04-006

Satellite Quantum Communications exploiting SLR at MLRO

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Objectives: Quantum Communications (QC) in Space are gaining a strong momentum for both providing the way to realize tests on the interplay of Quantum Physics and Gravity on very long scale and for terminals in relative motion [1] as well as to provide a network of secure communications on planetary scale [2].

In our study we addressed the extension of the single photons exchange, initially demonstrated for LEO orbits [3,4] to a source in MEO orbit [5] and we extended the physical degree of freedom used for the encoding of the qubit from the polarization initially used, to the temporal modes [6]. In both cases, QC are referenced to the SLR pulses used at MLRO - Matera Laser Ranging Observatory of the ASI Italian Space Agency, in Matera, Italy.

Experiment: The source of single photons from Space was devised in [3] exploiting the orbiting retroreflectors used in the SLR network. The initial demonstration was relative to the emission of pulses at about 17 kHz from Ajisai, that were detected using MLRO at expected times of arrival defined by the precise reconstruction of the orbit. We modified this approach by devising an interleaved transmission to the satellite including the train of pulses that shall realize the single photon stream and the MLRO intense pulses for SLR (100 mJ, 10 Hz, 532 nm, <100 ps). In this way, the precision in reconstruction of the times of arrival improved by an order of magnitude.

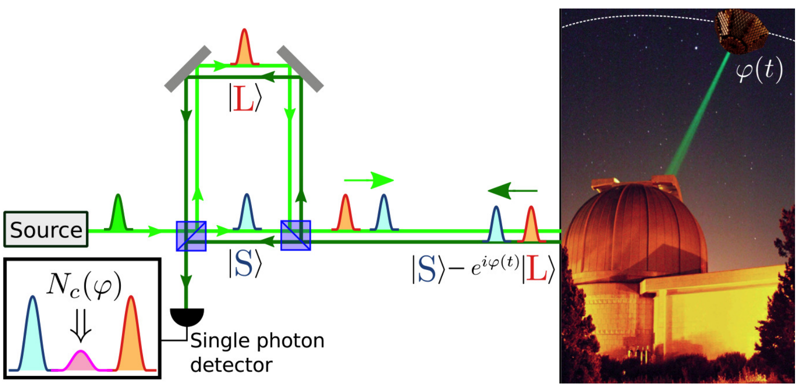

Fig. 1 – Scheme of the setup for the interference observation. L and S refer to long and short paths.

Consequently, it was possible to reduce the noise at the receiver by reducing the temporal window in the criteria for selecting the returned photons. In this way, a peak at the expected time for the single photon return from LAGEOS-2 was observed with a statistics better that 5 std with respect to the noise. The slant distance exceeded 7000 km, thus extending to the MEO class the results so far reported for the LEO [3,4,5].

The exploitation of the temporal modes of the photon is an intriguing aspect of QC, that has been exploited extensively on ground optical communications along fibre links. However it was never reported its use in a free-space link. We investigated the study of the propagation, reflection and detection of a two-modes state, created with an unbalanced Mach-Zehnder Interferometer (MZI), as in the scheme of the experiment shown in Fig. 1. In order to reject the background and dark counts, a synchronization of the transmitter and receiver is required at the nanosecond scale, obtained again by time-tagging SLR pulses provided by the MLRO unit, which has few picosecond accuracy. 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 MZI was fed with pulses at 100 MHz, extracted from the SLR setup and converted to the second harmonics.

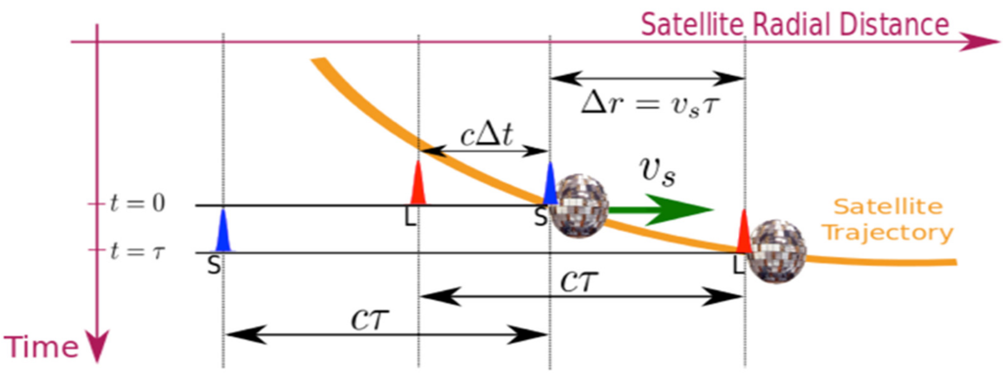

Fig. 2 – Process at the satellite reflection which originates the phase modulation in the single photon interference measured at the receiver.

In the reflection at the satellite, a phase shift to the second pulse, separated of Δt from the first one, is induced as a function of the instantaneous relative velocity, as sketched in Fig. 2. By reconstruction the phase function φ(t) using the velocity measurements done on the base of the SLR signal, the instant in which constructive or destructive interference (see inset in Fig. 1) may be pointed out along the orbit.

The intererence of the quantum superpositoin of the two temporal modes in a single photon state, or time-bin qubit, is detected by pass. These are shown in Fig. 3 in the case of the Beacon-C satellite.

By investigating interference for Beacon-c, Ajisai and Stella, we confirmed the visibility of the interference with a visibility up to 67% [6].

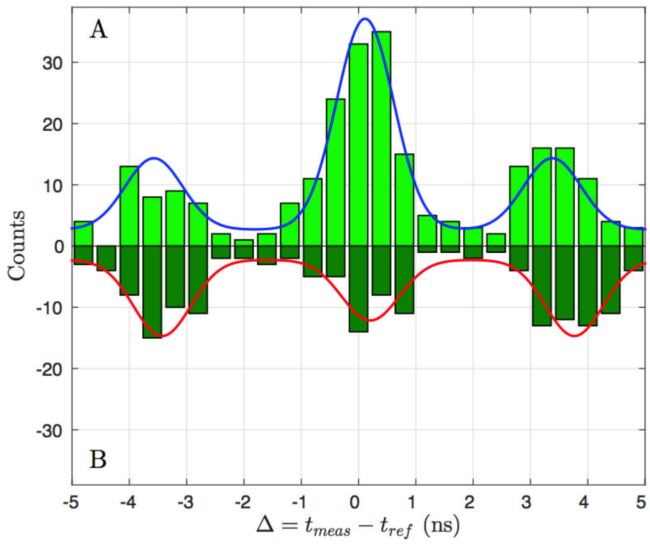

Fig. 3 – Interference for a passage of Beacon-C corresponding to constructive condition, in panel A) and to destructive condition, in panel B).

In conclusion, the SLR pulse reference is continuing to demonstrated a very valuable framework for realizing demonstration in Space QC. Possible applications of the present results spans from precise metrology of satellite dynamic, investigation on quantum correlations over long distances as well as secure communications on planetary scale.

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