

A new quantum reality

In the first quarter of the 20th century, renowned and brilliant figures such as Albert Einstein, Max Planck, Niels Bohr, Werner Heisenberg and Erwin Schrödinger discovered new fundamental laws of nature, explaining microscopic phenomena through physics and quantum mechanics. This was the first quantum revolution, a step that allowed the advent of technologies such as nuclear weapons, lasers, semiconductors, and navigation and geolocation systems such as the US GPS or the European Galileo. Now, the second quantum revolution is underway.

Quantum physics is dedicated to exploring, investigating, understanding and attempting to explain a world reigned by uncertainty—the atomic and subatomic scales and the elementary particles, the smallest known today (quarks, leptons, neutrinos, bosons, etc.). At the current state of science, it is believed that they are not made up of smaller components, nor have they been shown to possess internal structure. There are two types, the building blocks that constitute and shape our known universe—matter—which are grouped together and which we call fermions, and the particles in charge of the interactions between them, known as bosons.

The behaviour of small entities and energy in this realm is peculiar, with a high involvement of probability or the uncertainty principle, and unimaginable things happen, such as a particle being in two states or places at the same time. This is the famous Schrödinger's cat paradox, in which, according to quantum physics, the cat can be both alive and dead at the same time—a huge challenge to our understanding of reality and the universe or what we call “normality”.

To learn about the extravagant designs of quantum physics, in addition to the work or advanced research currently being carried out by physicists and scientific institutions worldwide, a unique tool is used: the particle accelerator. This device, as its name suggests, accelerates particles using magnetic fields so that they interact (collide with each other) and give rise to other particles, antiparticles, photons, etc. with which to simulate or help to make theories that allow us to advance our knowledge of this world and its possibilities. Although the best known, especially in Europe, is CERN in Geneva, there are more than 20,000 around the world.

Quantum technologies fall into three broad groups. Quantum measurement (quantum sensing), which measures and detects very weak signals, such as submarine traces. Quantum communication, which allows secure transmission of information over long distances and at higher speeds than current communications. And the application that is closest to reality and in which major nations are investing the most, quantum computing. Although the approaches diverge, it promises to solve problems more efficiently, accurately and faster than classical computing using the principles of quantum physics.

Pioneering and emerging, both experimentally and industrially, it goes beyond what we perceive and apply classical laws to, incorporating the different states of photons or electrons into an extravagant property, superposition, a theoretical possibility that has now become a reality. The fundamental component in quantum computing is the quantum bit or “qubit”, a basic particle of physics like photons, electrons, trapped atomic ions, superconducting circuits or atoms. Unlike the bit in classical computing, it can simultaneously adopt any linear combination between 0 and 1 and intermediate states since one of its properties is that it can be in several states at once. Superposition together with interference and entanglement—described by Einstein as “ghost action at a distance,” multiplies the information processing and transmission capacity in a much more powerful way.

Despite advancements, quantum computing still faces significant limitations today. One of the main obstacles to progress is that, by their very nature, qubits are unstable because they continuously interact with each other, and the more complex a quantum computer is, the more qubits it has, the more they interact and the more errors occur, distorting the accuracy of the results. Other obstacles are the increasing costs, as the larger the quantum computers are, the more cooling they need (their operating conditions require temperatures close to absolute zero) or more complex maintenance, as well as the fact that they are incredibly sensitive to interferences or ‘noise’ from their environment such as vibrations, heat, light, microscopic defects in materials, electromagnetic interference, cosmic rays or ionising radiation—imperceptible alterations that can disrupt calculations and alter the result, a problem exacerbated as the system grow in size.

A quantum world in competition

We begin 2025, declared the Year of Quantum Science and Technology by the United Nations¹, with a change that will define the world and its relations in the coming years, the arrival of Donald Trump in the White House. Technology is clearly one of his priorities and the war between Washington and Beijing in this area is already “official”. Shortly after taking office, surrounded by the heads of the world's leading technology companies, he signed Stargate², a project that will have an estimated investment of 500 billion dollars and which aims to keep the US as the world's leading power in artificial intelligence to compete, with an advantage, against the rapid rise of China and its commitment to quantum in military technology.

The consultancy McKinsey³ estimates that by 2030 there will be 5,000 quantum computers in operation. However, until 2035, the necessary hardware and software to address most complex problems will not be fully developed. Despite major experimental and scientific breakthroughs, practical and accessible real-world applications are still years away. Their progress will have a significant impact on scientific research and development, but also on finance, medicine, industrial processes, logistics and, of course, communications, cryptography and defence.

Beyond the obvious economic or commercial applications of quantum technology, there are growing national security issues that dominate relations between Washington and Beijing. It is difficult to predict, or even imagine, the power that one of them, or their major companies, would have if they achieve quantum supremacy. It is possible, however, to glimpse the economic and political urgency to achieve it before the global balance shifts or drastically disintegrates in a race in which winning is the only possible goal and losing is not an option for either the US or China.

The winner will have the symbolic laurels, as well as, in its hands, advantages in cryptology, information sensing and processing, in the contested military and strategic domains, or the hegemony of quantum governance and a new ‘quantum economy’ that

¹ "2025 Año Internacional de la Ciencia y la Tecnología Cuánticas". UNESCO. Available in: <https://quantum2025.org/es/>. Date of consultation: 06/03/25.

² JIMÉNEZ DE LUIS, Ángel. "Trump anuncia una inversión de 500.000 millones de dólares para mantener a EEUU como la primera potencia mundial de inteligencia artificial". El Mundo. Available in: <https://www.elmundo.es/economia/2025/01/22/6790f322e4d4d895538b4581.html>. Date of consultation: 06/03/25.

³ "What is quantum computing?". McKinsey & Company. Available in: <https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-quantum-computing>. Date of consultation: 06/03/25.

could create a huge technological, industrial and knowledge gap with other nations. Quantum computing alone is expected to reach a global market value of \$1 trillion by 2035.

While the fundamental nature of warfare remains constant, military strategies must evolve in response to the capabilities enabled by new emerging and disruptive technologies. The three most promising applications are quantum computers, quantum communications to provide a high level of security, and quantum sensors, which could revolutionize intelligence, surveillance and reconnaissance (ISR), detecting electromagnetic emissions, locating and neutralising submarines or hidden adversary forces, identifying underground structures and detecting nuclear materials, among other possibilities.

The potential application of quantum promises breakthroughs in a wide range of areas and domains by significantly improving the measurability, detection, accuracy and computational power, as well as the efficiency of current and future military technology. Quantum optimisation algorithms could increase operational efficiency and reduce resource requirements, such as logistics planning, missile defence or the management of deployed forces. Quantum cryptanalysis could diversify cybernetic operations and quantum simulation, favour the development of materials that are more robust, lighter, more efficient, cheaper to manufacture, and more cost-effective...

For the time being, in the short term, quantum technology will not replace existing technologies but will enhance them by adding to them. Most of the technologies of the second quantum revolution are still decades away from practical and regular applications.

US Complex quantum leadership

In October 2019, a team of researchers at Google achieved a breakthrough, beating the most powerful conventional computers to claim they had achieved quantum supremacy with a quantum-based computer. Their latest leap has been the new “Willow”⁴ quantum chip, recently unveiled, capable of completing a quantum computational task. recently unveiled, capable of completing a standard benchmark task used to measure performance in a test in less than five minutes, when a classical supercomputer would take, by a ‘small margin’, longer than the known age of the universe. “Willow” stands out

⁴ CASTELVECCHI, Davide. “A truly remarkable breakthrough’: Google’s new quantum chip achieves accuracy milestone”. Nature. Available in: <https://www.nature.com/articles/d41586-024-04028-3>. Date of consultation: 06/03/25.

not only for its speed, but also for overcoming a problem that has limited progress since 1995—the exponential reduction of quantum errors as the size of the system increases.

Google, together with other US technology giants such as Amazon with “Ocelot” 5, Intel, Microsoft with “Majorana 1” or IBM, the world leader with its error-mitigating Heron (5K) platform or the 1,121 qubit superconducting quantum processor “Condor”, together with dozens of smaller companies or entrepreneurs, are competing globally to be at the forefront in all disciplines of the race for quantum supremacy.

Thanks to a strong mix of public subsidies, academic institutions and the competitiveness of large private corporations, the United States had always maintained a strong lead in the quantum computing race. In the 1990s, the US administration saw quantum computing as having gigantic potential and supported its development, paving the way for subsequent breakthroughs, and quantum technology has been a priority area of federal research and development (R&D) for the past administrations.

During his first term, the Trump Administration announced, through the White House Office of Science and Technology Policy (OSTP), the launch of Quantum.gov⁶, the official website of the National Quantum Coordination Office, and published the ‘Quantum Frontiers Report’, which identifies key areas for continued research in quantum information science. In addition, the then President enacted the National Quantum Computing Initiative⁷ to accelerate US leadership in quantum information science and technology and to try to prevent China from becoming a global power. This commitment has since led to hundreds of millions of dollars of federal funding being invested, resulting in years of cutting-edge research and strengthening the US quantum industry.

His successor, President Joe Biden, signed the CHIPS and Science Act in 2022 to provide greater funding for critical quantum research initiatives. In addition, the US government has a public national strategy for quantum science⁸, as well as more detailed

⁵ "Ocelot, el nuevo chip cuántico de Amazon que avanza en la corrección de errores". Infobae. Available in: <https://www.infobae.com/america/agencias/2025/02/27/ocelot-el-nuevo-chip-cuantico-de-amazon-que-avanza-en-la-correccion-de-errores/>. Date of consultation: 06/03/25.

⁶ "Trump Administration Announces Quantum.Gov and Quantum Frontiers Report". The White House. Available in: <https://www.quantum.gov/trump-administration-announces-quantum-gov-and-quantum-frontiers-report/>. Date of consultation: 06/03/25.

⁷ "National Quantum Initiative Supplement to the President's FY 2025 Budget". The National Science and Technology Council (NSTC). Available in: <https://www.quantum.gov/wp-content/uploads/2024/12/NQI-Annual-Report-FY2025.pdf>. Date of consultation: 06/03/25.

⁸ "National Strategic Overview for Quantum Information Science". The National Science and Technology Council

reports on specific subareas, with more than a dozen agencies in the federal ecosystem, including the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), the Department of Energy (DoE), the Department of Defence (DoD), the National Aeronautics and Space Administration (NASA), the National Security Agency (NSA) and the Intelligence Advanced Research Projects Activity (IARPA). The Defence Advanced Research Projects Agency (DARPA), with its Quantum-Assisted Sensing and Readout (QuASAR) programme, has made significant advances in quantum magnetometry.

In the mid-1940s, still amid World War II, Robert Oppenheimer provided decisive technological superiority to the United States. The recent discoveries in quantum physics opened the door to a new, nuclear world order in which the United States was the first hegemonic power. Decades later, with other competitors, the United States is still in the race to unlock the full potential of quantum technology, and achieving the ultimate weapon of the 21st century is already one of the Pentagon's top priorities.

Although the gap is closing rapidly, the US military still maintains some advantages over China. The US National Quantum Initiative Advisory Committee (NQIAC) has urged more investment “to ensure that the United States maintains and expands its leadership in all quantum technologies”⁹. The US National Quantum Initiative Advisory Committee (NQIAC) has urged more investment ‘for the United States to maintain and expand its leadership in all quantum technologies’. The Department of Defence has long invested in quantum research, as have intelligence agencies, which also benefit from advances by major US technology companies and those made by a broad academic community and their political and military allies in areas such as sensing, navigation and positioning, cyber activities, and more.

Most technologies of the second quantum revolution are still decades away from practical application, but a recent NATO study, in which the Alliance analyses the ten most disruptive areas of the scientific landscape between now and 2043 in terms of military application, unsurprisingly includes ‘quantum technologies’ alongside other relevant

(NSTC). Available in: https://www.quantum.gov/wp-content/uploads/2020/10/2018_NSTC_National_Strategic_Overview_QIS.pdf. Date of consultation: 06/03/25.

⁹ "NQIAC Report Highlights Strategic Investments and Recommendations to Secure U.S. Leadership in Quantum Networking and Communications". Quantum Insider. Available in: <https://thequantuminsider.com/2024/09/09/nqiac-report-highlights-strategic-investments-and-recommendations-to-secure-u-s-leadership-in-quantum-networking-and-communications/>. Date of consultation: 06/03/25.

technologies such as AI, robotics and autonomous systems, biotechnology and bioengineering, energy and propulsion, hypersonics and space technologies.

The most urgent threat posed by hostile quantum power—for the United States, and any other country—is cybersecurity. Whoever achieves quantum dominance will have a clear advantage in cyber warfare, information gathering and data security. This advantage will become apparent on “Q-day”—the crucial moment when quantum computers will render the strongest encryption systems, we use today useless, disrupting the global balance of power. In fact, a team of researchers at Shanghai University (China) has successfully cracked SPN (Substitution-Permutation Network) 10 encryption using a quantum computer from D-Wave Systems, a Canadian company. Following this breakthrough, Chinese scientists have concluded that the most secure military encryption algorithms, such as AES-256, could be closer than ever to becoming obsolete.

All major powers are developing their own post-quantum cryptography technologies to ensure that no one gains access to sensitive classified information or critical infrastructure, among other vulnerable assets that still guarantee the national security of the United States and its partners, as well as the West's waning military and economic dominance. The US National Security Agency (NSA) is collaborating with the National Institute of Standards and Technology (NIST) to develop and standardise encryption algorithms resistant to future quantum cyberattacks¹¹.

Quantum cryptography, which enables secure communication and ensures its inviolability, establishes stronger security through quantum-generated randomness (QRNG) and Quantum Key Distribution (QKD)—a theoretically unbreakable encryption method that generates random, secret keys between a sender and receiver. If a hacker gains access to a qubit stream, its mixed state immediately ‘collapses’, destroying the quantum information and leaving an obvious sign that an espionage attempt has been made. According to Statista figures, the quantum security market was valued at less than \$500 million in 2022. By 2030, it is expected to be worth \$9.8 billion¹².

¹⁰ Available in: <https://cjc.ict.ac.cn/online/onlinepaper/wc-202458160402.pdf>. Date of consultation: 06/03/25.

¹¹ "NIST to Standardize Encryption Algorithms That Can Resist Attack by Quantum Computers". NIST. Available in: <https://www.nist.gov/news-events/news/2023/08/nist-standardize-encryption-algorithms-can-resist-attack-quantum-computers>. Date of consultation: 06/03/25.

¹² "Quantum security market revenue worldwide from 2021 to 2030". Statista. Available in: <https://www.statista.com/statistics/1332857/quantum-security-market-revenue/>. Date of consultation: 06/03/25.

China, the quantum contender

For now, the US maintains its superiority in the development of quantum capabilities. In 2022, GlobalData estimated that the US had a five-year advantage over China, but today the assessment is that both countries are “almost even.” Since Xi Jinping became president of the communist power, there are many fields in which Beijing competes with the United States to define a new world order, but among them, beyond military capabilities or the economy, all those related to science and technology, and the positive impact they have on prestige and in favouring geopolitical strategies¹³, are the ones that have gained most importance in high-level government plans, with quantum technologies among the most prominent ones.

The Chinese Communist Party has called for a “new-style whole nation system”, trying to revive the spirit of the late 1960s when, when China rapidly developed the atomic bomb. Beijing is well aware that whoever develops quantum technologies first will gain tangible military advantages in cryptology, communication and information processing, and that mastering them will be critical for national, information and cyber security. Driven by the government, the Communist Party and the military, rather than by companies such as Alibaba and Baidu or private capital, as in the West, China's leading quantum companies are already leading the development of quantum communications and the total number of patents and scientific publications on quantum technology.

China's 2006 Science and Technology Innovation Plan for 2020 included "quantum control" and outlined a long-term strategy with guaranteed financial, industrial, and academic support from the state. Since 2022, China has invested \$15 billion in industrial research and development to catch up with the United States, and today spending is four times higher than in the US and accounts for more than half of the estimated global public investment in quantum technology.

These quantum ambitions are central to Beijing's strategic goal of becoming a superpower, a power with a strong scientific and technological foundation. While China has historically absorbed and copied foreign advancements, it is now entering a new phase, seeking truly disruptive innovations in emerging technologies deemed strategic.

¹³ KANIA, Elsa B. y COSTELLO, John. "Quantum Hegemony?". Center for a New American Security. Available in: <https://www.cnas.org/publications/reports/quantum-hegemony>. Date of consultation: 06/03/25.

As China's national strategy of “civil-military integration” progresses, these critical technologies will also be harnessed for military and security-related applications.

To establish new quantum research centres in universities, the government is providing generous funding and counts on the \$10 billion National Quantum Information Science Laboratory as the centre of China's quantum goals and a hub for working relationships between the Chinese Academy of Sciences, government research institutes, universities and companies.

Although, like many of China's other emblematic projects, quantum research is notorious for its opacity and secrecy, its successes and advances in fields such as detection, cryptography, communications, computing, navigation and radar, among others, are well known. Its first milestone was in 2016, with the launch of the “Micius” satellite, the world's first quantum satellite, and in 2017, the year in which the National Laboratory for Quantum Information Science (NLQIS) was created, it starred in a videoconference between Vienna (Austria) and Beijing (China) that was inaccessible to hackers. China has the world's largest quantum communications network, 12,000 kilometres long, linking the country's major cities to transmit sensitive data from institutions and companies such as banks, banks and companies to the world's largest quantum network.

The China Electronics and Technology Corporation (CETC), China's largest defence electronics company, unveiled a prototype radar in 2018 that they claim can detect stealth aircraft as they fly. Other quantum applications include sensors capable of detecting magnetic field signals from a submarine or the one proposed by Chinese scientists in collaboration with the Institute for Quantum Optics and Quantum Information (IQOQI) in Vienna to transport matter more efficiently, and, among matter, quantum projectiles¹⁴.

Baidu, one of China's leading technology companies, presented its first quantum computer in 2022. In 2024, a 72-qubit computer was achieved, and the communist power now has Tianyan-504, a supercomputer with a 504-qubit Xiaohong chip, jointly developed by China Telecom's Quantum Group, the quantum technology company QuantumCTek and the Centre of Excellence in Quantum Information and Quantum Physics of the Chinese Academy of Sciences, from which several successful companies in the field of

¹⁴ TRILLO, David; LE, Think P. y NAVASCUÉS, Miguel. "Quantum advantages for transportation tasks - projectiles, rockets and quantum backflow". Nature. Available in: <https://www.nature.com/articles/s41534-023-00739-z>. Date of consultation: 06/03/25.

quantum technologies have emerged.

In response to the United States and some European countries, which have placed much of China's quantum ecosystem on lists of companies with trade restrictions on the grounds that their dual-use technologies support the development of Beijing's military ambitions and power, quantum technology is now part of the Catalogue of Banned and Export Restricted Technologies. In this way Beijing controls that all its advances do not fall into unwanted foreign hands and that exports, if any, only happen after approval by the government.

Europe, lagging behind

While the US and China compete for world leadership, Europe is trying not to be left behind or left out—despite the fact that European Nobel laureate Anton Zeilinger laid the foundations of this technology. European countries are leaders in quantum research but have struggled to translate their research results into practical applications, hampered by a lack of infrastructure, deployment, budgets and joint EU-wide frameworks to promote the scientific and industrial development of quantum capabilities.

In June 2019, to change this picture, the European Commission announced “EuroQCI,” its proposal for the creation of the European Quantum Communications Infrastructure. Since then, the first quantum communications nodes have been deployed in the Czech Republic, Germany, Spain, France, Italy and Poland. These urban nodes will be connected to each other via satellite communications and their invulnerability will be guaranteed thanks to IRIS2, the secure satellite communications system promoted by the Commission and developed by a consortium in which Hispasat participates. A year later, in 2020, the “Strategic Research Agenda for the Quantum Flagship”¹⁵ was presented, a 10-year, €1 billion initiative aimed at setting a clear direction for the future development of quantum research and innovation in Europe. The promotion and development of quantum technologies is also pursued through initiatives such as the Horizon Europe Programme or the European Chips Act, which includes measures to encourage low-cost, high-volume quantum chip manufacturing in the EU.

ESA's “Eagle-1”¹⁶, the European Space Agency's first satellite to incorporate quantum-

¹⁵ “The future is Quantum”. Quantum Flagship. Available in: <https://qt.eu/>. Date of consultation: 06/03/25.

¹⁶ “Eagle-1”. ESA. Available in: https://www.esa.int/Applications/Connectivity_and_Secure_Communications/Eagle-1. Date of consultation: 06/03/25.

encrypted communications, a joint project between ESA, the European Commission and European space companies, is scheduled for launch by the end of 2025. Also underway is “QKD-GEO”¹⁷, the first Spanish geostationary quantum key distribution system, which is expected to be ready by 2026, the most advanced civilian project of its kind in the world. It is one of several initiatives in our country.

“Quantum Spain”, a joint venture led by GMV and Qilimanjaro Quantum Tech, was set up in 2021 with the aim of building a 30-qubit quantum computer. This computer, the first Spanish quantum computer with 100% European technology¹⁸, has been housed since September 2024 in the Barcelona Supercomputing Center-National Supercomputing Centre (BSC-CNS)¹⁹, an institution of the RES (Spanish Supercomputing Network), which includes 14 nodes across various universities and research institutions throughout Spain.

In 2022, the Galician Supercomputing Centre (Cesga) of the University of Santiago and Fujitsu reached an agreement to establish a quantum centre with a 32-qubit computer. The Basque Foundation for Science and IBM announced an agreement in 2023 to install a Quantum Computing Centre in San Sebastian. The ‘CUCO’ project (Quantum Computing in Strategic Industries), the first major national and corporate quantum computing project, will invest up to 200 million euros in companies dedicated to the development of quantum computing in Spain. Subsidised by the CDTI with the support of the Ministry of Science, Innovation and Universities and the Secretary of State for Digitalisation and Artificial Intelligence, CUCO is led by GMV and includes companies and institutions such as BBVA, Repsol, Tecnalia, Das Photonics, AMATECH Group, the Spanish National Research Council (CSIC), the Institute of Photonic Sciences (ICFO), the Polytechnic University of Valencia (UPV) or Donostia International Physics Center (DIPC).

¹⁷ "Conoce el primer proyecto español de misión geoestacionaria de distribución cuántica de claves". Gobierno de España. Available in: <https://planderecuperacion.gob.es/noticias/Conoce-primer-proyecto-espanol-mision-geoestacionaria-distribucion-cuantica-claves-perte-aeroespacial-prtr>. Date of consultation: 06/03/25.

¹⁸ "El Barcelona Supercomputing Center acoge su primer ordenador cuántico que, con tecnología 100% europea, llevará a España hacia una nueva era de la computación.". Gobierno de España. Available in: <https://www.lamoncloa.gob.es/serviciosdeprensa/notasprensa/transformacion-digital-y-funcion-publica/Documents/2025/060225-primer-ordenador-cuantico-infografia.pdf>. Date of consultation: 06/03/25.

¹⁹ BRACERO, Francesc. "España estrena en el BSC el primer ordenador cuántico creado con tecnología europea". La Vanguardia. Available in: <https://www.lavanguardia.com/vida/20250206/10359654/espana-estrena-bsc-primer-ordenador-cuantico-creado-tecnologia-europea.html>. Date of consultation: 06/03/25.

Pending the Government's forthcoming presentation of the National Strategy for Quantum Technologies, Quantum Spain, in whose development the Ministry of Defence, the Spanish Supercomputing Network and the most cutting-edge research institutions are participating, is working on the creation of Spain's first quantum computing infrastructure.

In this silent yet highly complex race against time, accelerated by artificial intelligence, quantum computing is exponentially increasing its chances of success with every passing minute.

However, for humanity, this success comes with great uncertainties. As with other technologies and weaponry, will the great powers or international institutions be able to establish rules of the game that go beyond the framework of confrontation and that are accepted and respected by the international community? Will agents, states or even companies, of a lower level than the 'big' ones, gain access to these technologies for non-peaceful purposes? Where will the developments that come about thanks to a better knowledge of subatomic particles and their unimaginable potential in combination with Artificial Intelligence applications lead to?

The history of atomic energy, the Internet, AI, cryptocurrencies, and many other scientific breakthroughs calls for caution. At the very least, it urges us to be meticulously prepared to ensure that our values and way of life are not disrupted by the harmful use of this new technological arsenal.

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