QUANTUM OPTICS EXPERIMENTS IN SPACE

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CISAS G. COLOMBO

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

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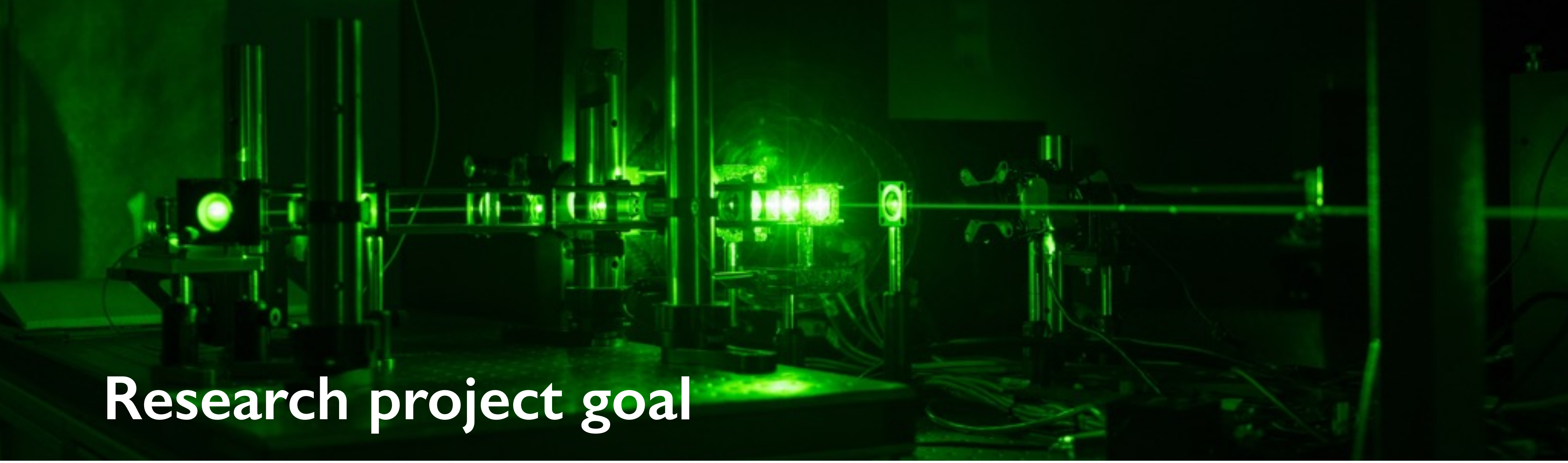
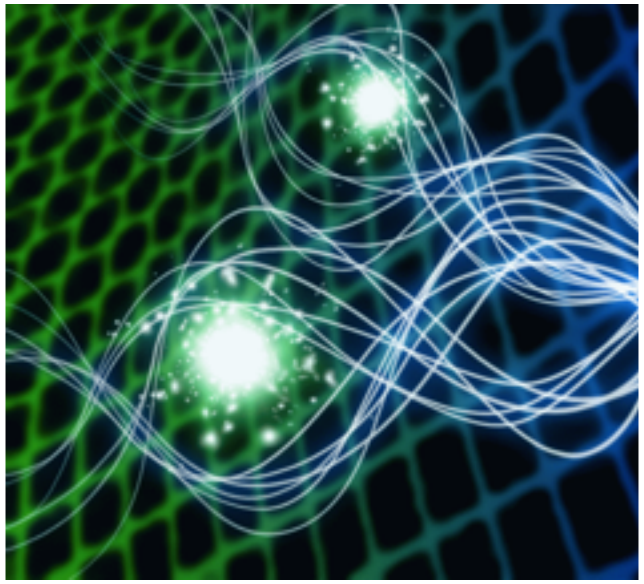
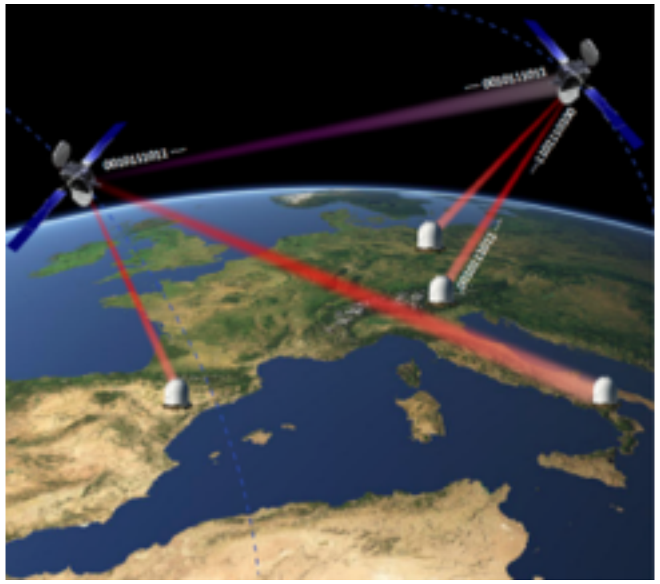


Research project goal

Study the feasibility, from the theoretical and experimental point of view, of different experiments involving Quantum Optics in Space with multiple purposes and applications.



Fundamental tests combining
Quantum Mechanics and General Relativity



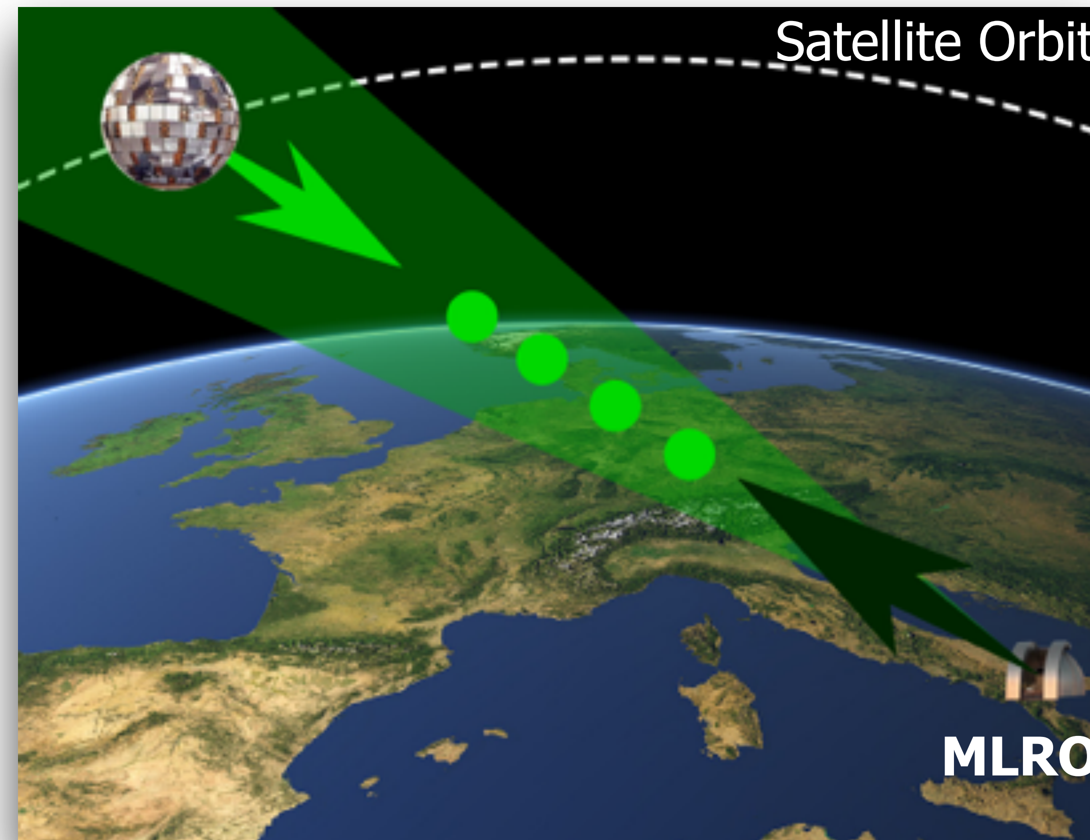
Secure communications
at planetary scale

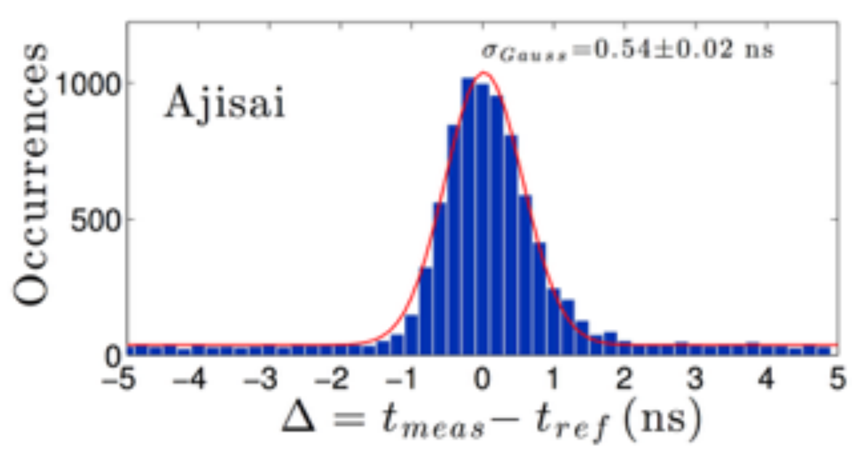
Space Quantum Communications

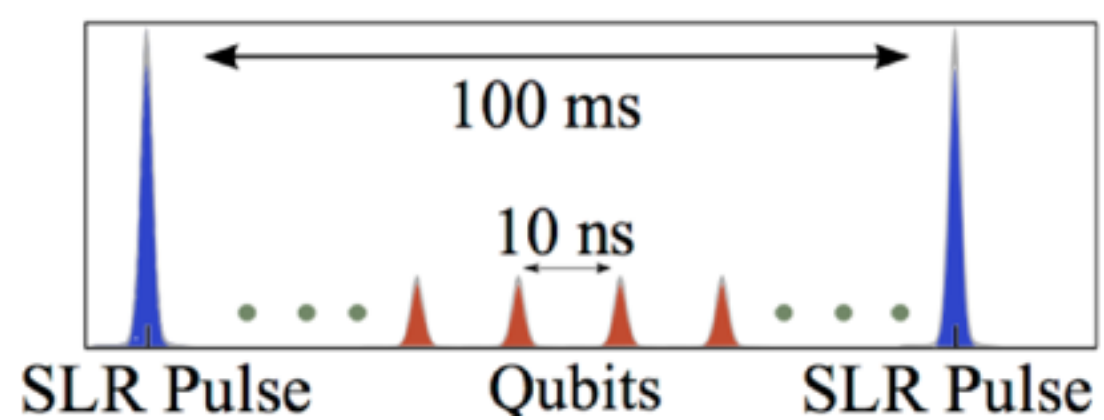
- **Quantum Communication (QC) is the faithful transmission of quantum states** between two distant locations
- QCs are at the heart of these experiments, but they are nowadays limited to within few hundreds of kilometers
- The aim of Space QCs is to **extend the frontiers of QC to satellite distances**
- Novel and **very active research field** (Europe, Canada, Japan, Singapore, China…)

Main idea of our experiments

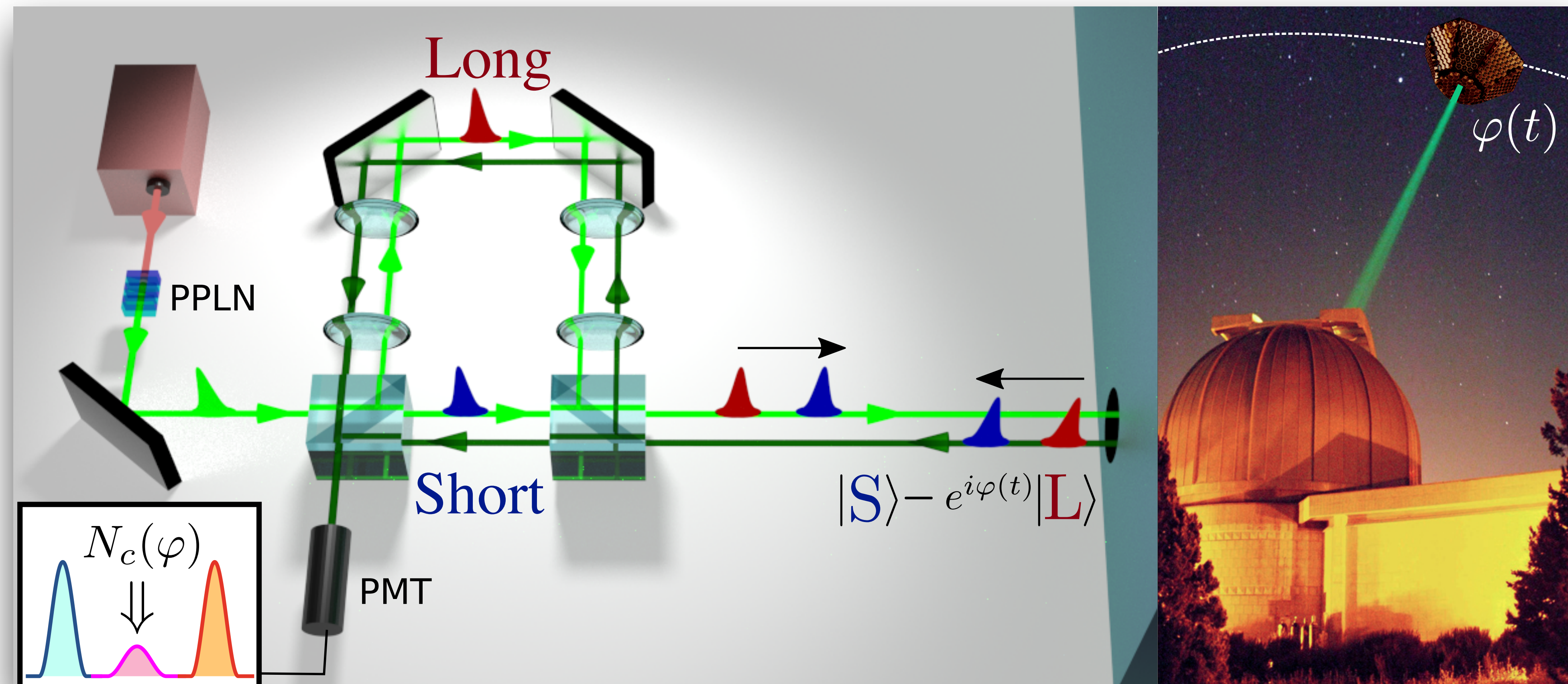
- **Mimic a quantum source in orbit** by exploiting **retroreflectors on satellites**
- MLRO for **sending pulses towards the satellites**
- **Mean photon-number per pulse very low at the reflection**
- Histogram of **single-photon detections** with 1 ns accuracy
- **Various** photon **degrees of freedom available for encoding information (polarization, temporal modes)**







Observing single-photon interference through Space

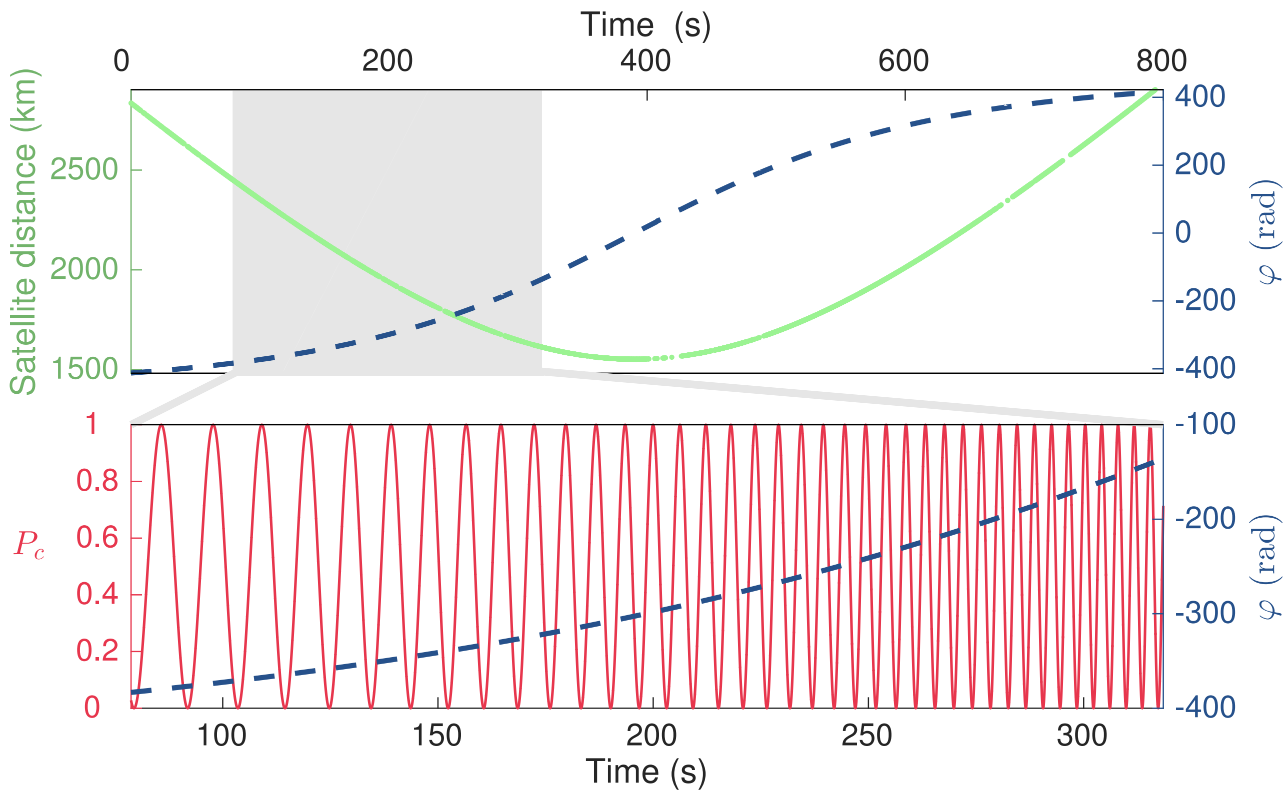


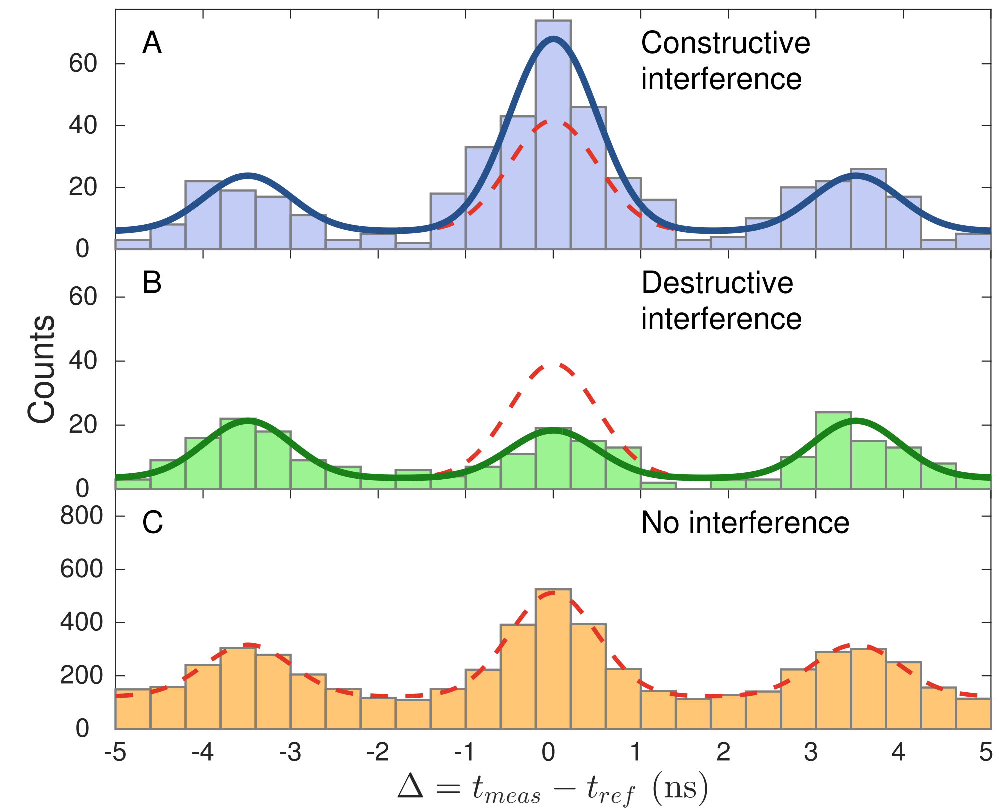
Two short pulses of light delayed by few nanoseconds are sent to the satellite which bounces them back to Earth where they are collected at the single-photon level because of the long journey. At the reflection **the satellite introduces a phase-shift** between the two pulses, **due to its relative velocity respect to the ground station**. **When the photons are temporally recombined at the ground station, they interfere** accordingly to the modulation imposed by the satellite motion.

G. Vallone et al., Interference at the Single Photon Level Along Satellite-Ground Channels, Phys. Rev. Lett. 116, 253601 (2016)

Experimental results

Since the radial velocity is continuously changing along the orbit, the detection probability in the central peak is varying accordingly





$$P_c(t) = \frac{1}{2}\left[1 - \mathcal{V}(t)\cos\varphi(t)\right]$$

$$\mathcal{V}(t) = e^{-2\pi\left(\frac{\Delta t}{\tau_c}\frac{\beta(t)}{1+\beta(t)}\right)^2}$$

$$\varphi(t) = \frac{2\beta(t)}{1+\beta(t)}\frac{2\pi c}{\lambda}\Delta t \approx \frac{4\pi}{\lambda}v_r(t)\Delta t$$

$$\beta(t) \equiv \frac{v_r(t)}{c} \qquad \Delta t \approx 3.4 \text{ ns}$$

We can **select single-photon detections** corresponding to phase-shift **for constructive and destructive interference.**

Without any data selection the interference is washed out!

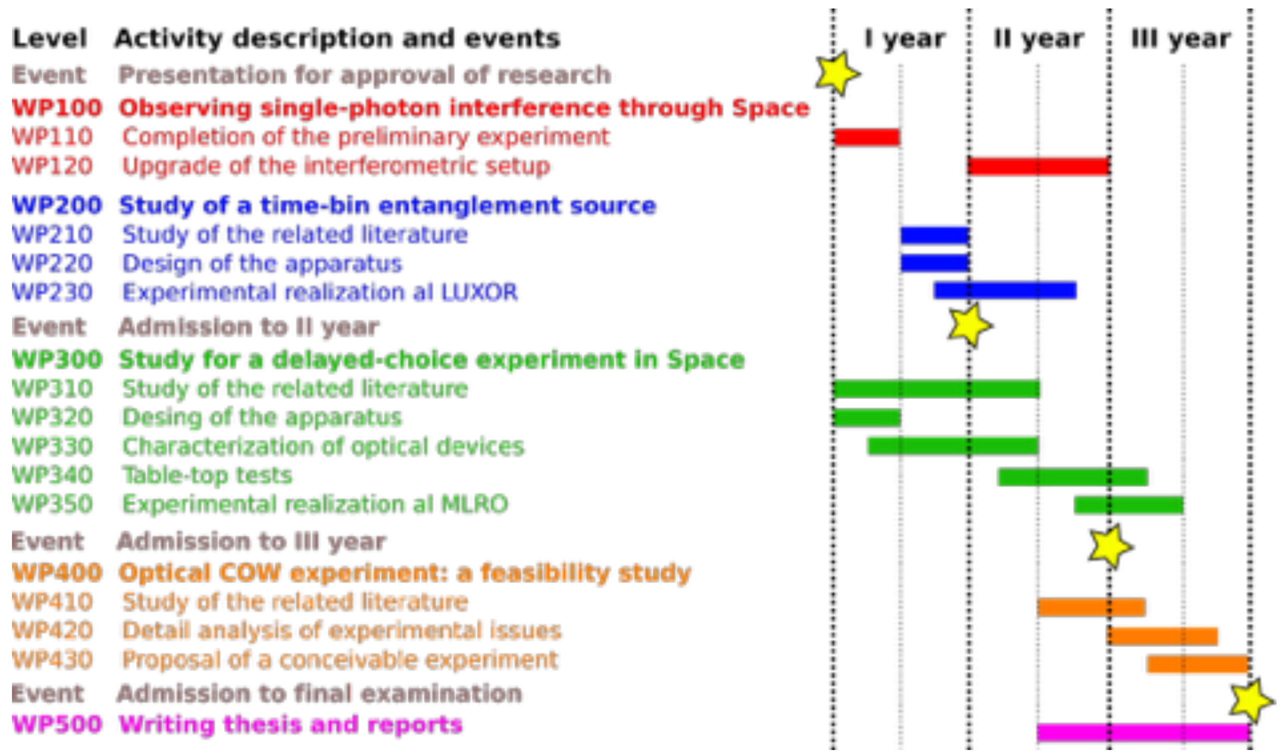
Results and future perspectives

The interference patterns measured in this experiment demonstrate that **the coherent superposition between the two temporal modes holds in the photon propagation** and its interference can be indeed observed **over very long free-space channels involving moving satellites** at fast relative velocity respect to the ground station.

Other conceivable Quantum Optics **experiments** in Space:

- Satellite version of the Wheeler's **delayed-choice experiment**
- Optical version of the **Colella-Overhauser-Werner (COW) experiment**

Research project plan and activities done



Attained 18,46 ECTS

RQI-N Conference 2016

Publications:

- G. Vallone et al., *Satellite quantum communication towards GEO distances*, Proc. SPIE 9900, Quantum Optics, 99000J (April 29, 2016)
- G. Vallone et al., *Interference at the Single Photon Level Along Satellite-Ground Channels*, Phys. Rev. Lett **116**, 253601 (2016)

Participation at conferences:

- Contributed talk: *Quantum Interference Along Satellite-Ground Channels* at Relativistic Quantum Information North Conference 2016, IQC, Waterloo, Canada
- Poster: *Observing Single-Photon Interference Along Satellite-Ground Channels* at Italian Quantum Information Science Conference 2016, Rome, Italy