COVER STORY

The Quantum Edge

China is making huge strides in quantum technologies. Should the U.S. be worried?

BY ANASTASIIA CARRIER AND CHLOE FOX — JANUARY 23, 2022

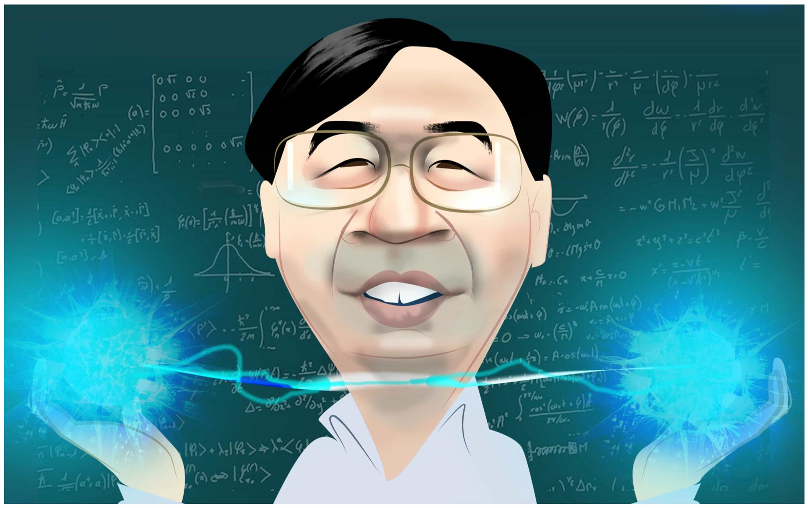

Illustration by Luis Granena

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With more than 400 Chinese companies on the U.S. Commerce Department's list of sanctioned firms — the so-called U.S. Entity List — it hardly even registers as news when more are added. But on the Wednesday before last Thanksgiving, the federal agency quietly made a bold announcement: eight more China-based "entities" were being added to the list, this time "to prevent U.S. emerging technologies from being used for the PRC's quantum computing efforts."

While the U.S. government has moved to promote quantum science domestically, the Commerce Department's sanctions represented the first time the federal government was acting defensively, and it underscored what observers in the field have been warning about for years: China is rapidly closing the quantum gap.

"It's a recognition that quantum computing is a very crucial technology for the military in the future, and also for the capabilities of the U.S. in the strategic competition with China, particularly," says Alexander Vuving, who teaches at the Daniel K. Inouye Asia-Pacific Center for Security Studies in Hawaii. "The fact that China is head-to-head with the United States in quantum superiority is not lost on the minds of those people who made the list. There is an aspect of recognition that China is very advanced in quantum technology."

China has made a number of quantum breakthroughs during the past six years. One of the most notable arrived in 2016, when the Chinese Academy of Sciences launched Micius, the world's first quantum satellite, and then used it the following year to make the first quantum-secured video call.

At the time, few in the U.S. were alarmed since quantum computers — not communications — had been America's primary focus. Had the U.S. wanted to, analysts say, it could have released its own quantum satellite, ahead of China. But since then, China has doubled down on its commitment to quantum communications — completing in 2021, for instance, roughly 3,000 miles of a ground-based quantum communications network — while also making significant advancements in quantum computing. A sense of urgency is now percolating up in the United States.

"Just a couple of years ago, American companies and researchers appeared to be relatively confident that American research and innovation were still perhaps a decade or so ahead of China when it came to cutting-edge advances in techniques and quantum computing," says Elsa Kania, an adjunct senior fellow at the Center for a New American Security and an expert on China's quantum science and technologies. "And what we've seen since is that that gap is closing more quickly than expected across multiple modalities of, or pathways to, quantum computing."

Indeed, if a Russian satellite named Sputnik defined the 20th century race for advanced technology, a Chinese satellite called Micius seems poised to do the same in the 21st century. And like the great "space race," the applications of quantum technologies often seem as if they've been pulled from the pages of a science fiction novel. Most of us, after all, are used to the laws of Newtonian physics, not those of quantum physics, which govern subatomic particles. But in the 20th century, quantum physicists learned that subatomic particles behave much differently: electrons, for example, can spin clockwise and counterclockwise at the same time, and a proton can be present in two places at once. With such findings, even teleportation is on the table.

As the science has moved from Schrödinger's infamous cat, which was at once, both dead-and-alive in a steel chamber, to real-world applications, such as the "entangled" photons that Micius creates and sends over great distances — the technologies harnessing these strange behaviors promise to unlock a revolution in computing, encryption, medicine and artificial intelligence.

Micius, the world's first quantum satellite, launches into orbit propelled by the Long March 2D carrier rocket at the Jiuquan Satellite Launch Center in 2016. *Credit: China National Space Administration*

By highlighting specific Chinese quantum companies and citing their military applications — from counter-stealth to "unbreakable encryption" — the Commerce Department's targeted sanctions underscored the reality that quantum technologies are no longer in the realm of the theoretical.

Analysts say China is making huge strides in the field of quantum cryptography, which would enable it to ensure that its own communications are un-hackable, while also allowing the nation's cyber forces to penetrate virtually all the standard public key encryption technologies currently in use. Some analysts even theorize that bad actors could be storing today's encrypted data — from banks, companies and governments — with the goal of decrypting it with quantum technologies in the future.

"The threat is that your email, your banking records, your health records, and your internal company documents that contain intellectual property could be stolen and then decrypted later," says Laura Thomas, a former CIA officer and a current Vice President of Corporate Strategy at ColdQuanta, a cold atom quantum technology solutions company in Boulder, Colorado.

Quantum cryptography, in other words, is like producing a master key to every digital diary currently on the planet. And it's the threat, analysts say, that has most mobilized the U.S.

government.

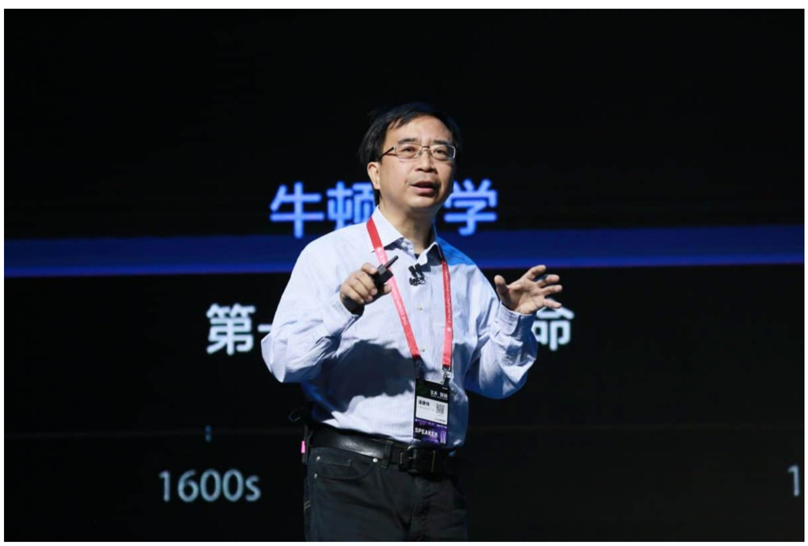
William “Curt” Barker, a guest researcher at the National Institute of Standards and Technology (NIST), specializes in planning and preparing for post-quantum cybersecurity. While he is confident that there are “quantum-resistant” algorithms that we can start using, he also notes there isn’t time to waste in getting them implemented.

“There are some people who think that we don’t have to worry about this too much, because it may be 20 years before there’s quantum computing that can execute against our current devices,” Barker says. “But betting against technological advancements is not a generally successful strategy. People make leaps forward, and the indication seems to be that we shouldn’t sell China short in terms of their ability to advance quantum computing.”

It is important to note that, right now, even the best quantum computers are not capable of solving real-world problems, but with the field moving so quickly, analysts say the practical applications of the quantum revolution are hard to overstate. It’s often said, for instance, that with certain kinds of problems, quantum computing will make today’s fastest supercomputer look like an abacus. In fact, the technologies are so different that scientists say it’s like comparing a candle to a lightbulb or a car to a helicopter. And while quantum mechanics itself is difficult to understand — a common refrain from Niels Bohr is that if you’re not shocked by quantum, you’re not getting it — the power quantum technologies are almost sure to wield is very simple.

“It could have a transformative effect, even larger than the effects of the development of the Internet,” says Paul Lipman, the president of Quantum Information Platforms at ColdQuanta. “Any government, any company needs to be planning for what that will mean for their country, their economy, their businesses, because this is inevitably coming.”

CHINA’S ‘FATHER OF QUANTUM SCIENCE’



Pan Jianwei, a Chinese quantum physicist and founder of the Quantum Information Laboratory at the University of Science and Technology China (USTC), attends the launch ceremony of Quantum Computing Cloud platform in Hangzhou, October 2017. *Credit: Imaginechina/AP Photo*

In 1998, the year the very first quantum computer was built by a collaboration of U.S.-based scientists, a young Chinese physicist named Pan Jianwei was working towards his doctorate at the University of Vienna in Austria.

Pan himself characterized the state of quantum science in China at the time as “relatively backward,” but Pan, who was studying under Anton Zeilinger, wanted to change that. In 2001, he returned to China to join the faculty of one of the country’s most prestigious schools, the University of Science and Technology of China (USTC), which is sometimes called “China’s Caltech.” There, he helped establish the school’s Quantum Information

Laboratory.

"We were only the follower and the learner at the birth of modern information science," Pan said in a 2018 interview with the MIT Technology Review. "Now we have a chance … to be a leader."

Pan's role developing quantum science in China eventually earned him the moniker of China's "father of quantum science." In 2011, at 41 years old, he became the youngest-ever member of the Chinese Academy of Sciences, the country's most important scientific and research institution.

But it wasn't until June of 2013 that China's quantum ambitions kicked into high gear. In that month, former National Security Agency (NSA) contractor Edward Snowden leaked classified documents allegedly showing that the U.S. had been regularly hacking into computers in Hong Kong and mainland China.

China's vulnerability to U.S. cyber intelligence, observers say, hit the country hard. In addition to amping up traditional cyber measures, China's leaders also started exploring options to "leap-frog" U.S. cyber capabilities. Quantum communications, with their unhackable properties, were of immediate interest.

Chinese President Xi Jinping (left) with Pan Jianwei (center) visiting the Institute of Advanced Technology in University of Science and Technology of China, April 2016. *Credit: State Council Information Office*

Most current public-key encryption technologies rely on mathematical problems (generally involving very long numbers) to protect electronically sent information since it would take even the best supercomputers years to solve them. But quantum communication technologies use photons, or light particles, to transmit information, and in their quantum states, photons can be "entangled," which means two particles remain connected even over great distances. (If it sounds far fetched, you're not alone. Even Albert Einstein dismissed quantum entanglement as "spooky action at a distance.") The big plus for encryption is that this state of entanglement is so fragile that any effort to intercept it breaks it, automatically revealing hacking efforts.

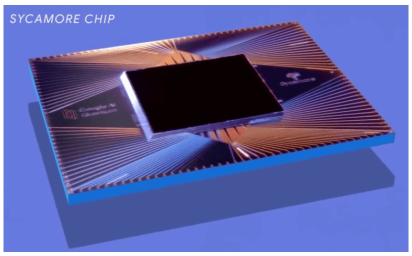
"With current cryptography, people hope that the eavesdroppers cannot find a new algorithm," says Greg Kuperberg, a mathematician at the University of California at Davis who studies quantum algorithms. "What's exciting about quantum key distribution is that there's unconditional proof that it's safe. You don't even need to hope."

Just three months after Snowden's leaks, in September of 2013, Xi Jinping was meeting with the nation's top quantum scientists, including Pan, and getting a demonstration of quantum communications technology from Quantum Ctek,[1] a commercial enterprise that is housed at China's University of Science and Technology (USTC).

Just 10 months later, China started building the largest quantum communications network in the world, which spans more than 3,000 miles and was completed last year.

By 2015, quantum technologies were named a strategic development priority in the country's "Made in China 2025" and "China Standards 2035" government plans, allowing the sector to enjoy increased government funding and other forms of assistance. While China's spending on quantum technologies is unknown, the government has announced that it is spending $10 billion to build the National Laboratory for Quantum Information Sciences in the city of Hefei, the largest laboratory of its kind.

Pan played a "key role" in the new laboratory, which is not far from his university, according to a report in The South China Morning Post. And with a team of more than 100 researchers, he went on to spearhead many of China's aforementioned quantum leaps, including the Micius satellite and the quantum video call (which connected Pan to Zeilinger, who had served as his PhD advisor in Austria). His lab has also built two of the world's fastest quantum computers — Zuchongzhi 2 and Jiuzhang 2 — which are experimenting with different quantum technologies. Last October, in a peer-reviewed study, Zuchongzhi claimed to have completed a random sampling task 10 million times faster than Google's quantum computer, Sycamore. Jiuzhang, meanwhile, can reportedly perform a random sampling task a trillion trillion (10^{24}) times faster than a conventional computer could.



Google's Sycamore Quantum Computing Chip. *Credit: Google/Wikimedia Commons*

"Pan is brilliant. A fantastic scientist. I credit a lot of [China's] big successes directly to him," says Robert Young, director of the Lancaster Quantum Technology Centre in the United Kingdom. "Plenty of other countries have put lots of money into fundamental quantum research and not [reached] quite the same results."

Artur Ekert, a professor of quantum physics at the University of Oxford, first proposed the theory behind the Micius satellite as a graduate student in the 1980s and says he never thought "it would be implemented on such a grand scale in my lifetime." After knowing Pan for 30 years, Ekert says he holds Pan's scientific abilities in high regard. Moreover, he says, Pan "managed to put together an impressive team of people and he elevated research in quantum technologies in China to the level of national priorities. This alone is quite an achievement."

Pan's success is largely attributed to his clear thinking, his congenial personality and how he runs his labs, says Barry Sanders, who was recruited to collaborate with Pan and USTC through the Thousand Talents Program and who now serves as the director of the Institute for Quantum Science and Technology at the University of Calgary.

"When you're with him personally, it feels like a bond. He's a person who cares," says Sanders, who has known Pan since Pan was a graduate student. "He's extremely good at managing the team. People have a lot of positive feelings and loyalty to him, in part because his integrity is very high. It's a culture where everybody is willing to go out of their way to help each other."

> **"As quantum information technology still has a long way to go for applications to benefit all humans, we believe that extensive and open international cooperation is necessary."**
>
> *— Pan Jianwei, Professor of Physics at the University of Science and Technology of China.*

Even outside of the physics community, Pan, now 51, has earned international praise. In 2017, *Nature* named him one of the top ten people who made a significant impact in science that year. The following year, Pan and his team became the first mainland Chinese scientists to win the Newcomb Cleveland Prize, one of America's most prestigious awards. (In perhaps a sign of the brewing geopolitical tensions, Pan's visa wasn't processed in time, causing him to miss the ceremony.) That same year, *Time* magazine put him on its list of the year's 100 Most Influential people.

"As quantum information technology still has a long way to go for applications to benefit all humans, we believe that extensive and open international cooperation is necessary," Pan told The South China Morning Post in 2019.

But that year, Strider Technologies, a Washington, D.C.-based risk intelligence firms, said Pan has connections with Chinese defense contractors. Pan and his team, Strider said in the report, were behind numerous breakthroughs in quantum military applications, including such technologies as "quantum radar to detect stealth aircraft, quantum magnetometers to detect submarines, and quantum key distribution (QKD) to enable encrypted communications for the Chinese military, including on Chinese naval vessels in the 'far seas.'"

Pan, who did not respond to *The Wire*'s requests for comment and has largely stayed out of the Western media in recent years, has downplayed the findings of the report, telling *The Washington Post* that the findings did not mean that he and his team supported military research. "We are focused on the development of quantum information technology itself," he said. "Whether these technologies would be used in the military field is not my business and out of our control."

According to data from WireScreen, Pan is connected to two quantum companies. He holds an 8.3 percent stake in Quantum Ctek, which was one of the eight Chinese companies added to the U.S. Entity List in November. In its filing, the U.S. Commerce Department said that Quantum Ctek and several other firms were involved in "acquiring and attempting to acquire U.S.-origin items in support of military applications." Pan also has a 4.4 percent stake in state-controlled CAS Quantum Communication Network Company.

According to Kania, at the Center for a New American Security, these types of connections between Pan and the Chinese military are not surprising, considering how inherently "dual-use," or applicable, quantum technologies are to both the private sector and the military.

"To some extent, dual-use doesn't quite capture it," she says of quantum research. "If you look even just at the history of classical computing and the history of information technology, there's often a strong connection between the scientific research and the military elements of it — whether that is the funding or the early applications."

Pan's focus, quantum information and cryptography, she says, is a prime example since private companies have less of an incentive or need for it.

"If you are the average company, you don't really care that, notionally, in 10 years, somebody with a quantum computer could decrypt a lot of what you have encrypted through classical means," she says. "But if you are a government or a military or intelligence organization, you do have that time horizon, and you do care."

JUST TOYS?

A man works in the quantum computing lab at the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., February 2018. *Credit: Seth Wenig/AP Photo*

Perhaps the only thing more confusing than quantum physics itself is the timeline of the coming quantum revolution. Depending who you talk to, the world will start undergoing its long-promised quantum leap sometime in the next three to a hundred years. The lack of a clear finish line makes the race — and how fast you should run it — a difficult thing to judge.

Many scientists, for instance, are reluctant to say one country or company is ahead of another since many of the achievements thus far have been narrowly defined.

"Right now, these [quantum computers] are just toys. They are excellent at being something that classical computers can't match, but they offer shortcuts to something that has no use whatsoever," says Kuperberg, the mathematician at UC Davis. "It's not that their focus is narrow; it's that their breakthroughs are narrow. And specific benchmarks and breakthroughs don't give you a picture of any comprehensive advantage in research."

Most analysts agree that while the nature of comprehensive research in quantum science is still generally international and collaborative, China has a unique advantage when it comes to reaching defined benchmarks, both because of its strong engineering talent pool and its propensity to throw a lot of resources at a given problem.

This leg up, some argue, should worry the United States since it could have spillover effects.

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>
> — *Graham Allison, Douglas Dillon Professor of Government at Harvard University*

"You always have to consider [quantum technologies] in a systemic context," says Ralph Thiele, chairman of Political-Military Society, a Berlin-based political forum, and President of EuroDefense Germany, an international initiative devoted to European security and defense systems. With multiple disruptive technologies already on the table — such as AI and nanotechnology, which China is also doubling down on — Thiele says quantum is like the T-Rex in Jurassic Park: "It completely messes up everything. Many of these technologies intertwine with each other and cause multiplying effects — so there is an exponential curve of capabilities."

Given the stakes, some argue the U.S. needs to be doing more to stay ahead of that curve.

"Many people are still stuck on the idea that China can't really innovate and can't really invent new things and can't really lead in these tech arenas," says Graham Allison, the former dean of the John F. Kennedy School of Government at Harvard University, who co-authored a recent report on the state of the technology race between the U.S. and China. "But quantum is one of the areas that they've concentrated on, and they are currently spending about four times as much on quantum as the U.S. is, and they're generating a lot more patents. They're also showing some applications that are surprising to Americans and American competitors."

Vuving, at the Daniel K. Inouye Asia-Pacific Center, says the quantum race should be thought of as part of the so-called "Great Power Competition" between the U.S. and China, which means that every attempt to get ahead is fair game.

"Quantum computing will revolutionize everything," he says. "If the U.S. wants to emerge victorious from the great power competition with China, then it has to be ahead of China in quantum computing."

But many push back against such zero-sum framing, especially considering the "chilling effect" it can have on scientific collaboration, the very human toll it takes on those caught in the middle, and the enormous benefits to humanity as a whole — in terms of medicine and even climate change — that could come from quantum technologies.

"I sincerely hope the field will not become another political battlefield," says Artur Ekert at the University of Oxford.

Some even argue that, counterintuitively, quantum technologies could ease geopolitical tensions. Zhanna Malekos Smith, a senior associate at the Center for Strategic and International Studies (CSIS) in Washington, is the author of a CSIS report called "Quantum Zoo of International Relations" that imagines a potential glass-half-full element to a post-quantum cryptology world.

"Quantum computing could theoretically be used to help enable 'confidence building measures,' which is a term of art in international relations. They're stabilizing actions that promote trust in diplomacy by mitigating potential hostilities and misunderstandings — sort of like a crisis hotline between two countries," she says. "So assuming that we've reached a state of universal quantum computing, these systems could help enhance transparency."

> **Government investment in education, training, talent development, workforce development is absolutely critical for building and expanding a quantum ready workforce.**
>
> *— Paul Lipman, President of Quantum Computing at ColdQuanta*

Regardless of how one sees the "China threat," most of the observers *The Wire* talked to for this article agreed that there are positive and proactive changes the U.S. should be making when it comes to quantum — namely, safeguarding current encryption technologies, as Barker at NIST is doing, and boosting the talent pool. With generally broad political support, both of these efforts will likely build off of the National Quantum Initiative Act, which was passed in 2018 and provided a framework for government agencies to create and operate programs for the improvement of quantum science and technology.

"Where the government money is important is in the development of the quantum ecosystem," says Lipman, of ColdQuanta. "Government investment in education, training, talent development, and workforce development is absolutely critical for building and expanding a quantum ready workforce."

"The issue in quantum is always talent," says Matt Langione, a partner at Boston Consulting Group and an expert on industrial applications of quantum computing. "Very, very few people have the technical skills to contribute meaningfully to hardware development in quantum computing."

According to Langione, private companies are also starting to realize this shortfall. Excluding tech companies, he says, private industry has invested about $490 million in quantum technologies in 2021, an increase of about 30 percent from the previous year. And it shows no sign of slowing. By 2025, according to the technology research and consulting company Gartner, nearly 40 percent of large companies are expected to create quantum-computing initiatives.

Google, IBM and Microsoft, meanwhile, have together pledged billions of dollars to the effort and, so far, remain the most visible American participants in the quantum jockeying. In May, Google said it was planning to build a reliable and large-scale quantum computer by 2029, an announcement that came on the heels of China's most recent breakthrough with its Zuchongzhi computer.

"The science that was reported [from China] is absolutely phenomenal, and now, American companies are trying to, and probably are, catching up," says Young, of Lancaster Quantum Technology Centre. "It's a proper race, and that's what makes it exciting."

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COVER STORY

Pole Position

BY EYCK FREYMANN

In public, Chinese diplomats and climate negotiators deny that they see any link between climate change and geopolitics. But there is a deeply cynical consensus within China's academic and policy communities that climate change creates geopolitical opportunities that China can exploit — and must exploit before its rivals do. Greenland was the proof of concept for this strategy. And it caught the U.S. flat-footed.

THE BIG PICTURE

Transsion's Triumph

BY GARRETT O'BRIEN

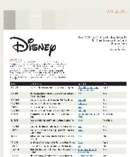
A look at Transsion's monumental growth, unique marketing strategies and future growth potential.

Q & A

Jörg Wuttke on China's Self-Destruction

BY ANDREW PEAPLE

The EU Chamber of Commerce in China president talks about China's self-inflicted problems; how he gets away with being so outspoken; and why he believes in China's comeback gene.



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