Quantum Communications Demostrated For Satellite Downlink At MLRO

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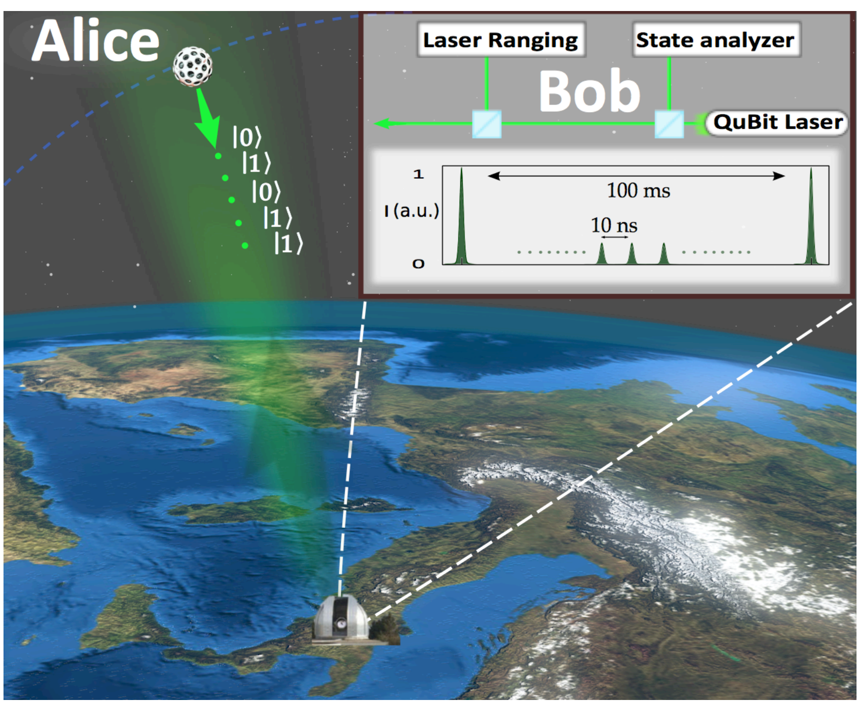
Introduction: We study the exchange of quantum bits – or qubits - from Space to ground exploiting a setup based on SRL scheme. The results suggest that the SLR network is suitable to allow for a rapid expansion of the Quantum Communications in Space.

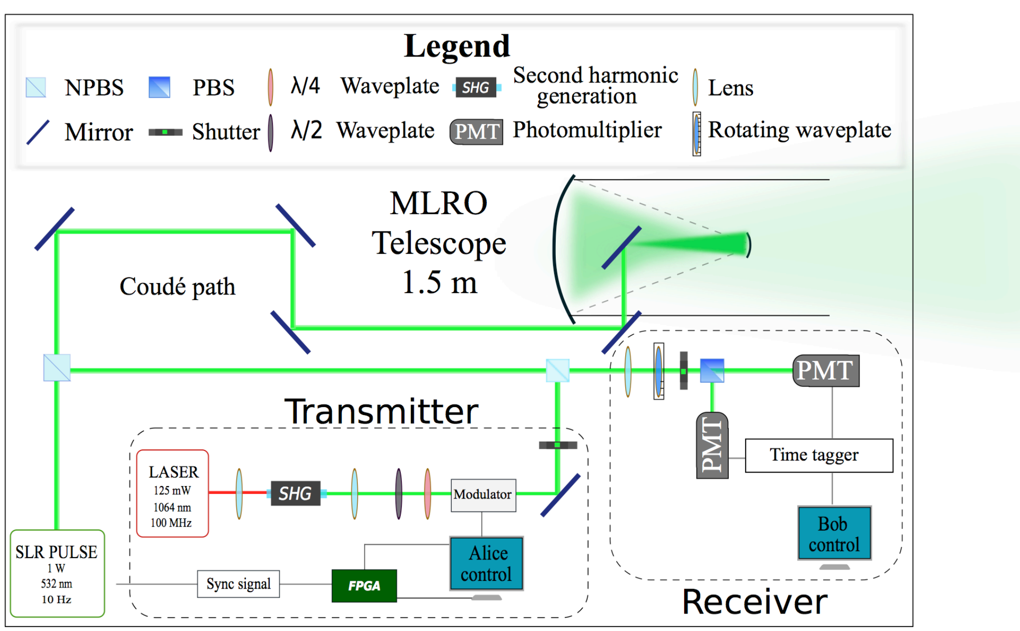
Objectives: Quantum Communications (QC) on planetary scale require complementary channels including ground and satellite links [1]. As the former have progressed up to commercial stage using fiber-cables, it's very important the study of links for space QC and eventually the demonstration of protocols such as quantum-key-distribution (QKD) and quantum teleportation along satellite-to-ground or intersatellite links. In recent announcements, the launch of dedicated mission was envisaged [2,3]. However, these approaches require a complete terminal to be realized and qualified, launched and operated in space, including a telescope with very accurate pointing and tracking, focal plane instrumentation for two wavelengths – one for the qubits and one for the synchronization – quantum state source with lasers and accurate electronic control for encoding and synchronization.

In our study, the two-way scheme of the SLR is used for the quantum channel in parallel to normal operation of satellite ranging at Matera Laser Ranging Observatory, MLRO of the Italian Space Agency located in Matera, Italy. We aim to demonstrate the complementarity of the SLR and quantum channels as well as to point out the means for realizing the quantum state measure from a space channel.

Experiment: The overall scheme of the experiment is shown in the figure below.



The faithful transmission of qubits from Space to ground required the generation of a train of laser pulses at the wavelength used by MLRO exploiting satellite corner cube retroreflectors acting as transmitter in orbit [4]. Conventionally this corresponds to the transmitter – or Alice – on the satellite and the state analyzer, or Bob, on ground. Qubit pulses are sent at 100 MHz repetition rate and are reflected back at the single photon level from the satellite, thus mimicking a QKD source on Space. We used the satellite equipped with metallic coating on the corner cube retroreflector in order to realize the polarization encoding of the quantum state. Synchronization is performed by using the bright SLR pulses at repetition rate of 10 Hz. Indeed, In order to reject the background and dark counts, synchronization at Bob is required at the nanosecond scale. For actual qubits discrimination, we realized a state analyzer with the time-tagging of referenced to SLR pulses provided by the MLRO unit, which has few picosecond accuracy. Indeed, by dividing the intervals between two consecutive SLR detections in 10^7 equidistant subintervals, we determined the sequence of expected qubit times of arrival t_{ref}. This technique compensates for the time scale transformation due to satellite motion with respect to the ground. Our detection accuracy σ was set equal to the detector time jitter (0.5 ns), as other contributions to time uncertainties coming from detection electronics or laser fluctuations are negligible.
The satellite laser ranging (SLR) signal is generated in a comb of strong pulses (10 Hz repetition rate and 100 mJ pulse energy). The laser seed at 100 MHz is extracted from the SLR setup, converted to the second harmonics and used by Alice in the qubit preparation. Two non-polarizing beam splitters were used in the optical path in order to merge and split the outgoing and incoming SLR signal and qubit stream. We note that this sub-nanosecond qubit arrival identification represent a factor of ten improvement with respect to the technique based on orbital parameters and exploited in the first demonstration of the single photon exchange with satellites [5]. The setup for the QC at MLRO is sketched in the figure below.



We demonstrate the achievement the exchange of qubits with a value of quantum bit-error-rate – or QBER - of 3.7% (LARETS) and 6,7 % (STARLETTE), suitable for QKD applications.

The return frequencies of the qubits for the above satellites were typically in the range of several hundred bits per second, with the notable exception of Starlette, which exceeded one thousand. From the satellite link budget derived from the radar equation, the mean photon number of the state leaving the satellite has been estimated to be of the order of unity, as required for QC. According to this estimate and the downlink losses, the return rate prediction were compared to the experimental results and found in good agreement. Uncertainties in the orbital parameters and beam pointing affect trend of the return rate beyond shot noise. The twin satellites Stella and Starlette show different behavior despite similar characteristics, but in line with the SLR statistics, which report unequal returns rates. We note that, if the outgoing and incoming beams travel through the same optical path, the polarization transformation induced in the uplink by the telescope movements is compensated in the downlink. Therefore on the base of present results on the state discrimination, we may envisage a two-way QKD protocol exploiting modulated retroreflectors that necessitates a minimal payload on satellite, with a further advantage in the case in the case of finite key [6], thus facilitating the expansion of Space QC and Quantum Physics tests in Space.

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