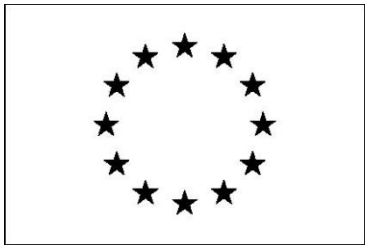

PROJECT PERIODIC REPORT

Grant Agreement number**:248095**

Project acronym: **Q-ESSENCE**

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

Funding Scheme:**Collaborative Project (Large-Scale Integrating Project)**

Date of latest version of Annex I against which the assessment will be made:**2011-11-24**

Periodic report: **1st☐2nd■3rd ☐4th ☐**

Period covered: from **2011-02-01** to **2012-01-31**

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Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate)[1]:

  ☐ has fully achieved its objectives and technical goals for the period;

  ■ has achieved most of its objectives and technical goals for the period with relatively minor deviations.

  ☐ has failed to achieve critical objectives and/or is not at all on schedule.

- The public website, if applicable

  ■ is up to date

  ☐ is not up to date

- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: Konrad Banaszek

Dr hab. Konrad Banaszek

Date: 30 / 03 / 2012

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism.

[1] If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.

3.1 Publishable summary

The Q-ESSENCE project exploits quantum entanglement to enable disruptive technologies that will solve outstanding issues in information and communication technologies (ICT) related to trust, privacy protection, and security in two- and multi-party transactions, novel or enhanced modes of operation of ICT devices, reference standards, sensing, and metrology. The practical exploitation of entanglement requires groundbreaking levels of robustness and flexibility for deployment in real-world environments which can be reached only through radically new designs of protocols, architectures, interfaces, and components. Q-ESSENCE targets these breakthroughs by a concerted application-driven effort covering relevant experimental, phenomenological, and fundamental aspects. The objectives of the project are pursued by three closely interacting subprojects that are oriented towards specific application areas of quantum technologies.

The main objective of Sub-Project 1 "Quantum Metrology and Sensing" is to design and implement techniques that enable sensing and measurement beyond what has been possible with classical resources. This includes the use of quantum states of light and/or matter to determine with ultimate precision parameters such as time, distance, magnetic or gravitational fields, as well as to estimate the properties of one quantum system by non-destructively interfacing with another. The key research goals are to sustain super-precision in the face of decoherence in real world applications and to design fully integrated quantum sensors. In the second year of the project again considerable progress has been achieved. Starting from well-developed first sources for non-classical states of light novel tools have been devised, for example for a re-configurable conditional preparation aimed to generate non-Gaussian states or for the de-Gaussification of continuous variable states. Complementary to this, amplification of photonic states was investigated yielding significantly improved measurement precision. Most impressively, combining two continuous-wave squeezed light sources, developed within Q-Essence during the first year, the Einstein-Podolsky-Rosen correlation parameter evaluating the non-classicality of two-mode squeezed states was improved by more than an order of magnitude compared to state-of-the-art. In addition, the consortium has developed several tools analyzing the mathematical structure of the decoherence process. As a result, we found a number of instances, e.g., entanglement in an intermediate regime of the number of qubits, or non-Markovian noise, where the entanglement enhancement can be maintained even in the presence of noise and decoherence.

Important steps have been undertaken towards quantum enhanced imaging and microscopy beyond the diffraction limit and for the future implementation of real-world quantum sensors. In this respect an improved classical encoding was deduced from a quantum range finding scheme, which, however, is still superior under post selection or when sing quantum memories, such as spin-photon entanglement devices. Based on fiber-in-Sagnac or cavity-enhanced down-conversion multi-photon experiments enabled the comparison of 2- 4- and even 6-photon interferometry fringes with a correspondingly increasing resolution for phase estimation. This is combined with an effort pursuing the development of various waveguide platforms enabling integrated sensors in the future. As a first result the consortium implemented the first micro-fluidic quantum sensor, and, using entangled two-photon states, the protein concentration in a bovine serum in an aqueous buffer was successfully measured. The novel opto-fluidic device was designed to couple a waveguide interferometer to a micro-fluidic channel. Small refractive index changes, of about 1% were observed using two-photon coincidences from a 2-photonN00N state showing the promising potential of practical quantum metrology to light sensitive samples in biological scenarios.

The ultimate goal of a measurement is to observe a quantum system by means of another one. The investigation of such a quantum-quantum interface resembles directly the measurement concept as described by von Neumann and will enable unprecedented measurement sensitivity and the ultimate studies of decoherence. In close interaction between theory and experiments the consortium addresses the coupling between nanomechanical systems and various quantum states of light in order to enable ultrasensitive read out of otherwise inaccessible properties of complex systems by direct coupling and state transfer along the quantum-quantum interfaces. Various coupling mechanism have been proposed for different systems such as nano-cantilevers or membranes with a quality factor Q exceeding 10^6 at

room temperature. The state of the mechanical system can be read out using cw-squeezed or pulsed light and is designed to achieve strong coupling and cooling at the same time. Alternatively, coupling to spin systems or to electronic circuits is under discussion. Particularly attractive is the usage of pulsed light fields. Theory was developed showing that various kinds of linear and non-linear coupling of the light field with the nano-mechanical system are possible, ranging from a standard beam splitter operation to quantum non-demolition and three-wave mixing non-linear interactions. The latter will allow the preparation of squeezed mechanical states or of two-mode squeezed states, where the entanglement between light and mechanical states will enable teleportation across the quantum-quantum interface.

For the next generation quantum metrology systems the consortium aims to extend the concepts and thus also the performance of current state-of-the-art methods by generalizing to non-linear evolution sand the possibility to simultaneously determine several phases. The phase measurement enhancement was investigated for various quantum states to the measurement of unknown nonlinear phase shifts. It has been shown that the optimal phase estimation precision of the even entangled coherent state (ECS) is better than that of the NOON states and of odd ECS states with the same average particle number $\langle n \rangle$. Quantum enhancement of the measurement has been derived for nonlinearities of arbitrary order of the unitary nonlinear phase evolution operator. A very general, simple geometrical method was developed which allows to calculate precision bounds on linear quantum metrological schemes with generic decoherence models. Multi-parameter estimation was developed and demonstrated experimentally for the first time along two alternative routes. The first is based on introducing an external reference beam which in addition to enable the access to two independent phases increases the precision in the presence of loss. Secondly, symmetric Dicke states where shown to enable the simultaneous measurement along two usually complementary directions (σ_x, σ_y) on the Bloch sphere. This does not contradict the Heisenberg uncertainty relation as the expectation value for σ_z vanishes. Sub-shot noise phase estimation was demonstrated for up to six photon states.

The Sub-Project 2 “Enabling Technologies for Quantum Communication” is targeting the development of resources and methods needed to overcome limitations for both high-speed and long-distance quantum communication, with an emphasis on the distribution and storage of bipartite entanglement suitable for diverse quantum communications tasks. This effort integrates the development of architectures, protocols and component technologies while targeting improved robustness, interconnectivity and scalability in systems that can exploit existing real world communication infrastructures.

Last year of the project has seen significant advances for detector operation, including self-differencing InGaAs avalanche photodiodes(APDs) with gigacount/s and record low after pulsing rates for telecom detectors. Silicon(Si) photon number resolving(PNR) detectors have also been demonstrated with > 70% efficiency. So called red-enhanced Si APDs have achieved efficiencies of 40% while maintaining good jitter and dark count characteristics that ideal for free space communication. The SME partner IDQuantique has commercialised a detector module (id210) with an order of magnitude increase (now 100MHz) in operational rates over previous systems. The consortium has developed the first waveguide coupled detectors based on superconducting parallel nanowires. These devices are expected to provide 90% absorption for the incoming field, overcoming one of the principle problems facing previous coupling techniques.

The project also continues to develop sources suitable for: long-range high-speed quantum communications (free space and fibre), quantum interfaces, memories and repeaters, quantum metrology, and quantum information processing .This year we have several exciting firsts including small (100 micron long) 4-wave missing sources in silicon photonic crystal waveguides and new approach for generating pure narrow band telecom photons in integrated optical parametric oscillator waveguide cavities. Semiconductor photon sources have also been realised with emission rates reaching 19% and device efficiencies of 24%, as well as triggered entangled photon pair sources that have demonstrated two-photon interference visibilities of up to 57%. We have also advance the efforts for comparing photonic sources with an updated comparison table as well as initiating plans for a review article, involving input from across the project, for publication in the final year.

A multitude of technologies are being developed within SP2 with the aim of improved device and system efficiencies. Significant progress has been made across the board, ranging from the spin

storage measurements in quantum dot (12ns) and atomic frequency comb (10 μs) memories as well as >150 micros for Zeeman qubit storage times in neutral atoms. Stokes/Anti-Stokes emission for high bandwidth quantum memories using diamond has also been observed this year. All partners also contributed to updating a comparison table with a view to dissemination of specifications and needs associated with the different systems under development that may be of use to other members of the consortium.

In the area of design and comparison of quantum communication technologies, research has continued on both objectives 1 and 2, with significant results presented on both themes. For 1, we present a significant new quantum repeater protocol and a detailed study of how detector imperfections can affect conclusions about entangled sources for repeaters that they are used to characterize [UNIGE]. Clearly this latter contribution is also important for verification scenarios that employ such detectors, and thus 2. The main results for 2 comprise three quantitative verification methods for quantum resources and we note that one of these methods arises from collaboration between experimentalists and theorists and one has been tested experimentally on a photonic cluster state.

The consortium also continued efforts to demonstrate the technologies for long-distance quantum communication. To achieve global communication infrastructure technologies for both satellite-based free space systems and fibre-optic telecommunication networks are developed. There have been several landmark demonstrations this year, including: the entanglement distribution between remote (20m) single atom quantum memories; the demonstration of quantum entanglement between two separate macroscopic objects which was maintained for as long as an hour, as well as first results for experimental device independent QKD, demonstrating a heralded single photon amplifier in the telecom regime.

Sub-Project 3, entitled "Distributed Quantum Information Processing", is concerned with exploratory research developing new modes of distributed quantum information processing. In the focus of attention are novel theoretical ideas, thinking outside the box, as well as new experimental techniques and technological developments. The effort is grouped into five workpackages. In the second reporting period, again a plethora of strong results could be achieved, both in theory as in experiment.

The first work package assesses the potential of continuous-variable entanglement distribution, focusing on aspects of network compatibility and the ability of distillation, including approaches combined with photon counting, multipartite and bipartite settings, in theory and experiment. Continuous-variable approaches are expected to have significant advantages in local area networks when very high speeds and network compatibility through typically well defined modes are the predominant figures of merit to be optimised. In the second year, progress was fast. In particular, experiments have been realized sending a squeezed laser field over a free link of 1.6 km length and measured about 1 dB of squeezing. A 4 mode bound entangled state has been prepared, now including an improved detection of Gaussianity. The distribution of two-mode squeezed entangled light with a non-classical bandwidth of more than 1 GHz has also been realized. New theoretical work introduces two new schemes for continuous-variable long-distance entanglement distribution. Experiments towards the first entanglement distillation counteracting real environmental noise (atmospheric fluctuations) have been performed, as well as further steps towards pulsed bulk-optics implementation of the Brown-Eisert-Plenio CV entanglement distillation scheme. A big-picture goal is implementing a genuine iterative distillation protocol. Significant challenging technical issues had and have to be overcome to pave the way for this goal.

Work package 3.2 aims at exploring new modes of distributed and secure processing and communication in QIFT in the first place, having the potential to give rise to groundbreaking applications in distributed, multi-user information protocols. In the second reporting period, a number of new and quite promising protocols could be identified. Research focused to a large extent on the potential improvement of feasible quantum-based privacy protocols, such as anonymous voting, anonymous function evaluation and others. Important results include a comparison between quantum and classical voting protocols with respect to security under certain types of attacks, as well as notions of privacy and verifiability. A number of unexpected new results have also been achieved: This list includes schemes for distributed continuous-variable measurement based computing, ideas of directed percolation effects emerging from super-additivity of quantum networks and other novel schemes

based on quantum networks. In summary, a rich portfolio of new schemes could be collected in the second reporting period.

Work package 3.3 is concerned with developing novel tools for systems identification, the certification of success, and the measurement of properties of states and processes. Just as in the previous period, work has progressed at a fast pace, both with new theoretical developments. Notably, a quantum detector tomography method for the reconstruction of the POVM of a coherent optical detector has been introduced. This work both has a computational classical component, was well one directly relating to experiments with detectors having a weak phase reference. In other work novel tools for studying non-Markovianity as well as estimating decoherence rates have been proposed. New ways of analysing the effective continuous-variable entanglement with a channel length of up to 40 km have been established. The common paradigm that in the overwhelming majority of experiments in classical and quantum physics an a-priori assumption about the dimension of the system under consideration has been successfully challenged. A new theory of quantum compressed sensing for continuous-variable systems has also been introduced, significantly outperforming standard quantum state tomography based on homodyning or direct measurement of the Wigner function. Again, theoretical and experimental work was closely intertwined in this reporting period.

Work package 3.4 has essentially two components: On the one hand, it collects work on actual implementations of distributed protocols. On the other hand, work on classical control theory provides tools to actually experimentally implement new protocols in a resource-efficient way. Progress has been made in both directions of research. In particular, a method of least-square approximation by elements from matrix orbits by gradient flows on compact Lie groups has been introduced, a unifying programming framework in order to compare, optimize and benchmark quantum control algorithms has been formulated, and ways of performing optimal control for generating quantum gates in open dissipative systems have been investigated. Significant progress was also made concerning experimental implementations. This includes the quantum simulation with light and the experimental generation of complex noisy photonic entanglement. A highlight was the implementation of blind computing and a dynamical quantum simulation.

Work package 3.5, finally, is a work package that collects theoretical efforts of entanglement-based quantum information processing. Again, in this second reporting period, work in this work package was prolific beyond all expectations, and a very large number of results could be achieved. The body of work is too large to give a detailed overview, and for this, we refer to the deliverable report and the list of publications. Significant new results could be achieved on notions of information causality, and on new notions of non-locality. New ideas on resource theories related to notions of quantum statistical received quite some attention, as well as new ideas that quantum noise can actually help in achieving protocols, not be detrimental, here in cooling by heating in opto-mechanical small thermal machines by partner FUB. This work is in context with ideas of non-Markovianity assisted steady state entanglement and the robust dynamical decoupling with concatenated continuous driving. Notions of undecidability have been introduced into the computer science assessing the hardness of certain quantum tasks, and a difference in analogous quantum and classical problems has been found, relating also to other work of the computational complexity in this work package. In summary, this has again be a creative period for this work package giving theoretical guidance to the SP as a whole.

Project public website: **www.qessence.eu**

3.2 Core of the report for the period: Project objectives, work progress and achievements, project management

3.2.1 Project objectives for the period

WP1.1: Quantum metrology in real-world environments

Quantum metrology was shown to enable unprecedented signal to noise ratio and resolution of measurements, at sensitivities unreachable with conventional measurement schemes. However, in real world applications, the quantum systems are exposed to various sources of noise and decoherence which threaten to erase the gain of the ideal system. It is thus indispensable to redesign and optimize quantum metrology systems to make them the tool of choice for real world applications. In the first year it is thus the objective of this work package to make the first steps to

- develop entanglement enhanced metrology for real world environment causing decoherence and loss
- optimize quantum sensing for limited resources
- design setups for entanglement enhanced metrology

In the second phase this work package focused on improving the state of the art of sources of entangled states of light and ways for manipulating them, as well as on analysing the effect of loss and decoherence in interferometric set-ups and identifying states which are best suited to fight the decoherence.

WP1.2: Quantum sensor applications

In order to ensure early application of the techniques developed in Q-ESSENCE, in this work package the achievements from other WPs will be adopted in typical sensor applications. This WP has the main goal to demonstrate the feasibility of entanglement enhanced sensors, using state-of-the art photonic and atomic technologies. These will serve as test beds for elementary parameter estimation protocols, and then for more advanced robust protocols developed in WP1.1 and 1.4, with a view to practical applications in temperature, motion, position and rotation sensing.
Particular goals of the second year are:

- to demonstrate entanglement enhanced performance
- to apply entanglement enhanced sensing in an integrated optics sensor

WP1.3: Metrology at the quantum-quantum interfaces

This work-package aims to extend the objective of entanglement enhanced metrology to the measurement of quantum properties read out with quantum systems. The realization of this quantum-quantum interface resembles the original concept of a measurement in quantum physics described in the seminal works by von Neumann and allows reaching ultimate measurement sensitivity.
In particular, year two aims to progress to strong coupling and interfacing quantum states.

WP1.4: Multiparameter Estimation and Non-Linear Metrology

The next generation quantum metrology systems will extend the concepts and thus also the performance of current state-of-the-art methods by generalizing the evolution determined by the measurement parameters. For the definition of future quantum metrology systems main goals in the second year where

- to investigate non-linear quantum enhanced interferometry schemes both in the absence and in the presence of loss and to analyze their performance for different input probe states.
- to analyze the effects of polarization mode dispersion (PMD) on interferometric experiments and investigate the possibility of preparing entangled states of light robust against PMD.
- to demonstrate quantum enhancement of precision in multi-parameter estimation protocols.

WP2.1: Quantum Optical Detectors and Random Number Generators

We will develop photon detectors and random number generators with functionality and performance far beyond the current state of the art. Below we reproduce from the proposal the objectives for the 3 years of the project.

Superconducting parallel nanowire detectors: [TUE, UNIGE] Parallel nanowires detectors based on superconduction promise exceptional performance in terms of noise, efficiency, potential count rate and photon number resolving capabilities. The efficiency for single-photon and photon number detection is one of the first priorities that will be addressed. The main challenge is to incorporate a cavity to enhance the detection efficiency. Ultra-thin (4-5nm) NbN films will be deposited on GaAs/AlAs Bragg mirrors and processed into 100nm-wide wires covering a 5x5 $\square m^2$. Dielectric multilayers will be deposited on the top of the detector to produce a full microcavity at the design wavelengths of 880 and 1550 nm for quantum memories and fibre communications, respectively. We target a device detection efficiency of 70% at M24 and 90% at M36. Robust techniques for high detector-fibre coupling efficiency will also be investigated to increase this > 50%.

Actively quenched avalanche photodiodes (APDs): [POLIMI, MPD, UoB, idQ] In the first year large area Si single photon APDs (diameter>0.2mm) with low time jitter (<100ps) will be developed for free space communications. The main challenge for Si APDs is a new planar, shallow junction structure for both low jitter (<100ps) and detection efficiency (>30%). It will incorporate (a) improved photon absorption probability in a wider depletion layer; (b) electric field distribution designed for high avalanche probability at low bias (<100V); (c) epitaxial layer design to reduce the slow tail in the photon timing distribution. An optimised detector module will be available at M36. The properties of shallow and deep-junction Si APDs will be compared. We will build low f-number free space Si receivers, which integrate active quenching circuits. For InGaAs APDs, we will survey and characterise the range of available devices and develop appropriate active quenching circuitry.

High count rate Geiger mode APDs: [TREL, idQ] We will investigate novel gating schemes that look to significantly increase the potential detection rates (>0.5-1.0 Gcount/s) and reduce jitter (<50ps) and design circuits to allow the frequency to be tuned in different communication systems. We will improve the cancellation of background signals in self-differencing circuits to facilitate detection of weaker avalanches that should allow photon detection efficiencies to approach the intrinsic absorption efficiency of 80-90%. Fast gating schemes will be systematically tested on the different APDs available from commercial vendors to find a stable supply for high performance detectors. The device will be thermoelectrically cooled and integrated into a compact module with associated high-speed electronics.

Quantum optical random number generation: [MPD, POLIMI, idQ, LMU, UoB, TREL] The fast, high count rate detectors developed here will be implemented in quantum random number generators (RNGs) where the bit values are assigned on the basis of photon detection time, detection by a particular element in an array, or the parity of the total count in a fixed time interval and read out by programmable fast electronics. True quantum RNGs passing statistical tests without the application of whitening algorithms will be developed. We target random bit rates in excess of 250 Mbps. In the latter stages the industrial partners will integrate the most promising quantum optical schemes into compact modules for >100 Mbps RNG.

WP2.2: Quantum light sources

This workpackage continued to develop sources suitable for:

- long-range high-speed quantum communications (free space and fibre)
- quantum interfaces, memories and repeaters (feeding to WP2.3)
- quantum metrology (feeding to WP1.2)
- quantum information processing (feeding to WP3.4-5)

The sources being developed include those based on pair generation by spontaneous parametric processes in crystals (UNIGE), waveguides (UoB, UNIGE) and fibres (UoB), as well as those based on the emission of a single semiconductor quantum dot (TREL).

The former have the attraction of producing high entanglement fidelity and pure states, while the latter can be used as an 'on-demand' source with high repetition frequencies. A further goal will be to demonstrate associated circuits on the same 'chip' as integrated sources. In year goals include the preparation of comparative data for the different sources in readiness for D2.2.2.

WP2.3: Quantum memories and interfaces

The maximal distance of point-to-point quantum communication is limited by unavoidable loss of information in the quantum channel due to attenuation. A potential solution to overcome this limitation is the use of quantum repeaters. This WP will develop quantum memories (QMs) and light-matter interfaces suitable for integration in quantum repeater architectures developed in WP2.4 and with a view of laboratory and field trials of quantum communication protocols in WP2.5. Objectives of this WP for the 2nd period are:

a) Develop new techniques for fast and efficient read-out of stored QM states, thereby allowing e.g. deterministic interface-measurements
b) Develop new high bandwidth light-matter interfaces
c) Investigate and compare different materials and approaches which will allow long-lived stoarge of quantum information in quantum memories

These devices are realised in different systems like quantum dots [TREL, UoB], ensembles of rare-earth doped solids [UNIGE], single trapped atoms [LMU], bulk diamond [UOXF], and hot atomic vapours [UCPH, UOXF, UWAW] with an emphasis on high-fidelity operation and scalability.

WP2.4: Design and comparison of quantum communication technologies

The objectives of WP2.4 are to theoretically study, design, develop and verify quantum communication technologies, with particular emphasis on optimising architectures for the long distance distribution of entanglement. The two keys objectives are to develop:

O1. Designs for entanglement distribution architectures (both fibre and free-space), determine relevant limitations and provide techniques for optimisation of architectures.
O2. Methods for the quantitative verification of distributed entanglement.

A close involvement with experimental aspects of the project is envisaged, thus providing a reference point for comparing enabling technologies and setting the device benchmarks necessary for successful demonstrations of key quantum communication primitives and verification of useful entangled resources.
More emphasis for WP2.4 in year 2 of the project is on the second objective O2 (as reflected in the year 2 deliverable and milestone). However, research has continued to progress on all our objectives, as laid out in this WP report.

WP2.5: Quantum communication test beds

The objective of this WP is to demonstrate the technologies for long-distance quantum communication. To achieve global communication infrastructure technologies for both satellite-based free space systems and fibre-optic telecommunication networks are developed. In the second period of QESSENCE we were focusing on

- Adaptive optics system based on blind optimization for long-distance communication
- Heralded quantum amplification
- Entanglement between independent quantum memories.

WP3.1: Distribution of continuous-variable entanglement

Continuous variable (CV) entanglement distribution will not be able to reach distances possible in the discrete variable (DV) regime, but may offer advantages that may be employed in rather local area networks, e.g. very high speeds and network compatibility through typically well defined modes. In hybrid settings

(CV with DV assistance) resource for universal quantum computing and universal distillation protocols are available. Continuous-variable entanglement distribution and distillation: [MPL, LUH, FUB, UULM].

- Characterization of the influence of atmospheric turbulence, stray light and loss mechanisms in a real world urban environment km long CV quantum link.
- Distribution of squeezed states over free-space links.
- Demonstration of four-partite CV entanglement distribution.
- Preparation of resources for CV quantum computation in a hybrid setting.
- Development of new theoretical protocols and technology delivering a high rate of entangled pairs.

These tasks will lead to implementation of entanglement distribution over a real free space link including entanglement distillation of non-Gaussian atmospheric noise. This will then serve as a realistic test bed to study the obstacles that might turn up when distributing multipartite entangled states (which is possible by a simple scaling of resources and/or applying more complex spatial/wavelength encoding). New protocols of continuous-variable entanglement distillation approaches: [FUB, UOXF.DU, UULM, LUH] Novel instances of continuous-variable entanglement distillation protocols will be experimentally realized using local photon subtraction and other local filters using photon number counting and instances of weak homodyning, bringing together advantages of CV and discrete-variable Phase-sensitive photon-number resolving / weak-field homodyne detectors based on temporal and spatial multiplexing will be built, characterized and compared.

WP3.2: New protocols

Development of new protocols for distributed quantum information processing: [IMPERIAL, UNIGE , UoB, IPSAS, UH, LUH]
We will systematically explore the potential of quantum distributed protocols beyond the standard cryptographic settings, including instances of secure quantum privacy (such as anonymous quantum voting) and the remote comparison of distant fields. We will explore the role of locally held information in enabling quantum benefits for distributed information processing tasks. We will generalise ideas of ``quantum private queries" - instances of symmetric private information retrieval - including the appropriate security analysis. The distribution of an entangled state of the GHZ type allows for the reliable and anonymous transmission of one bit of information within a quantum network. A communication protocol is said to be anonymous if at any stage of the protocol is equally likely for any node to be the sender and the sender cannot be identified even if a malicious party has access to all the resources (distributed state and measurement records). Generalized Greenberger-Horne-Zeilinger-states are known to possess anonymous entanglement. Here we will characterize the states that possess anonymous entanglement and determine optimal protocols for the anonymous transmission of single bits when various different entanglement resources are provided. Furthermore, simple protocols obtained in this way will be analysed in detail from the perspective of experimental implementation employing technology developed in SP1 and SP2.

Quantum information processing with uncharacterized devices: [ICFO, LUH]
We will systematically explore the implementation of quantum information protocols where the parties do not have to make any assumption on their devices. In the most paranoid meaningful scenario, these devices can have been prepared by an adversarial party, but these ideas are also relevant to make the protocols more robust against devices imperfections. We will introduce general security proofs for this important setting of uncharacterized devices, but also other protocols, like the design of device-independent quantum random number generators.

New quantum networks beyond point-to-point architectures: [ICFO, FUB]
It will be theoretically explored how quantum resources, mainly entangled states and secret bits, can be distributed over complex networks beyond the standard point-to-point repeater architecture, making use of percolation ideas, novel architectures of secret-key distribution, and random networks.

Non-additivities in capacities: [UG, UoB, LUH]
Recently, the power of entanglement was once more impressively demonstrated in communication, as the classical Holevo capacity and the quantum capacity were shown to be super-additive. We will analyze other

capacities, or other quantum properties, regarding their (non-)additivity, try to bound the degree of additivity violation, and shall explore upper and lower bounds on the regularised capacity (this involves also finding new coding protocols) We shall optimise the usage of noisy/imperfect quantum communication networks/primitives especially focusing on non-additivity properties. This project will include the analysis and optimisation of multi-user classical and quantum communication for small networks e.g. two senders versus two receivers. We plan to give possibly good upper and lower bounds for the capacity regions and determine the cases where quantum networks beat the classical performance. Proposals of experimental schemes providing the proof of principle in discrete/continuous variables will be provided.

WP3.3: Verification and identification methods

Work will proceed along several closely interconnected and intertwined lines of work addressing issues of verification in states, processes, environments and detectors and their properties. Close contact with experiments that are planned and carried out within the project will be kept. Results from this workpackage will be deployed in experiments within this project and concrete experimental settings and challenges will motivate more specific work, specializing the general theoretical frameworks to these concrete experimental settings. The proposed work will be carried out both in the bi-partite and multi-partite setting and be applied to qubits, qudits, as well as infinite dimensional systems such as the continuous variable degree of freedom of photons.

System and detector characterization: [UULM, ICFO, UOXF.DU, FUB]
We plan to work on the study of uncharacterized quantum systems and detection devices. The goal is to extract information about a given, possibly distributed, system from some observed statistics alone, without any, or as few as possible and well defined, assumptions on the nature of the system. More precisely, from given probability distributions obtained from observations, we want to estimate several properties of the quantum system, such as its dimension or entanglement. These estimation techniques are device-independent, because they use only the minimum amount of information, namely the observed statistics, without making any further assumption on the system or the applied measurements. In this context, we are planning to extend also work on the assumption-free characterisation of quantum detectors and apply them to the experimental realisation in distributed settings that are being explored in SP1 and SP2.

Advanced methods for quantum process characterization: [UULM, UOXF.DU, FUB, TUM, IPSAS]
Especially in the setting of distributed quantum networks, the characterisation of quantum processes is overburdened by an exponential increase in complexity of a system with the number of elementary components. Hence, a full characterisation of such processes is often unfeasible - yet additional a-priori knowledge can often be used. We will introduce novel methods of characterising quantum states, processes and detectors based on as little information as possible, making use of all a-priori information. Novel ideas such as quantum tomography with error bars using Kalman filter ideas will be systematically explored, and ideas of identifying aspects of physical processes with less knowledge than full process tomography at many time steps. Novel algorithms for noise identification and protection will be designed and performance of quantum detectors will be verified experimentally with the aim of using them subsequently in distributed settings.

Properties of states and environments: [UULM, IPSAS, LMU, MPL, TUM, UG, UH, UoB, UOXF.DU, FUB]
We will aim at systematically estimating particular characteristics and properties of quantum systems such as entanglement, entropies, capacities, decoherence rates, and the Markovian character of a process. The basic idea here is to use a finite number of measurement settings that are not necessarily tomographically complete to set quantitative bounds on such quantities of interest. This uses the techniques of optimisation theory to set the bounds, upper and lower. In this context we will also develop approaches of interferometric contrast in the multi-partite and multi-photon setting and explore their link to Bell inequalities and entanglement criteria. We will experimentally explore effective entanglement in fibers making use of appropriate entanglement criteria. We will also pave new ways for probing spin-boson environments as well as those arising in the context of quantum dynamics of bio-molecules. While considering noise to be Markovian is an important simplification, noise in real systems is often substantially non-Markovian. Our aim is to

understand typical dynamical behaviour in such systems and in particular the dynamics near equilibrium in this case. This is intimately related to fundamental questions in quantum statistical mechanics.

Finite resource verification: [IPSAS]
Although quantum theory is statistical, there are situations and problems in which conclusions based on only a finite number of experimental runs are possible. The role of finite resources in quantum verification tasks will be identified. In particular, we shall consider problems leading to minimum-error and unambiguous conclusions and predictions based on finite sequences of clicks. The goal of these tasks is to exploit a minimal number of resources in order to identify (either with minimal error, or with certainty) specific properties of preparation devices, processes and measurements. On top of that, we shall investigate repeated usability of resources already used. Noise stability of the verification methods developed will also be addressed.

WP3.4: Implementation of distributed protocols

New generations of atomic teleportation protocols and memories: [UCPH]
High fidelity atomic teleportation protocols will be experimentally implemented between distant memories. Implementation of deterministic hi-fi teleportation between memories is a crucial step towards efficient quantum networking. High fidelity quantum memories at room temperature will contribute as new experimental primitives to distributed protocols. Room temperature gases in decoherence-protected cells are arguably the most robust and simple building blocks for quantum networking. Development of new protocols with such memories including non-Gaussian states will be undertaken.

"Digital" continuous variables states and other sophisticated encodings: [UCPH, UNIGE]
"Digital" continuous variable states - atomic Schrödinger cat states for quantum communication - will be experimentally generated. This approach will allow combining high efficiency homodyne measurement of continuous variables with the possibility of purification and error correction associated with non-Gaussian states. One of the scaling routines will be the efficient growth of cat states in the memory. We will investigate storage and processing of higher-order time-bin encoding, for instance qutrits. We analyse the possibility of performing general transformations equivalent to linear optics (beamsplitters and phase shifters) using a quantum memory. This builds on the possibility of performing photon bunching experiments, analogous to a beamsplitter in free space. We will be doing both theoretical and experimental work for programmable linear optic components in solid state devices.

Photonic realization of distributed protocols and key primitives: [UG, OEAW]
Important linear optical primitives and non-linear elements such as single photon non-linear elements such as the conditional phase shift gate will be experimentally realized. We will perform the optimization of photonic realizations of distributed protocols. New sources and new detection techniques allow for the realization of quantum protocols involving four or more partners.

Integrated optics and waveguides: [UoB, OEAW]
The key to unlocking the potential of scalable quantum information processing is the complete integration of every component from the source throughout the detector of a quantum circuit. In a combination of the above sources and detector integration work packages we will fabricate complete quantum optical systems that are monolithic (and therefore perfectly stable) using established photonic component packaging systems. Recently demonstrated 3D waveguide fabrication facilities open the opportunity to fabricate 2,3,4,5... degree scattering quantum random walk platforms. For the first time it will be possible to perform optical quantum simulation and computing on random walk graphs. We will develop integrated quantum photonic circuits to execute scattering quantum random walks and use these schemes to perform quantum search algorithms. This will provide an important test-bed for quantum communication schemes, and in particular of schemes for dealing with errors such as decoherence and localisation.

Preparation of multi-partite photonic entanglement: [UWAW]
We will prepare various types of noisy multipartite entanglement, verify it using characterization tools targeting specific properties, and demonstrated its application in distributed quantum information processes, based on an approach to simulate various environments for a polarization qubit.

New photonic processes: [UG, UoB]
New photonic processes allowing for multi-qubit or multi-qudit entanglements will be introduced. The influence of various new approaches to phase matching conditions on indistinguishability of photons will be studied and new interferometric setups, leading to multi-particle entanglement established. This will allow for a systematic assessment of multi-qudit entanglement in interference experiments.

Toolbox of optimal control methods as a service interface to experimental efforts: [TUM]
We will introduce a toolbox of optimal control methods to be used for distributed protocols, integrated circuits and other parts of this integrating project in close exchange with WP 3.3. Optimised modules shall extend the concepts of using standard quantum circuits distributed to spatially separated quantum-computer nodes. We build on recent advantages of assembling effective m-qubit modules (CISC) by optimal control instead of standard 1-2 qubit universal gates. This allows for specifically addressing experimental settings with realistic errors and noise behaviour rather than using standard models tailored to local sources of noise and relaxation. Analysis of scaling of resource requirements: [UULM, UoB, FUB] We will also analyse the communication requirements in the implementation of distributed protocols and those on the quality of entanglement distribution to achieve efficient operation.

WP3.5: Entanglement-based quantum information processing

Noise-driven quantum information processing: [ICFO, FUB, IMPERIAL]
Entanglement theory was usually studied for closed systems with decoherence being an obstacle to be avoided. However, dissipative processes can also assist in quantum information processing. We will study how entanglement is affected by decoherence, and how decoherence can be useful for driving many-body systems through quantum phase transitions, or even for performing quantum computation by means of dissipative processes.

New tools in quantum information processing based on pseudo-randomness and random walks: [FUB, UoB, LUH, IPSAS]
Important properties of quantum systems in statistical physics and in quantum information theory can be shown for generic systems, i.e. for random states that have been drawn from a meaningful probability measure. We will explore de-randomization methods for such constructions using unitary k-designs and quantum expanders, and relate such constructions to distributed quantum information protocols such as private quantum channels. We shall utilize quantum walks in the quantum analogue of classical Markov chains, and their rapid mixing properties. The aim is to speed up random sampling based algorithms, such as for approximating the permanent, and to develop new, purely quantum algorithms for these tasks. Further, we quantize classical algorithms based on a sequence of Markov chains with adaptive step size. This could greatly speed up methods related to simulated annealing. The role of decoherence will be studied, and entanglement-enhanced quantum walk algorithms introduced. A theory of inhomogeneous quantum walks (a fundamental part of the theory of classical walks for many decades, hardly explored in the quantum domain) will be developed. Thus, the range of possibilities for new quantum algorithms will be extended.

Distributed quantum information processing and foundations of entanglement theory: [UG, UoB, OEAW, LUH, LMU]
We will investigate the relationship between the study of distributed quantum information protocols and essential features of quantum theory. We shall study: non-local computation, Leggett-like inequalities, the relation of Bell's theorem and Kochen-Specker theorem with fundamental quantum informational processes and protocols, the role of non-signalling and symmetries in foundations quantum information, entangled higher dimensional systems, quantification of classical resources required to simulate protocols as considered in quantum communication, minimal reference-frame resources needed for entanglement detection, and new

versatile entanglement criteria. All schemes of quantum key distribution can be translated to entangled based ones. However it is not known whether arbitrary entangled state offers secure key. We shall approach this fundamental question by finding new such states, and by developing the formalism of ``private bits" We shall apply information theoretic tools to the study of problems related to loopholes to Bell inequalities and discuss the violation of Bell inequalities for non-i.i.d. sources.

3.2.2 Work progress and achievements during the period

WP1.1: Quantum metrology in real-world environments

Develop sources for entangled states of light and ways for manipulating them:
The source for continuous-variable (CV) entangled, two-mode squeezed entangled states was finally finished by LUH with impressive results (see highlight). Using two *continuous-wave* squeezed light sources developed in the first year of Q-ESSENCE, about 10 dB of two-mode squeezing was achieved. UPB is developing engineered sources of *pulsed* non-classical light states with optimized control of the spatio-spectral properties. In collaboration with MPL a new experimental setup was built, which allows the generation of degenerate pulsed two-mode squeezing with genuine spatio-spectral single-mode characteristics. This work is targeted towards the implementation of CV entanglement distillation, as multi-mode properties have been identified as one major obstacle to accomplish efficient photon number subtraction from squeezed states. In connection with this goal, UOXF.DU was developing an advanced system for the re-configurable conditional preparation of non-classical and non-Gaussian states. The system is based on the use of time-multiplexed detectors, with the capability to resolve photon number, in combination with high quality dispersion-managed parametric down-conversion sources, which deliver pulsed two-mode squeezed states with high brightness and negligible timing jitter. As an alternative approach for generating de-Gaussified states the partners have proposed a new scheme, which allows the coherent filtering on pulsed modes by use of sum frequency generation [BAE12]. As a first step towards the realisation of full entanglement distillation, enabling enhanced interferometric precision, UOXF.DU has thus implemented an adjustable "photon catalyser", in which a weak coherent state is controllably de-Gaussified by mixing it with a single photon on a beam splitter and heralding the transmission of the photon. Although the non-classical resource - the single photon - is never “used up”, the coherent state is nonetheless converted into a highly non-Gaussian, and indeed non-classical state, for certain values of the beam splitter reflectivity. In a related approach the so called quantum pulse gate was demonstrated based on four-wave mixing (Fig. 1.1.1)

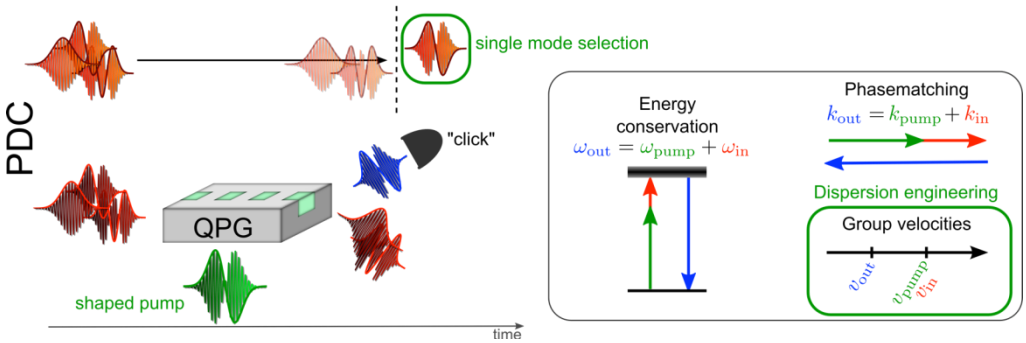


Fig 1.1.1: Four-wave mixing with shaped pump pulses enables the implementation of a quantum pulse gate [BEC1-11] or the de-Gussification of CV-states.

For the generation of advanced states it was planned to implement a toolbox, which comprises linear logic as well as local photon subtraction and other non-Gaussian filters. With these combined techniques the ultimate goal is to combine the advantages of CV and discrete-variable approaches. The implementation of non-Gaussian filters implies very stringent requirements on the single-mode character of the source states applicable for conditional state preparation. Additional work is needed, and has been started, to achieve efficient non-Gaussian filtering for MS115. MS115 aims at the demonstration of de-gaussified squeezed light sources with entanglement distillation protocols implemented. For achieving this goal we find that

multi-mode characteristics as well as interferometric stabilization of vaccum states pose unexpected difficulties, which caused delays. However first results, demonstrating a "photon catalyser", in which a weak coherent state is controllably de-Gaussified by mixing it with a single photon on a beam splitter and heralding the transmission of the photon, have been achieved. Furthermore, work for the implementation of pulsed genuine single-mode states is under way to overcome current challenges. These delays will not have a critical impact on other tasks of this project.

Analyse applicability of particular quantum states:

To provide an example for benchmarking the performance of conditional state preparation UP has evaluated limits on the deterministic creation of pure single-photon states using parametric downconversion. The analysis takes into account the impact of higher-photon components as well as multiple frequencies or pulsed modes and shows a maximum state creation probability of 25 % for single mode fields and a degraded single-photon state preparation fidelity for multi-mode fields [CS12].

In the context of metrology, when using large photon number states, observing quantum effects such as superpositions and entanglement in macroscopic systems requires not only a system that is well protected against environmental decoherence, but also sufficient measurement precision. Motivated by recent experiments, UNIGE has studied the effects of coarse graining in photon number measurements on the observability of micro-macro entanglement that is created by greatly amplifying one photon from an entangled pair [RSS1-11]. The results obtained for a unitary quantum cloner, which generates micro-macro entanglement, have been compared with a measure-and-prepare cloner, which produces a separable micro-macro state. The distance between the probability distributions of results for the two cloners approaches zero for a fixed moderate amount of coarse graining (Fig. 1.1.2). Proving the presence of micro-macro entanglement therefore becomes progressively harder as the system size increases. UNIGE studied how much detection accuracy is needed to see entanglement in micro-macro states, produced by cloning one photon of an entangled photon pair.

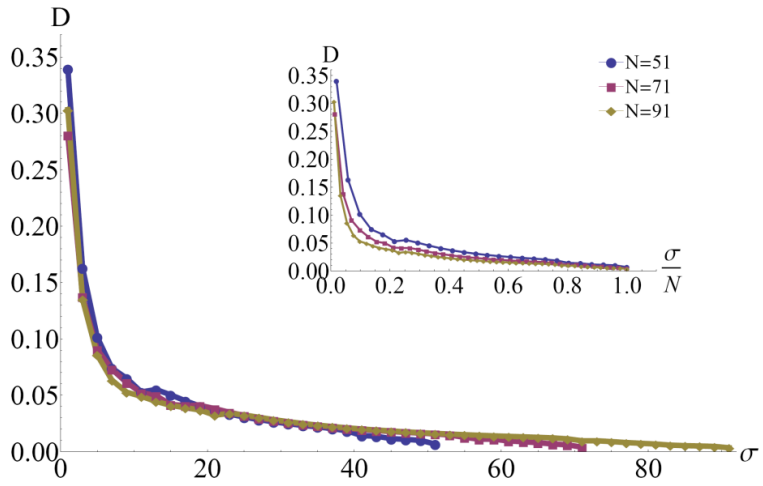


Fig. 1.1.2: The distance between the probabilitydistributions for the unitary and measure-and-prepare cloner,quantified by the Manhattan-norm distance D, as afunction of the bin size σ. The distance decreaseswith σ in a way that is almost independent of the photon number$N$. As a consequence, as shown in the inset, the distancedecreases faster and faster as a function of the relative errorσ/N, when N is increased.

Analyze effects of loss and decoherence:

Previously, in a collaboration of UG and LMU it was shown that the Fisher information F for a linear two-mode interferometer cannot exceed the number of particles if the input state is separable. Recently, bounds on F have been deduced for several multiparticle entanglement classes. These bounds imply that genuine multiparticle entanglement is needed for reaching the highest sensitivities in quantum interferometry. The concept was further generalized to mixed states as they occur in various noise models. As a matter of fact,

even bound entangled states seem to be suited for entanglement enhanced metrology. The strengths of various states was demonstrated, also based on experimental data ([HLK1-10], updated).
The direct effect on improved phase estimation was studied by UULM and UWAW. In [CHP1-11] optimal bounds for precision spectroscopy in the presence of general, non-Markovian phase noise are analyzed. UULM demonstrated that for non-Markovian noise clear improvement over the classical SNL can be achieved while a metrological equivalence of product and maximally entangled states holds under Markovian dephasing (Fig. 1.1.3). Using an exactly solvable model of a physically realistic finite band-width dephasing environment, it is shown that the ensuing non-Markovian dynamics enables quantum correlated states to outperform metrological strategies based on uncorrelated states but otherwise identical resources. This conclusion is a direct result of the coherent dynamics of the global state of the system and environment and, as a result, possesses general validity that goes beyond specific models. UWAW developed a significantly simplified estimation on analytical bounds in quantum enhanced metrology. The analysis of the mathematical structure of the decoherence process allows for an intuitive geometric picture [deliverable D11.2].

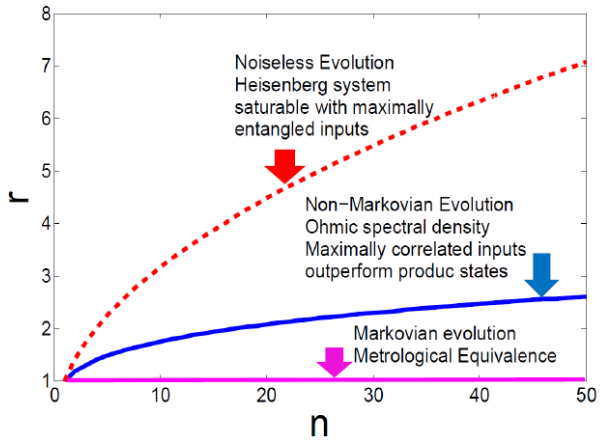


Fig. 1.1.3: The improvement over the classcal SNL r depending on the number of qubits. While there is no gain for Markovian noise, clear improvement is obtained for non-Markovian evolutions.

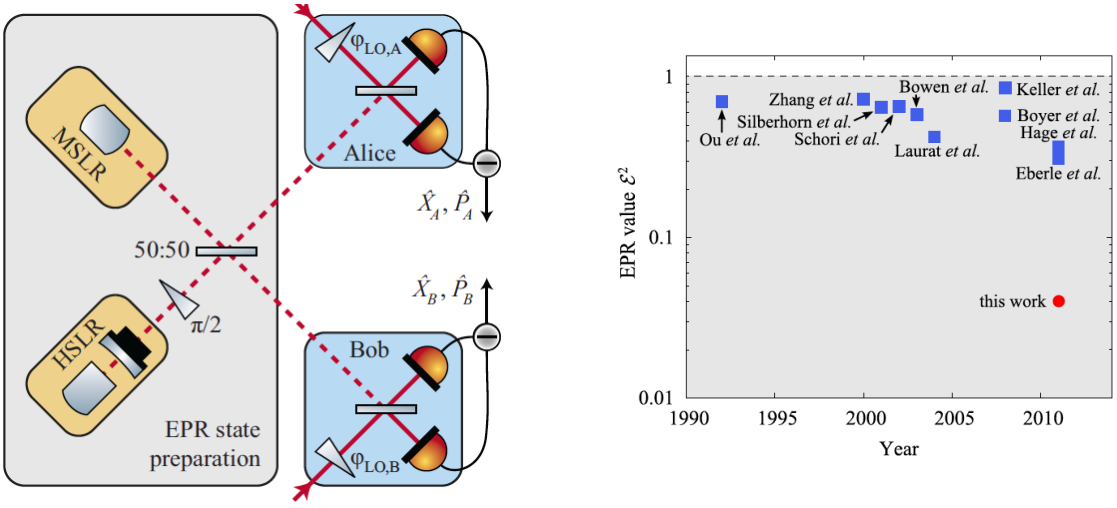


Fig. 1.1.4: Source of ultrastrong two-mode squeezing and comparison with previous results.

WP1.1 Highlight
LUH has set up an experiment with two continuous-wave squeezed light sources during the first year of Q-ESSENCE. By overlapping the light from these two OPOs on a beam-spitter a CV entangled, two-mode squeezed state was obtained. Both modes showed a greater 99% overlap with single spatial mode optical

local oscillators proving their applicability in high-power laser interferometers. The results go well beyond the current state-of-the-art. Clearly exceeding the original plan of 6 dB squeezing [MS112] the team achieved even about 10 dB of two-mode squeezing [SBE1-12]. The overlap of two highly squeezed beams enabled the generation of highly entangled CV-states of light. Using the Reid-criterion $\mathcal{E}^2_{B|A} = \Delta^2_{B|A}\hat{X} \cdot \Delta^2_{B|A}\hat{P} < 1$ the new record value outperforms previous work by an order of magnitude (Fig. 1.1.4).

WP1.2: Quantum sensor applications

UOXF.DU is pursuing two waveguide platforms (both UV-written and femtosecond-written), two source platforms (both down-conversion and four-wave-mixing) and two detection platforms (both avalanche photodiodes and superconducting transition edge sensors). This is because integrated optics is central to the achievement of the goal of quantum-enhanced sensing. The technical challenges are considerable but progress in the development and optimisation of these technologies has been steady.

UoB is investigating the concept of entanglement based rangefingding where entanglement is used to provide enhanced signal to background. A possible realisation based on broad band (hyperentangled) parametric pair photon sources is illustrated in Fig. 1.2.1. The constraint on the source is that it be brighter than background scattered sunlight. The reflected light from rough (Lambertian) targets could be obtained out to about 1km and longer range returns could be obtained from focal plane retro-reflections (eg. in CCD cameras). The use of hyperentanglement and multiphoton entanglement can provide significant sensitivity gain but this can be reproduced largely by classical sources when confining measurements to the computational bases. The concept is thus extended to entanglement post selection rangefinding where a quantum memory, e.g., using spin-photon entanglement devices, is used.

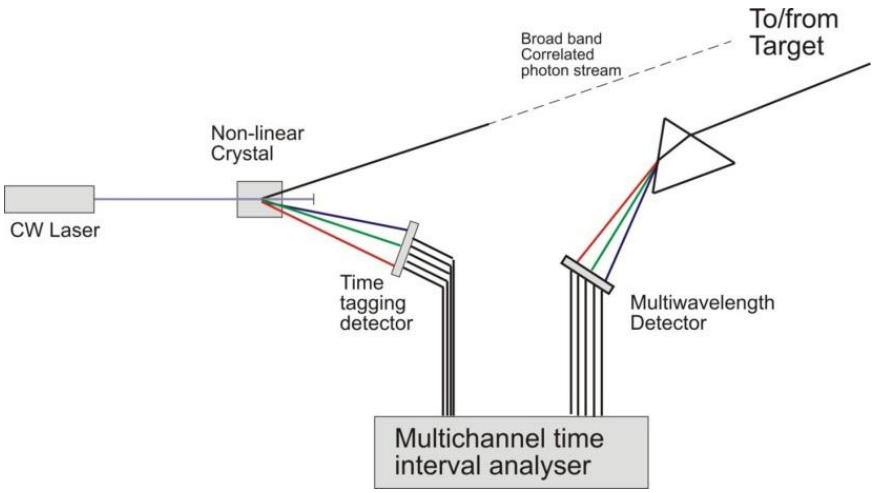


Fig. 1.2.1. Multi-wavelength rangefinder

UOB has used a six-photon source to herald two- and four-photon path entanglement on chip [MPB1-11]. In recent work we have also developed a fibre-in-Sagnac interferometer scheme for showing 1-, 2-, 4-, and 6-photon interference fringes shown in Fig 1.2.2 [MS123]. The scheme is extremely efficient and self-aligning thus shows high visibility fringes up to four photon level, i.e., 1/4 of the wavelength of the interfering light. We see evidence of 6-photon fringes at a rate of around 4 six-fold coincidences per minute and are working to improve visibility.

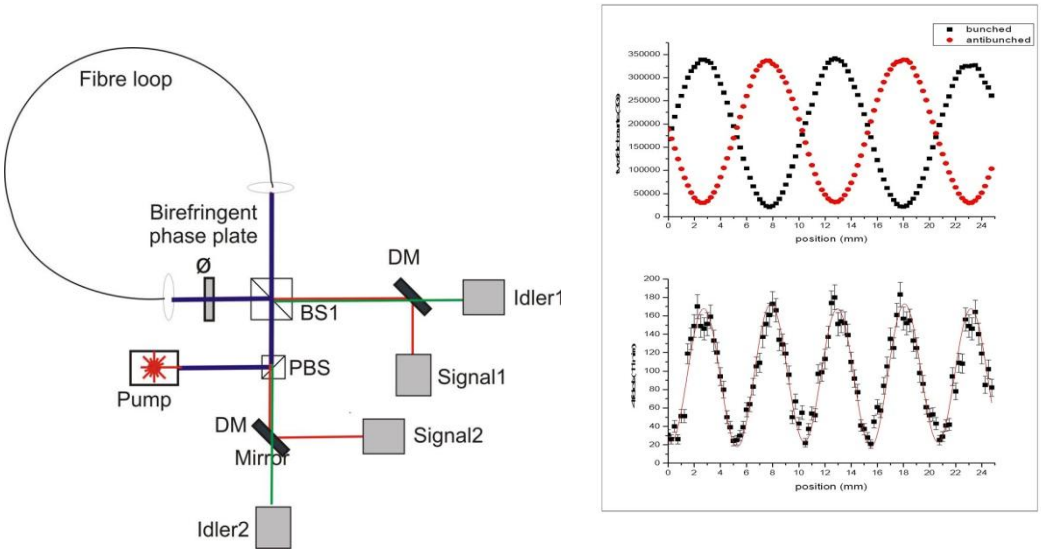


Figure 1.2.2 (left) Fibre-in-Sagnac interferometer scheme for showing 1-, 2-, 4-, and 6-photon interference, (right) 2- and 4- photon fringes showing oscillations at 2x and 4x the entangled photon wavelength [MS123]

In analogy to entanglement enhanced phase estimation, mode-entanglement obtained from a SPDC source in principle should allow enhanced optical resolution in imaging. LMU could show this nonclassical narrowing in first demonstrations (Fig.1.2.3), however, the ultimate goal, to achieve spatial resolution below the diffraction limit of the SPDC-light [MS124], was not achieved. Problem here is the fact that the necessary two-photon resolution is obtained only for settings, where the single-photon resolution is completely blurred. The necessarily large illumination area reduces the detection probability for two-photon reflection at a single subwavelength object considerably. The set-up is improved now, to enable long measurement times for high two-photon resolution. We expect to achieve MS124 in month 30.

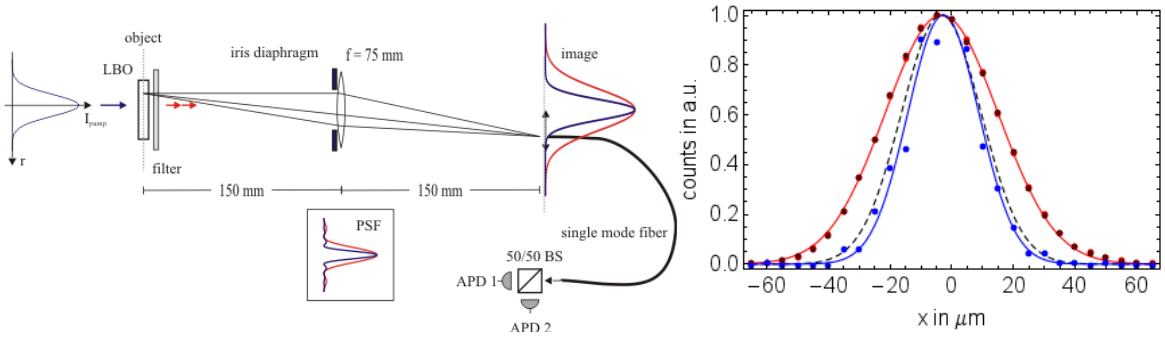


Fig. 1.2.3.: Two photon imaging: (left) set-up where a certain region of the nonlinear LBO crystal is iluminated by the pump beam. Down-converted photons are imaged by a lens. Scanning the image reveals the area for the focusing of entangled photons. (right) Relative count rates in the image plane for single photon detection (red) and detection of both momentum entangled photons (blue). The latter curve reveals a waist, which after deconvolution with the point-spread function is narrower by a factor 1.73 compared to the single photon waist. Incoherent two photon detection would have resulted at best in a reduction by a factor 1.41 (√2).

WP1.2 Highlight

The first quantum sensing in a micro-fluidic sensor was performed by UOB (in collaboration with Politechnico di Milano). Using entangled two-photon states UoB has successfully measured the protein concentration in a bovine serum in an aqueous buffer. The novel optofluidic device was designed to couple a waveguide interferometer to a microfluidic channel (Fig. 1.2.4). Small refractive index changes, of about 1% were observed using two-photon coincidences from a 2-photon N00N state [MS 125]. This post-selected

scheme shows the promising potential of practical quantum metrology to light sensitive samples and represents a seminal breakthrough in the interfacing of quantum technologies in biological scenarios[CLM1-11].

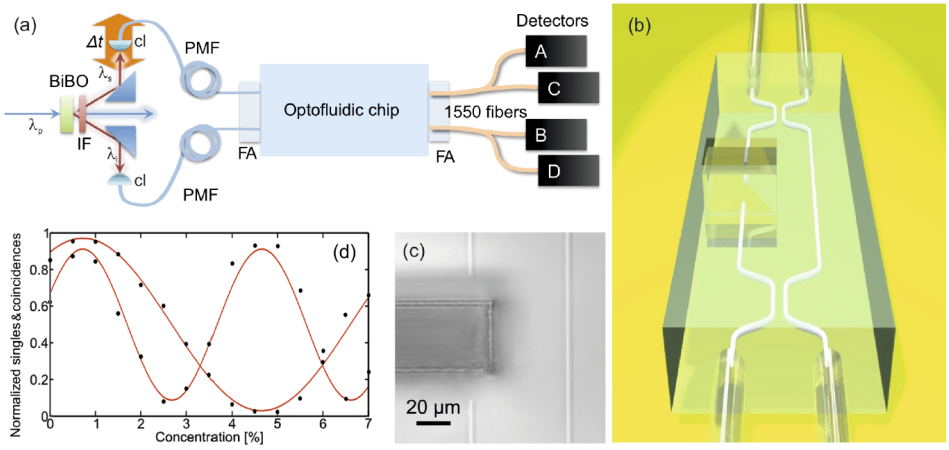


Fig. 1.2.4: Quantum metrology in an optofluidic device. (a) Schematic of the experimental setup: A pump laser at λ_p = 392.5 nm generates pairs of downconverted photons at $\lambda_s = \lambda_i$ = 785 nm in a Bismuth Borate (BiBO) crystal. IF: interference filter, cl: collection lenses, PMF: polarization maintaining fibers, FA: fiber array. (b) Schematic of the Mach-Zehnder interferometer (MZI) interfaced to the microchannel. The fluidic channel has rectangular cross-section 500 μm x 55 μm and extends from the top to the bottom surface of the glass substrate (1 mm thickness). (c) Top image of the optical-fluidic interface. (d) Quantum interference fringes: Normalized single photon counts and two photon coincidences for different concentrations of bovine serum albumin in a buffer solution.

WP1.3: Metrology at the quantum-quantum interfaces

In close interaction between theory and experiments we address the coupling between nanomechanicalsystems and the quantum states of light fields in order to enable ultrasensitive read out of otherwise inaccessibleproperties of complex systems by direct coupling and state transfer along thequantum-quantum interfaces [MS131].

The reference point was the 2009 demonstration of the strong coupling regime between a micromechanical resonator and an optical cavity field [S. Gröblacher, K. Hammerer, M. R. Vanner, M. Aspelmeyer, *Observation of strong coupling between a micromechanical resonator and an optical cavity field*, Nature **460**, 724-727 (2009)]. In this work, the strong coupling regime manifests itself in form of (optomechanical) normal mode splitting, which we observe via direct spectroscopy of the optical field emitted by the cavity. In a subsequent theoretical analysis [AKA1-11], we proposed single-photon opto-mechanics in the strong coupling regime. Along this line of research we have demonstrated the ground state cooling of a nanomechanical oscillator for the first time with an optical cavity [CAS1-11] and we have developed theoretical proposals for new pulsed cooling schemes that have the potential to lead to orders of magnitude improvement in cooling performance [CMA3-11]. Furthermore, micro/nanomechanical resonators are studied as a new interface between quantumsystems. This requires above all the ability of coherent state transfer between mechanical modes and a coupledquantum system [MS133]. In a collaboration between OEAW and UP we investigated the feasibility of mappingthe mechanical quantum state to non-photonic systems such as solid-state spin qubits.

Coherent state transfer between light and mechanical motion is an important ingredient for full quantum control of micromechanical motion. The main idea is to utilize an effective “beamsplitter” interaction between optical and mechanical excitations to implement a full Rabi-swap. The necessary conditions for such an operation to be successful are: (1) operation in the sideband-resolved regime, (2) operation in the strong coupling regime, and (3) Rabi frequenciesthat are larger than both optomechanical coupling rate andcavity decay rate in order to drive a coherent state swap. In a current experiment we have started to investigate directly the correlations between mechanical and optical quadratures. The generalized

optical and mechanical quadratures are obtained from two independent, time-synchronized homodyne measurements of the driving and the locking beam, respectively. In the regime where the rotatingwave approximation is valid the interaction between the optical and the mechanical mode is effectively given by a "beam splitter" Hamiltonian and the observed correlations between mechanical and optical quadratures show that in this regime the mechanical quadratures are directly mapped onto the optical quadratures (Fig. 1.3.1). The next steps include correlation measurements induced by the "downconversion" Hamiltonian, which should generate optomechanical two-mode squeezing and, eventually, entanglement, which provides a basis for alternative quantum state transfer protocols such as quantum state teleportation [HWA1-11]. The single-photon-level state transfer in the strong coupling regime is also investigated [AKA1-11]. We have also developed a new scheme that allows quantum state reconstruction of mechanical states based on pulsed interactions [VPC2-11]. The essence of quantum state tomography is to make measurements of a specific set of observables over an ensemble of identically prepared realizations. The set is such that the measurement results provide sufficient information for the quantum state to be uniquely determined. Our pulsed scheme provides a means for precision measurement of the mechanical quadrature marginals, thus allowing the mechanical quantum state to be determined.

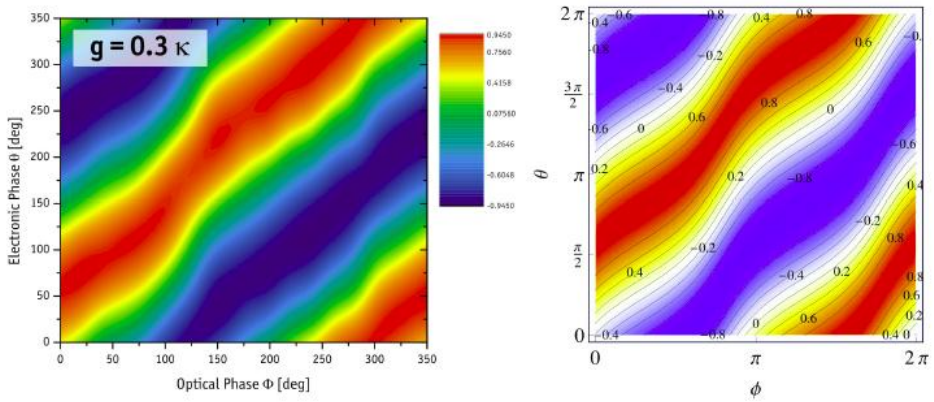


Fig. 1.3.1: Mapping between optical and mechanical quadratures. The density plots depict comparison between experiment (left) and theory (right).

UCPH has been pursuing the big picture goal "the coupling between nanomechanical systems and light fields in order to enable ultrasensitive read out of otherwise inaccessible properties of complex systems". Specifically, the applicability of cavity cooling scheme was extended towards new frontiers, e.g., 1) optically-active semiconductors and 2) electronic excitations in LC-circuit: Regarding 1) the cavity cooling of mechanical modes in optically-active semiconductor membrane was experimentally demonstrated for the first time [LUN1-11], [UNB1-10]. Regarding 2) a novel method was theoretically explored for laser cooling and optical detection of excitations in a room temperature LC electrical circuit by using a nanomechanical oscillator as a transducer between optical and electronic excitations [TSM1-11].

Motivated by recent experiments IPSAS formulated a non-linear theory of spin transport in quantum coherent conductors. It was shown how a mesoscopic constriction with energy-dependent transmission can convert a spin current injected by a spin accumulation into an electric signal, relying neither on magnetic nor exchange fields. When the transmission through the constriction is spin-independent, the spin-charge coupling is non-linear, with an electric signal that is quadratic in the accumulation. As a consequence gated mesoscopic constrictions can have a sensitivity that allows to detect accumulations much smaller than a percent of the Fermi energy.

In a further study a global quantitative picture of the phonon-induced two-electron spin relaxation in GaAs double quantum dots is investigated using highly accurate numerical calculations. Wide regimes of interdot coupling, magnetic field magnitude and orientation, and detuning are explored in the presence of a nuclear bath. Most important, the unusually strong magnetic anisotropy of the singlet-triplet relaxation can be controlled by detuning switching the principal anisotropy axes: a protected state becomes unprotected upon detuning, and vice versa (Fig. 1.3.2). It is also established that nuclear spins can dominate spin relaxation for unpolarized triplets even at high magnetic fields, contrary to common belief. These findings

are central to designing quantum dots geometries for spin-based quantum information processing with minimal environmental impact.

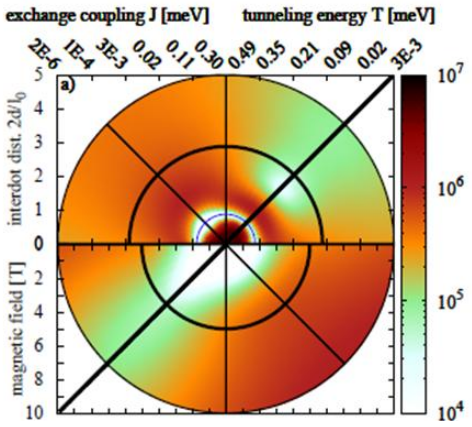


Fig. 1.3.2: Spin-orbit versus nuclear induced electron spin relaxation in double dots.Calculated relaxation rates of the first excited state as a function of the in-plane magnetic field orientation ([100] on the horizontal, [010] on the vertical), and the interdot distance (at B = 5 T, upper halfs) and the magnetic field magnitude (at T = 0.1 meV, lower halfs), displayed along the radii. The rate is given in inverse seconds by the color with the scale on the right. The thick half circles mark the coincidence line, where the parameters of the upper and lower half disk match. The thick diagonal line represents the orientation of the dots, [110].

Neither [MS131] nor [MS133] have been fully achieved yet. The reason is that OEAW has moved their labs in 2010 (from the Austrian Academy of Sciences to the University of Vienna) and experimental progress has been delayed. These milestones and the related milestones/deliverables [MS134, D13.3] are expected to achieve by M36.

WP1.3 Highlight

UCPH demonstrated that suspended single-crystal GaAs nanomembranes can exhibit mechanical Q-factors exceeding 2×10^6 at room temperature, which makes them a very promising platform for optomechanics (Fig. 1.3.3). Because of the completely removed substrate and their millimeter-scale lateral size, the membranes can be incorporated in macroscopic optical cavities for quantum optomechanics experiments. This work paves the way for optomechanical experiments with direct band gap semiconductors in which not only radiation pressure but also other mechanisms involving embedded light emitters could be exploited for quantum optical control of massive mechanical systems.

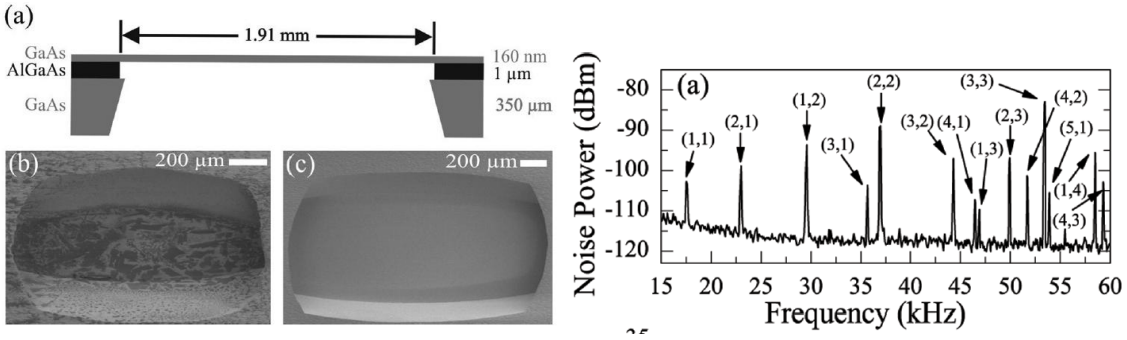


Fig. 1.3.3: Left: Details of the nanomembrane: (a) cross section sketch (b) SEM of the backside of the nanomembrane before and (c) after cleaning processes. Right: Measured frequency noise spectrum in the 10 kHz-60 kHz range presenting a series of peaks corresponding to the different mechanical modes labeled by the mode numbers in the parentheses. The (4,3) mode at 59.5 kHz exhibited a Q-factor of 2.3 x 10^6

WP1.4: Quantum metrology in real-world environments

Multi-parameter estimation

UWAW has analyzed the role of an external phase reference in quantum interferometry. Interferometric schemes with and without an external phase reference have been investigated and a proper way to use quantum Fisher information in both situations has been shown. In the presence of the reference beem the problem is inherently a two-parameter estimation problem and requires the use of the quantum fisher information matrix. Estimation precision as a function of the intensity of the reference beam has been calculated numerically. The extreme cases of a strong reference beam and the lack of reference beam have been recovered and some inconsistencies present in the literature on the subject have been pointed out. Additionally, it has been shown that the availability of the reference beam increases the precision of phase estimation only in the presence of losses [JD1-12]. MS142

Nonlinear interferometry

UWAW has developed a very general, simple geometrical method allowing to calculate precision bounds on linear quantum metrological schemes with generic decoherence models. In order to calculate the bound one only needs to compute a simple measure of distance of a given channel representing the decoherence model from the boundary of the convex set of all quantum channels. It remains an open question whether these tools may be applied to nonlinear models [DGK1-12].

ULEEDS has investigated the phase measurement enhancement from application of various quantum states to the measurement of unknown nonlinear phase shifts, akin to the beating of the standard quantum limit through use of non-classical states to measure an unknown linear phase. It has been shown that the optimal phase estimation precision of even entangled coherent state (ECS) is better than that of the NOON states and of odd ECS states with the same average particle number ⟨n⟩. Quantum enhancement of the measurement has been demonstrated for nonlinearity of arbitrary order k, where k is the power of the mode number operator in the exponent of the unitary nonlinear phase evolution operator. A method to create an approximate ECS (AECS) from a squeezed vacuum state has been proposed and a detailed calculations reveal that this practical state is even slightly better than even ECS states for large ⟨n⟩. Additionally the effect of decoherence in the form of photon loss in the interferometer arm that contains the nonlinearity for a fixed ⟨n⟩ has been examined and has revealed robustness against small loss for various degree of nonlinearity – see Figure 1.4.1 [JPJ1-12].

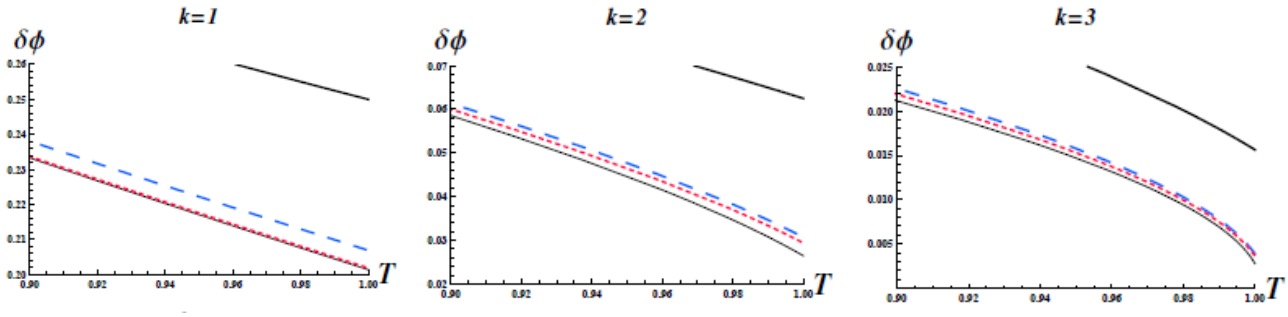


Figure 1.4.1: The phase sensitivity with small lossy conditions for the nonlinear interaction power k = 1, 2, 3 (T : transmission rate of the BS mimicking photonlosses). The thick solid line is for NOON states and the thinsolid line is for AECS which is very similar to dashed lines foreven (short-dashed) and odd (long-dashed) ECSs.

There have been no deviations from the original workplan in WP1.1. The consortium achieved all critical objectives on schedule.

WP1.4 Highlight

In the context of multi-parameter LMU has investigated both theoretically and experimentally the possibility of estimating rotation angles in two complementary directions on the Bloch sphere. A novel criterion has been introduced with which the usefulness of the Dicke and two-mode Fock states have been demonstrated. Polarization interferometric experiment has been been carried out using the particular properties of the multi-partite entangled symmetric Dicke-state.For this state, the expectation value of σ_z vanishes and thus enables the simultaneous measurement of otherwise non-commuting observables (Fig 1.4.2). For the first time sub-shot noise measurement for σ_x - *and* for σ_y-type measurements was achieved.

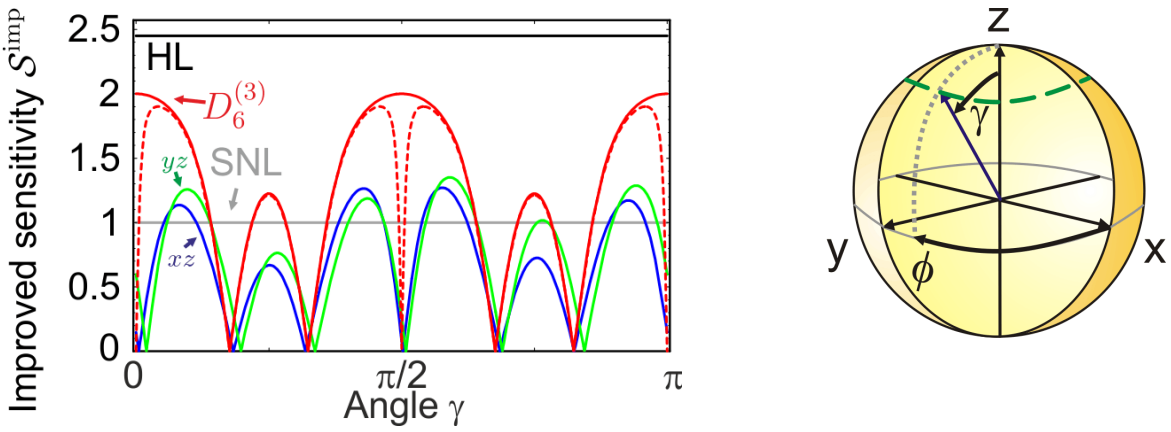


Fig. 1.4.2: Improved sensitivity S^{imp} of a measurement of the polarization rotation with the six-photon Dicke-state. Both aσ_x- (green) *and* a σ_y-measurement (blue) achieve sub-SNL performance (S^{imp}>1).

WP2.1: Quantum Optical Detectors and Random Number Generators

Superconducting parallel nanowire detectors: [TUE, UNIGE]
The TUE group has worked on photon-number-resolving (PNR) detectors based on parallel nanowires. By integrating SSPNDs into waveguide structures, the group has achieved a maximum detection efficiency of ~20%, a dead time of ~10ns, and a timing resolution of ~60ps for single photon detection. For detail, see [SGS1-11].TUE have also developed novel series connections of multiple superconducting nanowires, which should allow higher quantum efficiencies. First experimental demonstration with four pixel device has shown promising photon number solution.

Actively quenched avalanche photodiodes (APDs): [POLIMI, MPD, UoB, idQ]
The POLIMI group has developed a new technology for the fabrication of Si single photon APDs (SPADs) with low timing jitter and improved photon detection efficiency (PDE) in the red wavelength range. The key feature of the red-enhanced (RE) SPAD structure is a high-low electric field profile that provides a thick (about 10 um) absorption region (with low electric field, no multiplication and negligible field-enhanced carrier generation) and a shallow multiplication region (with a peaked electric field profile to enhance the avalanche triggering probability and to reduce the photon timing jitter). The electric field was designed in the two regions to achieve the optimal trade-off between operating voltage, avalanche triggering probability (thus PDE), DCR, and photon timing jitter. A first batch of SPAD devices with 50 um active area diameter were fabricated on 4 wafers at the CNR-IMM (Bologna-Italy) silicon facility. The RE-SPADs were included in compact photon counting modules developed on purpose in collaboration with MPD and their performance was assessed both at room temperature and at moderately low temperature (+ 5 C) [MS214]. Experimental measurements showed a significantly improved PDE in the red region, reaching 40% at 800

nm wavelength (i.e. a factor 2.5 higher than the PDE of standard SPADs) and 60% at 550 nm wavelength. The devices exhibit a remarkable DCR of less than 1000 c/s at room temperature, decreasing to a few tens of c/s at 5 C. Although the active volume of RE-SPADs is considerably larger than that of standard SPADs, due to the increased thickness of the absorption layer, the DCR of the two detectors is comparable at room temperature. This is a distinct advantage of the new design. The thicker absorption region does not significantly contribute to the DCR, since the low electric field results in negligible field-enhanced generation of carriers. The dominant contribution to the DCR comes from the high-field multiplication region, whose design remained substantially unchanged. Using a pulse pick-up circuit for processing the avalanche current, a timing jitter of 93 ps FWHM was obtained at room temperature, with picosecond laser pulses at 820nm wavelength. The jitter is higher than the typical figure of standard SPADs (30-50 ps). This is due to the fundamental limit set by the increased thickness of the absorption (drift) region. Photons are absorbed randomly in the drift region. Since the saturated e-speed is 10^7 cm/s, a timing jitter of 100ps can be roughly estimated for a 10 um thick absorption region. A total afterpulsing probability lower than 1.5% was measured over the entire temperature range. Summarizing, the measured performance of the fabricated RE-SPAD devices outperforms the target specifications. The fabricated devices are of interest for free-space entanglement distribution. Furthermore the red-enhanced technology is fully planar, opening the way to the fabrication of arrays of RE-SPAD detectors.

The MPD research team has been working, in close collaboration with the PoliMi group, in order to design and assemble a compact single photon detector module based on a high voltage Active Quenching circuit (AQC) and on the new RE-SPAD devices designed and fabricated by the PoliMi group. The key component of the detection module, apart from the detector itself, is of course the AQC, which is needed for properly operating the SPAD detector. A new AQC design has been engineered in order to quench the avalanche current by controlling the detectors anode bias voltage, and to be able to generate quenching pulses equal to or higher than 24V. Quenching the SPADs avalanche current from the anode makes it possible to connect the avalanche pulse pick-up circuit to the SPAD cathode, where parasitic capacitances are smallest. In this way it is possible to obtain very high performances in detecting the photon arrival time, i.e. a timing jitter better than 100ps FWHM. Applying 24V or higher quenching pulses allows to bias the SPAD with over-voltages up to 20V and to achieve the already presented characteristics in terms of detection efficiency and timing resolution. Such a high quenching pulse has been attained by designing the high voltage quenching and resetting driving electronics with discrete components while all the other parts of the AQC (comparators, control electronics, delayers, etc.) have been integrated in a single chip using a standard, commercially available, CMOS technology. The discrete components are mainly very fast MOSFETs directly controlled by the integrated part of the AQC which, as said, has been developed as an application specific integrated circuit (ASIC) and it has been fabricated using a standard 350nm CMOS technology. The circuit design allows a minimum time delay between avalanche ignition and quenching and between quenching and reset, and an overall detection module dead time which is now about 80ns but it can be shortened to smaller values. A dead time of 80ns corresponds to a maximum saturated counting rate of about 12 Mcps. The photon detection module auxiliary electronic circuits includes: a programmable voltage source for supplying the bias voltage to the SPAD, a driver circuit for the thermoelectric cooler, a patented timing board which, by means of a linear network connected to the high voltage terminal of the SPAD, feeds a fast ECL comparator and logic and provides a NIM output pulse that marks the photon arrival time with less that 50ps jitter for the standard thin junction devices (up to 200um diameter diodes) and less than 100ps for red-enhanced devices. The circuit controlling the Peltier cooler has been redesigned using a fully integrated Peltier driver IC that contains also an analogue PID controller for optimal temperature stabilization. The new Peltier controller is based on a full bridge design so it is possible to set and control all the temperature levels from room temperature down to -10 degrees C or more. The whole system is managed by an on-board microcontroller, which constantly monitors the NTC thermistor, used to sense the diode temperature, and the other internal voltages, and switches off the module in case one of the monitored parameters is found out of ranges that are set internally inside the microcontroller EEPROM. SPAD detectors delivered by PoliMi group have been mounted on a double-stage thermoelectric cooler, with the NTC thermistor used for controlling the device temperature, packaged in a TO-8 microelectronic case, and sealed in Nitrogen with a window cap which minimizes the distance of the SPAD active area to the top glass surface. Detector cooling is included for having the possibility of reducing further the dark counting rate of the SPAD devices, thus increasing the performance of the final assembled module. Since new Red-enhanched SPADs have relatively low

breakdown voltages ranging from 40V to 60V and are biased about 20V above breakdown, a new SPAD bias DC/DC converter has been also completely re-designed and engineered in order to handle the higher voltage while maintaining the bias voltage ripple very low. This is essential in order to achieve a photon timing resolution of about 100ps or lower. It is also worth noting that even if the breakdown voltage is higher than previous generation SPADs, it not so high as thick junction devices, which have more than 250V as breakdown voltage, and thus the power dissipation is reasonably low, although a little higher than standard SPADs. Such low power dissipation makes this detector, and in turn the module, very robust, reliable and not sensible to accidental exposure to ambient light. The packaged SPAD, the AQC and auxiliary electronics have been assembled in a compact module and enclosed in a metal case that serves also as head exchanger for the Peltier element used to cool down the SPAD. The module is powered by a single unregulated voltage supply ranging from 5 V to 12 V and provides also a standard TTL output pulse to a 50 Ohm load each time a photon is detected. A prototype module has been fully characterized in terms of dark counting rate, photon detection efficiency, after-pulsing probability, timing resolution and is available to the consortium.

High count rate Geiger mode APDs: [TREL, idQ]
After achieving the milestone 2.1.3 "*Photon number resolving detector with detection efficiency >70%*", TREL has made further progress on practical photon number detectors using electric-field modulated Si APDs. Clearly discerned multiphoton signals are obtained by applying sub-nanosecond voltage gates in order to restrict the detector current. See Thomas *et al*. [TS1-12].

Self-differencing InGaAs APDs have been optimised for long distance quantum communications. A significant reduction in the afterpulsing probability has been obtained, to a value of just 0.23% at a detection efficiency of 11.8%. This afterpulse probability is the lowest measured so far for InGaAs APDs with GHz gating frequencies. Secondly, the reduction in the afterpulsing allows a higher detector bias yielding higher detection efficiencies. At a detection efficiency of 33.7% the aftepulsing probability remains as low as 2.1%. For more detail, see the document *Deliverable 2.1.2: Detectors for long-distance quantum communications*.

TREL also developed a novel technique to evaluate photon field statistics, the knowledge of which has profound effect on the security of quantum communications. By exploiting the photon number resolution (PNR) in the SD-APDs, it is now possible to access higher order photon correlation with a simple Hanbury-Brown Twiss setup (HBT). See [DYS1-11].

In separate experiments, TREL continued investigation on the security of InGaAs APDs for quantum communications [YDS1-11,YDS2-11]. TREL experimentally proved that monitoring the APD photocurrent is sufficient to foil the "faint after-gate attack" proposed by Lydersen et al. [Lydersen *et al*, Phys. Rev. A**84**, 032320 (2011); Appl. Phys. Lett.**99**, 196101 (2011)].

IDQ's work on fast gated APD has led to the development of a high-performance product, which can be gated at a maximal frequency value of 100MHz. This is smaller than the values demonstrated by the self-differencing technique, but is much higher than other commercially available products. This increase of the gating frequency rate has been possible thanks to a 'compensation branch' which is used to reduce the interference signal due to the derivative of the front edge of the gates applied on the APD. The idea of this technique of 'compensation branch' has been motivated by the excellent performances at GHz frequency gates which have been demonstrated by several research groups, while allowing the gate frequency to be tuned and the APD to be operated in free running mode. For more detail, see the document *Deliverable 2.1.2: Detectors for long-distance quantum communications*.

Quantum optical random number generation: [MPD, POLIMI, idQ, LMU, UoB, TREL]
The milestones and deliverables for this task are concentrated in Year 3. The POLIMI and MPD groups are currently working on a SPAD-based QRNG featuring high bit rate (up to 100 Mb/s or more by exploiting a monolithically integrated SPAD arrays), robust structure, compact size and no need of post processing. First prototype based on a 32x32 SPAD array already available at PoliMI is expected by 1Q 2012.

There have been no deviations from the original workplan in WP2.1. The consortium achieved all critical objectives on schedule.

WP2.1Highlight

TREL has developed a practical photon number resolving detector using Electric-Field Modulated Silicon avalanche photodiodes shown in Fig. 2.1.1. Clearly discerned multiphoton signals are obtained by applying sub-nanosecond voltage gates in order to restrict the generated avalanche current as evident in Fig. 2.1.2. For further details see [TS1-12].

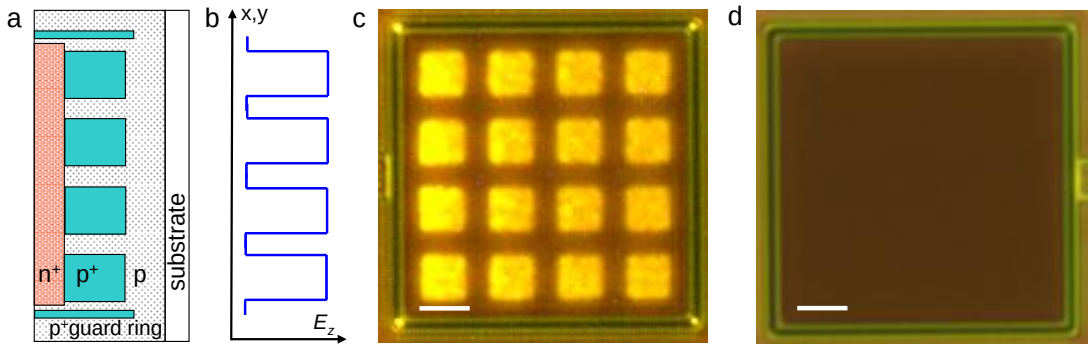


Figure 2.1.1: Device structure and microscopy. (a) Schematic of the lateral doping profile of an electric field modulated Si-APD, shown in cross-section through the x-y plane. (b) Schematic representation of the lateral electric field profile in the x-y plane. (c) Dark-field emission micrograph, measured for a large dc bias applied beyond the reverse breakdown voltage. The scale bar corresponds to 10 μm. (d) Optical micrograph showing the uniform detector surface, as defined lithographically. The scale bar corresponds to 10 μm.

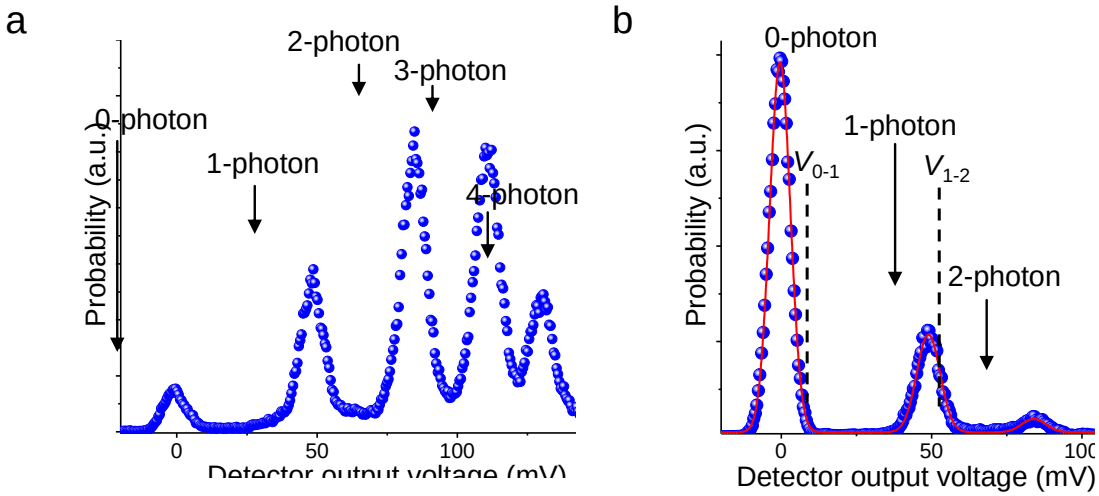


Figure 2: **Distribution of detector output voltages.** (a) Distribution of the output voltage pulses from an electric field modulated Si-APD, measured for a detected photon flux μ = 4.8 photons/pulse. (b) Output voltage distribution (symbols) measured for a detected photon flux μ = 0.92 photons/pulse, for which there are only contributions from 0, 1 and 2 detected photons. The dashed lines correspond to discrimination levels use to determine the photon number error between adjacent photon number states, which are modelled using Gaussian fits (red curves).

WP2.2: Quantum Sources

TREL continued the work on semiconductor quantum dots as triggered quantum light sources. They developed an in-plane emission source collecting single photons from a semiconductor QD in a photonic crystal waveguide [SKF1-11]. The dot coupled to the propagating mode of a photonic crystal waveguide showed enhanced emission due to slow-light effects with single-photon emission rates reaching 19 MHz and device efficiency of 24% under optical excitation. This will prove to be an ideal source for integrated quantum photonics.

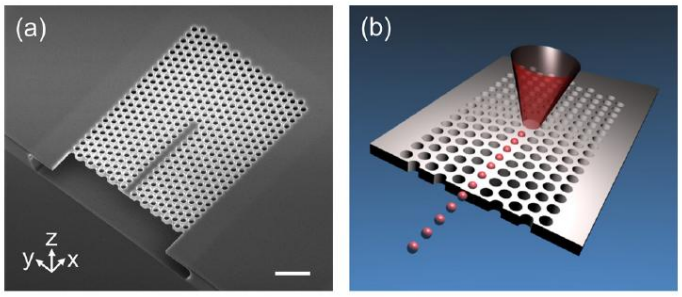


Fig 2.2.1 Quantum dot coupled to a photonic crystal waveguide (TREL)

TREL have also continued to refine their quantum dot based entangled light source based on an electrically driven InAs quantum dot within a p-i-n junction. They have now shown record entanglement from an electrical source through improved spatial filtering by fibre coupling, and better time resolution using SSPDs. More details in highlight presentation.

MACQ and UoB in collaboration with Universities of Sydney and St Andrews have developed waveguide pair photon sources based in highly nonlinear slow-light silicon PC waveguides.These sources are 100 microns in length and constitute the smallest pair photon sources known. Correlated photon pairs are generated in the telecom C-band at room temperature from a dispersionengineered silicon photonic crystal waveguide. The spontaneous four-wave mixing process producing the photon pairs is enhanced by slow-light propagation enabling an active device length of less than 100 μm. With a coincidence to accidental ratio of 12.8 at a pair generation rate of 0.006 per pulse, this ultracompact photon pair source paves the way toward scalable quantum information processing realized on-chip [XMC1-11].

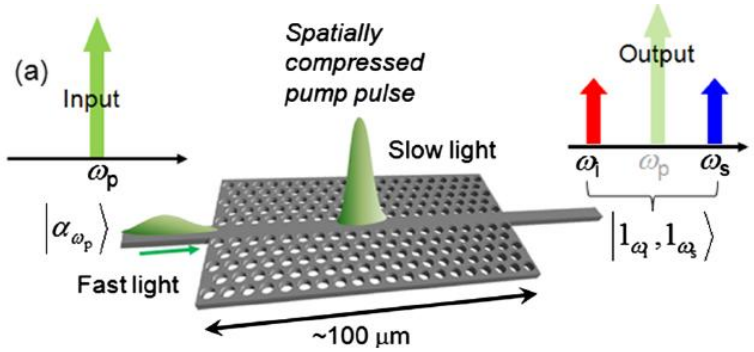


Figure 2.2.2 Slow light pair photon generation in a photonic crystal waveguide

UOB has continued to develop fibre pair photon sources recently publishing a detailed study of fibre narrowband sources [CFB1-11] for demonstrating cluster state generation and metrology applications. In our cluster state experiment we have characterised a fusion gate used to make the cluster [BCT1-12] and will report on cluster characterisation in year 3. We have also used our fibre sources to develop a 6-photon metrology experiment which is described in more detail WP1.2.

UNIGE working with new consortium member University of Paderborn (**UPB**) has developed an improved resonant cavity based waveguide source of photon pairs [PSO1-12] which forms milestone M2.3.3 (see the milestone report for more details).

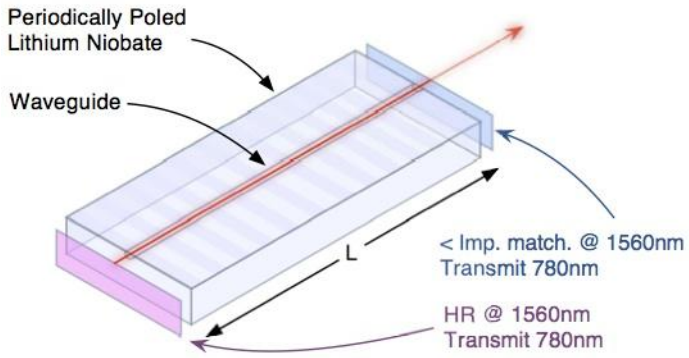


Figure 2.2.3 Resonant cavity waveguide photon pair source (UNIGE)

LMU (with UoB, ICFO Barcelona and spin out company Qutools) focused its efforts in developing robust entangled pair photon sources for space terminals.

There have been no deviations from the original workplan in WP2.2. The consortium achieved all critical objectives on schedule.

WP2.2 Highlight

Indistinguishable Entangled Photons from an LED
TREL have continued to refine their quantum dot based entangled light source based on an electrically driven InAs quantum dot within a p-i-n junction. They have shown record entanglement from an electrical source through improved spatial filtering by fibre coupling, and better time resolution using SSPDs. The measured fidelity is now 0.85±0.01 for DC driven devices and 0.87±0.04 for pulsed devices running at a rep rate of 476MHz. They have managed to improve photon coherence times over 200 ps thus have also been able to show indistinguishability between subsequent exciton (X) emissions and even between biexciton (XX) emission events using a time delaying Mach Zehnder interferometer. Hong Ou Mandel interference visibilities of 0.57±0.04 (XX) and 0.52±0.03 (X) have been recorded. This means that milestone 2.2.5 (month 36) has been achieved earlier than expected and the work has recently been published in PRL [SSN1-11]

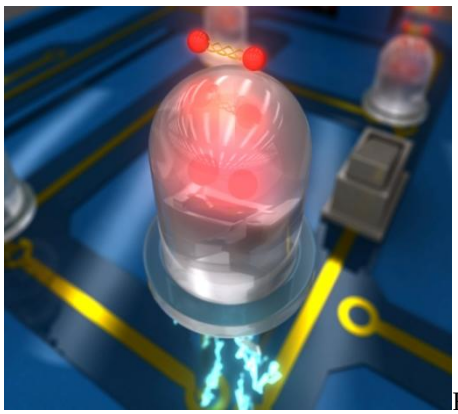


Figure 2.2.4 Artist's impression of an entangled light emitting diode

WP2.3: Quantum memories and interfaces

UCPH has improved the hybrid quantum repeater protocol of deliverable D2.3.1 [BRP1-10] by modifying the protocol in two ways. First, step one and two of the protocol have been interchanged such that now step one is local processing and step two is non-local entanglement generation. The motivation for this improvement was that non-local processing is assumed to be far more time-demanding than local processing and it should therefore be one of the later steps. Secondly the local processing has been optimized to be more efficient. The two modifications result in a significantly enhanced performance of the proposed hybrid protocol.

TREL continued the work on semiconductor quantum dots as quantum memory devices. The group investigated the role of the nuclear magnetic field of the host material and demonstrated that it has a strong impact on the decoherence of a stored superposition of states [BPS1-11]. Additionally, by using a double quantum dot (quantum dot molecule), TREL successfully demonstrated a device able to store single photons up to 1 μs and spin information for more than 12.5 ns with 80% fidelity [GSS1-11]. Combined with recent advances on quantum light sources based on quantum dots in WP2.2 and photon number resolving detectors in WP2.1, this technology highlights the potential of solid state devices for quantum information processing.

UoB has developed new schemes for efficient state teleportation and entanglement swapping using a single quantum-dot spin in an optical microcavity based on giant circular birefringence [HR1-2011]. State teleportation or entanglement swapping is heralded by the sequential detection of two photons and is finished after the spin measurement (see Fig. 2.3.1). The spin-cavity unit works as a complete Bell-state analyzer with a built-in spin memory allowing loss-resistant repeater operation. This device can work in both the weak coupling and the strong coupling regime, but high efficiencies and high fidelities are achievable only when the side leakage and cavity loss is low. The Bristol team assessed the feasibility of this device and showed that it can be implemented with current technology. Also optical spin manipulation methods at single-photon levels are proposed, which could be used to preserve the spin coherence via spin echo techniques.

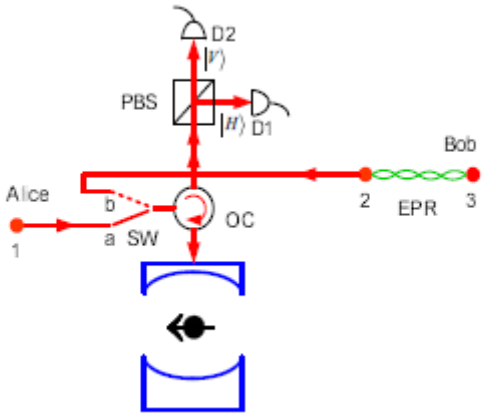
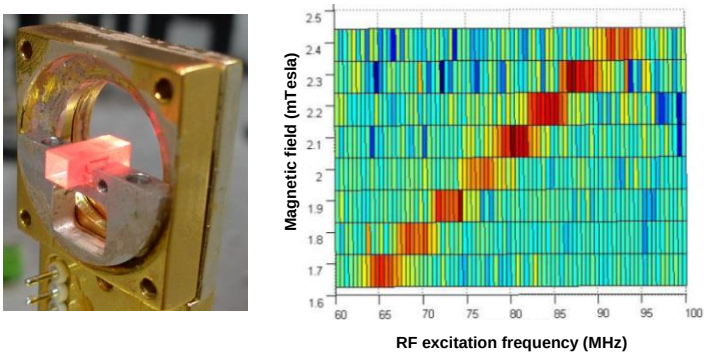


Figure 2.3.1:Schematic of state teleportationwith a Qdspin in a single-sidedmicrocavity (type I). In this case, the spin-cavity unit works as a three-photon GHZ-state generator and a complete Bell-state analyzer. SW(optical switch), OC (optical circulator), PBS (polarizing beam splitter), D1 and D2 (photon detectors).

LMU focused its efforts in two directions. The Munich group developed a new detection scheme (based on photo-ionization and subsequent registration of the correlated ion-electron pairs) which allows the deterministic state analysis of single optically trapped atoms in less than 1 μs [HKH1-10]. In comparison with the frequently used fluorescence method this new detector combines a 100 fold enhancement in speed with scalability to a large number of atoms. In the future it might thus be applied for site-specific readout of atoms in optical lattices, a mandatory requirement for entanglement purification. Quite recently – by applying the entanglement swapping protocol – the LMU team demonstrated the first heralded entanglement between two single-atom quantum memories at a distance of 20 m (see related milestone M2.5.1 and deliverable report D2.5.2).

UNIGE has worked along three directions; 1) rare-earth (RE) spin spectroscopy and coupling of RE spin ensembles to superconducting circuits for microwave-to-optical conversion, 2) storage of light as spin excitation in Eu:Y2SiO5 and 3) the investigation of light-light interfaces, including nonlinear frequency conversion of single photons. In the first direction, the long-term goal is to store light in electronic spin levels (Zeeman/hyperfine) in Nd or Er doped materials. Another exciting application is to couple such spin ensembles to superconducting circuits operating in the GHz regime, to achieve coherent conversion of qubits from the microwave (MW) to optical regime. UNIGE collaborates on this theme with the Chalmers group led by Prof. Delsing and Dr. Wilson. In a first series of experiments [SHK1-12] we have observed coupling of an Er:Y2SiO5 ensemble to a superconducting MW cavity, which is an important first step, but the coupling was weak primarily due to a large inhomogeneous spin broadening of 75 MHz. UNIGE performed optically-detected electron-spin resonance experiments on Nd-doped Y2SiO5, finding a much smaller linewidth of about 5 MHz (see Fig. 2.3.2). Ongoing experiments at Chalmers suggests that stronger coupling to a MW cavity can indeed be achieved using Nd:Y2SiO5. In near future UNIGE plans to characterise the suitability of these ensembles for long-duration storage by measuring spin coherence times.

Fig 2.3.2: Optically-detected spin spectroscopy of Zeeman levels in a Nd:Y2SiO5 crystal (left). The spin resonance (right) shows an extremely narrow inhomogeneous linewidth of 5 MHz.



UNIGE also carried out light-storage experiments in the nuclear hyperfine states of Eu-doped Y2SiO5, so-called spin-wave storage, using the storage protocol based on an atomic frequency comb (AFC). So far, spin-wave storage using an AFC was only done once in Pr-doped Y2SiO5. Europium-doped materials are known for longer spin coherence times, thus also potentially longer storage times. UNIGE succeeded in performing the first spin-wave experiments in Eu:Y2SiO5, with storage times up to 10 microseconds [TLU1-12]. UNIGE expects a significant increase in storage time to 10 ms by application of spin echo techniques.
UNIGE also continues its efforts on frequency conversion. In particular the group is looking at the feasibility of performing sum-frequency generation at the single photon level. This has recently been shown to provide an interesting route towards efficient heralded entanglement [N. Sangouard *et al.*, Phys. Rev. Lett. **106,** 120403 (2011)]. Already with efficiencies of 10^{-8}, this approach is more efficient than schemes based only on linear optics. UNIGE expects that with an optimised PPLN waveguide an efficiency approaching 10^{-6} will be feasible. The team currently tests nonlinear PPLN waveguides as a possible route towards this challenging goal. UNIGE has previously tested this at the single photon level using weak coherent light and are now starting to test this with single photons generated via SPDC.

There have been no deviations from the original workplan in WP2.2. The consortium achieved all critical objectives on schedule

WP2.3 Highlight

UOXF has successfully demonstrated correlated Stokes/anti-Stokes emission from diamond. In particular, the team has implemented a quantum-memory-type interaction in diamond, in which an ultrafast "write" pulse spontaneously scatters a Stokes photon, whose detection heralds the creation of a single optical phonon within the diamond. The non-classical character of this phonon state was then verified by converting the phonon into an anti-Stokes photon by means of a second ultrafast

"read" pulse. The cross-correlation of the Stokes and anti-Stokes modes is clearly observed to violate the Cauchy-Schwarz inequality that demarcates the boundary between classical and quantum correlations, showing that a non-classical state of motion has been created within the diamond (see Fig. 2.3.3 below) [LSS1-11].

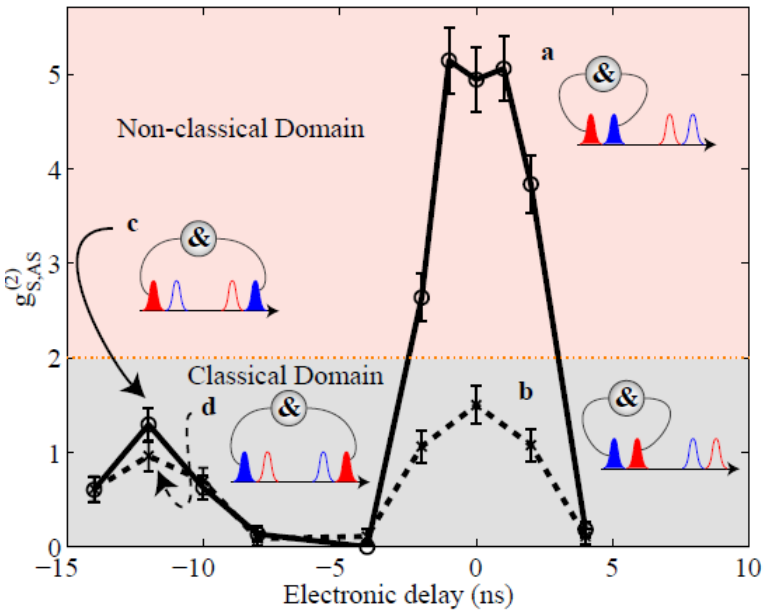


Figure 2.3.3: Violation of Cauchy-Schwarz inequality by Stokes/anti-Stokes cross correlation.

WP2.4: Design and comparison of quantum communication technologies

The two keys objectives are to develop:

O1. Designs for entanglement distribution architectures (both fibre and free-space), determine relevant limitations and provide techniques for optimisation of architectures.

O2. Methods for the quantitative verification of distributed entanglement.

Research has continued on both objectives O1 and O2, with significant results presented on both themes. For O1 we present a significant new quantum repeater protocol – which is also featured as a highlight from this WP – and a detailed study of how detector imperfections can affect conclusions about entangled sources for repeaters that they are used to characterise. Clearly this latter contribution is also important for verification scenarios which employ such detectors, and thus O2. The main results for O2, which form the basis for the WP deliverable for this period, comprise three quantitative verification methods for quantum resources. It should be noted that one of these methods arises from collaboration between experimentalists and theorists and one has been tested experimentally on a photonic cluster state.

Objective O1 progress summary:

O1i) *Quantum repeaters based on heralded qubit amplifiers*

We have recently incorporated the idea of heralded amplification to improving protocols for quantum repeaters. Previously we have shown that heralded amplification can be exploited for Device-Independent QKD, thus bringing this into the realms of experimental physics. This recent proposal for quantum repeaters based on heralded qubit amplifiers provides for the remote creation of highly entangled states even with imperfect devices, as shown in Fig. 2.4.1. The Fidelity is preserved even when distributed over long distances without the need for post-selection. This is currently the most efficient quantum repeater protocol based on atomic ensembles and linear optics and opens the way towards DI-QKD over long distances [MRS1-12].

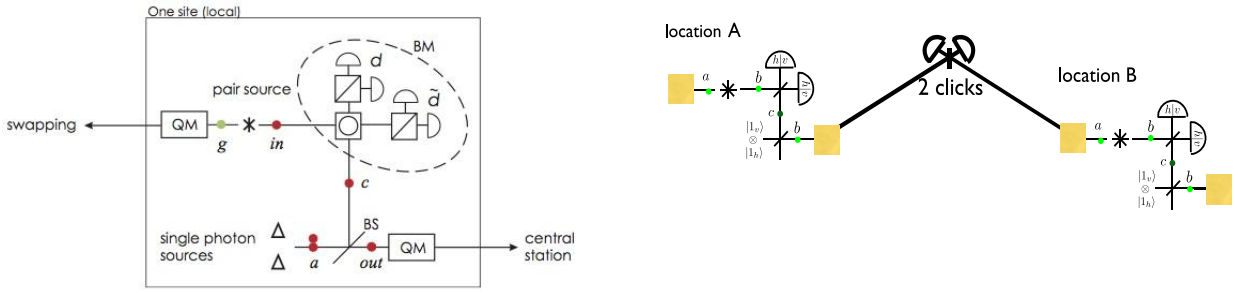


Fig. 2.4.1: (Left) Heralded source of entangled pairs, QM - quantum memories, BM - Bell measurement. A pair source (star) produces a polarization entangled state in a probabilistic way in modes in and g. Two single-photon sources (triangles) produce a product state of two photons with orthogonal polarizations in the same spatial mode a. The mode a is sent through a beam splitter (BS) with tunable reflectivity R (in intensity) and the two photon coincidence detection d-d̃ teleports the mode in to the mode out (up to a unitary transformation). This leads to the entanglement between the modes g and out which are then stored in the memories. (Right) Schematic of an elementary quantum repeater link using heralded qubit amplifiers.

O1ii) *Detector imperfections in photon-pair source characterisation*

Important issues for quantum repeaters are the quality of entangled resources and also the perceived quality of these resources as measured by actual detectors, which clearly also feeds into the verification scenario. We have been addressing the problem of how photon detector imperfections can affect the characterisation of photon pair sources through measurement. In [SSB1-11], we give detailed derivations and exact formulas for practical quantum optical tests, such as:

- Auto & cross correlations
- HOM Interference
- Bell Interference

In Fig. 2.4.2 we see the typical sort of analysis with the visibility for a HOM interference dip as a function of the pair creation rate and for different detector dark count characteristics. Further details can be found in [SSB1-11]. We expect that this will greatly benefit work within SP1 and SP2 that relies on photon pair sources, thus extending well outside this WP.

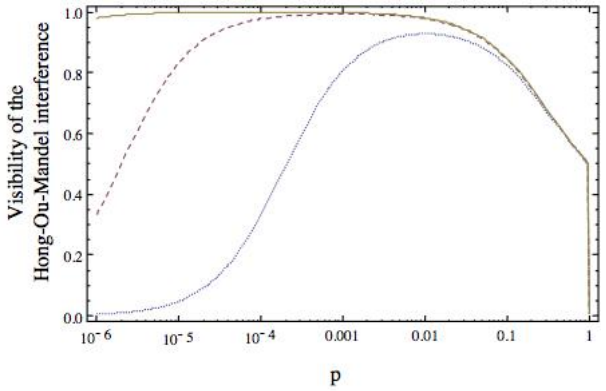


Fig. 2.4.2. Visibility of the HOM interference for a two-mode squeezed state as a function of the emission probability p for dark count probability

- $p_{dc} = 10^{-6}$ (solid)
- $p_{dc} = 10^{-5}$ (dashed)
- $p_{dc} = 10^{-4}$ (dotted)

Objective O2 progress summary:

O2i) *Loophole-free Bell test with one atom & less than one photon*

In a collaborative effort between experiment (the group at LMU) and theory (the group at UNIGE), a proposal for a loophole-free Bell test with one atom & less than one photon has been proposed [SBG1-11] – less than one photon refers to the single photon entanglement that is used. A substantial violation of a Bell inequality, crucially with homodyne detections on the optical mode, can be realised for systems with low detection and transmission efficiencies. This is demonstrated in Fig. 2.4.3 and may open the way for a loophole-free Bell test. Such a test provides a verification tool for distributed atom-photon entanglement.

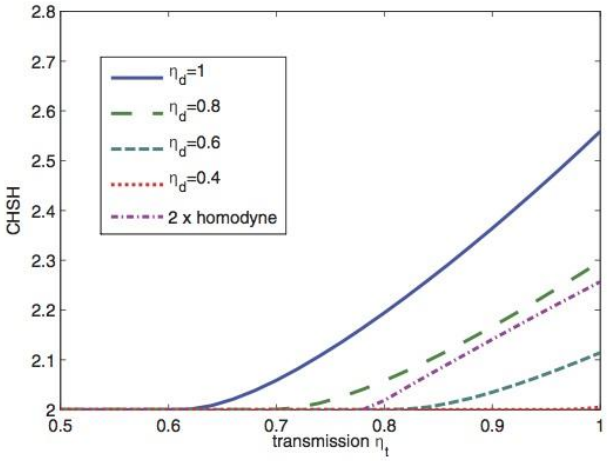


Fig. 2.4.3: Robustness of the CHSH violation with respect to the transmission efficiency.

O2ii) *Efficient quantum state tomography*

Given a promise of the form of quantum resources provided from an experiment, a method for efficient quantum tomography of such states has been proposed [CPF1-10]. Conventional quantum tomography requires exponential (in N, the number of component quantum systems in the resource) verification effort and is thus impractical for anything other than very small N quantum resources. Efficient tomography in principle requires only linear (in N) verification effort and is also able to provide signatures of failures, thus effectively heralding the breaking of the promise, or the incorrectness of the additional information. As an example, the creation of W-states up to N=20 could be verified with high fidelity – as illustrated in Fig. 2.4.4 – whereas conventional tomography would fail around N=8 from the sheer impracticality of exponential measurement and post-processing requirements.An extension of these ideas to density matrices has been pursued by partner UULM and is in preparation for publication.

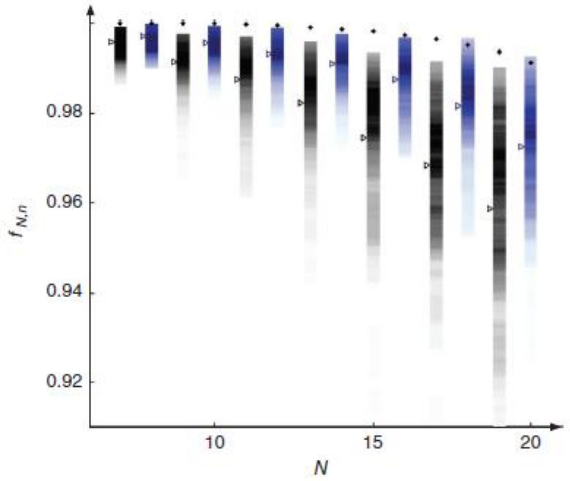


Fig. 2.4.4: The fidelity of the verification algorithm for W states as a function of qubit number for N up to 20. Conventional tomography fails for N in excess of about 8. Further examples of the application of efficient tomography are given in the published report [CPT1-10].

O2iii) *Optimal verification of entanglement in a photonic cluster state experiment*

Cluster states are useful universal quantum processing resources. The optimal verification of experimentally produced four- and six-photon cluster states has been demonstrated [WVM1-10]. The states were produced through hyper-entangled (in polarisation and linear momentum) photon states, as illustrated in Fig. 2.4.5. This work also addressed the question of the scaling of entanglement bounds from incomplete tomographic information on the density matrix under realistic experimental conditions.

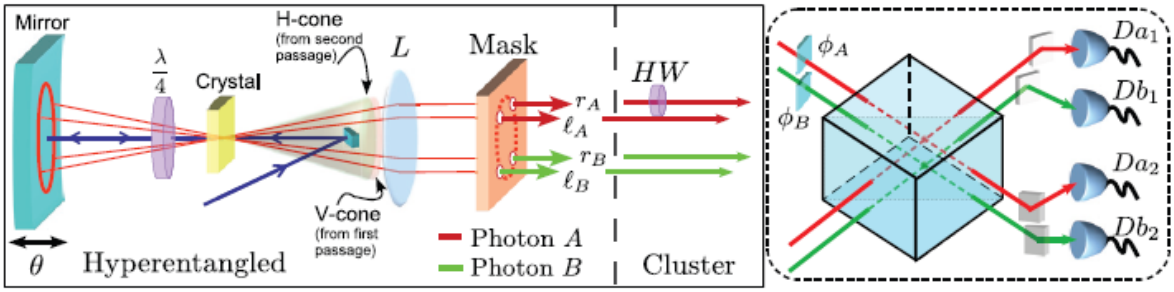


Fig. 2.4.5: The left panel illustrates the source of the optical polaristaion-path hyper entangled state leading to the cluster state. The right panel illustrates the measurement arrangement for the path degress of freedom.

The experimental results for four- and six-qubit cluster state verification are summarised below.

Table 3. Summary of experimental results.

	Fidelity	Purity	Minimal global robustness	Minimal relative entropy
Four qubits	0.880 ± 0.006	0.778 ± 0.005	2.519 ± 0.012	1.449 ± 0.013
Six qubits	0.645 ± 0.006	0.424 ± 0.010	4.507 ± 0.047	1.492 ± 0.027

There have been no deviations from the original workplan in WP2.4. The consortium achieved all critical objectives on schedule.

WP2.4 Highlight

The recent proposal by UNIGE for a quantum repeater protocol based on heralded qubit amplifiers provides the most efficient quantum repeater protocol based on atomic ensembles and linear optics to date [MRS1-12]. The scheme, shown in Fig. 2.4.1, incorporates the idea of heralded amplification that provides for the remote creation of highly entangled states even with imperfect devices. It is shown that any potential errors, resulting from the use of non-unit efficiency devices, are purified by the entanglement swapping operation serving as heralding for the preparation of entanglement in the elementary link. The quality of the entanglement is preserved even after many entanglement swapping operations such that the proposed quantum repeater does not require post-selection as usually done in repeaters with atomic ensembles and linear optics. This leads to entanglement distribution rates similar to the ones that would be obtained from ideal photon-pair sources. Furthermore, this opens a way for the realisation of device-independent quantum key distribution over very long distances.

WP2.5: Quantum communication test beds

Adaptive optics system based on blind optimization:

In order to increase the link efficiency of a turbulent free-space linkOEAW implemented an adaptive optics system as illustrated in the Figure 2.5.1 below. A beacon laser with 780nm wavelength was attached and aligned to the 1m telescope in Tenerife, both pointing to La Palma. By the use of a stochastic parallel gradient descent algorithm (SPGDA) the coupling of the 780nm signal into single mode fiber on La Palma was maximized with a tip-tilt mirror (TTM) and deformable mirror (DM). A wavelength division multiplexer (WDM) for 780nm and 808nm separated/combined the incoming 780nm and the outgoing 808nm light. The signal of the outgoing 808nm laser was predistorted by the optimized settings of the DM and TTM in order to precompensate for the turbulences over the link. Finally the transmitted 808nm signal was collected by the 1m telescope of the OGS in Tenerife with a powermeter in the focal point measuring the received intensity. With the adaptive mirrors in zero position we first aligned the pointing and focusing of the sending telescope. To do so we used the standard procedure that was applied over the past years to set up the link

between the islands. Once the link was perfectly aligned, we started to measure the power of the received 808nm light on Tenerife with the AO system running and switched off (see Figure 2.5.1 right).
Although the lenses of the AO setup in La Palma were not optimized for system performance, the obtained results give us a first estimation on the effectiveness of the scheme. In our setup we used a 5cm sending aperture, which is in the order of the fried cells for weak turbulence, therefore not using the full potential of the DM. Also the whole lens system was not perfectly achromatic for 780nm and 808nm, thus optimization on the incoming 780nm didn't perfectly match the optimum settings for 808nm. Nevertheless we consistently saw an improvement of the link budget with the use of the AO system.

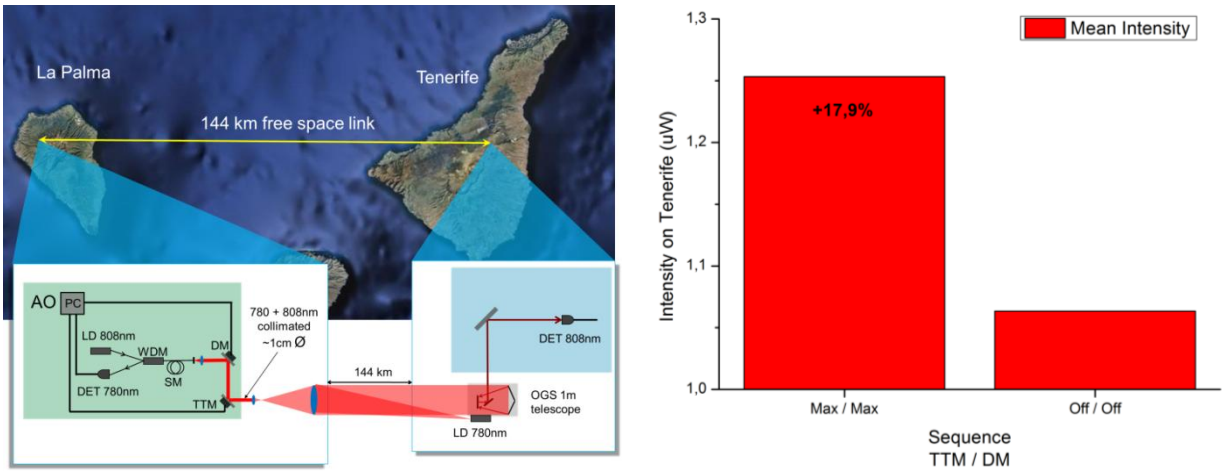


Figure 2.5.1: Left: Experimental setup for the AO test between La Palma and Tenerife. Right: Mean intensity of the received 808nm signal, measured with a powermeter in the focal point of the 1m telescope on Tenerife. The bar Max/Max corresponds to the TTM and DM in optimization mode. Off/Off means that the AO system was switched off.

Heralded quantum amplifier

Loss is one of the most fundamental obstacles for long distance quantum communication. It is well known that the amplification of a quantum state cannot be deterministically performed with unit fidelity. Indeed, it can be shown that this would lead to faster than light signalling. However, approximate quantum amplification is possible and probabilistic noiseless amplifiers have recently attracted a lot of attention. This was the case for a recent proposal for Device Independent Quantum Key Distribution (DI-QKD) which was based on the concept of heralded photon, or even qubit, amplification [GPS1-10].
Heralded noiseless amplification based on single-photon sources and linear optics is ideally suited for long-distance quantum communication tasks based on discrete variables. The University of Geneva (UNIGE) has experimentally demonstrated such an amplifier, operating at telecommunication wavelengths. Coherent amplification has been performed with a maximum gain of G≈2 obtained.
One interesting aspect that we can see in the experimental set-up, shown in Fig. 2.5.2(left), is the resemblance to an entanglement swapping experiment. The two sources of entanglement are realised after the photons pass VBS1 and VBS2; a Bell state measurement at BS1 then entangles the two remaining (upper and lower) arms. Entanglement can be verified by interfering these two modes. Furthermore, if, for example VBS2 is not 50/50, it will produce a non-maximally entangled state, but by appropriately varying VBS1 we can recover a maximally entangled state after the swapping operation in a Procrustean-like purification process. Finally, an important element for any distributed quantum communication scenario is that the systems can function independently – i.e. they do not need to have a phase-stabilised reference between them. Although using only a single pair of SPDC photons, we have been able to demonstrate that using this approach there is no need for such a stable phase reference between the initial signal state (in) and the local auxiliary photon (c) used by the amplifier. Normally, there is no phase dependence between the photons used in this demonstration and as such we see in Fig. 2.5.2(right), a visibility approaching 1. However, if we turn the l/2 waveplate before the PBS we have aphase dependent state in the system. As the phase between the two input arms is varying so rapidly (as would be the case for a distributed system) the interference is

completely destroyed leaving only the phase independent (50% max visibility) component. These results highlight the potential of heralded quantum amplifier in long-distance quantum communication based on quantum repeaters and bring device-independent quantum key distribution, one step closer.

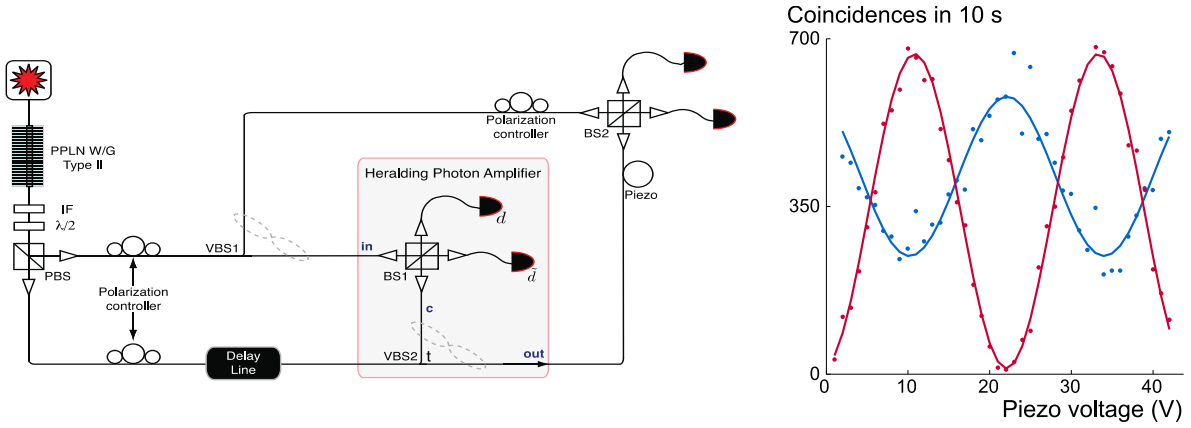


Fig. 2.5.2: (left) Experimental set-up for testing the heralded photon amplifier; (right) Two visibility curves.

Entanglement between independent quantum memories

Entanglement is the essential feature of quantum mechanics. Its importance arises from the fact that observers of two or more entangled particles will find correlations over arbitrary large distances which cannot be explained by classical statistics. In order to make it a useful resource for e.g. long-distance quantum communication, entanglement between remote massive quantum systems is necessary. LMU reported on the generation and analysis of heralded entanglement between spins of two single Rb-87 atoms, trapped independently 20 meters apart. Independently UCPH reported on an experiment where dissipation continuously generates entanglement between two macroscopic objects. This is achieved by engineering the dissipation using laser and magnetic fields, and leads to robust event-ready entanglement maintained for 0.04 s at room temperature. Their system consists of two ensembles containing about 1012 atoms and separated by 0.5 m coupled to the environment composed of the vacuum modes of the electromagnetic field. By combining the dissipative mechanism with a continuous measurement, steady state entanglement is continuously generated and observed for up to 1 h.These achievements form the starting point for new experiments in quantum information science, as well as for fundamental tests of quantum mechanics.

The ambitious milestone M2.5.1: “Demonstrate entanglement between remote independent quantum memories” has been reached. Heralded entanglement between remote stationary quantum memories is a key resource for future applications of long-distance quantum communication, like quantum repeaters and distributed quantum networks. Within this context both partners LMU and UCPH demonstrated entanglement between independent quantum memories. In LMU scheme the heralded preparation and analysis of entanglement between two single optically trapped Rb-87 atoms over a distance of 20 m via entanglement swapping (see Fig. 2.5.3). In detail, the spin of each of the atoms was entangled in a first step with the polarization state of a single spontaneously emitted photon. The photons were then guided to an interferometric Bell state measurement (BSM) setup where they were projected onto a polarization entangled state, thereby swapping the entanglement onto the remote atomic spins.

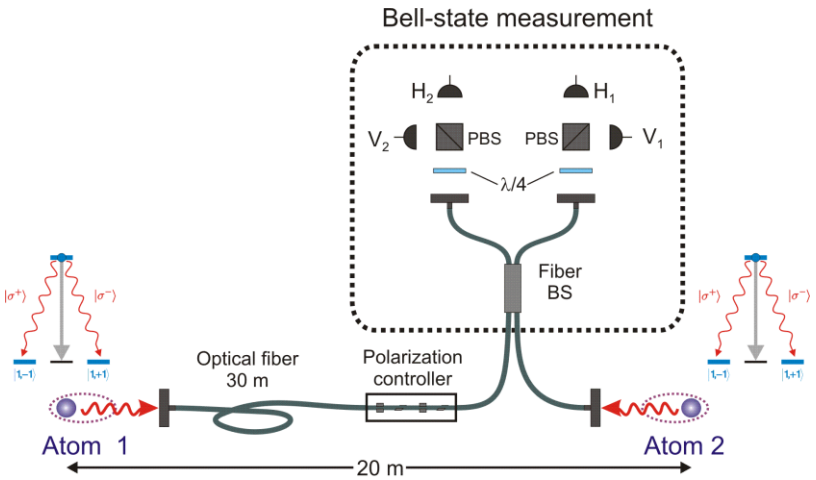


Figure 2.5.3: Principle of atom-atom entanglement generation via entanglement swapping. The trapped atoms are entangled with a photon each in a spontaneous emission process (lambda-type atomic transition). The photons are coupled into optical fibers and guided to an intermediate location where a Bell-state measurement is performed, thereby swapping the entanglement onto the atoms.

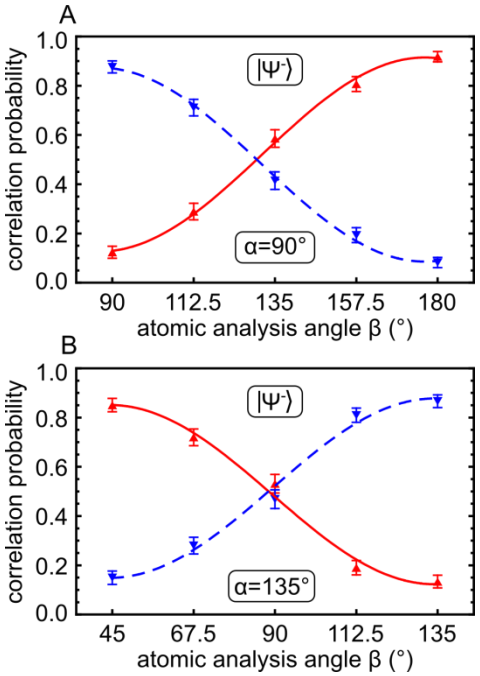


Figure 2.5.4: Atom-atom correlations obtained after Bell-state projection of the photons onto the anti-symmetric state $|\Psi^-\rangle$. Plotted are the measured correlation $\frac{1}{N}(N_{\uparrow\uparrow}^{(\alpha,\beta)} + N_{\downarrow\downarrow}^{(\alpha,\beta)})$ probabilities (red solid line) and anti-correlation $\frac{1}{N}(N_{\uparrow\downarrow}^{(\alpha,\beta)} + N_{\downarrow\uparrow}^{(\alpha,\beta)})$ probabilities (blue dashed line) in two complementary atomic measurement bases. The overall number of analyzed entangled pairs of atoms was 2200, observed within 67 hours measurement time.

After optimization of the entanglement fidelity of both atom-photon interfaces and the fidelity of the applied Bell-state projection the team characterized the entanglement between two remote atoms. Triggered on the coincident detection of a horizontally and a vertically polarized photon in two different output ports of the BSM arrangement (coincidences H_1V_2 and V_1H_2) – this heralds a successful projection of the photons onto the anti-symmetric Bell-state $|\Psi^-\rangle$ – entanglement between the atoms was evaluated. For this purpose the group performed spin-correlation measurements in two complementary measurement bases (see Fig. 2.5.4), yielding an atom-atom entanglement fidelity of 0.82. This number proves that an entangled state between two atoms at a distance of 20 m was generated, clearly above the classical threshold of F=0.78 necessary to violate a CHSH Bell-type inequality. Worth mentioning is that the design of trap 2 allows rather straightforward extension of the distance between the two traps to several 100 m. The recent achievements of partner LMU make this experiment a crucial milestone for future developments in long-distance quantum communication.

The achievement of MilestoneMS252 is be delayed. Preliminary teleportation results of UCPH have been achieved and they aim to conclude the experiments in the cause of this year.

WP2.5 Highlight

UNIGE has proposed Device Independent Quantum Key Distribution (DI-QKD) that is based on the concept of heralded photon, or qubit, amplification [GPS1-10]. They has taken the first experimental steps in the direction of DI-QKD by realizing heralded noiseless amplification. The scheme is based on single-photon sources and linear optics and is ideally suited for long-distance quantum communication tasks based on discrete variables. A schematic of the heralded photon amplifier is illustrated in Fig.2.5.5(left). This is easily understood in the context of teleportation, where initially we generate (single photon) entanglement between modes "c" and "out". The mode "c" undergoes a Bell state measurement with an unknown input state "in", at which point it is teleported to the output mode "out". We have experimentally demonstrated such anamplifier, operating at telecommunication wavelengths and observed, see Fig. 2.5.5(right) a heralded gain of $G \approx 2$. The interference visibility is also shown to ensure that the process is a coherent one.

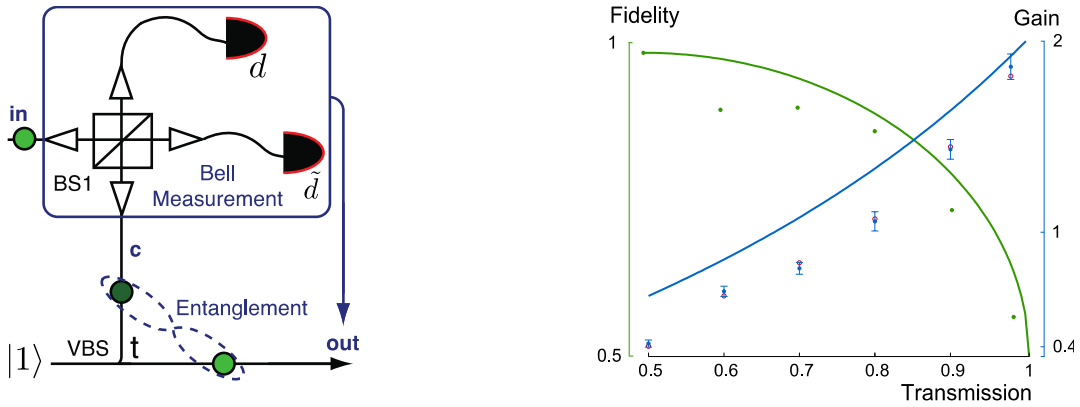


Fig. 2.5.5: (left) Heralded single photon amplification. By changing the variable beam-splitter (VBS) transmission (t) a heralded gain can be achieved. (right) Results for the Gain and the interference visibility (which ensures the process is coherent) as a function of the transmission in the amplifier.

Another highlight of this WP is UCPH demonstration of quantum entanglement between two separate macroscopic objects which is maintained for as long as an hour. This achievement disproves a popular belief that quantum entanglement, the main component in quantum information processing, is a fragile property which can only exist for a limited time. The novel method used to produce this unusual result is based on employing dissipation for generation of entanglement. Dissipation, or, in other words, uncontrolled interaction with the environment, so far has been the major reason for ruining quantum entanglement. We engineer dissipation for atomic ensembles containing thousands of billions of atoms so that it generates entanglement rather than impairing it. The „ready-to-use" entanglement produced in our work demonstrates that dissipation can be used for quantum information processing. Applications range from quantum communication to quantum sensing. The work has been highlighted by PhysOrg, ScienceDaily and other outlets. [KMJ1-11].

WP3.1: Quantum distribution of continuous-variable entanglement

M3.1.2, M3.1.3, and M3.1.5 were fully achieved: The partner MPL sent a squeezed laser field over a free link of 1.6 km length and measured about 1 dB of squeezing. LUH demonstrated a 4 mode bound entangled state, which is the first demonstration of continuous variable bound entanglement. This result is published in Phys. Rev. Lett. [GSH1-10], and was already mentioned as a highlight of the first reporting period of WP3.1. And LUH achieved the distribution of two-mode squeezed entangled light with a nonclassical bandwidth of more than 1 GHz [ASM1-12]. There is also progress towards M3.1.4, however, this milestone requires additional time of up to 6 months. D3.1.1 is a report, which includes the achieved milestone M3.1.5. The report was delivered by LUH.

The work package partners also made progress towards the remaining milestones and deliverables. Two theoretical research results were achieved, which represent significant steps towards D3.1.2 and

towards continuous-variable long-distance entanglement distribution in general. Both works were published in Phys. Rev. Lett. in 2012 [DZN1-11,CE1-11] and are highlights of the second reporting period of work package WP3.1.

At MPL the experiments towards the first entanglement distillation counteracting real environmental noise (atmospheric fluctuations) continued. The performance of our 1.6 km free space CV quantum channel could further be improved in terms of stability and transmission. Through the implementation of an active beam stabilization and optimized optics, it now operates stable at a mean transmission > 70% over 4 hours and can even stand thunderstorms without losing track.

In addition to that, we succeeded in developing two sources of squeezed light. The first design is an asymmetric Sagnac interferometer with a fiber acting as the nonlinear medium. This setup generates amplitude squeezed states at 1560 nm. The second design, that will serve as the squeezed light source for the free space distribution, is a single-pass fiber setup in which the polarization field variables are squeezed. Here we work at 780nm created in a Second Harmonic Generation process, enabling to reduce the size of the optical components. The nonlinear medium is a Photonic Crystal Fibre (PCF). All components have successfully been assembled and together, they form a compact and truly portable squeezing source that up to now could achieve around 1.5dB of squeezing.

At LUH design work for a squeezing source of greater 3 dB squeezing at 1550 nm over a bandwidth of greater 1 GHz has continued. Such a source will be realised in the last year of Q-ESSENCE. Here the big-picture goal is entanglement-based quantum key distribution with a GHz key rate. In [EHD1-11, EHD1-12, SBE1-12] LUH report on the generation and analysis of Einstein-Podolsky-Rosen-steering. In [5] EPR steering was observed based on a single squeezed mode. In [EHD1-12] it was shown that even a secret key can be generated based on a single squeezed mode. In [SBE1-12] the so far strongest CV entanglement was realized. The EPR correlation according to Reid's criterion was improved by almost an order of magnitude compared to previous works.

At UOXF.DU experiments towards pulsed bulk-optics implementation of the Brown-Eisert-Plenio CV entanglement distillation scheme have continued. Issues with phase stability of the local oscillator modes required for phase-sensitive detection (weak-field homodyning using quasi-photon-number-resolving time-multiplexed detectors) have been solved by means of a novel two-colour phase lock, which takes advantage of polarisation optics to provide improved common-mode phase-noise rejection. Initial experiments involving conditional preparation of non-classical states using a single down-conversion source and number-resolving measurements have confirmed the theoretical model for our detection statistics, incorporating all losses and inefficiencies. A new FPGA-based data acquisition system has enabled analysis of multi-click events and a second down-conversion source is currently being installed. Finally, theoretical work to develop an efficient entanglement witness based on phase sensitive correlations is now focussed on improving the numerical stability of the inversion algorithm in the presence of experimental noise. A big-picture goal, led by UOXF.DU, is implementing a genuine iterative distillation protocol. It has brought us face-to-face with a number of challenging technical issues that have so-far required considerable effort to overcome. Careful detector calibration, improved source and detector design, new phase stabilisation systems, an entirely redesigned data acquisition system with enhanced flexibility, and carefully implemented numerical algorithms for state tomography and entanglement detection have all been developed in order to bring together all the components required for the protocol.

In addition, we have developed the theory of a new distillation protocol [3] that uses non-ideal quantum memories as active elements to change the resource scaling from doubly exponential in time and space, to linear in time and constant in space. Simultaneously we are developing such quantum memories within our group, along with integrated sources and photonic circuits. With these developments, we are confident that a genuinely scalable distillation system will become part of the tool-box available to the photonic quantum information processing community. With milestone M.3.1.4 achieved, we anticipate rapid progress towards the ultimate goal of demonstrating a single round of the Browne-Eisert-Plenio distillation protocol. However, at this stage we cannot guarantee that our system will be capable of demonstrably increasing the entanglement of the initial two-mode squeezed state; this will depend on our ability to mitigate losses. Initial measurements suggest that this will be possible, but in any case we are confident that we will be able to demonstrate an increase in entanglement over the post-loss state.

With two theoretical works [DZN1-11,CE1-11] important progress was achieved in the field of CV distillation and thus long distance CV entanglement distribution. In [DZN1-11] the project partners UOXF.DU and UUL introduce a new scheme for continuous-variable entanglement distillation that requires

only linear temporal and constant physical or spatial resources, both of which are exponential improvements over existing protocols. Our scheme uses a fixed module - an entanglement distillery - comprising only four quantum memories of at most 50 % storage efficiency and allowing a feasible experimental implementation. Tangible quantum advantages are obtained by using non-ideal quantum memories outside their conventional role of storage. By creating, storing and processing information in the same physical space, the scheme establishes a potentially valuable technique for designing stable, scalable protocols across different quantum technologies. In [CE1-11] the partner FUB/UP introduce a new primitive to construct hybrid (CV-DV) entanglement distillation schemes. It gives rise to a large class of new distillation protocols, including multi-partite ones, and those that allow for an experimentally desirable trade-off between success probability and output quality. On the other hand, building on a new non-commutative quantum central limit theorem, the work presents a unified view on how Gaussian states may emerge in quantum mechanics.

There have been no deviations from the original workplan in WP3.1. The consortium achieved all critical objectives on schedule.

WP3.1 Highlight
The theory work [DZN1-11,CE1-11] identifying novel ways of thinking about continuous-variable and hybrid entanglement distillation by three partners UOXF.DU, FUB, and UULM have been selected as highlights by the workpackage leader. In particular, they offer new ways of trading success probability versus the quality of the distilled states, as well as are much more resource-efficient than previously known schemes.

WP3.2: New protocols

The main objectives of this workpackage are to investigate the full potential of quantum distributed protocols and their resource scaling, beyond the standard quantum communication and quantum cryptography scenarios. The workpackage is structured along the four main topics:

1) Development of new protocols for distributed quantum information processing: the main objective of this part for the current reporting period was to explore the potential of quantum distributed protocols beyond the standard cryptographic settings, such as anonymous quantum voting.

2) Quantum information processing with uncharacterized devices: the main objective of this part was to understand how Bell inequalities can be used for the design of device-independent quantum random number generators.

3) New quantum networks beyond point-to-point architectures: the main objective was to explore how entanglement can be distributed over quantum networks beyond the standard point-to-point repeater architecture.

4) Non-additivity in capacities: the main activity was devoted to the study of the non-additivity of the zero-error channel capacity.

The main results achieved in this reporting period are presented in what follows according to this structure.

Development of new protocols for distributed quantum information processing
Partner IPSAS studied the security of several protocols for quantum voting. In [BBH1-11], they present a number of schemes that use quantum mechanics to preserve privacy. In particular, they show that entangled quantum states can be useful in maintaining privacy. They further develop the original proposal introduced in Phys. Lett. A **349**, 75 (2006) for protecting privacy in voting, and examine its security under certain types of attacks, in particular dishonest voters and external eavesdroppers. Actually, a variation of these quantum-based schemes can also be used for multiparty function evaluation. They consider functions corresponding to

group multiplication of *N* group elements, with each element chosen by a different party and show how quantum mechanics can be useful in maintaining the privacy of the choices group elements.

In [OE1-11], partner FUB introduced a new scheme for measurement-based quantum computation with continuous-variable systems. These schemes are based on suitable non-Gaussian resource states that can be prepared using interactions of light with matter systems or even purely optically. Gaussian measurements such as optical homodyning as well as photon counting measurements are required, on individual sites. These schemes overcome limitations posed by Gaussian cluster states, which are known not to be universal, unless one is willing to scale the degree of squeezing with the total system size.

In [CAA1-12], partner ICFO presents a simple recipe for the systematic enhancement of the resistance of multipartite entanglement against any local noise with a privileged direction in the Bloch sphere. In contrast to previous techniques resorting to complex logical-qubit encodings, such enhancement is attained simply by performing local unitary rotations before the noise acts. The scheme is therefore highly experimentally-friendly, as it brings no overhead of extra physical qubits to encode logical ones.

Quantum information processing with uncharacterized devices

In [AMP1-12], partner ICFO studies the use of quantum non-locality for randomness certification. They show that two-outcome quantum correlations with arbitrarily little non-locality or states with arbitrarily little entanglement can be used to certify that close to the maximum of two bits of randomness are produced. From a practical point of view, these results imply that device-independent quantum key distribution with optimal key generation rate is possible using almost-local correlations and that device-independent randomness generation with optimal rate is possible with almost-local correlations and with almost-unentangled states.

New quantum networks beyond point-to-point architectures

Partner UG studies in [GHH1-12] the problem of sharing entanglement over large distances in networks whose nodes share noisy entangled pairs. They exploit an isomorphism between storing quantum information in systems of dimension *D* and transmission of quantum information in D+1-dimensional networks. Using this isomorphism, they show that it is possible to obtain long distance entanglement in 2D network. For 3D networks, much simpler schemes are possible, e.g. due to existence of Kitaev topological quantum memory on a 2D lattice.

In [PLA1-11], partner ICFO analyzes entanglement distribution on networks with full-rank bi-partite mixed states linking qubits on nodes. In particular, they introduce new protocols that combine entanglement swapping and purification to partially entangle widely separated nodes. The new improved protocols are applied to the Erdös-Rényi network and obtain results including low density limits and an exact calculation of the average entanglement gained at the critical point.

Non-additivity in capacities

In [CCH3-11], partner UoB provides two quantum channels that individually cannot send any information, even classical, without some chance of decoding error. But together a single use of each channel can send quantum information perfectly reliably. This proves that the zero-error classical capacity exhibits superactivation, the extreme form of the superadditivity phenomenon in which entangled inputs allow communication over zero capacity channels. But the result is stronger still, as it even allows zero-error quantum communication when the two channels are combined.

Finally, in [CCH2-11] partner UG considers the non-additivity of classical communication channel capacity in networks. Communication lattices consisting of entanglement breaking channels are assisted, in a probabilistic manner, by identity channels. Using percolation ideas, it is shown how the classical capacity between nodes in the network displays super-additivity effects. As a byproduct, a new type of entanglement based quantum capacity percolation phenomenon is derived.

There have been no deviations from the original workplan in WP3.2. The consortium achieved all critical objectives on schedule.

WP3.2 Highlight

The work by partner ICFO "Secure device-independent quantum key distribution with causally independent measurement devices", L. Masanes, S. Pironio, A. Acín, published in Nature Communications [MPA1-10] has been selected by the workpackage leader as this year's highlight of this workpackage.

WP3.3: Verification and identification methods

Partners ICFO, IPSAS, FUB, UG, MPL and UULM have reported activity that will be summarized in the following. In [ZCD1-11] partner UULM (in collaboration with partner UOXF.DU) introduce a quantum detector tomography method for the reconstruction of the POVM of a coherent optical detector. This method is applied to two variations of a weak-homodyne detector: photon-counting and photonnumber-resolving detector (PNRD). The POVM elements of such detectors have both phase and number sensitivity, denoted by their off-diagonal and diagonal matrix elements respectively. Our experimental procedure can be universally applied to any optical detector. It uses only classical optical states as probes, yet, with the resulting POVM we can predict the detector response to any quantum state, including non-classical ones. Full quantum tomography is only made possible by developing a new recursive algorithm that radically reduces the computational complexity of reconstructing the POVM from quadratic to linear per recursion in the dimension d of the POVM elements. By defining the transformed version of the Husimi distribution (Q function), we cast the reconstruction problem as a tractable semi-definite program, allowing us to determine both diagonal and o-diagonal elements. This enables us to characterize the detectors' tunability between registering the particle and wave behaviors of an input quantum state, making our experiment the first full quantum tomography of phase-sensitive optical detectors. This work achieves Milestone M3.3.2.

In another work partner UULM studied the question of non-Markovianity. Surprisingly, it turns out the concept of (non)Markovianity is not uniquely defined. One approach is based on the idea of the composition law which is essentially equivalent to the idea of divisibility (Wolf and Eisert 2008). A related approach was taken recently by Rivas, Huelga and Plenio [RHP1-10] to construct quantitative measures of non-Markovianity, that is, they measure the deviation from divisibility. A different approach is advocated by Breuer, Laine and Piilo. They define non-Markovian dynamics as a time evolution for the open system characterized by a temporary flow of information from the environment.

In [CKR1-11] partner UULM has also analyzed two recently proposed measures of non-Markovianity: one based on the concept of divisibility of the dynamical map and the other one based on distinguishability of quantum states. In [CKR1-11] they provide a toy model to show that these two measures need not agree. In addition, they discuss possible generalizations and intricate relations between these measures. This work contributes to deliverable D3.3.2. In the fiber-based continuous variable quantum key distribution (CVQKD) system being developed in the MPL lab, they have continued to investigate effective entanglement with a channel length of up to 40 km. They have worked on the quantification of this effective entanglement, in collaboration with a theoretical group from IQC Waterloo (N. Killoran, H. Haeseler, N. Lütkenhaus, Quantum Throughput: Quantifying quantum communication devices with homodyne measurements, Phys. Rev. A 83, 052320 (2011)). After minimizing different noise sources, such as phase noise, and also losses over this extreme distance, they find positive values of effective entanglement for a large range of parameter. They can also show that increased noise gradually deteriorates and finally breaks effective entanglement between sender and receiver.

Partner IPSAS has addresses several questions in the area of verification and identification. Firstly, in unpublished work (submission expected in April 2012 in order to include various generalizations of the results) partner IPSAS has studied the estimation of decoherence rates. Here they asked the question whether it is possible to directly estimate the decoherence rate providing that the channel is promised to be from the family of pure decoherence channels, which is equivalent to family of generalized phase-damping channels for qubits. The goal was to find an experiment in which the recorded statistics contains as little irrelevant information as possible, i.e. determines the smallest possible number of parameters.

Partner IPSAS was finally able to reduce this number to the minimal possible value although the experiment is formally performed on two copies of the channel. The final suggested procedure is very simple indeed. One picks two copies of the source of some pure state and applies the same random unitary rotation to each one of them and send them through the channel. At the output one performs "symmetry

measurement", i.e. two-valued projective measurement with the effects being the symmetric and antisymmetric projections. This measurement is associated with a SWAP operator and the expectation value is directly related to the decoherence rate. The modified relation (with x) is a correction if the original source is not pure (in particular x is the length of the Bloch vector).

This work achieves D3.3.2 and will be described in the deliverable report. In a separate effort, partner IPSAS has also studied the question how much information is left (for other observers) in already observed physical system. Given an unknown state of a qudit that has already been measured optimally, can one still extract any information about the original unknown state? Clearly, after a maximally informative measurement, the state of the system collapses into a postmeasurement state from which the same observer cannot obtain further information about the original state of the system. However, the system still encodes a significant amount of information about the original preparation for a second observer who is unaware of the actions of the first one.

In [RCM1-11] partner IPSAS studied how a series of independent observers can obtain, or can scavenge, information about the unknown state of a system (quantified by the fidelity) when they sequentially measure it. They give closed-form expressions for the estimation fidelity when one or several qudits are available to carry information about the single-qudit state, and study the classical limit when an arbitrarily large number of observers can obtain (nearly) complete information on the system. In addition to the case where all observers perform most informative measurements, they study the scenario where a finite number of observers estimates the state with equal fidelity, regardless of their position in the measurement sequence and the scenario where all observers use identical measurement apparatuses (up to a mutually unknown orientation) chosen so that a particular observers estimation fidelity is maximized.

In a third effort partner IPSAS was trying to design an experiment which successfully and unambiguously compared all states given that one has access to its outcome statistics. This makes it different from single shot comparisons which is known to be impossible without strong apriori information on states purity. It was of especial interest to find simple experiments which are not informationally complete. In general, partner IPSAS showed that sameness (for any state) cannot be concluded if one takes into account statistical uncertainties. They showed that universality requires infocompleteness. This is a perhaps unexpected result as one would have expected that complete tomography would not be required in this simple problem. Nevertheless, partner IPSAS also showed that almost universality (comparing almost all pairs with respect to usual measures) can be achieved by a simple factorized measurement. In particular, for qubits one performs the same projective measurement on both qubits.

Partner ICFO argues that an overwhelming majority of experiments in classical and quantum physics make a priori assumptions about the dimension of the system under consideration. In [HGM1-11] they addressed the problem whether it would be possible to assess the dimension of a completely unknown system only from the results of measurements performed on it, without any extra assumption. They demonstrate that the concept of a dimension witness answers this question, as it allows one to bound the dimension of an unknown classical or quantum system in a device-independent manner, that is, only from the statistics of measurements performed on it. In [HGM1-11] they report on the experimental demonstration of dimension witnesses in a prepare and measure scenario. They use pairs of photons entangled in both polarization and orbital angular momentum to generate ensembles of classical and quantum states of dimensions up to 4. Then they use a dimension witness to certify their dimensionality as well as their quantum nature. These results open new avenues for the device-independent estimation of unknown quantum systems and for applications in quantum information science.

In [ONG1-12] Partner FUB (formerly UP) have introduced a novel theory of quantum compressed sensing for continuous-variable systems, significantly outperforming standard quantum state tomography based on homodyning or direct measurement of the Wigner function.

Partner UG has contributed with a variety of results. In [BHH1-12] quantum privacy witnesses were studied. While it is usually known that the mean value of a single observable is enough to detect entanglement or its distillability, the counterpart of such an approach in the case of quatum privacy has been missing.

Partner UG developed the concept of a privacy witness, i.e. a single observable that may detect presence of the secure key even in the case of bound entanglement. They also developed the notion of secret key estimation based on few observables and discussed the witness decomposition into local measurements. The surprising property of the witness is that with the help of a low number of product measurements involved, it may still report the key values that are strictly above distillable entanglement of the state. For an

example of a four-qubit state studied in a recent experiment [DKD1-10] this means 6 Pauli operator product measurements versus 81 needed to carry out the complete quantum state tomography. The present approach may be viewed as a paradigm for a general program of experimentally friendly detection and estimation of task-dedicated quantum entanglement.

In [GPA1-11] the same partner studied the characterizing of quantumness via entanglement creation. In [PGA1-11] an activation protocol had been introduced which maps the general non-classical (multipartite) correlations between given systems into bipartite entanglement between the systems and local ancillae by means of a potentially highly entangling interaction.

Partner UG studies how this activation protocol can be used to entangle the starting systems themselves via entanglement swapping through a measurement on the ancillae. Furthermore, they bound the relative entropy of quantumness (a naturally arising measure of non-classicality in the scheme of Piani et al. above) for a special class of separable states, the so-called classical-quantum states. In particular, we fully characterize the classical-quantum two-qubit states that are maximally non-classical.

In [LMP1-11] partner UG studies correlation-tensor criteria for genuine multiqubit entanglement which represents a development of a geometric approach to entanglement indicators. The method is applied to detect genuine multiqubit entanglement. The criteria are given in the form of nonlinear conditions imposed on correlation tensors. Thus they involve directly observable quantities, and in some cases require only few specific measurements to find multiqubit entanglement. The nonlinearity of each of the criteria allows detection of entanglement in wide classes of states. In contrast to entanglement witnesses, which in the space of Hermitian operators define a hyperplane, these conditions define a geometric figure encapsulating the nonfully entangled states within it.

In [LRS1-11] the same partner studies the experimental Schmidt decomposition and entanglement detection. They introduce an experimental procedure for the detection of quantum entanglement of an unknown quantum state with as few measurements as possible. The method requires neither a priori knowledge of the state nor a shared reference frame between the observers. The scheme starts with local measurements, possibly supplemented with suitable filtering, that can be regarded as calibration. Consecutive correlation measurements enable detection of the entanglement of the state. Partner UG utilizes the fact that the calibration stage essentially establishes the Schmidt decomposition for pure states. Alternatively they develop a decision tree which reveals entanglement within few steps. These methods are illustrated and verified experimentally for various two-qubit entangled states.

There have been no deviations from the original workplan in WP3.3. The consortium achieved all critical objectives on schedule.

WP3.3 Highlight

Three highlights have been selected by the workpackage leader for the last reporting period. These are, by partners UULM, FUB, and ICFO:

- "Measuring entanglement in condensed matter systems", M. Cramer, M. B. Plenio, H. Wunderlich, Phys. Rev. Lett. 106 020401 (2011) [CPW1-10]
- "Continuous-variable quantum compressed sensing", M. Ohliger, V. Nesme, D. Gross, J. Eisert, submitted to Commun. Math. Phys (2011) [ONG1-12]
- "Experimental estimation of the dimension of classical and quantum systems", M. Hendrych, R. Gallego, M. Micuda, N. Brunner, A. Acín, J. P. Torres, submitted to Nature [HGM1-11]

WP3.4: Implementation of distributed protocols

As part of the big-picture goal of quantum technology, this work package addresses the means to implement distributed schemes. Therefore steering increasingly large quantum systems efficiently and with high

precision is an essential. While optimal control lends itself to tackle these engineering problems numerically, quantum systems theory provides a powerful formal framework to assess the feasibility of these engineering tasks in terms of controllability, observability and simulability. It gives the dynamic fingerprint of the quantum architecture (i.e. coupling type & topology) and it interplay with coherent controls.

TUM: Based on the controlled master equation, the algorithmic framework DYNAMO [MSG1-10] provided by TUM as a convenient and cutting-edge MATLAB toolset solves a large set of standard quantum control problems. Now in [SSK1-11] the paradigmatic scenario of exploiting subspaces largely (but not fully) protected against decoherence was addressed. In a realistic example, controls optimised by DYNAMO allowed for a CNOT with a fidelity > 95%, while paper-and-pen solutions were limited to fidelities < 15%. In preparation for addressing large-scale quantum systems, versatile numerical tensor contraction methods have been designed in [HWS1-12]. Moreover, TUM made progress on the mathematical side: From characterising the set of all reachable directions the dynamics of a closed quantum system can take by symmetries of the system Lie algebra [ZS1-10] they have moved to open systems, which are much more demanding. In [MDS1-12] the set of all reachable directions (i.e. the Lie wedge) has been determined for several examples of Markovian *n*-qubit channels under coherent control. This is an important step to approximate reachable sets of controlled open systems more accurately than by majorisation, which typically turns very crude with increasing system size.

OEAW: In view of connecting distributed modules coherently and in an entangled fashion, the partners at OEAW already developed a novel photon sources with sufficient interferometric stability and brightness for experimental observation and analysis of six-photon interference [D3.4.1] (see previous report and [BCZ1-10]).

Quantum computers, besides offering substantial computational speedups, are also expected to preserve the privacy of a computation. Now, in [BKB1-12], OEAW presented an experimental demonstration of blind quantum computing in which the input, computation, and output all remain unknown to the computer. They exploit the conceptual framework of measurement-based quantum computation that enables a client to delegate a computation to a quantum server. Various blind delegated computations, including one- and two-qubit gates and the Deutsch and Grover quantum algorithms, are demonstrated. The client only needs to be able to prepare and transmit individual photonic qubits. Their demonstration is crucial for unconditionally secure quantum cloud computing and might become a key ingredient for real-life applications, especially when considering the challenges of making powerful quantum computers widely available.

UWAW: In joint work with UG, UWAW has focussed on witnessing quantum privacy. Since the development of the theory of quantum privacy it has been known that the quantum mechanical guarantee for secret communication is not directly related to the amount of entanglement. This led to an important question how to characterize quantum privacy without complete quantum state tomography. In [BHH1-12], the general concept of quantum privacy witnesses has been developed. Bounds on the amount of distillable key following from detection of one or few observables have been derived. UWAW has also investigated waveguide sources of down-conversion photons. Nonlinear waveguides hold the promise of higher pair production rates and better photon number correlations than standard bulk media used for parametric down-conversion. In [KRB1-12], UWAW demonstrated a general technique for generating spatially pure photon pairs in multimode wave guiding structures. The technique exploits intermodal dispersion, which separates spectrally down-conversion processes involving different triplets (pump, signal, and idler) of spatial modes. The beam quality factors were measured in the heralded mode to be less that 1.03 for both modes and horizontal and vertical spatial scans.

UULM: In [CSV1-10] the partners at UULM already proposed an experimentally realizable optical network scheme for the demonstration of the basic mechanisms underlying noise-assisted transport in biological systems. Now, UULM has applied theoretically open-loop quantum optimal control techniques to provide methods for the verification of various quantum coherent transport mechanisms in natural and artificial light-harvesting complexes under realistic experimental constraints. In [CMC1-11] they have demonstrated that optimally shaped laser pulses allow to faithfully prepare the photosystem in specified initial states (such as localized excitation or coherent superposition, i.e. propagating and non-propagating states) and to probe efficiently the dynamics. These results provide a path towards the discrimination of the different transport pathways and to the characterization of environmental properties, enhancing our understanding of the role that coherent processes may play in biological complexes.

FUB/UP: The partners at FUB/UP already identified and experimentally implemented at IPSAS a tunable linear optical phase gate operating at the theoretically maximum success probability [LCS1-10]. Now, they have theoretically studied quantum simulations and have supported an experiment with ultra-cold atoms in optical lattices simulating Bose-Hubbard dynamics. For short times, one can certify the correctness of the quantum simulation of strongly correlated dynamics classically efficiently essentially up to machine precision. For long times, the quantum experiment presumably outperforms the classical simulation by far, and one can answer relevant questions on equilibration and thermalization based on the quantum simulation, not on the numerical classical simulation, see Trotzky et al., Nature Physics, in press (2012) [TCF1-11].

UCPH: Different settings for state transfer of the quantum state of one atomic ensemble (input) to another one (target) were investigated. A teleportation protocol for two Cesium ensembles, situated in a magnetic field with parallel macroscopic spins has been developed. A light beam which is detuned by around 1GHz from the D2 line is directed through both atomic ensembles. After a measurement on the outgoing light, the measurement results are fed back to the target ensemble via a magnetic RF pulse. First experimental results show a good agreement between the predicted optimal settings for the duration and strength of the light pulse. Last year UCPH reported on using a Gaussian measurement (homodyne detection on the output of a Mach-Zehnder Interferometer) to produce a spin-squeezed state, which allowed them to demonstrate an atomic clock with a precision better than the projection noise limit (see M1.2.1 and D1.2.4). - UCPH then focused on creating non-Gaussian atomic states. Using a weak optical light pulse, they weakly drive atoms from one long-lived hyperfine state into the other level. The success probability is kept so low, that a forward scattered photon with a frequency that is bigger than the excitation pulse by the hyperfine splitting energy corresponding to 9GHz can be used to herald a single transfer. This event signifies the preparation of a single excitation of a collective zero-transverse-momentum spin wave in the atomic ensemble. Using a subsequent microwave pi-pulse prepares a collective entangled state with a non-Gaussian population-difference between the two hyperfine levels.

There have been minor deviations from the workplan in WP3.4: to speed up achievement of overdue M3.4.5 UCPH purchased lasers, fiber splitters etc. to operate the nanofiber-setup independently from their old experiment. This way the two experiments can be run in parallel by the 2 new PhD students that joined UCPH recently. Moreover, in the atomic clock experiment UCPH originally planned to concentrate efforts on the ability to perform a rigorous quantum state analysis and on the preparation of non-Gaussian states. Due to the large number of atoms (which improve the sensitivity of the system when used as a sensor) technical noise affects the capability to analyze and to prepare complex quantum states such as Fock states which, for example, would allow to implement proposals originating from WP1.1. Instead UCPH focused on using squeezed states to implement entanglement enhanced metrology in a neutral atom clock, which already now led to successful achievement of M1.2.1 and the delivery of D1.2.4

WP3.4 Highlight

The two results on the experimental realization of blind quantum computing by partner OEAW, Science 335, 303 (2012), [BKB1-12], and the realization of a Bose-Hubbard quantum dynamical simulator by the experimental group at the Max Planck institute for quantum optics in collaboration with partner FUB, published in Nature Physics (2012), [TCF1-11], have been selected as highlights of the past reporting period by the workpackage leader.

WP3.5: Entanglement-based quantum information processing

The main objectives in this WP are studies of basic entanglement primitives, the foundations of entanglement-based quantum information processing, and exploration of new quantum computational models. Most of the tasks are open-ended, with emphasis on novel unknown solutions. Within this broad set of problems we have shown/studied the following in the last reporting period:

- Quantization of Markov chain Monte Carlo. As a result we receive faster methods of estimation, and related results.

- Translations to adiabatic quantum computing (esp., a natural adiabatic version of a quantum walk algorithm).

- Noisy one-way quantum computations (esp. the role of correlations).

- We have shown that applying quantum algorithmic approaches to classical problems directly does not always produce speedups.

-In [TMS1-11] we have shown that adding a requirement of a continuous reversible transformations between any pure states in a theory whose local state space is quantum mechanical, forces the joint state space to be quantum mechanical.

- In [AS1-11] The principle of Information causality has been investigated from both a probabilistic and entropic standpoint.

- Hidden influences lead to signalling: correlations that violate Bell inequalities, could in principle be explained by model in which influences travel faster than light. We show in J. D. Bancal et al., arXiv:1110.3795, that any such model that reproduces quantum correlations, will also predict in certain situations correlations that can be exploited for superluminal communication. (Highlight)

- Hamiltonian quantum cellular automata in 2D.

- Uselessness for an oracle model with internal randomness (the oracle acts on the target with a permutation which is selected according to internal random coins. We show new exponential quantum speedups which may be obtained over classical algorithms in this oracle model. We describe several problems which are impossible to solve classically but can be solved by a quantum algorithm using a single query, etc.).

- We present several families of total boolean functions which have exact quantum query complexity which is a constant multiple (between 1/2 and 2/3) of their classical query complexity, and show that optimal quantum algorithms for these functions cannot be obtained by simply computing parities of pairs of bits.

- Quantifying correlations that may be not classically simulable because of their quantumness.

- Methods of estimating pre and post-selected ensembles.

- We have studied `hyperbits' as generalizations of quantum bits: their state spaces are d-dimensional Euclidean balls (d=3 is the Bloch sphere of qubits). With these we have proven a stronger form of the Information Causality inequality for messages of 1 bit; it encapsulates not only the known information limitations of quantum theory but also complementarity.

- We have introduced a quantity analogous to entanglement monotone for NS boxes called anti-robustness. It is found that it does not decrease under locality preserving operations. We show that if broadcasting were possible, anti-robustness would increase under broadcasting (thus broadcasting of
any 2x2 non-local box is not possible).

- We have studied thermodynamics by quantum information methods, using e.g. analogies with entanglement. Important problems include: the efficiency of very small refrigerators; how do close quantum many-body system come to equilibrium, when do they apparently thermalize; fundamental limitations for thermodynamics in micro-regime.

- Cooling opto-mechanical systems with incoherent, hot laser light, constituting a small thermal machine.

- Quantum complexity (estimating the computational hardness (or easiness) of quantum tasks).

- A dissipative Church Turing Theorem.

- How fast one can approximate a random unitary by applying random gates?

Specific results already published or put as e-prints:

*Tight Bell inequalities with no quantum violation from qubit unextendible product bases [AFK1-12].*Investigation of the relation between unextendible product bases (UPB) and Bell inequalities found recently in [R. Augusiak et al., Phys. Rev. Lett. 107, 070401 (2011)]. It is shown that: if a set of mutually orthogonal product vectors can be completed to a full basis, then the associated Bell inequality is trivial. This implies that the relevant Bell inequalities that arise from the construction all come from UPBs, which adds additional weight to the significance of UPBs for Bell inequalities. New examples of tight Bell inequalities with no quantum violation constructed from UPBs are given.
Fully nonlocal quantum correlations [AGA1-11].Quantum mechanics is not saturating the no-signaling principle. However, there exist quantum correlations that exhibit "maximal nonlocality": they are as nonlocal as any non-signaling correlations and thus have a local content, quantified by the fraction *pL* of events admitting a local description, equal to zero. Exploiting the link between the Kochen-Specker and Bell's theorems, from every Kochen-Specker proof, Bell inequalities maximally violated by quantum correlations are given. These Bell inequalities lead to experimental bounds on the local content of quantum correlations which are significantly better than those based on other constructions. An experimental demonstration of a Bell test originating from the Peres-Mermin Kochen-Specker proof, providing an upper bound on the local content $pL \approx 0.22$ has been performed.

Information causality from an entropic and a probabilistic perspective [AS1-11].Despite its clear physical motivation, information causality principle is formulated in terms of a rather specialized game and figure of merit. Different perspectives on information causality are explored, discussing the probability of success as the figure of merit, a relation between information causality and the non-local `inner-product game', and the derivation of a quadratic bound for these games. An entropic formulation of information causality is put forward, with which one can obtain the same results, arguably in a simpler fashion.

Bell inequalities with no quantum violation and unextendible product bases [ASH1-11].Violation of Bell inequalities is implies that quantum mechanics can outperform classical physics at tasks associated with such Bell inequalities. There exist situations in which this is not the case. An intriguing class of bound entangled states, constructed from unextendable product bases (UPBs) can be associated with a wide family of tasks, for which (i) quantum correlations do not outperform the classical ones but (ii) there exist supraquantum nonsignalling correlations that do provide an advantage.

Quantum locking of classical correlations and quantum discord of classical-quantum states [BAC1-11].A locking protocol between two parties: Alice gives an encrypted classical message to Bob which she does not want Bob to be able to read until she gives him the key. If Alice is using classical resources, and she wants to approach unconditional security, then the key and the message must have comparable sizes. But if Alice prepares a quantum state, the size of the key can be comparatively negligible. This is quantum locking. Entanglement does not play a role in it. We show that the quantum discord quantifies the advantage of the quantum protocol over the corresponding classical one for any classical-quantum state.

Frustrated Quantum Spin Models with Cold Coulomb Crystals[BAS1-11].The geometry of a zig-zag cold-ion crystal in a linear trap is used to propose the quantum simulation of a paradigmatic model of long-ranged magnetic frustration. Such a quantum simulation would clarify the complex features of a rich phase diagram that presents ferromagnetic, dimerized antiferromagnetic, paramagnetic, and floating phases, together with previously unnoticed features that are hard to assess by numerics. A detailed analysis is given of the experimental feasibility, and supporting numerical evidence on the basis of realistic parameters in current ion-trap technology.

Can apparent superluminal neutrino speeds be explained as a quantum weak measurement?[BBP1-11] A negative answer is given.

Prisoners of their own device: Trojan attacks on device-independent quantum cryptography [BCK1-11].
Device-independent cryptographic schemes aim to guarantee security to users based only on the output statistics of any components used, and without the need to verify their internal functionality. Since this would protect users against untrustworthy or incompetent manufacturers, sabotage or device degradation, this idea has excited much interest, and many device-independent schemes have been proposed. A critical weakness of device-independent quantum cryptography for tasks, such as key distribution, that rely on public communication between secure laboratories has been shown. Untrusted devices may record their inputs and outputs and reveal encoded information about them in their outputs during later runs. Reusing devices compromises the security of a protocol and risks leaking secret data. Possible solutions include securely destroying used devices or isolating them until previously generated data need no longer be kept secret. However, such solutions are costly and impose severe constraints on the practicality of many device-independent quantum cryptographic schemes.
Bound non-locality and activation [BCS1-11].Non-locality distillation is investigated using measures of non-locality based on the Elitzur-Popescu-Rohrlich decomposition. For a certain number of copies of a given non-local correlation, two quantities of interest are defined: (i) the non-local cost, and (ii) the distillable non-locality. It is found that there exist correlations whose distillable non-locality is strictly smaller than their non-local cost. Thus non-locality displays a form of irreversibility which we term bound non-locality. Non-local distillability can be activated.

Quantum Theory and Beyond: Is Entanglement Special?[BD1-11].Quantum theory makes the most accurate empirical predictions and yet it lacks simple, comprehensible physical principles from which the theory can be uniquely derived. A broad class of probabilistic theories exist which all share some features with quantum theory, such as probabilistic predictions for individual outcomes (indeterminism), the impossibility of information transfer faster than speed of light (no-signalling) or the impossibility of copying of unknown states (no-cloning). A vast majority of attempts to find physical principles behind quantum theory either fall short of deriving the theory uniquely from the principles or are based on abstract mathematical assumptions that require themselves a more conclusive physical motivation. The Q-ESSENCE result is: classical probability theory and quantum theory can be reconstructed from three reasonable axioms: (1) (Information capacity) All systems with information carrying capacity of one bit are equivalent. (2) (Locality) The state of a composite system is completely determined by measurements on its subsystems. (3) (Reversibility). Between any two pure states there exists a reversible transformation. If one requires the transformation from the last axiom to be continuous, one separates quantum theory from the classical probabilistic one. A remarkable result following from the reconstruction is that no probability theory other than quantum theory can exhibit entanglement without contradicting one or more axioms.

The Resource Theory of Quantum States Out of Thermal Equilibrium[BHO1-11].The ideas of thermodynamics have proved fruitful in the setting of quantum information theory, in particular the notion that when the allowed transformations of a system are restricted, certain states of the system become useful resources with which one can prepare previously inaccessible states. The theory of entanglement is perhaps the best-known and most well-understood resource theory in this sense. The basic questions of thermodynamics using the formalism of resource theories developed in quantum information theory were investigated. It was shown that the free energy of thermodynamics emerges naturally from the resource theory of energy-preserving transformations. Specifically, the free energy quantifies the amount of useful work which can be extracted from asymptotically-many copies of a quantum system when using only reversible energy-preserving transformations and a thermal bath at fixed temperature. The free energy also quantifies the rate at which resource states can be reversibly interconverted asymptotically, provided that a sublinear amount of coherent superposition over energy levels is available, a situation analogous to the sublinear amount of classical communication required for entanglement dilution.

Electron-Mediated Nuclear-Spin Interactions Between Distant NV Centers[BJP1-11]. A scheme has been given enabling controlled quantum coherent interactions between separated nitrogen-vacancy centers in diamond in the presence of strong magnetic fluctuations. The proposed scheme couples nuclear qubits

employing the magnetic dipole-dipole interaction between the electron spins and, crucially, benefits from the suppression of the effect of environmental magnetic field fluctuations thanks to a strong microwave driving. This scheme provides a basic building block for a full-scale quantum information processor or quantum simulator based on solid-state technology.

Virtual qubits, virtual temperatures, and the foundations of thermodynamics[BLP1-11].Thermal machines can be understood from the perspective of 'virtual qubits' at 'virtual temperatures': The relevant way to view the two heat baths which drive a thermal machine is as a composite system. Virtual qubits are two-level subsystems of this composite, and their virtual temperatures can take on any value, positive or negative. Thermal machines act upon an external system by placing it in thermal contact with a well-selected range of virtual qubits and temperatures. These claims are demonstrated by studying the smallest thermal machines. This perspective provides a powerful way to view thermodynamics, by analyzing a number of phenomena. This includes approaching Carnot efficiency (where we find that all machines do so essentially by becoming equivalent to the smallest thermal machines), entropy production in irreversible machines, and a way to view work in terms of negative temperature and population inversion. An idea of "genuine" thermal machines is introduced, and a concept of "strength" of work is investigated.

"Quantum nonlocality" based on finite-speed causal influences leads to superluminal signalling[BPA1-12]. Experimental violation of Bell inequalities using spacelike separated measurements precludes the explanation of quantum correlations through causal influences propagating at subluminal speed. Yet, it is always possible, in principle, to explain such violations with models based on hidden influences propagating at a finite speed v>c, provided v is large enough. It is shown that for any finite speed v>c, such models predict correlations that can be exploited for faster-than-light communication. This superluminal communication does not require access to any hidden physical quantities, but only the manipulation of measurement devices at the level of our present-day description of quantum experiments. Hence, assuming the impossibility of using quantum non-locality for superluminal communication, any possible explanation of quantum correlations in term of finite-speed influences is excluded.[This publication is considered to be a "Research Highlight"]

Robust Trapped-Ion Quantum Logic Gates by Microwave Dynamical Decoupling[BSP1-11].A hybrid scheme that combines laser-driven phonon-mediated quantum logic gates in trapped ions with the benefits of microwave dynamical decoupling. It is demonstrated theoretically that a strong driving of the qubit decouples it from the external magnetic noise, and thus enhances the fidelity of two-qubit quantum gates. Moreover, the scheme does not require ground-state cooling, is inherently robust to undesired ac-Stark shifts, and simplifies previous gate schemes thus decreasing the effort in their realization.

Feasibility of loophole-free nonlocality tests with a single photon [CB1-11]. Recently much interest has been directed towards designing setups that achieve realistic loss thresholds for decisive tests of local realism, in particular in the optical regime. The feasibility of such Bell tests based on a W-state shared between multiple parties, which can be realized for example by a single photon shared between spatial modes, is analyzed. A general error model to obtain thresholds on the efficiencies required to violate local realism is given. Two concrete optical measurement schemes are studied.

An entropic approach to local realism and noncontextuality [CF1-12].For any Bell locality scenario or marginal scenario, the joint Shannon entropies of local (or noncontextual) probability distributions define a convex cone for which the non-trivial facets are tight entropic Bell (noncontextuality) inequalities. This entropic approach is explored: tight entropic inequalities for various scenarios are given. One advantage of entropic inequalities is that they easily adapt to situations like bilocality scenarios, which have additional independence requirements that are non-linear on the level of probabilities, but linear on the level of entropies. Another advantage is that, despite the nonlinearity, taking detection inefficiencies into account turns out to be very simple. When joint measurements are conducted by a single detector only, the detector efficiency for witnessing quantum contextuality can be arbitrarily low.

Robust dynamical decoupling with concatenated continuous driving [CJP1-11].The loss of coherence is one of the main obstacles for the implementation of quantum information processing. The concept of

concatenated continuous dynamical decoupling was put forward, which can overcome not only external noise but also fluctuations in driving fields that implement the decoupling sequences and thus holds the potential for achieving relaxation limited coherence times. The proposed scheme can be applied to a wide variety of physical systems including, trapped atoms and ions, quantum dots and nitrogen-vacancy (NV) centers in diamond, and may be combined with other quantum technologies challenges such as quantum sensing or quantum information processing.

Infinitely many constrained inequalities for the von Neumann entropy [CLW1-11].Infinitely many new, constrained inequalities for the von Neumann entropy are given. They are independent of each other and the known inequalities obeyed by the von Neumann entropy (basically strong subadditivity). The new inequalities were proved originally by Makarychev et al. [Commun. Inf. Syst.**2**, 147(2002)] for the Shannon entropy, using properties of probability distributions. The new approach extends the proof of the inequalities to the quantum domain, and includes their independence for the quantum and also the classical cases.

Noisy One-Way Quantum Computations: The Role of Correlations [CM1-11].A scheme to evaluate computation fidelities within the one-way model is developed and explored to understand the role of correlations in the quality of noisy quantum computations. The formalism is applied to many computation instances, and unveils that a higher amount of entanglement in the noisy resource state does not necessarily imply a better computation.

Highly Entangled States With Almost No Secrecy [CSW2-10].The relation between entanglement and secrecy was studied, by providing the first example of a quantum state that is highly entangled, but from which, nevertheless, almost no secrecy can be extracted. Two bounds on the bipartite entanglement of the totally antisymmetric state in dimension d x d are given. It is shown the amount of secrecy that can be extracted from the state is low, and that the state is highly entangled in the sense that we need a large amount of singlets to create the state: entanglement cost is larger than a constant, independent of d. Representation theory, linear programming and the entanglement measure known as squashed entanglement were used. The findings also clarify the relation between the squashed entanglement and the relative entropy of entanglement.

Quantum measurement occurrence is undecidable [EMG1-12]. The halting problem is undecidable. Formally, an undecidable problem is a decision problem for which one cannot construct a single algorithm that will always provide a correct answer in finite time. It is shown that simple problems in quantum measurement theory can be undecidable even if their classical analogues are decidable. Undecidability appears as a genuine quantum property. The problem which was considered is determination whether sequentially used identical Stern-Gerlach-type measurement devices, giving rise to a tree of possible outcomes, have outcomes that never occur. Implications for measurement-based quantum computing and studies of quantum many-body models are given. A plethora of problems may indeed be undecidable.

Entropic Inequalities and the Marginal Problem [FC1-11].The marginal problem asks when a given family of marginal distributions for some set of random variables can be extended to a joint distribution of these variables. It is shown that the existence of a joint distribution imposes non-trivial conditions already on the level of Shannon entropies of the given marginals. For every marginal problem, a list of such conditions in terms of Shannon-type entropic inequalities can be calculated by Fourier-Motzkin elimination. A software interface to a Fourier-Motzkin solver for doing so has been developed. For the case that the hypergraph of given marginals is a cycle, a complete analytic solution to the problem of classifying all tight entropic inequalities is given. It is used to obtain a bound on the decay of correlations in stochastic processes. Shannon-type inequalities for differential entropies are not relevant for the continuous-variable marginal problem; non-Shannon-type inequalities are, both in the discrete and in the continuous case. The framework easily adapts to situations where one has additional (conditional) independence requirements on the joint distribution, as in the case of graphical models.

Local two-qubit entanglement-annihilating channels[FRZ1-12].The problem of the robustness of entanglement of bipartite systems (qubits) interacting with dynamically independent environments was addressed. The focus was on characterization of so-called local entanglement-annihilating (EA) two-qubit

channels, which set the maximum permissible noise level allowing us to perform entanglement-enabled experiments. The differences, but also the subtle relations, between entanglement-breaking and local EA channels have been emphasized. A detailed characterization of the latter ones has been provided for a variety of channels including depolarizing, unital, (generalized) amplitude-damping, and extremal channels. The convexity structure of local EA qubit channels is studied, and a concept of EA duality is introduced.

Quantum correlations require multipartite information principles [GWA1-11].Identifying which correlations among distant observers are possible within our current description of Nature, based on quantum mechanics, is a fundamental problem in Physics. Recently, information concepts have been proposed as the key ingredient to characterize the set of quantum correlations. Novel information principles, such as, information causality or non-trivial communication complexity, have been introduced in this context and successfully applied to some concrete scenarios. A fundamental limitation of this approach was shown: no principle based on bipartite information concepts is able to single out the set of quantum correlations for an arbitrary number of parties. The results reflect the intricate structure of quantum correlations and imply that new and intrinsically multipartite information concepts are needed for their full understanding.

An operational framework for "nonlocality"[GWA1-12]. Due to the importance of entanglement for quantum information purposes, a framework has been developed for its characterization and quantification as a resource based on the following operational principle: entanglement among *N*parties cannot be created by local operations and classical communication, even when *N*-1 parties collaborate. More recently, "nonlocality" has been identified as another resource, alternative to entanglement and necessary for device-independent quantum information protocols. An operational framework for "nonlocality" based on a similar principle is introduced: "nonlocality" among *N*parties cannot be created by local operations and allowed classical communication even when *N*-1parties collaborate. It is shown that the standard definition of multipartite nonlocality, due to Svetlichny, is inconsistent with this operational approach: according to it, genuine tripartite nonlocality could be created by two collaborating parties. Alternative definitions for which consistency is recovered were discussed.

Renormalization algorithm with graph enhancement [HKH1-11].Applications of the renormalization algorithm with graph enhancement (RAGE). The analysis extends the algorithms and applications given for approaches based on matrix product states introduced in [Phys. Rev. A 79, 022317 (2009)] to other tensor-network states such as the tensor tree states (TTS) and projected entangled pair states (PEPS). The investigation covers the suitability of the bare TTS to describe ground states, showing that the description of certain graph states and condensed matter models improves. Graph-enhanced tensor-network states are analyzed, demonstrating that in some cases (disturbed graph states and for certain quantum circuits) the combination of weighted graph states with tensor tree states can greatly improve the accuracy of the description of ground states and time evolved states. Delineating the boundary of the classically efficiently simulable states of quantum many-body systems has been commented.

Fundamental limitations for quantum and nano thermodynamics[HO1-11].The relationship between thermodynamics and statistical physics is valid in the thermodynamic limit when the number of particles involved becomes very large. Thermodynamics in the opposite regime at both the nano scale, and when quantum effects become important was studied. Applying results from quantum information theory it was possible to construct a theory of thermodynamics in these extreme limits. In the quantum regime, one can find that the standard free energy no longer determines the amount of work which can be extracted from a resource, nor which state transitions can occur spontaneously. Criteria for thermodynamical state transitions are derived. Two free energies are found: one which determines the amount of work which can be extracted from a small system in contact with a heat bath, and the other which quantifies the reverse process. They imply that generically, there are additional constraints which govern spontaneous thermodynamical processes. There are fundamental limitations on work extraction from nonequilibrium states, due to both finite size effects which are present at the nano scale, as well as quantum coherences. This implies that thermodynamical transitions are generically irreversible at this scale. The degree to which this is so is quantified, and the condition for reversibility to hold is given. There are particular equilibrium processes which approach the ideal efficiency, provided that certain special conditions are met.

Non-Markovianity assisted Steady State Entanglement[HPR1-11].The dependence of steady state entanglement in a dimer system with a coherent exchange interaction and subject to local dephasing on the degree of Markovianity of the system-environment interaction has been analyzed. Non-Markovianity of the system-environment interaction is an essential resource that may support the formation of steady state entanglement whereas purely Markovian dynamics governed by Lindblad master equations results in separable steady states. This result illustrates possible mechanisms leading to long lived entanglement in purely decohering local environments. A feasible experimental demonstration of this non-Markovianity assisted steady state entanglement using a system of trapped ions is presented.

No-broadcasting of non-signaling boxes via operations which transform local boxes into local ones [JGH1-11].Families of probability distributions satisfying non-signaling condition, called nonsignalling boxes and consider class of operations that transform local boxes into local ones (the one that admit LHV model). Any operation from this class cannot broadcast a nonlocal box in 2x2 case. A function called anti-Robustness cannot decrease under these operations. The proof reduces to showing that anti-Robustness would decrease after broadcasting.

QCMA with one-sided error equals QCMA with two-sided error [JN1-12].QCMA is the set of decision problems such that if the answer is yes, there exists a classical bit string, or proof, that can be efficiently verified by a quantum computer. The verifier is allowed a small probability of rejecting a valid proof or accepting invalid proofs. For all problems in QCMA, the acceptance probability for valid proofs can be amplified to one, thus QCMA with one-sided error is equal to QCMA. This is a quantum analog to the result of Zachos and Furer, that the classical complexity class MA with one sided error is the same as MA with two-sided error. Because a quantum oracle separating QCMA and QCMA with one sided error is known, the result provides an example of a quantumly non-relativizing proof.

Unconditionally Secure Bit Commitment by Transmitting Measurement Outcomes [K1-11].A new unconditionally secure bit commitment scheme based on Minkowski causality and the properties of quantum information. The receiving party sends a number of randomly chosen BB84 qubits to the committer at a given point in space-time. The committer carries out measurements in one of the two BB84 bases, depending on the committed bit value, and transmits the outcomes securely at light speed in opposite directions to remote agents. These agents unveil the bit by returning the outcomes to adjacent agents of the receiver. The security proofs rely only on simple properties of quantum information and the impossibility of superluminal signaling.

Dynamical features of interference phenomena in the presence of entanglement[KAN1-11].A strongly interacting, and entangling, heavy non recoiling external particle effects a significant change of the environment. Described locally, the corresponding entanglement event is a generalized electric Aharonov-Bohm effect, which differs from the original one in a crucial way. A gedanken interference experiment was proposed. The predicted shift of the interference pattern is due to a self-induced or private potential difference experienced while the particle is in vacuum. All nontrivial Born-Oppenheimer potentials are private potentials. The Born-Oppenheimer approximation to interference states is applied. Using the approach, the relative phase of the external heavy particle is calculated, as well as its uncertainty throughout an interference experiment or entanglement event.

Quantum Walks on Necklaces and Mixing [KN1-12]. An analysis of continuous-time quantum walks on necklace graphs - cyclical graphs consisting of many copies of a smaller graph (pearl). Using a Bloch-type ansatz for the eigenfunctions, one can block-diagonalize the Hamiltonian, reducing the effective size of the problem to the size of a single pearl. One can then present a general approach for showing that the mixing time scales (with growing size of the necklace) similarly to that of a simple walk on a cycle. Results for mixing on several necklace graphs were presented.

Correlation Complementarity Yields Bell Monogamy Relations [KPR1-10].The complementarity relation between dichotomic observables leads to the monogamy of Bell inequality violations. One can introduce a simple condition for the squares of expectation values of complementary observables that is satisfied by all physical states. This condition is used to study multi-qubit correlation inequalities involving two settings per

observer. In contrast with the two-qubit case a rich structure of possible violation patterns was shown to exist in the multipartite scenario.

Opto- and electro-mechanical entanglement improved by modulation [ME1-12].One of the main milestones in the study of opto- and electro-mechanical systems is to certify entanglement between a mechanical resonator and an optical or microwave mode of a cavity field. It is shown how a suitable time-periodic modulation can help to achieve large degrees of entanglement, building upon the framework introduced in [Phys. Rev. Lett. 103, 213603 (2009)]. It is demonstrated that with suitable driving, the maximum degree of entanglement can be significantly enhanced, in a way exhibiting a non-trivial dependence on the specifics of the modulation. Such time-dependent driving might help experimentally achieving entangled mechanical systems also in situations when quantum correlations are otherwise suppressed by a thermal noise.

On exact quantum query complexity [MJM1-11]. Several families of total boolean functions which have exact quantum query complexity which is a constant multiple (between 1/2 and 2/3) of their classical query complexity are presented. Optimal quantum algorithms for these functions cannot be obtained by simply computing parities of pairs of bits. Also characterization is given of the model of nonadaptive exact quantum query complexity in terms of coding theory and completely characterize the query complexity of symmetric boolean functions in this context. These results were originally inspired by numerically solving the semidefinite programs characterizing quantum query complexity for small problem sizes. Numerical results are obtained giving the optimal success probabilities achievable by quantum algorithms computing all boolean functions on up to 4 bits, and all symmetric boolean functions on up to 6 bits.

Estimating pre and post-selected ensembles [MP1-11].In analogy with the usual quantum state-estimation problem, one can introduce the problem of state estimation for a pre- and postselected ensemble. The problem has fundamental physical significance since, as argued by Y. Aharonov and collaborators, pre- and postselected ensembles are the most basic quantum ensembles. Two new features are shown to appear: (1) information is flowing to the measuring device both from the past and from the future; (2) because of the postselection, certain measurement outcomes can be forced never to occur. Due to these features, state estimation in such ensembles is dramatically different from the case of ordinary, preselected-only ensembles. A general theoretical framework for studying this problem is developed and illustrated with several examples. General theorems are constructed establishing that information flowing from the future is closely related to, and in some cases equivalent to, the complex conjugate information flowing from the past. The approach is illustrated with examples involving covariant measurements on spin-1/2 particles. All state-estimation problems can be extended to the pre- and postselected situation. The work thus lays the foundations of a much more general theory of quantum state estimation.This publication is considered to be a "Research Highlight"; Quantum state estimation is an extremely important issue in quantum information in particular and in quantum mechanics in general. Indeed, it addresses one of the most fundamental questions about a quantum system one can imagine: how to find out what its state is. While classically there is no problem in principle to identify what the state of a system is - just perform an appropriate measurement, in quantum mechanics the situation is dramatically different: Each measurement gives only some partial answer about the state while at the same time it disturbs it irreversibly. hence one need an infinite number of systems, all prepared in the same state in order to be able to identify what the state is. For a finite number of systems one can only find partial information; How much this partial information is, and how to get most of it is the core of the problem. Entanglement is a necessary ingredient. Here we discuss for the first time the issue of state estimation for quantum systems which are pre- and post-selected, i.e.systems whose state is determined both by their past (i.e. initial conditions) and future (i.e. final conditions).

The complexity of energy eigenstates as a mechanism for equilibration [MRA1-11].Understanding the mechanisms responsible for the equilibration of isolated quantum many-body systems is a longstanding open problem. Some of them have been identified, but a complete picture is still missing. A link between equilibration and the complexity of the Hamiltonian's eigenvectors is obtained. Hamiltonians with generic eigenvectors equilibrate, and provide a simple closed formula for the equilibration time-scale. This allows one to obtain the equilibration time-scale for random Hamiltonians. One can also attempt to quantify the complexity of the energy eigenvectors, by considering Hamiltonians whose diagonalizing unitary is a

quantum circuit. When the circuit size is quadratic or larger equilibration is expected, whereas when it is linear or smaller equilibration is not expected.

Fault tolerant Quantum Information Processing with Holographic control [PBT1-11 and PBT2-12].A fault-tolerant semi-global control strategy for universal quantum computers.*N*-dimensional array of qubits where only (*N*-1)-dimensional addressing resolution is available is compatible with fault-tolerant universal quantum computation. Measurements and individual control of qubits are required only at the boundaries of the fault-tolerant computer, i.e. holographic fault-tolerant quantum computation. The model alleviates the heavy physical conditions on current qubit candidates imposed by addressability requirements and represents an option to improve their scalability.

All non-classical correlations can be activated into distillable entanglement [PGA2-11].A protocol is given, in which general non-classical multipartite correlations produce a physically relevant effect, leading to the creation of bipartite entanglement. In particular, the relative entropy of quantumness, which measures all non-classical correlations among subsystems of a quantum system, is equivalent to and can be operationally interpreted as the minimum distillable entanglement generated between the system and local ancillae in our protocol. The key role plays state mixedness in maximizing non-classicality: mixed entangled states can be arbitrarily more non-classical than separable and pure entangled states

From Qubits to Hyperbits [PW2-11].A study 'hyperbits' as generalizations of quantum bits. Their state spaces are *d*-dimensional Euclidean balls (*d*=3 is the Bloch sphere of qubits), while they can be subjected to binary measurements corresponding to any direction in d-dimensional Euclidean space. Sending and using one hyperbit from one player to another one is in a certain sense equivalent to sharing arbitrary entanglement and sending 1 classical bit - at least in the context of certain non-local games. A fundamental identity for hyperbits exists, limiting their information processing capabilities. As a consequence, a stronger form of the Information Causality inequality for messages of 1 bit can be put forward; it encapsulates not only the known information limitations of quantum theory but also complementarity.

Thermalization in nature and on a quantum computer [RGE1-11]. It is shown how Gibbs or thermal states appear dynamically in closed quantum many-body systems, by completing the program of dynamical typicality and by introducing a novel general perturbation theorem that is robust under the thermodynamic limit, rigorously capturing the intuition of a meaningful weak coupling limit. A fully general quantum algorithm for preparing Gibbs states on a quantum computer with a certified runtime is given, including full error estimates, complementing quantum Metropolis algorithms which are expected to be efficient but have no known runtime estimate.

Uselessness for an Oracle Model with Internal Randomness [RH1-11].A generalization of the standard oracle model in which the oracle acts on the target with a permutation which is selected according to internal random coins. One can show new exponential quantum speedups which may be obtained over classical algorithms in this oracle model. Several problems which are impossible to solve classically but can be solved by a quantum algorithm using a single query are given. Such infinity-vs-one separations between classical and quantum query complexities can be constructed from any separation between classical and quantum query complexities (in the unbounded-error regime). Conditions are given which determine when oracle problems - either in the standard model, or in any of the generalizations we consider - cannot be solved with success probability better than random guessing would achieve. In the oracle model with internal randomness where the goal is to gain any nonzero advantage over guessing, one can prove (roughly speaking) that (k) quantum queries are equivalent in power to (2k) classical queries, thus extending results of Meyer and Pommersheim, and Montanaro, Nishimura and Raymond.

On the efficiency of very small refrigerators [SBL1-11].It has been investigated whether size imposes a fundamental constraint on the efficiency of small thermal machines. A model of a small self-contained refrigerator consisting of three qubits has been analyzed. This system can reach the Carnot efficiency. Thus, there exists no complementarity between size and efficiency.

Filtering of the absolute value of photon-number difference for two-mode macroscopic quantum states[STS1-11].A filter that selects two-mode high number Fock states whose photon-number difference exceeds a certain value is suggested. Such a filter is important for the engineering of macroscopic quantum states of light and for the control of bright light beams. It improves distinguishability of some states but preserves macroscopic superpositions. An operational implementation of such a filter is sketched.

Deriving quantum theory from its local structure and reversibility[TMS1-11]. The investigation covers the class of physical theories with the same local structure as quantum theory, but a potentially different global structure. It has previously been shown that any bipartite correlations generated by such a theory must be simulable in quantum theory, but that this does not hold for tripartite correlations. It was investigated whether imposing an additional constraint on this space of theories - that of dynamical reversibility - will allow us to recover the global quantum structure. In the particular case, in which the local systems are identical qubits, it is shown that any theory admitting at least one continuous reversible interaction must be identical to quantum theory.

Homogenization of Bell inequalities [W1-11].A technique, which we call homogenization, is applied to transform CH-type Bell inequalities, which contain lower order correlations, into CHSH-type Bell inequalities, which are defined for highest order correlation functions. A homogenization leads to inequalities involving more settings, that is a choice of one more observable is possible for each party. This technique preserves the tightness of Bell inequalities: a homogenization of a tight CH-type Bell inequality is still a tight CHSH-type Bell inequality. As an example are obtained 3 x 3 CHSH-type Bell inequalities by homogenization of 2 x 2 x 2 CH-type Bell inequalities derived by Sliwa in [Phys. Lett. A 317, 165 (2003)].

Mappings of open quantum systems onto chain representations and Markovian embeddings[WGC1-11]. A sequence of measures whose corresponding Jacobi matrices have special properties and a general mapping of an open quantum system onto 1D semi infinite chains with only nearest neighbour interactions is given. One can use the sequence of measures and the properties of the Jacobi matrices to derive an expression for the spectral density describing the open quantum system when an increasing number of degrees of freedom in the environment are embedded into the system. Convergence theorems for these residual spectral densities are derived.

There have been no deviations from the workplan in WP3.5 as revised in the second amendment to the Grant Agreement. The consortium achieved all critical objectives on schedule.

WP3.5 Highlight
Two highlights have been selected. These are, by partners UNIGE, ICFO, and FUB,

- "Quantum nonlocality based on finite-speed causal influences leads to superluminal signalling", J.-D. Bancal, S. Pironio, A. Acin, Y.-C. Liang, V. Scarani, and N. Gisin, arXiv:1110.3795 [BPA1-12]
- "A dissipative quantum Church-Turing theorem", M. Kliesch, T. Barthel, C. Gogolin, M. Kastoryano, J. Eisert, Phys. Rev. Lett. **107**, 120501 (2011) [KBG1-11], see also discussion in the Physics viewpoint "Quantum simulation hits the open road", Physics **4**, 72 (2011).

3.3 Deliverables and milestones tables

TABLE 1. DELIVERABLES

Del. no.	Deliverable name	Version	WP no.	Lead beneficiary	Nature	Dissemination level[1]	Delivery date from Annex I (proj month)	Actual / Forecast delivery date Dd/mm/yyyy	Status No submitted/Submitted	Contractual Yes/No	Comments
1.1.1	Report on optimal phase estimation with diffusion like a priori phase distribution	21.1	1.1	UWAW	R	PU	12	31/01/2011 (accepted in 1st review)	Yes	Yes	We have studied the problem of quantum phase estimation in a situation where partial a priori knowledge on the estimated phase is available. Until now only extreme cases of this problem have been considered i.e. no a priori knowledge (global approach) and almost perfect knowledge (fisher information based – local approach). We have solved the problem for arbitrary a priori knowledge and derived an explicit formulas both for the optimal precision and the structure of the optimal estimation strategies. In particular we have applied the procedure to the natural choice of a priori phase distribution resulting from a diffusion on a circle. We have compared the precision for various diffusion times and different number of photons. The derived states are optimal in the whole regime ranging from almost perfect knowledge to no a priori knowledge and approach the states known as optimal for these

[1] **PU** = Public
PP = Restricted to other programme participants (including the Commission Services).
RE = Restricted to a group specified by the consortium (including the Commission Services).
CO = Confidential, only for members of the consortium (including the Commission Services).
Make sure that you are using the correct following label when your project has classified deliverables.
EU restricted = Classified with the mention of the classification level restricted "EU Restricted"
EU confidential = Classified with the mention of the classification level confidential " EU Confidential "
EU secret = Classified with the mention of the classification level secret "EU Secret "

											extreme cases [D1-11].
1.1.2	Report on analytical bounds for single parameter estimation in open quantum systems	21.2	1.1	UULM	R	PU	18	31/07/2011	Yes	Yes	Analytical bounds in quantum enhanced metrology and the geometry of quantum channels (UWAW) and bounds for precision spectroscopy in the presence of general, non-Markovian phase noise (UULM) have been derived
1.1.3	Report on source for continuous-variable entangled states compatible with high-power interferometers	21.2	1.1	LUH	R	PU	24	31/01/2012	Yes	Yes	We observed an unprecedented strong unconditional Einstein-Podolsky-Rosen (EPR) entanglement. The product of the measured conditional variances $Var(X_{A\|B})\cdot Var(P_{A\|B})$ was as low as 0.04, where values below unity quantify steering. [arXiv:1112.0461]
1.2.1	Comparison of classical and entanglement enhanced metrology SNR's	21.1	1.2	UoB	R	PU	12	31/01/2011 (accepted in 1st review)	Yes	Yes	Work by partners UOXF.DU and UULM addresses the issue of classical and entanglement enhanced metrology and report the experimental generation of 2-photon Holland-Burnett states in [TSD1-10].The work [TLD1-11] considers the similar problem, now proposing a modular solution in the form of integrated photonic circuits. In [MPB1-11] we report the heralded generation of multi-photon entanglement for quantum metrology using a reconfigurable integrated waveguide device in which projective measurement of auxiliary photons heralds the generation of path entangled states.
1.2.2	Report on time correlated and entanglement based low light level position measurements	21.2	1.2	UoB	R	PU	24	31/01/2012	Yes	Yes	UoB analysed the concept of entanglement enhanced range finding where entanglement is used to provide enhanced signal to background. We described possible realisations based on broad band (hyperentangled) parametric pair photon sources where an SNR gain of *M* can be obtained where *M* is the number of hyperentangled modes. We went on to show that higher order entanglement could provide exponential sensitivity gain when post selection and quantum memory is used and we describe a possible implementation using spin photon entanglement devices. However it is clear that all these measurements are made in the computational basis thus could be reproduced using sophisticated classical encoding schemes.
1.4.1	Feasibility study of nonlinear	21.1	1.4	UULM	R	PU	12	31/01/2011	Yes	Yes	Quantum optical model of a two-mode trapped BEC has been employed to demonstrate the super-Heisenberg scaling of

	metrology using nonlinear optics							(accepted in 1st review)			parameter estimation precision. The effective Hamiltonian describing the interaction between the two modes is nonlinear (quadratic) in mode occupation number operators. For small number of atoms n one easily gets $1/\sqrt{n^3}$ estimation uncertainty scaling using product states. Due to the expansion of the condensate, however, the scaling becomes less favourable with increasing n, and an appropriate trapping potential need to be employed to counteract this effect [TBD1-10].
1.4.2	Report on entanglement enhanced pointing	21.2	1.4	LMU	R	PU	24	31/01/2012	Yes	Yes	Polarization interferometry measurements of two complementary direction on the Bloch sphere beating the classical limit have been performed with up to six-photon Dicke states. The Dicke-state or the Twin-Fock state, respectively, exhibit both Heisenberg scaling, i.e., similarly to the GHZ (N00N) state show a measurement uncertainty proportional $1/N$. Contrary to the GHZ-state, the Dicke state has vanishing $<\sigma_z>$-expectation value and thus enables the simultaneous sub-SNL measurement of both σ_x and σ_y.
1.4.3	Assessment of quantum-enhanced measurement approaches for non-linear quantities such as phase	21.2	1.4	ULEEDS	R	PU	24	31/01/2012	Yes	Yes	Various quantum states of light have been analyzed from the point of view of precision enhancement to the measurement of unknown nonlinear phase shifts. It has been shown both in linear and nonlinear regimes that phase estimation of even entangled coherent state (ECS) is better than that of the NOON states and of odd ECS states with the same average particle number $\langle n \rangle$. Robustness against small loss have been demonstrated for various forms of non-linearity. Additionally a novel method for preparation of an approximate ECS has been proposed [DGK1-12].
2.1.1	Report on photon number detection with semiconductor and superconductor devices	21.1	2.1	TUE	R	CO	12	31/01/2011 (accepted in 1st review)	Yes	Yes	The deliverable report D2.1.1 describes progress on both semiconductor and superconducting photon number resolving detectors. Semiconductor photon number resolving detectors have been developed using a self-differencing circuit that allows detection of very weak avalanches. The ability to sense weak avalanches allows the device to be operated with much lower multiplication gain, thereby avoiding the avalanche saturation effect which removes photon number resolution from conventional Geiger mode operation. As described in the report photon number resolution has been demonstrated at both telecom and visible wavelengths using InGaAs and Si devices, respectively. We have also worked on photon-number-resolving (PNR) detectors based on superconducting parallel nanowires. A device structure for efficient PNR detection of 0, 1 and 2 photons at telecom wavelength has

											been designed, based on 4 closely packed parallel wires integrated within a microcavity structure. A first fabrication run of these closely-packed parallel wires has been carried out, leading to a preliminary demonstration of PNR detection. In parallel, the technology for the integration of superconducting wires with cavities has been optimised, leading to the demonstration of cavity-enhanced single-photon detection.
2.1.2	Report on detectors for long distance quantum communications	21.2	2.1	TREL	R	CO	24	31/01/2012	Yes	Yes	The deliverable report D2.1.2 describes progress on both semiconductor and superconducting single photon detectors. Based on InGaAs APDs, TREL's SD-APDs have achieved a high photon count rate of 1 Gigacount/s and a record low afterpulsing rate. IdQ has developed a detector module id210 with focus on reliability rather than counting performance. TUE has developed detectors based on superconducting parallel nanowires
2.2.1	High brightness sources for long-distance free space and fibre quantum communications experiments	21.1	2.2	UNIGE	R	CO	12	31/01/2011 (accepted in 1st review)	Yes	Yes	Our research efforts in the development of high brightness sources is highlighted by the demonstration of an entangled-photon pair LED, published recently in Nature. In addition, we developed methods for electrical control of both the excitonic emission energy and fine structure splitting in semiconductor quantum dots [BPS1-10, BPS2-10]. In the area of non-linear fibre sources we have developed naturally pure state and narrowband sources and have detailed the design process in a recent NJP paper [CBF1-11]. We have developed a promising new source of pair photons from chalcogenide waveguides which could lead to bright fully integrated pair photon sources [XMP1-11].
2.2.2	Tabulated performance comparison and benchmarking of the different sources	21.2	2.2	UoB	R	CO	24	31/01/2012	Yes	Yes	We have updated our table describing the performance of our various quantum light sources including latest results on pair photon and heralded single photon sources as well as recent improvements to the triggered single and pair photon sources based on solid state systems.
2.3.1	Proposal for deterministic entangled "digital" continuous variable QM states	21.1	2.3	UCPH	R	PU	12	31/01/2011 (accepted in 1st review)	Yes	Yes	There are a variety of quantum information protocols for both continuous and discrete variables. Both of these approaches have their own advantages and disadvantages depending on the task at hand. UCPH has developed a hybrid continuous-discrete variable protocol for quantum communication based on digital continuous variable states [BRP1-10]. Such digital states may be realised for continuous variables by using superpositions of two coherent states $\|\alpha\rangle$ and $\|-\alpha\rangle$. Non-local entanglement is generated by conditioning on the detection of a photon, whereas, the local processing of the

											entanglement is achieved by efficient homodyne detection. The combination of efficient homodyne detection for deterministic entanglement swapping provides an interesting first demonstration for the potential benefits in combining discrete and CV approaches for quantum repeater architectures and protocols.
2.3.2	Report on comparison of QM and interfaces with links to technologies developed in WP2.1 and WP2.2	21.2	2.3	LMU	R	PU	24	31/01/2012	Yes	Yes	Approaches to quantum memories represented in Q-ESSENCE are quite diverse, including solid-state atomic ensembles in rare-earth doped crystals (UNIGE), single trapped atoms (LMU), semiconductor quantum dots in optical micro-cavities (Trel, UoB), room-temperature atomic gases (UOXF, UCPH, UWAW), and optical phonons in bulk diamond (UOXF). In order to perform a meaningful comparison of all these approaches we employed a recently developed common language [C. Simon et al.,Eur. Phys. J. D **58**, 1 (2010)] and compiled a comparison table (see table 1 of the deliverable report) which summarizes and compares updated achievements of all project partners with links to technologies developed in WP2.1 and WP2.2. We emphasize that several partners of the Q-ESSENCE consortium achieved within the last two years significant progress towards long-distance quantum communication, demonstrating by the way heralded (LMU, UOXF, UNIGE) and deterministic entanglement (UCPH) between remote quantum memories up to a distance of 20 m.
2.4.1	Report on architecture and perspectives for long distance entanglement distribution	21.1	2.4	ULEEDS	R	PU	12	31/01/2011 (accepted in 1st review)	Yes	Yes	Detailed studies of various aspects (architectures, enabling technologies and strategies/protocols) of long distance entanglement distribution have been performed and reports produced. New enabling technologies: Loss-resistant state teleportation and entanglement swapping using a quantum-dot spin in an optical microcavity has been studied and reported (see publication report [HR1-11]). Quantum repeaters based on atomic ensembles and linear optics have also been studied, reviewed in detail and reported (see publication report [SSR1-11]). Strategies/protocols: A strategy for device-independent quantum key distribution (DIQKD) (which relies on a Bell test to verify long distance entanglement) using a heralded qubit amplifier has been proposed, studied and reported (see publication report [GPS1-10]). Architecture: An architecture for establishing long distance entanglement through a quantum repeater network based on the rapid firing of repeater nodes has been proposed, studied and reported (see publication report [MHS1-10]). A review of quantum communication technology and the perspective on the aspects of this that rely on long distant entanglement has also been reported

											(see publication report [GT1-10]).
2.4.2	Report on quantitative verification techniques for methods in an SP2 experiment	21.2	2.4	UULM	R	PU	24	31/01/2012	Yes	Yes	Three reports on quantitative techniques for the verification of useful quantum resources have been made in the form of published papers. Additional reports on further verification techniques are anticipated to follow. A theory-experiment collaboration has reported a technique for verification of distributed quantum resources through a Bell test [SBG1-11]. Efficient quantum tomography, for wide classes of useful quantum states, requiring only linear rather than exponential effort, has been reported [CPF1-10]. Application of entanglement measures to experimentally quantify photonic cluster states has been reported [WVM1-10].
2.5.1	Report on techniques for stabilisation and synchronisation of quantum channels.	21.1	2.5	OEAW	R	CO	12	31/01/2011 (accepted in 1st review)	Yes	Yes	During the first year of the project OEAW improved the quality of the 144 km free-space link over which the quantum teleportation will be taking place in the future. The atmospheric turbulences cause the laser beam to bend and deviate from its aim (the second telescope). Thus the photons cannot reach the detector at Bob's side. OEAW developed an Adaptive Optics system to compensate for the atmospheric turbulences. UNIGE have significantly improved the stability of their photon pair sources , necessary for experiments over extended periods. UOXF.DU have been working on the stabilisation of phase and polarisation in interferometers which will also assist with measurements over extended periods. LMU have improved the temporal synchronisation for the Bell state measurement, in the entanglement swapping experiment, and now have reduced the timing jitter between the two systems to < 400ps.
2.5.2	Report on entanglement distribution between remote quantum memories	21.2	2.5	LMU	R	CO	24	31/01/2012	Yes	Yes	We performed generation and analysis of heraldedentanglement between spins of two single Rb-87 atoms, trapped independently20 meters apart. This achievement forms the starting point for new experiments in quantum information science, as well as for fundamental tests ofquantum mechanics. For details, see the deliverable report.
3.1.1	Report on and demonstration of a high-speed entanglement source in the CV setting	21.2	3.1	LUH	R	PU	24	31/01/2012	Yes	Yes	Partner LUH realized the required light source and observed a squeezing bandwidth of greater 2GHz [ASM1-12].The new light source produces Gaussian CV continuous-wave squeezed light at 1550nm. It is a parametric down-conversion source based on periodically poled potassium titanyl phosphate crystal (PPKTP). The source does not exploit any resonant enhancement for the fundamental wavelength. This concept should allow the production of squeezed light within the phase-matching bandwidth of several

											nanometers. The spatial mode of the squeezed light is defined by the spatial mode of the cavity-enhanced second harmonic pump field. We measured the squeezing to be up to 0.3 dB below the vacuum noise from 50MHz to 2GHz limited by the measuring bandwidth of the homodyne detector.
3.2.1	Report on estimates for capacity regions of multi-user quantum channels	21.1	3.2	UG	R	PU	12	31/01/2011 (accepted in 1st review)	Yes	Yes	The capacity regions of quantum multiple access channels were studied in [C1-11]. In particular the total rate was analyzed and showed to be significantly increased by the use of entangled states at the input. Interestingly, a strong super-additivity effect was observed: channels with almost zero capacities achieve total capacity equal to one using entanglement.
3.2.2	Report on resource analysis and potential improvement of quantum-based privacy protocols	21.2	3.2	IPSAS	R	PU	24	31/01/2012	Yes	Yes	This deliverable has been fully achieved, see the deliverable report. Partner IPSAS studied the security of several protocols for quantum voting in [BBH1-11] and provided a number of schemes that use quantum mechanics to preserve privacy. They develop the original proposal introduced in Phys. Lett. A 349 75 (2006) and examine its security under certain types of attacks, in particular dishonest voters and external eavesdroppers.
3.3.1	Report on joint experimental and theoretical efforts in process and state characterization	21.1	3.3	UoB	R	PU	12	31/01/2011 (accepted in 1st review)	Yes	Yes	Project partners have submitted several papers in which theory and experiment are collaborating in the design, realisation and analysis of the experiment. In [MKN1-10] theory partner UP designed a novel and very efficient way to probe the non-classicality of the state of light or any other physical system that realises a harmonic oscillator degree of freedom. Here the non-classicality is defined operationally in terms of the distinguishability of a given state from one with a positive Wigner function. This approach can infer the non-classicality from the measurement of two conjugate variables alone. The theoretical method has then been applied to data from experimental optical Fock state preparation obtained in the lab of experimental physics partner UCPH, demonstrating the viability of the approach. In [WVM1-10] the theory team from UULM applied analytical results and numerical techniques for the determination of quantitative lower (and upper) bounds on the purity, entropy and entanglement content (quantified by the robustness of entanglement and the relative entropy of entanglement) to experimental data from a group in Rome (not partner in QESSENCE) that support the generation of 4-6 qubit cluster states. The number of observables that are required scale linearly in the number of qubits and yield very good lower bounds only

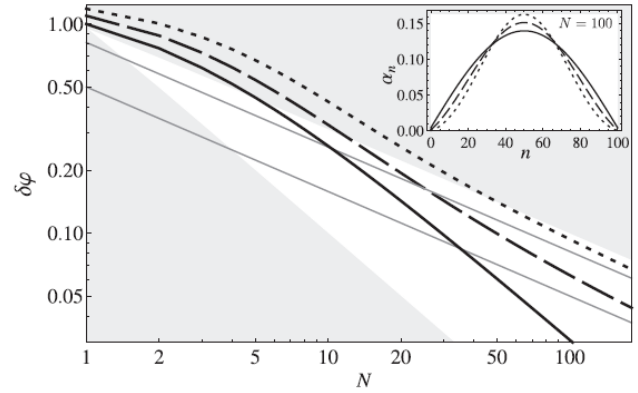
											marginally lower than the estimates obtained from full state tomography (requiring an experimental effort that is scaling exponentially in the number of qubits) in the 4 qubit case.
3.3.2	Raport on decoherence identification protocols	21.2	3.3	IPSAS	R	PU	24	31/01/2012	Yes	Yes	The question of non-Markovianity was investigated by partner UULM. They analyzed two proposed measures of non-Markovianity based on two conceptually different features of Markovian dynamics. One approach is based on the idea of the composition law which is essentially equivalent to the idea of channel divisibility introduced by Wolf and Eisert (2008). This approach was used recently by Rivas, Huelga and Plenio [RHP1-10] to construct the corresponding measure of non-Markovianity, that is, they measure the deviation from divisibility. A different approach is advocated by Breuer, Laine and Piilo (2009). They define non-Markovian dynamics as a time evolution for the open system characterized by a temporary flow of information from the environment quantified by an increase of trace distance between the states. Surprisingly, it turns out the concept of (non)Markovianity is not uniquely defined. In [CKR1-11] the partner UULM provide a toy model to show that these two measures need not agree. In addition, they discuss possible generalizations and intricate relations between these measures.
3.4.1	Report on development of sources with stability and brightness for 6-photon interference	21.1	3.4	OEAW	R	PU	12	31/01/2011 (accepted in 1st review)	Yes	Yes	The results have been reported in [BCZ1-10], fully achieving this deliverable.
3.5.1	Report on new protocols for reducing communication complexity of computing joint functions	21.1	3.5	UG	R	PU	12	31/01/2011 (accepted in 1st review)	Yes	Yes	This deliverable has been fully achieved, with results being published as [LPB1-10], [GLZ1-10], [PKP1-10], [LLP1-10], and [MKT1-10].
4.1.1	Annual scientific report	21.1	4.1	UWAW	R	PU	14	31/03/2011 (accepted in 1st review)	Yes	Yes	Preparations for the scientific report and gathering the information on the scientific production of Q-ESSENCE was launched by the coordinator at the end of 2010. Q-ESSENCE intranet was used to collect the detailed information on the scientific results. To facilitate efficient communication within the consortium the

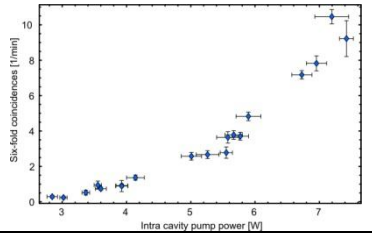
											established project hierarchy, involving (Coordinator -) SP Leaders - WP Leaders - beneficiaries, was used. The information on the scientific production was used also to update the project webpage. The preparations of the report were completed by the end of March 2011.
4.1.2	Annual scientific report	21.2	4.1	UWAW	R	PU	26	31/03/2012	Yes	Yes	Preparations for the scientific report and gathering the information on the scientific production of Q-ESSENCE was launched by the coordinator at the end of 2011. Q-ESSENCE intranet was used to collect the detailed information on the scientific results. To facilitate efficient communication within the consortium the established project hierarchy, involving (Coordinator -) SP Leaders - WP Leaders - beneficiaries, was used. The information on the scientific production was used also to update the project webpage. The preparations of the report were completed by the end of March 2012.
4.2.1	Annual project report	21.1	4.2	UWAW	R	PU	14	31/03/2011 (accepted in 1st review)	Yes	Yes	Preparations for the Q-ESSENCE annual project report have been launched by the Q-ESSENCE coordinator already at the end of year 2010. They included technical report and, later on, the financial report. The cost claim NEF session was opened in the beginning of February 2011, letting the beneficiaries upload the necessary financial information. The preparations of the technical part of the report involved entire consortium, exploiting communication between individual beneficiaries, WP and SP Leaders, and the coordinator. The preparations of the report were completed by the end of March 2011.
4.2.2	Annual project report	21.2	4.2	UWAW	R	PU	26	31/03/2012	Yes	Yes	Preparations for the Q-ESSENCE annual project report have been launched by the Q-ESSENCE coordinator already at the end of year 2011. They included technical report and, later on, the financial report. The cost claim NEF session was opened in the beginning of February 2012, letting the beneficiaries upload the necessary financial information. The preparations of the technical part of the report involved entire consortium, exploiting communication between individual beneficiaries, WP and SP Leaders, and the coordinator. The preparations of the report were completed by the end of March 2012.
4.3.1	Webpage initialization	21.1	4.3	UWAW	R	PU	2	31/03/2010 (accepted in 1st review)	Yes	Yes	Q-ESSENCE website was initiated already in February 2010, within the QUIE2T platform. The www.qessence.eu addressed became active in March 2010, when the .eu domain name was acquired. The information on the project structure and goals was then provided, and the website was being updated regularly. This included information on project related events, news and results.

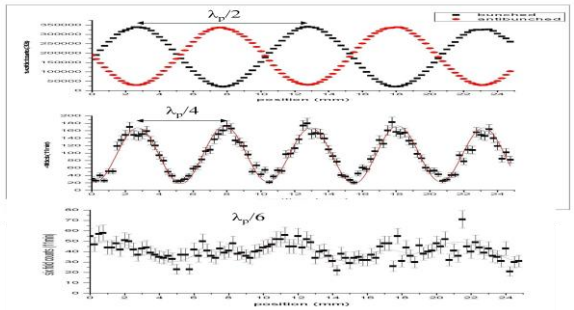
											The website was equipped with the information on the Meetings and Training activities within Q-ESSENCE consortium, and the respective calls were announced.
4.3.2	Webpage update	21.1	4.3	UWAW	R	PU	13	28/02/2011 (accepted in 1st review)	Yes	Yes	The update of the Q-ESSENCE website was initiated already in the 12th month of the project duration. The list of publications, presentations and media appearances was updated, basing on the information received from the consortium, at the end of the first project year. Information on the new partner in the project (University of Paderborn) was provided.
4.3.3	Webpage update	21.2	4.3	UWAW	R	PU	25	29/02/2012	Yes	Yes	The project website has been continuously maintained along with the development of the project. In months 25-26, after the second year of the project duration, the QESSENCE website was fully updated, in order to include all the information received from consortium partners, i.e.: organisational changes, current results, research highlights, dissemination activities and other project related news.
4.4.1	Call for proposals	21.1	4.4	IPSAS	R	PU	4	28/06/2010 (accepted in 1st review)	Yes	Yes	Meetings and Training Committee (MTC)defined eligibility criteria for Q-ESSENCE support of meetings and mobility. Once those rules were given, the Coordinator established formal rules of financial support/reimbursement. A model mobility agreement was prepared. A call for proposals of meetings and mobility were announced in June 2010, on the project website and among consortium. A minor delay (not exceeding one month) of public announcement of calls was due to technical and administrative problems related to the preparation of mobility agreements. Information on the MTC call is available at project website: http://qurope.eu/projects/qessence/committee
4.4.2	Annual MTC report	21.1	4.4	IPSAS	R	PU	12	31/01/2011 (accepted in 1st review)	Yes	Yes	A report on the activity of MTC was presented during the project meeting in Munich, 28-29th January 2011. The list of supported events and future plans were presented. (Presentations from the meeting in Munich are available on the Q-ESSENCE intranet.) In 2010 the committee received and made decision on 5 requests (3 conferences and 2 schools). Because of their quality MTC recommended to support all of them and agreed to allocate altogether 25 180 EUR from its budget for those events.
4.4.3	Annual MTC report	21.2	4.4	IPSAS	R	PU	24				In 2011 the Meeting and Training Committee accepted following events to support: 1) QIP 2011 Workshop, Singapore 5,000 EUR 2) Quantum Science and Technologies, Rovereto, Italy 10,000 EUR 3) Scottish Universities Summer Schools in Physics:

											Quantum Information and Coherence, Glasgow 9,350 EUR 4) Cluster Review 2011, Warsaw, Poland, 2,250 EUR 5) Signatures of Quantumness in Complex Systems, Nottingham, UK, 2,500 EUR 6) CEQIP 2011, Znojmo, Czech Republic, 2,900 EUR 7) Workshop on superconducting single-photon detectors, Eindhoven, Netherlands, 2,500 EUR 8) International Symposium "Quantum Metrology with Photons and Atoms", Toruń, Poland 1,000 EUR 9) QIPC 2011, Zurich, Switzerland 10,000 EUR and mobilities: 1) Tom Lawson, UoB → Id Quantique, 200 EUR 2) Marcin Pawłowski, UoB → ICFO 800 EUR A report on the activities of MTC was presented during the project meeting in Barcelona (9th February 2012)

TABLE 2. MILESTONES

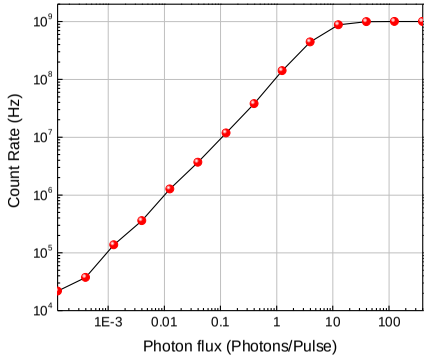
Milestoneno.	Milestone name	Work package no	Lead beneficiary	Delivery date from Annex I dd/mm/yyyy	Achieved Yes/No	Actual / Forecast achievement date dd/mm/yyyy	Comments
1.1.1	Optimal states and measurements for single parameter estimation in open quantum systems identified.	1.1	UULM	31/01/2011	Yes	31/01/2011	We have formulated and solved the problem of optimal phase estimation in an optical interferometer subject to loss when no a priori knowledge and the estimated phase is available [KD1-10]. We have shown that the optimal measurement is unchanged as compared to the lossless case while the optimal states change significantly. Figure MS1.1.1.1 depicts exemplary results for optimal phase estimation using up to N=100 photon states. Additionally, we have derived a fundamental analytical lower bound on the phase estimation uncertainty, which shows that in the presence of loss, asymptotic scaling of phase estimation uncertainty losses the $1/N$ character and quantum precision enhancement amounts at most to a constant factor improvement over classical strategies.  Figure MS1.1.1.1: Log-log plot of optimal phase estimation uncertainty as a function of number of photons used for three different levels of loss (equal in both arms): η = 1 (solid), η = 0.8 (dashed), η = 0.6 (dotted). White area in the middle of the picture corresponds to $1/N < \delta\varphi < 1/\sqrt{N}$. Gray lines represent asymptotic analytical bounds for η = 0.8, η = 0.6. The inset depicts the structure of the optimal states for the three levels of loss for N = 100.

1.1.2	6-photon source for entanglement enhanced metrology with rates > 10/min	1.1	LMU	31/01/2011	Yes	31/01/2011	With a novel SPDC pump source based on a femtosecond enhancement cavity in the ultraviolet wavelength regime we increased the available pump power by an order of magnitude to more than 7W. The enhancement cavity proved to be an excellent down conversion pump source with long-term stability, a well-defined pump mode spatial profile and ultrashort pulses of 175 fs length. Our new pump source allowed us to observe the 6-photon Dicke state with a coincidence rate of 11/min at a pump power of 7.2W.  Fig. MS1.1.2. 6-fold coincidence detection rate when observing the multipartite entangled Dicke state $D_6^{(3)}$.
1.1.3	Optimal states and measurements identified for precision parameter estimation under losses	1.1	UWAW	31/07/2011	Yes	31/07/2011	Detailed analysis, largely based on the quantum Fisher information measure for a number of noise models identified states for precision parameter estimation [HLK1-10]. Alternatively, for more general POVM-type measurements we found alternative states. Depending on the a priori knowledge we find (for high a priori knowledge) the optimal state to be close to the NOON state while it strongly deviates for low a priori knowledge.
1.1.4	Observation of continuous-variable entangled states compatible with 6 dB two-mode squeezing achieved	1.1	IPSAS	31/07/2011	Yes	31/07/2011	We observed an unprecedented strong unconditional Einstein-Podolsky-Rosen (EPR) entanglement. The product of the measured conditional variances (Reid-criterion) $\mathrm{Var}(X_{A\|B})\cdot\mathrm{Var}(P_{A\|B})$ was as low as 0.04, which corresponds to a two-mode squeezing of even about 10 dB.
1.1.5	De-gaussified squeezed light sources with entanglement distillation protocols implemented	1.1	UPB	31/01/2012	No	31/07/2012	MS115 has not yet been achieved due to unexpected difficulties arising in the course of implementing non-Gaussian filters. First results demonstrate de-Gaussification of coherent states. Additional work to accomplish single-mode source characteristics, which will allow simplified de-Gaussification is under way.

1.2.1	Demonstrate a complete clock sequence with an entangled atomic state	1.2	UCPH	31/01/2011	Yes	31/01/2011	In [LAR1-10] partner UCPH reports a modified Ramsey-sequence to measure the atomic transition frequency and implementation of a full clock-protocol that takes advantage of the reduced projection noise that spin-squeezing can provide: Over a short integration time the squeezing enhanced atomic clock performs better by 1.1 dB compared to using standard Ramsey spectroscopy [LAR1-10]. In fact, the phase sensitivity of our clock is so high that already with an interrogation time of less than 100 μs we can resolve fluctuations of the clock-transition frequency by 7.5Hz between successive experimental cycles that are 5 s apart. We attribute this technical noise mainly to instabilities in the trapping potentials. In an ongoing effort we are replacing the old trapping laser for a fiber laser and are hoping to increase our trap lifetime and to decrease the intensity noise. However, since no magic trapping wavelengths for the Cesium clock states exist, trap induced level shifts most likely will remain a precision limiting factor.
1.2.2	Demonstrate waveguide based fully integrated single photon interferometer, Vis>90%	1.2	UoB	31/01/2011	Yes	31/01/2011	[MPB1-11] reported the non-classical interference of two photons with almost 97% fidelity. The experiment was performed on silica-on-silicon waveguides forming directional couplers and interferometers.
1.2.3	Interferometry with lambda/4 fringe spacing achieved for ultra-low light level distance measurements	1.2	UoB	31/07/2011	Yes	31/07/2011	We have generated 2-,4-,6-photon N00N state using fibre-loop geometry. The work is being prepared for publication, but we present some of the main experimental results below. These low intensity states are optimal for estimating small distances when we post-select on the specified number of photons. The scheme is extremely efficient and self aligning thus shows high visibility fringes up to four photon level which is a wavelength 1/4 of the pumping wavelength. We see evidence of 6-photon fringes at a rate of around 4 six-fold coincidences per minute and are working to improve visibility before publication. 

1.2.4	Entanglement enhanced microscopy beyond the diffraction limit of lambda/2 demonstrated	1.2	LMU	31/07/2011	No	31/07/2012	This milestone is delayed. A newly designed microscope set-up should be stable enough to enable the observation even for long measurement times.
1.2.5	Demonstrate quantum-enhanced, integrated-optic sensor for measuring small refractive index changes	1.2	UOXF	31/01/2012	Yes	31/01/2012	This milestone has been achieved, with an impressive experimental implementation constructed by UoB, in which a microfluidic cell, integrated into a waveguide interferometer on-chip, enabled the measurement of the refractive index of bovine serum --- a solution well-known to biochemists --- using NOON states measured in post-selection, showing the characteristic "2-phi" fringes, which cannot be reproduced with classical light. [arXiv:1109.3128]
1.3.1	Demonstration of strong coupling between a micromechanical system and photons	1.3	OEAW	31/07/2011	No	31/01/2013	Coupling was observed as mode splitting, however, not at the single quantum level yet.
1.3.3	Demonstration of coherent state transfer between a micromechanical system and an optical field	1.3	OEAW	31/01/3012	No	31/01/2013	Several schemes for cw- or pulsed readout have been developed but could not be implemented yet due to delays after moving labs.
1.4.1	Demonstrate theoretical feasibility of nonlinear metrology using nonlinear optics	1.4	LMU	31/01/2011	Yes	31/01/2011	Non-linear optical model with Kerr-like Hamiltonian has been analyzed from the point of view of optimal parameter estimation, as documented by [RL1-10]. Calculating the quantum Fisher information, it has been demonstrated that using a coherent input state one can obtain super-Heisenberg scaling of estimation precision. Moreover, it has been observed that unlike in linear models, the optimal probe states need not necessarily be pure, and an example has been provided where a mixture of vacuum and coherent state outperforms a pure coherent state with the same mean energy.

1.4.2	Two-paramter estimation below the standard quantum limit achieved	1.4	UWAW	31/07/2011	Yes	31/07/2011	The role of a reference beam in quantum enhanced Mach-Zehnder interferometry has been analyzed. In the presence of a reference beam the problem is inherently a two-parameter estimation task and the proper way to approach it has been described. The optimal strategies using squeezed and coherent states have been developed and shown to beat the standard quantum limit both in the absence and presence of photon loss [JD1-12]. Additionally, it has been demonstrated experimentally that multipartite entangled Dicke states allow to achieve better than standard scaling precision for two complementary directions on the Bloch sphere .
1.4.3	Decision on comparison of two approaches to fight PMD in interferometry done	1.4	UWAW	31/01/2012	Yes	31/01/2012	A model of Hong-Ou-Mandel interference in the presence of polarization mode dispersion (PMD) in one of the arms of the interferometer has been proposed. It has been shown that one can make the interference visibility immune to the 1st order PMD by preparing a frequency anticorrelated polarisation singlet state of two photons. In order to benefit from this feature one needs to fight the 0th order PMD effect using standard compensation techniques e.g. based on a feedback loop. Hence, both approaches, the entanglement based and the feedback based need to accompany each other for the optimal performance.
1.4.4	Impact of decoherence on linear and non-linear schemes for quantum metrology evaluated	1.4	UG	31/01/2012	Yes	31/01/2012	In the linear regime a universal geometric method has been developed allowing for a simple derivation of fundamental bounds on quantum precision enhancement in the presence of generic decoherence models [DGK1-12]. In the non-linear models of phase estimation, the effect of a small photon loss have been analyzed and the entangled coherent states have been demonstrated to be both more sensitive and robust against loss compared to the N00N states [JPJ1-12].

2.1.1	InGaAs APD with photon detection rate >0.5 Gc/s	2.1	TREL	31/01/2011	Yes	31/01/2011	During the last year TREL have developed InGaAs single photon detectors for high photon count rate. They have optimised the design of the self-differencing avalanche photodiode so that it now allows both the operation frequency and the splitting ratio to be tuned. The new self-differencing circuit has a much improved performance: the cancellation of the gating frequency is measured to be 62dB, and its overall cancellation is 17dB better than the previous non-tuneable circuit. The new circuit enables higher gating frequencies to be used, now up to 2 GHz. This allowed a maximum photon count rate of 1Gc/s to be demonstrated for the first time using a single pixel APD (Fig. MS2.1.1).  Fig. MS2.2.1. Photon count rate as a function of optical attenuation for a self-differencing APD gated at 2GHz. A maximum count rate of 1 Gc/s is achieved.

2.1.2	Large-Diameter >200 µm Si APD with timing jitter < 100ps	2.1	POLIMI	31/01/2011	Yes	31/01/2011	The POLIMI group has realised large-area Si SPADs (diameters up to 0.5mm) with timing jitter better than 100ps FWHM. A large number of devices were fabricated and characterised using wafers from a variety of sources (Figure MS2.1.2. Several 0.5mm devices were found with dark count rates lower than 200 kc/s at room temperature. The photon detection efficiency (PDE) is comparable to that of previous SPAD generations (50% @550nm, >30% up to 700nm). Using a patented pulse pick-up circuit for processing the avalanche current, a timing jitter of 35 ps FWHM was obtained at room temperature with SPAD devices having 0.2 and 0.35mm active area diameters. A slightly higher jitter of 55 ps FWHM was measured with 0.5mm SPADs, likely due to the large parasitic capacitance of these devices. The fabricated devices are of interest for free-space entanglement distribution.

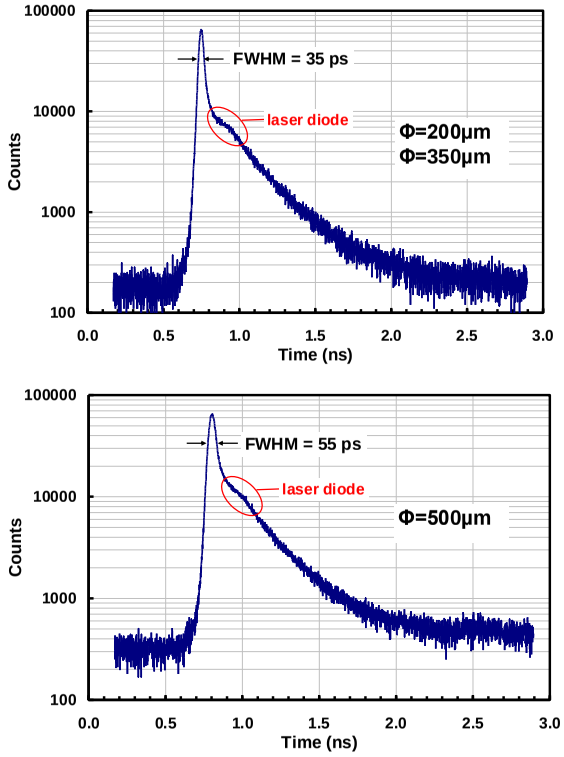
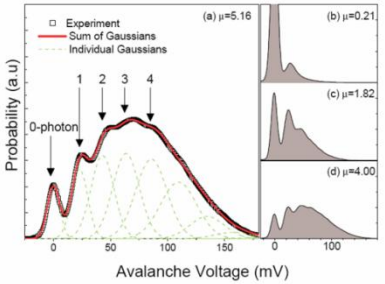
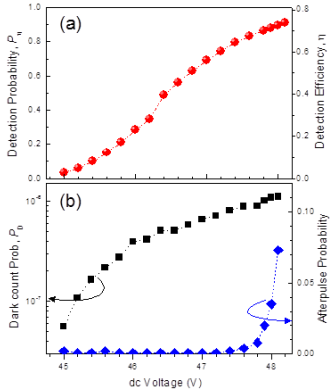
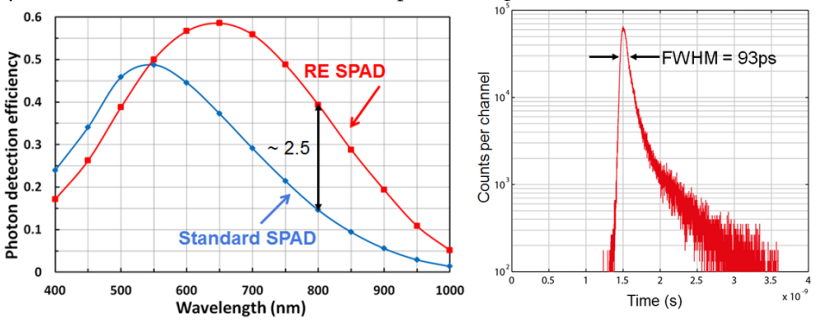
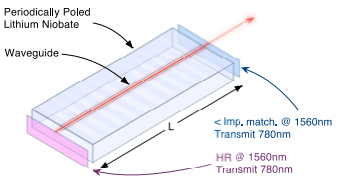
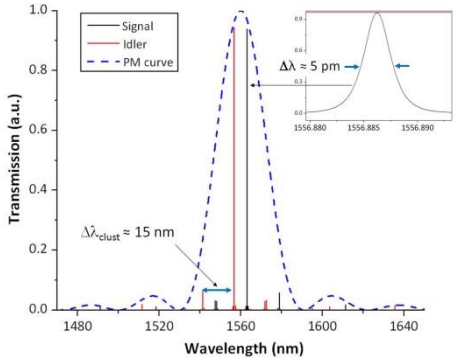
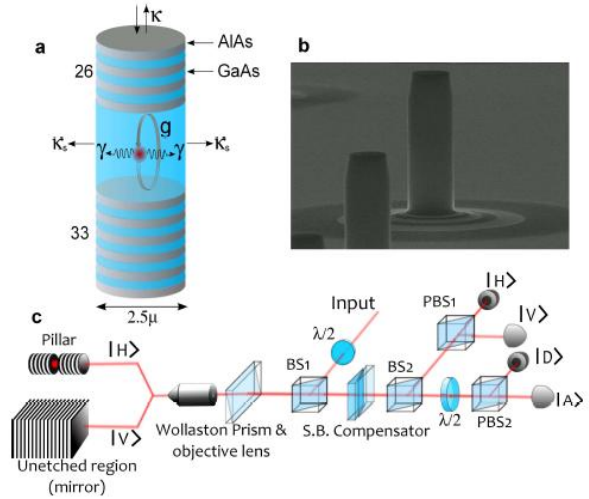


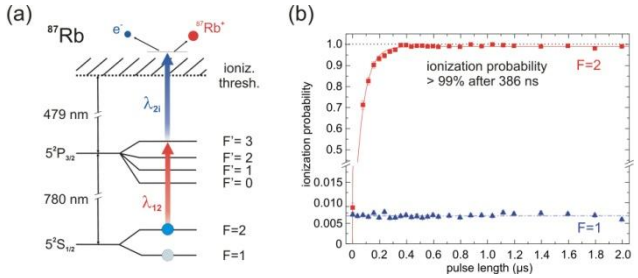
Figure MS2.1.2: Jitter in the photon detection time recorded using a pulsed diode laser and time correlated single photon counting, recorded for (a) devices with 0.2 or 0.35mm (b) 0.5mm diameter.

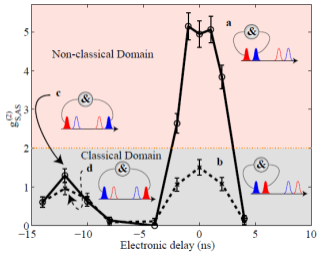
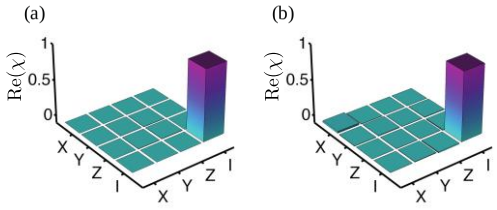
2.1.3	Photon number resolving detector with detection efficiency > 70%	2.1	TUE	31/01/2012	Yes	31/01/2012	TREL have developed an efficient photon number detector using single-pixel Si-APDs. Operated in self-differencing mode, these APDs are able to resolve up to four incident photons in an optical pulse. The detection efficiency at 600nm is measured to be 73.8%, corresponding to an avalanche probability of 91.1% of the absorbed photons with a dark count probability < 1.1×10^{-06} per gate.   Left: Probability distribution for avalanche amplitudes measured for various incident photon fluxes; Right: detector performance measured at various biasing conditions.

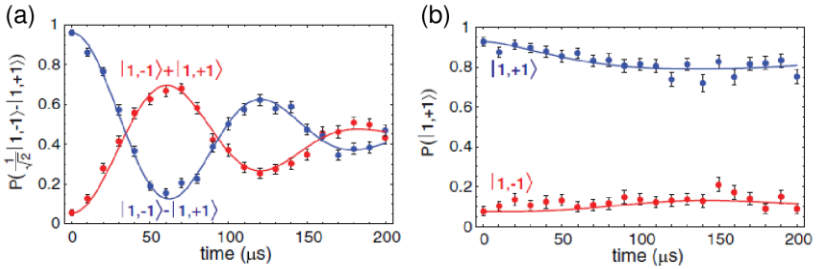
2.1.4	Free space (800nm) detection module:- efficiency > 30%, jitter < 100ps, dark count < 1kHz	2.1	UoB	31/01/2012	YES	31/01/2012	The POLIMI group has realised a free-space detection module for single photons using red-enhanced Si SPAD devices. At 800 nm, they have obtained a factor of 2.5 times improvement in detection efficiency over standard SPAD devices. A detection efficiency of 40% is obtained at 800nm. The group has aslo demonstrated a timing jitter of < 93ps and a dark count rate of < 600 Hz c/s for a 50µm diameter SPAD under room-temperature operation.  Left: photon detection efficiency as a function of wavelength; Right: Jitter in the photon detection time recorded using a pulsed diode laser and time correlated single photon counting.
2.2.1	All-fibre heralded and entangled photon source in the visible region	2.2	UoB	31/01/2011	Yes	31/01/2011	We have developed a range of heralded and entangled photon sources based on photonic crystal fibre. Of relevance to this milestone are our all fibre source of 1550nm heralded photons completed in 2009 (Opt. Exp. **17**, 6156-65, 2009). During this project year we have been developing two narrowband pure state entangled pair photon sources [CBF1-11]. These sources show raw coincidence to single rates approaching 20% thus are ideal for making multi-photon experiments. We are presently preparing an entanglement swapping and four photon cluster state experiment using a fusion gate to link our sources.
2.2.2	Sources: Compatibility with Applications, meeting	2.2	UoB	31/07/2011	Yes	31/03/2012	Members of the consortium met to discuss the sources and their comparability and compatibility with the various applications. Meetings were arranged at the single photon workshop in Braunschweig (June 27-30th 2011), at ECOC in Geneva (Sept 18-22nd, 2011) and at the annual Q-essence meeting in Barcelona (Feb 9-10th 2012). So far an initial table has been prepared with a short report summarising the various source specific properties including definitions of brightness units for the various types of source and highlighting application-specific advantages of particular sources. A decision to work on a general review of quantum sources was made at the annual meeting with an aim to submit a joint review paper before January 2013 that will incorporate input from across the entire project.

2.2.3	Cavity-enhanced, efficient photon pair source	2.2	UNIGE	31/01/2012	Yes	31/01/2012	The ability to engineer and control well defined states of light for quantum information applications is of increasing importance as the complexity of quantum systems grows, for example, when interfacing multiple sources in a quantum network. In order to interface multiple independent systems, high multi-photon interference visibility is required and can be realised by adopting single mode sources. We have recently proposed a spontaneous parametric down conversion source based on an integrated cavity-waveguide that takes advantage of the clustering effect, provided by the intrinsic dispersion of the nonlinear crystals, to select single narrow-band, eventually distinct, spectral modes for the idler and the signal field. In combination with a CW laser and fast detection this provides a means to engineer a source that efficiently generates pure photons, without additional, or lossy, filtering, that is compatible with long distance quantum communication. The approach is extremely flexible and could easily be adapted to a wide variety of wavelengths and applications and provides a basis for building up pure multi-photon states.  **Figure MS2.2.3.1**: Integrated cavity OPO using a Type II PPLN waveguide.  **Figure MS2.2.3.2**: Output spectrum of optimised integrated OPO. In this scheme we use an integrated OPO cavity using PPLN waveguide (Fig. MS2.2.3.1) - the OPO is formed by placing reflective coatings on the end facets of the waveguide device. Photon pairs are generated in symmetric single modes around the degeneracy point (1560nm) of around 5pm bandwidth – see Fig. MS2.2.3.2. The results and more details can be found in [PSO1-12].

2.3.1	Observation of conditional phase-shift from quantum dots in micro-cavities	2.3	UoB	31/01/2011	Yes	31/01/2011	UoB has developed a high resolution reflection spectroscopy technique capable of measuring the intensity and phase of light reflected from a pillar microcavity, shown in Figure MS2.3.1 [YOH1-10]. High Q-factor microcavities were sourced from Wurzburg University, capable of showing strong coupling to quantum dots. When a quantum dot is placed in such a cavity both a change in reflectivity and a phase shift, conditional on the dot being on or off resonance, is observed. **UoB** aims to extend these experiments to the study of charged quantum dots, where it would be possible to realise a spin photon interface.  Figure MS2.3.1: (a) A schematic diagram of a 2.5μm diameter pillar with 33/26 bottom/top mirror pairs, containing a single QD. (b) SEM image of a pillar microcavity defined by electron beam lithography and reactive ion etching. (c) Schematic diagram of the setup used to measure the phase shift caused by a single QD coupled to a pillar microcavity. BS1 and BS2 are both 50:50 non-polarising beamsplitters, the Soleil babinet compensator allows us to initialise the setup with $\sin\varphi = 0$.

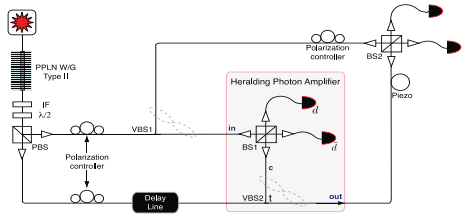
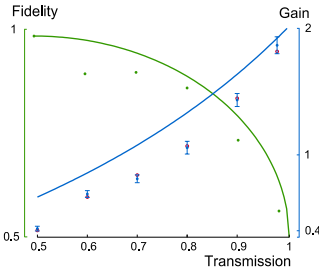
2.3.2	Demonstration of highly-efficient (>90 %) sub-µs state detection of an atomic quantum memory	2.3	LMU	31/01/2012	Yes	31/01/2012	For atomic quantum memories **LMU** has experimentally demonstrated a new detection scheme suitable for deterministic state analysis of single optically trapped atoms in less than 1 µs with a readout fidelity of F=99.2% [HKH1-10]. The method is based on hyperfine-state-selective photo-ionization (Fig. MS2.3.2.1(a) and subsequent registration of the correlated ion-electron pairs (see activity report of WP2.3 from 2011). In detailed experiments, efficiency, speed, and hyperfine-state-selectivity of the photo-ionization process was studied on a single optically trapped Rb-87 atom. Hyperfine-state-selectivity was achieved by a two-step, two-color photo-ionization scheme, using the $5^2P_{3/2}$, F'=3 level as resonant intermediate state. To evaluate the state-selectivity of the photo-ionization process, the atom was initially prepared either in the $5^2S_{1/2}$, F=1 or F=2 hyperfine ground state. Then, the corresponding ionization probability was measured for different excitation pulse lengths (see Fig. MS2.3.2.1b). For an atom initially prepared in F=2 an ionization probability of 0.99 is achieved after 386 ns, while an ionization probability of 0.007 was observed for atoms in F=1. Out of these numbers a readout fidelity of 99.2% was derived [HKH1-10]. In combination with the highly-efficient registration of the correlated ionization fragments (ion-electron pairs) via two opposing channel electron multipliers an overall state-detection efficiency of 98% and an overall detection time of (802 +/-17) ns was determined [HKH1-10]. In comparison with the frequently used fluorescence method this new technique combines an 100 fold enhancement in speed with scalability to a large number of atoms.  **Figure MS2.3.2.1: (a)** Level scheme in Rb-87 used for photo-ionization. **(b)** Hyperfine-state-selective, single-atom ionization probability for different laser pulse lengths. In a series of continuative experiments the Munich group built on these results, extending the photo-ionization technique with the help of a Stimulated Raman Adiabatic Passage (STIRAP) process for sub-µs state analysis of Zeeman qubits. Quite recently LMU applied this technique for the first observation of heralded entanglement between two trapped Rb-87 atoms at a distance of 20 m (see achieved milestone M.2.5.1).

2.3.3	Correlations between Stokes- & Anti-Stokes signals in bulk diamond and atomic vapours	2.3	UOXF	31/01/2012	Yes	31/01/2012	**UOXF.DU** has successfully demonstrated correlated Stokes/anti-Stokes emission from diamond. In particular, the team has implemented a quantum-memory-type interaction in diamond, in which an ultrafast "write" pulse spontaneously scatters a Stokes photon, whose detection heralds the creation of a single optical phonon within the diamond. The non-classical character of this phonon state was then verified by converting the phonon into an anti-Stokes photon by means of a second ultrafast "read" pulse. The cross-correlation of the Stokes and anti-Stokes modes is clearly observed to violate the Cauchy-Schwarz inequality that demarcates the boundary between classical and quantum correlations, showing that a non-classical state of motion has been created within the diamond (see Fig. MS2.3.3.1 below) [LSS1-11].  **Figure MS2.3.3.1:** Violation of Cauchy-Schwarz inequality by Stokes/anti-Stokes cross correlation  **Figure MS2.3.3.2:** Reconstructed process matrices for the polarisation channel for (a) unstored light (b) light stored and then retrieved from the memory. Both processes are nearly indistinguishable from the "identity" process (no change in polarisation. **UOXF** has also developed a viable quantum memory for use in realistic quantum communications and photonic processing protocols, based on Raman scattering in room-temperature cesium vapour. The storage bandwidth is 1.5 GHz, and the storage time is currently limited by magnetic dephasing to ~5 μs. Although longer storage times are possible with improved magnetic shielding, the memory already has a time-bandwidth product in excess of 2000, which is the largest demonstrated to date. This is the key figure of merit for future synchronization applications. UOXF recently demonstrated that the memory was capable of operating at the quantum limit (i.e. at the single photon level, with sufficiently low noise that no classical memory could perform equivalently) at room temperature [RML1-11]. It was also showed that polarization qubits could be stored by splitting the incident signal into its polarization components and implementing a pair of identical memories in parallel, to form a single polarization memory (see Fig. MS2.3.3.2 below) [EMC1-12]. UOXF has not yet demonstrated operation with true single photons, but hopes to achieve this in the coming year.

2.3.4	Zeeman qubits stored in single neutral atoms with long coherence times (> 150µs)	2.3	LMU	31/01/2012	Yes	31/01/2012	Long-distance quantum communication via quantum repeaters is only possible if photonic quantum information can be buffered in quantum memories for long times. In a detailed article [RVW1-11] partner **LMU** experimentally investigated the coherence properties of a qubit stored in the Zeeman sub-states $m_F = \pm 1$ of the $5^2S_{1/2}$, F=1 hyperfine ground level of a single optically trapped Rb-87 atom. Larmor precession of the atomic spin was investigated by initially preparing the atom in a defined spin state and then measuring the resulting state after a programmable period of free evolution (see Fig. MS2.3.4.1). Additionally, maximum knowledge about the spin coherence was gathered by performing a partial quantum-state tomography of the spin-1 space. With the help of an active magnetic field stabilization and without application of a static magnetic guiding field, the LMU team achieved transverse and longitudinal dephasing times of T_2= 150 µs (see Fig. 1a) and T_1>0.5 ms (see Fig. 1b), respectively. The team could show, that the measured atomic spin coherence was limited mainly by residual position- and state-dependent effects in the optical trapping potential.  **Figure MS2.3.4.1:** Temporal evolution of different atomic spin states. (a) Evolution of the initially prepared states |1,-1> + |1,+1> (red) and |1,-1> - |1,+1> (blue) in an effective magnetic guiding field of 5.5 mG along the quantization axis. The corresponding T_2 time is on the order of 150 µs. (b) Evolution of the initially prepared states |1,-1> (red) and |1,+1> (blue) in an actively compensated magnetic field environment (B<2 mG). On basis of this improved understanding partner LMU currently investigates approaches to enable even longer coherence times. On the one hand a new dipole trap design is tested, promising a higher accuracy to align the polarization of the dipole-trap light. On the other hand the trapped atom is intended to be cooled to lower temperatures, reducing the state-dependence of the optical trapping potential.

2.4.1	Comparison of potential architectures and dependence on enabling technologies for long distance entanglement distribution	2.4	ULEEDS	31/01/2011	Yes	31/01/2011	The study and comparison of a variety of different systems and approaches has been realised. This has covered ongoing work focused on a bottom up perspective -linear optics and atomic ensembles for example, and highlighted different approaches to hybrid schemes proposed by the Copenhagen and Geneva groups. These groups have now initiated discussions to look how to combine the advantages of the two different schemes. The top down approach has also attempted to put some solid numbers on their protocol and architecture and have identified an experimental system, currently being developed in Q-ESSENCE that would be well suited.
2.4.2	Development of quantitative verification methods for SP2 experiments	2.4	UULM	31/01/2012	Yes	31/01/2012	Three quantitative verification methods have been developed, with one being employed experimentally to demonstrate its applicability. A loophole-free Bell test for atom-photon entanglement has been developed, which only requires homodyne detection on the optical mode [SBG1-11]. This provides a verification method for distributed atom-photon entanglement.An efficient method for quantum state tomography has been developed [CPF1-10]. For large classes of useful N-way quantum resources, this method provides a verification tool requiring only a linear in N number of measurements, rather than the exponential number in N that would be required for full quantum tomography.Entanglement measures have been employed experimentally as a verification tool for four- and six-qubit cluster states based on hyper-entangled (in polarisation and linear momentum) photons [WVM1-10]. This provides a practical demonstration of the application of entanglement measures for verification of useful entangled resources.Further quantitative verification techniques are under development.
2.5.1	Demonstrate entanglement between remote independent quantum memories	2.5	LMU	31/01/2011	Yes	31/07/2011	Heralded entanglement between remote stationary quantum memories is a key resource for future applications of long-distance quantum communication, like quantum repeaters and distributed quantum networks. Within this context both partners LMU and UCPH demonstrated entanglement between independent quantum memories. In LMU scheme the heralded preparation and analysis of entanglement between two single optically trapped Rb-87 atoms over a distance of 20 m via entanglement swapping.Independently, UCPH demonstrated entanglement between independent memories for which the key ingredients are a controlled dispersive interaction of a light field with the atoms and quantum measurement on the outgoing light. By carefully engineering dissipation by means of laser- and magnetic fields, the system is driven into an entangled state. Combining this with a continuous measurement on the outgoing light, entanglement between the atomic ensembles was measured to prevail for over an hour. For a detailed presentation of results, see WP2.5 report in Section 3.2.2.

2.5.2	Demonstrate deterministic quantum teleportation between distant atomic quantum memories	2.5	UCPH	31/01/2012	No	31/12/2012	UCPH investigated theoretically and experimentally the optimal settings to achieve deterministic teleportation between two Cesium ensembles at room temperature (MS252). The setup was adjusted accordingly for the teleportation experiment. Feedback via a magnetic RF pulse onto the atomic spin of the target ensemble according to a measurement outcome on light was implemented. The possibility for a read-out of the quantum state of the target ensemble via a light beam was realized, so that the teleportation fidelity can be evaluated. For this task also new methods for a precise calibration of the state read out needed to be developed. The first teleportation trials where different displaced coherent states were transferred between the atomic ensembles were conducted. The preliminary results indicate that fidelities above the classical limit for small displacements are achievable. Instabilities in the experimental setup leading to classical noise brought about a delay in the further progress of the experiment.

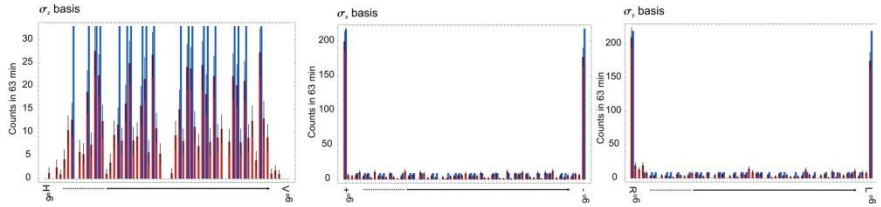
2.5.3	Experimental realisation of a purification protocol	2.5	UNIGE	31/01/2012	YES	31/12/2011	The original proposal for single photon entanglement purification was performed ahead of schedule [D Salart *et al.*, Phys. Rev. Lett. **104**, 180504 (2010)]. As such we redirected our efforts towards the recent proposal for heralded photon amplification. This proposal was focused on Device Independent QKD and requires a heralded qubit amplifier, which we see inset the box of Fig.x,. Although, only a relatively recent idea, we have experimentally realised the first step – a heralded single photon amplifier. In Fig.MS2.5.3.1, we see the experimental set-up for testing this scheme. In the context of entanglement purification one can see the similarity with the standard entanglement swapping scenario, however, now that we have access to an extra degree of freedom – a variable beamsplitter (VBS2) – we can perform a procrustean-like purification on the output modes that is heralded by the Bell state measurement (BSM), of the swapping operation, at BS1.  Figure MS2.5.3.1: Experimental set-up for testing the heralded photon amplifier.  Figure MS2.5.3.2 The performance of this heralded amplifier is characterised by the Gain – the ratio of photons arriving at "in" compared to those heralded at "out". These results are presented in Fig.MS2.5.3.2, where a Gain of ~2 is achieved. We have also measured the heralded single photon interference between a detector at BS1 and one at BS2 to verify the coherence of the process. Although not shown here, the lower visibility for t→1 could be recovered (back towards V→1) by adjusting VBS2, thus performing purification of the single photon entanglement. At the time of reporting, this work is being written up and should be published soon.

3.1.1	Establishment and characterization of a free space link (1.6 km) for CV state distribution	3.1	MPL	31/01/2011	Yes	31/01/2011	The partner MLP established a 1.6 km free space link that is applicable for the distribution of CV quantum states. The link is characterized under realistic environmental conditions. Measurements of the spatial intensity distribution of the transmitted states show, that on average more than 95% of the beam intensity lies within the area defined by the size of the receiving aperture (15cm diameter). It could be shown that vibration and movement of the buildings do not play a detrimental role. Overall channel losses achieved are less than 40%, which will be reduced further by utilizing adapted coatings and improved optical components.
3.1.2	Distribution of squeezed states over a free space link	3.1	MPL	31/01/2012	Yes	31/01/2012	The MPL partner established a 1.6 km free space link that is applicable for the distribution of CV quantum states. A portable source of continuous variable (CV) polarization squeezed states was realised. The source is based on the nonlinear interaction during a single-pass through a photonic crystal fibre (PCF). Locally, about 3dB of squeezing was measured. The free space quantum channel has about 50% transmission @780nm. For the first time squeezing was measured after an atmospheric optical link (about 1dB).
3.1.3	Characterization of distributed four-partite entanglement	3.1	LUH	31/01/2012	Yes	31/01/2012	LUH demonstrated a 4 mode bound entangled (BE) state, which is the first demonstration of continuous variable bound entanglement. The generation of BE was also unconditional. The theoretical work required for this experiment was provided by UP. The results were published in [GSH1-11].
3.1.4	Measurement of coherence between different photon-number components of a CV-entangled field	3.1	UOXF	31/01/2012	Yes	31/01/2012	The experimental work towards this goal is continuing but the milestone is not yet achieved. Difficulties that caused delay include phase instability of the local oscillator modes, the complexity of the data acquisition system required for use with multiple photon-number-resolving detectors, and more mundane technical problems with our laser system and air conditioning. These have now all been solved.
3.1.5	Observation of CV entangled laser beams with GHz bandwidth	3.1	LUH	31/01/2012	Yes	31/01/2012	The Q-ESSENCE partner LUH realized a new concept of a Gaussian CV continuous-wave squeezed light source at 1550nm. This source is a parametric down-conversion source based on periodically poled potassium titanyl phosphate crystal (PPKTP). We measured the squeezing to be up to 0.3 dB below the vacuum noise from 50MHz to 2GHz limited by the measuring bandwidth of the homodyne detector. The results are summarized in a submitted manuscript [ASM1-12]. In subsequent work, the squeezed mode was split on a balanced beam splitter and the quadrature amplitudes (X1,X2) were measured by the two homodyne detectors A and B. Their covariances fulfilled the entanglement criterion by Duan and co-workers [Phys. Rev. Lett. 84, 2722 (2000)].

3.2.1	Report on characterization of entangled states possesing anonymous entanglement	3.2	ICFO	31/01/2011	Yes	31/01/2011	An *n* qubit entangled state of the GHZ form allows for the reliable and anonymous transmission of one bit of information from any sender to the remaining *n*-1 receiving nodes. Anonymity is defined so that at no stage of the protocol can the probability of any node to be the sender increase, nor can the sender be identified if a malicious party would get hold of all the resources. It has been shown that GHZ states are the only entangled states that allow for anonymity with perfect probability of retrieval, modulo arbitrary local rotations. If a different state is distributed, one cannot find an LOCC protocol that allows the perfect retrieval of the original message if the sender is to remain anonymous. This result singles out GHZ states as possessing a distinctive capability to which a clear operational meaning can be associated.
3.2.2	Report on non-additivity of communication capacities in multi-user quantum channels	3.2	UoB	31/01/2011	Yes	31/01/2011	In the project carried out by the partner UG, the influence of thermal noise on the beam splitter channel capacity region was studied. The analysis shows that even small amounts of noise make the capacity gain using entanglement negligible. The results determine requirements for experimental setups to observe these non-additivity effects. In the same work, it was shown that in some situations multiparticle entanglement is needed to approach the regularized classical capacity region. Finally, a new example of super-additivity was presented in [C1-11].
3.2.3	Report on new protocols for entanglement and/or secret key distribution over quantum networks	3.2	ICFO	31/01/2012	Yes	31/01/2012	This milestone has been achieved. New schemes for long-distance entanglement distribution over networks were presented in [GHH1-12], by partner UG, and in [PLA1-11], by partner ICFO. The first work proves that long-distance entanglement distribution with constant resources per node is possible in 2-dimensional networks consisting of noisy entangled states. The second work introduces new protocols for this problem that combine entanglement swapping and purification. These protocols are then applied to networks with random structure, such as Erdös-Rényi.
3.3.1	Report on decoherence identification protocols and estimation of rates of unknown channels	3.3	ICFO	31/01/2011	Yes	31/01/2011	This milestone has been effectively been achieved, but not in the sense originally anticipated: [CEW1-10] represents work towards the milestone within the consortium albeit with a negative conclusion concerning the general case. More precisely, in [CEW1-10] it was found that the determination of the dynamical equations based on data that has been obtained from measurements at different times is a challenging task. In fact, [CEW1-10] demonstrates that this process is a provably computationally intractable problem as it is NP-hard. That is, even for a moderately complex system, no matter how accurately or completely we have specified the data, discovering its dynamical equations can take an infeasibly long time. This interesting but negative result does not necessarily rule out the possibility of determining single parameters such as decoherence rates or dynamical equations under promises efficiently though.

3.3.2	Report on assumption-free characterisation of phase-sensitive photodetectors	3.3	UOXF	31/01/2012	Yes	31/01/2012	This milestone was achieved by partner UULM. In [ZCD1-11], we introduce a quantum detector tomography method for the reconstruction of the POVM of a coherent optical detector. This method is applied to two variations of a weak-homodyne detector: photon-counting and photon number-resolving (PNRD). The POVM elements of such detectors have both phase and number sensitivity, denoted by their off-diagonal and diagonal matrix elements respectively. Our experimental procedure can be universally applied to any optical detector. It uses only classical optical states as probes, yet, with the resulting POVM we can predict the detector response to any quantum state, including non-classical ones. Full quantum tomography is only made possible by developing a new recursive algorithm that radically reduces the computational complexity of reconstructing the POVM from quadratic to linear per recursion in the dimension *d* of the POVM elements. By defining the transformed version of the Husimi distribution (*Q* function), we cast the reconstruction problem as a tractable semi-definite program, allowing us to determine both diagonal and off-diagonal elements. This enables us to characterize the detectors' tunability between registering the particle and wave behaviours of an input quantum state, making our experiment the first full quantum tomography of phase-sensitive optical detectors.

3.4.1	Input from experimental groups turned into optimal control description, providing guidelines	3.4	TUM	31/01/2012	Yes	31/01/2012	With the experimental parameters of the controlled master equation as input, the algorithmic framework DYNAMO[MSG1-10] by TUM provides a versatile and cutting-edge MATLAB toolset for optimal control. This includes initial conditions for combining several hardware modules in distributed quantum protocols. The partners at UULM provided a simplified set of parameters of an experimentally realizable 4-site optical network scheme in [CSV1-10] for the demonstration of the basic mechanisms underlying dephasing noise-assisted exaction transfer in biological systems. An extended parameter set for the biologically important light-harvesting FMO complex is given in [CMC1-11] for a 7-site complex and it has recently been refined to an 8-site complex. In order to systematically exploit noise assistance besides coherent control, the DYNAMO package has been extended by TUM such as to allow for all standard types of Markovian noise to be modulated in time by making the noise amplitudes explicit control parameters. To our knowledge, this has never been done on a general scale before. Then TUM calculated optimised time-modulated dephasing noise profiles for the above model networks with up to 8 sites. As a guideline, the results show how in complex networks swapping coherences to relay stations are to be delayed as long as they may destructively interfere with fast main transfer routes. On the other hand, the time modulations of both coherent and incoherent processes provided by optimal control are tailored to the experimental setup. Being optimised, they are more intricate than simple rules of the thumb such as to decouple potential sources of loss entirely. For instance, in [SSK1-11] tailored decoupling schemes by optimal control have been shown to be far superior to Trotter-based bang-bang controls. Again, as a general guideline, decoupling can readily be integrated into performing target operations. Thus beyond helping to elucidate guidelines, the optimal control toolbox provides means to combine coherent and incoherent controls in a fashion tailored to the experimental setup.

3.4.2	Report on demonstration of 6-photon multi-partite entangled state observed with rates >5/min	3.4	LMU	31/01/2011	Yes	31/01/2011	The six-photon Dicke state was observed with high fidelity and count rate. Figure MS3.4.2 shows the six-photon rates when analyzing all photons with the same polarization, either along H/V, +/- 45° linear, or R/L circular polarization. The rates oberved in this measurement are about 6,7 6-fold detection per minute. The measurements shown are sufficient to estimate the fidelity to 0.5785 +/- 0.067.  Figure MS3.4.2: Observation of six-photon Dicke state
3.4.3	Report on preliminary test of a quantum state transfer between atomic ensembles	3.4	UCPH	31/07/2011	Yes	31/01/2012	A state transfer protocol between two atomic was developed and optimized by UCPH. Different settings for state transfer of the quantum state of one atomic ensemble (input) to another one (target) were investigated. A teleportation protocol for two Cesium ensembles, situated in a magnetic field with parallel macroscopic spins has been developed. A light beam which is detuned by around 1GHz from the D2 line is directed through both atomic ensembles. After a measurement on the outgoing light, the measurement results are fed back to the target ensemble via a magnetic RF pulse. First experimental results show a good agreement between the predicted optimal settings for the duration and strength of the light pulse.
3.4.4	Improvement of rates and suppression of unwanted higher-order emission of parametric down-conversion	3.4	UG	31/01/2012	Yes	31/01/2012	In [KRB1-12] a general technique for generating spatially pure photon pairs in multimode wave guiding structures has been demonstrated. The technique exploits intermodal dispersion, which separates spectrally down-conversion processes involving different triplets (pump, signal, and idler) of spatial modes. The beam quality factors were measured in the heralded mode to be less that 1.03 for both modes and horizontal and vertical spatial scans.
3.4.5	Report on demonstration of a non-Gaussian "digital" continuous variable state of an atomic memory	3.4	UCPH	31/01/2012	No	31/01/2012	To speed up achievement of M3.4.5, UCPH purchased lasers, fiber splitters etc. to operate the nanofiber-setup independently from their old experiment. This way the two experiments can be run in parallel by the 2 new PhD students that joined UCPH recently. With the current progress, UCPH expects to see first results of non-Gaussian statistics during reporting period 3 in their old setup. In the same time frame they expect to see atomic projection noise in the nano-fiber setup.

3.5.1	Resources for simulating quantum communication, reference-frames in entanglement detection	3.5	UG	31/01/2011	Yes	31/01/2012	One of the principal tasks one faces when analyzing the communication reducing properties of quantum correlations is to estimate what would be the additional classical communication input to simulate the quantum correlations. Our results are the following: [PKP1-10]: Bells theorem is a no-go theorem stating that quantum mechanics cannot be reproduced by a physical theory based on realism, freedom to choose experimental settings and two locality conditions: setting (SI) and outcome (OI) independence. We provide a novel analysis of what it takes to violate Bells inequality within the framework in which both realism and freedom of choice are assumed, by showing that it is impossible to model a violation without having information in one laboratory about both the setting and the outcome at the distant one. While it is possible that outcome information can be revealed from shared hidden variables, the assumed experimenters' freedom to choose the settings ensures that the setting information must be non-locally transferred even when the SI condition is obeyed. The amount of transmitted information about the setting that is sufficient to violate the CHSH inequality up to its quantum mechanical maximum is 0.736 bits. The basic results concerning usefulness of various entangled states in communication complexity reduction protocols: [LPB1-10]: Properties of states of many qubits, which arise after sending certain entangled states via various noisy channels (white noise, colored noise, local depolarization, dephasing, and amplitude damping). Entanglement of these states and their ability to violate certain classes of Bell inequalities are reported. States which violate them allow a higher than classical efficiency in solving related distributed computational tasks with constrained communication. This is a direct property of such states not requiring their further modification via stochastic local operations and classical communication, such as entanglement purification or distillation procedures. We report on families of multi-particle states which are entangled but nevertheless allow the local realistic description of specific Bell experiments (that is can be emulated with classical communication processes). For some of them, the gap between the critical values for entanglement and violation of Bell inequality remains finite even in the limit of infinitely many qubits. [GLZ1-10]: This paper covers the cases which cannot be addressed by analytical reasonings. We resort to a very extensive numerical analysis of such cases. Because of the numerical nature of the study, we solely analyze the non-classicality of correlations of some important families of multiqubit entangled states (required in many quantum informational protocols as, for example, in cryptography, secret sharing and the reduction of communication complexity).

3.5.1 cont'd							The part concerning reference-frames in entanglement detection was not fully reached in the previous reporting period. This is now reached. In a preliminary work published by our consortium [F. Costa, N. Harrigan, T. Rudolph, and C. Brukner, New J. Phys. **11**, 123007 (2009)] the following was established: Quantum experiments usually assume the existence of perfect, classical, reference frames, which allow for the specification of measurement settings (e.g. orientation of the Stern Gerlach magnet in spin measurements) with arbitrary precision. If the reference frames are "bounded" (i.e. quantum systems themselves, having a finite number of degrees of freedom), only limited precision can be attained. Using spin coherent states as bounded reference frames their minimal size needed was found, which allows for violations of local realism for entangled spin systems. For composite systems of spin-1/2 particles reference frames of very small size are sufficient for the violation; however, to see this violation for macroscopic entangled spins, the size of the reference frame must be at least quadratically larger than that of the spins. Unavailability of such reference frames gives a possible explanation forthe non-observance of violation of local realism in everyday experience. The physics of quantum reference frames was further developed in [ABP1-10]. Several scenarios were investigated involving a small number of quantum particles, whereby one promotes one of these particles to the role of a quantum observer. The question was asked: what is the description of the rest of the system, as seen by this observer? Interesting aspects of such questions were highlighted by presenting a number of apparent paradoxes. By unraveling these paradoxes, one obtains a better understanding of the physics of quantum reference frames.

3.5.2	Quantumwalk-based approximation algorithm beating classical sampling	3.5	UoB	31/01/2011	Yes	31/01/2012	The first results were reported in the manuscript [YNW1-10], entitled "Simulation of classical thermal states on a quantum computer: A renormalization group approach". In this work, a hybrid quantum-classical algorithm has been suggested to simulate thermal states of classical Hamiltonians on a quantum computer. The scheme employs a sequence of locally controlled rotations, building up the desired state by adding qubits one at a time. A class of classical models has been identified for which our method is efficient and avoids potential exponential overheads encountered by Grover-like or quantum Metropolis schemes. The algorithm also gives an exponential advantage for two-dimensional Ising models with magnetic field on a square lattice, compared with the previously known Zalka's algorithm. On top of this work, we studied classical Markov Chain Monte Carlo algorithms, which form the basis of many classical approximation algorithms. One of them is the algorithm for approximating the permanent. It is based on a mapping to counting perfect matchings in a graph, which can in turn be done by evaluating the partition function of the Potts model. This is done by estimating ratios of partition function values at a sequence of decreasing temperatures (according to a cooling schedule). Our previous general work on approximating partition functions allowed us to quantize this algorithm, while it was necessary to add several specific ingredients. The state of the art permanent-approximating algorithm involves an adaptive cooling schedule, while it requires adjustments of the parameters (weights) of the Markov Chains involved along the way. We have solved these obstacles, and found a quantum algorithm for approximating the permanent within (1+-error)P(M) working in O(n5+n4/error) steps, compared to O(n7+n6/error2) steps for the classical algorithm, up to logarithmic factors.

3.5.3	Identification of a new and simpler translation between the adiabatic QC model and the circuit model	3.5	UoB	31/01/2012	Yes	31/01/2012	We have found two novel ways of connecting adiabatic quantum computation to other computational models. First, we translated the circuit model to a Hamiltonian computation model (based on the Feynman computer) with 2-body, constant-norm terms, which can be made geometrically local. This Hamiltonian can be also used for adiabatic quantum computation. What is interesting about it is that it does not use the usual perturbation gadgets to achieve 2-locality, and thus the energy gap for this translated Hamiltonian does not suffer from this overhead. To prove this computational model is working, we have investigated the mixing time for continuous-time quantum walks on necklace graphs. The second contribution is a quantum annealing algorithm for the glued-trees traversal problem (one of the few problems for which we have an exponential separation between classical and quantum computing). A simple translation from the quantum walk algorithm to an adiabatic one is not working, as the lowest energy gap becomes exponentially small. However, we came up with a new annealing schedule involving 3 terms, which although having two exponentially small gaps, these do not hinder but rather help the algorithm. A crucial part of the algorithm is symmetry in the evolution, and that the relevant gap between the second and third energy levels is lower bounded by an inverse polynomial in the system size. It is also very interesting that our algorithm only uses stochastic Hamiltonians. [arXiv:111.4433 accepted in IJQI, arXiv:1002.0420 submitted, third manuscript in preparation Feb. 2012].

3.5.4	Result illustrating the computational power of mixed state processing	3.5	IPSAS	31/01/2012	No	31/01/2013	This milestone has been partially achieved: [CM1-11] A scheme to evaluate computation fidelities within the one-way model is developed and explored to understand the role of correlations in the quality of noisy quantum computations. The formalism is promptly applied to many computation instances, and unveils that a higher amount of entanglement in the noisy resource state does not necessarily imply a better computation. [RH1-11] We consider a generalization of the standard oracle model in which the oracle acts on the target with a permutation which is selected according to internal random coins. We show new exponential quantum speedups which may be obtained over classical algorithms in this oracle model. Even stronger, we describe several problems which are impossible to solve classically but can be solved by a quantum algorithm using a single query; we show that such infinity-vs-one separations between classical and quantum query complexities can be constructed from any separation between classical and quantum query complexities (in the unbounded-error regime). We also give conditions to determine when oracle problems - either in the standard model, or in any of the generalizations we consider - cannot be solved with success probability better than random guessing would achieve. In the oracle model with internal randomness where the goal is to gain any nonzero advantage over guessing, we prove (roughly speaking) that k quantum queries are equivalent in power to 2k classical queries.
3.5.5	Development of models of hybrid quantum-classical computations	3.5	IPSAS	31/01/2012	No	31/01/2013	There has been significant progress reported, but to date, the milestone has not quite yet been reached: Applying quantum algorithmic approaches to classical problems directly does not always produce speedups. One of the examples of this is the quantization of the algorithm for approximating the permanent. Although one obtains a square-root speedup using quantized Markov chains instead of regular random walks, one can lose this speedup by trying to quantize other parts of the algorithm (specifically, for sampling to adjust the weights of the MC's required for the success of the algorithm). A hybrid quantum-classical approach is used, with preparing coherent encodings of Gibbs states and then classical processing of the results to adapt the algorithm along an adaptive cooling schedule. This approach retains (at least some of) the speedup, while allowing the second part of the algorithm (approximating using phase estimation, based on a sequence of quantum Markov chains) to be sped up as well. A draft in already in progress.
4.1.1	Annual Steering Committee meeting	4.1	UWAW	31/01/2011	Yes	08/07/2010	The Steering Committee Meeting was organized during the project meeting in Oxford on 8th July 2010.

4.1.2	Steering Committee Meeting	4.1	UWAW	31.01.2012	Yes	09/02/2012	The Steering Committee Meeting was organized during the project meeting in Barcelona on 9th February 2012.
4.2.1	Project kick-off meeting	4.2	UWAW	28/02/2010	Yes	6/03/2010	Q-ESSENCE project kick-off meeting was organized by coordinator and the OEAW, in Vienna on 5-6th of March 2010. It included presentations related to management, meetings and training and dissemination and scientific part of the project. A few day delay occurred due to the optimal choice of the project meeting date, accepted by all the partners.
4.2.2	General Assembly	4.2	UWAW	31/01/2011	Yes	28/01/2011	Q-ESSENCE partners gathered already three times during the first year of the project: at the kick-off meeting (March 2010), mid-term meeting in Oxford (July 2010) and reporting meeting in Munich (January 2011). Presentations are available on the intranet.
4.2.3	General Assembly	4.2	UWAW	31/01/2012	Yes	09/02/2012	Q-ESSENCE partners had general face-to-face meetings two times during the second year of the project:, mid-term meeting in Zurich (September 2011) and reporting meeting in Barcelona (February 2012). Presentations are available on the intranet.
4.3.1	Annual press release	4.3	UOXF	31/01/2011	Yes	31/01/2011	The first Q-ESSENCE press release was prepared by the beneficiary UOXF.DU and distributed among the entire consortium. It is available at the project website / (Results / Communications).
4.3.2	Annual Press release	4.3	UOXF	31/01/2012	Yes	31/01/2012	The second Q-ESSENCE press release was prepared by the beneficiary UOXF.DU and will be distributed among the entire consortium.
4.4.1	Formation of MTC	4.4	IPSAS	31/03/2010	Yes	05/03/2010	The Meetings and Training Committee (MTC) includes Antonio Acin ICFO, Spain), Caslav Brukner (OEAW, Austria), Susana Huelga (UULM, Germany), Brian Smith (UOXF.DU, United Kingdom), Mario Ziman (IPSAS, Bratislava). Its activities are managed and coordinated by Mario Ziman. The MTC was established during the project kick-off meeting in Vienna (5-6/03/2010).
4.4.2	Annual MTC planning meeting	4.4	IPSAS	31/01/2011	Yes	29/01/2011	The planning meetings are part of regular Q-ESSENCE review meetings. The first took place during the kick-off meeting in Vienna (5-6/03/2010). The following one took place during the annual internal project meeting organized in Munich (28-29/01/2011). In addition, MTC is in regular contact via e-mail to handle current matters.
4.4.3	Annual MTC planning meeting	4.4	IPSAS	31/01/2012	Yes	09/02/2012	The annual MTC planning meeting took place during the Q-ESSENCE project meeting in Barcelona, 9thFebruary 2012. The members discussed the current issues related to supporting scientific events and mobility, presented the summary of the activity to the project partners and suggested ways to enhance the usage of the funding, in an optimal way.

3.2.3 Project management during the period

Project management and coordination of RTD activities

Management tasks within the Q-ESSENCE project are conducted by the Q-ESSENCE coordinator, University of Warsaw (UWAW). The coordinating person is Prof. Konrad Banaszek and the management office is led by Ms Anna Zuchowska (from 1st July 2011, before that date by Dr Agata Checinska). The management tasks for the entire project include communication with the European Commission, financial management, project meetings organization, administrative support.

Legal matters

In the beginning of the second year of the Q-ESSENCE project the annual report for the first year of project duration was presented to the European Commission, together with the financial report. Both reports received positive reviews allowing smooth transition to the second year of project execution.

The Coordinator prepared and managed the documentation related to the second amendment to the grant agreement. The Coordinator and the representative of European Commission signed the amendment on the 1st November 2011. The role of the second amendment was to terminate participation of University of Potsdam in the project (date of termination: 31st January 2012) and to add two new institutions: Freie Universitaet Berlin and University of Cambridge. The changes were a consequence of two principal investigators taking up new academic posts: Prof. Jens Eisert (also SP3 leader) and Prof. Richard Jozsa.

During the second year of the project duration there has been a personal changes on the European Commission side of the project. From 07th of December 2011 Mr David Guedj has become the new Project Officer for Q-ESSENCE project (letter no. Ref. Ares (2011)1321294_07/12/11) and was replaced by Mr Daniel Pasini from 1st of March 2012 (letter no. Ref. Ares(2012)201202-22/02/2012) afterwards.

Consortium agreement

In year 2, a modification of the consortium agreement has been prepared due to the termination/accession of the beneficiaries, a consequence of the second amendment to the grant agreement.

All changes were accepted by the General Assembly through consensus.

Further prospects of an enlargement of the consortium

At this point no steps are planned towards enlarging the consortium.

Participant's portal & NEF

The coordinator communicates with the Q-ESSENCE Project Officer on the issues related to the NEF sessions. If required, the coordinator advised the beneficiaries about using the NEF system for reporting.

Assistance to Meetings and Training Committee (MTC)

The coordinator assists MTC and manages its budget. In the second year of the project the coordinator used the mobility scheme to manage the documentation related to scientific mobility. The coordinator manages also the financial documentation related to the support of scientific meetings, once the approval of MTC is given. The consortium aimed to intensify the usage of the mobility scheme in the second year and continues to do so in the third year of the project duration.

Reporting

Building on the successful reporting strategy from the year 1 of the project duration, the relevant preparations for the second report we undertaken. This included applying hierarchical lines of communication, involving the coordinator, Sub-Project Leaders, Workpackage Leaders, and individual Workpackage beneficiaries to enable efficient transfer of information and monitoring consistency.

Future amendments

At this point, the consortium foresees no further amendments to the grant agreement.

Financial management

The first financial report was submitted in the month 14 of the project and was accepted by the European Commission. The interim payment received by the coordinator was then distributed among the project partners according to the requests submitted in beneficiaries Form Cs. The only delay of the money transfer occurred in case of beneficiary LUH. This transfer was delayed owing to incorrect bank details of LUH account received by the coordinator. The delay did not generate any problems in the execution of the project.

Financial management & New Partners

Once the amendment was signed, University of Cambridge, as a new beneficiary in Qessence project received a pre-payment of 24 901 EUR following the same algorithm as the one used to calculate first transfers for other beneficiaries.

Freie University of Berlin together with University of Potsdam agreed to share the initial budget of UP.

Financial assistance to MTC

Coordinator manages the budget of MTC. In the second year of the project University of Warsaw processed financial documentation related to the scientific mobility of students and young researchers, as well as support for scientific meetings.

Communication

The coordinator serves as a point of contact with the Q-ESSENCE Project Officer on a regular basis. The communication refers to project documentation, outcomes/deliverables, interpretation of guidelines, reporting, events and website. When required, the information and documents are distributed among project partners.

Communication within consortium

Coordinator communicates with Q-ESSENCE beneficiaries on a regular basis (e-mail/telephone/in person during meetings). Current list of contact information is maintained, accessible for all partners. The coordinator distributes the information related to the consortium and its documentation, as well as information received from the Commission, and responds to any inquiries related to the project. All partners are informed about project meetings, documentation, reporting procedure, press releases, and calls. If necessary, the coordinator conducts voting among project partners by electronic means.

In the case of changes to the documents and consortium related decisions, when acceptance of the General Assembly is required, the coordinator gathers necessary information/acceptance. Changes to the consortium agreement and amendment to the grant agreement also required an official acceptance, given by the General Assembly. The coordinator keeps the record of above-mentioned decisions. According to specific needs, the coordinator communicates with either scientific or administrative contact persons.

Intranet and website

Project partners participate in the project intranet available in the QUIE2T platform, related to the Q-ESSENCE website (http://www.qessence.eu). Additionally, Q-ESSENCE internal intranet is available.

The Q-ESSENCE internal intranet is accessible at http://qessence.fuw.edu.pl. In the intranet (accessible also by the Project Officer), partners have access to the current project documentation. After each project meeting the coordinator collects the material/presentations and uploads it to the intranet. That way detailed meeting minutes are made available. Project documents are also accessible in the intranet, in the management section.

Project meetings, dates and venues

Cluster Review / FET QIFT Open Day, 14/15.04. 2011, Warsaw

This meeting was organized by Q-ESSENCE coordinator, University of Warsaw, together with coordinators of other large-scale integrating project funded via Call FP7-ICT-2009-4: AQUTE and SOLID, as well as with additionally QUIE2T Coordination Action and National Laboratory for Quantum Technologies, a Polish infrastructure project supported by European Regional Development Funds.

The review of the three projects took place on 14th of April, the FET QIFT Open Day on 15th of April. FET QIFT Open Day was an occasion to promote all the projects among wider audience and discuss FET related issues. The audience included authorities of the University of Warsaw and representatives of Polish science funding bodies.

Website: http://qift2011.fuw.edu.pl/

Q-ESSENCE meeting: 9th September 2011, Zurich, Switzerland

The meeting included verification of scientific achievements in the second reporting period with the summary related to each workpackage. Reports on the activities of management and MTC were presented as well. A presentation from the meeting is available at Q-ESSENCE intranet.

Q-ESSENCE meeting: 9-10th February 2012, Barcelona, Spain

This meeting included scientific and management presentations, with the summary related to the reporting on each workpackage, including report on the activity of MTC. Presentations from the meeting are available at Q-ESSENCE intranet.

Cluster Review: 18-20th April 2012, Mainz, Germany

This meeting is organized by AQUTE coordinator and co-organized by Q-ESSENCE and SOLID coordinators. The meeting will include a review of the three projects and will be an occasion to promote all the projects among wider audience and discuss FET related issues.

Delays and deviations

Several milestones have been delayed as reported in the scientific part of the document. Corrective actions have been discussed during meetings and the project is considered to be on track to achieve all its objectives.

Development of the project website

Q-ESSENCE website is available at http://www.qessence.eu. It was updated with the relevant information related to the project evolution throughout the year.

Dissemination activities

Website

The public project website is available at the integrated platform of Coordination Action QUIE2T at http://www.qessence.eu. The website presents crucial information on the project and its results.

The information on the project goals and structure is provided. The partners are invited to participate in the QUIE2T platform, using it as a tool for information exchange. When necessary, the coordinator introduces modification in the description, related for example to the amendments to the grant agreement.

The information on the project meetings appears in the 'News' section. The latter presents also news on the relevant ICT calls, scientific highlights and Q-ESSENCE MTC calls. The MTC section of the website presents the detailed information on the calls, including rules for participation.

Along with preparations for the reporting in the last months of the second year of the project, the website was updated with respect to the project results. This refers to publications, presentations and media appearance (plus public talks). Q-ESSENCE Coordinator initiated the website update at the end of the second project year, continuing into the month 25-26 of the project duration. The publications announced on the website are there ones accepted or already published in the peer-reviewed magazines, which guarantees high scientific quality of the website. If not yet available, the preprints are used as a temporary means of communicating the results. The update of the website included also the list of public presentations (conferences, workshops, seminars, schools) and media appearances.

Information on the workshops organized by project beneficiaries is available at *Communications* section. To facilitate the communication in the consortium, the public website is linked to the Q-ESSENCE intranet.

Prior to the Cluster Review in April 2011, the relevant website of the meeting was created and announced on the Q-ESSENCE project website (http://qift2011.fuw.edu.pl).

Press release

The Coordinator together with beneficiary UOXF.DU (University of Oxford) works on the dissemination activities, including preparation of the project press release. The next press release was prepared by Dr KamnaPruvost and Dr Joshua Nunn. After the annual project meeting it will be distributed among project partners and announced on the project website. Section *Results* and its subsections *Communicatons / In the media*, contain materials related to the dissemination activities and press releases, available to the wider public.

Dissemination of project and its results

Q-ESSENCE partners are informed how to acknowledge the project in the publications and presentations, this includes the use of the project logo and local distribution of the project related information and highlights. The results of the project are presented

During the second year of the project, the consortium can claim a significant number of publications, many of them published in the most prestigious scientific journals, acknowledging Q-ESSENCE (please refer to *Results / Publications* at project website). The scientists within Q-ESSENCE consortium participate in various activities, providing the dissemination of the entire QIFT community. The list of appearances is given in the *Results / In the media & Presentations* section at the Q-ESSENCE website.

Q-ESSENCE support is visible on the of the community's most popular portal, Quantiki.org (*About* section). In a similar fashion, the events supported through Q-ESSENCE Meetings & Training Committee are asked to acknowledge the support publicly, usually by the display of the project logo.

On the 15th of April 2011 in Warsaw the Coordinator of Q-ESSENCE, together with the coordinators of other IPs: AQUTE and SOLID, organized the FET QIFT Open Day. The event was an opportunity to present the three projects to the wider audience. The details of the meeting can be found at http://qift2011.fuw.edu.pl/qift2011.html and the list of presentations can be found at http://qurope.eu/content/fet-qift-open-day-april-15th-2011-presentations.

A publishable summary, a part of the annual project report, was submitted to European Commission, with the aim of disseminating the project and highlighting its results.

Industrial Forum of Entanglement-Enabled Technologies

This year the Q-ESSENCE project assisted in the organization of the industrial session at the QIPC Conference. This is the conference for quantum information in Europe and our target vehicle for previous industrial sessions. Previous years have seen a focus on quantum communication, this being one of the more advanced areas for quantum technologies, and we have brought people in from outside of the community. This year however it was decided to have a mix of "external" and "internal" speakers covering computing as well as communication, on the industry side and from within the community we brought forward the idea of quantum metrology, one of the central themes of Q-essence. The speakers were:

- Dr Walter Riess, Head of the Science and technology Department of IBM-Zurich,
- DrGrégoireRibordy, CEO of IDQ
- Dr Jürgen Appel from the Niels Bohr Institute in Copenhagen
- Dr Bruno Sanguinetti from the Group of Applied Physics in Geneva.

It is notable that three out of four speakers originated from Q-ESSENCE institutions. The session provided an excellent forum in which to illustrate how we are looking to take fundamental concepts to the real world and to industry.

Meetings and training

The main task of QESSENCE Meeting and Training Committee (MTC) is to make decision on proposals for research mobilities of individuals and on proposals for supports of scientific meetings (conferences, workshops and schools). The application forms for both these activities are available on the QESSENCE public website (http://qurope.eu/projects/qessence/committee). The activities of MTC are coordinated by Mario Ziman.

The activities of MTC are in accordance with the schedule. According to the plan we supported the organization of a summer school in Glasgow, organized Cluster Review meeting in Warsaw, internal review meetings and several focused research workshops on the QESSENCE goals.

The meetings and training committee already made decisions on several workshops scheduled for the third year of the project. The mobility scheme for young researchers was used at a slower pace than anticipated at the beginning of the project. The MTC and the Coordinator undertook efforts to raise awareness about the mobility scheme for young researchers which resulted in an increased number of applications for 2012. In parallel, however, the project received applications to support a number of high-quality scientific meetings in 2012 which will undoubtedly raise the visibility of the Q-ESSENCE project and enhance the scientific exchange. Therefore there is a consensus that the tentative division of funds between meetings support and the mobility scheme should be revised in favour of the former activity. Given that the project is entering the last year of its duration, the most convenient solution is to create a joint fund to create both types of activities.

Supported meetings in 2011:

1) QIP 2011 Workshop, Singapore 5,000 EUR
2) Quantum Science and Technologies, Rovereto, Italy 10,000 EUR
3) Scottish Universities Summer Schools in Physics: Quantum Information and Coherence, Glasgow 9,350 EUR
4) Cluster Review 2011, Warsaw, Poland, 2,250 EUR
5) Signatures of Quantumness in Complex Systems, Nottingham, UK, 2,500 EUR
6) CEQIP 2011, Znojmo, Czech Republic, 2,900 EUR
7) Workshop on superconducting single-photon detectors, Eindhoven, Netherlands, 2,500 EUR
8) International Symposium “Quantum Metrology with Photons and Atoms”, Toruń, Poland 1,000 EUR
9) QIPC 2011, Zurich, Switzerland 10,000 EUR

Supported mobilities in 2011

1) Tom Lawson, UoB→ Id Quantique, 200 EUR
2) Marcin Pawłowski, UoB→ ICFO 800 EUR

Q-ESSENCE also supports the organization of the next Cluster Review / FET QIFT Open Day which will take place in Bingen, Germany, 18-20 April 2012.

3.4 Explanation of the use of the resources

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 1 (UWAW) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
1.1, 1.4, 2.3, 3.4	RTD - Personnel direct costs	85 075,27 €	Remuneration of staff involved in the RTD activities (WP 1.1 – 6,4 PM; WP 1.4 – 3,2 PM; WP2.3- 8,7 PM; WP3.4 – 14,3 PM)
1.1, 1.4, 3.4	RTD - travel costs	7 466,26 €	Attendance to conferences and project meetings
1.1, 1.4, 2.3, 3.4	RTD – research equipment	6 613,00 €	Two single-photon detectors for the experiments executed in the project and minor laboratory consumables
4.2	MNG - Personnel direct costs	26 323,08 €	Project manager (10,4 person-months), financial management (1,24 person-months)
4.1, 4.2	MNG - travel costs	1 808,31 €	Cost of travel necessary to carry out project management tasks
4.2	MNG - Subcontracting	1 735,36 €	Organization of project meetings, minor office tasks
4.4	Other direct cost	24 882,74 €	Support for scientific meetings (part of the joint collaborative task) • QIPC2011 Zurich, Switzerland: 10 keuro, • QMPA Torun, Poland 1keuro, • Summer School Glasgow,UK: 9 keuro • SQCS 2011 Nottingham, UK: 2,5 keuro • N-SSPD2011Eindhoven, Netherlands: 1euro • Mobility Scheme: 1 keuro
4.4	Subcontracting	21 520,68	Organization of scientific events • QIP2011 Singapore 5keuro; • Quantum Science and Technologies, Rovereto, Italy 10 keuro; • N-SSPD2011Eindhoven, Netherlands: 1,4 euro, • CEQIP Znojmo, Czech Republic: 2,9 keuro, • Cluster Review,Warsaw, Poland: 2keuro)
	Indirect costs	91 299,00 €	Special transitional flat rate
	TOTAL COSTS	266 723,70 €	

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 2(UULM) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount	Explanations
1.1, 1.4, 3.3	Personnel costs	69 733,15 €	Salaries of postdocs (deVega 2months, Machnes 13months and Cramer 1month) and one lab technician for 18 months each
1.1, 1.4, 3.3	Other direct costs	828,97 €	Computing Equipment, Office consumables, Literature,
1.1, 1.4, 3.3	Other direct socts	7 411,71 €	Travel costs: conferences, visitors
	Indirect costs	46 784,30 €	Special transitional flat rate
	TOTAL COSTS	124 758,13 €	

TABLE 3.3 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 3 (UNIGE) FOR THE PERIOD 01/02/2010 – 31/01/2011

Work Package	Item description	Amount	Explanations
1.1, 2.1, 2.2, 2.3, 2.4, 2.5	Personnel costs	123 215,00€	Partial salaries of 3 postdoctoral students and 2 PhD students - 22 PM in total
1.1, 2.1, 2.2, 2.3, 2.4, 2.5	Consumables	4 678,00€	Consumables - electronic (diodes, resistors, switches) and optical (lenses, mirrors, filters and opto-mechanical supports etc) components.
1.1, 2.1, 2.2, 2.3, 2.4, 2.5	Travel and subsistence	4 105,00€	Travel for project meetings
1.1, 2.1, 2.2, 2.3, 2.4, 2.5	Remaining direct costs	1 620,00€	publication costs and depreciation on equipment
	Indirect costs	80 170,00€	Special transitional flat rate
	TOTAL COSTS	**213 788,00€**	

TABLE 3.4 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 4 (OEAW) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount	Explanations
2.5	Personnel costs	15 039,15 €	Salaries of CaslavBrukner from 02/2011-01/2012
2.5	Personnel costs	49 274,30 €	Salaries of Johannes Koflerfrom 02/2011-10/2011
3.4, 3.5	Personnel costs	17 210,87 €	Salaries of BorivojeDakicfrom 02/2011-07/2011
1.3	Personnel costs	18 845,66 €	Salaries of Stephen Minter from 10/2011-01/2012
	Travel costs	8 882,46 €	Travel costs for project-related tours
	Travel costs guests	560,14 €	Travel costs for project-related tours
	Indirect costs	109 812,58 €	
	TOTAL COSTS		

TABLE 3.4.1 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 4 (OEAW) FOR THE PERIOD 01/02/2010 – 31/01/2011 ADJUSTMENT

Work Package	Item description	Amount	Explanations
3.5	Overhead costs Period 1	572,90 €	Overhead/ indirect costs - Brukner
3.4	Overhead costs Period 1	2 770,59 €	Overhead/ indirect costs - Dakic
2.5	Overhead costs Period 1	11 656,57 €	Overhead/ indirect costs - Kofler
	Indirect costs	15 000,06€	
	TOTAL COSTS	**15 000,06€**	

TABLE 3.5 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 5 (UCPH) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
3.4	Personnel direct costs	15 319,00 €	Salary of Jean – Baptiste Beguin
	Indirect costs	9 191,00 €	Special transitional flat rate
	TOTAL COSTS	**24 510,00 €**	

TABLE 3.6 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 6 (IPSAS) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
1.3, 3.2, 3.3, 3.5	Personnel direct costs	55 442,20 €	Salaries of - principal investigator: Mario Ziman - professor: Vladimir Buzek - postdocs: Beatrix Hiesmayr, Daniel Nagaj, Daniel Reitzner, Peter Stano, Peter Rapcan, Andrej Gendiar, Michal Sedlak - PhD students: Peter Rapcan, Tomas Rybar, Michal Daniska 22,44 PM in total (WP 1.3 – 3,74PM; WP 3.2 – 2,53PM; WP 3.3 – 6,09PM; WP 3.5 – 10,08PM)
4.2	Personnel direct costs	1619,40€	Salaries of management
3.5	Personnel direct costs - adjustments to previous period	332,00 €	Salaries of - PhD student: Peter Rapcan
	Indirect costs	31 255,91 €	Special transitional flat rate
	TOTAL COSTS	**88 649,51 €**	

TABLE 3.7 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 7 (UOXF.DU) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
2.3	Personnel direct costs	14 987,37 €	Personnel Costs for T. Champion (11 personmonths)
2.3	Other Direct Costs	8 950,21 €	Smaller items to build up & run experiments, including mirrors, lenses, mounts and other opto-mechanical components.
2.3	Other Direct Costs	3 064,21 €	PI & Post-Doc's - Winter School, Geneva, Munich Meetings / Summer Schools / Talks at Conferences
	Indirect costs	16 200,00 €	Special transitional flat rate
	TOTAL COSTS	43 201,79 €	

TABLE 3.8 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 8 (UOB) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
1.2, 1.4, 2.2, 2.3, 2.5	Personnel direct costs	56 098,78€	6% Salary for John Rarity for entire period, 100% salary for Dr Xiao-Qi Zhou (Researcher) for 6 months, 21.5 months of project studentships
1.2, 1.4, 2.2, 2.3, 2.5	Consumables	2 930,63€	General Project Consumables
1.2, 1.4, 2.2, 2.3, 2.5	Travel	13 248,95€	Travel to project meetings (Brussels, Warsaw, Geneva), conference attendance and general project travel
	Indirect costs	43 367,02€	Special transitional flat rate
	TOTAL COSTS	**115 645,38€**	

TABLE 3.9 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 9 (LMU) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
1.1; 1.2; 1.4; 2.1; 2.3; 2.5	Personnel direct costs	60 732,87 €	Salaries of PhD Students: Ortegel 12 PM, Krischek 2 PM, Liebermeister 6 PM, Krug 4.5 PM, Marjenburgh 4.5 PM, 1 Student Research Assistant 4PM
1.1, 1.2, 1.4,2.1,2.3, 2.5,	Consumables	31 446,43 €	Electronical and Optical Components,
1.1; 1.2; 1.4; 2.1; 2.3; 2.5	Travel	4 821,36 €	Project Meetings, International Conferences, Scientific Collaboration
	Indirect costs	58 200,40 €	Special transitional flat rate
	TOTAL COSTS	**155 201,06 €**	

TABLE 3.10 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 10 (MPL) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
3.1	Personnel direct costs	59 323,89 €	Salary of one PhD student (12 PM)
3.1	Other direct costs	278,20 €	Travel cost
	Indirect costs	83 053,45 €	
	TOTAL COSTS	142 655,54 €	

TABLE 3.11 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 11 (LUH) FOR THE PERIOD 01/02/2011– 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
1.1; 1.2; 3.1,	Personnel direct costs	38 692,96 €	Salaries corresponding to 8 person months
1.1; 1.2; 3.1, 3.2; 3.5	Other direct cost	755,00 €	travel (Q-ESSENCE annual meeting April 2011 + Munich Feb. 2011)
1.1; 1.2; 3.1	Other direct cost	5 752,50 €	Adjustable holders for mirrors and lenses
1.1, 1.2, 3.1	Other direct cost	1 496,00 €	consumables
1.1, 1.2, 3.1	Other direct cost	1 200,00 €	mirror flip mounts
1.1	Other direct cost	2 145,00 €	laser crystals
	Indirect costs	30 024,88 €	Special transitional flat rate
	TOTAL COSTS	80 066,34 €	

TABLE 3.12 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 12 (UP) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in €with 2 decimals	Explanations
1.2, 1.3, 3.1, 3.2, 3.3, 3.4, 3.5	Personnel direct costs	17 628,32 €	Salaries for 1 PhD student (4 PM)
1.2, 1.3, 3.1, 3.2, 3.3, 3.4, 3.5	Personnel direct costs	52 886,77 €	Salaries for 1 PostDoc (12 PM)
4.2	Personnel direct costs	400,31€	Salaries for a permanent administrative staff member (14 h)
1.2, 1.3, 3.1, 3.2, 3.3, 3.4, 3.5	Other direct costs- Travel	10 722,08 €	Diverse project meetings and conferences, e.g. in Dresden (March 2011), Hannover (February 2011), Finnland (December 2010), QIP 2011 Conference in Singapore, Squint Meeting
3.1	Other direct costs	25,17 €	Literature
	Indirect costs	48 997,59 €	Special transitional flat rate
	TOTAL COSTS	130 660,24 €	

TABLE 3.13 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 13 (TUM) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
3.4	Personnel direct costs	35 086,70 €	12 months 51% senior scientist (Dr Thomas Schulte-Herbrüggen),
3.4	Travel	1 914,02 €	3 international conferences,
	Indirect costs	22 200,43 €	*Special transitional flat rate*
	TOTAL COSTS	59 201,15 €	

TABLE 3.14 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 14 (UG) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
1.1, 1.4, 2.4, 3.2, 3.3, 3.4, 3.4	Personnel direct costs	33 907,76 €	Salaries of 1 researcher post-doc (12 personmonths), 1 lab technician (5,5 personmonths), 1 professor (1,54 personmonths)
3.5	Travel	2 890,98 €	Travel costs to Q-ESSENCE meeting, and to Q-ESSENCE partners and to scientific collaborators
	Indirect costs	22 079,24 €	Special transitional flat rate
	TOTAL COSTS	58 877,98 €	

TABLE 3.15 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 15 (ICFO) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
3.2; 3.3; 3,5	Personnel direct costs	36 805,18 €	Salary of 2 postdoctoral researchers for 12 months and 1 month each.
3.2; 3.3; 3,5	Remaining direct costs	3 501,15 €	Attendance to conferences such as: 13-15 April 2011, Review project Q-Essence, Warsaw.; 06-07 June 2011, Colloquium Vienna Graduate School, Vienna.; 01-12 August 2011, III Quantum Information School and Workshop, Paraty.; 12-25 june 2011, Quantum Information, Benasque. Consumables such as PC rentings.
	Indirect costs	24 183,80 €	Special transitional flat rate
	TOTAL COSTS	**64 490,13 €**	

TABLE 3.16 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 16 (TUE) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
2.1	Personnel direct costs	52 327,74 €	Salaries of 1 postdoctoral scientist Dr. Giulia Frucci (12 pm)
2.1	Remaining direct costs	1 796,67 €	Small laboratory electro-optical equipment and consumables. Travel for project meetings
	Indirect costs	54 697,78 €	Actual indirect costs
	TOTAL COSTS	**108 822,19 €**	

TABLE 3.17 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 17 (POLIMI) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
2.1	Personnel direct costs	18 748,60 €	Labor cost of faculty members (M. Ghioni - 0.75 month, I. Rech - 1 month, A. Gulinatti - 1 months) and one PhD student (F. Panzeri - 2.75 months). Total of 5.5 months.
2.1	Remaining direct costs	5 647,78 €	Optical components, silicon substrates, epitaxial growth process. Travelling costs.
	Indirect costs	9 768,02 €	52.1% of personnel costs
	TOTAL COSTS	**34 164,40 €**	

TABLE 3.18 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 18 (ULEEDS) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
1.4 2.4	Personnel direct costs	44 940,93€	Salary of DrJaewooJoo (researcher) for 12PM (WP 1.4- 9,5 PM, WP2.4 – 2,5 PM)
1.4 2.4	Remaining direct costs (Travel)	4 969,50 €	QIP Singapore Conf in Feb 11 (Jaewoo, wp14), QPIC in Zurich Oct 11 (Jaewoo wp14), Review meeting in Warsaw May 2011 (Jaewoo (wp14) and Tim (wp24)) and visit to Imperial College in London Nov 2010 (item not charged to grant until after reporting period closed)
	Indirect costs	29 946,26 €	Special transitional flat rate
	TOTAL COSTS	**79 856,69 €**	

TABLE 3.19 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 19 (TREL) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
2.1, 2.2, 2.3, 2.5	Personnel direct costs	52 028,00 €	R&D staff working in WP2
2.1, 2.2, 2.3, 2.5	Travel	732,00 €	Travel to project meeting in Warsaw (April 2011)
2.1, 2.2, 2.3, 2.5	Consumables	11 908,00 €	Optics, fibre optics, component mounts etc
	Indirect costs	41 622,00 €	Actual indirect costs
	TOTAL COSTS	**106 290,00 €**	

TABLE 3.20 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 20 (IDQ) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
2.1	Personnel direct costs	43 223,81 €	Salaries: test engineer (1.3 man x month), software engineer (2.3 man x month), optical engineer (1.5 man x month), hardware engineer (0.7 man x month),physicist (0.2 man x month)
2.1	Electronic boards and components	6 262,48 €	Cost of the electronic boards and components for the development of 2 single-photon detection modules
	Indirect costs	29 691,77 €	Special transitional flat rate
TOTAL COSTS		**79 178,06 €**	

TABLE 3.21 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 21 (MPD) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
2.1	Personnel direct costs	41 892,25€	Labor cost of 1 senior engineer (Andrea Giudice) and 2 skilled technicians (Federico Picin and Georg Simmerle) for a total of 9.2 man months on WP21
2.1	Remaining direct costs	6 537,35€	IC fabrication, electronic components and travel costs
	Indirect costs	9 685,92€	20% STD flat rate
TOTAL COSTS		**58 115,52 €**	

TABLE 3.21.1 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 21 (MPD) FOR THE PERIOD 01/02/2010 – 31/01/2011 - ADJUSTMENT

Work Package	Item description	Amount in € with 2 decimals	Explanations
2.1	Personnel direct costs	5 189,00 €	Cost adjustment due to change in personnel hourly rate, now calculated using actual personnel working hours, as requested by an Auditor who verified us on another FP7 project
2.1	Other direct costs	-82,00 €	Travel costs minor correction
		1 021,00 €	20% STD flat rate
TOTAL COSTS		**6 128,00 €**	

TABLE 3.22 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 22 (MACQ) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
2.2, 2.3, 3.4, 3.5	Personnel direct costs	46 198,00€	Salaries of persons involved in the RTD activity
	Indirect costs	42 040, 00€	
	TOTAL COSTS	**88 238,00 €**	

TABLE 3.23 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 23 (UPB) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
1.1	Personnel direct costs	38 986,00 €	Salaries of 1 PhD student for 3,96 months and 1 PhD student for 4,62 months
1.1	Other direct costs (Travel)	4 237,00 €	travel costs: Summer School Glasgow, Conference Munich, Project meeting Warsaw
	Indirect costs	25 933,00 €	Special transitional flat rate
	TOTAL COSTS	**69 156,00 €**	

TABLE 3.24 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 24 (FUB) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
	Personnel direct costs	0,00 €	
	Other direct costs	0,00 €	
	Indirect costs	0,00 €	
	TOTAL COSTS	**0,00 €**	

TABLE 3.25 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 25 (UCAM) FOR THE PERIOD 01/02/2011 – 31/01/2012

Work Package	Item description	Amount in € with 2 decimals	Explanations
3.5	Personnel direct costs	10 106,00 €	Salary costs for Dr Skrzypczyk (3 person-months)
	Indirect costs	6 063,00 €	Special transitional flat rate
	TOTAL COSTS	**16 169,00 €**	

FP7 - Grant Agreement - Annex VI - Collaborative project

Summary Financial report - Collaborative project

Project acronym	Q-ESSENCE	Project nr	248095	Reporting period from	01/02/2011	to	31/01/2012	Page	1/1

Funding scheme	CP

				Type of activity								Total				
				RTD (A)		Demonstration (B)		Management (C)		Other (D)		Total (A+B+C+D)				
Benef. nr	If 3rd Party, linked to benef.	Adjustment (Yes/No)	Organisation Short Name	Total	Max EC Contrib.	Total	Max EC Contrib.	Total	Max EC Contrib.	Total	Max EC Contrib.	Total	Max EC Contrib.	Req. EC Contrib.	Receipts	Interest
1		No	UWAW	158,646	118,984	0	0	46,744	46,744	61,333	61,333	266,723	227,061	227,061	0	0
2		No	UULM	124,758	93,568	0	0	0	0	0	0	124,758	93,568	93,568	0	
3		No	UNIGE	213,788	160,341	0	0	0	0	0	0	213,788	160,341	160,341	0	
4		No	OEAW	298,278	223,708	0	0	0	0	0	0	298,278	223,708	223,708	0	
4		Yes (1)	OEAW	15,000	11,250	0	0	0	0	0	0	15,000	11,250	11,250	0	
5		No	UCPH	24,510	18,382	0	0	0	0	0	0	24,510	18,382	18,382	0	
6		No	IPSAS	85,527	64,145	0	0	2,590	2,590	0	0	88,117	66,735	61,005	0	
6		Yes (1)	IPSAS	531	398	0	0	0	0	0	0	531	398	398	0	
7		No	UOXF.DU	43,201	32,400	0	0	0	0	0	0	43,201	32,400	32,400	0	
8		No	UoB	115,646	86,734	0	0	0	0	0	0	115,646	86,734	86,734	0	
9		No	LMU	155,201	116,400	0	0	0	0	0	0	155,201	116,400	116,400	0	
10		No	MPL	142,655	106,991	0	0	0	0	0	0	142,655	106,991	106,991	0	
11		No	LUH	80,067	60,050	0	0	0	0	0	0	80,067	60,050	60,050	0	
12		No	UP	130,019	97,514	0	0	640	640	0	0	130,659	98,154	98,154	0	
13		No	TUM	59,201	44,400	0	0	0	0	0	0	59,201	44,400	44,400	0	
14		No	UG	58,878	44,158	0	0	0	0	0	0	58,878	44,158	44,158	0	
15		No	ICFO	64,489	48,366	0	0	0	0	0	0	64,489	48,366	48,366	0	
16		No	TUE	108,823	81,617	0	0	0	0	0	0	108,823	81,617	81,617	0	
17		No	POLIMI	34,164	25,623	0	0	0	0	0	0	34,164	25,623	25,623	0	
17		Yes (1)	POLIMI	-359	-269	0	0	0	0	0	0	-359	-269	-269	0	
18		No	ULEEDS	79,857	59,892	0	0	0	0	0	0	79,857	59,892	59,892	0	
19		No	TREL	106,290	53,145	0	0	0	0	0	0	106,290	53,145	53,145	0	
20		No	idQ	79,177	59,382	0	0	0	0	0	0	79,177	59,382	59,382	0	
21		No	MPD	58,114	43,585	0	0	0	0	0	0	58,114	43,585	43,585	0	
21		Yes (1)	MPD	6,128	4,596	0	0	0	0	0	0	6,128	4,596	4,596	0	
22		No	MACQ	88,238	66,178	0	0	0	0	0	0	88,238	66,178	0	0	
23		No	UPB	69,156	51,867	0	0	0	0	0	0	69,156	51,867	51,867	0	
24		No	FUB	0	0	0	0	0	0	0	0	0	0	0	0	
25		No	UCAM	16,169	12,126	0	0	0	0	0	0	16,169	12,126	12,126	0	
Total				2,416,152	1,785,531	0	0	49,974	49,974	61,333	61,333	2,527,459	1,896,838	1,824,930	0	

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	UNIWERSYTET WARSZAWSKI	Participant Identity Code	999572294
Organisation Short Name	UWAW	Beneficiary nr	1

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	85,075	0	26,323	0	111,398
Subcontracting	0	0	1,735	21,521	23,256
Other direct costs	14,079	0	1,808	24,883	40,770
Indirect costs	59,492	0	16,878	14,929	91,299
Total costs	158,646	0	46,744	61,333	266,723
Maximum EU contribution	118,984	0	46,744	61,333	227,061
Requested EU contribution					227,061

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

3. Declaration of interest yielded by the pre-financing (to be completed only by the coordinator)

Did the pre-financing you received generate any interest according to Art.II.19 ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?	No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Prof. Wlodzimierz Lengauer
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	UNIVERSITAET ULM	Participant Identity Code	999882209
Organisation Short Name	UULM	Beneficiary nr	2

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	69,733	0	0	0	69,733
Subcontracting	0	0	0	0	0
Other direct costs	8,241	0	0	0	8,241
Indirect costs	46,784	0	0	0	46,784
Total costs	124,758	0	0	0	124,758
Maximum EU contribution	93,568	0	0	0	93,568
Requested EU contribution					93,568

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	PROF. M. PLENIO R. JERG
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	UNIVERSITE DE GENEVE	Participant Identity Code	999974650
Organisation Short Name	UNIGE	Beneficiary nr	3

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	123,215	0	0	0	123,215
Subcontracting	0	0	0	0	0
Other direct costs	10,403	0	0	0	10,403
Indirect costs	80,170	0	0	0	80,170
Total costs	213,788	0	0	0	213,788
Maximum EU contribution	160,341	0	0	0	160,341
Requested EU contribution					160,341

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Prof. Nicolas Gisin Henri Wacongne
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	OESTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN	Participant Identity Code	999823912
Organisation Short Name	OEAW	Beneficiary nr	4

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	100,370	0	0	0	100,370
Subcontracting	0	0	0	0	0
Other direct costs	9,443	0	0	0	9,443
Indirect costs	188,465	0	0	0	188,465
Total costs	298,278	0	0	0	298,278
Maximum EU contribution	223,708	0	0	0	223,708
Requested EU contribution					223,708

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Prof. Arnold SUPPAN, Prof. Anton ZEILINGER
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	Yes
To	31/01/2012	Adjustment relates to Period :	1

Legal Name	OESTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN	Participant Identity Code	999823912
Organisation Short Name	OEAW	Beneficiary nr	4

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	0	0	0	0	0
Subcontracting	0	0	0	0	0
Other direct costs	0	0	0	0	0
Indirect costs	15,000	0	0	0	15,000
Total costs	15,000	0	0	0	15,000
Maximum EU contribution	11,250	0	0	0	11,250
Requested EU contribution					11,250

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Prof. Arnold SUPPAN, Prof. Anton ZEILINGER
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	Kobenhavns Universitet	Participant Identity Code	999991043
Organisation Short Name	UCPH	Beneficiary nr	5

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	15,319	0	0	0	15,319
Subcontracting	0	0	0	0	0
Other direct costs	0	0	0	0	0
Indirect costs	9,191	0	0	0	9,191
Total costs	24,510	0	0	0	24,510
Maximum EU contribution	18,382	0	0	0	18,382
Requested EU contribution					18,382

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Max Holm
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	FYZIKALNY USTAV SLOVENSKEJ AKADEMIE VIED	Participant Identity Code	998915119
Organisation Short Name	IPSAS	Beneficiary nr	6

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	55,442	0	1,619	0	57,061
Subcontracting	0	0	0	0	0
Other direct costs	0	0	0	0	0
Indirect costs	30,085	0	971	0	31,056
Total costs	85,527	0	2,590	0	88,117
Maximum EU contribution	64,145	0	2,590	0	66,735
Requested EU contribution					61,005

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	RNDr. Stanislav Hlavac, CSc.
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	Yes
To	31/01/2012	Adjustment relates to Period :	1

Legal Name	FYZIKALNY USTAV SLOVENSKEJ AKADEMIE VIED	Participant Identity Code	998915119
Organisation Short Name	IPSAS	Beneficiary nr	6

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	332	0	0	0	332
Subcontracting	0	0	0	0	0
Other direct costs	0	0	0	0	0
Indirect costs	199	0	0	0	199
Total costs	531	0	0	0	531
Maximum EU contribution	398	0	0	0	398
Requested EU contribution					398

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?	No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	RNDr. Stanislav Hlavac, CSc.
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF OXFORD	Participant Identity Code	999984350
Organisation Short Name	UOXF.DU	Beneficiary nr	7

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	14,987	0	0	0	14,987
Subcontracting	0	0	0	0	0
Other direct costs	12,014	0	0	0	12,014
Indirect costs	16,200	0	0	0	16,200
Total costs	43,201	0	0	0	43,201
Maximum EU contribution	32,400	0	0	0	32,400
Requested EU contribution					32,400

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?	No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Stephen Barker
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	UNIVERSITY OF BRISTOL	Participant Identity Code	999974262
Organisation Short Name	UoB	Beneficiary nr	8

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	56,099	0	0	0	56,099
Subcontracting	0	0	0	0	0
Other direct costs	16,180	0	0	0	16,180
Indirect costs	43,367	0	0	0	43,367
Total costs	115,646	0	0	0	115,646
Maximum EU contribution	86,734	0	0	0	86,734
Requested EU contribution					86,734

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Julie Coombs
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	LUDWIG-MAXIMILIANS-UNIVERSITAET MUENCHEN	Participant Identity Code	999978433
Organisation Short Name	LMU	Beneficiary nr	9

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	60,733	0	0	0	60,733
Subcontracting	0	0	0	0	0
Other direct costs	36,268	0	0	0	36,268
Indirect costs	58,200	0	0	0	58,200
Total costs	155,201	0	0	0	155,201
Maximum EU contribution	116,400	0	0	0	116,400
Requested EU contribution					116,400

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Willibald Seitz
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	MAX PLANCK GESELLSCHAFT ZUR FOERDERUNG DER WISSENSCHAFTEN E.V.	Participant Identity Code	999990267
Organisation Short Name	MPL	Beneficiary nr	10

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	59,324	0	0	0	59,324
Subcontracting	0	0	0	0	0
Other direct costs	278	0	0	0	278
Indirect costs	83,053	0	0	0	83,053
Total costs	142,655	0	0	0	142,655
Maximum EU contribution	106,991	0	0	0	106,991
Requested EU contribution					106,991

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Gerd Leuchs
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	GOTTFRIED WILHELM LEIBNIZ UNIVERSITAET HANNOVER	Participant Identity Code	999981828
Organisation Short Name	LUH	Beneficiary nr	11

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	38,693	0	0	0	38,693
Subcontracting	0	0	0	0	0
Other direct costs	11,349	0	0	0	11,349
Indirect costs	30,025	0	0	0	30,025
Total costs	80,067	0	0	0	80,067
Maximum EU contribution	60,050	0	0	0	60,050
Requested EU contribution					60,050

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Henning Howind
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	UNIVERSITAET POTSDAM	Participant Identity Code	999854855
Organisation Short Name	UP	Beneficiary nr	12

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	70,515	0	400	0	70,915
Subcontracting	0	0	0	0	0
Other direct costs	10,747	0	0	0	10,747
Indirect costs	48,757	0	240	0	48,997
Total costs	130,019	0	640	0	130,659
Maximum EU contribution	97,514	0	640	0	98,154
Requested EU contribution					98,154

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?	No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Dr. Rita Engelbart / Dr. Regina Gerber
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	TECHNISCHE UNIVERSITAET MUENCHEN	Participant Identity Code	999977463
Organisation Short Name	TUM	Beneficiary nr	13

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	35,087	0	0	0	35,087
Subcontracting	0	0	0	0	0
Other direct costs	1,914	0	0	0	1,914
Indirect costs	22,200	0	0	0	22,200
Total costs	59,201	0	0	0	59,201
Maximum EU contribution	44,400	0	0	0	44,400
Requested EU contribution					44,400

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Mrs. Bauer
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	UNIWERSYTET GDANSKI	Participant Identity Code	999876001
Organisation Short Name	UG	Beneficiary nr	14

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	33,908	0	0	0	33,908
Subcontracting	0	0	0	0	0
Other direct costs	2,891	0	0	0	2,891
Indirect costs	22,079	0	0	0	22,079
Total costs	58,878	0	0	0	58,878
Maximum EU contribution	44,158	0	0	0	44,158
Requested EU contribution					44,158

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?	No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Bernard Lammek
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	Institut de Ciencies Fotoniques, Fundacio Privada	Participant Identity Code	999619436
Organisation Short Name	ICFO	Beneficiary nr	15

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	36,805	0	0	0	36,805
Subcontracting	0	0	0	0	0
Other direct costs	3,501	0	0	0	3,501
Indirect costs	24,183	0	0	0	24,183
Total costs	64,489	0	0	0	64,489
Maximum EU contribution	48,366	0	0	0	48,366
Requested EU contribution					48,366

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Ms. Dolors Mateu
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	TECHNISCHE UNIVERSITEIT EINDHOVEN	Participant Identity Code	999977269
Organisation Short Name	TUE	Beneficiary nr	16

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	52,328	0	0	0	52,328
Subcontracting	0	0	0	0	0
Other direct costs	1,797	0	0	0	1,797
Indirect costs	54,698	0	0	0	54,698
Total costs	108,823	0	0	0	108,823
Maximum EU contribution	81,617	0	0	0	81,617
Requested EU contribution					81,617

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Mr.K.Kopinga
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	POLITECNICO DI MILANO	Participant Identity Code	999879881
Organisation Short Name	POLIMI	Beneficiary nr	17

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	18,748	0	0	0	18,748
Subcontracting	0	0	0	0	0
Other direct costs	5,648	0	0	0	5,648
Indirect costs	9,768	0	0	0	9,768
Total costs	34,164	0	0	0	34,164
Maximum EU contribution	25,623	0	0	0	25,623
Requested EU contribution					25,623

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Prof. Gianantonio Magnani
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	Yes
To	31/01/2012	Adjustment relates to Period :	1

Legal Name	POLITECNICO DI MILANO	Participant Identity Code	999879881
Organisation Short Name	POLIMI	Beneficiary nr	17

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	-229	0	0	0	-229
Subcontracting	0	0	0	0	0
Other direct costs	0	0	0	0	0
Indirect costs	-130	0	0	0	-130
Total costs	-359	0	0	0	-359
Maximum EU contribution	-269	0	0	0	-269
Requested EU contribution					-269

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Prof. Gianantonio Magnani
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	UNIVERSITY OF LEEDS	Participant Identity Code	999975426
Organisation Short Name	ULEEDS	Beneficiary nr	18

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	44,941	0	0	0	44,941
Subcontracting	0	0	0	0	0
Other direct costs	4,970	0	0	0	4,970
Indirect costs	29,946	0	0	0	29,946
Total costs	79,857	0	0	0	79,857
Maximum EU contribution	59,892	0	0	0	59,892
Requested EU contribution					59,892

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Lee Johnstone
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	TOSHIBA RESEARCH EUROPE LIMITED	Participant Identity Code	999958548
Organisation Short Name	TREL	Beneficiary nr	19

Funding % for RTD activities (A)	50.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	52,028	0	0	0	52,028
Subcontracting	0	0	0	0	0
Other direct costs	12,640	0	0	0	12,640
Indirect costs	41,622	0	0	0	41,622
Total costs	106,290	0	0	0	106,290
Maximum EU contribution	53,145	0	0	0	53,145
Requested EU contribution					53,145

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?	No		
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?	No		
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?	No		
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Dr Shuichi Uchikoga
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	ID QUANTIQUE SA	Participant Identity Code	999662892
Organisation Short Name	idQ	Beneficiary nr	20

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	43,224	0	0	0	43,224
Subcontracting	0	0	0	0	0
Other direct costs	6,262	0	0	0	6,262
Indirect costs	29,691	0	0	0	29,691
Total costs	79,177	0	0	0	79,177
Maximum EU contribution	59,382	0	0	0	59,382
Requested EU contribution					59,382

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Gregoire Ribordy
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	MICRO PHOTON DEVICES S.R.L.	Participant Identity Code	999552700
Organisation Short Name	MPD	Beneficiary nr	21

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	20

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	41,892	0	0	0	41,892
Subcontracting	0	0	0	0	0
Other direct costs	6,537	0	0	0	6,537
Indirect costs	9,685	0	0	0	9,685
Total costs	58,114	0	0	0	58,114
Maximum EU contribution	43,585	0	0	0	43,585
Requested EU contribution					43,585

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?	No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Roberto Biasi
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	Yes
To	31/01/2012	Adjustment relates to Period :	1

Legal Name	MICRO PHOTON DEVICES S.R.L.	Participant Identity Code	999552700
Organisation Short Name	MPD	Beneficiary nr	21

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	20

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	5,189	0	0	0	5,189
Subcontracting	0	0	0	0	0
Other direct costs	-82	0	0	0	-82
Indirect costs	1,021	0	0	0	1,021
Total costs	6,128	0	0	0	6,128
Maximum EU contribution	4,596	0	0	0	4,596
Requested EU contribution					4,596

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Roberto Biasi
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	MACQUARIE UNIVERSITY	Participant Identity Code	996467906
Organisation Short Name	MACQ	Beneficiary nr	22

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	N/A

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	46,198	0	0	0	46,198
Subcontracting	0	0	0	0	0
Other direct costs	0	0	0	0	0
Indirect costs	42,040	0	0	0	42,040
Total costs	88,238	0	0	0	88,238
Maximum EU contribution	66,178	0	0	0	66,178
Requested EU contribution					

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?	No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Professor James A Piper
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	UNIVERSITAET PADERBORN	Participant Identity Code	999837492
Organisation Short Name	UPB	Beneficiary nr	23

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	38,986	0	0	0	38,986
Subcontracting	0	0	0	0	0
Other direct costs	4,237	0	0	0	4,237
Indirect costs	25,933	0	0	0	25,933
Total costs	69,156	0	0	0	69,156
Maximum EU contribution	51,867	0	0	0	51,867
Requested EU contribution					51,867

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Daniela Gerdes
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	FREIE UNIVERSITAET BERLIN	Participant Identity Code	999994826
Organisation Short Name	FUB	Beneficiary nr	24

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	0	0	0	0	0
Subcontracting	0	0	0	0	0
Other direct costs	0	0	0	0	0
Indirect costs	0	0	0	0	0
Total costs	0	0	0	0	0
Maximum EU contribution	0	0	0	0	0
Requested EU contribution					

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?			No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?			No
Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Peggy Martin
	Date & signature

FP7 - Grant Agreement - Annex VI - Collaborative project

Form C - Financial Statement (to be filled in by each beneficiary)

Project Number	248095	Funding scheme	Collaborative project
Project Acronym	Q-ESSENCE		

Period from	01/02/2011	Is this an adjustment to a previous statement ?	No
To	31/01/2012		

Legal Name	THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF CAMBRIDGE	Participant Identity Code	999977172
Organisation Short Name	UCAM	Beneficiary nr	25

Funding % for RTD activities (A)	75.0	If flat rate for indirect costs, specify %	60

1. Declaration of eligible costs/lump sum/flate-rate/scale of unit (in €)

	Type of Activity				
	RTD (A)	Demonstration (B)	Management (C)	Other (D)	Total (A+B+C+D)
Personnel costs	10,106	0	0	0	10,106
Subcontracting	0	0	0	0	0
Other direct costs	0	0	0	0	0
Indirect costs	6,063	0	0	0	6,063
Total costs	16,169	0	0	0	16,169
Maximum EU contribution	12,126	0	0	0	12,126
Requested EU contribution					12,126

2. Declaration of receipts

Did you receive any financial transfers or contributions in kind, free of charge from third parties or did the project generate any income which could be considered a receipt according to Art.II. 17 of the grant agreement ?	No
If yes, please mention the amount (in €)	

4. Certificate on the methodology

Do you declare average personnel costs according to Art.II.14.1 ?	No
Is there a certificate on the methodology provided by an independent auditor and accepted by the Commission according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €), if charged under this project	

5. Certificate on the financial statements

Is there a certificate on the financial statements provided by an independent auditor attached to this financial statement according to Art.II.4.4 ?	No

Name of the auditor		Cost of the certificate (in €)	

6. Beneficiary's declaration on its honour

We declare on our honour that:

- the costs declared above are directly related to the resources used to attain the objectives of the project and fall within the definition of eligble costs specified in Articles II.14 and II.15 of the grant agreement, and, if relevant, Annex III and Article 7 (special clauses) of the grant agreement;
- the receipts declared above are the only financial transfers or contributions in kind, free of charge, from third parties and the only income generated by the project which could be considered as receipts according to Art.II.17 of the grant agreement;
- the interest declared above is the only interest yielded by the pre-financing which falls whithin the definition of Art.II.19 of the grant agreement;
- there is full supporting documentation to justify the information hereby declared. It will be made available at the request of the Commission and in the event of an audit by the Commission and/or by the Court of Auditors and/or their authorised representatives.

Beneficiary's Stamp	Name of the Person(s) Authorised to sign this Finanancial Statement
	Renata Schaeffer
	Date & signature