Space-QUEST:
satellites based quantum communication

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***Abstract*— The European Space Agency (ESA) has supported a range of studies in the field of quantum physics and quantum information science in space and a mission proposal Space-QUEST (Quantum Entanglement for Space Experiments) was submitted. We propose to perform space-to-ground quantum communication tests from the International Space Station (ISS). We present the proposed experiments in space as well as the design of a space based quantum communication payload.**

Keywords-component; quantum optics, quantum key distribution,

I. INTRODUCTION

Quantum entanglement is, according to Erwin Schrödinger in 1935 [1], the essence of quantum physics and inspires fundamental questions about the principles of nature. By testing the entanglement of particles we are able to ask fundamental questions about realism and locality in nature [2, 3]. Local realism imposes certain constraints in statistical correlations of measurements on multi-particle systems. Quantum mechanics, however, predicts that entangled systems have much stronger than classical correlations that are independent of the distance between the particles and are not explicable with classical physics. It is an open issue whether quantum laws, originally established to describe nature at the microscopic level of atoms, are also valid in the macroscopic domain such as long distances. Various proposals predict that quantum entanglement is limited to certain mass and length scales [4, 5] or altered under specific gravitational circumstances [6].

II. PROPOSED EXERPIMENTS SO FAR

Testing the quantum correlations over distances achievable with systems placed in the Earth orbit or even beyond 7] would allow to verify both the validity of quantum physics and the preservation of entanglement over distances impossible to achieve on ground.

Using the large relative velocity of two orbiting satellites, one can perform experiments on entanglement where—due to special relativity—both observers can claim that they have performed the measurement on their system prior to the measurement of the other observer. In such an experiment it is not possible anymore to think of any local realistic mechanisms that potentially influence one measurement outcome according to the other one. Moreover, quantum mechanics is also the basis for emerging technologies of quantum information science, presently one of the most active research fields in physics. Today's most prominent application is quantum key distribution (QKD) [8], i.e. the generation of a provably unconditionally secure key at distance, which is not possible with classical cryptography. The use of satellites allows for demonstrations of quantum communication on a global scale, a task impossible on ground with current optical fiber and photon-detector technology. Currently, quantum communication on ground is limited to the order of 100 of kilometers [9, 10]. Bringing quantum communication into space is the only way to overcome this limit with state-of-the-art technology.

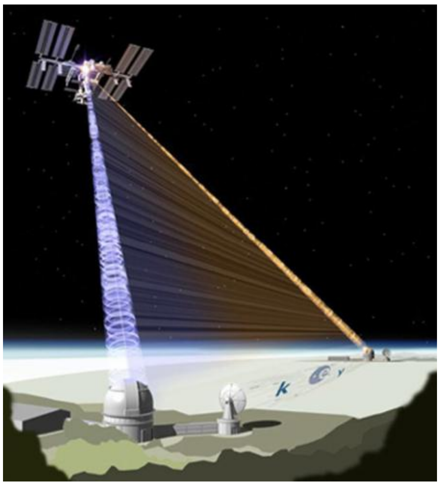

Figure 1 Distribution of pairs of entangled photons using the International Space Station (ISS). Entangled photon pairs are simultaneously distributed to two separated locations on Earth, thus enabling both fundamental quantum physics experiments and novel applications such as quantum key distribution. (Image courtesy ESA/GSRP).

Another area of applications is in metrology, where quantum clock synchronization and quantum positioning [11] are studied. Furthermore, sources of quantum states in space may have applications in the new field of quantum astronomy [12].

We propose to ESA to perform these experiments in space by placing a quantum transceiver on the external pallet of the European Columbus module at the ISS.

In our talk we will present the scientific background and the technological development to be tackled with within this project. We will present theoretical as well as experimental studies [13-16] performed so far as well as ongoing studies performed by several partners from academia as well as from industry.

III. PROOF-OF-PRINCIPLE EXPERIMENTS

We report a proof-of-principle experiment where we were able to generate a quantum cryptographic key over a record-breaking distance 144 km over a free-space link between the Canary Islands La Palma and Tenerife [14,15]. One photon from the entangled pair was measured locally. The second photon was sent via a transmitter telescope over the 144 km long free-space link to the Optical Ground Station (OGS) of the European Space Agency (ESA) on Tenerife. The OGS, originally built to act as a transmitter and receiver for classical laser communication to and from satellites, a 1 m Richey-Chrétien/Coudé telescope was used to collect the single photons. The atmospheric turbulence caused significant beam wander in the focal plane. A suitable optical system was implemented to prevent the beam from wandering off the single photon detectors with a quantum efficiency of about 40%. We measured a loss of -30 dB on the entire quantum link.

Each event in one of the detectors was locally labelled with a 64-bit computer generated tag, containing the detector channel and a time tag with a timing resolution of 156 ps synchronized with a 10 MHz oscillator directly disciplined by the Global Positioning System (GPS) with a relative drift of about 10-11 over 100 s. The identification of the coincident events where implemented by cross-correlating both sets of time tags using software which determined the offset (~487 µs) and unavoidable drift of the two timescales online. Future experiments with entangled photons will benefit from the increased precision of clock synchronization.

Entangled photons shared between the two parties were used to establish 178 bits unconditional secure key [**Fehler! Verweisquelle konnte nicht gefunden werden.**] in total. Any attempt by an eavesdropper to intercept and copy the key is obvious to the receiving party, who notices errors in the transmission. This experiment demonstrated for the first time the use of an entangled photon source delivering the pair production rate required to realize an optical downlink from low-Earth satellites, such as the International Space Station (ISS) [13], to optical ground stations on Earth. This would allow a separation of the two entangled photons by more than 1400 km, clearly exceeding the possible distances for today¹s fiber technology [9].

IV. CONCLUSIONS

We emphasize that the space environment will allow quantum physics experiments with photonic entanglement and single photon quantum states to be performed on a large, even global, scale. The Space-QUEST proposal aims to place a quantum communication transceiver containing the entangled photon source, a weak pulsed (decoy) laser source and single photon counting modules in space and will accomplish the first-ever demonstration in space of fundamental tests on quantum physics and quantum-based telecom applications. The unique features of space offer extremely long propagation paths to explore the limits of the validity of quantum physic's principles. In particular, this system will allow for a test of quantum entanglement over a distance exceeding 1000 km, which is impossible on ground.

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