NEWSLETTER N.3, December 2018

A collection of press articles headings published in 2018 about TEQ.

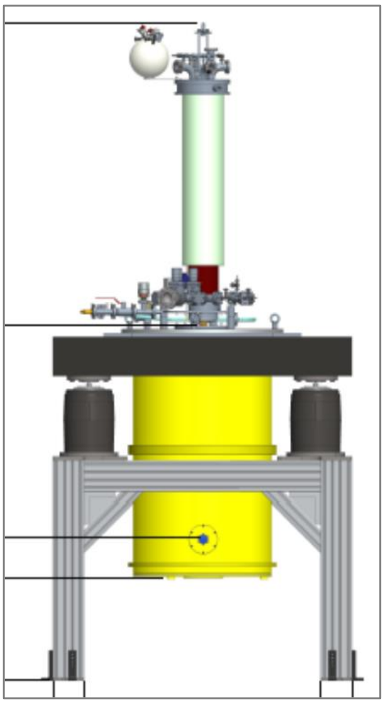
TABLE OF CONTENTS

UPDATE OF WORK DONE

The **UniTs** partner is working on a proposal by Milburn et al. for describing gravity as a classical communication channel, using concepts of continuous quantum measurements and feedback control theory. The goal is to generalize the model and to propose possible scenarios of experimental verification.
The team is currently studying one of the models proposed to solve the cosmological constant (dark energy) problem: the Quintessence Model. In particular, the researchers are checking whether by introducing random conditions on a scalar field, one can obtain a contribution to the evolution of the scale factor, which possesses properties similar to those of the standard cosmological constant. The final goal is to assess whether the collapse noise can be related to dark energy.
Work is also on going over the question of whether or not spontaneous collapse models can be made consistent with special relativity. This is done by checking if proposed collapse models predict probability distributions for the values of local observables which are Lorentz covariant. So far, it has been shown that an existing model proposed by Tulmulka cannot be extended to interacting or indistinguishable particles.
Additionally, studies are done on the decoherence effect induced on the dynamics of a matter field by a stochastic gravitational background. The aim is to derive a universal model in order to generalize the results already present in the literature, which are only valid in particular regimes of approximation, thus describing the decoherence in different eigenbasis and with different rates. This has been done for scalar bosons, and the team is currently working on the extension to spin 1/2 fermions. The models will be further extended in the future to allow for a description of the gravitational noise in terms of a quantum thermal bath of gravitons in order to look for experimental situations which are able to distinguish between classical and quantum gravity.
At UniTs, TEQ team is further working on experimental protocol to distinguish between collapse models and standard decoherence effects. In collapse models, each run of the experiment corresponds to a realization of the collapse noise. Researches are trying to exploit this fact to discriminate genuine collapse effects to decoherence effects in the dynamics of opto-levitated systems.
Finally, work is ongoing over the theoretical identification of possible new experimental verification of collapse models: first experimental bounds for the non-Markovian and dissipative extensions of collapse models were derived.

Within the TEQ project, the **LNF-INFN Frascati**, based on its long term expertise in analog electronics, has been appointed to design and realize, in collaboration with the other experimental groups participating to the project, the low-noise electronics to be used to reach the TEQ's objectives. In this first year of the project the low-noise electronics necessary for the ion trap has been realized. The fundamental requirement for the TEQ ion trap chamber is a low noise DC Supply, with a total electronic noise, calculated from the maximum noise tolerable in the ion trap within the TEQ requirements, having a maximum noise voltage density of 5×10^{-16} V^2/Hz, or, in other words, 22nV/√Hz. The low-noise electronics was designed, realized and characterized and it has been shown to be within the specifications. The corresponding delivery (report describing the work done) was produced. In particular, in the delivery report it is shown that the realized low-noise electronics has been measured and characterized and showed to have a total measured output noise of 2 V in an integrated bandwidth of 10kHz, which corresponds to a noise density of 20nV/√Hz, fully within the specifications, satisfying the TEQ requests for this deliverable.

Queen's University Belfast has focused on the characterisation of the effects of collapse mechanisms based on the investigation of the time dependence of the density noise spectrum. In particular, the group worked on the discrimination of dissipative and non-dissipative modelling of continuous spontaneous localisation, addressing both the vibrational and rotational dynamics of a levitated nanoparticle.
The framework that has been developed will enable the assessment of time-dependent variations of mass of the nanoparticle induces, for instance, by adsorption processes that cannot be controlled or prevented. The goal is to provide a fine characterisation of such processes on the dynamics of the nanoparticle, so as to calibrate them against the expected effect of collapse mechanisms.
QUB has also started addressing the description, in optomechanical terms, of the Schroedinger-Newton model, and the calibration of its effects in a standard levitated nano mechanical system.
Additional work related to the goals TEQ include the careful characterisation of the effects of light scattering from/into the driving light field by the nanoparticle, both in the Rayleigh and Mie configuration, and the design of a multi-tone driving protocol for the preparation of non-classical states of a mechanical oscillator with significantly negative Wigner function.



At the **University of Southampton**, progress with the TEQ experiment has been going on fast. Improved nanoparticles for internal cooling have been synthesised by TUD and show very promising preliminary results in optical refrigeration experiments at UCL. INFN have improved the Paul trap electronics (power supplies, amplifiers) to a record low noise level. The improved design will be tested on an existing atomic ion trap at AU. Meanwhile AU have designed the TEQ-trap and the blades have been manufactured by a laser cutting company. The blades are now gold coated at AU nano fabrication facilities and a first version of the TEQ-trap will be assembled and tested at UCL in the coming months. UCL and UoS have been working on the strategy for the TEQ-detection of the trapped particle and a related report will be finished soon, while related experimental tests have been performed at UCL. For on ideas for a TEQ-source have been started at UoS by a piezo-based system as well as UCL with electro-dynamic guiding systems after electro-spray ionisation loading. UoS was working on the realisation of the low-noise environment: a dedicated lab space has been refurbished with the needed infrastructure and a hoist system. The final drawings of the TEQ-cryostat (picture above) have been approved and the manufacturing of the dedicated equipment is going on at the minute. Expected delivery of the TEQ-cryostate to UoS is by end of February 2019.

The past months, the **AU** partner has been focusing its work on getting the first trap for the TEQ experiments ready for testing, as well as modifying existing DC supplies at AU to provide outputs with significantly lower noise levels.

With respect to the novel trap, all the blades electrodes have been laser machined and gold platted, and a monolithic holder for the electrodes are currently in production. A technical drawing of the first trap setup is presented in Fig. 1. In tight collaboration with the INFN partner, DC supplies currently used in atomic and molecular ion trapping experiments at AU are under modification. Two of the main sources of noise were identified to be the reference voltage of the DACs and the thermal noise in the amplifying units. Both problems have been carefully analyzed and solutions that significantly reduces both problems have been found, and are currently under implementation. First test of the modified supplies with trapped ions are expected in the beginning of 2019.

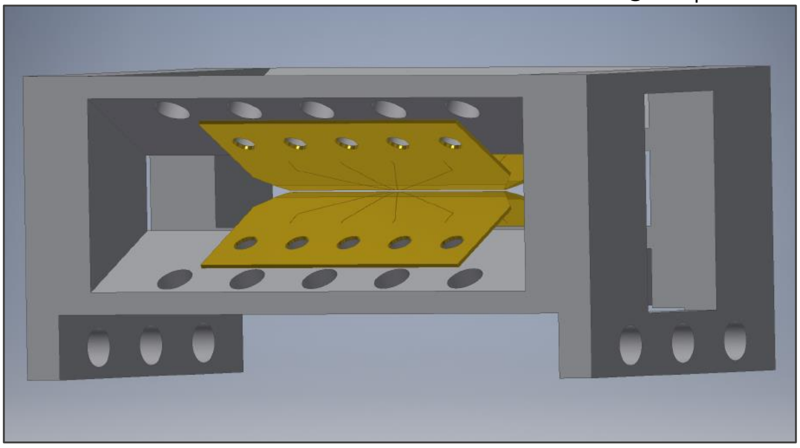
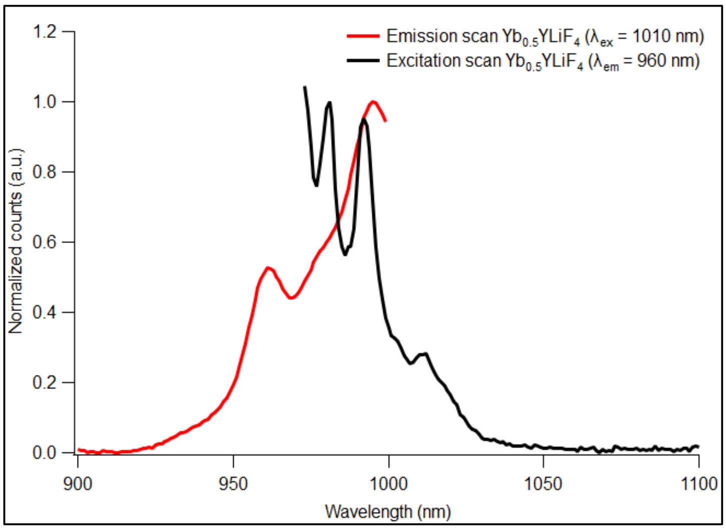


Fig. 1: Technical drawing of the first TEQ trap setup. For scale, the long side of the gold plated electrodes is 25 mm.

In the first 12 months, **TU Delft** was mainly focused on synthesizing and characterizing the nanoparticles that will be studied. Ytterbium doped yttrium lithium fluoride (Yb:YLF) was determined to be the material with the best properties. Amongst others, the particle size and shape are in the needed range. As an extra advantage, this material can be cooled by optical refrigeration (due to phonon-assisted anti-Stokes photoluminescence). Optical analysis for pure YLF showed little to no absorption at the wavelengths of the detection and cooling lasers (1064nm and 1550nm). Any absorption present is related to the solvent (hexane) and ligands (in solution and on the NC surface). Therefore, a ligand exchange was performed, in order to be able to change both the ligands and the solvent. Emission spectroscopy did not show any luminescence of the particles, indicating the host material (YLF) does not interfere with the cooling principle of the Yb doped particles. When doping the YLF with various fractions of Yb, absorption features between 900nm and 1000nm arose. These features are related to the 2F5/2 ← 2F7/2 transition of the Yb3+ ions. Emission spectroscopy showed that, when exciting at 1010nm, peaks are found at 960nm and 995nm (see graph). It can be noted that the emitted photon has a higher energy that the absorbed photon, proving the anti-Stokes photoluminescence. In this particular case, the added energy comes from phonons in the crystal that bring the excited electron to a higher energy level.



The reduction of the number of phonons in the crystal can be seen as the loss of (thermal) energy from the crystal, hence the crystal is cooling down.

The TEQ team at UCL has been working focusing on two main topics. These are:
1) Loading and Cooling in the Paul trap.
The team has developed electrospray loading of the Paul trap and can load in silica particles with sizes ranging from 200 to 600 nm. It has been found that these particles can have a few hundred up to 30000 elementary charges. Thomas Penney has measured large changes in the charge to mass ratio as a function of time after trapping and have shown that these changes are due to both initial losses in charge but also in mass. The mass loss is probably due to evaporation of electrospray solvent and surface impurities. These variations stabilise after some time at low pressures (10^-6), but we are still exploring trap frequency stability at low pressures. Thomas has also demonstrated parametric feedback cooling in all three axes of the trap motion. Here an optical measurement of particle displacement with time is used to feedback to trap voltages which damps/cools the motion to final temperatures in the 100 mK range. Work is currently ongoing over methods to understand the current temperature limits and push this down to the few mK range.
2) Laser trapping and refrigeration of Yb:YLF crystals.
Anis Rahman and Jonathan Gosling have successfully trapped the Yb:YLF crystals fabricated by the IIT and TUDelft teams at lower pressures than previously achieved (mbar range). They have also measured in trap Yb3+ spectra. They are yet to confirm strong cooling but are working on measurement of motional power spectral densities to determine the center of mass temperatures that would confirm internal cooling. It has been shown that the crystals orient along the a-crystallographic axis in an optical trap which is different to our previous result on crushed bulk crystals. It is expected to have lower refrigeration rates in this orientation.
3) Determining a measurement protocol for the TEQ experiments.
Antonio Pontin has developed a continuous measurement model to determine trapped nanoparticle temperatures using a low finesse cavity. Here the intensity is kept low to minimize perturbation of the trapped motion of the particle. In collaboration with the UoS team, he has shown that this type of measurement is feasible and is limited by laser frequency noise.

The Vienna node (OEAW) has finished the paper on a spacetime area law bound on quantum correlations. Area laws are a far-reaching consequence of the locality of physical interactions, and they are relevant in a range of systems, from black holes to quantum many-body systems. Typically, these laws concern the entanglement entropy or the quantum mutual information of a subsystem at a single time. However, when considering information propagating in spacetime, while carried by a physical system with local interactions, it is intuitive to expect area laws to hold for spacetime regions. In our work, we proved such a law for quantum lattice systems.
Our paper on quantum superposition of massive objects and the quantization of gravity has been accepted in PRD. In the work, we analysed a gedankenexperiment that involves quantum superpositions of charged and/or massive bodies (“particles”). We showed that the quantization of electromagnetic/gravitational radiation and vacuum fluctuations of the electromagnetic/gravitational field both are essential for avoiding apparent paradoxes with

causality and complementarity. This provides support for the view that (linearized) gravity should have a quantum field description.
Finally, we have completed the work on relativistic quantum reference frames and the operational meaning of spin. The method of quantum reference frames enables us to move to the particle's rest frame, define there the spin measurements (via the Stern-Gerlach experimental procedure), and then move back to the laboratory frame. In this way, we find a set of 'relativistic Stern-Gerlach measurements' in the laboratory frame, and a set of observables satisfying the spin su(2) algebra. This operational procedure offers a concrete way of testing the relativistic features of the spin, and opens to the possibility of devising quantum information protocols for spin in the special-relativistic regime.

CHANGES IN THE COMPOSITION OF THE CONSORTIUM

QUB: Oussama Houhou sadly had to leave the QUB team in October 2018. Luca Mancino has been appointed to work in the QUB team starting from January 2019.
OEAW: Si Chen was enrolled as PhD student and will work on TEQ topics.
AU: Vincent Jarlaud has been recruited as a post doc to participate in the TEQ activity.
UCL: Thomas Penney has been included in the TEQ team at UCL.

PUBLICATIONS

(for more info, please go to www.tequantum.eu, in 'Documents' → 'Dissemination')

Authors	Title	Journal	Volume	Pages	Year
Toroš, Marko, Muddassar Rashid, and Hendrik Ulbricht	Detection of anisotropic particles in levitated optomechanics	*Physical Review A.*	98	053803	2018
Winstone, George, Robert Bennett, Markus Rademacher, Muddassar Rashid, Stefan Buhmann, and Hendrik Ulbricht	Direct measurement of the electrostatic image force of a levitated charged nanoparticle close to a surface	Phys. Rev. A	*98*	053831	2018
Krisnanda, Tanjung, Chiara Marletto, Vlatko Vedral, Mauro Paternostro, and Tomasz Paterek	Probing quantum features of photosynthetic organisms	npj	4	60 (art. N.)	2018
Di Stefano, P. G., J. J. Alonso, E. Lutz, G. Falci, and M. Paternostro	Nonequilibrium thermodynamics of continuously measured quantum systems: A circuit QED implementation	Phys. Rev. B	98	144514	2018

Brunelli, M., L. Fusco, R. Landig, W. Wieczorek, J. Hoelscher-Obermaier, G. Landi, F. L. Semião, A. Ferraro, N. Kiesel, T. Donner, G. De Chiara, and M. Paternostro	Experimental Determination of Irreversible Entropy Production in out-of-Equilibrium Mesoscopic Quantum Systems	Phys. Rev. Lett.	121	160604	2018
Mishra, Ruchira, Andrea Vinante, and Tejinder P. Singh	Testing spontaneous collapse through bulk heating experiments: An estimate of the background noise	Phys. Rev. A	98	052121	2018
Guérin, Philippe Allard, and Časlav Brukner	Observer-dependent locality of quantum events	New Journal of Physics	20	103031	2018

DISSEMINATION ACTIVITIES

(for more info, please go to www.tequantum.eu, in 'Documents' → 'Dissemination')

In the first year of TEQ's lifetime (from January to December 2018), the dissemination activities held were a total of 83, addressing a total of more than 5 000 people. 61 talks were given to academic audiences, 13 lectures were given to high-school students while 9 presentations were delivered to the general public. The talks were given in a total of 45 cities situated in 20 different countries (8 of them out of the European Union). A detailed list of all talks can be found on the TEQ Website.

ANY OTHER RELEVANT INFORMATION

Dr Catalina Oana Curceanu, the PI of the Laboratori Nazionali di Frascati of the Istituto Nazionale di Fisica Nucleare group of TEQ, has been awarded the *George Southgate Fellowship* by the Adelaide University (Australia). In the framework of this award, she is spending a research visit at the Adelaide University in the period 3 to 26 December 2018, where she is discussing items related to strangeness nuclear physics and quantum physics with the Australian colleagues, including the foundation of quantum mechanics, in particular the underground experiments in the Gran Sasso laboratory testing collapse models and the TEQ project and its importance for the future quantum technologies.

In the frame of the TEQ project, the University of Trieste co-organizes an Advanced School and a Workshop titled "Ubiquitous Quantum Physics: the New Quantum Revolution". The fast growing use of quantum theory in technology-oriented and information-related fields is attracting the interest of an increasing number of researchers, especially young ones. The reborn interest in quantum physics has created a unique framework in which theoretical and experimental physics can fruitfully dialogue with information theory and computer science. The School intends to convey such an interdisciplinary spirit to graduate students and young researchers while the Workshop will bring together experts that will present their latest developments. The TEQ project plays a relevant role as PI prof. Angelo Bassi is co-organizer, prof. Mauro Paternostro (QUB) is Advisor and Lecturer and M. Carlesso and C. Jones are participants. The School will take place in Trieste (Italy) from 18th to 22nd February 2019 and the Workshop from 25th February to 1st March 2019 at the same location.

TEQ Consortium members have met on November 8 and 9, 2018, at TUD (Delft). The members of the Steering Committee agreed to extend the meeting to other members of the partners' research groups to further discuss the progresses of the TEQ experiments and theory. With this aim, a TEQ Junior Workshop was organized on the first day of the meeting to give space to the young researchers of TEQ and open up the discussion about the developments of the project. The second day was dedicated to the continuation of the scientific discussion (both theory and experiments). Below a group picture of the meeting.