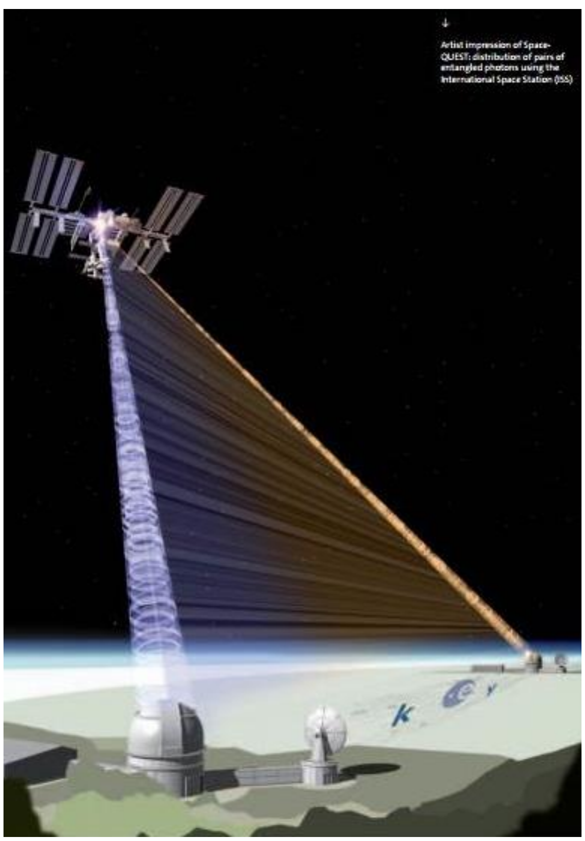
“Spooky Interaction” Experiment on the ISS

Having investigated the ESA ACES Experiment, soon to be conducted on the ISS – see also my previous article: “Einstein on the ISS” – I ran across an even more interesting “Einstein”- experiments dealing with the “spooky interaction” of entangled photons, the Space-QUEST experiments (Quantum Entanglement for Space Experiments).
The formation of a “Topical Team” for proposing the Space-QUEST experiments comprised researchers from academia actively involved in relevant scientific fields was initiated by ESA in 2007. At that time the programmatic roadmap for Space-QUEST experiments assumed an initiation date by end of 2014.
The first set of Space-QUEST experiments was originally submitted to ESA by Rupert Ursin and his international research Topical Team in 2008 [1] for the ELIPS program (European Life and Physical Sciences in Space). Quantum entanglement according to Erwin Schroedinger “is 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. 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.

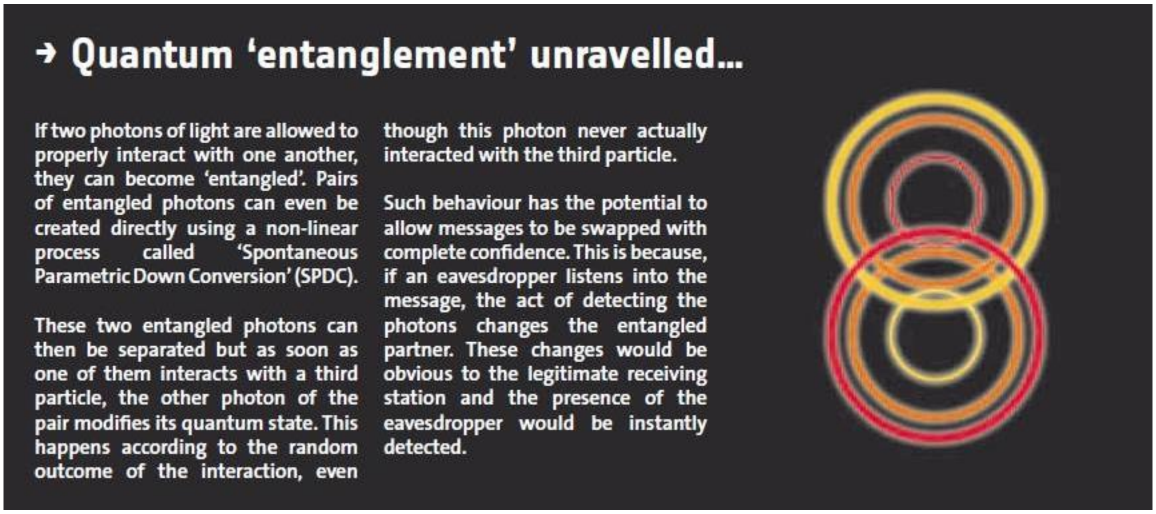
A variety of quantum experiments was proposed in [1]. One proposal was to use the large relative velocity of two orbiting satellites to perform experiments on entanglement where—due to special relativity—both observers can claim that they have performed the measurement on their system prior to the measurement of the other observer. In such an experiment it would not be possible anymore to think of any local realistic mechanisms that potentially influence one measurement outcome according to the other one.
As quantum mechanics is also the basis for emerging technologies of quantum information science, presently one of the most active research fields in physics with today's most prominent application, the Quantum Key Distribution (QKD) i.e., the generation of a provably unconditionally secure key at distance, which is not possible with classical cryptography, therefore the Topical Team also proposed to perform these experiments in space by placing a quantum transceiver on the external pallet of the European Columbus module at the ISS.



Why quantum communications?[3]
Security services are critical to modern tele-communications. For instance, they help ensure that a message received is the one that was sent, and that secrets remain secret.
The most sensitive information, such as bank transfers or military communications, can be encrypted very effectively. But some widely used encryption systems could be defeated by powerful computers, and even if information is encrypted, an eavesdropper can still tap into a conventional communications channel and listen to or copy a transmission without being detected.

Quantum mechanics offers the potential for ultra-secure communications because the act of observing an unknown quantum system changes its state. As a consequence, accurate copying is impossible, and changes caused by eavesdropping can be detected. Whereas today’s fibre-optic communication systems require bits of information made of thousands of photons, quantum communication uses single photons to transmit unique random secret keys of ones and zeros. These can be used in future secure encryption systems

Fig. 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 [1][3].



→ Quantum 'entanglement' unravelled...

If two photons of light are allowed to properly interact with one another, they can become 'entangled'. Pairs of entangled photons can even be created directly using a non-linear process called 'Spontaneous Parametric Down Conversion' (SPDC).

These two entangled photons can then be separated but as soon as one of them interacts with a third particle, the other photon of the pair modifies its quantum state. This happens according to the random outcome of the interaction, even though this photon never actually interacted with the third particle.

Such behaviour has the potential to allow messages to be swapped with complete confidence. This is because, if an eavesdropper listens into the message, the act of detecting the photons changes the entangled partner. These changes would be obvious to the legitimate receiving station and the presence of the eavesdropper would be instantly detected.

Fig.2: Quantum entanglement unraveled [3]

In 2009 ESA successfully conducted an "Inter-island link demonstration" experiment (within the experimental evaluation of quantum communications) for demonstration quantum communications applications as well as fundamental principles of quantum physics in space. The experiment was conducted between the transmitter on the island of La Palma and a receiver on Tenerife. The distance was 143 km – the longest distance covered so far, 2,3 km above sea level. [3].

In 2013 a simplification of the original experiment proposal [2]described above was promoted by T. Scheidl (IQOOI - Institute for Quantum Optics and Quantum Information, Vienna), E. Wille (ESA) and R. Ursin (IQOOI) by introducing a ground-to-space single-link scenario using the Cupola on the ISS and a photographer's lens mounted on a motorized camera pod for compensating the ISS orbital progress during the measurement period. A dedicated small add-on module with single photon detection, time-tagging and classical communications capabilities would facilitate the quantum optics experiment in space using as much available onboard capabilities as possible [2].

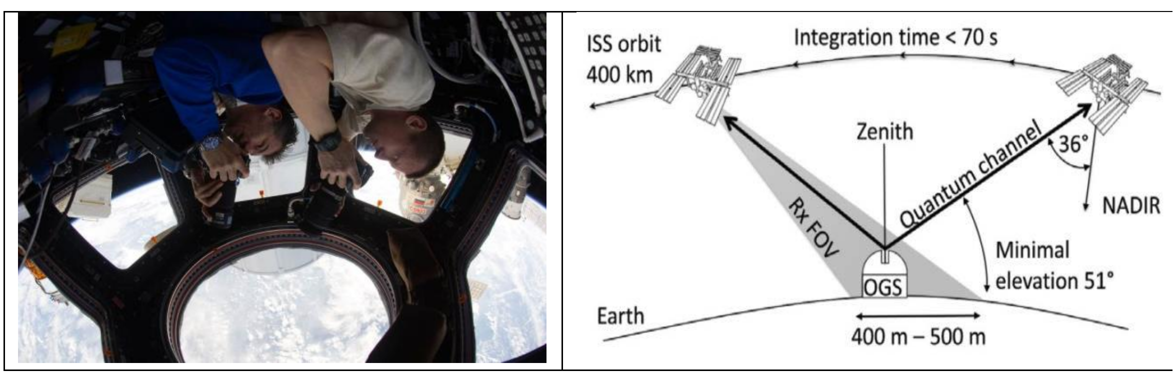


Fig 3 Single Link Orbit scenario for using the ISS (simplified scenario) [2]

More progress on "spooky entanglement" and proving that Einstein supposedly was wrong was reported in 2015 by a team from Australia's Griffith University and Japan's University of Tokyo. The team split a single photon in half and transmitted it to two separate labs. Upon analysis, they found that the particle not only exists in a superposition state until it is observed but that it never showed up in both labs at the same time. The superpositioning state and the following wave form collapse means that a particle in superposition effectively exists in both places at once until it is observed at either location, at which time the particle which is not looked at ceases to exist (wave function collapse). The disappearing particle seems to know that its twin has been discovered through some mechanism that happens instantly, literally traveling faster than the speed of light – a clear violation of Einstein's theory of relativity. [4]

Another such experiment was reported in October 2015 [5]: According to the study published in the journal *Nature*, researchers placed diamonds with a lone electron in two locations 1.3 kilometers (0.8 miles) apart and were able to demonstrate that the particles have a clear connection by observing a violation of Bell's inequality of $S=2.42 \mp 0.20$ (instead of $S \leq 2.0$ according to Bell's inequality for the local-realist theory). With those results the researchers believe they may have cemented over the loopholes from past experiments and claim that particles are entangled and always connected in a way that they can affect one another regardless of the distance.
More importantly, the Space-QUEST experiment will allow to explore the boundaries between quantum mechanics and gravitation, today one of the most active fields of research. The large variation of the gravitational potential encountered by the entangled photon while travelling from the ground station to the ISS allows to place limits on the de-coherence effects introduced by gravity on the entangled state [6].

After inquiry with ESA the current status of the experiment, Eric Wille (ESA Technology Development for entangled photon sources and other technologies for "quantum applications") explained: "ESA has developed several demonstrators to show different types of entangled photon sources for space experiments. The most mature demonstrator is planned to undergo first environmental testing this year (2016), but this is not yet a flight version (as there is no consolidated mission yet). But successful tests would of course increase the chances for candidate mission being evaluated positively. The optical terminal technology has been proven to work for many classical laser communication missions over the last years, so there is little need for development on that side at the moment. Apart from ESA's activities, several groups in and outside Europe are also working on national or bilateral projects. Also note that some of the activities are not directly related to the Space-QUEST proposal, but to other proposed projects involving entangled photons (for example for providing a quantum key service). Of course, the technology is very similar, so different missions will profit from the same technology development results. But some mission scenarios only need the laser source in space, others only need the detectors in space and some need both in space."

Luigi Cacciapuoti (ESA Astrophysics and Fundamental Physics office) the designated 'project scientist' of the Space-QUEST experiment added: "At the moment we are consolidating the Space-QUEST science case. The mission objectives as well as the set of scientific requirements driving the system architecture and the hardware design are being reviewed by the Space-QUEST science team and ESA. Based on this input, ESA will then start a phase A study to define the final experiment configuration. We expect that to happen by mid this year (2016). Funding is available"

Of course it is very desirable that this exciting experiment "makes its way" onto the ISS during the next two years to further enhance the reputation of the International Space Station as a world-class laboratory allowing to perform decisive research projects with a practical application potential only possible "in orbit". SpaceOps will be following the progress with utmost interest.

References

[1] 2008: Space-QUEST Experiments with quantum entanglement in space - Proposal (IAC 2008, R. Ursin et al "Topical Team")
[2] Quantum optics experiments using the International Space Station: a proposal (T. Scheidt, E. Wille, R. Ursin, New Journal of Physics 15, 213)
[3] 2009: ESA Bulletin 132: Leap ahead in Space Communications: 143 km Canary island transfer
[4] 2015 Spooky experiment proves quantum entanglement is real (Andrew Tarantola - Nature Communications): Transfer between Labs(?) of an Australian/Japanese team.
[5] Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometers (Nature letter http://www.nature.com/nature/journal/v526/n7575/full/nature15759.html.
[6] Ralph, T. C., and J. Pienaar. "Entanglement de-coherence in a gravitational well according to the event formalism."New Journal of Physics16.8 (2014): 085008.(http://arxiv.org/pdf/1406.3677v1.pdf)

(7) Video on Quantum entanglement https://www.youtube.com/watch?v=BFvJOZ51tmc
Quantum entanglement history and Alain ASPECT experiments (very good educational illustration)