Large-scale Quantum Communication Network

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Ji-Gang Ren

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Ping Xu

Yuan Cao

Jun Zhang

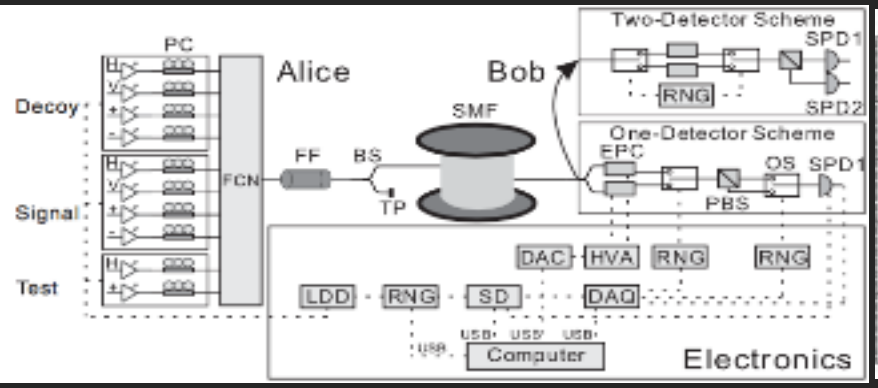
Teng-Yun Chen

Xiao Jiang

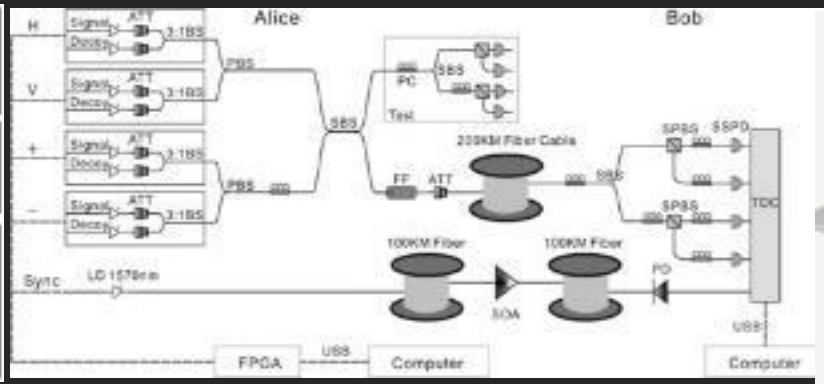
Qi Shen

Quantum Communication in China

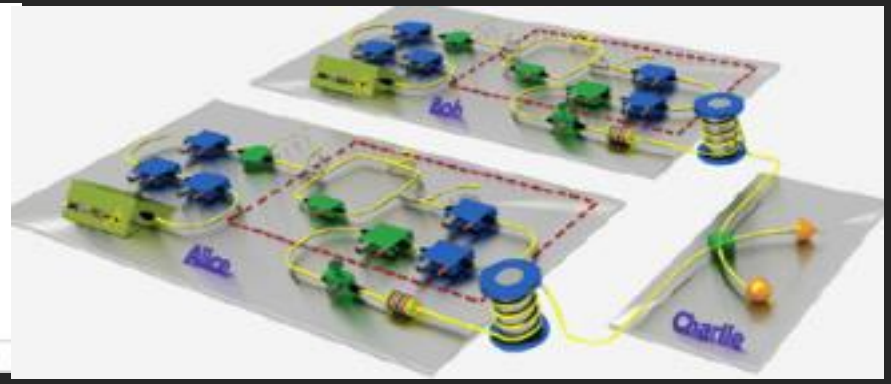
Fiber based Quantum Communication



100km Decoy-QKD
Peng *et al.*, PRL 98, 010505 (2007)



200km Decoy-QKD
Liu *et al.*, Optics Express 18, 8587 (2010)



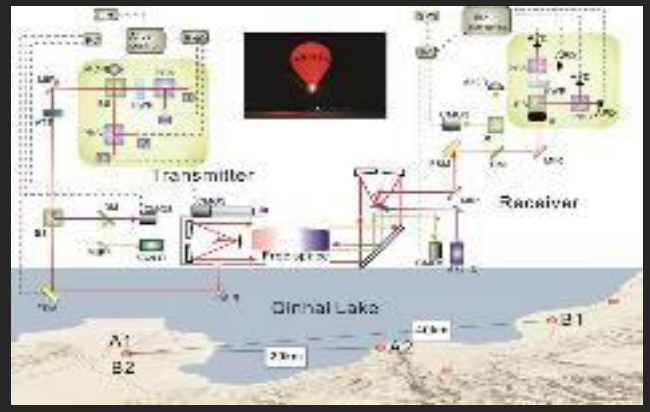
404km MDI-QKD
Yin, *et al.*, PRL. 117, 190501 (2016)

Free Space Quantum Communication

13km quantum entanglement distribution
Peng *et al.*, Phys. Rev. Lett. 94, 150501 (2005)

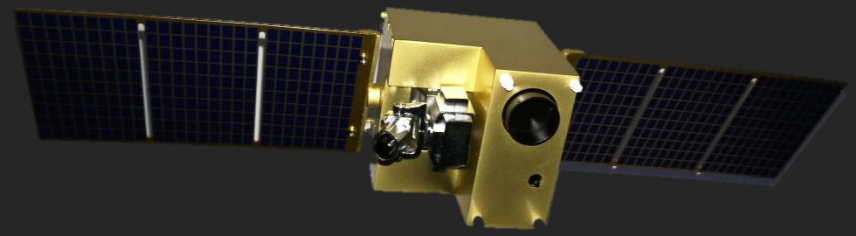
16km quantum teleportation
Jin *et al.*, Nature Photonics 4, 376 (2010)

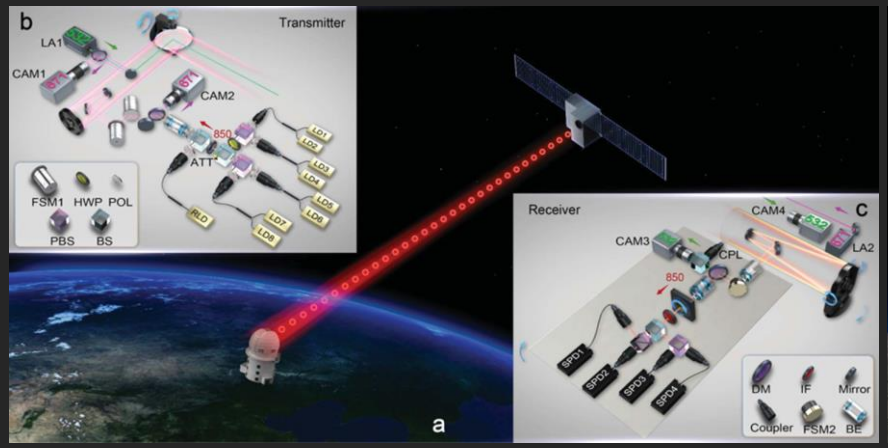
100km quantum entanglement distribution
Yin *et al.*, Nature 488, 185 (2012)



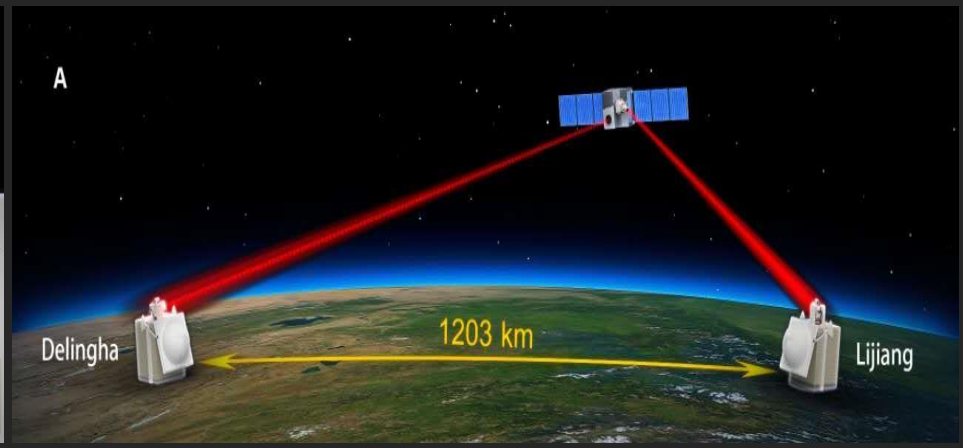
QKD toward satellite
Wang *et al.*, Nature Photonics 7, 387–393 (2013)

Background : Micius

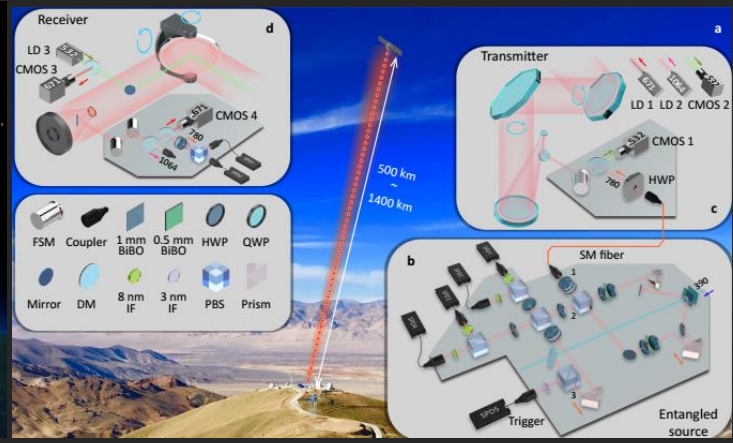




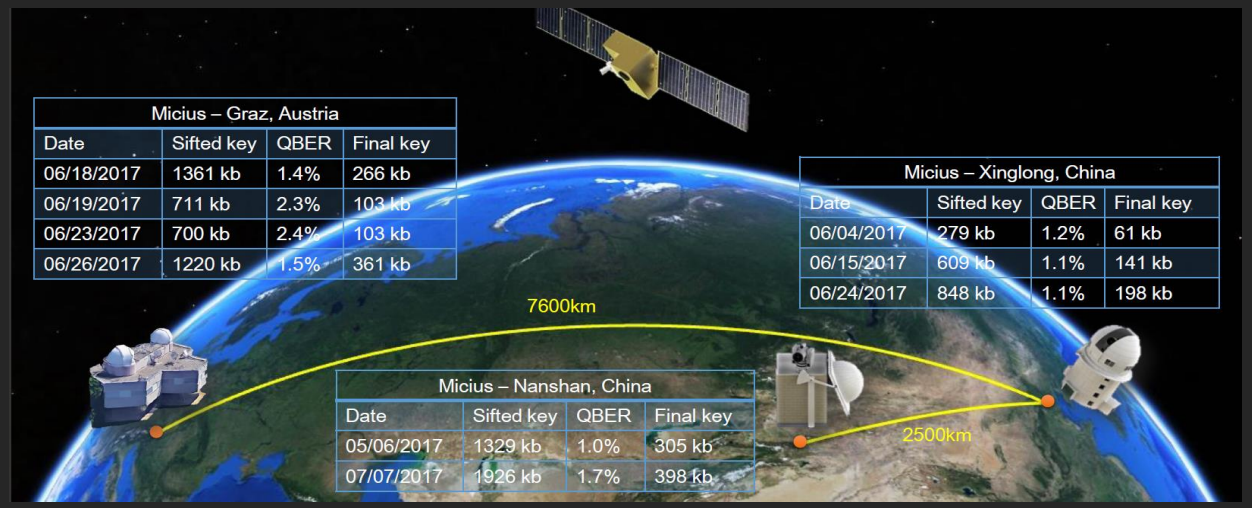
Satellite-to-ground QKD
Liao *et al.,* Nature 549, 43 (2017)]



Satellite-based quantum entanglement distribution
Yin *et al.,* Science 356, 1140 (2017)



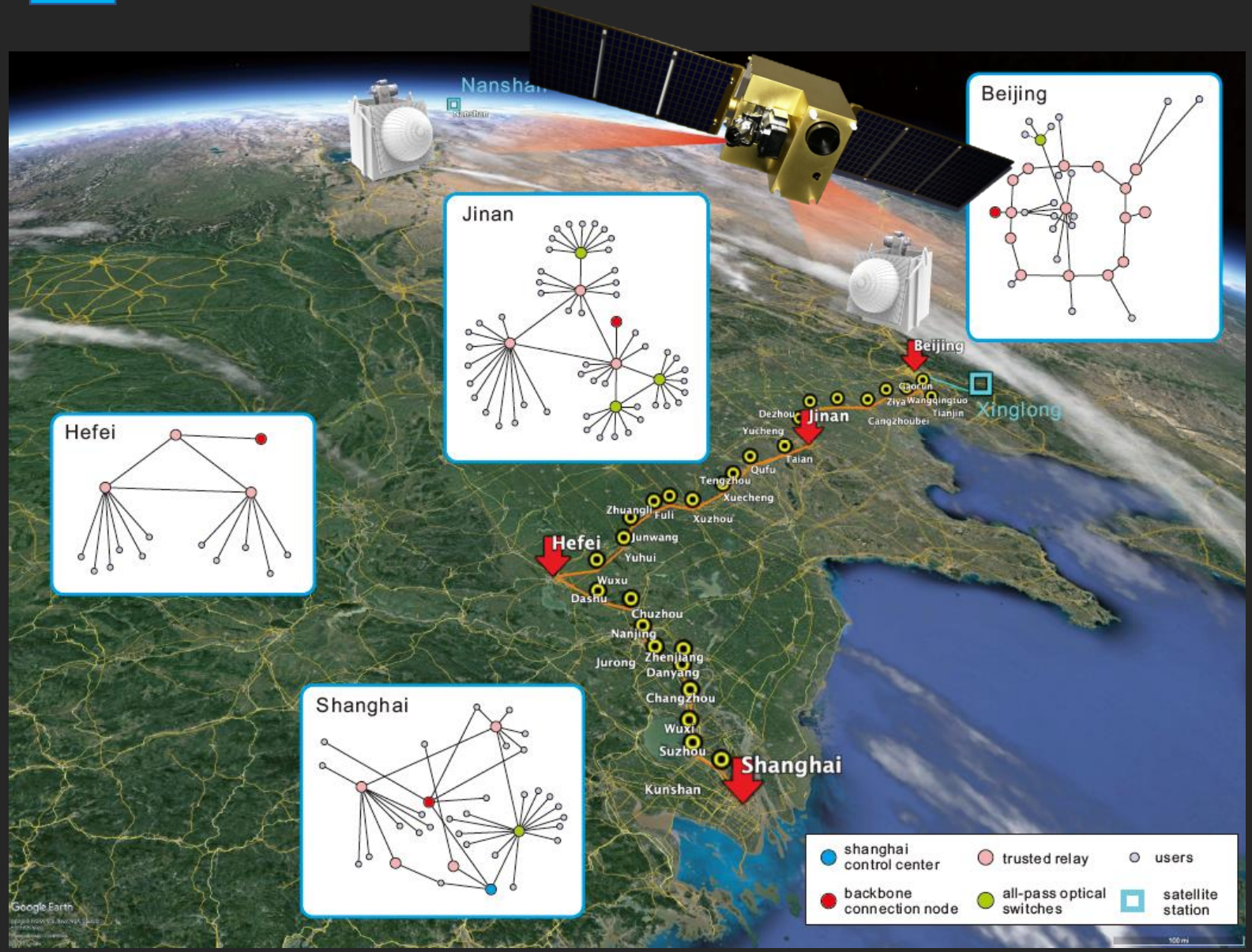
Ground-to Satellite teleportation
Ren *et al.,* Nature 549, 70 (2017)



Satellite-relayed intercontinental QKD
Liao *et al.,* Phys. Rev. Lett. 120, 030501 (2018)

Entanglement-based QKD
Yin *et al.,* Nature 582, 501 (2020)

Background: Micius & Backbone Fiber Link



- Four quantum metropolitan area networks in Beijing , Jinan, Shanghai, Hefei with a backbone fiber link over 2000 km.
- Two ground-satellite links that connect Xinglong and Nanshan separated by 2600 km.
- Xinglong is further connected to the Beijing's fiber network.

Let us have a chance to show the feasibility of the global quantum network.

Chen *et al.*, Nature 589, 214 (2021)

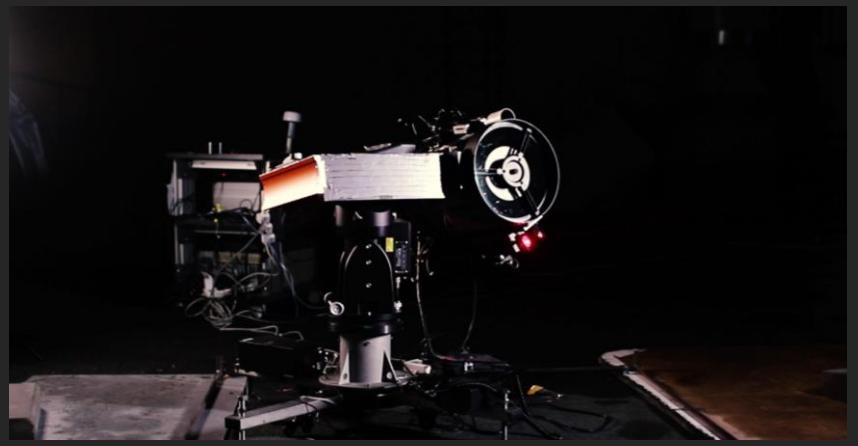
Recent progress with Micius - Cooperation

201804@Tenerife
High-speed Europe-China QKD

201910@Moscow

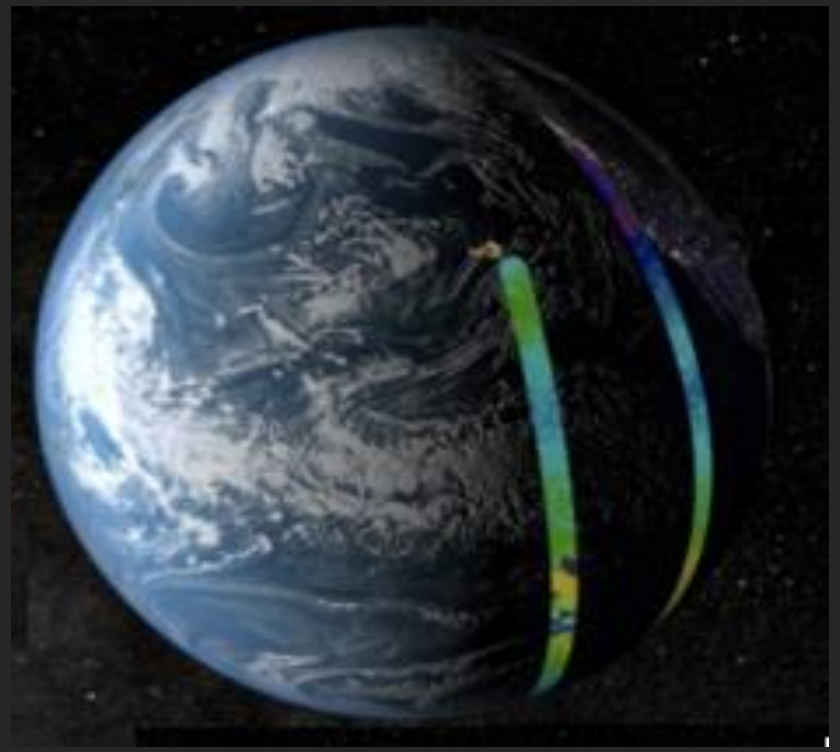
2021@Calgray

202011@Matera



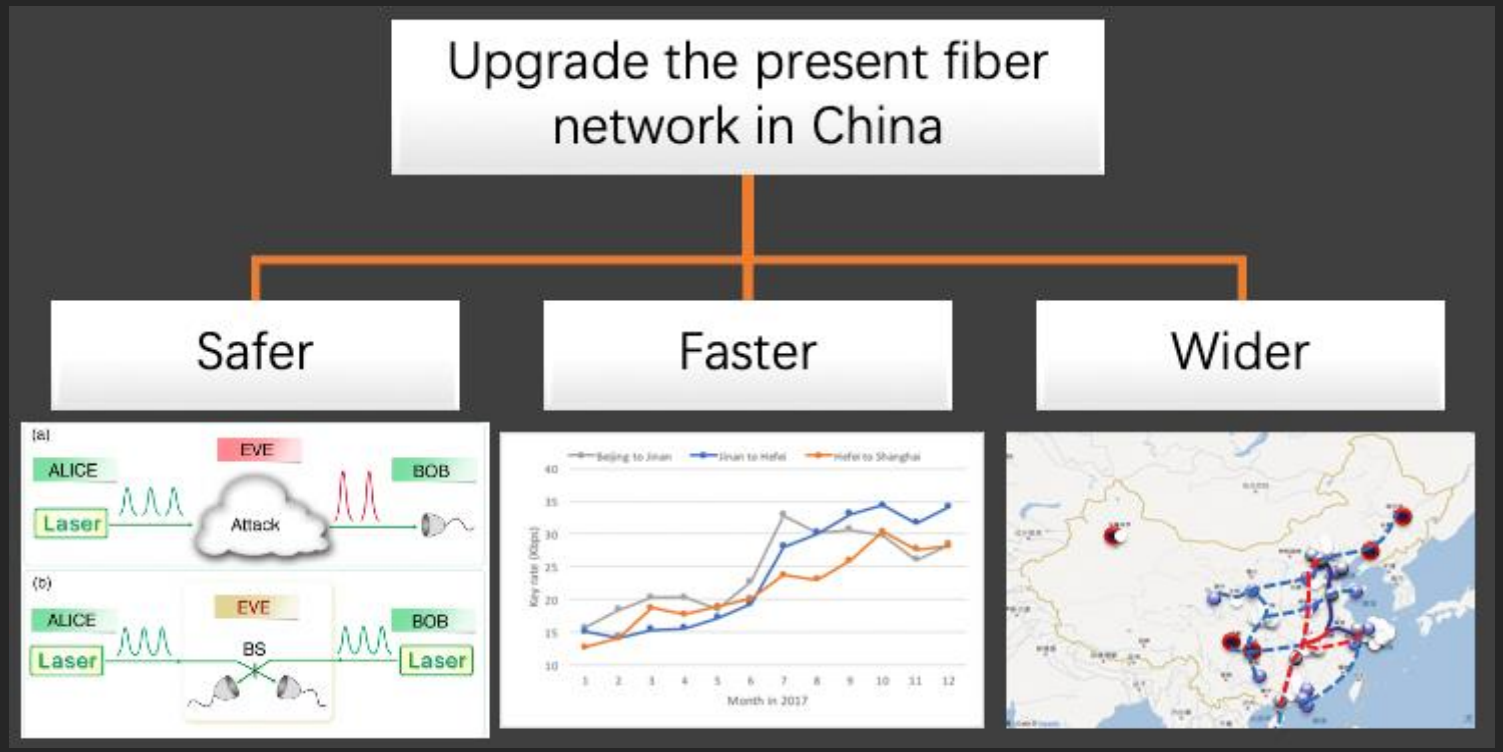
- South Africa, Australia…

Challenges of Practical Global-Scale Quantum Network



The limitation of Micius

- **Experiment time is ~ 6 minutes for each pass**
- **Coverage range is about 500km (Radius)**
- **Have to be in the shadow of earth**



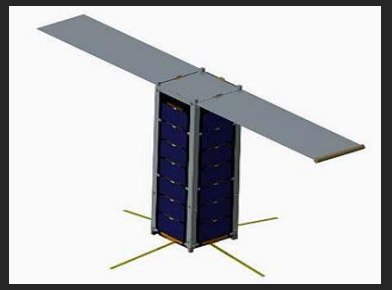
☑Quantum constellation with LEO nano satellites

☑The MEO-to-GEO quantum satellite

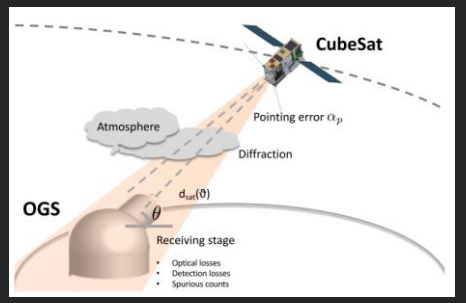
Quantum Communication Project

- LEO Quantum Satellite Plan (satellite-ground link in 2023)

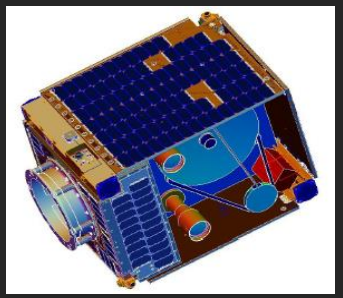
Singapore SpooQy-1 (2019)
Optica 7, 734-737 (2020)



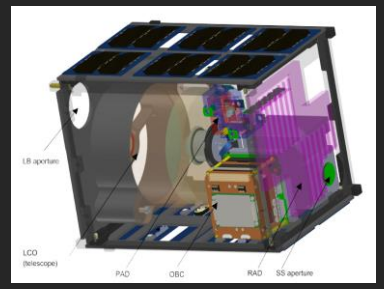
USA CAPsat (2021)
Detector



U.K QUARC
(Launch 2023)



Canada QEYSSAT
(End 2022)

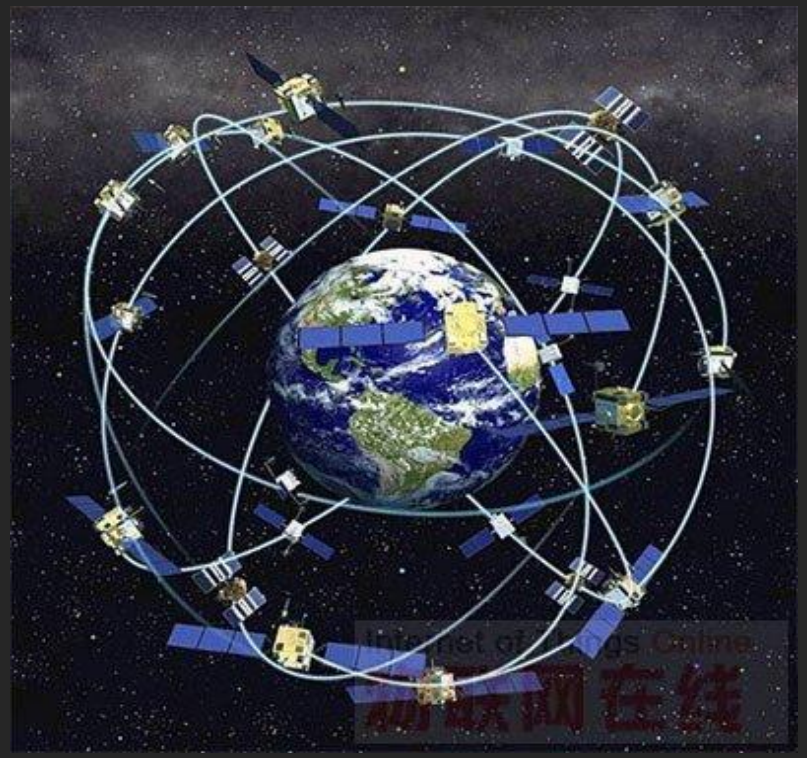


Austria &France
NanoBob

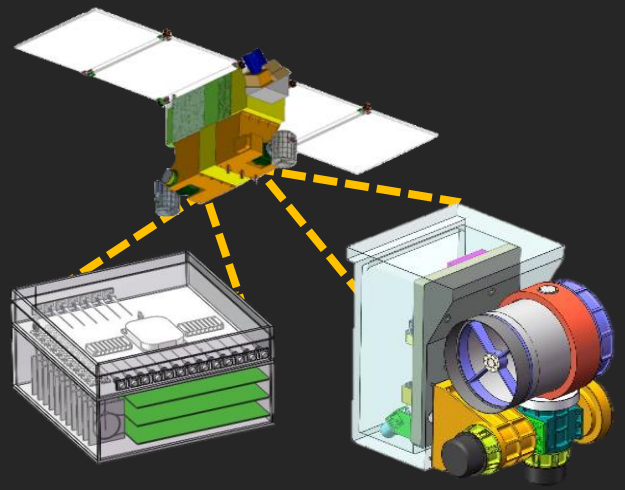
- June 2019, European Commission & ESA & All 27 EU Member States, (By 2027)
  "Quantum Communication Infrastructure" (EuroQCI)
- June 2021, G7
  "Federated Quantum System" (FQS)

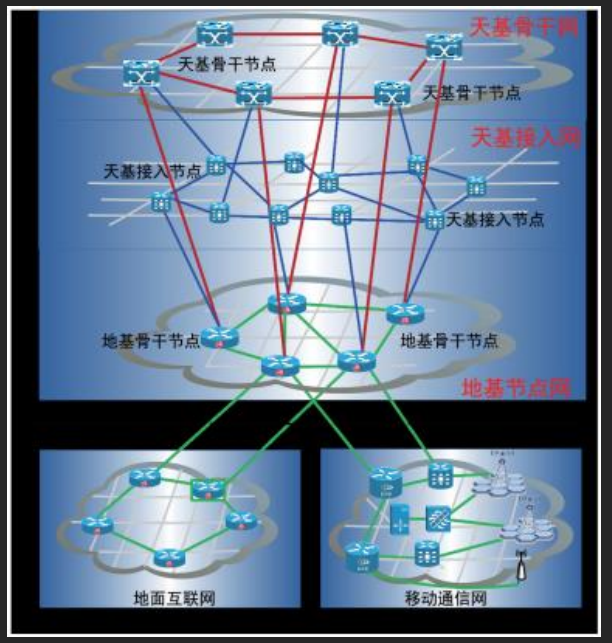
Building Quantum Constellation with Compact Payloads

"Quantum constellation"



Nano Satellites





- ✓Weight: 100kg (Compact QKD payload 35 kg)
- ✓Repetition Frequency: 625MHz
- ✓Real-time key extraction based on laser communication
- ✓Carrying the rocket of the Institute of Mechanics "Zhongke No. 1" (Launch in 2022)

Compact and Movable Ground Station

- Miniaturized and lightweight payload (500kg → 30kg)
- Compact and movable ground station system

Significantly reduce the development and launch costs of quantum satellites, laying a foundation for the large-scale and commercial applications of satellite-based quantum communication.

- ✓ **3 or 5 NanoSat in 5 years**
- ✓ **More than 100 users**
- ✓ **Key weekly update**
- ✓ **Deliver over 5 Gbits/year**

Typical weight: 13ton

Weight < 100kg

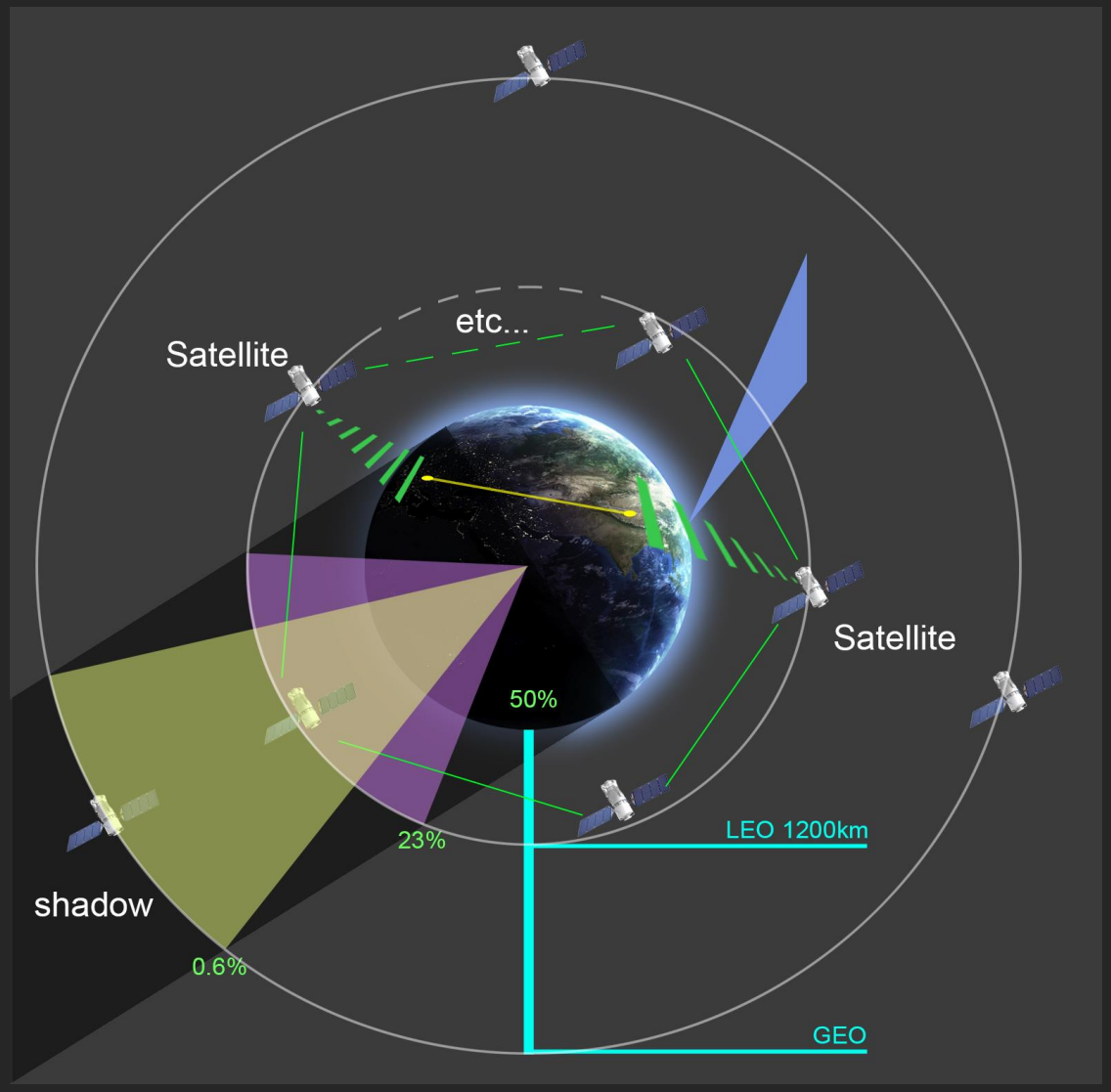
Compact and Movable Ground Station

☑ Shanghai, Lijiang, Weihai, Mohe, Jinan, Beijing, Fuzhou, Chongqing, Haikou

☑Smaller, lighter and cheaper (280 mm diameter, 100 kg)

☑The sifted key rate is ~ **2 kbps**

The MEO-to-GEO Quantum Satellite

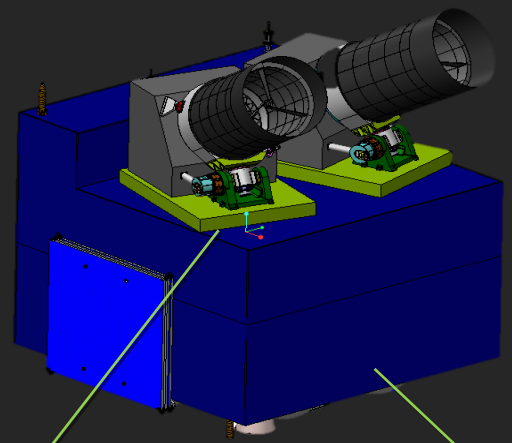


Focus on all-day quantum communications research and fundamental problems:

- ☑ Wider space scale
  - ☑ 10000-36000km （all over）
- ☑ Longer experiment duration
  - ☑ Form minutes to hours
- ☑ Breakthrough earth shadow limit
  - ☑ Generate Key 24 hours

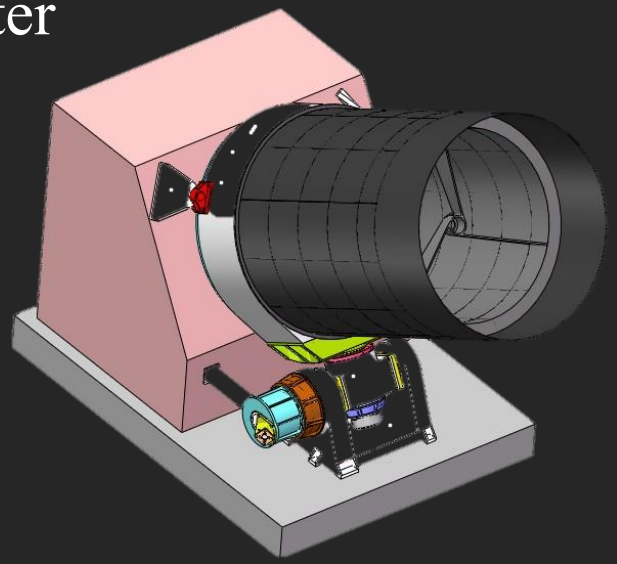
The MEO-to-GEO quantum satellite

- ☑ Ultra static and stable
- ☑ Orbital transfer ability

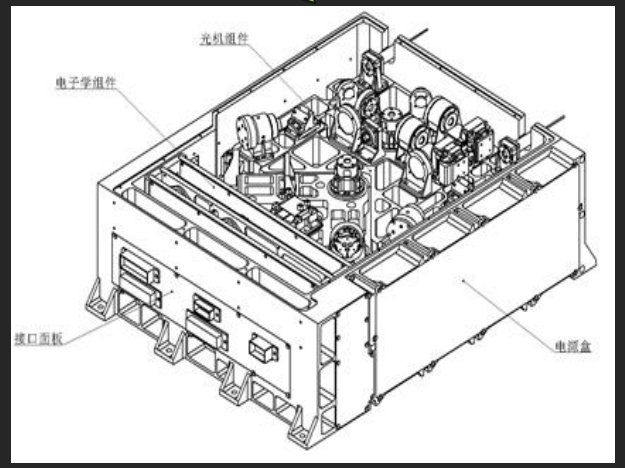


Satellite platform

- ☑ Over 600 mm diameter
- ☑ Divergence angle:
  < 3 μrad
- ☑ Tracking accuracy:
  < 100 nrad



Photon transmission

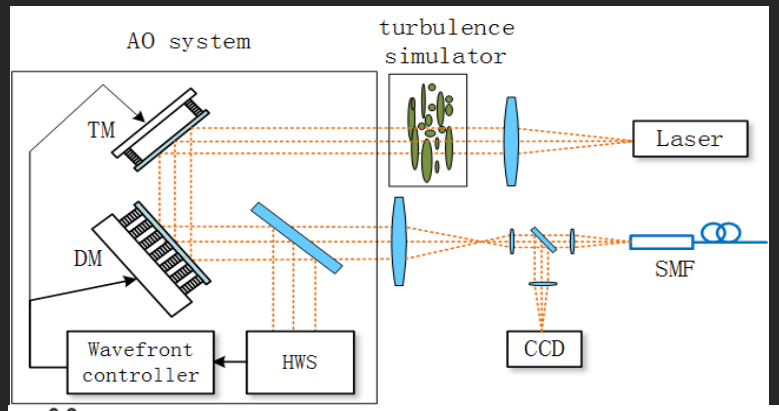


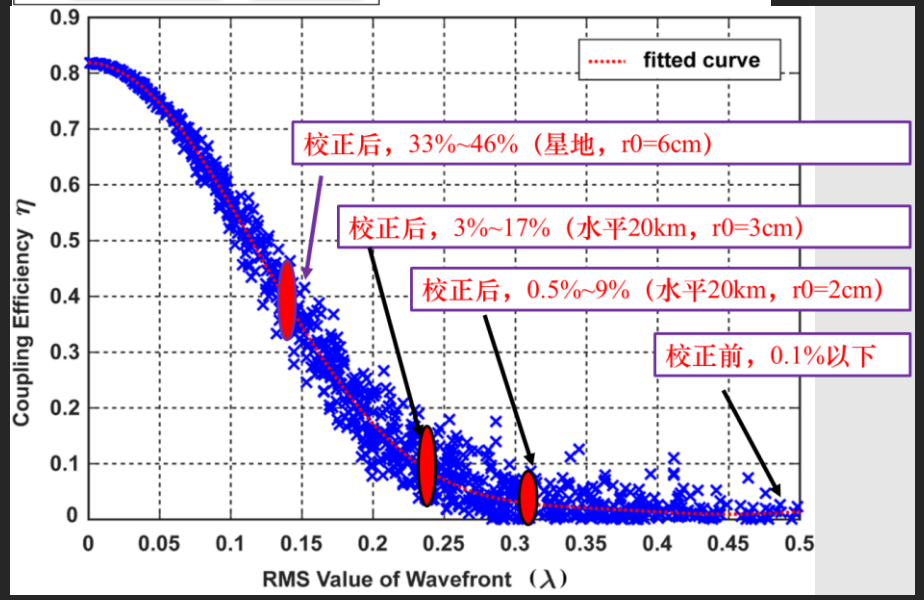
Quantum communication

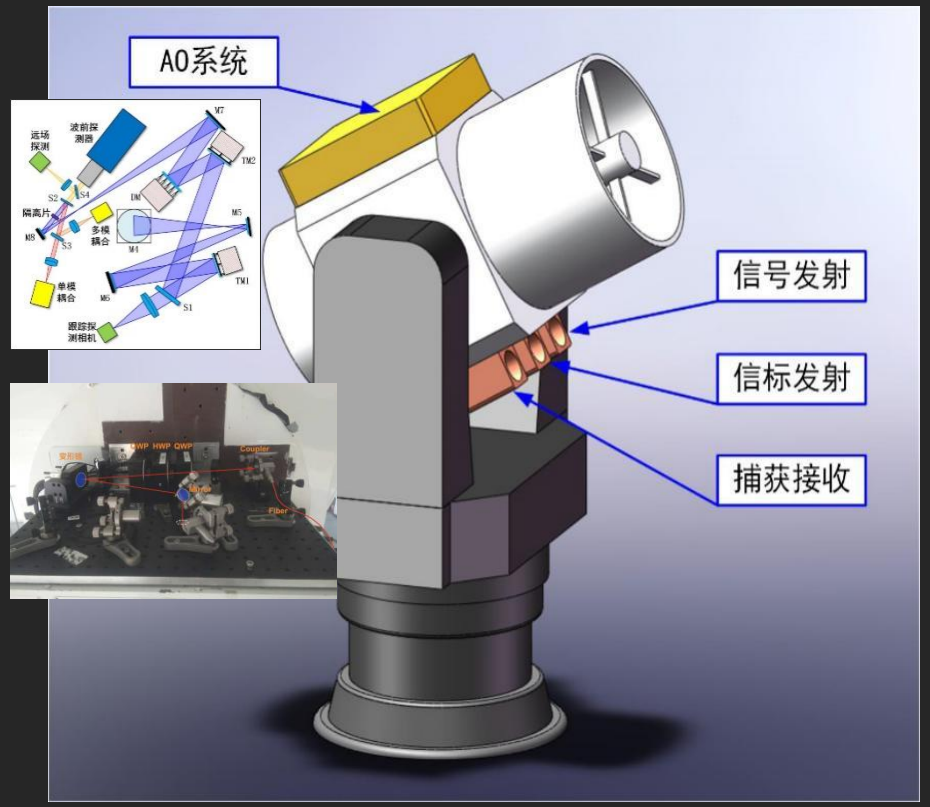
- ☑ GHz entanglement source
- ☑ GHz decoy state QKD source
- ☑ Laser communication

Key Technology for MEO-to-GEO Quantum Satellite

Develop adaptive optics to ground station
Breaking through the limitation of QKD only at night



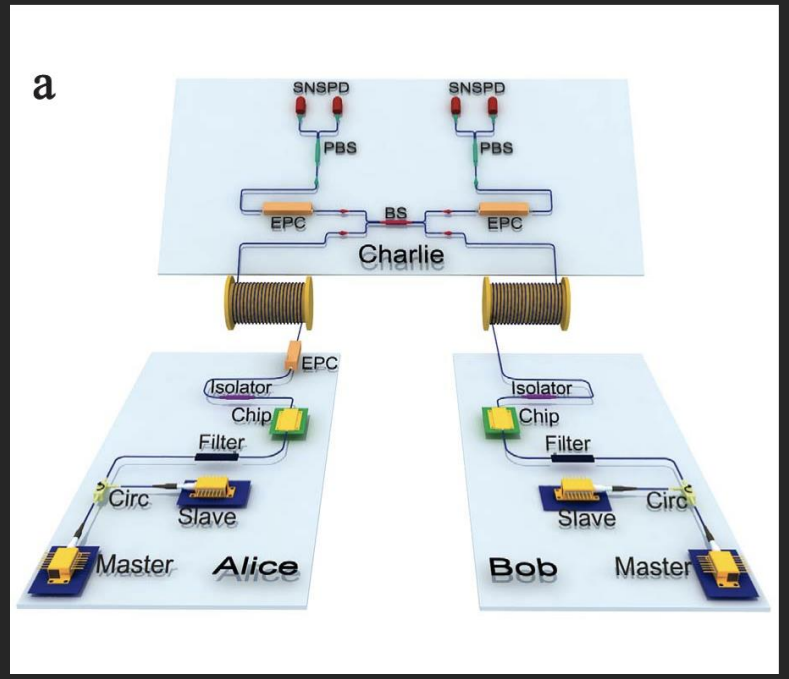




Upgrade the Current Fiber QKD Network in China

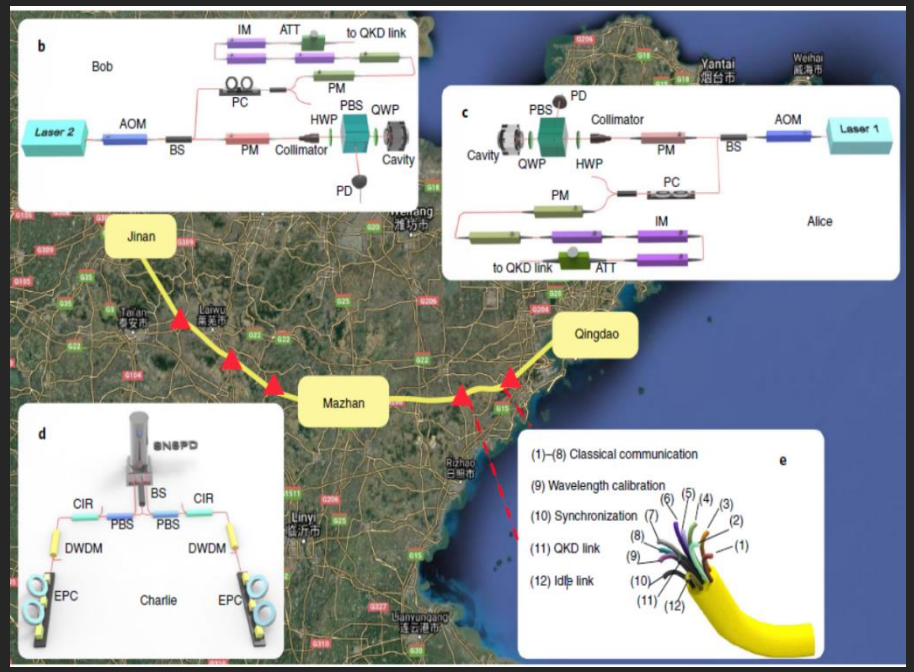
More safer, greater distance, and wider coverage

MDI QKD



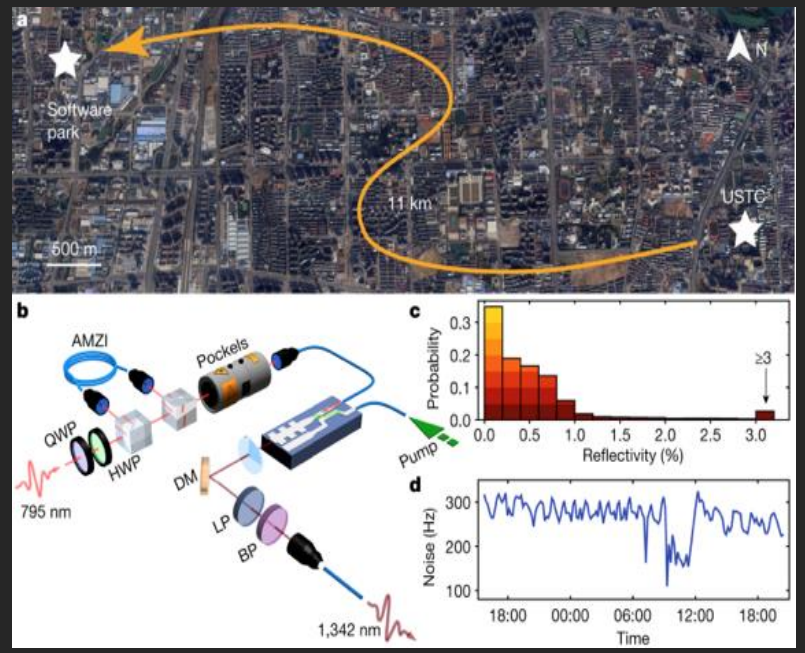
High-speed MDI QKD with integrated silicon photonics
Wei *et al.,* Phys. Rev. X 10, 031030 (2020)

Twin-Field QKD



511 km metropolitan areas:
Chen *et al.,* Nat. Photonics 15, 570 (2021)
509 km with low loss fiber.
Chen *et al.,* PRL 124, 070501 (2020)
Fang *et al.,* Nat. Photonics 14, 422 (2020)

Quantum Repeater



Entanglement of two quantum memories over 22 km.
Yong *et al.,* Nature 578, 240 (2020)

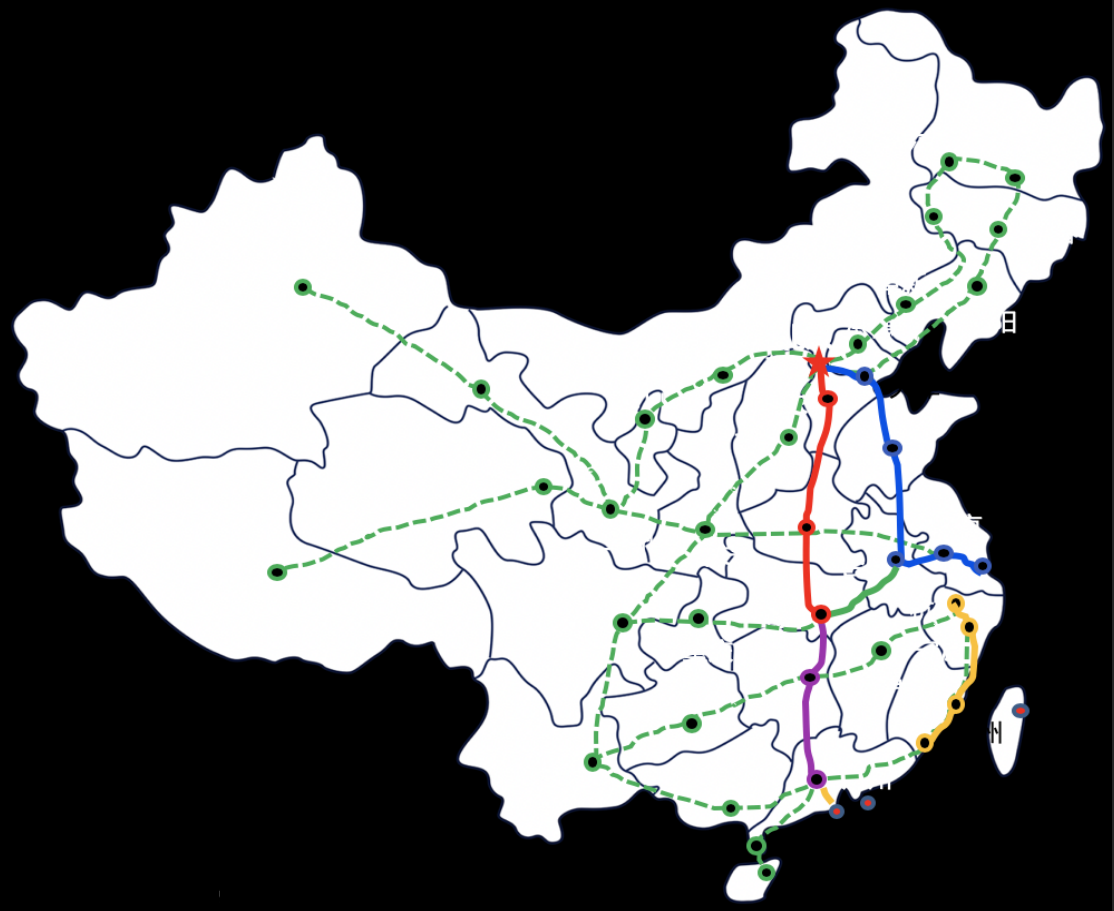
Upgrade the Current Fiber QKD Network in China

More safer, greater distance, and wider coverage

Lines	Longitudinal Backbone			
	Beijing-Shanghai	Beijing-Wuhan	Wuhan-Guangzhou	Extension of Shanghai-Hefei
Length(km)	1979	1700	1400	1400
Phase	Completed	Under Construction	Under Construction	Under Construction

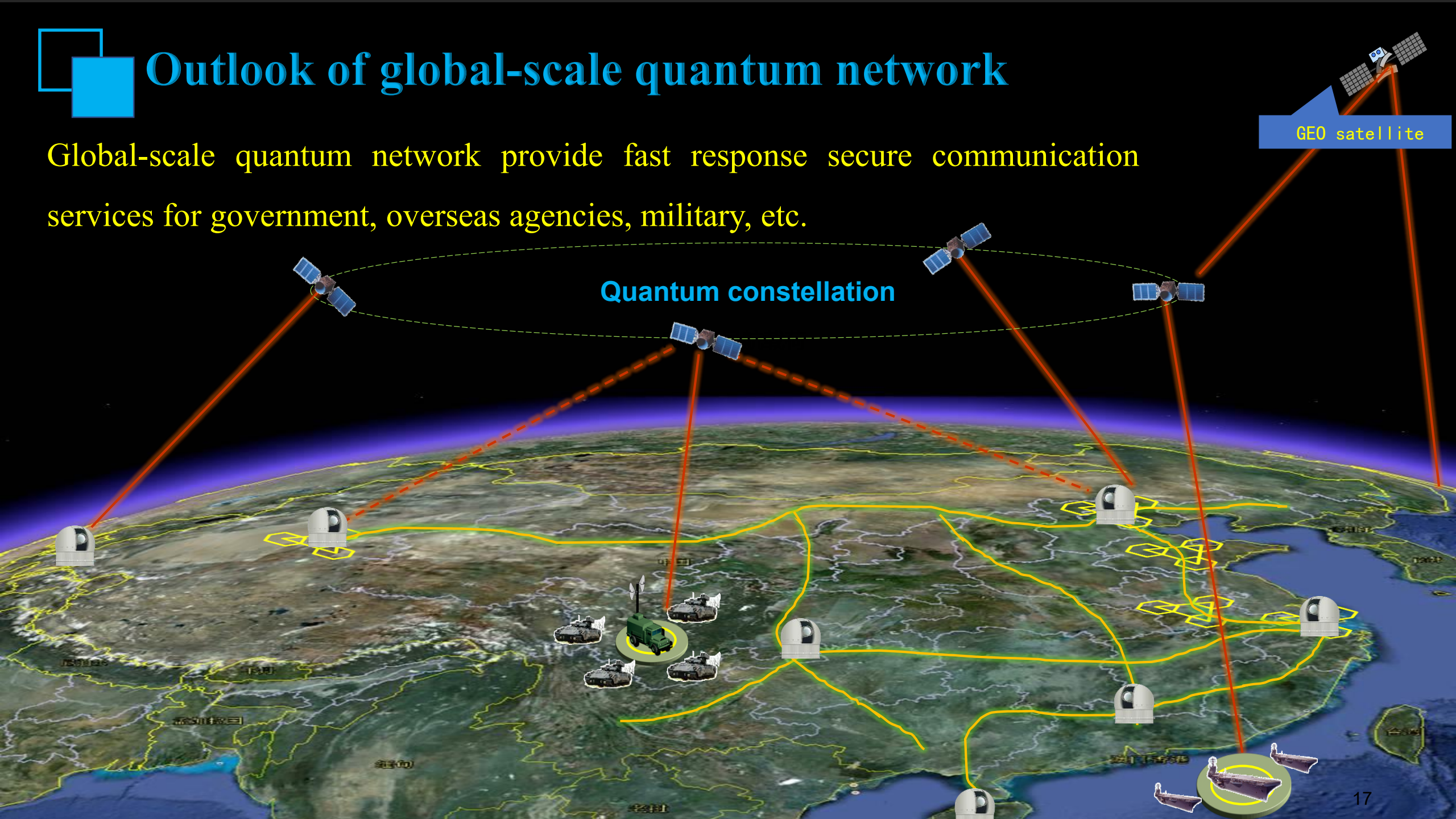
Lines	Transverse Backbone			
	Wuhan-Hefei	Guangdong-Hong Kong-Macao	Shandong	Jianghuai
Length(km)	693	180+180	/	2200
Phase	Completed	Under Construction	Under Review	Proposal

National Quantum Backbone Network



Outlook of global-scale quantum network

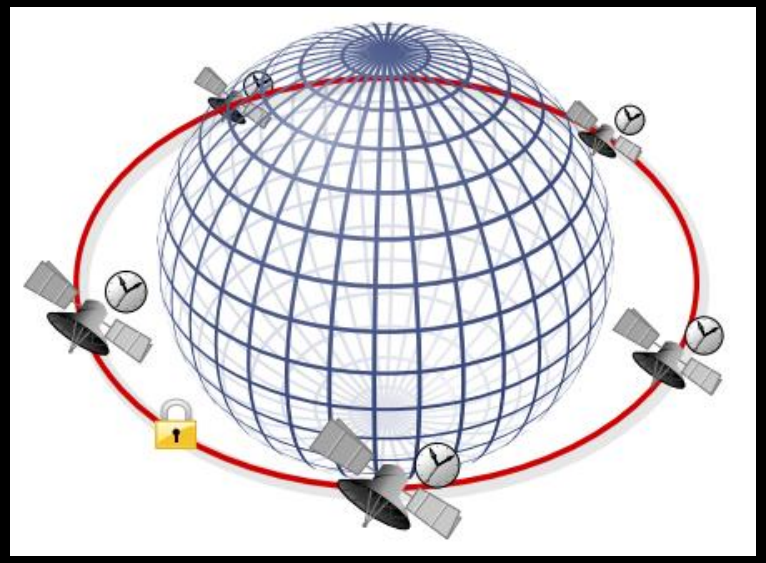
Global-scale quantum network provide fast response secure communication services for government, overseas agencies, military, etc.



Future Prospect

High precision time-frequency transfer network

4 magnitudes better than microwave scheme



Reading on the Earth license plates floating in Jupiter's orbit

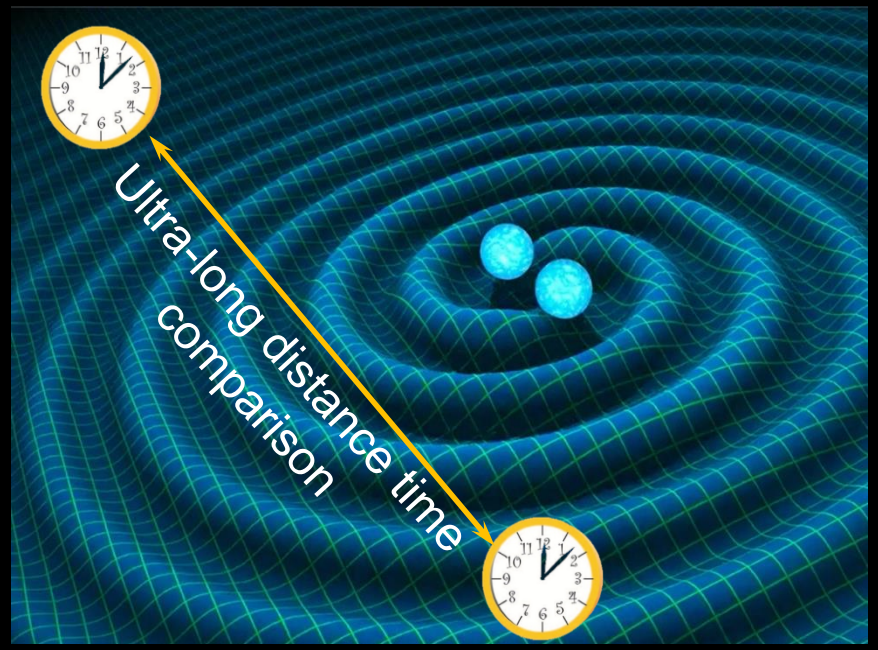
- Global quantum communication infrastructure ➡ "Quantum Internet"
- Combining photons from distributed telescopes worldwide by quantum teleportation in space ➡ Enormous spatial resolution

Nature 535, 478 (2016)

Future Prospect : Quantum Physics Vs. General Relativity

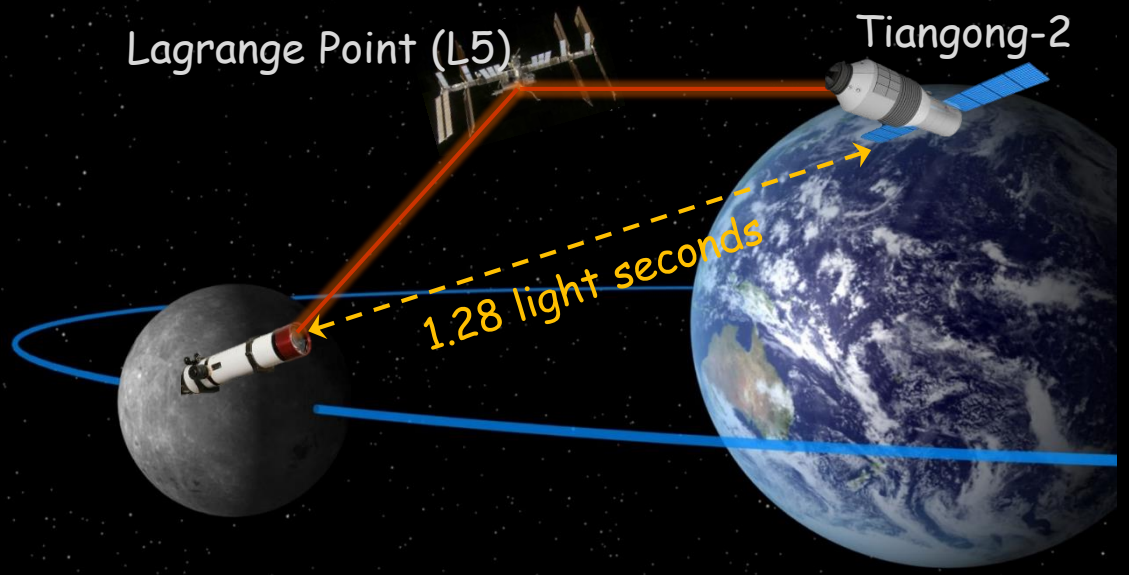
Ultra-high precision optical clocks + Large-scale quantum communication tech.

Long-term stability 10^{-21} (1s @ 10000 billion years)



Large-scale Bell test with Human-observer

Entanglement distribution between the Earth and Moon with China's future Moon landing project!



- Ultra-high-precision optical frequency standard ➡ Global new time reference
- Space-based ultra-high-precision optical clocks holds promise for detecting gravitational waves and dark matter.


Thanks!