# Experimental Quantum Communication with GEO satellites

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# QUANTUM COMMUNICATION

- **Quantum communication** is the area of study that deals with the transportation of quantum states between two observers, developing technologies and protocols of communication.
- **Applications**: QKD, technologies for physics experiments.

# FUNDAMENTAL PHYSICS EXPERIMENTS

We have two main theories: Quantum Mechanics and General Relativity.

- **Quantum Mechanics:** it is a well tested theory that explains phenomena at small length scales, from thousands of meters to $10^{-20}$ meters.
- **General Relativity:** it is a well tested theory that explains phenomena at very large length scales, from cosmic scale down to distances as small as 10 meters.

These two theories are incompatible with each other. To go beyond we need to perform experiments where we can observe both quantum and relativistic effects.

# FUNDAMENTAL PHYSICS EXPERIMENTS

We need to perform experiments on large length scales as Earth-Satellite distance and Earth-Sun distance.

The scientific community proposed a list of experiments, which includes:

- Long distance Bell test.
- Bell test with human observers
- Bell test with detectors in relative motion

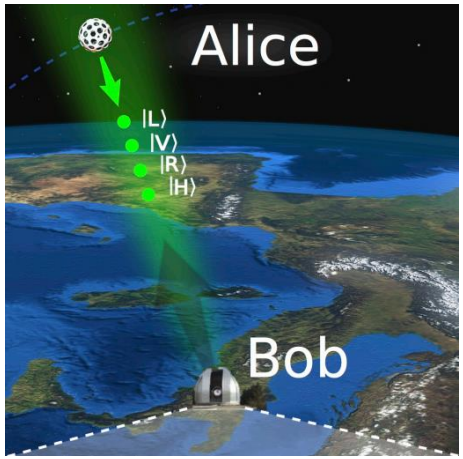
These experiments require the exploitation of Space Quantum Communication between Earth and Satellites.

# SPACE QUANTUM COMMUNICATION: STATE OF THE ART

First realization of Space Quantum Communication between Earth and LEO satellites by sending quantum states encoded with polarized photons, achieved by the QuantumFuture group at Padova.

[…We demonstrated the faithful transmission of qubits from space to ground by exploiting satellite corner cube retroreflectors acting as transmitter in orbit, obtaining a low error rate suitable for QKD.]
Phys. Rev. Lett. **115**, 040502

This is a major breakthrough toward the realization of Space QC, but still it is not sufficient to realize the experiments mentioned.



# MAIN RESEARCH OBJECTIVES

Extending Space QC with polarized photons exploiting GEO satellites: improve the apparatus performance by

- using detectors with higher efficiency
- improving the time resolution of photon detection

This is fundamental to perform long distance Bell test.

# BELL TEST

- **Bell test**: it defines an experimental test to prove that Quantum Mechanics does not satisfy Locality and Reality principle.
- **Locality principle:** if two measures occour in two events, space-like separeted, they cannot influence each other.
- **Reality principle:** if we can predict with certainty the value of a physical quantity, it's value has a physical reality: it is independent from the fact that we observe or not the system.

# BELL TEST


$$|\psi\rangle = \left(|\downarrow\uparrow\rangle - |\uparrow\downarrow\rangle\right)/\sqrt{2}$$

- Two observers, Alice and Bob, performs indipendent measures on the same system. The system is comprised of a couple of photons in an entangled state; one photon is sent to Alice, the other is sent to Bob.
- Based on the Locality and Reality principles, Bell derives the probabilities that Alice and Bob get certain outcomes from their measures. These probabilities should satisfy an inequality.
- It turns out that, using quantum mechanics to calculate the probabilities, the inequality is violated.

# LONG DISTANCE BELL TEST

**What happens when we consider Bell test in a relativistic scenario?**

If the events, corresponding to Alice and Bob's measures, are space-like separeted, the concept of time ordering is frame dependent: an external observer in relative motion with respect to the experiment would answer differently to the question "who measured first?".

This leads to a paradoxical situation since quantum mechanics assumes that, when a measure takes place, the state change suddenly in a way that depends on the measure.

Then, if Alice and Bob perform different measures, how does the state change?

# LONG DISTANCE BELL TEST

- The long term objective is to realize a Bell test using satellites as observers.
- A sufficiently power source of entangled photons is needed. Currently, we have a source of entangled photons that has been used to carry out Bell test on optical table. This source is not suitable for Space QC.
- The research includes the enhancement of this source, and the execution of double violation of Bell inequalities on optical table.