RSiS S. RAJARATNAM SCHOOL OF INTERNATIONAL STUDIES Nanyang Technological University, Singapore

Science, Technology and Security

April 2025

Published by the Future Issues and Technology (FIT) Research Cluster, RSIS. This Bulletin comes as a series of articles on science and technology from the angle of national security.

Quantum Technologies: Charting a Course for Collective Success | *Alexander Ling Euk Jin*

The space race, initially driven by geopolitics, evolved from competition to collaboration. In contrast, quantum technology is moving from an open collaborative global system towards closed-off ecosystems, thus hindering progress and increasing development costs. While investments in quantum computing grow, no unified global effort exists. Likewise, the rapid advances in quantum technology since the 1980s are at risk today due to increasing geopolitical contestation. As 2025 marks the International Year of Quantum Science and Technology, fostering global cooperation – akin to the International Space Station – could accelerate quantum technology's benefits for humanity.

When the space race kicked off in earnest in October 1957 with the launch of the Soviet Union's Sputnik 1 satellite, grand technological competition was the preserve of large nation-states. This competition had bleak origins, driven by geopolitics and born amidst a nuclear arms race. Gradually, competition gave way to cooperation, leading to outcomes such as the development of the International Space Station and multi-nation collaboration for space science and exploration.

As a quantum scientist studying global quantum communications using satellites, the space race offers a valuable reference point for understanding the trajectory of research and development in quantum technologies. Unfortunately, quantum technologies seem to be heading in the opposite direction of space exploration; we are at severe risk of moving from an open collaborative global system towards closed-off ecosystems. Such an outcome would slow down the pace of progress and increase the cost of development. This will ultimately delay the touted benefits of quantum technology. There are interesting comparisons to be made between the space and quantum tech race. Both technologies started to become viable in the background of increasing rivalry between nations, with the perception that mastery of the technology would confer strategic advantage. While the importance of the space sector, with its direct links to rockets and observation satellites, is more obvious, the value of quantum technologies remains an open question. Let’s take a brief look at how quantum technology reached its current stage and its possible applications.

The rise of Quantum 2.0

Quantum technology actually predates the space race. The first useful quantum application was an atomic clock built in 1955 at the National Physical Laboratory in the UK. And since then, many first-generation quantum technologies have been developed and deployed, ranging from semiconductors to lasers. These devices underpin our modern global economy, enabling an incredible range of applications from broadband internet communications to the emerging artificial intelligence revolution.

While the first wave of quantum technology devices was being developed for the market, basic research into quantum science continued. Many of the models and building blocks for quantum computers, communications, and sensors in the current wave of development (sometimes called Quantum Technologies 2.0) emerged during this period when scientists learned to manipulate individual quantum objects.

Around the same time, in the 1980s, scientists began to study information theory in the context of quantum physics. This new field, Quantum Information Science, studies how information can be stored, manipulated, and transmitted using physical systems that obey the principles of quantum mechanics.

This new wave of technologies inspired Nobel Prize laureate Richard Feynman to propose that a quantum computer would be capable of simulating quantum systems with a precision unattainable by conventional computers. This is because information stored in conventional machines is represented only in two states: 0 or 1. This binary representation of information can never fully replicate the behaviour of a quantum system which can only be fully understood using wave theory.

Conventional machines, even the largest supercomputers, would very quickly run out of computing capacity and storage needed for a truthful representation of simple molecules, let alone the complex ones encountered in organic chemistry or biochemistry. To this day, the simulation of nature and materials is the most often cited application for building a quantum computer, with the potential to revolutionise the fields of chemistry and materials and with corresponding translational impact on society.

In the last decade, billions of dollars have been raised for the development of quantum computing. There are several leading modalities for building such a computer: using trapped atoms (both neutral or charged), superconducting circuits, or photons (individual particles of light). The investments are distributed across the different modalities, with countries pursuing similar, parallel paths, yet the final form of these machines remains unclear.

In other words, the field of quantum computing is fragmented, and there is no unified, large-scale international collaborative endeavour similar to the International Space

Station. This fragmentation is partially due to the immature state of the field, but it is a sobering thought when considering that building a useful quantum computer may actually be on a scale akin to a civilisational challenge.

One positive outcome from recent investments is the advancement in control over quantum systems, which is beneficial for developing quantum sensors. These sensors harness the sensitivity of quantum systems to the environment (typically seen as a disadvantage, leading to noise in the computer). Quantum sensing technology has applications for electric, magnetic, and gravitational field sensing and is already deployed in field surveys. For example, Singapore has deployed gravitational quantum sensors to help search for geothermal energy sources. This application may be commercially viable earlier than computing, so keep an eye out for it.

Quantum information has also made a very strong impact in the field of communication security. A sufficiently powerful quantum computer can identify the prime number factors of large numbers. Modern encryption assumes that such factoring is beyond the reach of conventional computers. This makes existing communication vulnerable to “harvest-now-decrypt-later” attacks where an adversary records digital traffic in anticipation of decryption when quantum computing capacity has advanced sufficiently. Data with decadal shelf life is especially vulnerable (e.g., trade secrets, patient health data).

In response, governments have started to roll out policies dictating the transition to quantum-resistant encryption. This takes two forms. One approach is to identify new algorithms that are hypothesised to be resistant to quantum computers. These algorithms are collectively called post-quantum cryptography (PQC). The alternative is to use quantum technology to transmit encryption keys, an approach known as quantum key distribution (QKD). Hybrid PQC and QKD systems in appropriate locations are being actively explored in many testbeds around the world.

My own research seeks to understand how quantum signals may be transmitted globally using satellites as relays. Such a network could enhance the privacy of long-haul communication and even link quantum computers in distant locations similar to the internet today.

What is the status of the quantum race today? Expert consensus is that Western countries (the US and its allies) are leaders in quantum computing, with China close behind. In the context of quantum communications, China is the acknowledged world leader with a quantum network spanning thousands of kilometers of optical fiber and successful demonstration of quantum communication satellites.

Singapore has a unique role – far-sighted investments made by the National University of Singapore and the National Research Foundation in the early 2000s laid the foundation for a very strong research base. This has allowed Singapore to remain at the forefront of quantum research and to move quickly to identify application areas. Today, the nation has a vibrant basic research base as well as translational activities spanning the domains of computing, communication, and sensing.

Peak Quantum?

The second wave of quantum technologies has introduced a new paradigm for viewing how information can be generated, processed, and secured. It is difficult to overstate the significance of this development from a scientific perspective; the challenge is to translate the findings into beneficial applications for humanity.

Have we reached peak quantum? The rapid advances that we have witnessed in quantum technology development since the 1980s appear to be at risk today due to increasing geopolitical contestation. It should be noted that quantum technology developed rapidly during an era when the global system was more open, which also enabled the movement of talented scientists across countries and regions. This openness is certainly at risk today with fewer visits across the geopolitical divide. As a global meeting place, Singapore could be a natural venue for hosting more international scientific meetings to encourage dialogue and cooperation.

There is also an increasing array of export controls from all sides of the contest. An example is the recent wave of export controls announced by multiple countries on quantum computers, starting with very low performance machines. Furthermore, export controls could restrict access to the tooling that is used in R&D and other types of advanced manufacturing, cooling the overall rate of scientific research precisely at a time when we are on the cusp of breakthroughs.

Overall, such efforts will delay and increase the cost of development. It is unlikely, however, to enable a single “winner” in this domain because the foundations to Quantum Technology 2.0 were developed openly, primarily in university laboratories all over the world. The underlying principles of the technology are well understood and have been widely disseminated. In contrast, the space race could be developed in isolation.

In 2025, the International Year of Quantum Science and Technology, we may wish to consider how broader access to quantum technology can benefit humanity. To use the space analogy, we should build less Sputniks, and more International Space Stations. When the promised fruits of quantum technology become broadly available, we all become winners.

About the Author

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