RECONNECT CHINA

POLICY BRIEF 15

— Oct 2024 —

China's Quest for a Quantum Leap

Marc Julienne

Executive summary:

The global race to harness quantum science is intensifying. Recognizing the strategic potential of quantum technology for economic, military, and scientific advancement, China is focusing on quantum breakthroughs as a way to shift the balance of power, especially in its competition with the United States. President Xi Jinping has emphasized the importance of scientific innovation, particularly in quantum fields, to fuel national development and ensure security.

Chinese researchers, led by figures like Pan Jianwei, have made significant strides in quantum communication and computing. China is particularly advanced in quantum communication, building secure networks that use quantum key distribution (QKD), which is virtually unhackable. China has also launched quantum satellites, like Mozi and Jinan-1, to bolster its space-ground quantum network.

Despite its achievements, China may face challenges in keeping up with competitors. The quantum industry lacks robust private investment and relies heavily on state support, while geopolitical tensions, particularly with the U.S., risk isolating China from essential technologies. The coming decade will be crucial as China continues to navigate these obstacles in its quest for quantum supremacy.

Policy recommendations:

- *Given the strategic reach and military potential of quantum technologies, and given the central role of the Party and state in the quantum industry in China, any European partnership with and investment in China should be scrutinized carefully.*
- *Europe must keep up with quantum application developments and standardization so that it does not entirely rely on technology and norms developed by foreign powers in the future.*
- *Europe may play a constructive role in preventing the fragmentation of norms between the US and China.*

Introduction *

The great scientific powers are racing to unravel the mysteries of quantum science that appeared in the early 20th century, hoping to be the first to benefit from the revolutionary applications that it promises.

The People's Republic of China, whose national development is based on science and technology, puts great effort into quantum physics, and the government encourages a dynamic scientific ecosystem.

Chinese scientists focus primarily on two key areas of quantum physics: computing and communication.

* This paper builds up on a previous research published by the author in French in February 2022: Marc JULIENNE, « Le rêve quantique chinois: les aspirations d'un géant dans l'infiniment petit », *Études de l'Ifri*, février 2022.

Quantum computers could enable revolutionary applications and discoveries, such as new molecules in the fields of pharmacy or energy, new materials enabling progress in the efficiency of electric batteries or in the field of superconductivity, or significantly facilitate logistics problems, a crucial issue for companies and international trade.

The innovation potential of quantum computers in the civil sector obviously goes hand in hand with an equally important potential in the military sector: sensing, positioning and navigation systems, materials physics (new weapons), biological weapons, decryption of communications, etc.

Quantum communication aims at unbreakable encrypted communication. It no longer relies on mathematics to encrypt messages but on the principles of quantum physics, particularly entanglement.

One can understand the strategic reach of quantum physics, like artificial intelligence (AI), for states. The strategic advantage conferred by the potential economic, industrial, scientific and military benefits promised by quantum physics are driving a scientific race among great powers.

CHINA'S QUANTUM DOCTRINE

In Xi Jinping's China, technological innovation is seen as the main driver of national development. In a speech published in the Chinese Communist Party (CCP) Central Committee's bimonthly, *Qiushi*, in April 2022, Xi Jinping insisted "on placing scientific and technological innovation at the core of the overall national development."[1]

In his Report to the 20th National Congress of the CCP in October 2022, he insisted: "We must regard science and technology as our primary productive force, talent as our primary resource, and innovation as our primary driver of growth."[2]

In its strategic competition with the United States, Beijing is betting less on a quantitative catch-up in the military realm, which would require several decades, than on one or more technological breakthroughs that would redistribute the balance of power. Thus, among the most promising disruptive technologies, the Chinese state is investing massively in AI, space assets, and quantum applications.

Quantum research thus plays a significant role in China's national defence and strategic rise. As Xi put it in his most notable speech on quantum technology, delivered on October 16, 2020, before a working group of the Political Bureau of the CCP Central Committee on quantum technology: "Accelerating the development of quantum technology plays a very important role in promoting high-quality development and ensuring national security."[3]

In *Qiushi*, he further wrote: "Scientific and technological innovation has become the main battlefield of international strategic games, and the competition around the commanding heights of science and technology is unprecedentedly fierce. We must maintain a strong sense of crisis and make full ideological and work preparations."[4]

Quoting Xi Jinping is important to comprehend the strategic reach of science and technology, particularly quantum science. The Chinese quantum ecosystem must serve the CCP and follow the lead of the CCP's "core leader," Xi Jinping.

Xi made himself very clear when talking before engineers of the Chinese Academy of Science and the Chinese Academy of Engineering: "I hope that the majority of academicians will set an example of caring for the motherland and serving the people."[5]

The message was well received. In July 2023, Pan Jianwei (潘建伟), an academician and China's most prominent quantum scientist, wrote an Op-Ed in *Science and Technology Daily* glorifying how Xi Jinping played a decisive and inspiring role for him and other scientists to work even harder: "I was deeply inspired and excited to feel the General Secretary's attention to quantum technology up close, and I became more determined to tackle key problems and innovate in the field of quantum technology."[6]

CHINA'S NERVE CENTER OF QUANTUM RESEARCH

Prof. Pan Jianwei is known as the "father" of quantum science in China. He built up an academic ecosystem and several startups and initiated China's most ambitious quantum application programs. Born in 1970, Pan received his PhD from the University of Vienna in 1999 under the supervision of Anton Zeilinger, one of the world's leading experts on quantum entanglement and "teleportation." In 2003, he moved to the University of Heidelberg in Germany as a European Union (EU) Marie Skłodowska-Curie Excellence Fellow to work on quantum optics. He returned to China in 2008 to work at the University of Science and Technology of China (USTC), where he had been a student in the late 1980s. In 2011, he became a member of the Chinese Academy of Sciences (CAS). In 2014, he took over as head of the Center for Excellence in Quantum Information and Quantum Physics, founded by the China Academy of Science (CAS) and housed at USTC.[7]

Based in Hefei, Anhui Province, the USTC is the backbone of quantum research. The Department of Quantum Physics and Quantum Information was founded by Prof. Pan in 2001. The Department is involved in most of the major national quantum projects.

Beyond USTC, Hefei is the Chinese capital of quantum science. Yunfei Road is nicknamed "Quantum Avenue" (量子大街)[8], where over 20 start-ups have their headquarters, including QuantumCTek and Origin Quantum, two spin-offs of USTC specializing in quantum computing. Pan Jianwei co-founded the former in 2009, while Guo Guangcan and Guo Guoping established the latter in 2017, all professors at USTC. Guo Guangcan (郭光灿, born in 1942) is a physicist and academician, initially specializing in quantum information. While Pan has brought Chinese quantum science to another level, one may argue Guo Guangcan is the "real" father of quantum science in China having begun research in the field in the 1980s. He notably founded, in 2001, the CAS Key Laboratory of Quantum Information, housed at USTC in Hefei.

Because the Chinese state always maintains tight supervision on industry and science, even more so in strategic sectors, the state-owned enterprise (SOE) China Telecom has established, in May 2023 in Hefei, the wholly-owned subsidiary, China Telecom Quantum Group (中电信量子集团). The new company is said to "earnestly fulfill its role as the leading organizing and promoting unit, effectively performing the central state-owned enterprise's technological innovation, industrial control, and security support roles for building a modern industrial system and shaping a new development pattern. It will accelerate the creation of global leading quantum technology companies and an internationally competitive quantum industry cluster."[9]

Quantum Communication

Among all quantum application domains, China is singularly advanced in one: quantum communication. The basic principle of quantum communication is to produce unconditionally secured communication thanks to quantum physics laws.

Using the principles of superposition and entanglement, this communication is based on the Quantum Key Distribution (QKD) technique, consisting of encryption keys made of entangled photons (particles of light) exchanged between two parties. The quantum properties of the encryption key make it impossible to be copied, and any interaction with it by a third party would break the system's quantum state and instantly alert both parties. The exchanged encrypted message is transmitted via classic channels.

China's long-term plan is to build a "Space-ground integrated quantum secure communication network" (天地一体化量子保密通信网络), which includes a ground quantum communication network and a space-based infrastructure. Pan Jianwei played a key role in designing and propelling these projects.

The ground segment is already largely advanced with the 2.000km-long "Quantum secure communication Beijing-Shanghai trunk line" (量子保密通信京沪干线) completed in 2016. In the past years, this fiber optic network was extended to Hebei province, the Yangtze River Delta, Wuhan, Chengdu and Chongqing, as well as Guangdong province, Hong Kong and Macao, totaling 10.000 km.[10] The network is allegedly operational and used by the government, military, and banks for secured communication. However, the network is unlikely entirely quantum-secured because of the remaining difficulties in sustaining quantum signals over long distances.

The space segment started with the Mozi quantum satellite, which was put in orbit in August 2016. Mozi allowed to achieve several space-to-ground quantum key distribution experiments and ground-to-satellite quantum teleportation. In late 2023, the Mozi satellite appeared to be operational as it conducted a QKD experiment with Russia. The cooperation between the two countries started in 2020, and they successfully completed their first bilateral QKD test in 2022, as reported by the *South China Morning Post*.[11]

Mozi was only the beginning of the Chinese space-based quantum communication program. In July 2022, China launched a second quantum satellite named Jinan-1 (济南一号), the first of an announced constellation series. At roughly the same altitude of 500km, Jinan-1 is smaller, six times lighter (100kg), and cheaper than Mozi. It can generate quantum keys at speeds two or three magnitudes higher than Mozi. The ground station is also much smaller, cheaper and quicker to deploy.[12]

China's long-term goal is to integrate both ground and space segments and deploy a global quantum secure communication network.

Interestingly, China is the only country in the world to have developed quantum secure communication networks to this extent on Earth and in space. Russia is allegedly working on a quantum communication satellite prototype, though.[13] This may be the first time Beijing is taking its own path in a science and technology field. Over the past decades, China has mainly followed or adapted what other powers have developed, such as the USSR and the United States in the fields of space, nuclear power, military technologies, computing, and broader industrial processes or even science funding models (the American "New space" for instance). No other nation has had such an ambition as a space-ground integrated quantum communication network, at least so far.

One reason is that long-distance quantum communication is difficult to achieve. The fact that Guo Guangcan and Pan Jianwei dedicated most of their careers to quantum communication and trained a whole generation of scientists may explain China's focus on quantum communication. Another reason is that most countries prefer the relatively more accessible post-quantum cryptography (PQC) to secure communication with the advent of quantum computers. PQC is, in fact, classic cryptography based on complex mathematical algorithms (Shor's algorithm proof) contrary to QKD, based on quantum physics properties. In parallel to quantum communication, China is also one of the leading global players in the field of PQC. According to the ASPI's Critical Technology Tracker, China ranks first for academic publications on PQC.[14]

Quantum Computing

Quantum computing revolves around two main technological concepts: photonic quantum processors and superconducting quantum processors.

The former exploits the principle of superposition by entangling single photons in their quantum state to transmit information. The main difficulty lies in manipulating single photons and their entanglement. China is one of the most advanced countries in the field of photonic processors.

Pan Jianwei and Lu Chaoyang, from USTC, lead a team working on a photonic quantum processor named "Jiuzhang" (九章). In October 2023, they presented the third prototype, Jiuzhang 3.0, setting a new record in solving Gaussian boson sampling problems (with 255 detected photons).[15]

Superconducting quantum processors also exploit the principle of superposition, but the particles used are electrons in their quantum state. To reproduce this quantum state that allows superconductivity, lowering the processor's temperature close to absolute zero (around -270 °C) is necessary. This is the main challenge: maintaining the quantum state of the system at a very low temperature, essentially using liquid helium (which requires helium-3, very rare on Earth, very expensive, and therefore another growing competitive issue).

CAS Center for Excellence in Quantum Information and Quantum Physics and QuantumCTek, a spin-off company, have developed the "Zuchongzhi" (祖冲之) superconducting processor. From 66 qubits (quantum bits) in 2021, the Chinese team reached 176 qubits in 2023 and put the quantum computing platform online for public use, as IBM or Google have also done.

In April 2024, the same Center presented a 504-qubit superconducting quantum computing chip named "Xiaohong" (骁鸿). This chip is not a computer *per se*. It is a testing platform for QuantumCTek's independently developed qubits measurement and control system.[16] Because qubits are unstable and make a lot of errors, measurement and control are crucial to improving the performance of quantum computers.

In January 2024, the other leading startup in superconducting quantum computers, Origin Quantum, put online a 72-qubit computer named "Origin Wukong" (悟空芯)[17].

It is tricky and sometimes misleading to rank countries with the best quantum computers, and such a ranking can evolve very quickly. That said, the United States seems to have progressed faster than China over the past three years. As of October 2024, the American IBM, Google, and Atom Computing, as well as the Canadian D-Wave, demonstrate better results considering the number of qubits and the error correction ability, which is now one of the main focuses in improving quantum computers.

Challenges for Chinese Quantum Innovation

The global competition in quantum applications, and particularly in quantum computing, is harsh, notably amid the deepening strategic rivalry between the United States and China.

To achieve global leadership, one country needs to articulate top-level academic training and research, a science and technology ecosystem fueled by engineers, large enterprises, and startups capable of developing innovative applications and dynamic and diversified funding channels.

China now faces challenges in cumulating these criteria.

Firstly, China's startup ecosystem is far less vibrant than in North America or Europe. Although very promising, Origin Quantum and QuantumCTek are endogamous with the state-funded academic environment of USTC. Research and teams are intertwined. A private mastodont of the Chinese digital industry, Alibaba, abruptly shut down its Quantum Laboratory and fired the roughly 30-person team in November 2023, without public explanation.[18] The establishment of China Telecom Quantum Group looks very much like the Chinese Communist Party's old habit of setting up a new SOE to take control of a given sector, the quantum industry in this case. The SOE's ability to pull up innovation and fundings remains to be seen.

Secondly – a cause and a consequence of the first argument – there is little private investment in the Chinese quantum industry compared to other quantum powers. In China, most of the Chinese investment in quantum comes from the state, and China represents 50% of global public spending in the field, according to *The Quantum Insider*,[19] essentially because private investments are dominant in other countries. In short, it can be assessed that China's success in quantum applications will be state-led or simply will not be.

Thirdly, the Chinese quantum ecosystem seems increasingly isolated because of the geopolitical context. While there is increasing cooperation in science and technology among Europeans, North Americans, Australians, and Japanese, there is less and less cooperation between them and China. In addition, the US measures in export control and outbound investment screening regarding quantum technologies explicitly target the Chinese industry. To be precise, most of the Chinese entities named in this paper (USTC and related laboratories, QuantumCTek, Quantum Origin...) and many others are on the US Export Administration Regulations' Entity List. In May 2024, 37 Chinese quantum-related entities were added to the list.[20] In September, the US Department of Commerce's Bureau of Industry and Security (BIS) further tightened export controls on critical technologies, including quantum.[21]

Europe is following the same path, with Spain (2023) and France (2024) having taken export control measures on quantum technologies toward non-EU countries, in accordance with the European Union's Regulation 2021/821 from May 20, 2021, on dual-use export controls.

These sanctions may prevent China from accessing components or machinery necessary to the quantum technologies supply chain. Guo Guoping (郭国平), co-founder of Origin Quantum and member of the National People's Congress, considers it a top national priority to "resolve the foreign technological 'stranglehold' (卡脖子) on quantum computers, and strengthen China's independent quantum computer manufacturing chain." [22] He also pointed out that China should strengthen some core segments that are dominated by Western countries, such as the production of dilution refrigerators (used to create ultra-low temperatures for superconducting quantum computers), which is mainly controlled by companies from Finland, Britain, and the US.[23]

With intense research and government support worldwide, the coming decade will be crucial for developing potentially revolutionary quantum applications for human beings, but also decisive for power distribution and power competition.

WHAT'S IN FOR EUROPE?

Given the strategic reach and military potential of quantum technologies, and given the central role of the Party and state in the quantum industry in China, Europe must acknowledge the profound cultural difference between the two science environments. Consequently, any European partnership with and investment in China in quantum science and technology and other critical fields should be scrutinized carefully.

Europe must keep up with quantum application developments and standardization so that it does not entirely rely on technology and norms developed by foreign powers in the future.

Regarding standardization, Europe must be present in international forums and may play a constructive role in preventing the fragmentation of norms between the US and China.

Dr. Marc Julienne *is Director of the Center for Asian Studies at the French Institute of International Relations (Ifri). He mainly focuses on China's foreign and security policy, as well as on strategic issues.*

ENDNOTES

[1] Xi, J. (2022, April 30). Accelerate the construction of a strong country in science and technology and achieve high-level scientific and technological self-reliance (加快建设科技强国 实现高水平科技自立自强). *Qiushi* (求是). Retrieved from https://www.gov.cn/xinwen/2022-04/30/content_5688265.htm

[2] Xi. J. (2022, October 16). *Report to the 20th National Congress of the Communist Party of China.* Retrieved from https://english.www.gov.cn/news/topnews/202210/25/content_WS6357df20c6d0a757729e1bfc.html

[3] Xi. J. (2020, September 11). Speech at the Symposium of Scientists (习近平：在科学家座谈会上的讲话). Xinhua. Retrieved from http://www.xinhuanet.com/politics/2020-09/11/c_1126483997.htm

[4] Xi, J. (2022, April 30). *Op. Cit*.

[5] *Idem*.

[6] Pan, J. (2023, July 17). Looking back over the past decade: Quantum leap, promising future (十年回望：量子飞跃，未来可期). *Science and Technology Daily* (科技日报). Retrieved from https://www.stdaily.com/index/kejixinwen/202307/e701c9f8a5f84cdd8cfefba63c502544.shtml

[7] Pan Jianwei's biography available on USTC's website. Retrieved from https://quantum.ustc.edu.cn/web/en/node/32; Wang, M. (2017, January). "CAS Center for Excellence in Quantum Information and Quantum Physics: exploring frontiers of quantum physics and quantum technology". *National Science Review*, Volume 4, Issue 1, Pages 144–152. Retrieved from https://academic.oup.com/nsr/article/4/1/144/3092288

[8] Xinhua (2022, November 16). Hefei "Quantum Street": Bringing more innovative achievements from laboratories to thousands of households (合肥量子大街：让更多创新成果从实验室走向千家万户). Retrieved from http://cpc.people.com.cn/n1/2022/1116/c448544-32567029.html

[9] "'Quantum' empowers digital China" ("量子"赋能数字中国). Xinhua. 28 November 2023. Retrieved from http://www.news.cn/info/20231128/f4df190a5389450f885ed2912d4ffe8e/c.html

[10] "Quantum communication leads the future of safe and high-quality "quantum" development" (量子通信引领未来安全高质"量"发展), *Sina*, 15 May 2024. Retrieved from https://finance.sina.cn/tech/2024-06-01/detail-inaxevxw8551987.d.html?from=wap

[11] Bela, V. (2023, December 30). "China and Russia test 'hack-proof' quantum communication link for BRICS countries". *South China Morning Post*. Retrieved from https://www.scmp.com/news/china/science/article/3246752/china-and-russia-test-hack-proof-quantum-communication-link-brics-countries?module=inline&pgtype=article

[12] "From "Mozi" to "Jinan-1", deciphering the past and present of quantum satellites" (从"墨子号"到"济南一号"，解密量子卫星的前世今生). Beijing Association for Science and Technology (北京市科学技术协会). 16 August 2022. Retrieved from https://new.qq.com/rain/a/20220816A08OUG00

[13] Bela, V. (2023, December 30). *Op. Cit*.

[14] "How is United-States performing against China in Post-quantum cryptography". ASPI Critical Technology Tracker (2019-2023). Retrieved from https://techtracker.aspi.org.au/tech/post-quantum-cryptography/research-contribution/?c1=us&c2=cn

[15] "China's computational power gains new strength with 255-detected-photon quantum computer". Xinhua. 11 October 2023. Retrieved from https://english.news.cn/20231011/1dad728957b64b2189738e294391567f/c.html

[16] "China launches 504-qubit quantum chip, open to global users". Xinhua. 26 April 2024. Retrieved from https://www.chinadaily.com.cn/a/202404/26/WS662b15dfa31082fc043c431e.html ; "China's first quantum computing chip with over 500 bits released" (国产超 500 比特量子计算芯片发布). Xinhua. 26 April 2024. Retrieved from http://ah.news.cn/20240426/48d2e307e90f4815b783d5be6546b867/c.html

[17] "'Origin Wukong' Ushers in China's Quantum Computing Era". *Science and Technology Daily*. 14 May 2024. Retrieved from https://www.stdaily.com/web/English/2024-05/14/content_1960339.html ; Origin Wukong's website: https://qcloud.originqc.com.cn/

[18] Swayne, M. (2023, November 25). "China's Alibaba Shuts Down Quantum Lab". *The Quantum Insider*. Retrieved from https://thequantuminsider.com/2023/11/25/reports-chinas-alibaba-shuts-down-quantum-lab/

[19] P. J. (2023, April 13). "Chinese Quantum Companies and National Strategy 2023". *The Quantum Insider*. Retrieved from https://thequantuminsider.com/2023/04/13/chinese-quantum-companies-and-national-strategy-2023/ ; Velliet M. (2024, July). "Funding A Rival: When the United States and Europe Invest in Chinese Tech". *IFRI Studies*. Available at https://www.ifri.org/en/studies/funding-rival-when-united-states-and-europe-invest-chinese-tech

[20] Additions of Entities to the Entity List. Amendment of the Export Administration Regulations (EAR) by the Bureau of Industry and Security (BIS). *The Daily Journal of The United States Government*. 14 May 2024. Retrieved from https://www.federalregister.gov/documents/2024/05/14/2024-10485/additions-of-entities-to-the-entity-list

[21] Commerce Control List Additions and Revisions; Implementation of Controls on Advanced Technologies Consistent with Controls Implemented by International Partners. *The Daily Journal of The United States Government.* 6 September 2024. Retrieved from https://www.federalregister.gov/documents/2024/09/06/2024-19633/commerce-control-list-additions-and-revisions-implementation-of-controls-on-advanced-technologies

[22] "Representative Guo Guoping: Strengthening China's independent quantum computer manufacturing chain" (郭国平代表：壮大中国自主量子计算机制造链). *Science and Technology Daily* (科技日报). 29 February 2024. Retrieved from https://www.stdaily.com/index/kejixinwen/202402/5cb4d9e7deec44ceb289d83ead3e85fb.shtml

[23] Peng, D. (2024, March 1st). "'Two sessions' 2024: Chinese lawmaker urges Beijing to safeguard tech production chain to give nation a quantum edge". *South China Morning Post*. Retrieved from https://www.scmp.com/news/china/science/article/3253846/two-sessions-2024-chinese-lawmaker-urges-beijing-safeguard-tech-production-chain-give-nation-quantum

Funded by the European Union