# QKD in Satellite Communication

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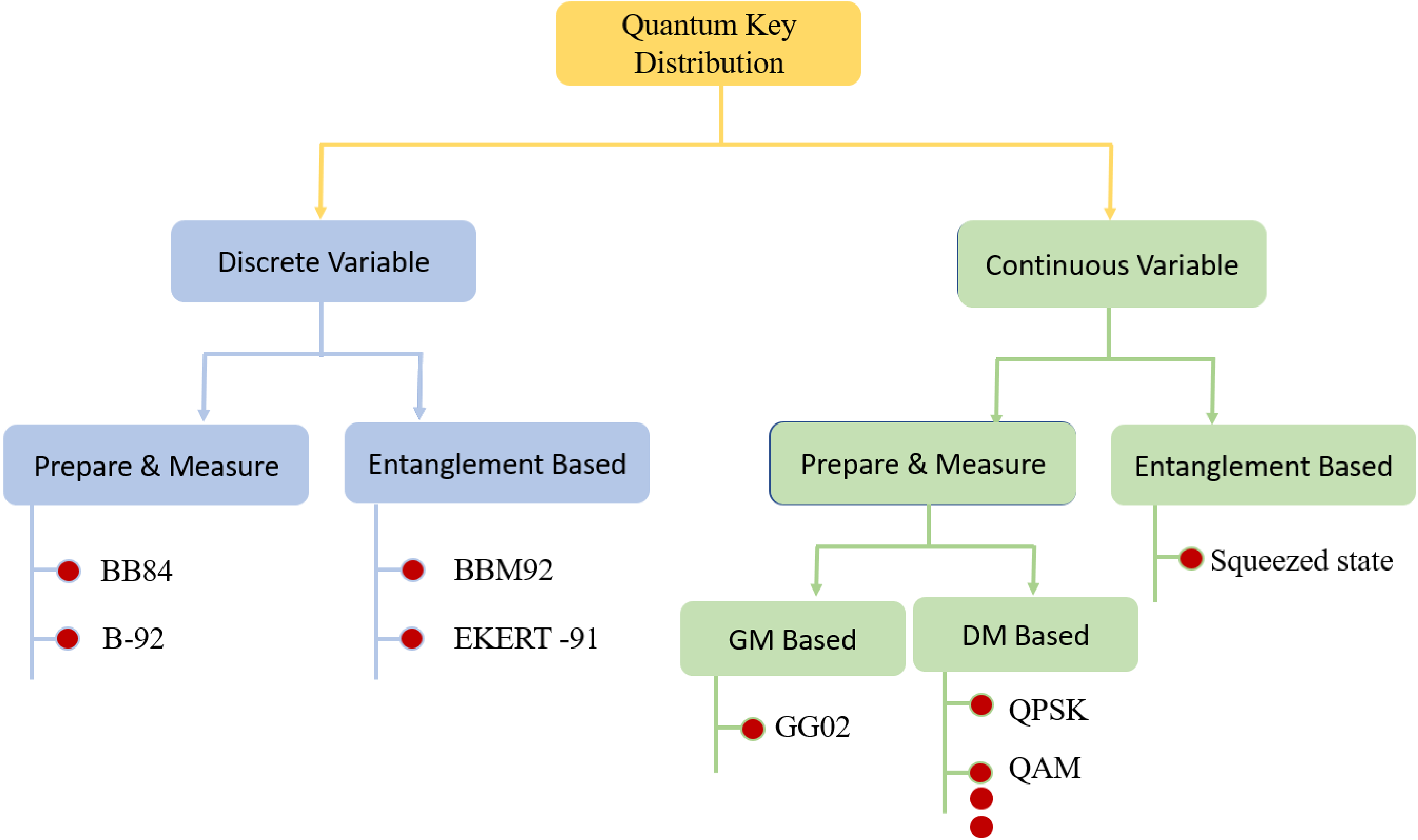
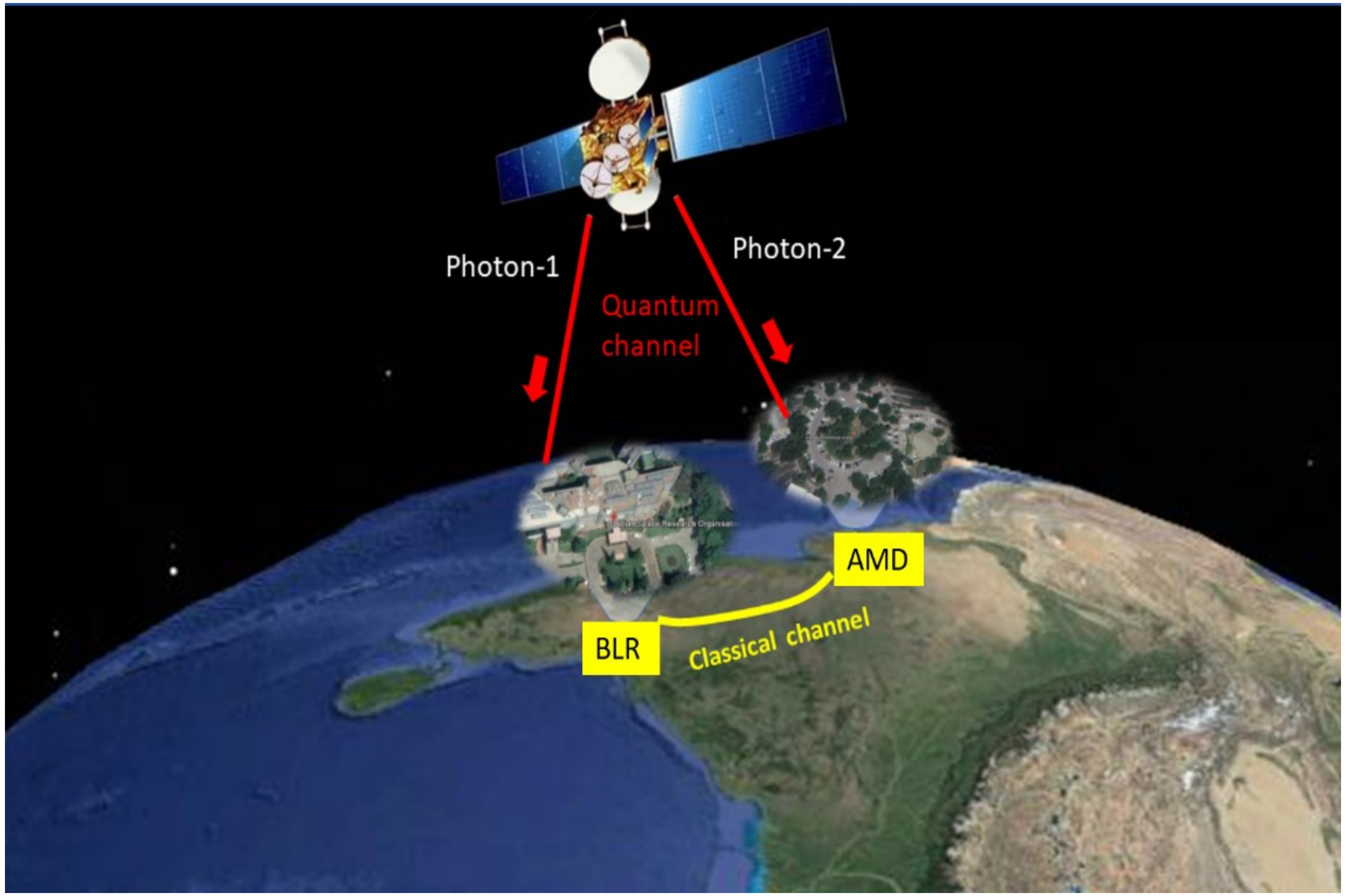
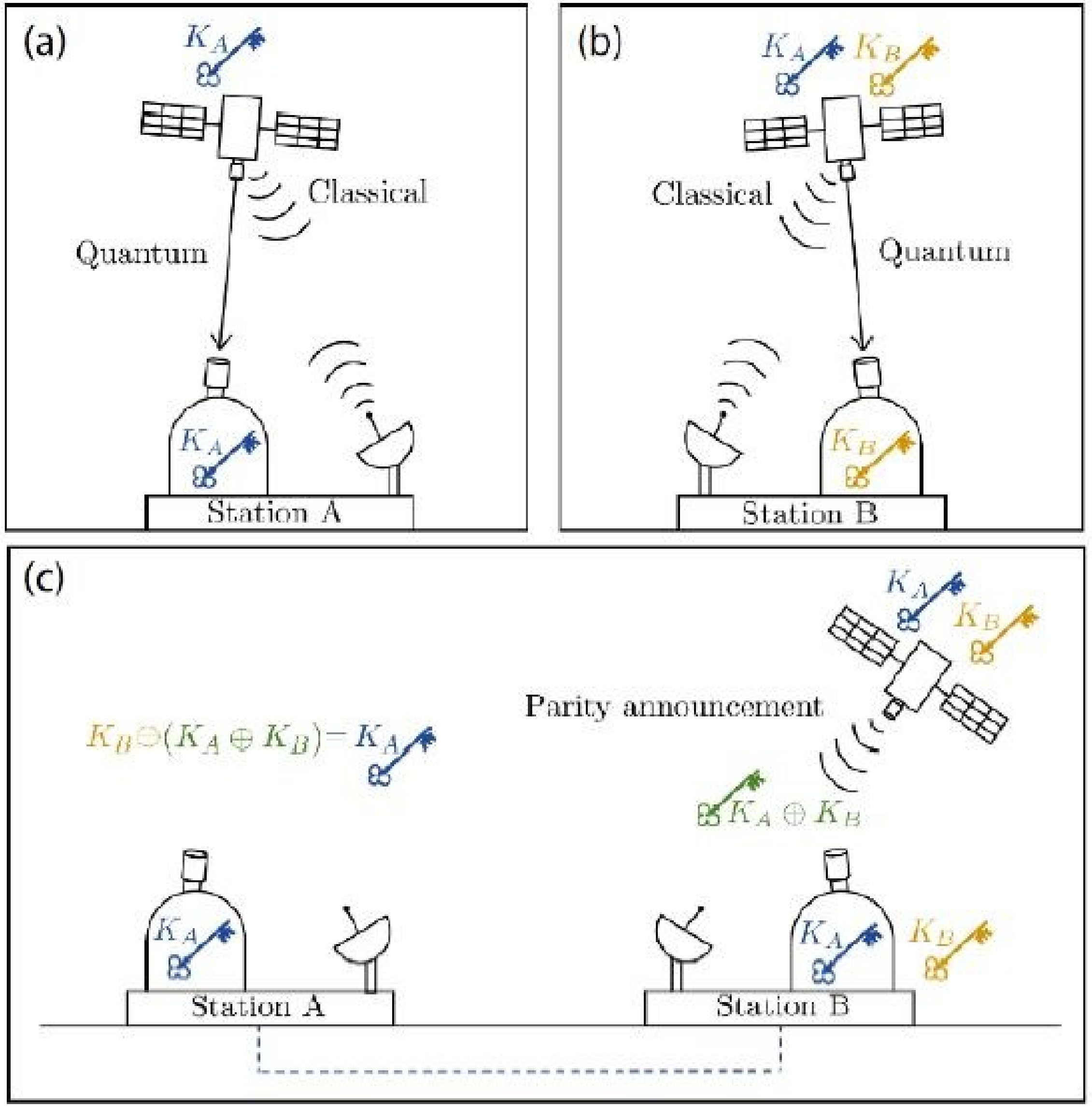
# Classification of QKD



# Securing communication using satellites





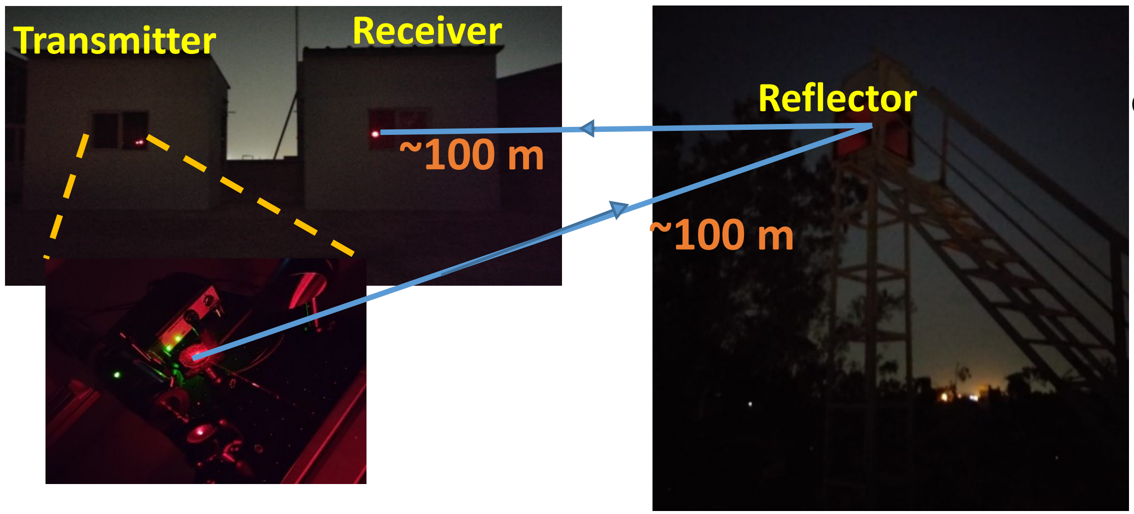




IAC-17-D5.4.4

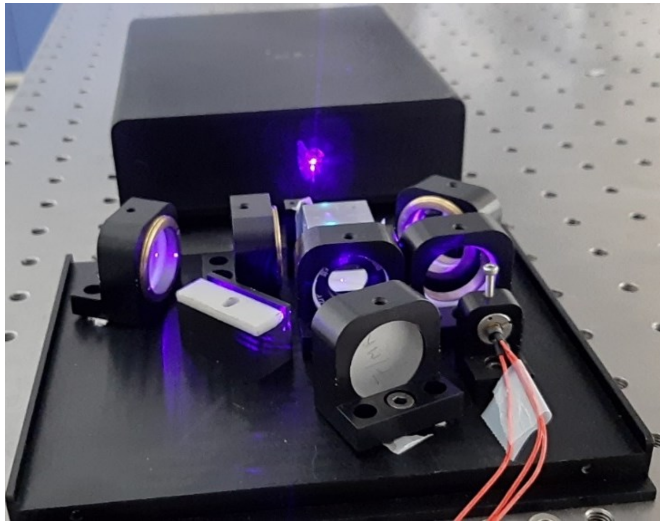
# Free space quantum communication: Road to satellite quantum communication (DST)

1. Implementation of BB84 QKD protocol in free space for 200 meters with weak coherent laser pulses, Sift key rate (~200 kbps) and Secure key rate (~150 kbps), QBER < 3%
2. Development of bright entangled photon source at 810 nm ($10^5$ photon pairs per second) - Scientific Reports (2017), AQT 2023
3. Implementation of BBM92 QKD protocol in free space for 200 meters with entangled photons, Sift Key rate (~4.5 kbps) and Secure Key rate (~2 kbps), QBER < 5% and effect of aerosols on the key rate - Journal of Optics (2022)
4. End to end encryption for audio and video with Space Application Centre (ISRO), Ahmedabad for free-space channel of 300 meters using BB84 as well as BBM92 protocol
5. New QKD protocol – CD Protocol – using weak coherent pulses that gives higher key rate compared to BB84/Decoy state protocol for same mean photon number per pulse – Optics Continuum (2022)
6. Side channel attack analysis for BB84 source using a new technique based on cross-correlation - IEEE J. Quantum Electron (2021)
7. Working towards development of Optical Ground Stations (OGS) for satellite-based QKD




Left: Field implementation of free space QKD

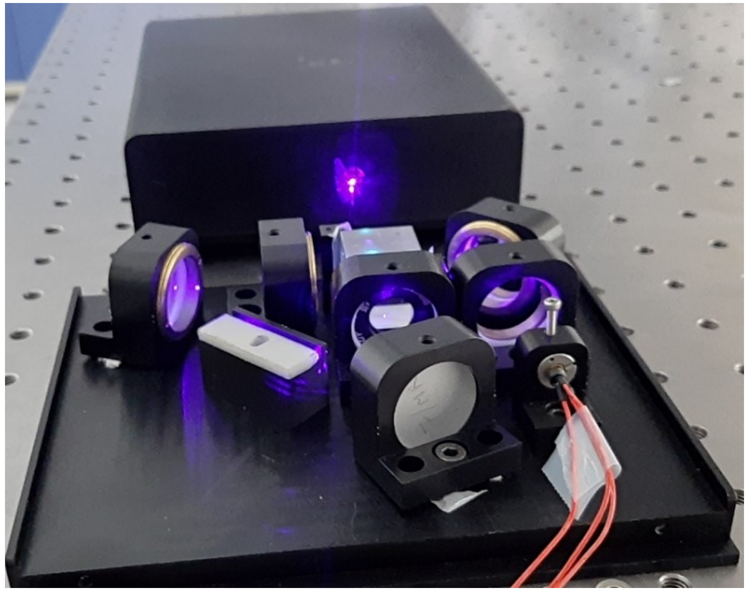
Right: Compact entangled photon source (810 nm) developed at PRL

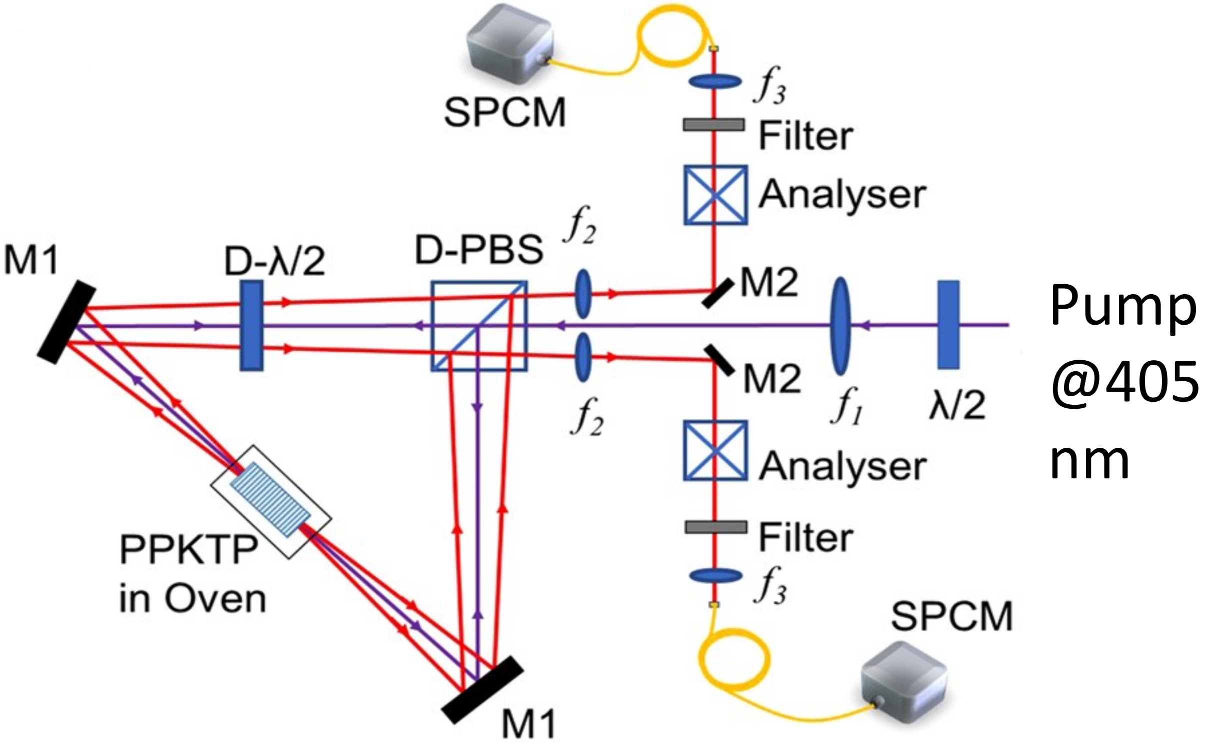


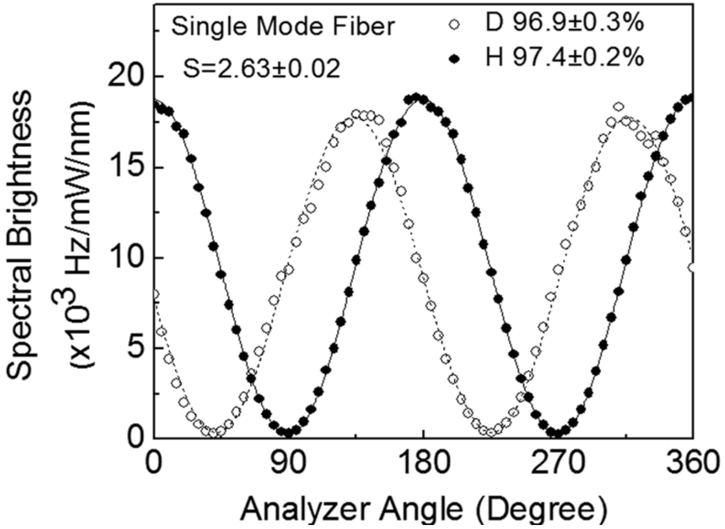
**Looking forward to second phase of funding as per recommendation of the project review committee**

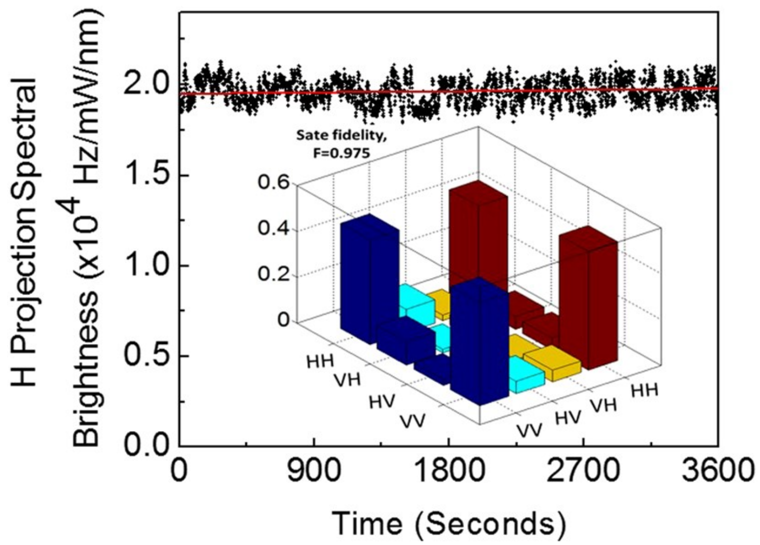
# Entangled photon source

## Prototype



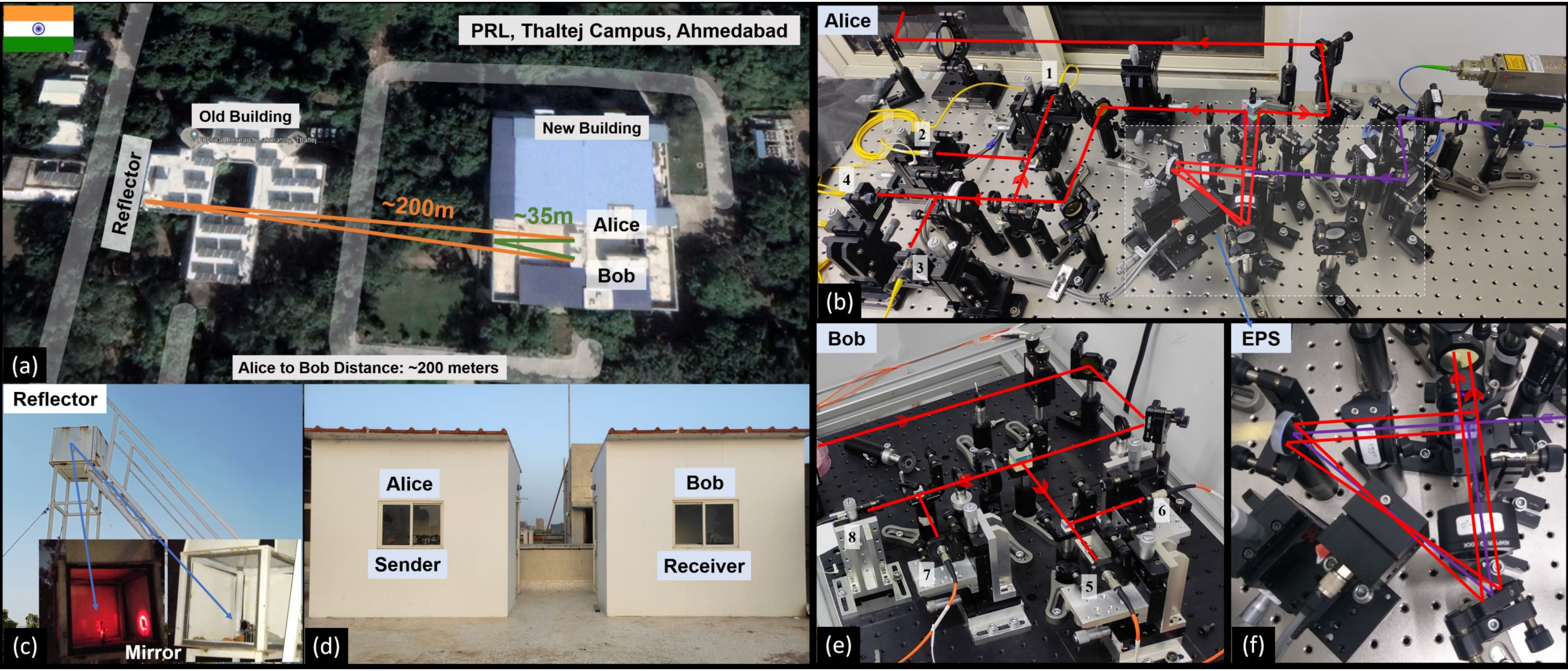


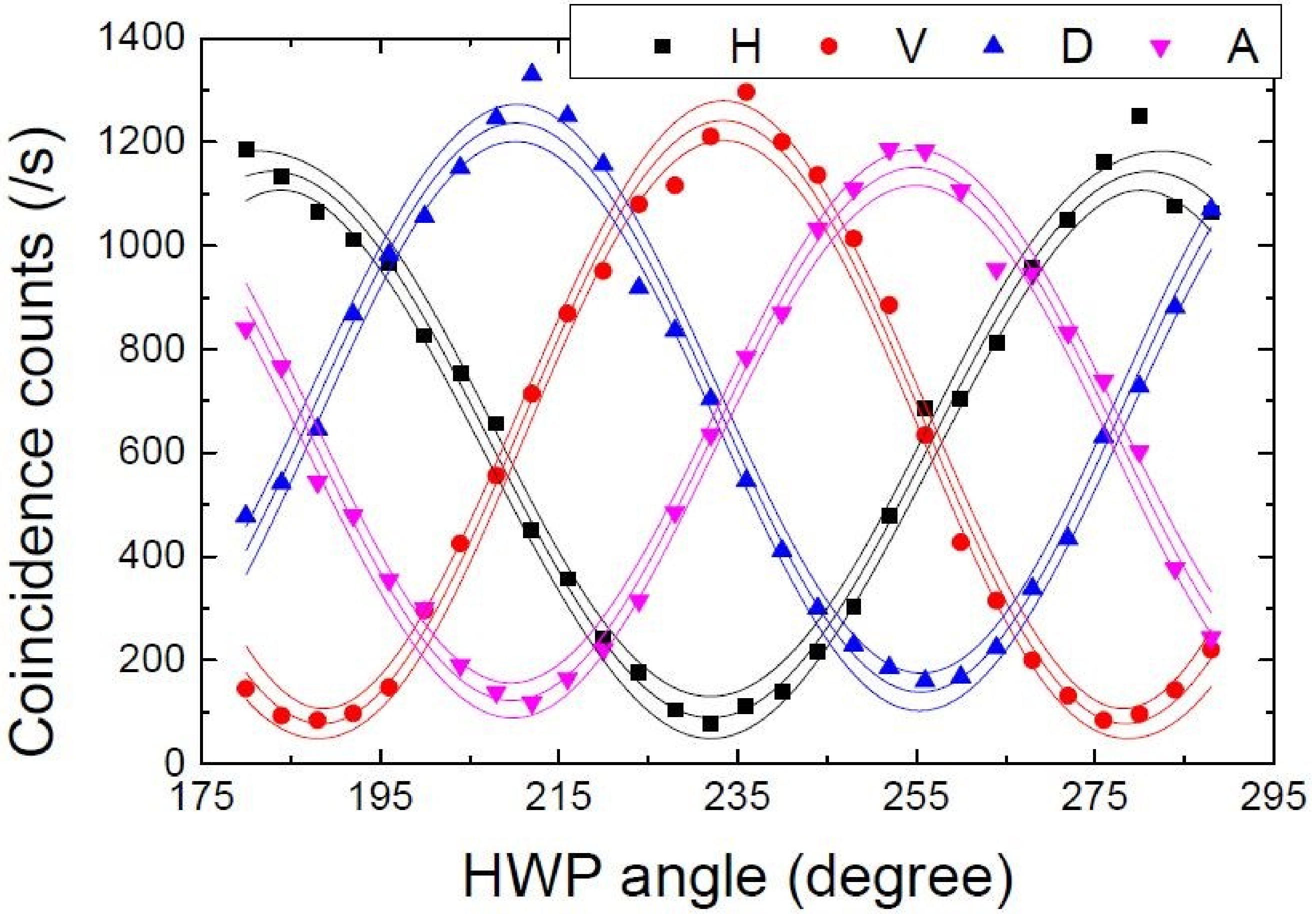

**QuantESS payload for entanglement and HOM interferometer study in space**

Jabir et al "Robust, high brightness, degenerate entangled photon source at room temperature", Scientific Reports 7 (1), 1-8 (2017)



PRL, Thaltej Campus, Ahmedabad
Old Building
New Building
Reflector
~200m
~35m
Alice
Bob
(a)
Alice to Bob Distance: ~200 meters
Reflector
Mirror
(c)
Alice
Sender
Bob
Receiver
(d)
Alice
1
2
3
4
(b)
Bob
5
6
7
8
(e)
EPS
(f)

# Entanglement Distribution over 200 meters




Correlation of polarization states between Alice and Bob

Coincidence window = 1 ns

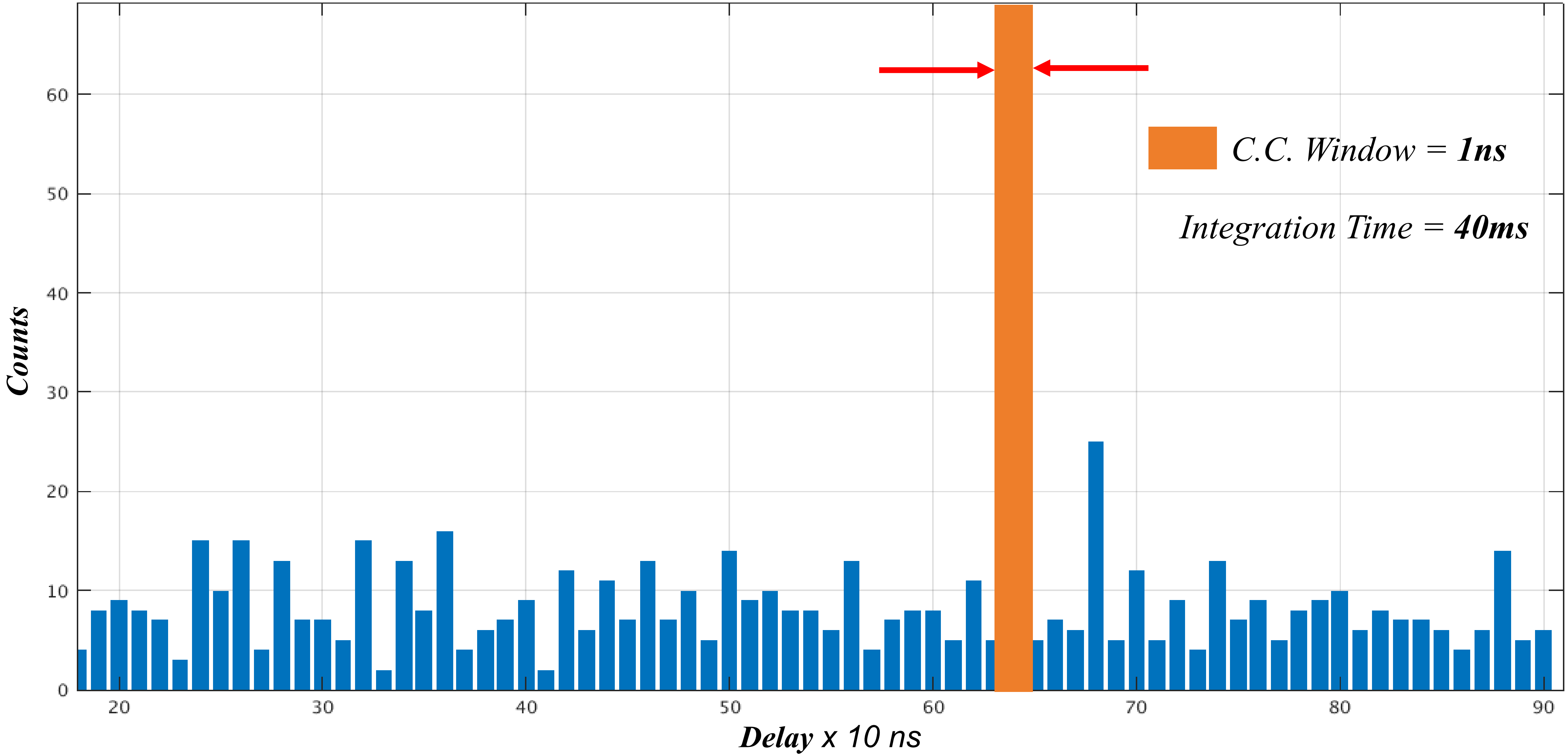
Bell's Parameter

**S=2.54**

Polarization Visibility

| H | V | D | A |
|---|---|---|---|
| 94.2% | 93.66% | 83.33% | 87.53% |

# Temporal Filtering




*Delay from Alice's **H** pol. state detector to Bob's **H** pol. State detector = **648ns***

# Parameter Estimation for BBM92 Protocol

Channel Transmissivity ($\eta_{Ch}$)=**0.70**

Overall Detector Efficiency($\eta_{det}$)=**0.4**

Background Coincidences=**40**

***TABLE:*** *Showing QBER and Key Rate for BBM92 Protocol*

| ALICE \ BOB | H | V | D | A |
|---|---|---|---|---|
| **H** | 1023 | 41 | 603 | 501 |
| **V** | 36 | 1167 | 661 | 592 |
| **D** | 408 | 671 | 1287 | 76 |
| **A** | 644 | 591 | 117 | 1140 |

***Average Sift Key Rate (K) = Total CC in correct basis detectors* = 4.5 kbps**

***QBER= CC in wrong detectors/total CC*= 4%**

***Secure key rate ~* 1.7 kbps**

# Atmospheric conditions, mean and variance from midnight to 6 AM (typical measurement time for our experiments)

| Date | Extinction (Mm-1) | Scattering (Mm-1) | PM2.5 (µg/m3) |
|---|---|---|---|
| 08/05/2021 | 76.41±7.78 | 62.73±5.82 | 2.87±0.26 |
| 10/05/2021 | 48.67±6.70 | 40.16±6.15 | 1.68±0.24 |

| Parameters | 35 m | 200 m |
|---|---|---|
| Channel transmission (%) | 94 | 70 |
| CHSH Bell parameter (S) | 2.51±0.06 | 2.54±0.06 |
| Mean visibility (%) | 88.85±5.39 | 90.99±5.89 |
| QBER (%) | 5.58 | 4.50 |
| Sifted key rate (kbps) | 6.37 | 4.89 |
| Key rate after EC (kbps) | 6.01 | 4.20 |
| Key rate after PA (kbps) | 2.33 | 1.71 |
| Secure key rate (kbps) | 2.33 | 1.71 |

Sarika et. al., Journal of Optics (2022)

# Key Parameters follow the atmospheric channel

$$T = \frac{N_{Out}}{N_{In}} = Sc \ \exp(-1.5 \times \gamma L)$$

$$f = \frac{Sc_{35} \ \exp(-1.5 \times \gamma_{35} 35)}{Sc_{200} \ \exp(-1.5 \times \gamma_{200} 200)} = 1.34$$

$$\frac{cc_{35}}{cc_{200}} = 1.28,$$

$$\frac{R_{sif \ 35}}{R_{sif \ 200}} = 1.30, \quad \text{and}$$

$$\frac{R_{sec \ 35}}{R_{sec \ 200}} = 1.36.$$

# CV-QKD: Parameter estimation and secure key rate

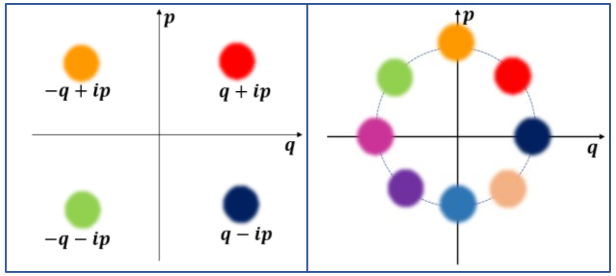
| | |
|---|---|
| Channel Transmissivity ($\eta_{Ch}$)= **0.912** | Overall Detector Efficiency($\eta_{det}$)=**0.76** |
| Mean Photon Number ($\mu$)=**1** | Repetition Rate of Laser ($f_{rep}$)= **80 MHz** |

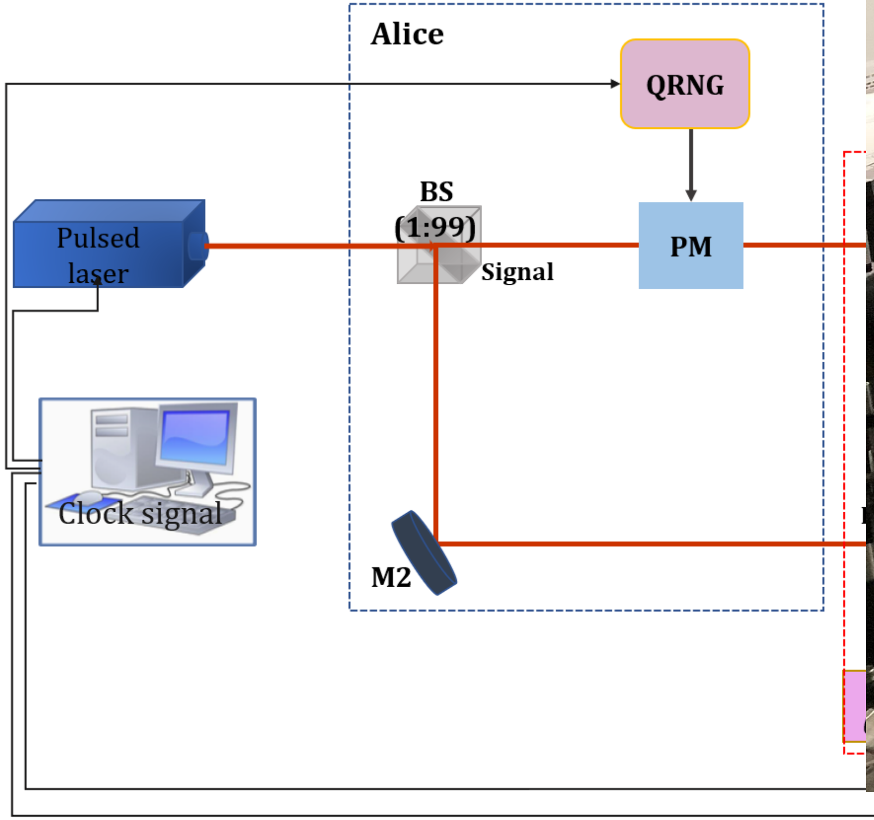
| **Parameters** | **Estimated values (Experimental)** |
|---|---|
| [redacted] | |
| Electronic noise | 0.51 SNU |
| [redacted] | |

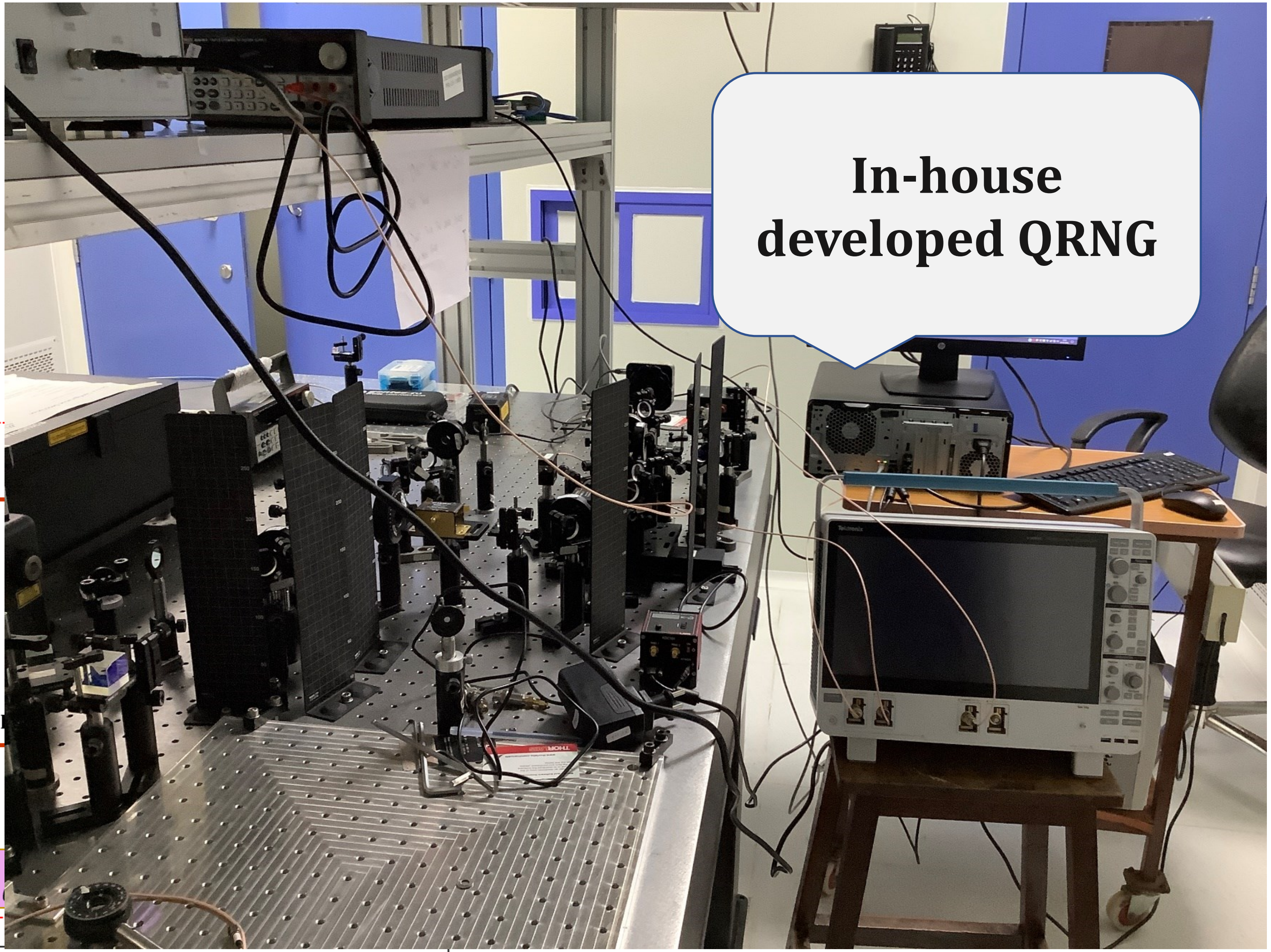
**Sifted key rate = 0.48 bits/pulse (Experiment)**
**Sifted key rate = 0.49 bits/pulse (Simulation)**
**Secure key rate = 0.30 bit/pulse**

# Ongoing work: Real-time CVQKD

## Discrete modulation CVQKD

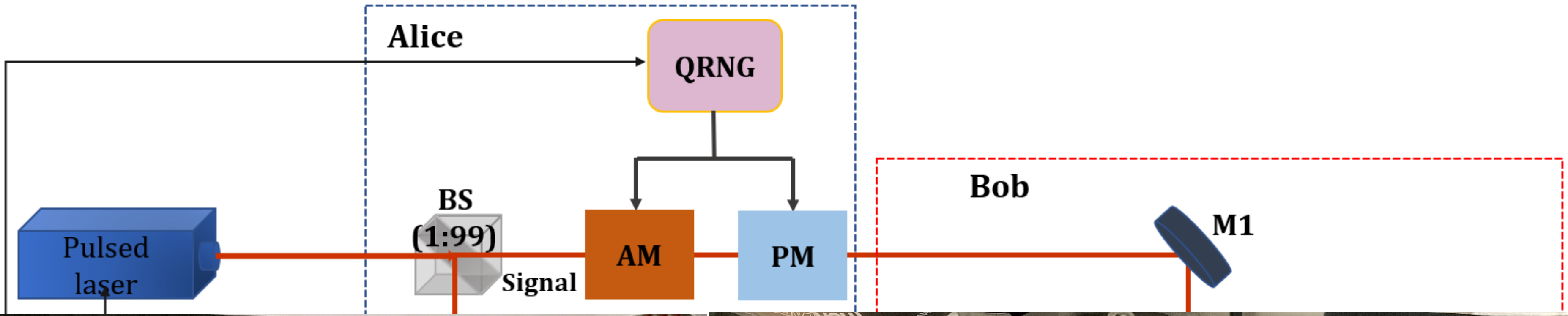


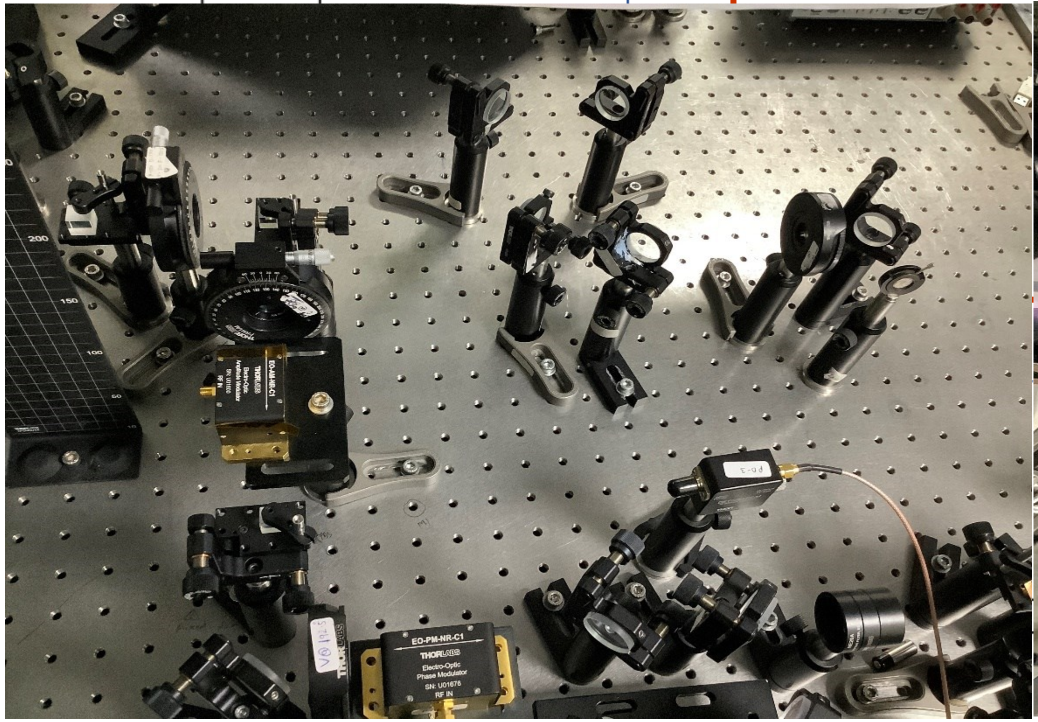



# Ongoing work

## Gaussian modulation CVQKD



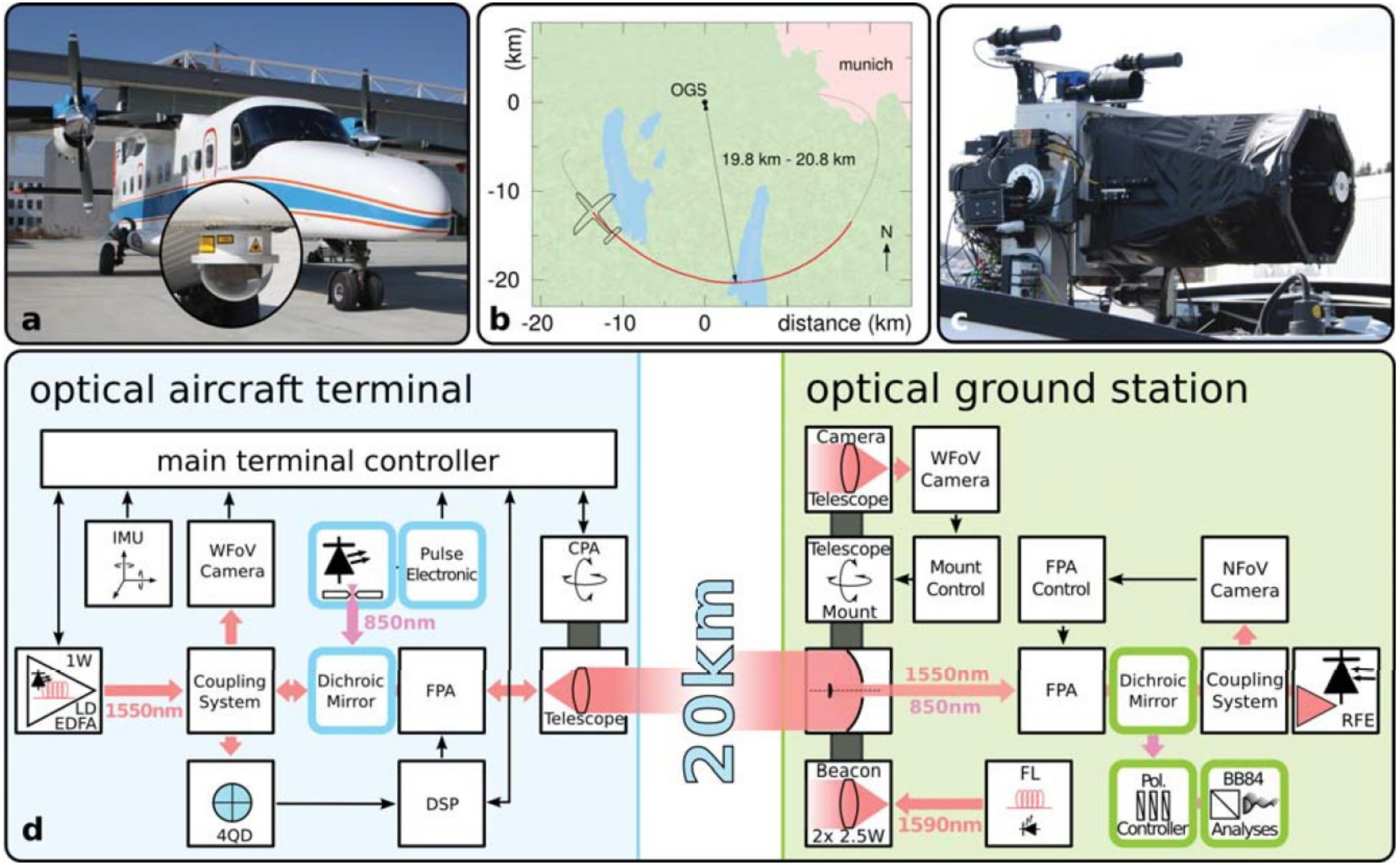
# The most notable

**Chinese scientists** have already sent a quantum communications satellite in Aug 2016, a first step towards building a quantum communications network.

**It has demonstrated a QKD system linking Asia and Europe, and expects to have a worldwide quantum-communications network in place by 2030.**

# QKD through flight, Germany

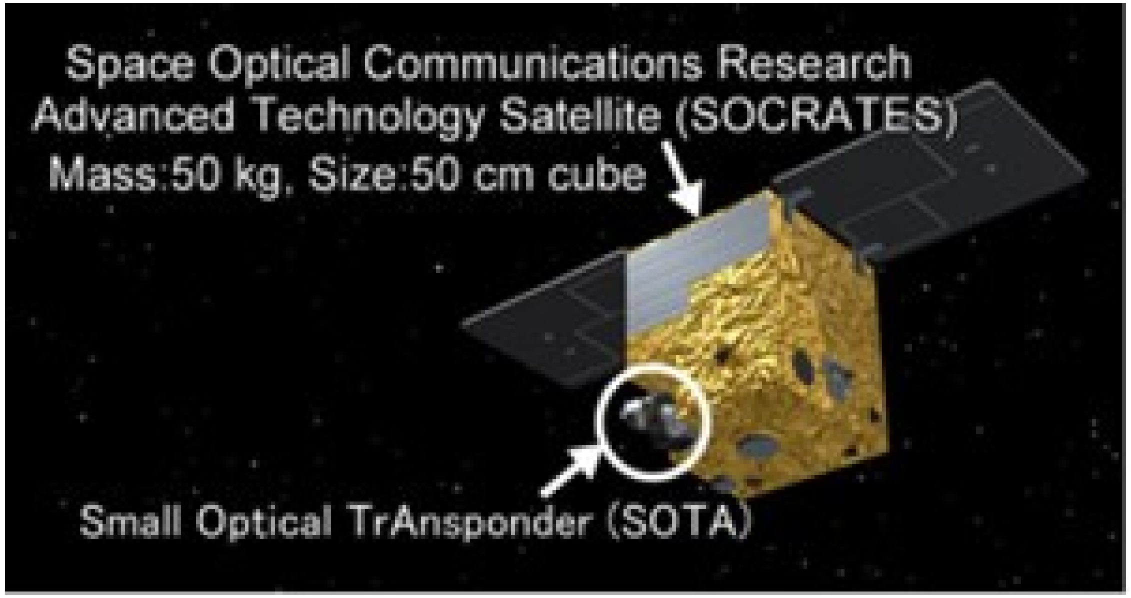
Nature Photonics, March 2013

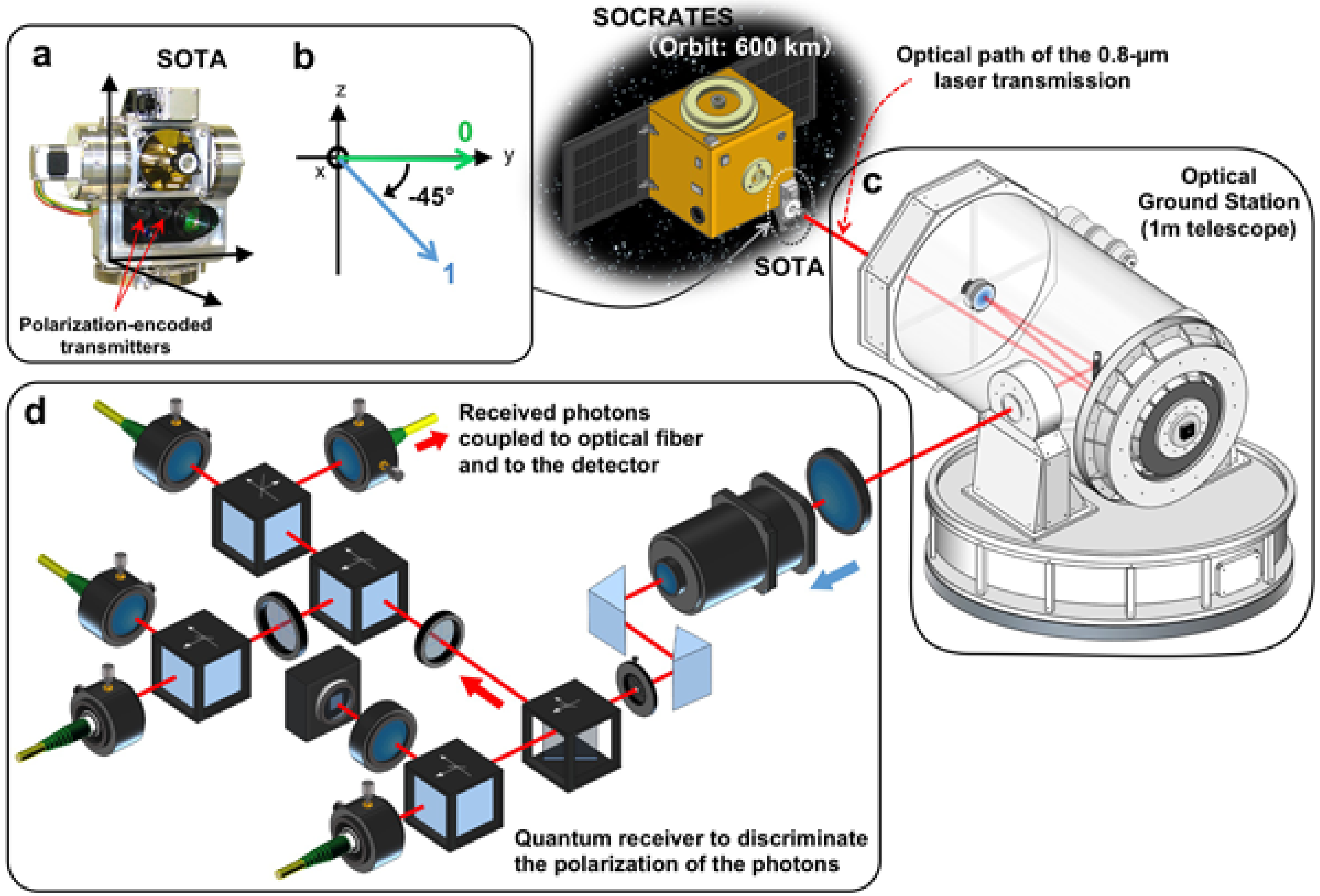


# World's First Demonstration of Space Quantum Communication Using a Microsatellite

**- A big step toward building a truly-secure global communication network - July 11, 2017**

National Institute of Information and Communications Technology, **Japan**

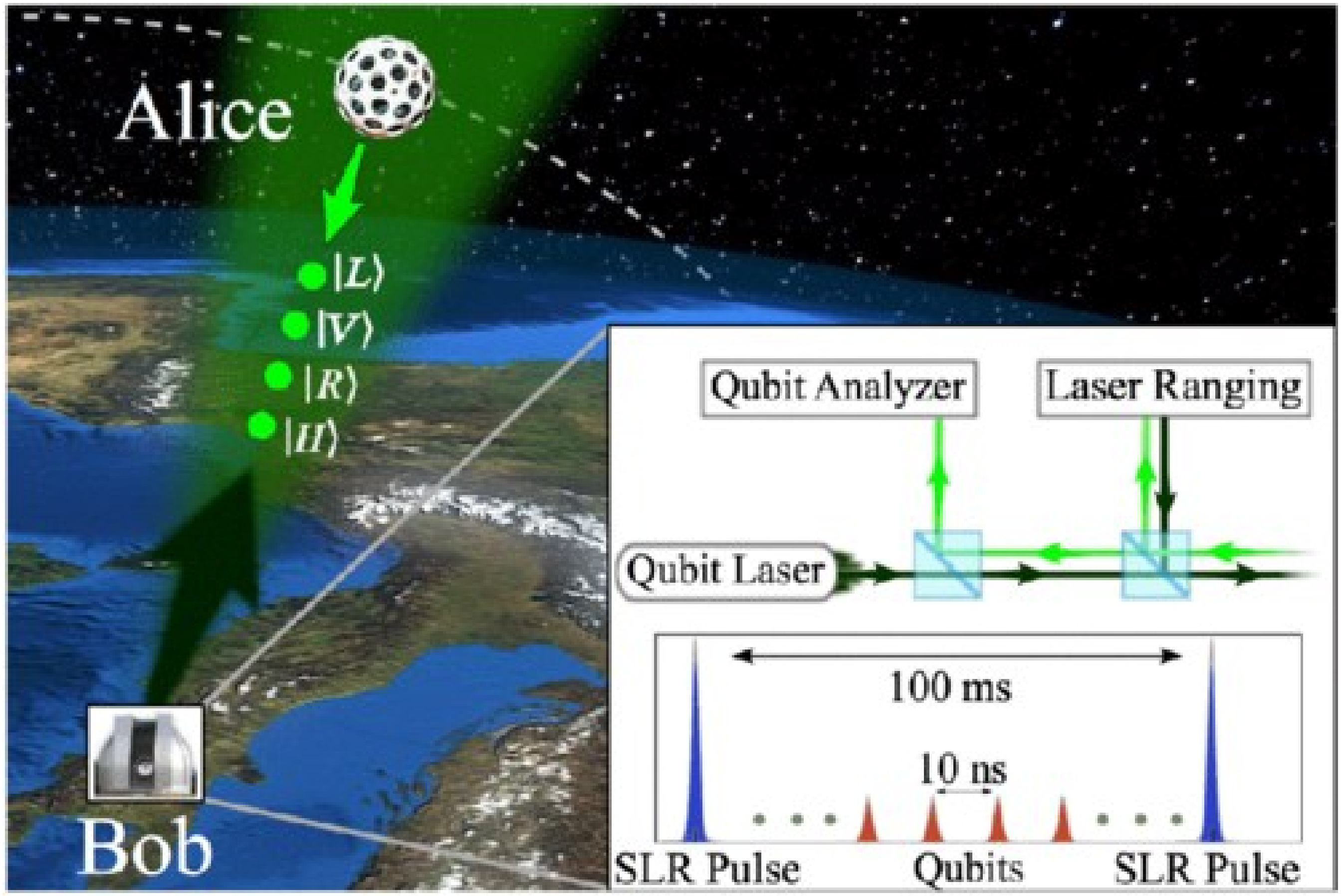



SOTA weighs 6 kg and its size is 17.8 cm length, 11.4 cm width and 26.8 cm height, Launched in May 2014

**Nature Photonics, July 2017**

# The first satellite based quantum communication demonstration (Italy)




Qubit pulses are sent at a 100 MHz repetition rate and are reflected back to the single photon level from the satellite, thus mimicking a QKD source in space. Synchronization was performed by using the bright SLR pulses at a repetition rate of 10 Hz.

Phys. Rev. Lett. 115, 040502 – Published 20 July 2015

# Future plan of work at QST Program @ PRL

- Effect of turbulence and how to mitigate it for terrestrial communication.
- Simulating conditions for uplink and downlink to check the key rate for satellite based quantum communication.
- Development of Device Independent QKD protocol.
- Entanglement swapping and quantum teleportation in free space for 200 meters towards setting QC network
- Using structured light such as - Vortex beam, Pencil beam, Gaussian Schell Model beam, Twisted Gaussian Schell Model beam - for robust and secure key distribution
- **Development of Photonic Quantum Computing since it is the best bet for quantum internet, World Wide Quantum Web (WWQB), the ultimate stage of quantum communication (China, Xanadu in Canada and Psi Quantum in USA, ORCA Computing in UK are making good progress)**

**“The greater danger for most of us lies not in setting our aim too high and falling short; but in setting our aim too low, and achieving our mark.”**

Michelangelo

*Thank You*