Micius Heralds an Era of Quantum Communications

By SONG Jianlan (Staff Reporter)

The early morning of August 16, 2016 witnessed the well-anticipated and successful launching of the first quantum satellite in the world, the satellite for Quantum Experiments at Space Scale (QUESS), on top of a Long March-2D rocket from the Jiuquan Satellite Launch Center in Gansu Province of northwestern China. Nicknamed "Micius" after Mozi (Mo-tse), an ancient Chinese scientist who demonstrated pin-hole imaging nearly 2,500 years ago, this satellite was designed to perform quantum communication experiments by transmitting quantum information from space to five ground stations, after three months of in-orbit testing. The aboard experiments are expected to extend the safe distance of quantum key distribution to about 1,200 kilometers, which are not possible if performed on the ground due to the energy decay caused by bounds of the


China launches the world's first quantum satellite, namely the Quantum Experiments at Space Scale (QUESS) satellite on top of a Long March-2D rocket from the Jiuquan Satellite Launch Center in Jiuquan, northwest China's Gansu Province, Aug. 16, 2016. Before its launch, the QUESS was given a nickname "Micius", after an ancient Chinese scientist living 5 century B.C. Sources said the 600-plus-kilogram QUESS "Micius" is expected to circle the Earth once every 90 minutes after it enters a sun-synchronous orbit at an altitude of 500 kilometers. (Photo: JIN Liwang, Xinhua)

photons with the molecules in the air or the optical fiber. Aside from helping establish a satellite-ground channel for future quantum communications, the satellite will also conduct some fundamental experiments that might have far-reaching implications to some basic principles of quantum mechanics.

Ultra-safe Encrypted Communication

"Micius" marked the third science satellite sent to space under the strategic priority research project in space science sponsored by CAS. Jointly developed by the University of Science and Technology of China (USTC) and the CAS Shanghai Institute of Technical Physics (SITP), the satellite is set to perform four major scientific experiments to establish the satellite-ground channel for quantum communications, including distribution of encrypted quantum keys, testing of the wide area network for quantum communications, and quantum teleportation at space scale.

The five ground stations, which are to receive the quantum information sent from the satellite 500 kilometers above the earth, include the one in Xinglong County in Hebei Province, the one in Ali prefecture of Tibet Autonomous Region, the Nanshan Station in Xinjiang Autonomous Region, the one in Lijiang of Yunnan Province, and the one in Qinghai Province, China.

In principle, the quantum keys to be sent from the satellite to a ground station are absolutely proof against any interception or spying, thanks to a principle of quantum physics called "no-cloning theorem". According to this principle, it is impossible to measure or copy the state of any a quantum particle, as the measurement or copying itself will change the quantum state and hence be easily detected by the sender or the receiver. Taking advantage of this, scientists found it possible to achieve absolutely secure encrypted communications: information could be encoded to the photons in a beam of polarized light and sent to the receiver; if any wiretapping or spying occurred, the system would be immediately interfered and the encoded information would be changed and lost. Therefore, absolute secure quantum communications will be achieved if we send the key, or the "code book" for a piece of encrypted message via quantum particles.

Since the first demonstration of quantum key distribution in 1995, major progress has been made by scientists around the world amid a "quantum communication race". A protocol for quantum key distribution has been established internationally and metropolitan secure communication networks have been developed and demonstrated in cities represented by Boston, Vienna, Beijing and Tokyo. A team at USTC led by CAS Member Prof. PAN Jianwei, who also serves as chief scientist of the GUESS project, is taking the lead in this international race. His team has solved a series of fundamental scientific problems aimed at applications in metropolitan area networks for quantum communications, and in 2014 successfully conducted “measurement-device-independent quantum key distribution” across a record distance of 200 km.

As early as in 2008, the team succeeded in building the first general quantum communication network in Hefei, the capital city of east China’s Anhui Province, and built up a special “quantum communication hotline” between important nodes to help secure smooth communication for the military parade celebrating the 60th anniversary of the founding of the People’s Republic. In 2009, the team took the lead in extending the distance of decoy state quantum communications to 200 km.

Global Coverage of Quantum Communication Networks in View

As mentioned at the beginning, however, photons undergo significant energy decay when travelling in the air or optical fibers, and this limits the possible distance photons can spread to about 100 kilometers. To solve this problem, repeaters of high quality have been developed and applied to the networks; and on the other hand, scientists are casting their attention to the near space, with hope to overcome this bottleneck. After all, if sent from a satellite to a receiver on the ground, the photons will only need to go across a thickness of about 10 km of air, and while travelling through the vacuum in outer space, it undergoes much less energy decay – so much less that it could be almost negligible. In short, if we succeed in establishing a channel for quantum communication between the satellite and the ground, global coverage of quantum communication networks might be possible by connecting different metropolitan area networks with satellites, and this will mark a long leap towards commercial application of quantum communications.

Naturally the "Micius" has emerged as a brainchild in this grand plan. A very important task for the satellite is to distribute quantum keys from space to the involved ground stations. It is expected that its successful implementation will extend the safe distance of quantum communication to a new level of over 1,000 kilometers

Shot on July 27, 2016, the photo shows technical staff installing the solar wing for the experimental quantum communication satellite at the Jiuquan Satellite Launch Center in Jiuquan, northwest China's Gansu Province. (Photo: Xinhua)

– if successful, this will connect the segments of secure quantum communication networks from Shanghai to Beijing altogether in "one step".

PAN's university is now striving to build a main line for encrypted quantum communications connecting Beijing and Shanghai. To be completed by the end of 2016, this 2,000 km information highway will mark the first backbone network for encrypted quantum communications in the world. Successful establishment of satellite-ground channel for quantum communications will undoubtedly further upgrade the performance of the networks.

According to PAN, China will send the second and the third quantum satellites into space if the "Micius" works well. This will make China one more step closer to its ambitious plan to set up the first global quantum communication network by around 2030, with aid from a satellite array consisting of dozens of quantum satellites and numerous ground-based quantum communication networks.

Based on this network, China will be able to establish an ultra-safe quantum Internet, a quantum communication industry, and a new generation of information security systems, scientists say.

Testing Einstein's Theory

Another important task of "Micius" is to test if quantum entanglement can maintain over a distance of about 1,200 kilometers. Quantum entanglement is a magical action through which quantum particles – photons for example – share the same state even when separated far apart. In other words, one particle of an entangled twin can affect the action of the other afar immediately – at a speed faster than light. This mysterious quantum phenomenon even puzzled Albert Einstein, who described it as "a spooky action at a distance" in 1948, as its existence challenges the great physicist's famous assumption in the theory of relativity that nothing can travel faster than light. The physicist, together with his colleagues Boris Podolsky and Nathan Rosen, challenged quantum mechanics in a thought experiment that were named the Einstein–Podolsky–Rosen paradox or the "EPR paradox". Meanwhile, to explain quantum entanglement within the framework of relativity theory, David Bohm *et al*. proposed the "hidden variable theory" based on the "EPR paradox", posing a further challenge to the completeness of quantum mechanics. On the other hand, John Stewart Bell proposed a theorem described as "Bell's inequality" to determine whether quantum mechanics or the "hidden variable theory", which supports the 'EPR paradox", is right. If experimental observations support Bell's inequality, Einstein will be proven to be right; if the experiments violate Bell's inequality, however, Einstein's belief will be weakened.

During its flight, "Micius" will perform a series of experiments to verify if "Bell's inequality" holds. If the observations violate Bell's inequality one more time – just as what a series of experiments over the past years, especially the loophole-free Bell inequality measurement made by Dutch physicists in 2015 did – it will lay a further milestone in the history of quantum physics, by strengthening this fascinating theory while weakening Einstein's "hidden variable theory". This prospect can be a footnote explaining why "Micius" deserves the anticipation of global physical community.

Quantum Teleportation over 1,000 km

Whatever the mechanism for quantum entanglement is, this magical connection has inspired the idea of quantum teleportation: sending quantum information (qubits) over a distance without physically sending the particle itself.

This idea was first articulated by six physicists in a paper appearing in 1993. Later in 1997, Austrian quantum physicist Anton Zeilinger first succeeded in experimental demonstration of quantum teleportation. Since then, scientists have competed to experimentally demonstrate teleportation in different systems and at different distance. Subsequently the record distance for quantum teleportation has been frequently updated, and the team at USTC led by Prof. PAN Jianwei, former student of Prof. Zeilinger, broke the record repeatedly.

In 2012 and 2013, PAN's team successfully realized quantum teleportation and performed entanglement distribution across a free space of 100 km distance. Now with "Micius", PAN's team is ready to send two entangled photons from the satellite 500 kilometers above in space simultaneously to two ground stations located about 1,200 kilometers apart.

PAN's team has to make sure the twin photons arrive at the receivers at exactly the same time. "That's like throwing two coins in succession from the space over 10,000 meters above and get them into the slots of two rotating piggy banks," PAN was quoted by *China Daily* describing the difficulty of targeting the receivers.

Difficult as it is, the tiny qubits to be transmitted from the space deserves the great efforts. Via the qubits quantum computers can communicate with each other – and this will further help establish a network of quantum computing.

PAN's former supervisor, Prof. Zeilinger will work together with him again in the QUESS project to establish the inter-continental channel between Austria and China for quantum communications.

Now the in-orbit testing is going well and in due time the well-anticipated experiments will answer the questions haunting many people's mind and might unveil a futuristic era.