SEVENTH FRAMEWORK PROGRAMME

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Project acronym: **Q-ESSENCE**

Project title: **Quantum Interfaces, Sensors, and Communication based on Entanglement**

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DELIVERABLE REPORT

Deliverable no.:	**D3.1.3**
Deliverable name:	**Successful demonstration of universal entanglement distillation including report**
Workpackage no.	**WP3.1**
Lead beneficiary	**UOXF.DU**
Nature	**R = Report**
Dissemination level	**PU = Public**
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Status	**Partially achieved**

This deliverable report summarises the status of efforts to implement entanglement distillation at UOXF.

UOXF has developed a dispersion-engineered down-conversion source that produces 2 mode squeezing with less than 5% contamination from higher squeezing modes [Mosley *et al.* Phys. Rev. Lett. **100,** 133601 (2008)]. We also developed photon-number resolving detectors based on time-multiplexing and off-the-shelf avalanche photodiodes [Achilles *et al.* J. Mod. Opt. **51** 1499 (2004)]. We combined these technologies to implement entanglement distillation based on the protocol developed by Browne, Eisert, Scheel and Plenio [Phys. Rev. A **67,** 062320 (2003)]. This requires a non-Gaussian operation. Photon subtraction, using a weakly reflecting beam splitter, provides this operation, and additionally boosts the entanglement directly by increasing the average photon number of the state (counter-intuitively, since those states where subtraction is successful are in fact the more highly populated states).

To verify that subtraction does indeed distill states with more entanglement than is present in the initial resource states, we developed an entanglement witness based on weak-field homodyne detection, employing our time-multiplexed detectors [Puentes *et al.,* New J. Phys. **12** 033042 (2010)]. The experiment was built at UOXF, and subtraction was successfully implemented on the source [Coldenstrodt-Ronge *et al*. CLEO/IQEC ITuB2 (2009)]. UP performed simulations of the witness performance in the presence of statistical fluctuations, phase noise, fluorescence and dark counts. The simulations indicated the witness would perform well, and provide both an upper bound on the initial entanglement, and a lower bound on the final entanglement (after subtraction) sufficient to establish the effect of the distillation operation.

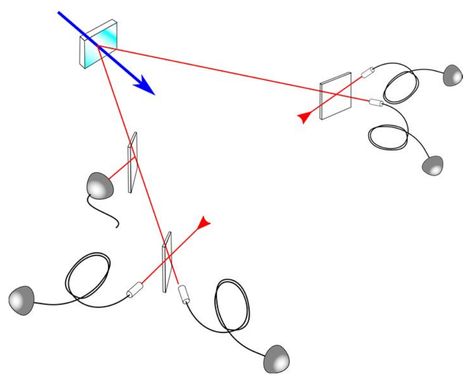

Figure 1: Entanglement distillation. The entanglement of a two-mode squeezed state is increased when an APD detects a single photon scattered by a weakly reflecting beam splitter in one arm. Weak-field homodyne detection with time-multiplexed detectors implements an efficient entanglement witness.

While the scientific objectives of this deliverable were largely achieved – in that we successfully developed the sources and detectors required for entanglement distillation, along with a novel entanglement witness based on weak-field homodyning, and a number of related theoretical and experimental advances that resulted in papers – technical difficulties prevented us from experimentally witnessing distillation in the lab. We constructed a two-colour phase lock [Jotzu *et al.,* J. Mod. Opt. **59**(1) 42 (2012)] to stabilize any drift in the squeezing phase, but a periodic variation in the temperature of our lab (caused by an under-performing air-conditioning system) introduced power fluctuations that rendered our data incompatible with a pure state. Because of this the witness algorithm was blinded to the entanglement in the state. Simulations at UP showed that without this drift, the experimental precision would otherwise have been sufficient. Our lab is being renovated this summer and the air-handling system will be upgraded. Although it is of course disappointing that we could not experimentally verify entanglement distillation within the lifetime of Q-ESSENCE, we are nonetheless satisfied with the scientific outcomes of this work. Our contributions advanced the theory of entanglement distillation protocols [Datta *et al.,* Phys. Rev. Lett. **108** 060502 (2012), Bartley *et al.,* Phys. Rev. A **87** 022313 (2013), Vidrighin *et al.* Quant. Meas. & Quant. Metr. **1** 5 (2013)], and produced a number of significant experimental advances [Bartley *et al.,* Phys. Rev. Lett. **110** 173602 (2013), Zhang *et al.* Nat. Phot. **6** 364 (2012), Bartley *et al.,* Phys. Rev. A **86** 043820 (2012)]. We are confident that the lab refurbishments this year will allow the stability to finally carry out the measurements necessary to certify distillation.