Entanglement-based QKD from Micius

Juan Yin

CAS Center for Excellence in Quantum Information and Quantum Physics

University of Science and Technology of China

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Team

Jian-Wei Pan

Chief scientist

Quantum Science Satellite

Cheng-Zhi Peng

Chief engineer

The scientific part of Quantum Science Satellite

Excellence Center for Quantum Information and Quantum Physics

University of Science and Technology of China (USTC)

Shanghai Institute of Technical Physics of the Chinese Academy of Sciences

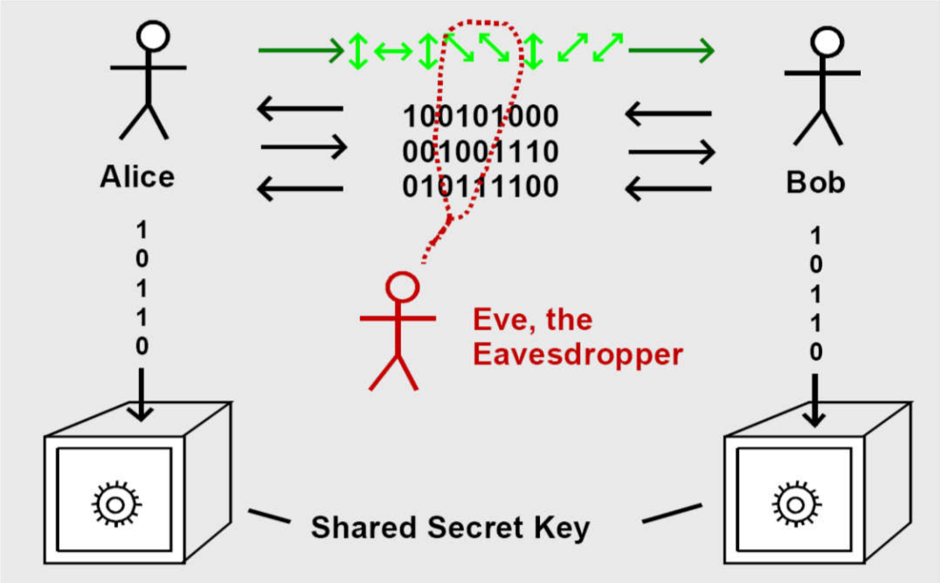
microsat

Shanghai Engineering Center for Microsatellite

The Institute of Optics and Electronics, the Chinese Academy of Sciences

National Astronomical Observatories, Chinese Academy of Sciences

Quantum Communication

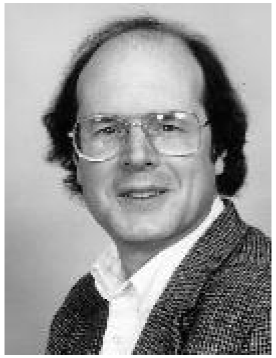


Single-particle-based secret key distribution

Bennett & Brassard (1984)

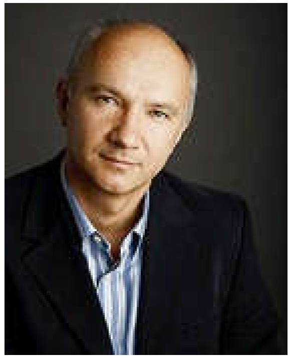
Entanglement-based secret key distribution

Ekert, PRL 67, 661 (1991)

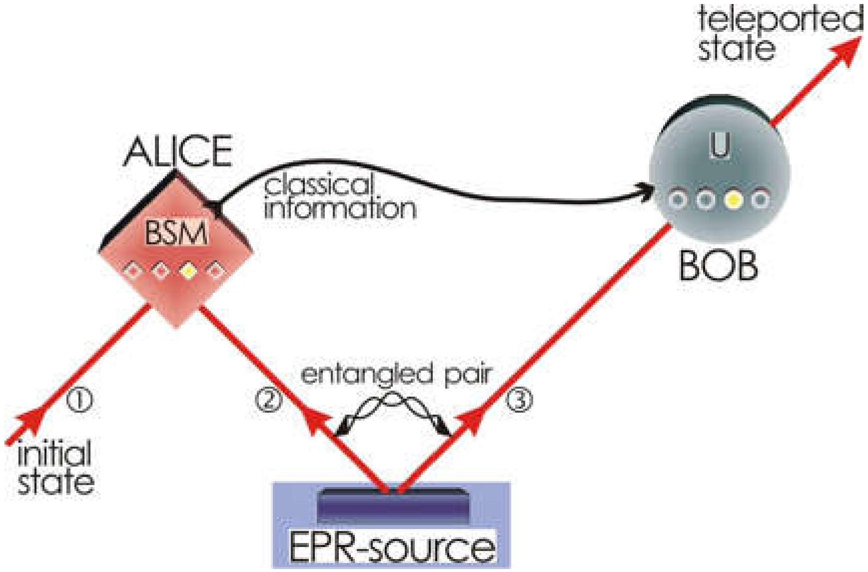


Charles H. Bennett

Gilles Brassard



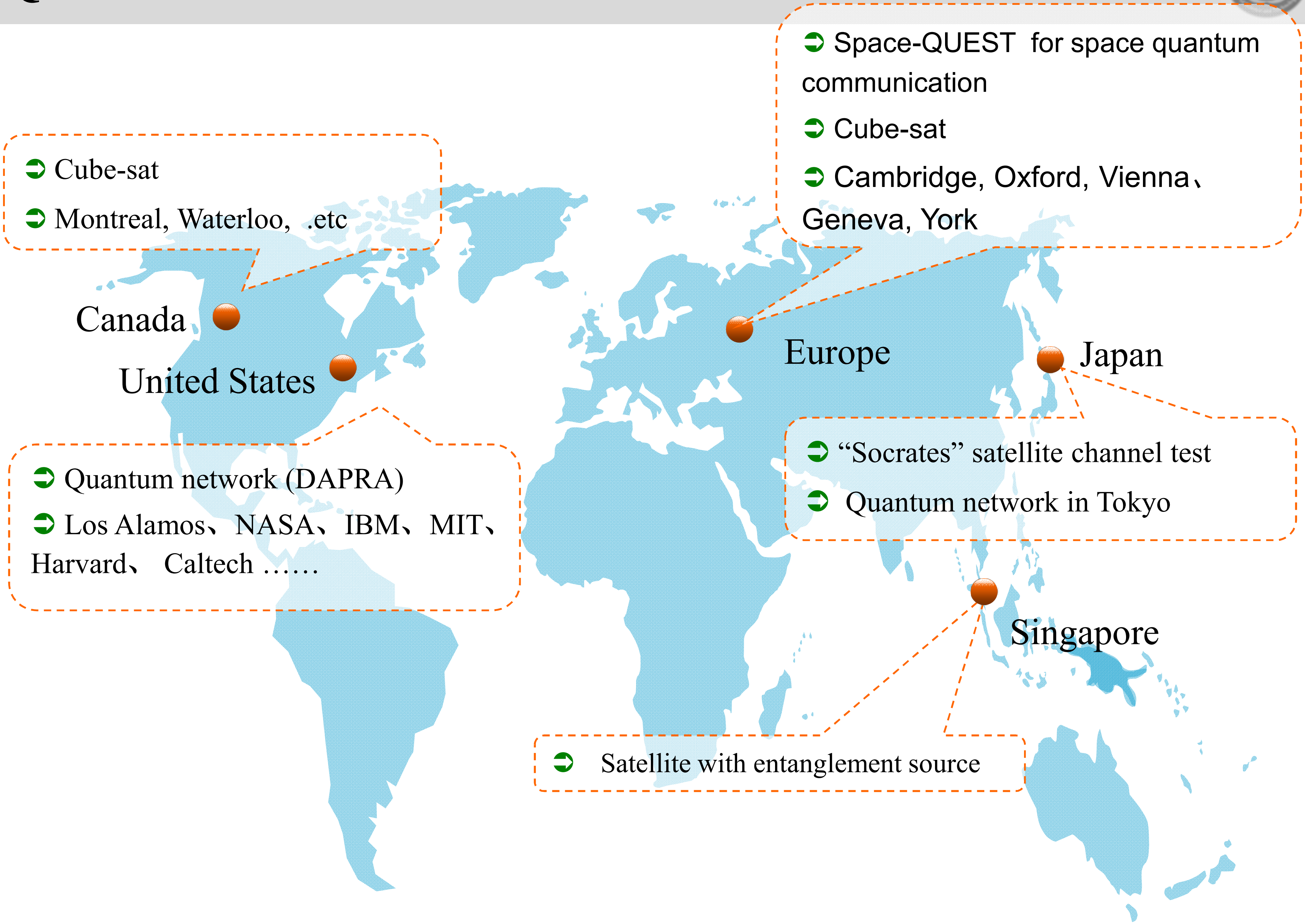
Artur Ekert



Bennett *et al.*, Phys. Rev. Lett. 73, 3801 (1993)

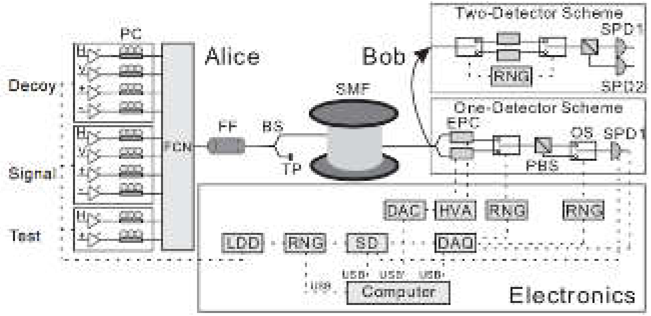
The six “fathers” of quantum teleportation

Quantum Communication

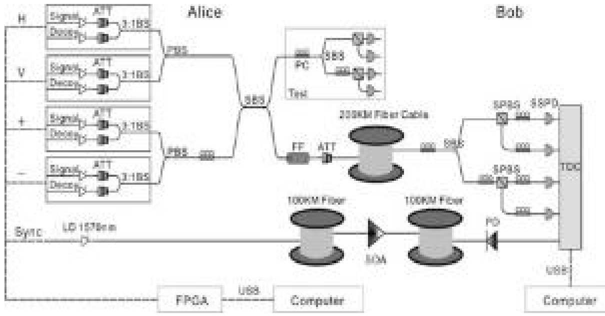


Quantum Communication in China

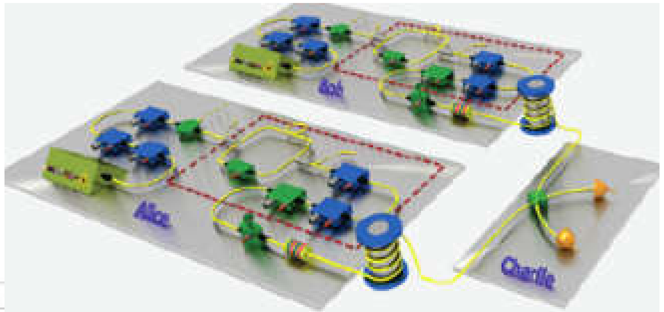
Fiber based Quantum Communication



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

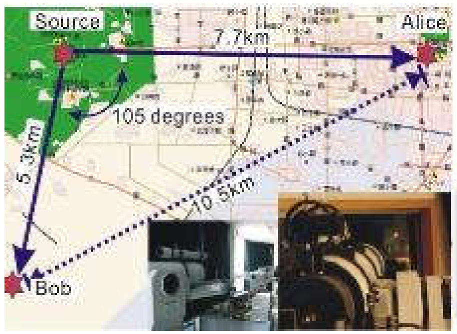


200km Decoy-QKD
Liu *et al.,* Optics Express 18, 8587 (2010)



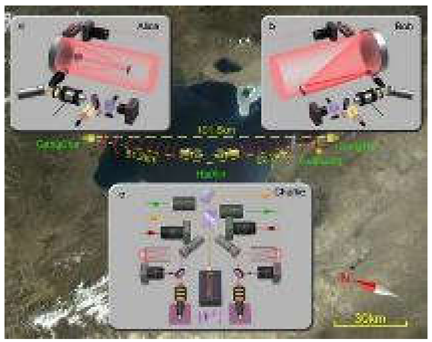
404km MDI-QKD
Yin, *et al.,* PRL. 117, 190501 (2016)

Free Space Quantum Communication

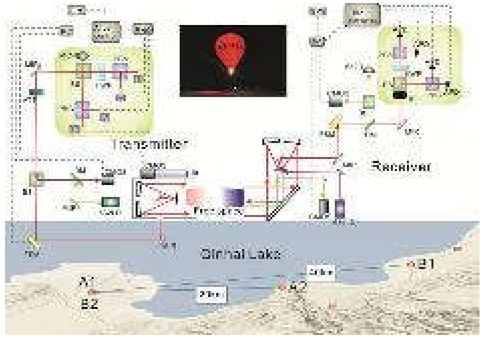


13km quantum entanglement distribution
Peng *et al.*, Phys. Rev. Lett. 94, 150501 (2005)

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)

The timeline of the satellite project

2011

The “Quantum Science Satellite” project was officially approved

2012

The first prototype satellite started

2014

The first prototype satellite was completed and the ground station in Xinglong was completed

2015

The flight model of the satellite was completed. The ground stations in Nanshan and Delingha were completed.

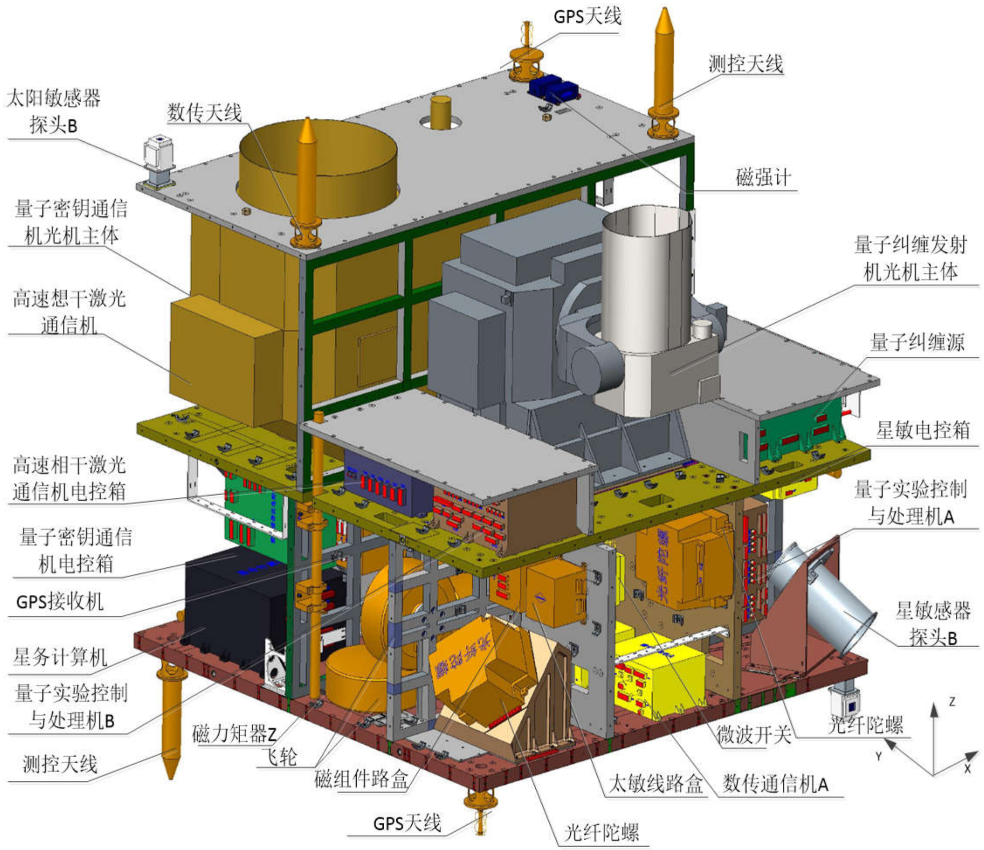
2016

Lijiang and Ali was complete.

The satellite was launched.

“Micius” Quantum Science Satellite

- Total weight of the satellite:631kg
- Average power:560W
- 500km sun synchronous orbit
- With the ability of pointing station

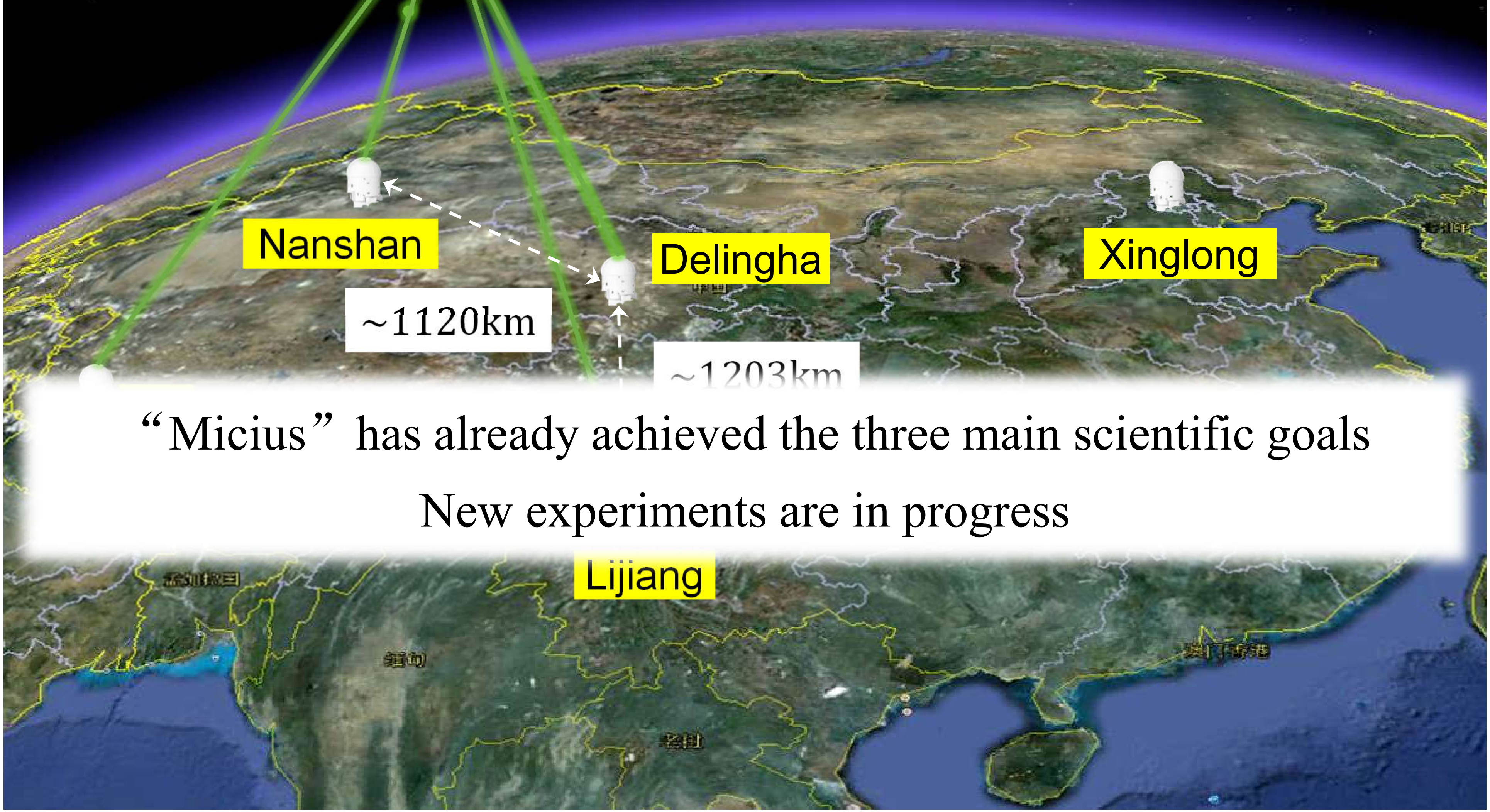


Launched on 16th Aug. 2016

- ✓ Tracking error is about 1urad
- ✓ Polarization visibility is over 100:1
- ✓ Satellite divergence angle is 10urad
- ✓ Channel loss is roughly 30 dB

Experiments of “Micius” Quantum Satellite

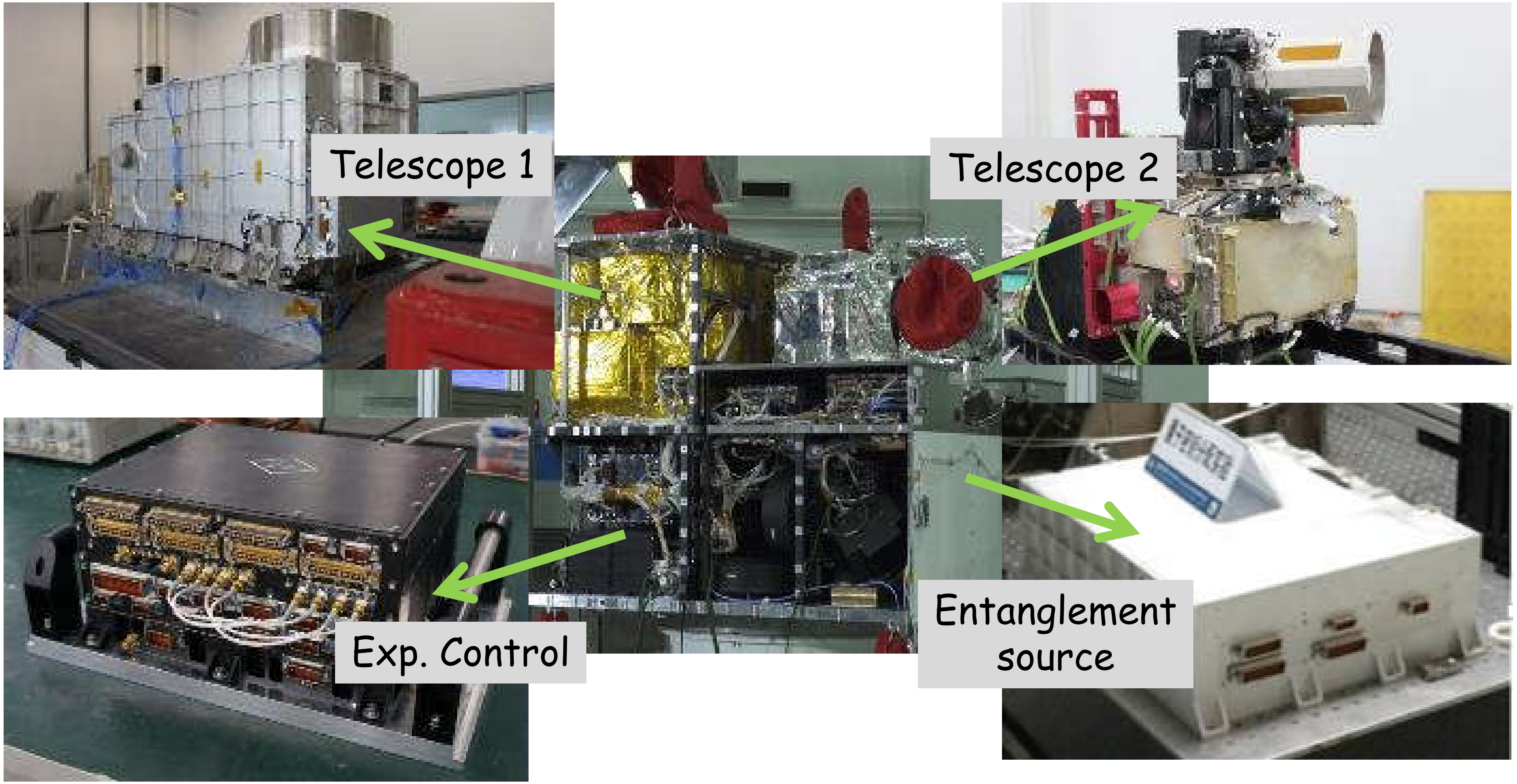
- Quantum key distribution from satellite to earth[Nature 549, 43 (2017)]
- Entanglement distribution over thousand km[Science 356, 1140 (2017)]
- Quantum teleportation from earth to satellite [Nature 549, 70 (2017)]



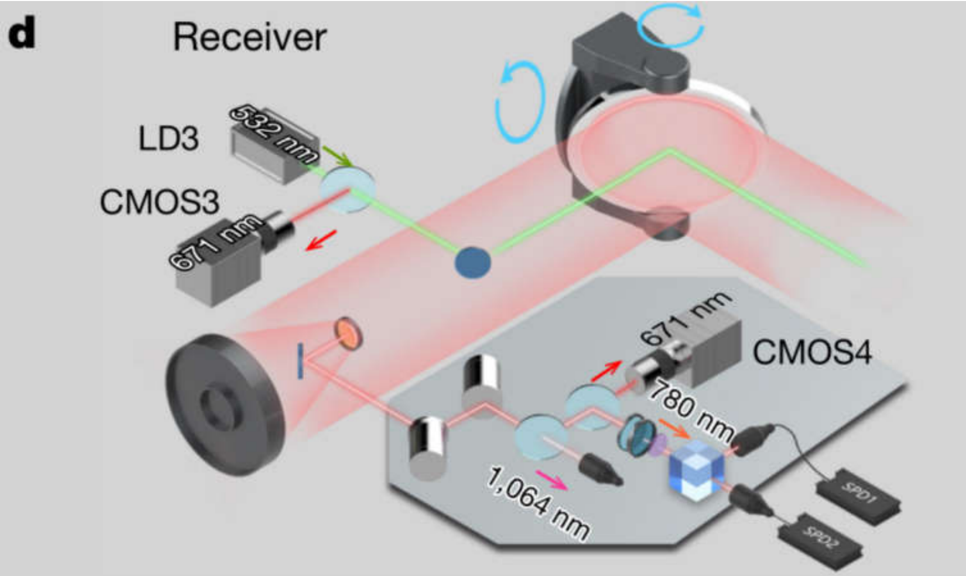
“Micius” has already achieved the three main scientific goals

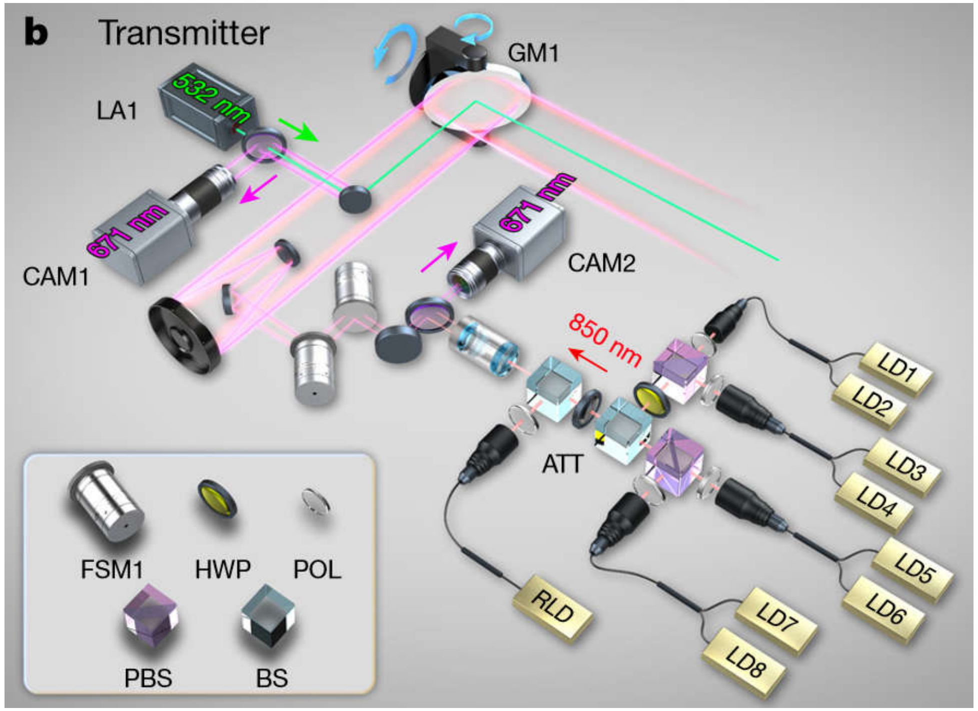
New experiments are in progress

“Micius” Quantum Science Satellite



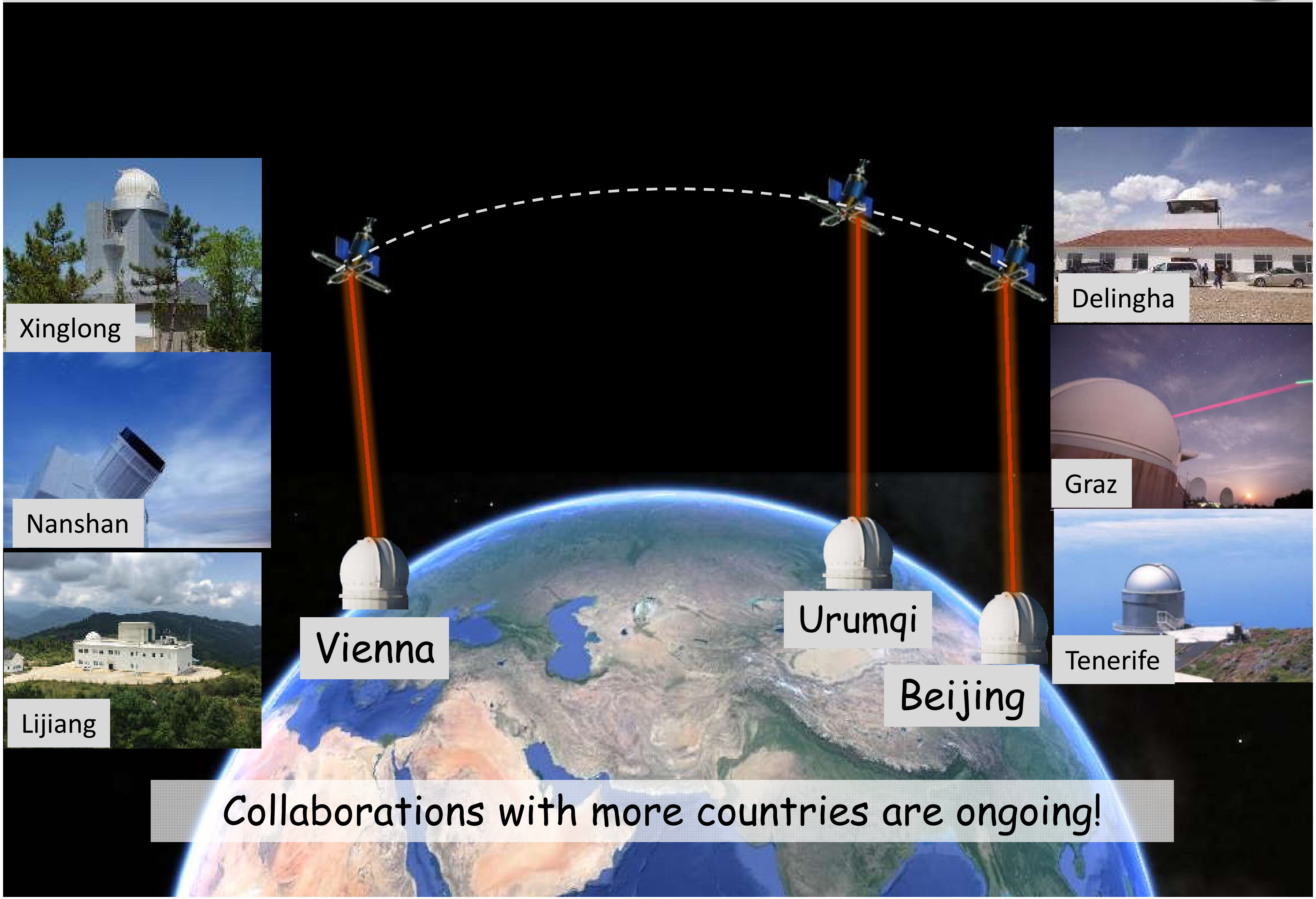
"Micius" Quantum Science Satellite



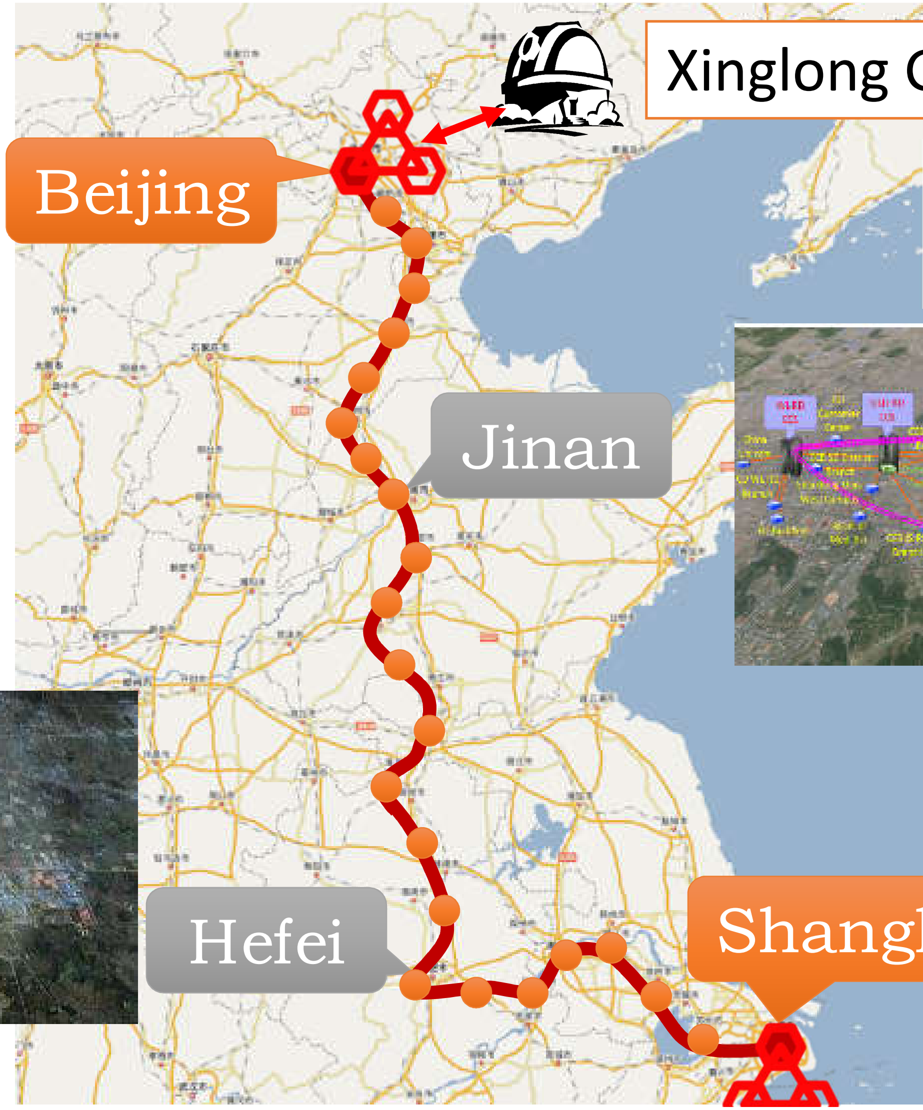


- ☑ 532nm beacon and synchrotron laser source
- ☑ 850nm synchrotron laser source
- ☑ 850nm decoy state source
- ☑ 671nm beacon laser detector
- ☑ 1064nm synchrotron laser detector
- ☑ 780nm quantum signal detector

Further Experiments with Micius



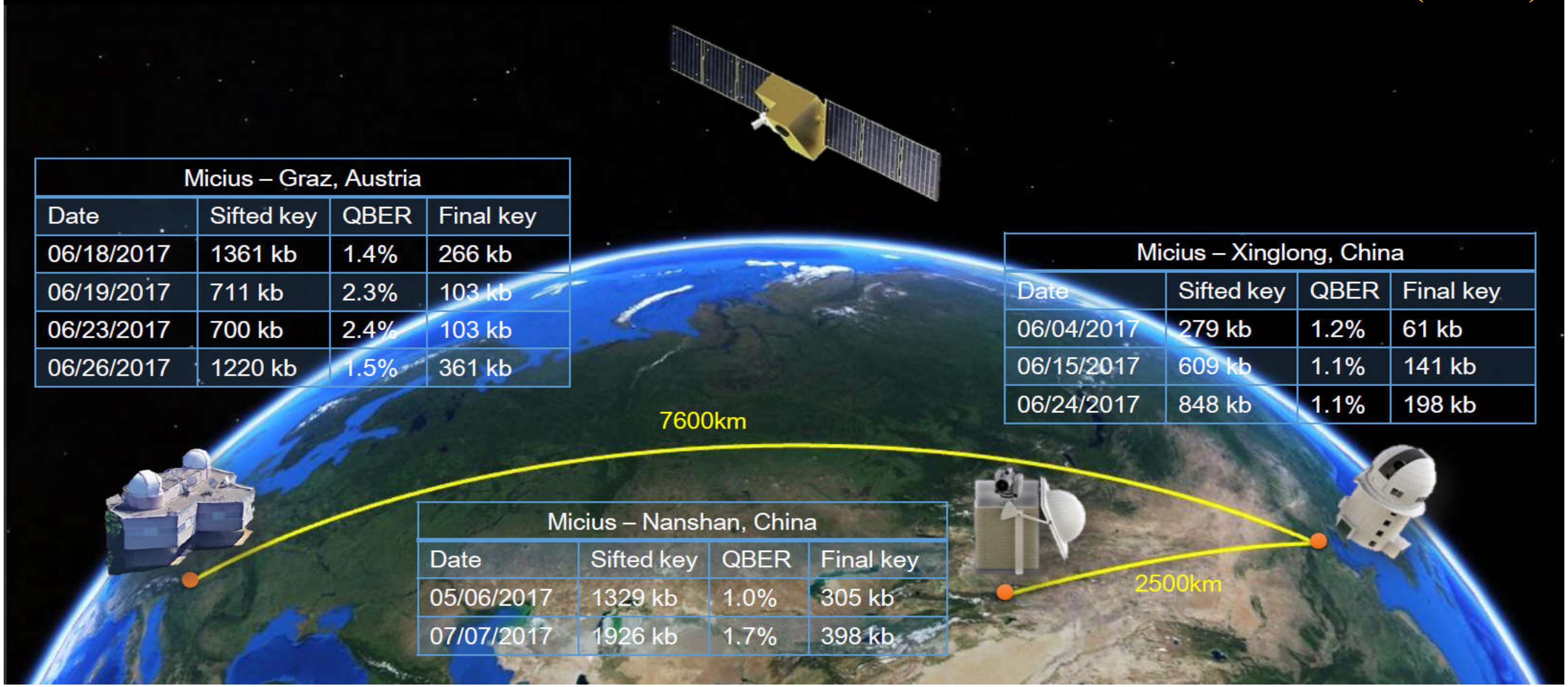
Satellite-relayed intercontinental QKD



Satellite-relayed intercontinental QKD

Intercontinental Quantum Key Distribution

Liao *et al.*, PRL 120, 030501 (2018)



Micius – Graz, Austria			
Date	Sifted key	QBER	Final key
06/18/2017	1361 kb	1.4%	266 kb
06/19/2017	711 kb	2.3%	103 kb
06/23/2017	700 kb	2.4%	103 kb
06/26/2017	1220 kb	1.5%	361 kb

Micius – Xinglong, China			
Date	Sifted key	QBER	Final key
06/04/2017	279 kb	1.2%	61 kb
06/15/2017	609 kb	1.1%	141 kb
06/24/2017	848 kb	1.1%	198 kb

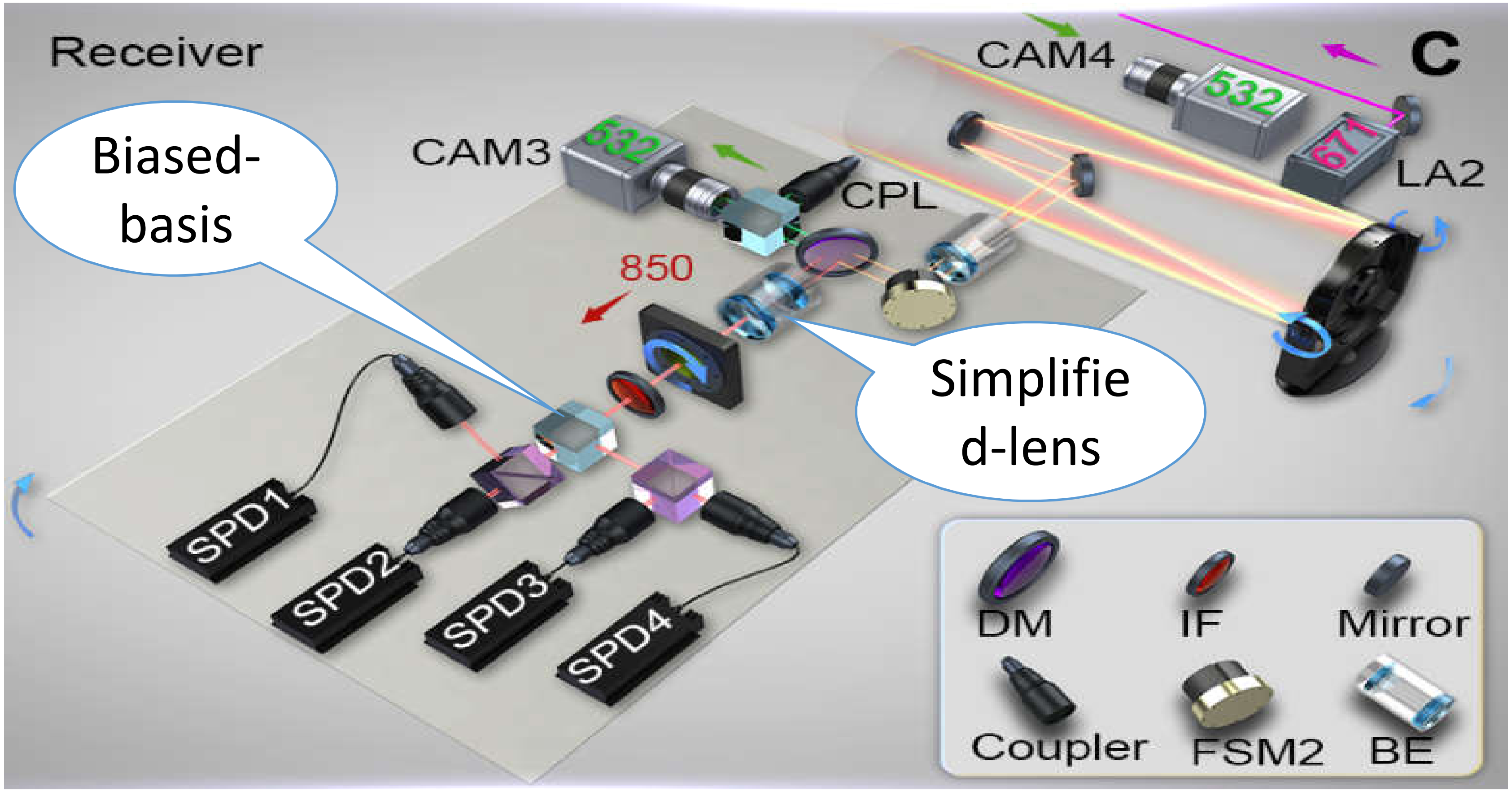
Micius – Nanshan, China			
Date	Sifted key	QBER	Final key
05/06/2017	1329 kb	1.0%	305 kb
07/07/2017	1926 kb	1.7%	398 kb

Jointly explore the feasibility of global QC

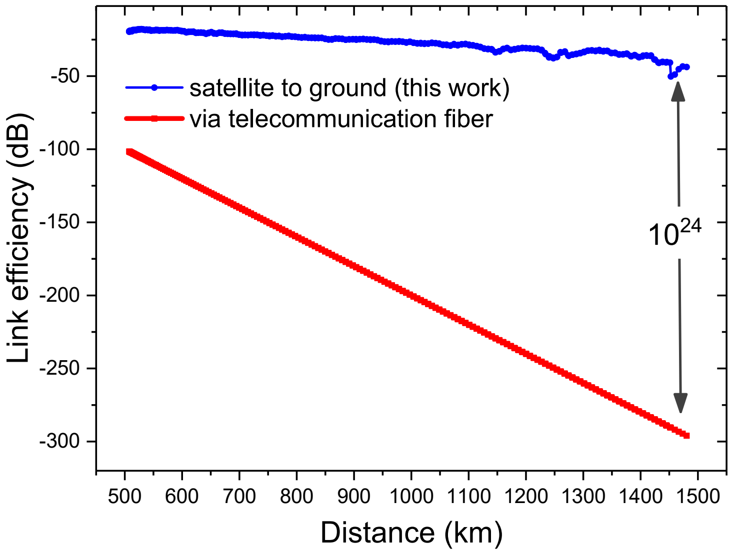
High speed satellite-to-ground QKD

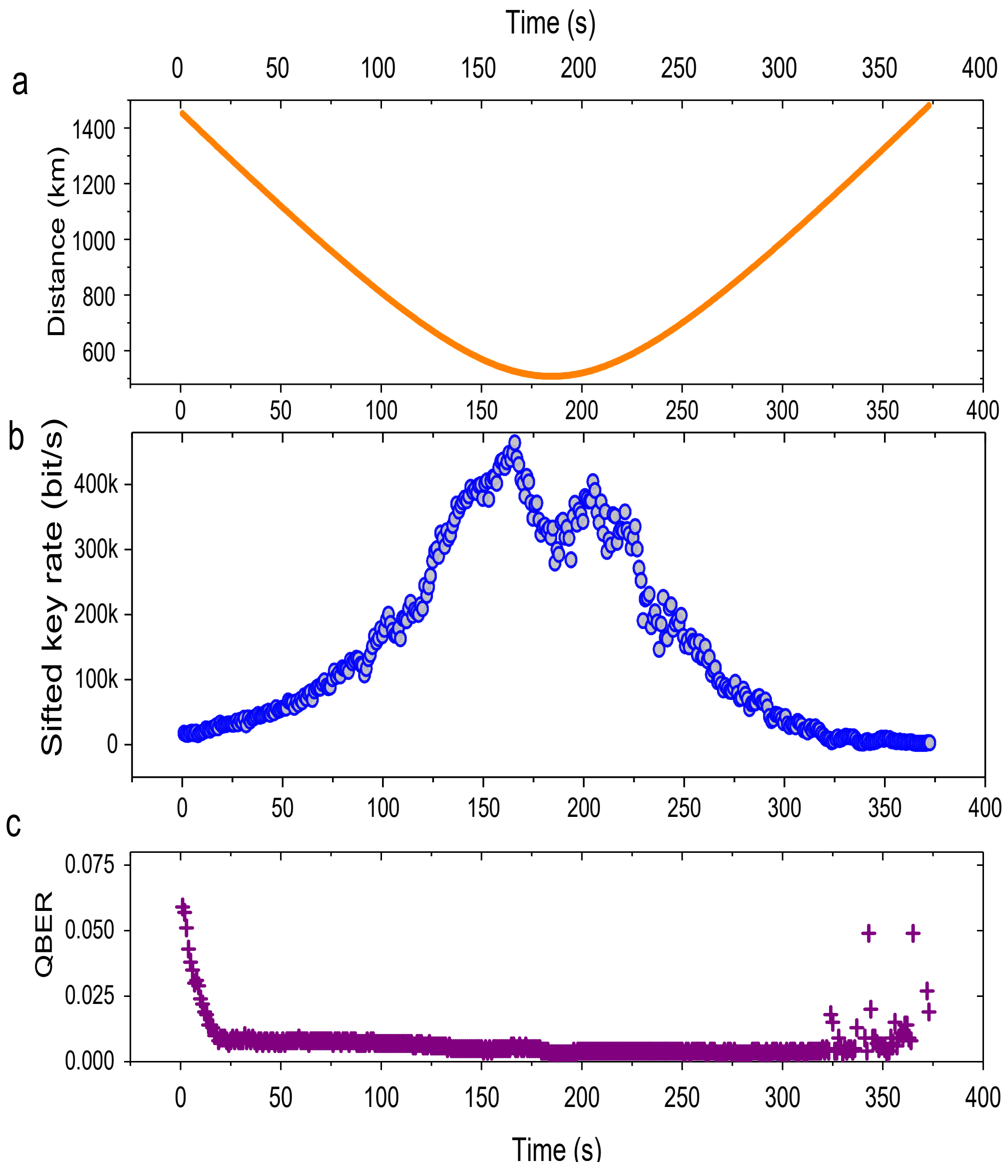
- ✓ Efficient BB84 QKD/ biased-basis QKD; Sifting efficiency 50% => 77%
- ✓ Repetition rate 100Mhz => 200Mhz
- ✓ Improved receiving efficiency 20% => 45%

Ground station upgrade



High speed satellite-to-ground QKD

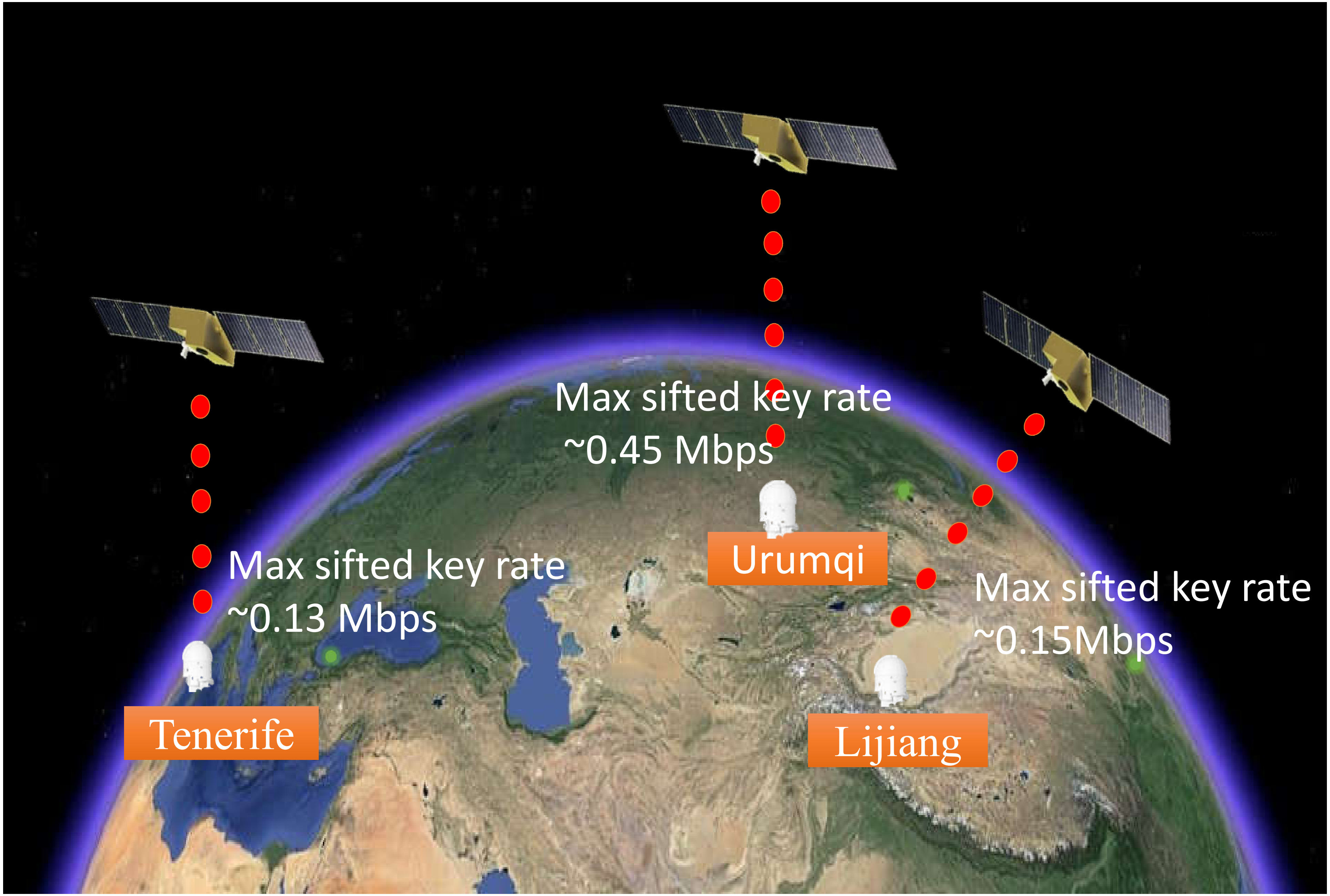




Micius->NanShan

- Max Sifted key rate **~450kbps**
- QBER ~1%
- Final key ~12 Mbits
- Final key rate ~40kbps

High speed satellite-to-ground QKD



Entanglement-based QKD

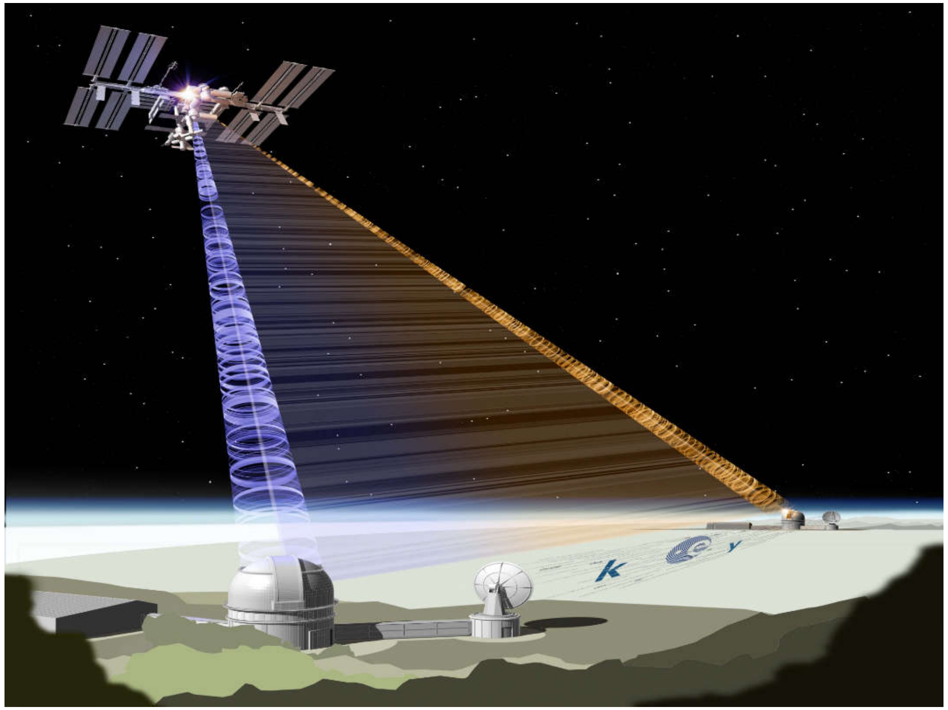
Quantum cryptography based on Bell's theorem

Ekert, PRL 67, 661 (1991)

Quantum cryptography without Bell's theorem

Bennett&Brassard&Mermin, PRL 68, 557 (1992)

Without relying on trustful relay



satellite/entangled photon source could even be in the hands of an adversary

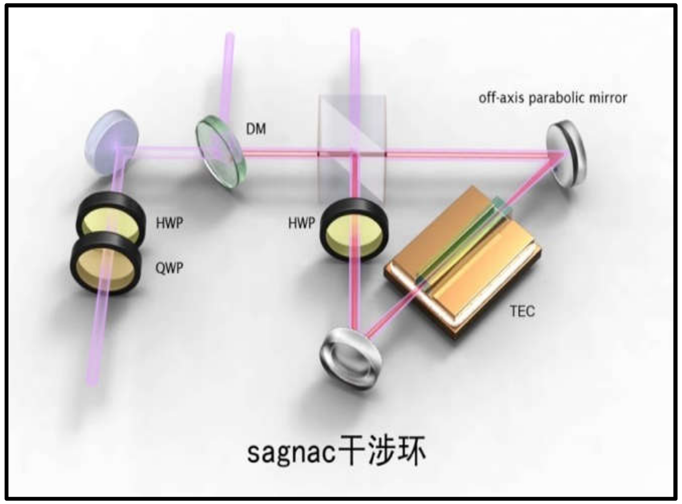
"This would achieve the holy Grail that all cryptographers have been dreaming of for thousands of years"

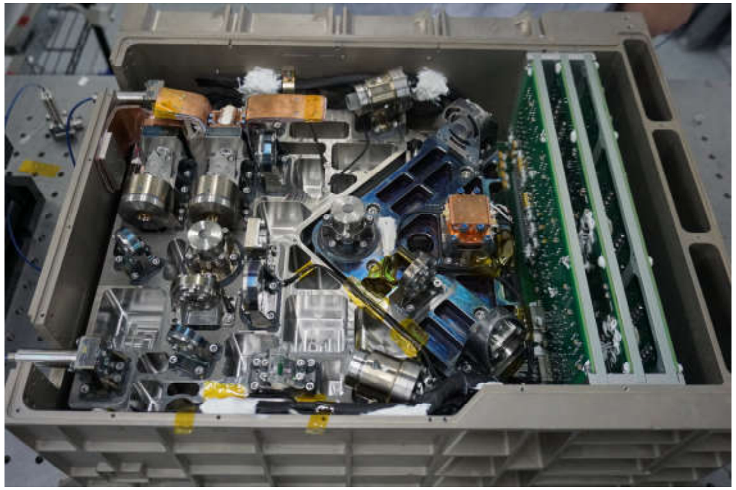
Entanglement-based QKD

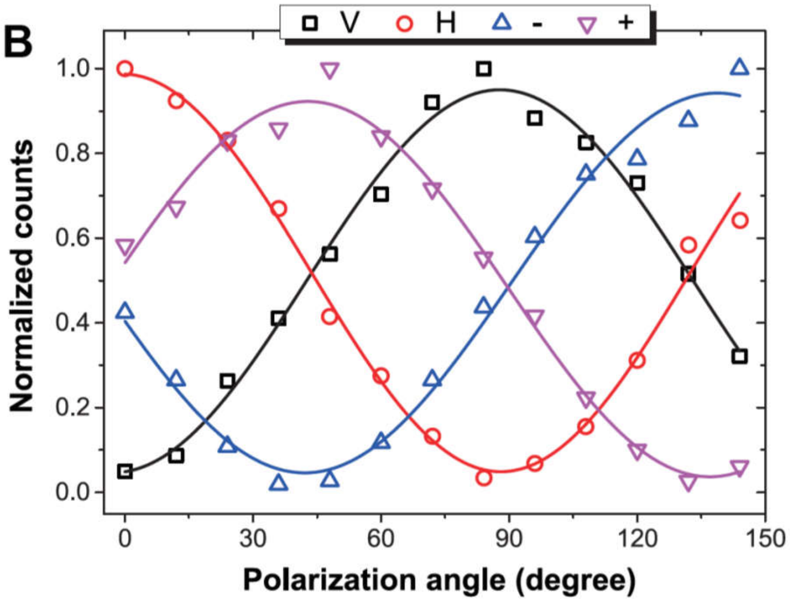
II-type PPKTP in Sagnac

In-orbit test

- Visibility 20:1@2M
- Rate 8 MHz

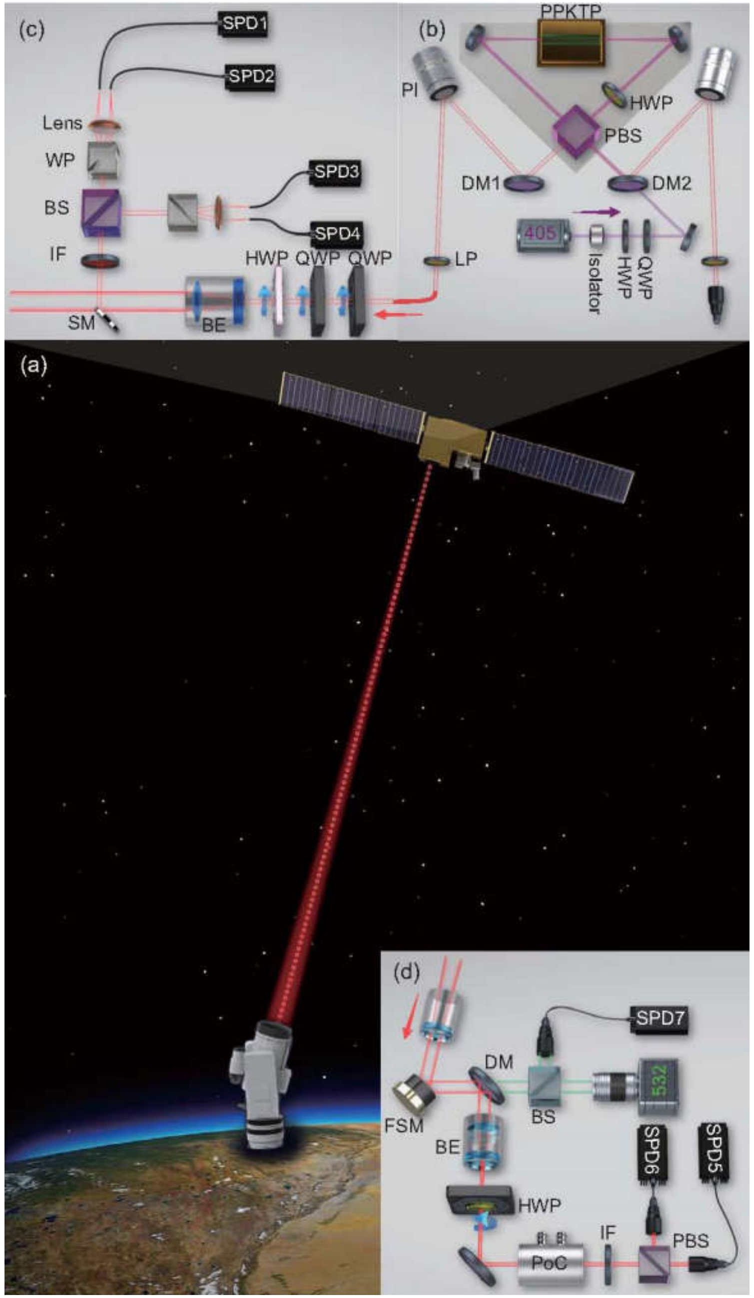






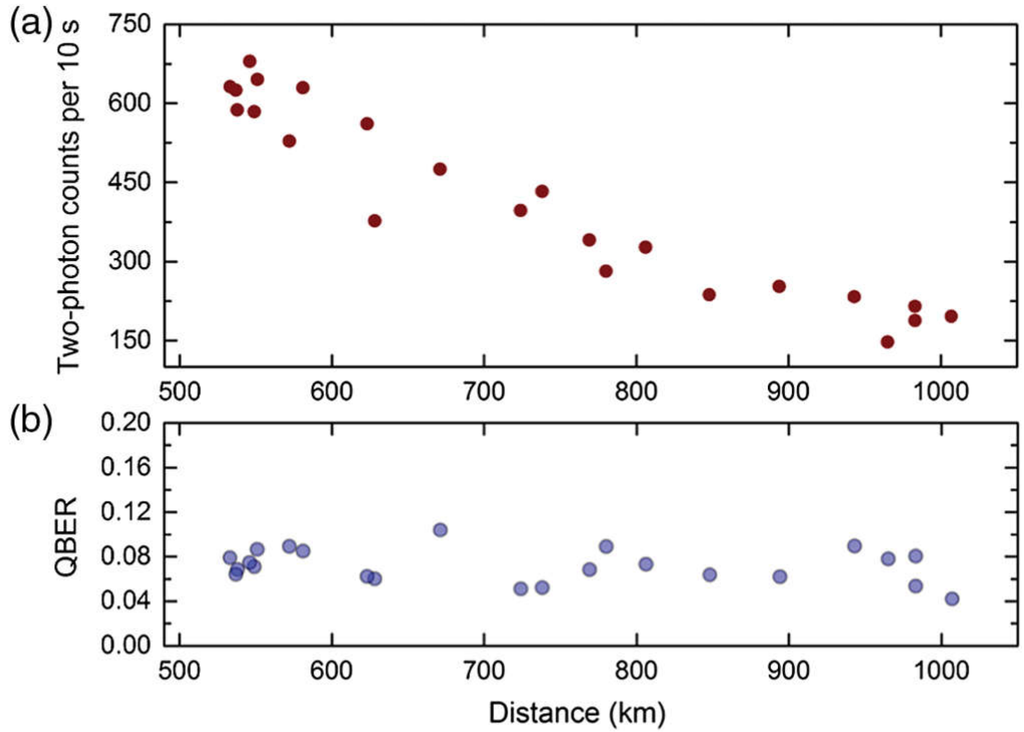
Date	S	σ	S. d.
2016.10.19	2.442	0.012	37
2016.10.20	2.436	0.012	36
2016.10.21	2.379	0.012	32

Entanglement-based QKD



Satellite-to-ground entanglement-based QKD

- Distance:530km-1000km
- Channel loss:29dB-36dB
- Final key: 3.5bits/s (1% sampling)

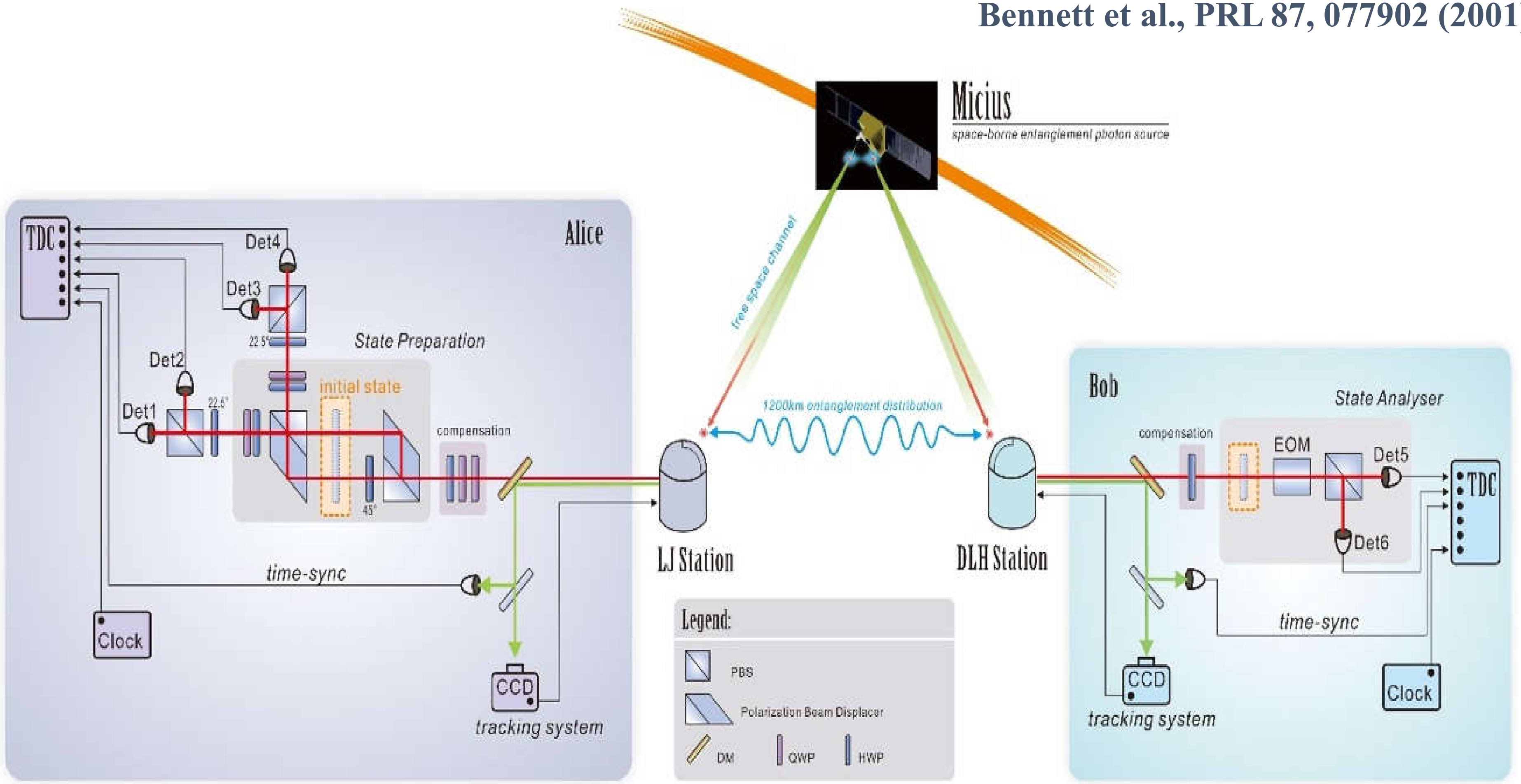


Yin *et al.*, PRL 119, 200501 (2017)

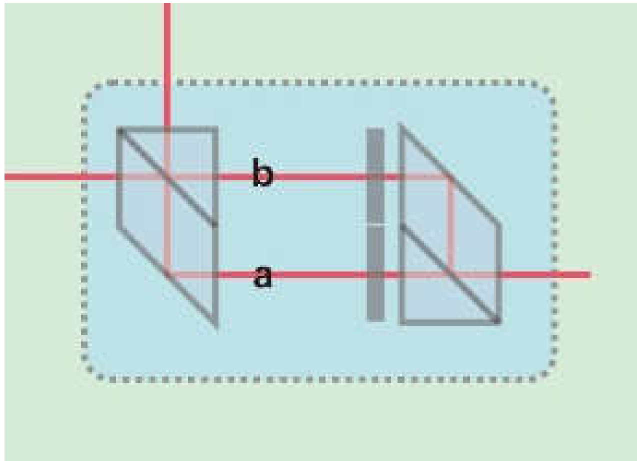
Remote state preparation

Remote state preparation

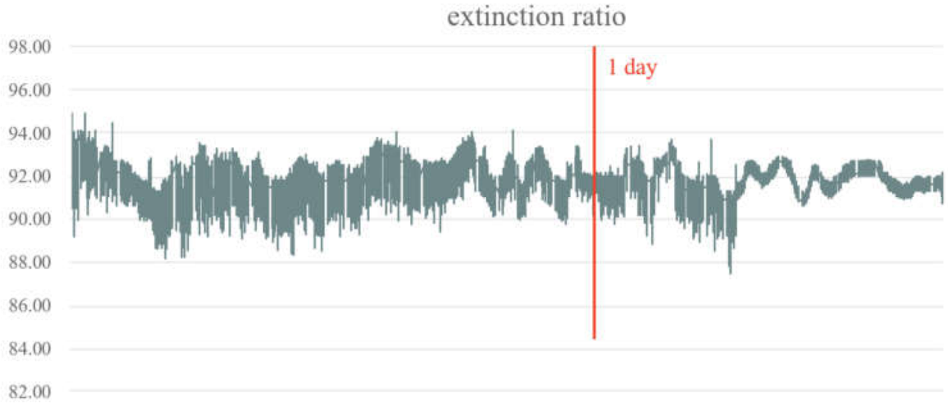
Bennett et al., PRL 87, 077902 (2001)



Some new attempts with satellite-borne entanglement source

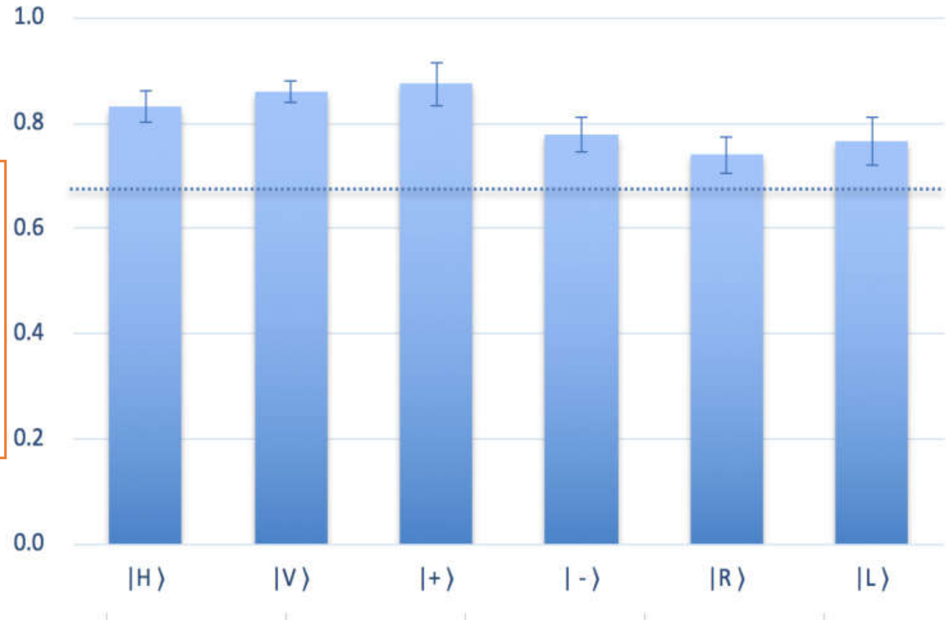


The integrated MZI



Extinction ratio of MZI lasting over 1 day

- Extinction ratio of MZI: > 88:1
- Channel loss: 64 dB - 82 dB
- Average fidelity: > 80%



Address loopholes in Bell Test

✓ Involve human observers for addressing the loopholes.

☒ **Freedom of choice loophole**: random number generators (RNGs) could be prior correlated ➡ the choice of measurement bases are not truly random

Brunner *et al.*, RMP 86, 419 (2014)

☒ **Collapse locality loophole**: measurement outcome is not defined until it is registered by a human consciousness ➡

Realized "events" have never been space-like separated

Kent, PRA 72, 012107 (2005)

Leggett, Compendium of Quantum Physics (Springer, 2009)

Requirement:

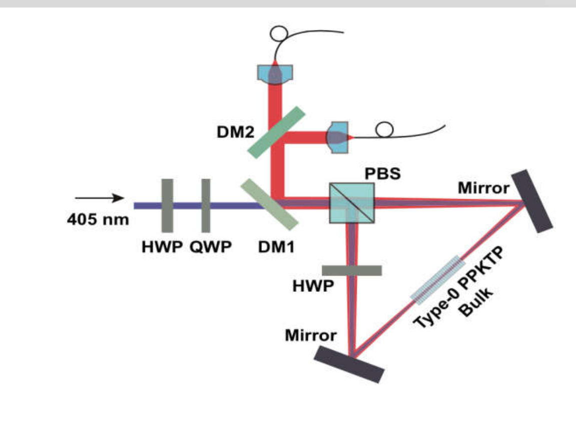
Quantum signal transit time exceeds human reaction 100ms ➡

- ✓ Entanglement distribution at a distance on the order of one light-second
- ✓ Ultra-high brightness Entanglement source is needed

Address loopholes in Bell Test

Present a proposal between Earth and Moon to address freedom-of-choice and collapse loopholes.

- Proof-of-principle exp.: Bell test with human supplying random measurement over simulated extremely high loss channel (103dB)



GHz entanglement source for the Bell test between Earth and Moon

Cao et al., PRL 120, 140405 (2018)

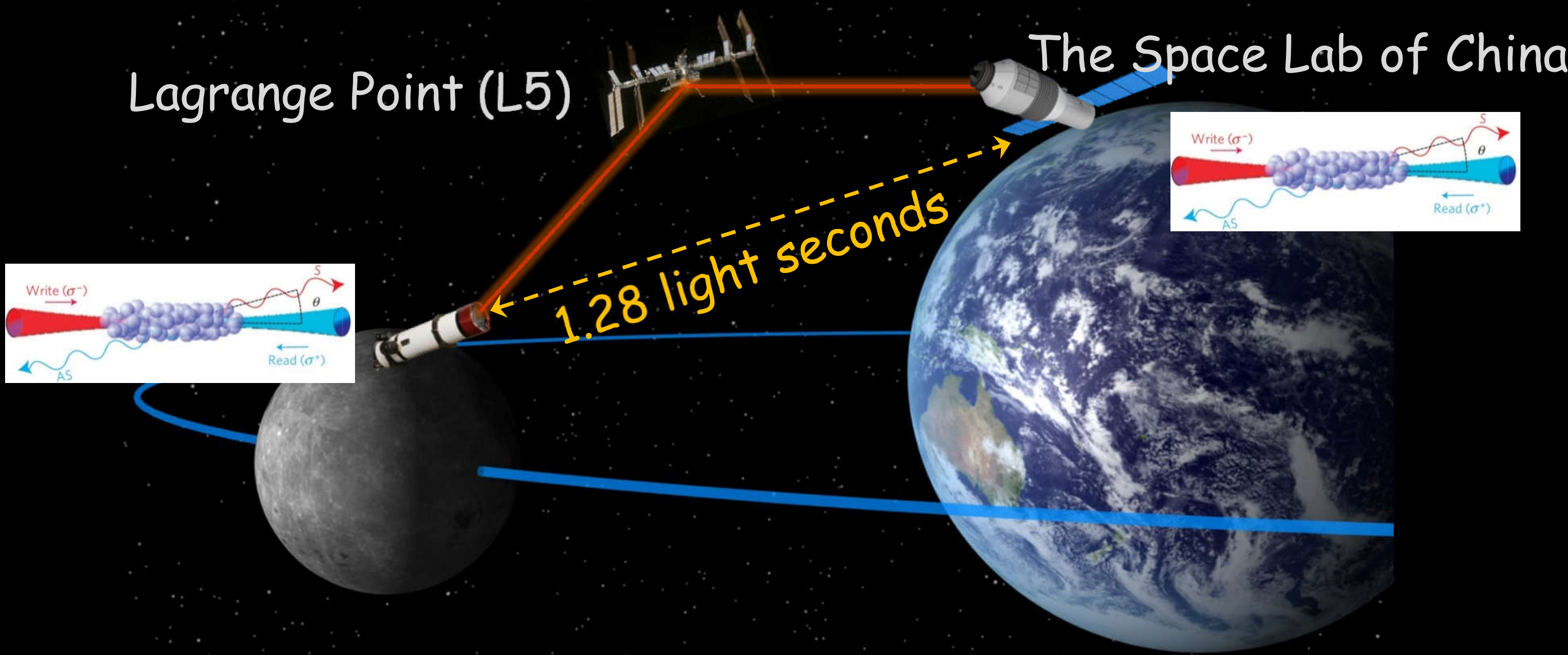
Challenging local realism with human choices

- Generating random numbers with the help of worldwide 100,000 volunteers' free will
- 12 labs run Bell tests with the human's random numbers (ICFO, ICREA, ETH Zurich, **USTC**, et al.)

Nature 557, 212-216 (2018)

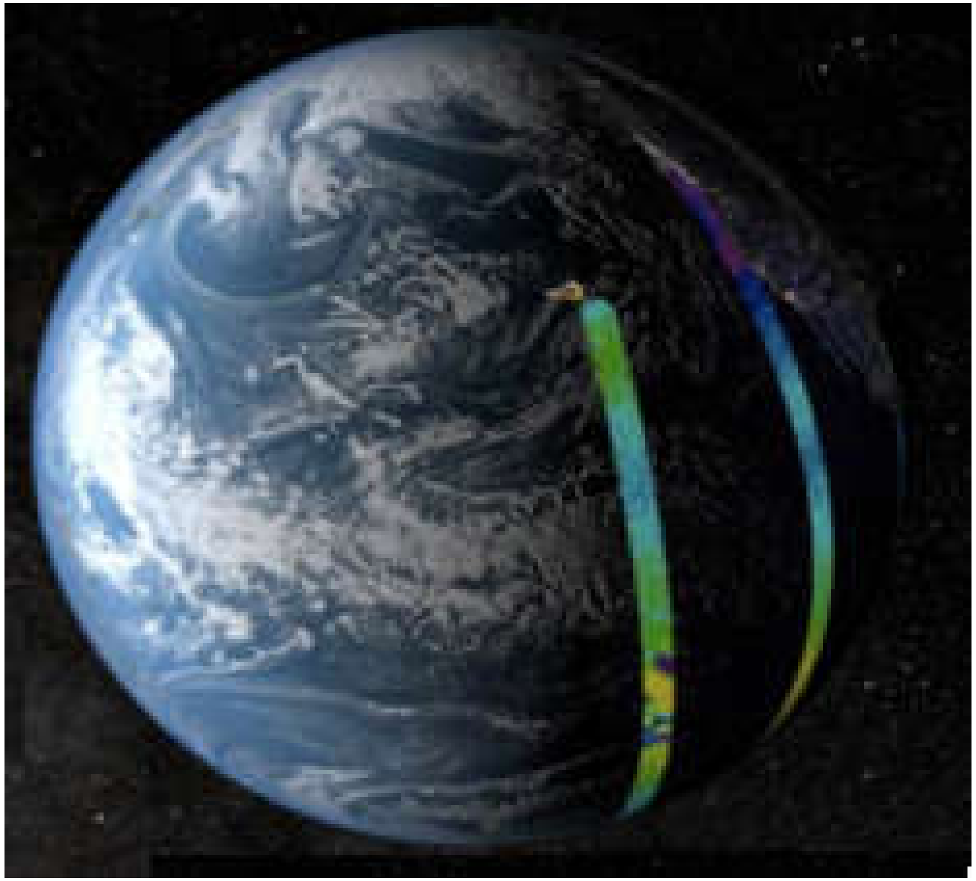
Future Prospect: Quantum Exp. Between Earth and Moon

- Large-scale Bell test with Human-observer
- Realize the truly loophole-free Bell test between Earth and Moon with quantum memory and event-ready scheme?



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

Future Prospect: Global Quantum Network



- Experiment time is ~ 8 minutes for each pass
- Coverage range is about 500km (Radius)
- Have to be in the shadow of earth
- Weather condition affects

☑ Fiber quantum network

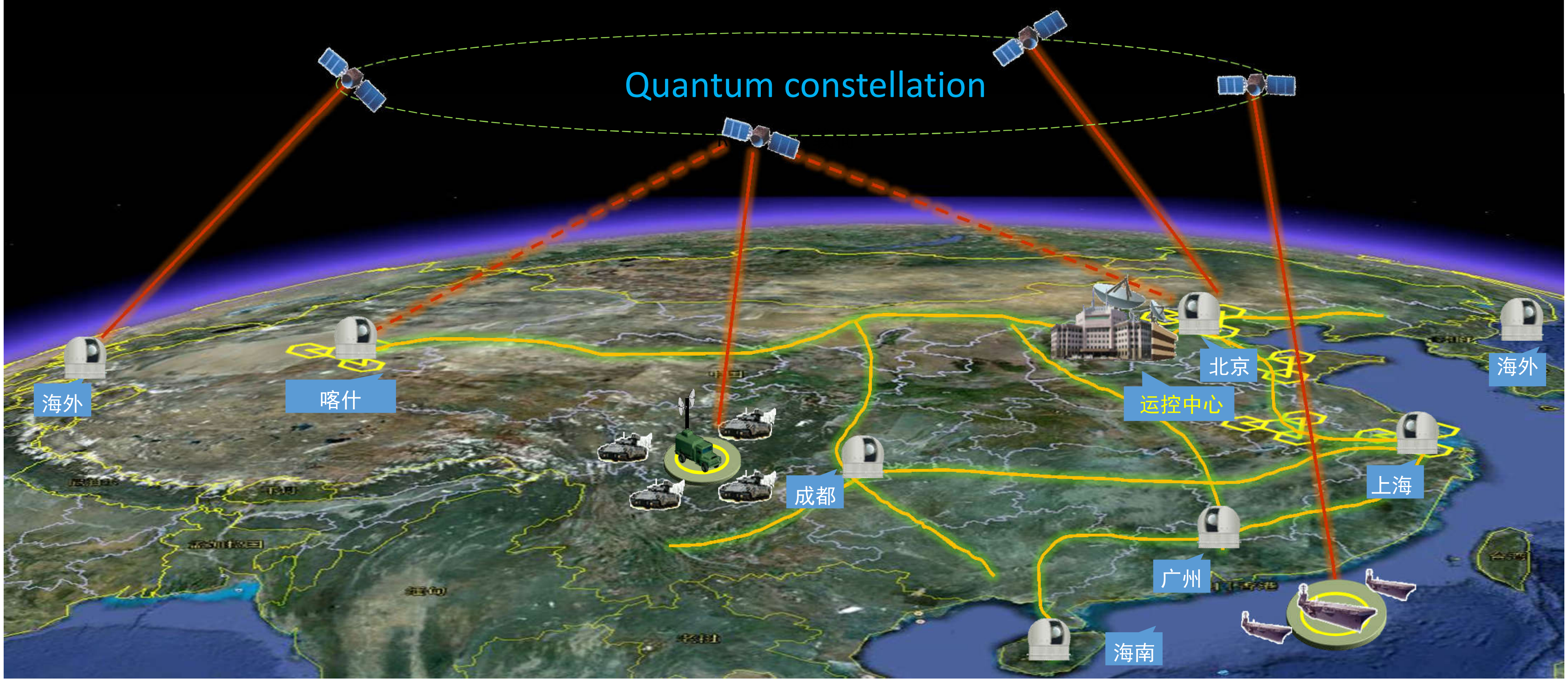
☑ Quantum constellation with LEO nano satellites

☑ GEO satellite

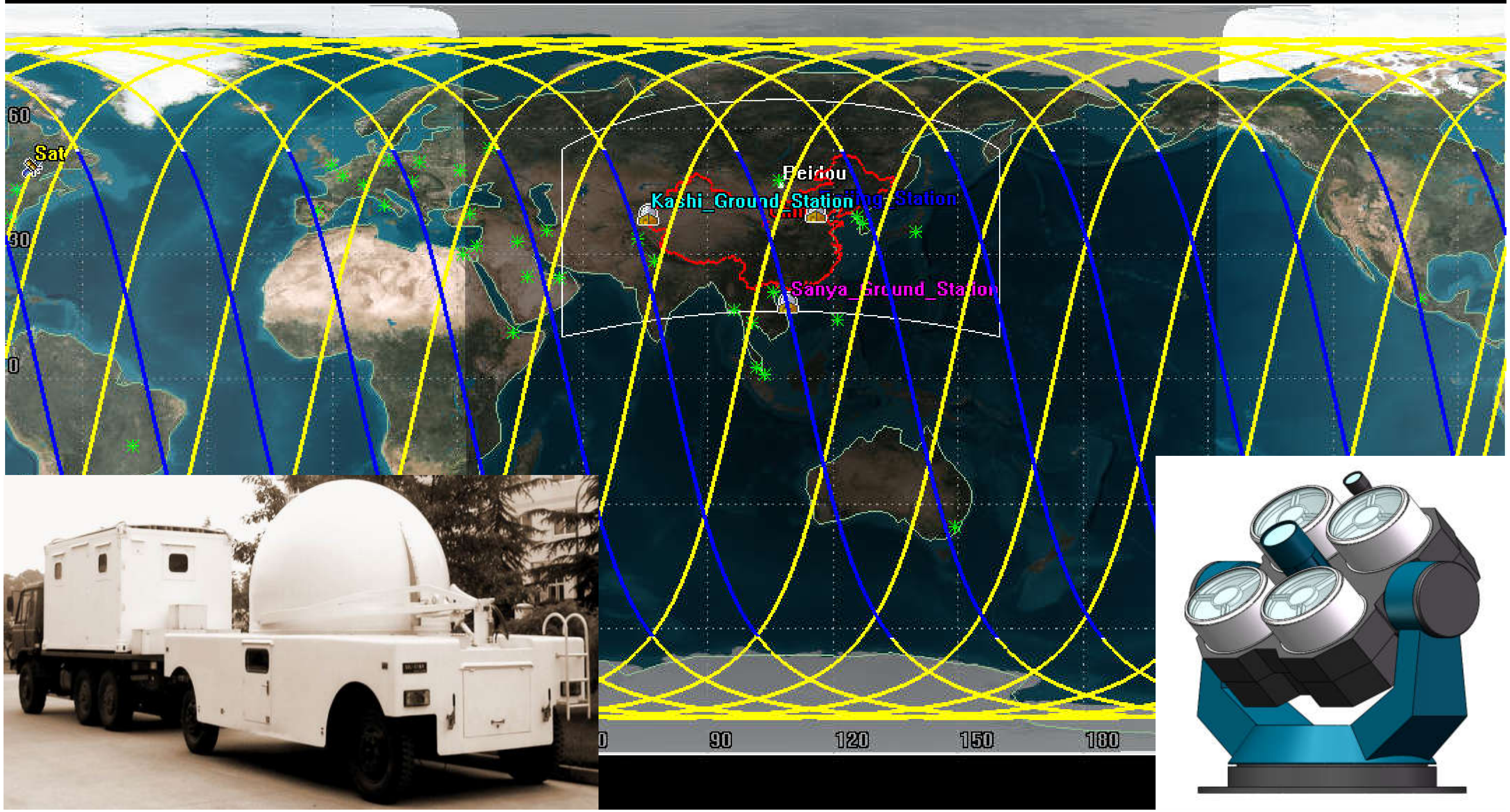
Challenge of global quantum network -- Quantum constellation

Quantum key satellite network

- 3-5 nano quantum satellites
- Provide key distribution services to more than 100 ground stations worldwide



Challenge of global quantum network -- Quantum constellation

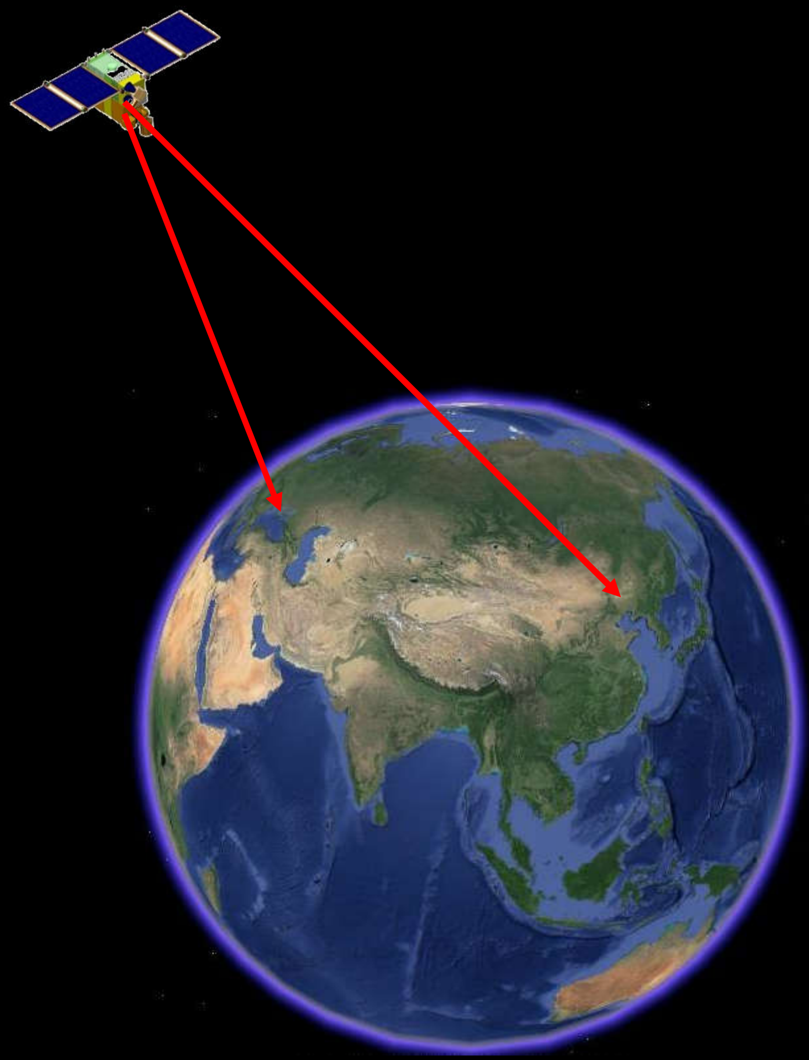


The movable ground station

The low-cost ground station

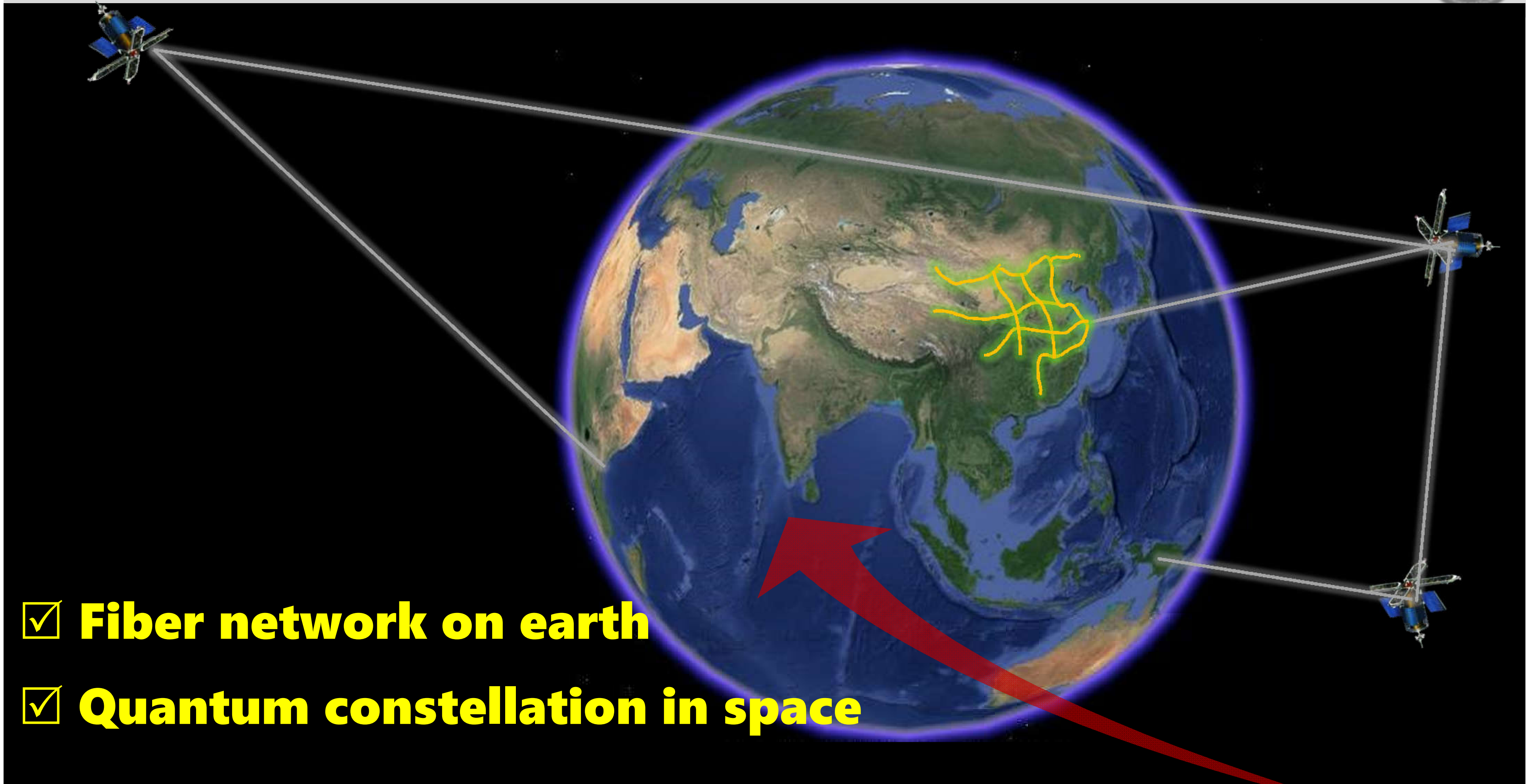
Challenge of global quantum network – GEO satellite

Quantum key distribution based on entanglement with GEO satellite



- Wider space scale
  - 10000-36000km（all over）
- Longer experiment duration
  - Form minutes to hours
- Better micro-gravity
  - 10^{-6}-10^{-7}g

Outlook: Global Quantum Network



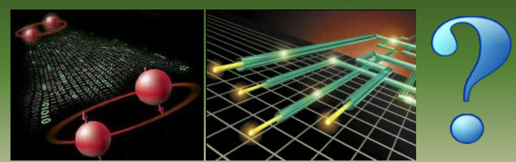
☑ **Fiber network on earth**

☑ **Quantum constellation in space**

letters

Phone

Internet



Quantum internet


Thank you!