Quantum Communications in space using satellites

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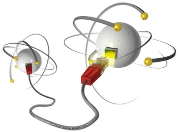
Summary

Summary

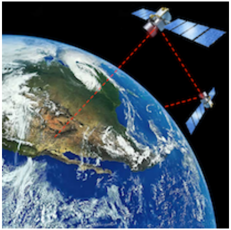
What is Quantum Communication?

- Quantum Communications is the ability of faithful transmit quantum states between two distant locations



- Ground QC have progressed up to commercial stage using fiber-cables

- Quantum Communications on planetary scale require complementary channels including ground and satellite links



Motivation

Why free-space quantum communications?

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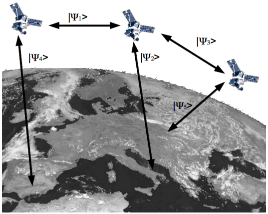

- Creation of a **worldwide quantum network**: overcome fiber-loss limitations

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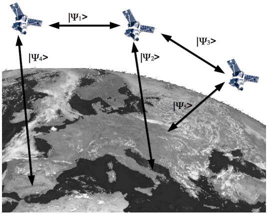
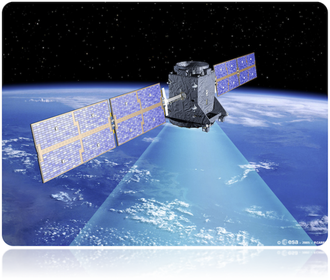


- Creation of a **worldwide quantum network**: overcome fiber-loss limitations

- **Explore the limits of Quantum Mechanics** and quantum correlations over very long distances

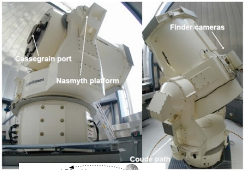
Context



- On May 24, 2014 Japan's NICT launched SOTA on Socrates satellite.
- Ongoing programs for QC on satellite in China and Canada as well as in Singapore and USA.

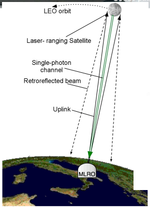
Summary

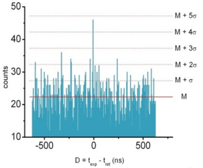
Timeline



UniPD Space QComms

University of Padova operated at **Matera Laser Ranging Observatory**, owned by the **Italian Space Agency** and directed by Dr. Giuseppe "Pippo" Bianco.





P. Villoresi et al.
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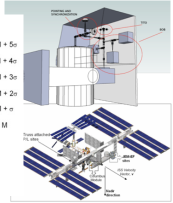
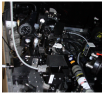
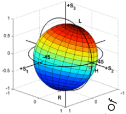
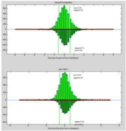








2003 – UniPD SpaceQ project

st MLRO tests

single photon receiver @ MLRO

Setup for the returns search

2008 – first single-photon return from Ajisai announced

2009 - Feasibility study for quantum payload in the ISS

Design and test of setup for polarization analysis

Characterization of MLRO Mueller Matrix

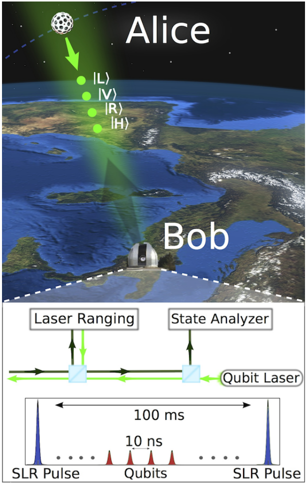
2012 - Analysis of response for different satellites CCR

2013 – state preparation, state analysis – satellite synchronization

2014 – Q-Comm on satellites downlink demonstrated

Objectives

- To simulate a quantum source in Space using orbiting retroreflectors
- To demonstrate the measurement of quantum states in the downlink
- To address the mitigation of the background noise
- To demonstrate quantum communication of a generic qubits from Space to ground
- To envisage the exploitation of this type of link

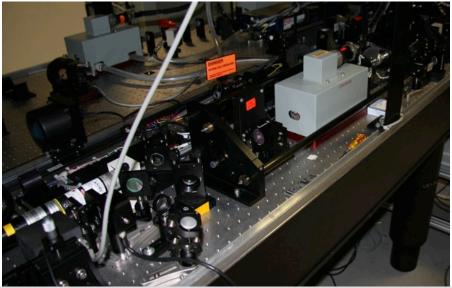


MLRO facility

Matera Laser Ranging Observatory (MLRO):
1.5 m telescope with millimeter resolution in SLR
research hub for Space QC since 2003

Dome

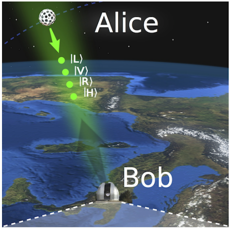
Laser



The making of the qubits

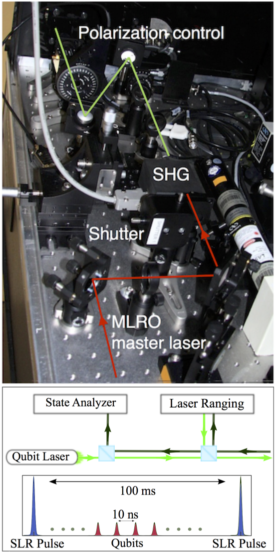
- Source on satellite simulated by a CCR
- Source (Alice) need to be at the single photon level
- Downlink attenuation from $\sim 3\ cm$ LEO sources in the range of 55-70 dB.
- Short pulses necessary for background rejection
- Not too short to prevent bandwidth opening and noise increasing

CCR:
Corner-Cube
Retroreflector

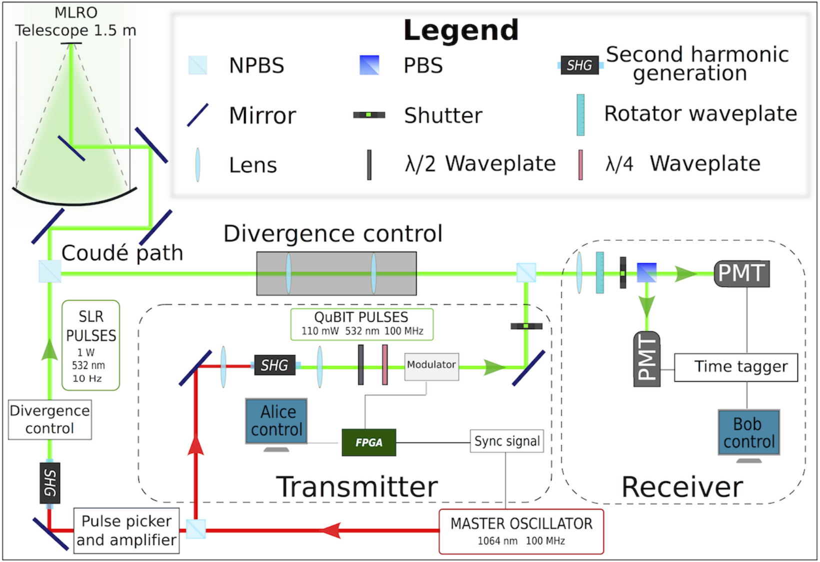


The making of the qubits

- MLRO master laser provided the solution: 100 MHz, 100 ps, 300 mW, 1064 nm
- Second harmonics needed for qubits
- First order (6.2 μm) PPLN
- MgO doped Congruent Lithium Niobate - 50 mm – thermally stabilized.

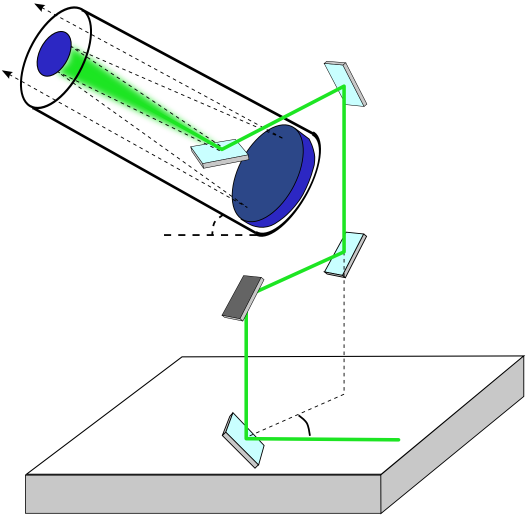


Setup

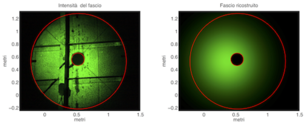


G. Vallone *et al.*, *Experimental Satellite Quantum Communications*, **[arXiv:1406.4051]**

Coudé path of in-and-out

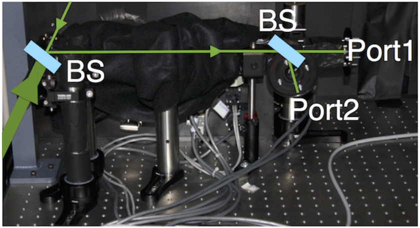


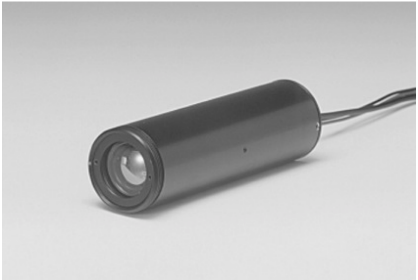
- Characterization of the polarization transformation
- Assessment of total transmission efficiency
- Mutual alignement of SLR and Qubit beams



Measuring the qubits

- The Coudé path is used in both directions for both the SLR beam and the qubits
- The upward and inward beams are combined using a non polarizing beam splitter (BS)
- Two large ares SPADs mounted to the exit ports, designed to address the velocity-aberration
- 81 ps timetagging of 8 channels





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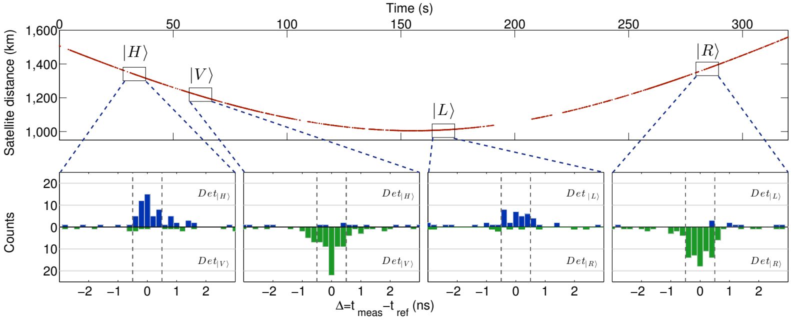
Summary

Single passage of LARETS

Orbit height 690 km - spherical brass body
24 cm in diameter, 23 kg mass,
60 Metallic coated Corner-Cube Retroreflectors

Apr 10th, 2014, start 4:40 am CEST



Detection of four polarization states received from satellite
10 s windows: arrival time within $0.5ns$ from predictions

Link Budget and photon return rate

Radar equation for the prediction of detected number of photons per pulse

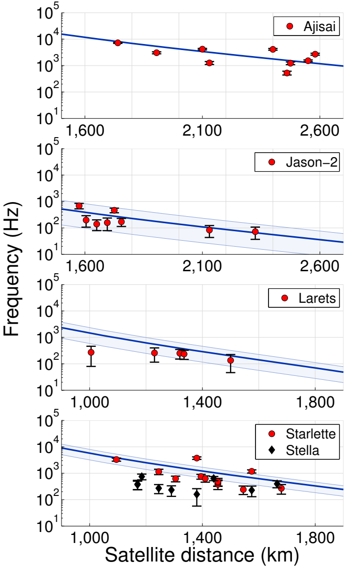
UPLINK

$$\mu_{sat} = \mu_{tx}\,\eta_{tx}\,G_t \rho A_{\text{eff}}\,\Sigma\left(\frac{1}{4\pi R^2}\right) T_a$$

DOWNLINK

$$\mu_{rx} = \mu_{sat}\frac{\Sigma}{\rho A_{\text{eff}}}\left(\frac{1}{4\pi R^2}\right) T_a A_t \eta_{rx}\eta_{det}$$

Radar equation model provides a precise fit for the measured counts and the μ_{sat} value for the different satellites



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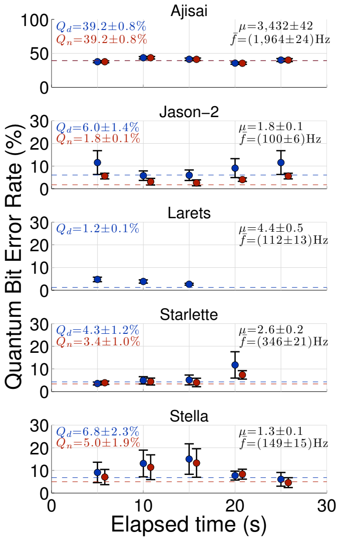
QBER: Quantum Bit Error Rate

Ajisai

Non polarization maintaining CCR:
Polarization Q-Comm not possible



Jason-2, Larets, Starlette, Stella

Polarization maintaining CCR:

- QBER compatible with applications
- Demonstration of stable QBER over extended link duration

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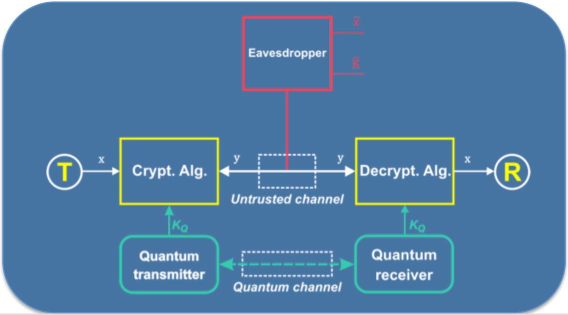
Summary

QKD: quantum key distribution

- A novel approach towards unconditionally secure communications
- Exploit quantum mechanics laws for establishing secure keys
- Single photon transmission for create keys and classical channel for send encrypted message



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New QKD satellite protocol using retroreflectors

On the base of this experiment, we propose a two-way QKD protocol for space channels:

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- The state measure is done as in present experiment

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New QKD satellite protocol using retroreflectors

The two-way QKD protocol:

- By this scheme, a decoy state BB84 protocol can be realised between satellite and ground
- Such protocol is currently realizable using few centimeter retroreflector as optical part in orbit

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Summary

Long term opportunities

Unique opportunity of Quantum Physics in Space

Possibility of testing quantum physics in new environment and probing the laws of nature at very large distance

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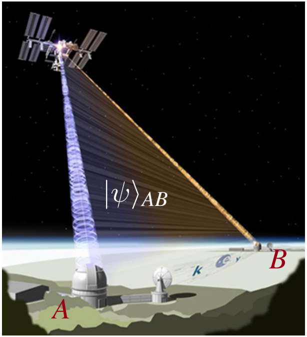
- Test of foundations of quantum field theory and general relativity

Entanglement distribution

$$|\psi\rangle_{AB} \neq |\phi\rangle_A \otimes |\chi\rangle_B$$



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- Entanglement is a unique resource for Quantum Information applications (teleportation, dense coding, etc..)

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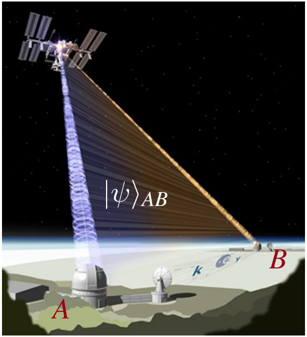

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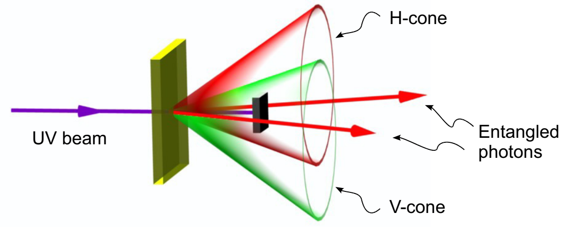
- Entanglement is a unique resource for Quantum Information applications (teleportation, dense coding, etc..)
  - Limits on the distance between two entangled systems?
  - Is entanglement limited to certain mass and length scales or altered under specific gravitational circumstances?

Entanglement distribution

Photons are the ideal candidate for distributing entanglement

- Easy to generate entangled photons



- Photons can travel over long distances without decoherence

Bell's test

If a set of correlation do not satisfy the Bell's inequality $S \leq 2$, the correlations cannot be explained by a local realistic theory.

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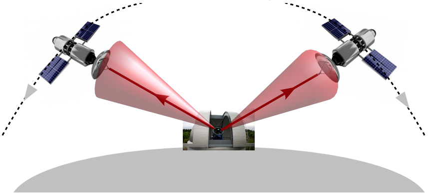
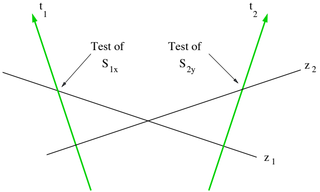
- Bell's test with moving terminals





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- QBER was found low enough to demonstrate the feasibility of quantum information protocols such as QKD along a Space channel
- The ability of propagating quantum correlation over large distance will have a great impact for fundamental physics and quantum information applications

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