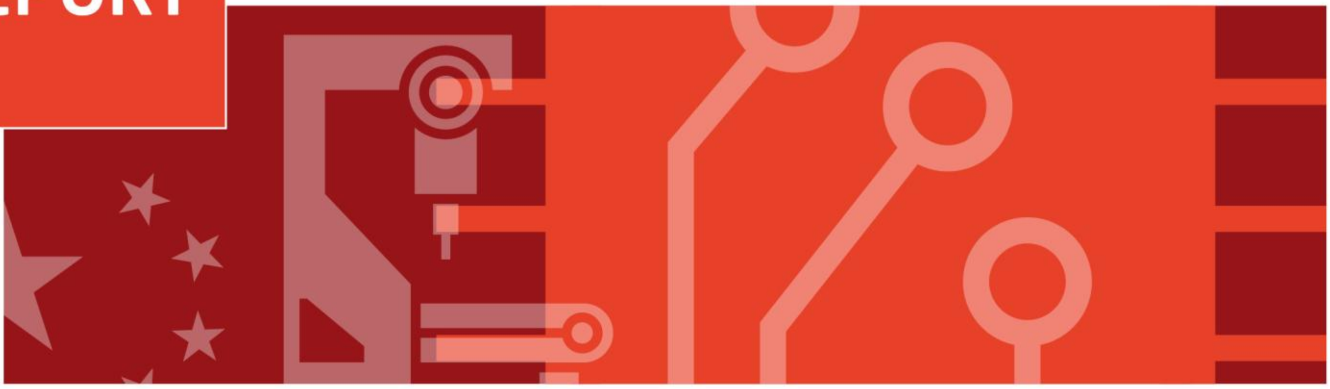
MERICS
REPORT



DECEMBER 2024

CHINA'S LONG VIEW ON QUANTUM TECH HAS THE US AND EU PLAYING CATCH-UP

JEROEN GROENEWEGEN-LAU AND ANTONIA HMAIDI

KEY FINDINGS

- China sees quantum technology as pivotal in global science and technology (S&T) competition and has stepped up government spending on scientific and industrial development to about USD 15 billion.
- Since 2022, China publishes more quantum-related research papers annually than any other country, including the United States.
- China's technology development in quantum is mostly state-governed. Beijing is keenly aware that whoever develops quantum technologies first will have palpable military advantages in cryptology, communication and information processing.
- The role of private capital and companies is much smaller in China than for instance in the US. China's key quantum companies are intermediaries between public research labs and state-owned clients of quantum services, with limited agency.
- China leads in quantum communications: it boasts the world's largest quantum communication network of a length of 12,000 kilometers, which includes two quantum satellites.
- The effectiveness of export restrictions issued by European countries, the US and others in 2023 and 2024 is being undermined by a lack of agreement on technical details and each country's commercial interests.
- European countries are leaders in quantum research but have struggled to translate these research results into practical applications. They should move beyond protecting EU technological advances by stepping up union-wide efforts to promote the scientific and industrial development of quantum capabilities.

China Tech Observatory

MERICS
Mercator Institute for China Studies

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ABOUT THE CHINA TECH OBSERVATORY

The China Tech Observatory (CTO) of Mercator Institute for China Studies (MERICS) is funded by the German Ministry for Education and Research (BMBF). The three-year research project takes stock of China's progress in developing and using globally critical technology. It provides information and analysis to help decision-makers in government, business and other areas to better understand China's aims and efforts in future technologies.

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China has entered the global competition over quantum technology leadership

Quantum technologies are seen around the world as pathbreaking technology, as quantum computing can do calculations not currently possible with digital computers, and quantum communication can ensure secure communication over long distances (see table 1). While quantum technologies are still in the research phase, any country that is able to deploy quantum tech first will have a first mover advantage. This early stage also means that front runners and technical approaches have not yet been consolidated.

However, researchers are making continuous breakthroughs. For instance, in October 2024, Chinese researchers used a quantum computer developed by the Canadian company D-Wave to break key components of advanced encryption standards (AES), an encryption system used by the military and considered state-of-the-art.[1] As working encryption is the basis for most communication today, including the internet, being able to break encryption at scale would be a game-changer.

The US and China have both elevated quantum technology to an arena of global technology competition similar to the Cold War rivalry over nuclear capabilities. Although the product is not a bomb but a computer, whoever develops quantum computing first will have palpable military advantages in cryptology, communication and information processing, not to mention a symbolic victory in a tech field all global powers agree is of strategic significance.[2]

The Chinese Communist Party has called for a "new-style whole of nation system," seeking to revive the spirit of the late 1960s, when China was able to develop the atomic bomb in a very short time.[3] Among the technologies in which China seeks to excel, quantum is most suitable to this state-led approach because the fundamental research is done at a handful of public research institutes using costly equipment, while the first downstream applications are military and security-related.

In addition, it now seems that China can brute-force its way to quantum supremacy simply by throwing resources at it. As many general principles are clear, and academic research is done publicly in peer-reviewed journals, the bulk of the remaining challenges are likely in engineering and funding. China's pioneering quantum physicist Pan Jianwei can be likened to Qian Xuesen, the US-trained scientist behind China's nuclear program. China is likely to outspend Europe, where British, German, French, EU and Dutch pledges add up to USD 12 billion. However, the exact magnitude of the support is in question, and we have not been able to verify the USD 150 billion amount that McKinsey reported on the basis of a non-public 14th Five-Year Plan for Quantum Technology (2021-2025).[4]

After China's progress in building a 72-qubit superconducting quantum computer in 2024, the US placed the creator, Origin Quantum, and large parts of the wider ecosystem on its entity list of trade-restricted companies for their support of China's military efforts.[5] Origin Quantum used German equipment to build its quantum computer,[6] and other European countries have recently added quantum technologies to their dual-use export restrictions (see Appendix).

Exhibit 1

The US leads in quantum tech, but China dominates communication

TYPE OF TECHNOLOGY	QUANTUM COMPUTING	QUANTUM COMMUNICATION	QUANTUM SENSING
What is it?	Computers using qubits (quantum bits) instead of traditional bits. Qubits can have multiple states at the same time, massively speeding up some calculations.	Using quantum effects for secure communication that cannot be intercepted.	Using quantum mechanics for better, more exact sensing.
Key potential applications	Breaking encryption, drug discovery	Quantum key distribution for safe communication, for instance for banks	Research in physics, for instance gravitational wave detectors; radars; optical quantum sensors for metrology and imaging, GPS
State of progress	Multiple quantum computers exist, but none are able to do all calculations	Quantum fiber-optic networks and quantum satellites exist and are being piloted for first applications	Currently in research and roll-out phases, with different types of sensors at very different technology readiness levels
Leading country/ group	US leads in quantum computing, with IBM rolling out quantum computing datacenters with a 133-qubit chip in 2024, as well as a >1,000 qubit computer. China's top quantum computer has 72 qubits.	China leads in quantum communication, with a 12,000 km quantum network with two satellites. Switzerland has a metropolitan (Geneva) network. The US is piloting a network on the East Coast (between banks).	The US enjoys a narrow lead on China, but China is closer to market with some innovations. Germany plays an outsized role in quantum sensing compared to quantum computing due to its traditional strength in precision machinery.
Different approaches	Approaches differ in how they achieve qubits. Superconducting, trapped ions, photonic, neutral atoms, semiconductor quantum dots (spin-based).	Quantum key distribution (via BB84); quantum teleportation	Too many to count, as sensors are fundamentally different to each other
Other names	Quantum control	Quantum networking	Quantum metrology

Source: MERICS

Many European countries thus share the assessment that China developing certain quantum technologies poses a national security risk, and they have implemented some controls. However, technology-specific export controls are more challenging in an emerging field like quantum technology where the frontrunners have not emerged.[7] And it is not clear at this time which approach to quantum computing will emerge victorious.[8]

While China and Europe both now see quantum computing as essential to future development, and both are focusing on both quantum computing and quantum communication, the US sees quantum computing as much more critical.[9]

This report looks at China's progress in quantum computing and quantum communication, leaving aside quantum sensing, i.e., the use of quantum effects to improve the sensitivity and precision of sensors like clocks. This is because despite quantum sensing being closest in readiness to military use, the improvements it delivers are quantitative in nature – making sensing more precise – instead of enabling completely new capabilities.[10] While quantum sensing is closest in readiness for military use, both international competition and Chinese innovation efforts have focused on the other quantum technologies.

BEIJING STEPS UP SUPPORT FOR QUANTUM RESEARCH AND DEVELOPMENT

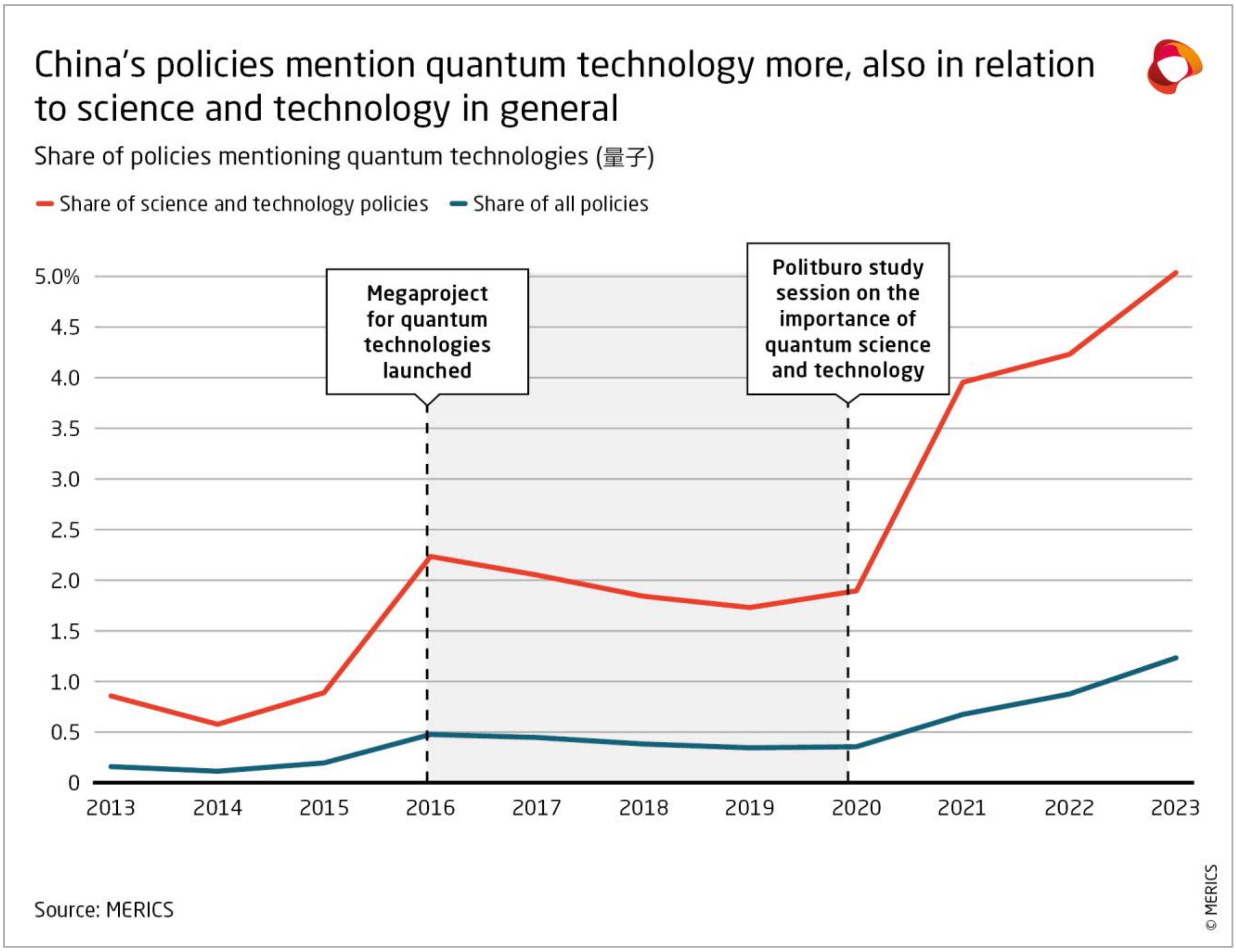
Under President Xi Jinping, science and technology have gained importance in high-level government plans, and quantum technology within these, as evidenced by Exhibit 2. In a Politburo study session on the technology in 2020, Xi dubbed quantum another front in global S&T competition.[11]

In 2006, China's groundbreaking 2020 science and technology plan listed "quantum control" among basic research areas, referring to efforts to manipulate quantum states starting with only a few particles.[12] Following a surge in mentions of quantum technologies in policy documents, the research field was elevated in 2016 with the announcement of an S&T megaproject on "quantum information and quantum computing," which made it one of China's 16 top S&T priorities for the 2021 – 2035 period. S&T megaprojects are a core component of China's long-term R&D plans. Each megaproject contains multiple sub-tasks, with researchers applying for funding for 3–5-year projects. "Quantum information" ranked second among the cutting-edge S&T fields that the Chinese government prioritized in its Five-Year Plan for 2021 – 2025, behind artificial intelligence but before semiconductors.[13]

To implement this, a National Lab for Quantum Information Science (NLQIS) was established in 2017. This places quantum technology among a small group of high-priority research areas. Only six national labs are on the official list. Although this list does not include NLQIS, the lab headed by Pan Jianwei almost certainly has central government backing. In his speaking notes for the Politburo study session, Pan praised the central government for endorsing the national lab.[14]

Beijing is also increasing support for the industry roll-out of quantum technologies. The Ministry of Industry and Information Technology (MIIT) issued plans for future technologies in January 2024 that included quantum computers among the ten most anticipated products.[15] The plan also called for future communications technology that includes quantum information, expanding on goals set forth in Made in China 2025, China's blueprint for industrial upgrading issued in 2015.[16]

Exhibit 2



China's flagship projects are secretive and expensive – the construction of the national lab started with a CNY 7 billion (USD 1 billion) investment but there is no public information on its yearly operational budget – and they are supported by a range of lower-level research programs and institutes.

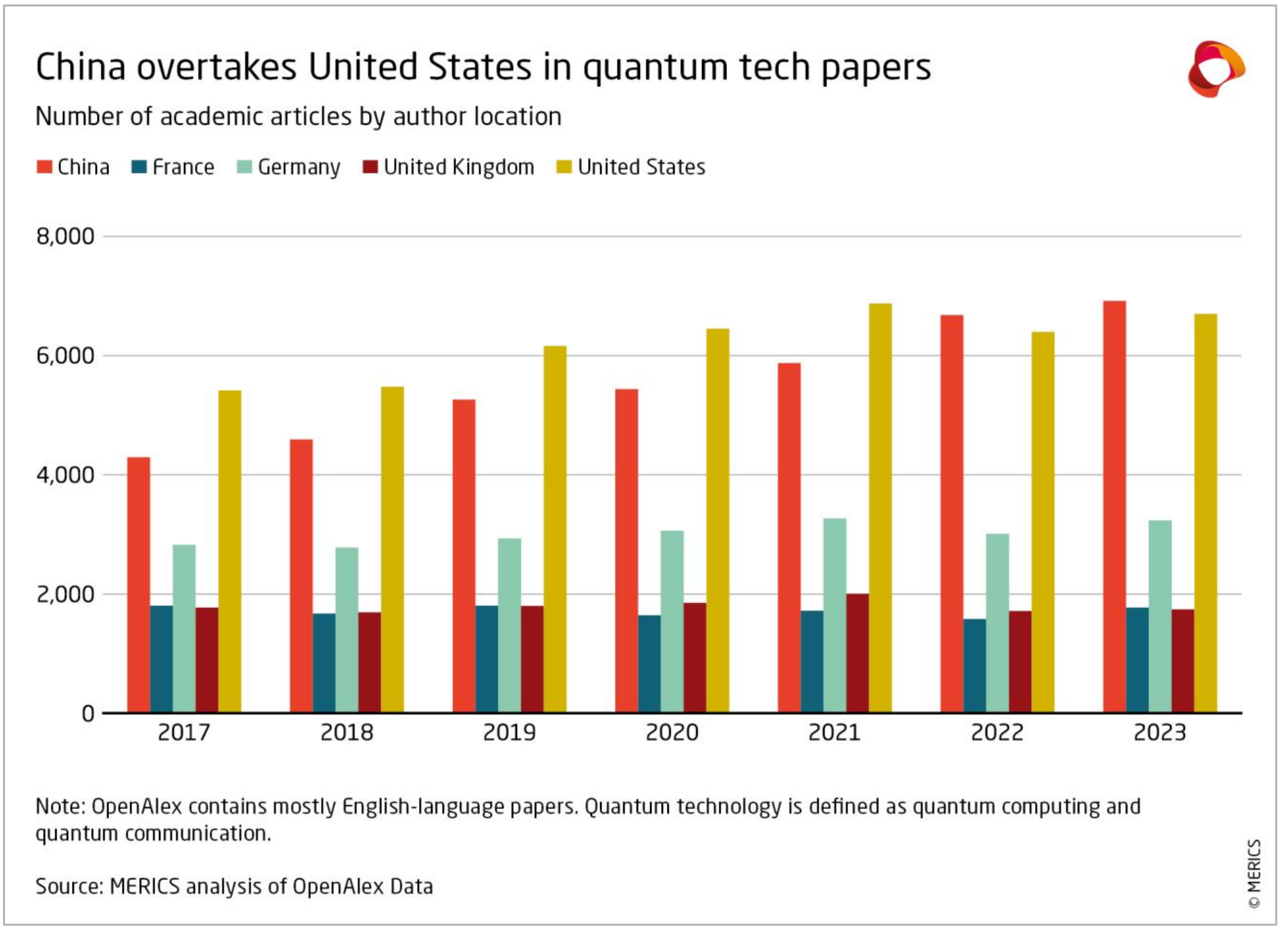
Over the past 20 years, China's quantum researchers have succeeded at obtaining high-level support from Beijing. But their heightened profile also brings restrictions. Quantum technology is part of China's expanded and updated framework for controlling foreign access to technology.[17] The centerpiece is the Catalogue of Technologies Prohibited and Restricted from Export. Quantum encryption technology was added as restricted in 2020, which means that quantum communication technology can only be exported with government approval.[18] Ultra-low temperature technology (below 6 Kelvin), required for most superconducting quantum computers, is also on the "restricted" list.

These restrictions extend to researchers. Quantum researchers and entrepreneurs have successfully emphasized the strategic importance of their work to attract funding, aided by scientific successes and lobbying by quantum scientists like Pan Jianwei at the National People's Congress and other high-profile events. However, their strategic importance has also restricted their freedom to engage with international peers. For instance, the passports of "strategic scientists" are held by their institutions and only released under strict conditions.[19] Despite having worked in Austria and Germany, Pan is now reportedly unable to travel overseas.

CHINA STILL LACKS RESEARCH COMMERCIALIZATION

China now publishes more quantum papers than the US, driven mostly by its quantum communications research (see Exhibit 3). China published more highly cited papers than any other country between 2019 and 2023. For quantum computing, the US is still in the lead.[20] The US government focuses much less on quantum communication.[21]

Exhibit 3



For patents, the picture is similar. China leads the world in quantum communication patents but lags the US in patents for quantum computing.[22] In 2023, the European Patent Office also found that while quantum computing patents in China are increasing, they still trail the US significantly.[23] This still likely overestimates Chinese output, as Chinese scientists are incentivized to apply for more patents than their international counterparts.

At least one German quantum researcher has said that while China has made great strides in engineering for quantum technology, the key breakthroughs do not tend to come from China.[24] Nevertheless, Chinese research groups have made major breakthroughs that require both deep theoretical knowledge and advanced engineering skills. For instance, China launched the first quantum satellite worldwide, Micius (Mozi, 墨子) in 2016, an achievement likened to the world's first satellite, Russia's Sputnik.[25]

As opposed to other countries like the US and Canada where most quantum progress is driven by private companies like IBM, Google, DWave, Rigetti and IonQ, much of China's quantum technology progress and funding comes from the government. China's public spending on quantum is four times higher than the US and China accounts for over half of the estimated global public investment in quantum technology.[26] This is true both in science and deployment.

Still, China has several successful firms in quantum technologies, most of which are spin-outs from the Chinese Academy of Sciences.[27] Origin Quantum is a Hefei-based quantum computing company and QuantumCTek a Hefei-based quantum communication company. However, since 2017, when the first quantum technology company received funding, only 22 quantum technology firms have received venture capital, according to Crunchbase, some with only dubious connection to quantum technologies.[28] QuantumCTek and Origin Quantum both have mostly state-led investors. Private tech firms like Alibaba and Baidu folded their quantum computing teams in 2023.

Chinese commentators lament the lack of corporate leadership. For instance, when the Chinese Academy of ICT, a state-led think tank, compared Chinese and American efforts in quantum computing in December 2023, it argued that China particularly lacks research commercialization.[29] This extends to private funding, which is limited in China, both compared to the US and compared to China's own public funding.[30]

In fact, Beijing does encourage quantum entrepreneurs with industry programs and platforms. For instance, Origin Quantum's latest quantum computer was included in China's national network of supercomputers in April 2024.[31]However, the overall approach limits private companies to policies and roadmaps that the state has formulated, with no choice but to partner with state institutions, either state-owned enterprises or research labs.

CHINA IS ON TRACK TO DEPLOY QUANTUM COMMUNICATION TECH FIRST

China's success in quantum communication shows how Beijing brings researchers and state-owned industry together to develop a technology with strategic and security implications. The construction of a national network in quantum secure communication is both a cutting-edge megaproject for western-trained Chinese scientists and an infrastructure construction effort involving state-owned enterprises with strong ties to China's security apparatus.

State investment into quantum secure communication has spurred an industry

A team led by Pan Jianwei and other researchers from the University of Science and Technology of China (USTC) in Hefei built a first quantum link in 2004, which used entangled photons to send an encryption key over 125 kilometers from Beijing to Tianjin, in a process called quantum key distribution (QKD). This method of sending encrypted information is fundamentally unbreakable without alerting the original message sender and receiver, even by quantum computers. Thus, quantum key distribution is very attractive for banks and other organizations that rely on secure communications.

USTC's success led to a large, state-led project to build a national backbone network for quantum secure communication, linking up major cities like Beijing, Shanghai and Guangzhou. The project, a first phase of which was completed in 2020,[32] enabled the USTC researchers to commercialize their technology and set up a firm, QuantumCTek (aka Guodun Quantum 国盾量子), in 2009. QuantumCTek provides the core QKD equipment, explains Chang Yingyong, its CEO, after which a systems integrator builds the link, involving a broad range of suppliers, including fiber optic cables and classical communication equipment.[33]

The whole backbone network is now 12,000 kilometers long, and several coastal cities have set up local networks as well. This is much larger than anything in Europe or the US, where the leading projects are a metropolitan network around Geneva and a pilot network between banks on the East Coast.

QuantumCTek relies on public sector clients and partners, including Chinese defense contractors like China Electronics Technology Corporation (CETC).[34] Although the company had never made a profit, it successfully launched on the Shanghai Stock Exchange in 2020, aided by expectations for government procurement of QuantumCTek products.

In March 2024, China Telecom, one of China's three state-owned telecommunications companies, acquired a 23 percent stake in the company and 41 percent of the voting rights.[35] Media are anticipating a merger, pointing to the incentives for state-owned enterprises (SOEs) to support future industries and the natural fit of a telecommunications company offering secure communications.[36] In 2021, QuantumCTek was added to the US Entity List, which bans it from sourcing US products.

Quantum satellites push the frontier, including for international collaboration

Building a ground network for quantum secure communication has become an industry, raising new challenges for scientists like Pan Jianwei. These include covering larger distances with quantum satellites.

Micius, the quantum satellite, was launched in 2016 to enable the world's first quantum-encrypted communication across continents, developed by a team from USTC and the University of Vienna. As part of the S&T megaproject in quantum computing and communication, a second satellite, Jinan-1, was put into low-earth orbit in July 2022. This microsatellite weighs a sixth of Micius but has a 2-3 orders of magnitude better accuracy in quantum communication.[37] China is planning a third quantum satellite for launch by 2026.[38] That satellite is to reach higher altitudes, which requires stronger lasers and higher precision.

Exhibit 4

China has built the world's largest quantum communication network

A quantum industry has emerged in the cities the network connects

1 BEIJING

Research institutes
- Beijing Academy of Quantum Information Science (BAQIS)
- State Key Lab of Low-Dimensional Quantum Physics at Tsinghua University

Firms
- Digital China Information Technology (DCIT): Quantum communication links
- Archlight: Quantum software
- Huayi Boao: Ion trap quantum computers
- QBoson: Photonic quantum computers

2 JINAN

Research institutes
- Jinan Institute of Quantum Technology, which contributes to China's quantum satellites and houses the National Technical Committee on Quantum Computing and Metrology Standards (TC 578)

3 HEFEI

China's largest quantum research cluster, including:

Research institutes
- University of Science and Technology China (USTC), where Pan Jian-wei is executive vice president
- National Lab for Quantum Information Science

Firms
- QuantumCTek: Quantum communication
- Origin Quantum: Quantum computers
- Ciqtek: Quantum measurement devices
- Qasky: Quantum cryptography equipment

4 NANJING

Firms
- CryoPride: Cryogenic cooling equipment

5 HANGZHOU

Research institutes
- Zhejiang University, to which Alibaba donated its quantum equipment and which developed the Taiyuan-1 quantum computer

Firms
- Qtec: Single photon generators and other equipment for quantum communication
- Liang'an Technology: Post quantum cryptography

6 SHANGHAI

Research institutes
- Shanghai Research Center for Quantum Sciences
- Shanghai University Key Laboratory of Specialty Fiber Optics and Optical Access Networks, where a team first used a quantum computer to break military-grade encryption

Firms
- TuringQ: Photonic quantum chips
- Fermi Instruments: Cooling and vacuum setups
- Precilasers: High-end lasers
- Photec: Optical quantum computing, with a European office in Naples

7 WUHAN

Research institutes
- Wuhan Institute of Quantum Technology

Firms
- HGLaser (a subsidiary of Huagong Tech): High-end lasers

8 CHENGDU

Firms
- Zhong Wei Da Xin (ZWDX): Quantum computing control and measurement technology

9 SHENZHEN

Research institutes
- Quantum Science Center of Guangdong-HongKong-Macao Greater Bay Area

Firms
- SpinQ: Quantum computing solutions

10 HONG KONG

Firms
- Siminics: Laser radar technology, including quantum sensing

Sources: Chinese Academy of Sciences Quantum Network Company (Quantumnet), Chinese Academy of ICT (CAICT), MERICS

The integration of China's quantum satellites and the backbone network[39] is a poster child for China's efforts to create a space-ground integrated information network. Such an all-encompassing, secure, reliable and global digital network across sea, land, air and space is a long-term ambition of the Chinese Communist Party (CCP), with clear military and security implications.[40]

China may open its quantum network to international partners. China and Russia tested a quantum satellite connection in December 2023.[41] Media speculate that this could be extended to BRICS countries, following the global promotion of BeiDou, China's alternative to the American satnav system GPS.

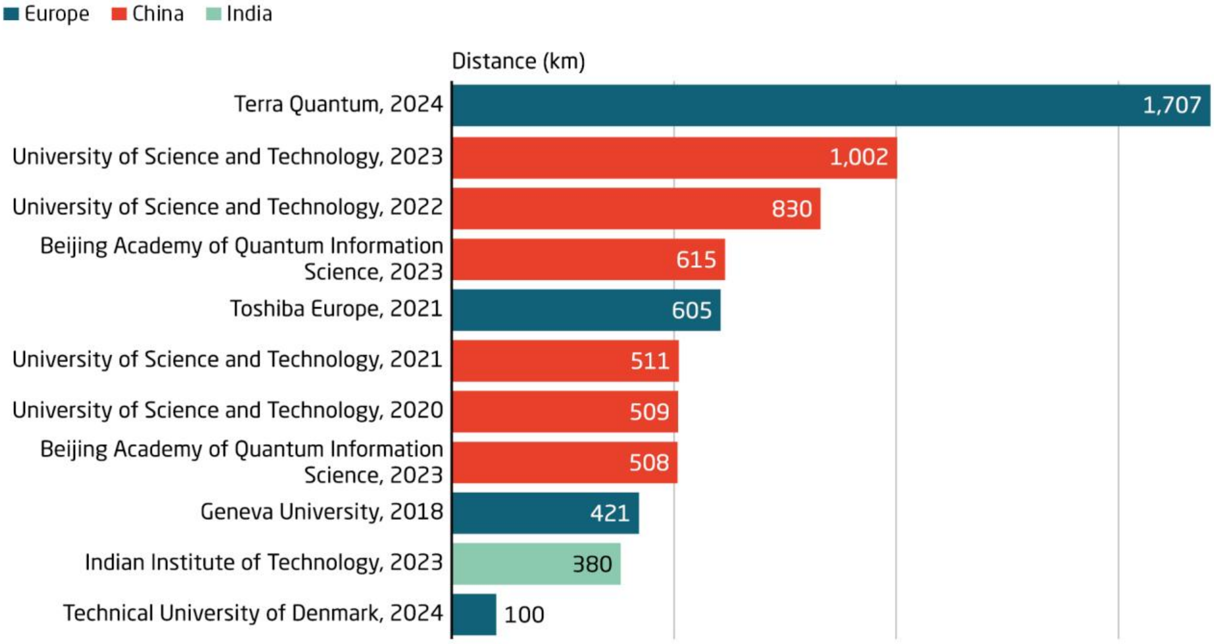
The arrival of quantum satellites enables ground networks to focus on relatively shorter distances between cities. Quantum key distribution is most secure if it is uninterrupted. Whereas ground signals need amplification stations, air signals do not, making quantum satellites much more suitable for large distances.

As a result, Chinese researchers working on terranean networks are prioritizing signal bandwidth and stability at 300-500-kilometer ranges over extending distances. Although USTC researchers broke the global long-distance record for ground-based QKD several times over the past years, this record is currently held by the Swiss firm Terra Quantum, who in August 2024 signed a contract with the US Airforce to develop a quantum communication network in America.[42]

Exhibit 5

China and Europe lead in long-distance quantum key distribution technology

Largest distance of successful key distribution, by experiment



Note: Experiments differ not only in distance, but also in the length of key that can be transmitted.

Source: MERICS

The US and Europe fall behind

Many US observers posit that China already leads in quantum communication. These include the US National Quantum Initiative Advisory Committee (NQIAC), which urges more investment "for the US to maintain and expand its leadership across all quantum technologies."[43] The focus on quantum computers over quantum communication reflects the interests of private capital, which drives innovation in the US.[44] As an infrastructure project, quantum communication requires government and military support, for which momentum has only started to build recently. For instance, Boeing announced in September 2024 that it is working on a quantum satellite.[45]

Europe lacks infrastructure and deployment, even though European Nobel laureate Anton Zeilinger laid the groundwork for the technology. The European Quantum Communication Infrastructure (EuroQCI) initiative hopes to change this but was only launched last year.[46]

With Europe strong on basic research but weak on deployments, and the US not really focusing on most quantum communication technologies, China, with its advanced deployment and future industrial policy is set to dominate this space.

CHINA AND EUROPE ARE DISENTANGLING FAST

Chinese quantum researchers and entrepreneurs are much more integrated with the West than nuclear physicists were during the 1960s, 1970s and 1980s. At the same time, governments on all sides are now increasingly preventing knowledge sharing.

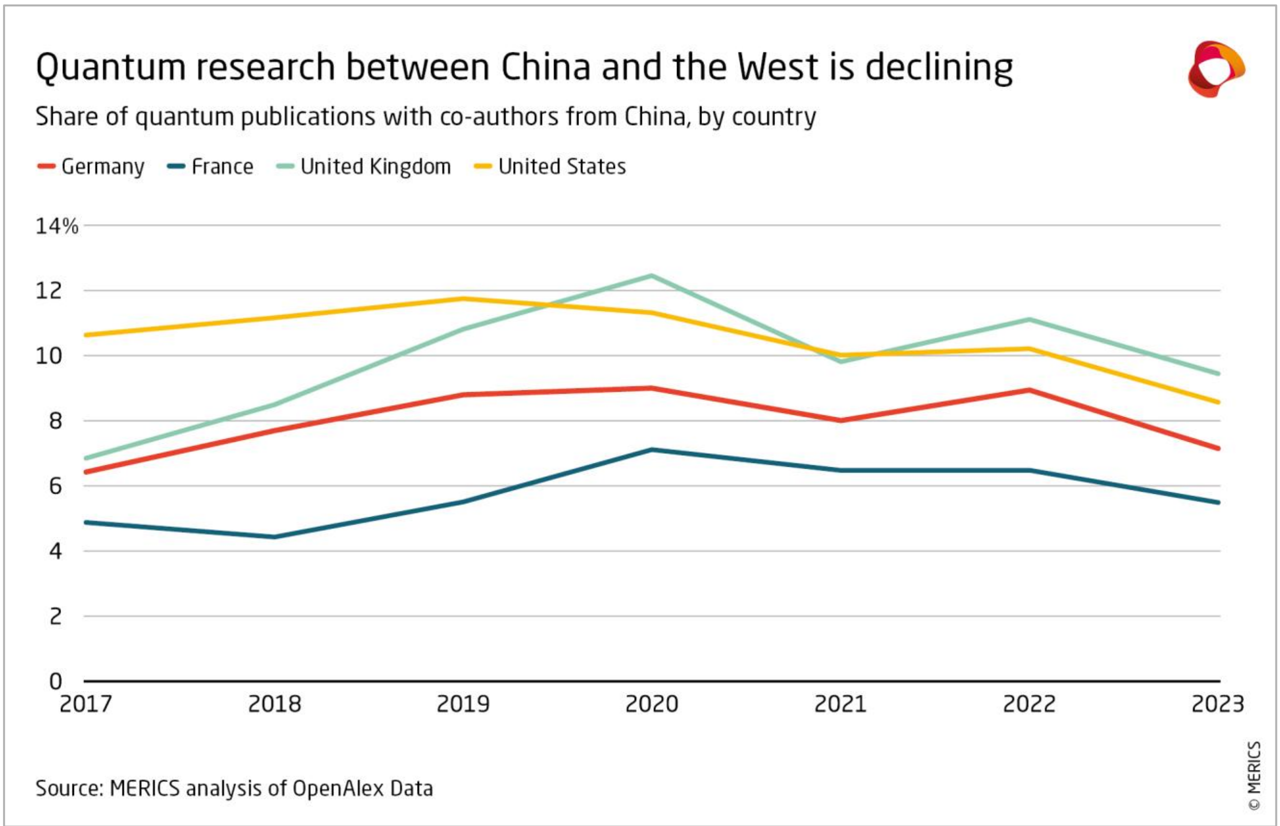
Experts who attended a MERICS roundtable with about 20 Europe-based quantum researchers in summer 2024 said that assessing China's progress is hampered by the difficulty of academic exchange, the lack of investment ties, and the growing intransparency of China's political system. Some called China's quantum development a "black box." Both China and Europe are restricting the export of some quantum-related technology, with China additionally seeking to remove any foreign companies from its supply chains.[47]

Europe and China have longstanding research collaborations in the quantum field

China's quantum leap was made in Europe.[48] Pan Jianwei, who has been so central in China's quantum communication and computing push, received his doctorate in 2003 from the University of Vienna, where he worked with Nobel-laureate-to-be Anton Zeilinger. After finishing a post-doctorate in Heidelberg, Pan returned to China in 2008. Encouraged to find external research funding, many of the leading European institutions set up joint projects with Pan and other Chinese scientists, and some researchers even took up secondary positions in China.

By contrast, collaboration with China in quantum technology has become highly contested since 2018, when the US started hinting that quantum could be exposed to the same kind of scrutiny as the semiconductor industry. The European Commission launched an investigation into quantum technology leaks to China in 2023.[49] These reservations are also reflected in joint papers. While the share of papers co-authored with China has increased for all European countries studied since 2017, it has been decreasing since 2020 (see Exhibit 6).

Exhibit 6



Many of the participants at our roundtable raised concerns over China's progress and intentions, urging Europe to act. Others warned against rash restrictions by non-specialists, arguing this would slow down fundamental research and the development of beneficial quantum technologies with no military implications. European quantum firms source almost all their equipment and materials from like-minded countries.

Quantum researchers in Europe almost exclusively rely on public funders, who invest more now than when Pan moved to China because quantum has become more strategic. For the same reasons, these funders are increasingly averse to Chinese project participation. Beyond project funding, European researchers maintain ties with Chinese researchers and occasionally travel to China to participate in academic exchanges and government-sponsored events.[50]

China and Europe are decoupling in quantum trade and investment

Over the last year, the Netherlands, Spain, France, the UK, Finland, Canada and the US have started to require permits for exporting quantum-related equipment (see Appendix). These steps are the result of discussions on the sidelines of the Wassenaar Arrangement (in which countries agree to support transparency on the export of conventional arms and dual-use goods),[51] with European lists referencing the 2021 EU Dual Use Regulation.[52]

The case of dilution refrigerators shows the challenge of getting these restrictions right. The British, Canadian and American lists restrict the sale of these fridges, which are required to maintain the temperatures close to absolute zero at which superconducting quantum computers operate. In particular, cryogenic systems that can deliver cooling power over 600 microwatts at a temperature of 0.1 Kelvin need an export license.

The US issued their restrictions only in September 2024, after five years of rumors that dilution refrigerators would be a good chokepoint because Finnish, British and US firms held 70 percent of the global market.[53] Moreover, the Finnish list is not yet finalized, which means that Finland's Bluefors can, in principle, export to China. In 2022, the Beijing Academy of Quantum Information Sciences purchased three Bluefors dilution refrigerators for RMB 18 million after the UK refused to give an export license for similar equipment by Oxford Instruments.[54] We did not find evidence that exports continued into 2024.

Additionally, QuantumCTek and the Anhui Quantum Computing Engineering Research Center announced in February 2024 that they had started factory production of a Chinese-made dilution refrigerator, the EZ-Q Fridge, which can deliver 450 microwatts at 0.1 Kelvin. The research center, which was set up by Origin Quantum and USTC in 2022, is developing a machine that can deliver 1,000 microwatts.[55]

This story illustrates that effective restrictions require high degrees of market and technical expertise as well as strong international alliances. It also shows China's resolve to develop an independent, de-westernized supply chain. This is visible across the supply chain, especially for superconducting supercomputers.

Competition focuses on enabling technologies for superconducting quantum computers

Quantum communication and computing rely on a broad range of technologies, devices and raw materials. Several of these were added to dual-use control lists (see Appendix), in particular CMOS integrated circuits and cryogenic cooling systems such as dilution fridges. Meanwhile, China announced breakthroughs in dilution fridges, high-density microwave connectivity modules[56] and ruthenium oxide thermometers[57] in the past year. This suggests there is a Chinese research program to foster self-reliance in supply chains for superconducting quantum computers.

By contrast, equipment used for photon quantum computers such as specialized laser systems, single-photon detectors and synthetic diamonds are not currently a focus – neither in Chinese breakthroughs nor in Western restrictions.[58]

China also has strengths in critical raw materials, especially silicon-28 and holmium copper.[59] The amount of these materials that European stakeholders need is still small enough to be covered through stockpiling. Moreover, China also has its own dependencies in critical materials: cryonic cooling systems require helium-3, which is produced in Russia and the US as a byproduct of nuclear weapons, and superconducting magnets require niobium, which is mostly mined in Brazil.

EUROPE AS A GLOBAL LEADER IN THE QUANTUM AGE

Quantum technology is an area with traditional European research strengths. Moving forward does not depend on digital technologies, an area where Europe is relatively underdeveloped. However, "Europe suffers from very limited private investments in quantum technologies vis-à-vis other geo-blocks," notes Mario Draghi in his report on the future of European competitiveness, calling on the EU to develop an internationally competitive ecosystem.[60]

Therefore, Europe should invest in quantum technology deployment and scale-ups. Additionally, it needs to address the hurdles for private investors that its patchwork of security and state measures creates. A quantum firm that receives start-up capital from one European country should be able to launch stock in another.

More generally, developing an effective mixture of protective and promotive measures requires technical expertise within government. This is particularly important for quantum technologies, which can easily overwhelm policymakers. Western countries should also invest in monitoring China's progress. China is investing significant resources in being the first country to harness quantum technologies, while also keeping key developments cloaked, and letting this unfold unnoticed can for instance cause Europe to keep encryption in use that has already been broken.

Next to "protect" and "promote," the third item in Europe's current approach to economic security is partnering. The coordinated addition of quantum-related technologies to dual-use lists provides a basis for further steps to trade, collaborate and share resources with like-minded countries.

In collaboration with other countries, Europe should adopt science diplomacy. Nuclear capabilities are obviously too sensitive to develop together with authoritarian countries, and the same goes for quantum communication and computing. But even during the Cold War scientists collaborated on fundamental physics. This eventually extended to benign applications in energy and medicine. Quantum technologies will not follow the exact same path – while it is relatively easy to make sure material and technology destined for atomic energy is not re-routed to develop atomic weapons, it seems much harder to ensure a quantum computer can only be used for benign purposes.

Nevertheless, these issues should become part of global quantum governance and science diplomacy, which start with the mutual recognition of each other's capabilities and acknowledging the limitations of collaboration.

As quantum is becoming more market-ready, standardization gains importance. Quantum standards are on the agenda for the Institute of Electrical and Electronics Engineers, a global standardization body.[61] When collaboration is limited, shared standards can contribute to mutual understanding. In addition, with China already having a standardization body in place,[62] and Beijing encouraging its companies to set international standards, there is a risk that standards become dominated by China. European governments should thus facilitate standardization in Europe, as well as the participation of European companies and standardization organizations in international forums.

APPENDIX

The table below shows which countries have added quantum-related technologies to their dual-use catalogs, and when. All countries in the table below now require an export permit for quantum computers and related electronic assemblies and components, for qubit devices, quantum control components and quantum measurement devices, and for qubit circuits containing or supporting "physical qubit networks." At the same time, there are a few differences between these catalogs. The table below shows the most salient differences in the third, fourth and fifth columns.

Exhibit 7

Western countries are somewhat aligning on quantum export controls

COUNTRY	DATE	SOFTWARE AND TECHNOLOGY; COMPLEMENTARY METAL-OXIDE-SEMICONDUCTORS	MATERIALS	CRYOGENIC COOLING SYSTEMS AND COMPONENTS
Netherlands and Spain	November 20, 2023	✗	✗	✗
France	February 2, 2024	✓	✗	✗
United Kingdom	April 2024	✓	✓	✓
Spain	May 26, 2024	✗	✗	✗
Finland*	June 18, 2024			
Canada	June 19, 2024	✓	✗	✗
Germany	July 22, 2024	✓	✗	✓
Italy	July 1, 2024	✓	✓	✓
Japan	July 8, 2024	✓	✗	✗
United States	September 6, 2024	✓	✓	✓
Netherlands	October 18, 2024	✓	✓	✓
Norway	November 3, 2024	✓	✓	✓

*The list has not yet been published.

Source: Official announcements by each country[63]

ENDNOTES

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IMPRINT

CONTACT

Jeroen Groenewegen-Lau
Head of Program
Science, Technology and Innovation, MERICS
jeroen.groenewegen-lau@merics.de

Antonia Hmaidi
Senior Analyst, MERICS
antonia.hmaidi@merics.de

EDITORIAL TEAM

Claudia Wessling
Director Communications
and Publications, MERICS
claudia.wessling@merics.de

Ellen Thalman
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GRAPHICS AND LAYOUT

Alexandra Hinrichs
Graphic Designer, MERICS

PUBLISHER

MERICS | Mercator Institute for China Studies
Alte Jakobstraße 85–86
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