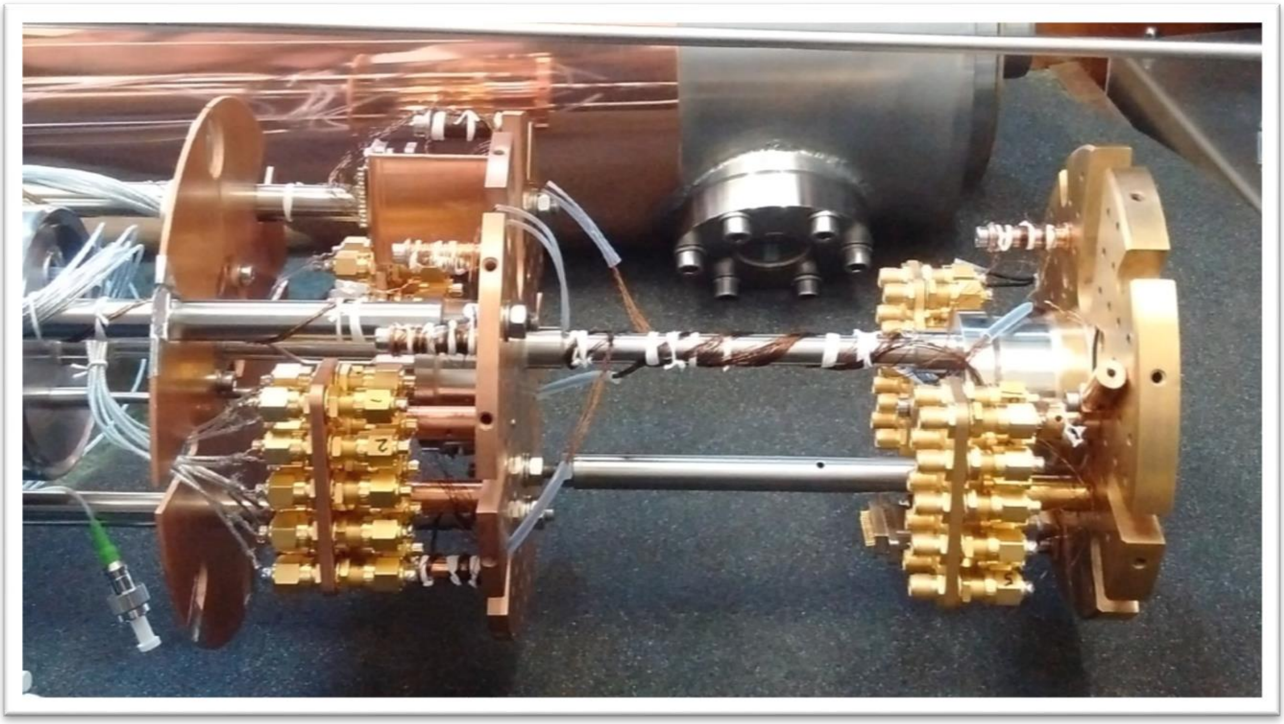
NEWSLETTER N.5, June 2019



A detail of the cryostat at the University of Southampton. *Credits: UoS.*

TABLE OF CONTENTS

UPDATE OF WORK DONE

During the last months, **UNITS** continued the studies the predictions of collapse models when applied to different physical systems, from cold atoms to astrophysical systems. It has been shown that the latter systems can provide experimental upper bounds that are comparable to those from phonon analysis in cryogenic experiments. This research was published in Adler et al., Physical Review D 99, 103001 (2019). More recently, work has been focusing on the application of collapse models to cold atom systems. In parallel, there has been work on the intertwining between gravity and quantum theory. The goal is to understand if gravity has a classical or quantum intrinsic nature. Two parallel projects are on-going. In the first, one assumes that gravity is fundamentally classical and it is mediated through a classical channel. Consequently, a decoherence effect appears, which are quantified. This is the idea beneath the models of Taylor-Kafri-Milburn and of Tilloy-Diosi. The two models are compared and the differences between them are quantified. In the second project, an optomechanical experiment has been proposed, that would be eventually able to discern whether gravity is fundamentally quantum or classical.

The **LNF-INFN** group continued the development of low-noise electronics after the successful first prototype design and tests, in collaboration with Aahrus, Southampton and UCL. The specifications of the power supply, in terms of electronic noise, were reviews, also in function of the latest tests performed in Aahrus which disentangled various sources of noise in order to make the noise even lower towards achieving TEQ final requirements. The interplay between voltage specifications, amplifier and other elements of the setup were reviewed. The voltage reference was identified to be a key-element towards lowering the noise level and it was reviewed by considering an intermediate stage to process the signal. A noise simulator was designed and run for various configurations and a new circuit built and tested showing a noise density of about 2.16 nV/ sqrt(Hz). The new circuit is under further testing and the next lower noise power supply under refinement/testing.

The **QUB** node was engaged in the conclusion of the analysis on time resolved methodologies for the discrimination of different formulations of collapse models. The work, which is being led by PhD student Marta Marchese, is a joint effort of QUB and UNITS (Matteo Carlesso and Angelo Bassi), and aims at demonstrating that coloured forms of collapse mechanisms would result in extra contributions to the two-time correlation functions of observable of a mechanical system. A second line of investigation currently being pursued in Belfast is the formulation of a framework for the thermalisation of levitated mechanical system being continuously monitored. the QUB team is exploring the non-equilibrium thermodynamics of such systems to pinpoint the quantum-limited formulation of thermalisation and explore the comparison with classical predictions. The work is a joint collaboration between QUB, SOTON, UCL, and UNITS.

UoS has continued to work on the installation of the cryostat together with the company ICE. There have been some issues with the achievement of the specified low temperature (300 mK) and the hold time (100 hours). So far these specifications have not been reached, but the company ICE is working to reach the specs. In the meantime, UoS has been working on magnetic trapping at 4K and has achieved first results which show promise for future tests of CSL with such systems. To levitate a permanent magnet at <10K temperature a lead (type-1) superconductor has been used. These magnetic levitations will be used to test the vibration levels in the TEQ cryostat after ICE has completed its work to a satisfactory level. UoS has been also working with partners from UCL, AU and INFN to design the 4-blade ion trap, which is assembled and now for tests on particle trapping at UCL. There has been further work with the named partners to design the DC and AC electronics for the ion trap. These electronics are aimed to be optimised to operate with low noise generation. A meeting took place in Frascati to discuss the next steps to achieve such electronics. A first paper on a feasibility study for the detection of the levitated particle in the ion trap has been published. Three different detection scenarios have been quantitatively compared. UoS will arrange a meeting to push forward the decision on the ultimate detection for the TEQ experiment.

Since the last newsletter, the **AU** partner has continued the work on improving on the electronic noise of the DC supplies to be used in the final TEQ experiments together with the INFN partner. By using batteries as voltages-references, AU have achieved a noise level of 10 nV/Hz1/2, in the whole frequency range 80-2000 Hz (See Fig. 1AU), and independent of the DAC output voltage in the range -10 V – 10 V.

With this result in mind, INFN has developed an extremely low noise circuit-based voltage reference for substituting the battery.

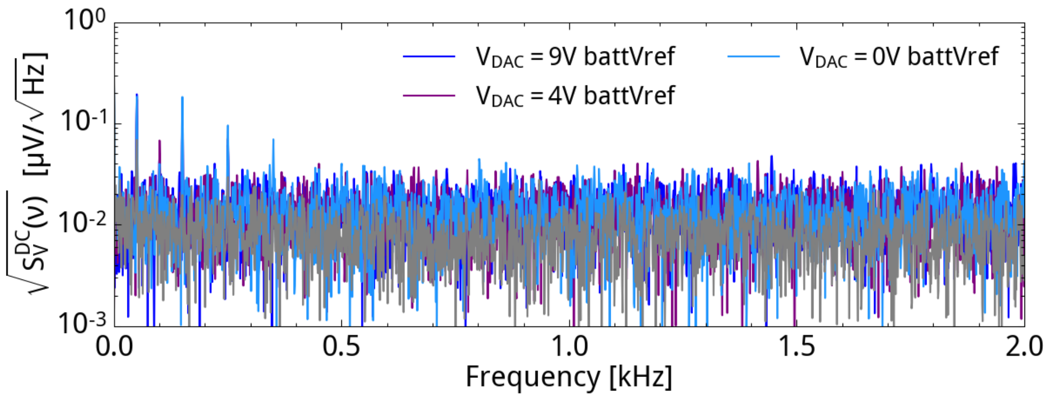


Figure 1. Examples of noise spectra recording at three output voltages of one DAC channel (VDAC) with a battery as voltage reference. The grey curve indicates the noise-floor of the measuring device.

A final DC source design based on combining the DAC previously used at AU with improved voltage-reference designed by INFN, and with the option of introducing an extra amplification stage has been developed, and now ready for print board lay-outing and production.

In parallel to the supply developments, AU has designed a versatile electrospray source (Fig 2), which should be suitable for injecting smaller nano-crystals as well as heavy complex molecular ions into an existing cryogenically cooled ion trap at AU, where such particles can be sympathetically cooled through coulomb interactions with laser cooled Ba+ ions. The various vacuum and electronic parts for the machine is currently in workshops at AU. Besides being a flexible platform for testing loading of nano-particles into a cryogenic charged particle trap, it will enable alternative avenues for testing quantum mechanics at the large scale.

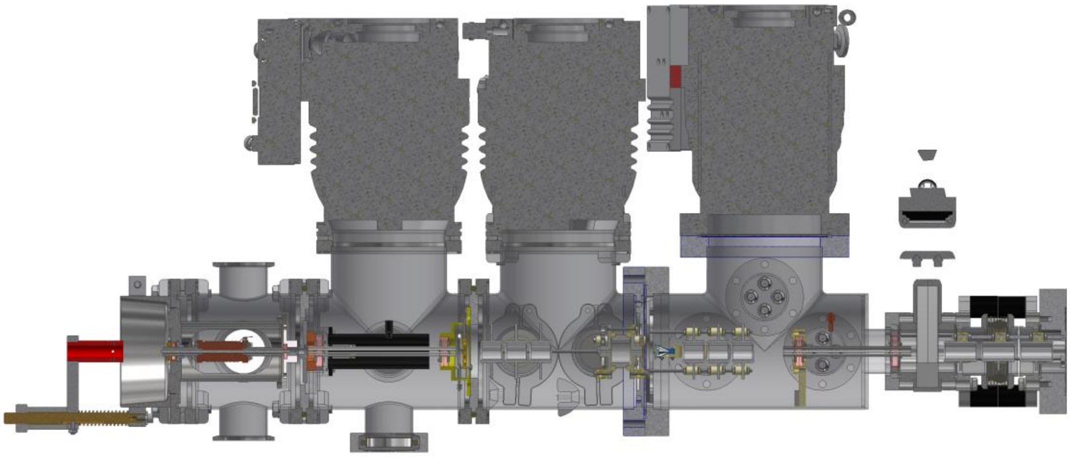


Figure 2. Sketch of the electrospray source currently under construction at AU. After injection at atmospheric pressure by a needle placed in the red isolating cylinder to the left, the charged particles move through four differentially pumped sections. In the first, any solvents are evaporated in a heated capillary tube, in the second the bare particles are transported by an octupole guide before reaching the third where the ions are focused (Einzel lens) in a pre-trap for charge-to mass analyzation. Finally, the fourth section consist of two focusing element (Einzel lenses) and an octupole guide to eventually bring the charged particle to the cryogenic trap.

At TU Delft, the work on the nanocrystals has been going on steadily. In order to obtain optical refrigeration from the Yb:YLF nanocrystals, a photoluminescence quantum yield (PLQY) of >95% needs to reached. As the PLQY of the Yb:YLF nanocrystals studied so far were significantly lower, the work at TU Delft has mainly been focused on improving the PLQY. By designing a core-shell NC synthesis, adapted from existing literature, a protective shell (of undoped YLF) was grown around the Yb:YLF NCs. From emission spectroscopic data, it was observed that the PLQY significantly increased. Due to difficulties in measuring the exact PLQY, only an estimation on the values could be determined. 20% Yb doped YLF core nanocrystals showed a PLQY of ~30% whereas the core-shell NCs reached a PLQY of ~85%. In order to see if the core-shell NCs are indeed an improvement for the TEQ-research, core and core-shell NCs with different doping levels (5, 10 and 20% Yb) were sent to UCL. The next steps for TU Delft are related to creating a broader (and preferably more exact) database of PLQY values for NCs with different doping levels, as well as getting a good insight in the changes of the emission spectra of NCs at different temperatures.

Over the last six months UCL has concentrated on the characterisation of the nanoparticle Paul trap and on testing the cooling and trapping properties of Yb:YLF nanocrystals provided by TUD.
Paul traps: in preparation for the TEQ blade trap, it has been measured the major sources of noise and stability of the traps constructed at UCL over a period of many weeks. It has been identified that electrical noise in DC and AC power supplies as the dominant source of noise and this will be improved by several orders of magnitude with the electronics that have been developed for TEQ by INFN and AU partners. Despite this noise, it has been shown that the charge on the trapped particles is stable for weeks and that the team was able to make a record breaking ultra-narrow line width measurement of the nano-oscillator formed by the charged particle in the trap. This linewidth is approximately 80 microHertz and it's believed that it is the lowest line width measured for any mechanical oscillator. A paper on this subject will be submitted soon. Two papers have been

submitted on the characterisation of the Paul trap. One paper outlines the use of super-resolution imaging for non-perturbative measurements of the particles motion over many days. This method demonstrates very low noise when compared to standard interferometric techniques(arXiv:1905.00884). Its use has allowed the UCL team to demonstrate low noise measurements of the nano-oscillators motion for very long time periods and to demonstrate attoNewton force sensitivity. Another paper describes in detail the characterisation of the nano-oscillator, including charge stability and trap stability (arXiv:1906.09580). As part of this work it has been also demonstrated the trapping of a nanodumbbell formed from two silica spheres. The very good mass sensitivity in the Paul trap, combined with good characterisation of the nanoparticles, allowed to differentiate between the trapping of single spheres and the nanodumbell.
Yb:YLF characterisation: the UCL team has continued to characterise the range of Yb:YLF crystals provided by both Delft and IIT. By measuring their mechanical linewidth and frequency of the Yb:YLF within the optical trap the UCL group has determined that so far the crystals heat at all trapping wavelengths. This is believed to be due to the low quantum efficiency. To increase the quantum efficiency core/shell crystals have been made by the Delft group. The have been tested at 1020 nm where cooling should be maximised and are currently working on comparing these results with measurements at a wavelength of 1064 nm to determine the crystal temperature.

OEAW has been working on an extension of its approach to the quantum reference frames (QRF) to temporal reference frames and also to a full relativistic quantum physics and quantum field theory. The aim is to define a notion of a QRF in relativistic and quantum field setting and to explore the Unruh effect as seen from a reference frame in a "superposition of accelerations" with respect to an inertial observer. OEAW will generalize the notion of covariance of dynamical physical laws in the case when one QRF is in a "superposition of Lorentz boosts" with respect to other QRF.

PUBLICATIONS

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

Authors	Title	Journal	Volume	Pages	Year
Adler, Stephen L., Angelo Bassi, Matteo Carlesso, and Andrea Vinante	Testing continuous spontaneous localization with Fermi liquids	Phys. Rev. D	99	103001	2019
Puebla, Ricardo, Giorgio Zicari, Iñigo Arrazola, Enrique Solano, Mauro Paternostro, and Jorge Casanova	Spin-Boson Model as A Simulator of Non-Markovian Multiphoton Jaynes-Cummings Models	Symmetry	11	695	2019
Feyles, Michele M., Luca Mancino, Marco Sbroscia, Ilaria Gianani, and Marco Barbieri	Dynamical role of quantum signatures in quantum thermometry	Phys. Rev. A	99	062114	2019
Luca Curcuraci, Stefano Bacchi, Angelo Bassi	Unitary time-evolution in stochastic time- dependent Hilbert spaces	Journal of Physics A	52	195301	2019

DISSEMINATION ACTIVITIES

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

In the first semester of 2019, the dissemination activities held were a total of 40, addressing almost 3 500 people. 17 talks were given to academic audiences, 14 lectures were given to high-school and school students and teachers while 9 presentations were delivered to the general public. The talks were given in a total of 13 cities situated in 11 different countries.

A detailed list of all talks can be found on the TEQ Website.

ANY OTHER RELEVANT INFORMATION

The paper "Information Content of the Gravitational Field of a Quantum Superposition" by Alessio Belenchia (QUB), Robert M. Wald, Flaminia Giacomini (OEAW), Esteban Castro-Ruiz (OEAW), Časlav Brukner (OEAW), Markus Aspelmeyer has won the First prize essay in the Gravity Research Foundation 2019 Essays on Gravitation.
See https://www.gravityresearchfoundation.org/announcement

The Quantum Mechanics Group led Prof. Angelo Bassi has organized a School on Quantum Foundations dedicated to Prof. GianCarlo Ghirardi on June 19-21 in Trieste (Italy). The School, as a TEQ-inspired activity, introduced Master and PhD students to the still outstanding problems in our understanding of quantum foundations. To give a deep look into the foundations of quantum mechanics, the school covered one topic a day: Collapse Models on day 1, Bohmian Mechanics on day 2, and Shape Dynamics on day 3. In the mornings, lectures were given by experts in the field. The afternoons were dedicated to tutorials where more applied aspects of each theory have been presented and discussed. In total, the School hosted 24 participants and was extensively appreciated receiving very positive evaluation feedback, especially on the format lecture + tutorial.

In the frame of the dissemination activities aimed at informing audiences about the TEQ project, Prof. Bassi (UniTs) has organized a conference titled "Towards a South-East European Quantum Network" in Trieste, on May 19. Goal of the meeting was to discuss the challenges to be faced, to create a quantum network in the Region Friuli-Venezia Giulia, to be connected to Central Europe via the QUAPITAL Project, 'the first reliable quantum internet on top of Europe's glass fiber network', of which Trieste is the Italian partner.
This meeting was kindly supported by TEQ as a TEQ-related activity: TEQ's technological spillovers are to be in the field of quantum technologies and here this conference found its frame.

Professor Mauro Paternostro from the QUB has been announced as a recipient of the Royal Society Wolfson Fellowship 2018 Round Three. The announcement by the Royal Society and the Wolfson Foundation brings to an end to the first year 2018 Round 3 of the new £8 million scheme which supports UK universities and research institutions to recruit and retain outstanding senior research scientists, particularly researchers from outside the UK. This scheme provides long-term support to UK universities and research institutions in making strategic research appointments through the recruitment and retention of outstanding senior researchers. The scheme covers all areas of the life and physical sciences, including engineering, but excluding clinical medicine"

Dr. Catalina Curceanu, head researcher at the Laboratori Nazionali di Frascati of INFN in Italy, has won the Gordon and Betty Moore Foundation Fundamental Physics Innovation Award that allowed her to visit the Institute for Advanced Study, Princeton, to discuss with Prof. Stephen L. Adler experiments testing collapse models in the underground laboratory of Gran Sasso (Italy). Her research aims towards a more profound understanding of the role of quantum theory in the Universe, and has implications for future quantum technologies.

The INFN partner hosted a TEQ working group meeting on May 31 in Frascati to discuss the status of the low-noise electronics for the TEQ project. The discussion focused on details of the tests done at Aarhus on the Paul trap and recent developments done in Frascati to further reduce the noise level to values compatible with TEQ aim. A visit to LNF-INFN laboratory has been included. The future steps in the work on electronics have been decided in agreement with all partners present, together with the detailed plan of activities.
Participants: Catalina Curceanu, Massimiliano Bazzi, Mario Bragadireanu, Alessandro Scordo (LNF-INFN), Hendrik Ulbricht (Southampton), Antonio Pontin (UCL), Michael Drewsen (AU).

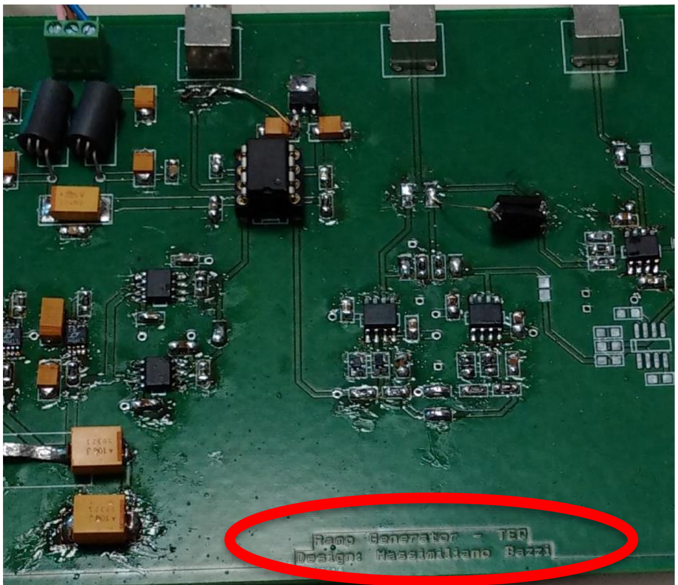


Figure 3. TEQ's ramp generator. *Credits: Hendrik Ulbricht*