protecting fragile quantum information from external disturbances that cause errors. Just like the noise-canceling headphones, he applies a series of rapid, carefully timed pulses to qubits. These pulses act like a shield, canceling out the effects of external noise and preserving their quantum state for longer. A leading expert in error correction and suppression, Lidar is refining the technique by accounting for the specific properties of the noise affecting the quantum system, allowing for more tailored and efficient ways to pulse them out.

Farewell, Photons

One approach for minimizing quantum errors is to develop better hardware. At USC Dornsife, experimental physicist **Eli Levenson-Falk** builds qubits out of superconducting circuits and explores new ways to suppress errors caused by the physical environment. His recent research demonstrates an ability to reduce errors by using a qubit as a refrigerator, cooling a circuit and removing photons from it. Removing these photons allows qubits to maintain quantum properties such as superposition and entanglement longer, reducing the likelihood of an error.

Stronger for Longer

Individual qubits are notoriously finicky, but by pairing them with other qubits and organizing them in a specific structure, they become more resistant to decoherence caused by their environment. Building on this idea, a team of USC Dornsife researchers led by physicist **Stephan Haas** recently demonstrated a significant advancement: By structuring qubits within a carefully designed matrix, the team was able to control and extend the duration these qubits can operate without losing coherence — a breakthrough that could 1help pave the way for highly reliable quantum sensors and computers.

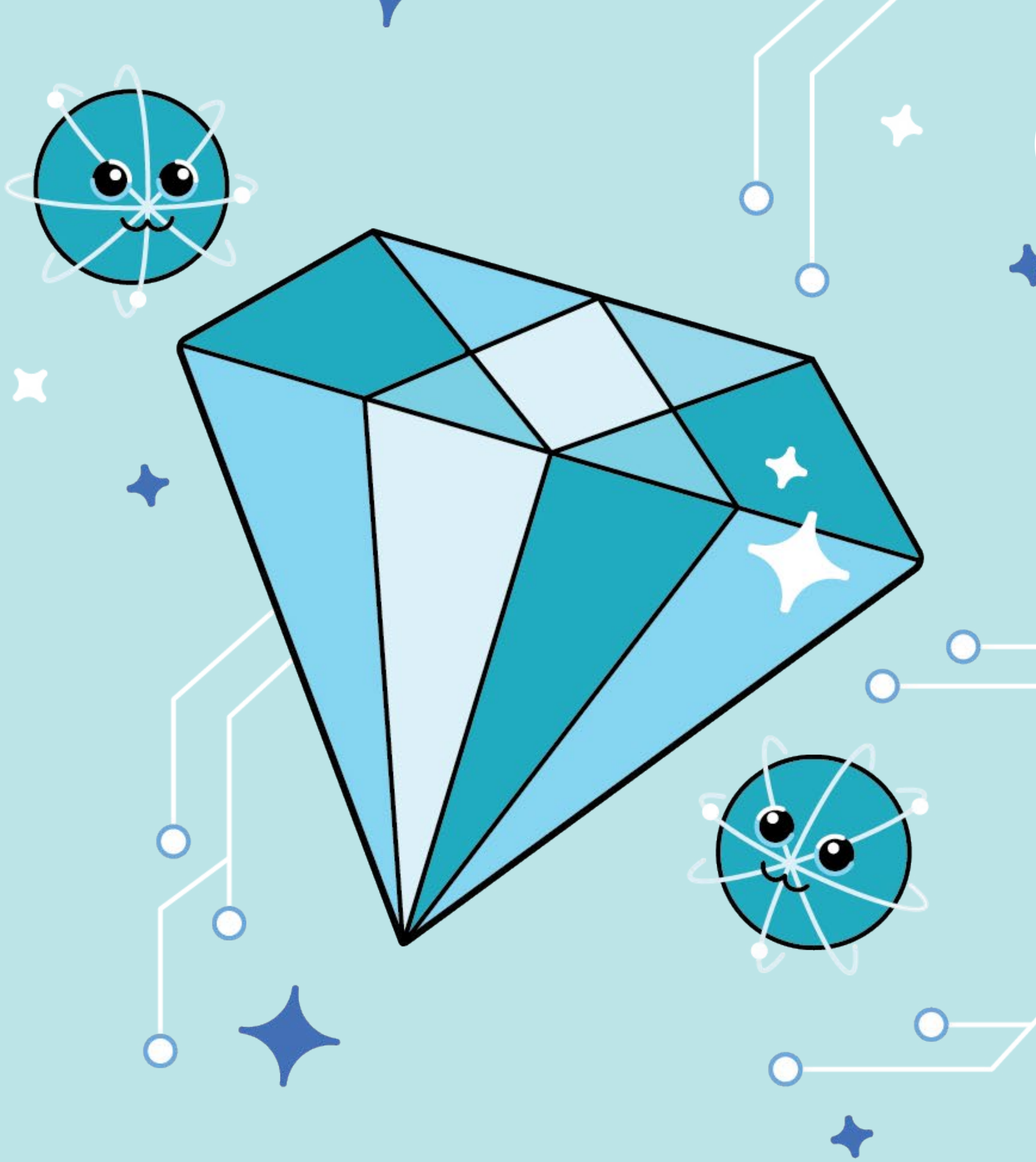


SENSITIVITY TRAINING

Leading Research in Quantum Sensing

Variation in temperature, magnetic fields, or pressure can affect a particle's quantum state. But researchers are turning this problem on its head — they're leveraging this sensitivity for, well … sensing. In fact, they are developing some of the most sensitive sensors ever made.

At USC, experts are uncovering new ways to exploit quantum sensing for detecting subtle changes in the physical environment with unprecedented precision. They are laying the groundwork for innovation that could change the way we understand and engage with the physical world.



Diamonds Are a Sensor's Best Friend

An appraiser might not know it, but that flaw in your diamond might have big scientific value. USC Dornsife chemist **Susumu Takahashi** explores the potential for using diamonds as quantum sensors. Small bubbles of nitrogen — often considered impurities — can create vacuums within these gemstones, which are essentially systems closed to the outside world. In fact, they are so resistant to variations in external environments that the nitrogen atoms within these bubbles demonstrate signs of quantum behavior. But what is really special is that these behaviors happen not at temperatures near absolute zero but at temperatures that are normal to our human environment. Takahashi sees promise in using these quantum-enhanced diamonds across a number of applications, including precision medical imaging. Just imagine being able to detect a single cancer cell using quantum diamond technology and removing it before it grows into a tumor.

Kelly Lou, an expert in electron spins, works with students in her USC Quantum Opto-Spintronics Lab.

Spin Doctors

Think of electrons as tiny spinning tops. In addition to buzzing around an environment to create electricity, they also spin in different ways and can exist in states of quantum superposition. By controlling the spin, scientists can use electrons as qubits that process information. At USC Dornsife, the Ultrafast Quantum Opto-Spintronics Group, led by physicist **Kelly Luo**, harnesses the power of spin using a unique class of materials that are only a few atoms thick. These ultra-thin materials have special properties that make them perfect playgrounds for electrons — with conditions that allow researchers to observe and test new techniques for manipulating spin. As understanding of this behavior grows, so does the potential for using controlled electrons not only as qubits, but also in quantum sensors that are capable of operating under a variety of conditions.

Squeezing the Universe

Imagine using a network of highly sensitive microphones spread across a vast wilderness to listen for the faint sound of a tiny bird. Each microphone captures part of the sound; and by working together, they filter out other noises, making it easier to hear the bird's call. Collaborating with a multi-university team of researchers, USC engineer and physicist **Quntao Zhuang** is using a similar approach with a network of quantum-enhanced sensors to hunt for dark matter — a mysterious component of the universe that scientists are confident exists but has never been directly detected. These sensors use quantum entanglement and a special technique known as "squeezing" to reduce background noise, enhancing their ability to detect the elusive signals of dark matter and expand our fundamental understanding of the universe.

EARLY TO WORK

Leading Research on Quantum Algorithms and Applications

Just as classical and quantum computers are fundamentally different, so are the algorithms they execute. Leveraging the laws of quantum physics, quantum algorithms have the potential to address tremendously complex problems.

Looking ahead, quantum technology could be used to drastically reduce the time needed to discover new medicines and sustainable materials, enable truly unbreakable encryption for cybersecurity, and solve mind-bending challenges like supply chain and electrical grid optimization.

But it's early in the game. The theoretical nature of quantum information science means that extensive research and testing is needed to apply this technology at scale in the real world.

At USC, researchers aren't waiting for the field to grow up. Our experts are breaking new ground to define and shape the quantum revolution.

A Quantum Advantage for Human Health

Modern biological research generates vast amounts of data — and harnessing this data using machine-learning methods for meaningful insights presents a formidable computational challenge. In a first-of-its-kind study conducted in 2018, a USC Dornsife research team including **Rosa Di Felice**, **Remo Rohs**, and **Daniel Lidar** mapped complex interactions between genes and regulatory proteins. They demonstrated that a quantum computer can achieve an advantage in machine-learning performance over state of the art classical methods using actual biological data. Because many diseases, including cancers, are caused by abnormalities in the way that proteins interact and regulate genes, understanding these relationships could one day underpin personalized treatments and prevention measures.

Stimulating Simulations

New materials are waiting to be discovered that could one day point us toward personalized next-gen products like lighter alloys for cars and spacecraft, better batteries, and efficient solar cells. At USC Dornsife, computational physicist **Itay Hen** is focused on improving the quantum algorithms that could help bring these materials to fruition by simulating how atoms interact. The algorithms crunch numbers in giant tables (matrices), which are then manipulated by multiplying them together many times — a process called matrix exponentiation. Hen devised a clever technique to speed up this process and has applied it to quantum computing, which could eventually enable researchers to simulate materials much more efficiently than before.

Training Quantum A.I.

Generative artificial intelligence uses machine learning techniques to recognize patterns within vast amounts of data. This training data is then used to generate new information such as text, images, and synthetic datasets to make predictions. While there is enormous potential for quantum systems to greatly enhance artificial intelligence with the ability to analyze even larger datasets, this also comes at a cost. With so much data to navigate, the model can lose its way while training and make mistakes. But USC Dornsife researchers **Xiaohui Chen** and **Quntao Zhuang** have developed a clever quantum A.I. learning model that may help avoid this pitfall. It purposely adds errors to the data and trains the model to generate new data from noise by systematically breaking its learning process into smaller, more manageable steps. While functional, quantum A.I. is still some years away, these researchers have built the algorithms and laid out the theoretical basis that may underpin this technology.

Guess! That! Bitstring!

Using an IBM quantum computer, USC's **Daniel Lidar** and former USC graduate student and IBM researcher Bibek Pokharel have demonstrated a quantum speedup advantage on a mathematical problem they call a "bitstring guessing game." In this game, a classical computer would require about 33 million guesses to identify a secret 26-bit string, while a perfectly functioning quantum computer could do it in just one guess. By using a quantum algorithm combined with a dynamical decoupling approach to suppress errors, Lidar and Pokharel successfully identified the strings for any number of bits up to 26. Although classical computers can currently solve the problem faster in absolute terms, the study shows that with proper error control, quantum computers can execute algorithms with better time-scaling as the number of bits increases, even in the current era of error-prone quantum computers.

The Quest for the Best Molecules

Quantum chemists think big. Like … molecule big! The potential for using complex molecules in quantum information science offers several advantages over atoms or small molecules, including greater versatility and higher information density. But not all molecules are created equal. So how do we know which are best-suited for the job? USC Dornsife quantum chemist **Anna I. Krylov** develops algorithms and software to screen molecules for suitability as qubits and designs molecular systems for laser cooling and manipulation. The work conducted by her research group is laying a foundation for research that could eventually translate to better energy solutions, better medicine, better materials, and better hardware for quantum information science.

RIDING THE WAVE

HOW QUANTUM TECHNOLOGY COULD SHAPE THE FUTURE

The demand for quantum technology is expected to grow rapidly, especially as it begins to deliver on the promise to solve certain problems — quantum problems — that are beyond the capabilities of our most sophisticated classical computers. And quantum problems are all around us. With advances in research, a wide range of fields and industries stand to benefit from quantum's amplified computing and modeling power.

Sustainable Energy Materials

By simulating complex chemical reactions and material properties, researchers might find compounds that increase solar panel efficiency from around 20% to 100%; or ways to improve EV batteries so they can go thousands of miles on a single charge.

Drug Discovery

The power of quantum computers could significantly accelerate the drug discovery process by simulating and identifying new compounds that target diseases, predict drug efficacy, and ultimately reduce the time and cost to bring new medicines to market.

Earthquake Prediction & Seismic Modeling

By measuring minute gravitational and magnetic field variations, quantum sensors could help researchers develop more accurate earthquake prediction models, saving lives and minimizing damage to infrastructure.

Transportation & Supply Chain Optimization

With the ability to analyze real-time data instantly — from traffic to weather conditions — quantum technology might be used to adjust transportation routes, optimize shipping logistics, or suggest the most fuel-efficient flight paths for an airline's entire fleet.

Banking & Finance

From optimizing investment portfolios in real-time to enhanced risk assessment and fraud detection, quantum technology could one day provide a framework for reliable simulations of market behaviors and refining investment strategies.

Sustainable Agriculture & Food Production

Feeding a growing global population will push the limits of traditional agricultural methods. By modeling crop growth under various conditions, quantum technology might assist in developing more productive varieties, improving soil health, and reducing the environmental impact of farming.

Cybersecurity & Cryptography

Harnessing the power of quantum mechanics to create unbreakable encryption, data encoded in quantum states would ensure secure communication and prevent malicious actors accessing protected systems.

Pollution Monitoring & Remediation

By providing real-time, high-resolution data on air, water, and soil quality, quantum sensors could help us identify and track the sources of pollution, enabling more targeted and effective cleanup efforts.

TRAINING THE QUANTUM WORKFORCE

Governments and commercial organizations worldwide are formulating critical strategies to train skilled professionals for the quantum economy. But in the burgeoning marketplace, demand far outpaces the talent available.

While the future will certainly require experts to develop quantum hardware and software, that's just the start. We will also need those who can operate quantum technology, those who understand how to apply the technology to specific problems, and those who can effectively communicate technical ideas to stakeholders.

Given USC's expertise in QIS, future-focused educational programs, and the uncommon access that our students have to quantum computers, the university is positioned to help fill this gap. In the coming years, USC will become a world leader in training the quantum workforce.

600%
(projected)
Growth in Quantum Computing Market by 2030
**Fortune Business Insights*

$700 BILLION
(projected)
Value of Quantum Tech Sector in 2035
**McKinsey & Company*

50%
(projected)
Jobs Filled in Quantum Sector in 2025
**McKinsey & Company*

Physics PhD Program

Quantum Information Science is among the areas of research specialization that attracts outstanding PhD students in the USC Dornsife Department of Physics and Astronomy.
Here, talented students work with faculty mentors to study the potential use of quantum mechanical systems (individual atoms, ions, photons, nanoscale solid state devices, and superconducting circuits) for information-processing tasks such as computation and communication. Graduates are in high-demand for careers in both academia and industry.

Master of Science in Quantum Information Science

The MS in QIS is a joint degree offered in collaboration between the USC Departments of Electrical and Computer Engineering, Physics and Astronomy, and Chemistry.
The program places an emphasis on the practical applications of quantum information science and computing including the use of quantum devices to solve real-world challenges.
By engaging with researchers and doctoral students working with hardware and software, the program aims to prepare its graduates for practical careers in this emerging field.

Illustrations by Rhiannon Montelius

USC Dornsife