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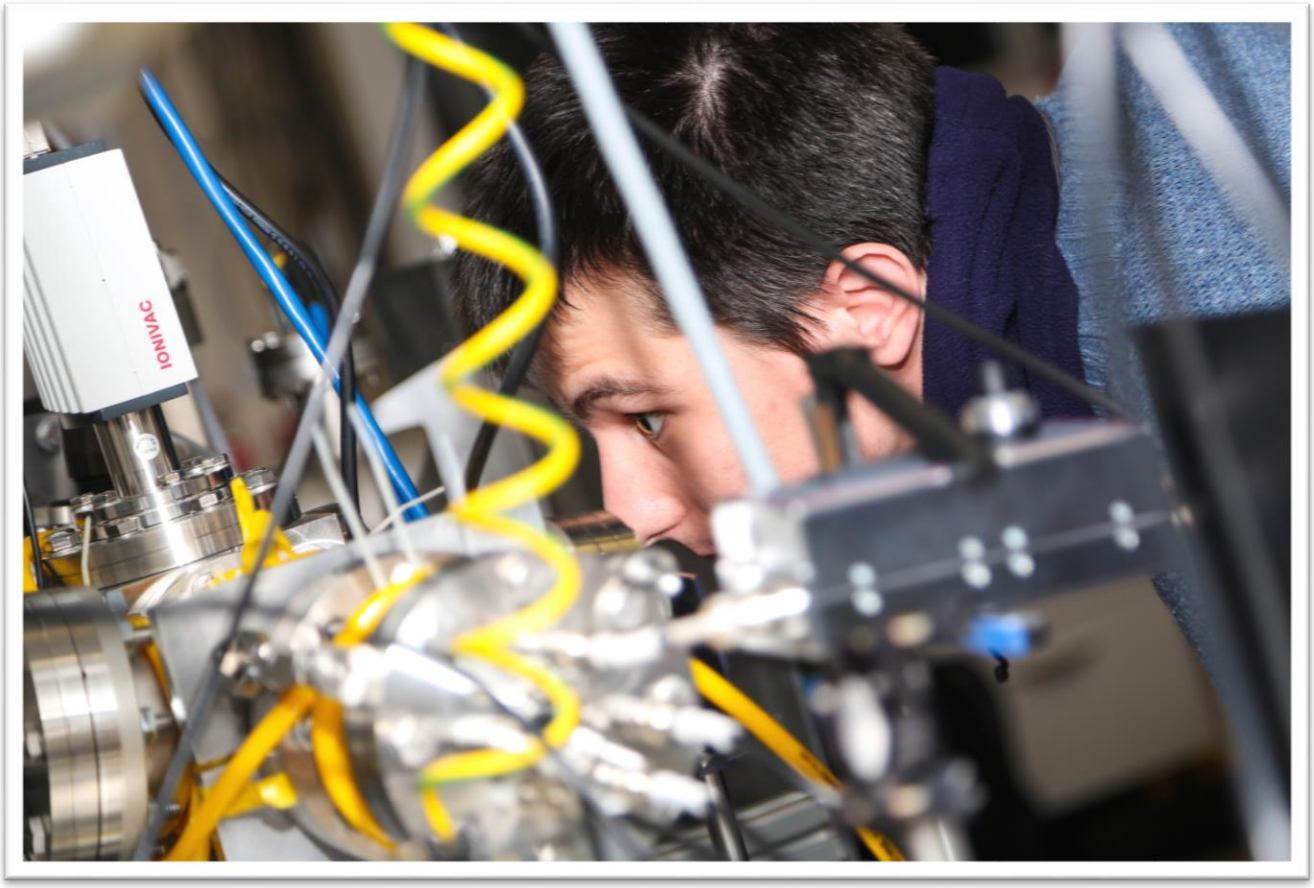

Undergraduate student working on TEQ experiments at UoS. *Credits: University of Southampton.*

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UPDATE OF WORK DONE

The **UniTs** Partner is involved in collaborations with other Partners of the Project for the theoretical investigation of collapse models made from several different perspectives. Between them we count:

- The study of the relativistic GRW for entangled, non-interacting, distinguishable particles and verification of a possible extension of the model to distinguishable and interacting particles, whilst remaining relativistic.

- The investigation of the collapse models equation as an effective theory generated by a corse-grained of a suitable and more fundamental dynamics, whose eventual identification will put light on the possible origin of the stochastic noise.

- A collaboration with the QUB Partner for the elaboration of a theoretical framework for the energy conserving extension of the CSL model, whose prediction are then compared with experiments to constrain the values of the model.

Moreover, UniTs points an eye on the experiments. In particular, we highlight:

- The theoretical development, together with the UoS Partner, of a multilayer modification and optimization of the cantilever experiment by Vinante to further constrain the CSL parameter space.

- The derivation of experimental bounds from the non-interferometric perspective for the colored and dissipative extension of the CSL model.

- A collaboration with UoS for the development of a magneto-levitated setup for studying quantum mechanics at mesoscopic scales.

During the first six months of TEQ, **UoS** has been making considerable progress with the setup of the various parts of the TEQ experiment. To this goal TEQ partners have been working on technical and administrational details of the cryostat. UoS team will set up a 300 mK He-3 cryostat, optimized for low noise amplitudes at low frequencies - a custom-made equipment by the company ICEOxford. The tender process has been concluded successfully and the final installation of the cryostat is planned for the end of 2018 at Southampton. The cryostat will sit on a vibration isolation system tailor-made to damp external vibrations in the frequency range of the expected mechanical motion of the trapped particle.

A huge effort has been already spent to work out the details (heating effects, noise requirements, trap frequency, properties of trapped particle) to decide the exact design of the particle ion trap for the TEQ experiment together with partners at AU and UCL. The ion trap needs improved low-noise AC and DC voltage supplies, which are under development at LNF-INFN with input from AU, UCL and UoS. UoS is further considering magnetic levitation as an alternative approach to achieve the scientific goals of TEQ.

Further investigations to decide the details of precise detection of the particle position and motion in the trap have started, optical as well as SQUID based detections are considered together with UoS. Measurement based control techniques to manipulate and cool the centre of mass motion of the particle have been realised at UCL and UoS already.

QUB is working on the characterization of noise in levitated optomechanics, focusing on a methodology for the dynamical inference of possible effects of dissipative CSL models on levitated optomechanics. The goal is to see if the intrinsically dynamical nature of the dissipative CSL model can offer better insight at finite times rather than at the steady state. Moreover, the thermal character of this model could affect the heating rate of internal degrees of freedom of a levitated optomechanical nano-particles, whose internal degrees of freedom are in general affected by the mechanical motion as well.

On a different side, QUB is exploring the possibilities offered by non-linear optomechanical interaction for the engineering of exotic (i.e non-classical) states of mechanical motion. Such states might offer sensitivity to the effects of environmental noise, including collapse-like mechanisms, that we aim at quantifying.

Finally, QUB's team is about to complete the framework for quantum hypothesis testing applied to the inference of CSL-like mechanisms. This is then to be extended, for instance, along the directions of dissipative versions of the model itself.

OEAW continues to work on:

- Page-Wooters notion of time
- Scaling properties of entropies in space-time
- Gravitational field stemming from superposition of masses

At LNF – INFN, discussions and meetings have been held towards the realization of the electronics for the ion trap, including design and proposal to adapt the present electronics with some changes versus realization of a completely new electronics. Elements for a prototype are being presently realized at LNF-INFN.

Much of the work at UCL has been focused on loading and charging nanoparticles and exploring their frequency stability in the current ion trap that we have been developing. Up to 1000 charges can be placed on 600 nm diameter spheres using electrospray. This results in secular frequencies in the range kHz range. We have found that that secular frequencies drift due to mass loss from heating if too much light is used. This is also a temporal drift from small changes in the trap potential. This is something we are still trying to understand and rectify. One solution that has been successful in stabilising the secular frequencies is to phase locking the secular frequency of the levitated particle to an external reference. This will allow us to measure the internal and centre of

mass temperatures more accurately than we can currently do in the Paul trap. UCL is ready for refrigeration work having received nanocrystals IIT/Delft.

In addition to this, UCL has developed a small, single frequency, external cavity diode tunable laser that is tunable from 980 nm to 1050 nm. This has an output power of 200 mW which will be suitable for some of our cooling experiments which does not require the high power and frequency stability of the M2laser system.

The first half year of TEQ, the AU partner has mainly been focusing its work on various design-aspects of the cryogenically cooled linear ac trap to be built for the key experiment to be carried out in US, and issues related to internal and external cooling of the nano-crystals to become the main objects of the investigations. The work has led to internal TEQ working documents, which include a detailed discussion on the physical requirements to the trap in terms geometry and materials to secure sufficiently optical access and proper heat management features, the needed properties of the electrical dc and ac supplies to reach the level of sensitivity required to achieve beyond state-of-the-art results, as well as the prospects of both radiative cooling and helium buffer gas cooling of the nano-crystal for initializing the experiments. Together with results obtained in parallel by the other TEQ partners on other design issues, the full trap design including the intricate cryogenic cooling system should be finalized in June 2018.

TUD devised a colloidal synthesis of $LiYF_4$ Nanocrystals (NCs) that is based on the use of $LiCO_3$, Y_2O_3, Trifluoroacetic acid as metal and halide precursors, and oleic acid as the surfactant. Thanks to this route rombohedral shaped NCs having a size of ~200nm (longest direction) and good size dispersion are produced. The XRD analysis of the product confirmed the expected lithium yttrium fluoride crystal structure (YLF, ICSD number 73709) with no presence of secondary phases. The same synthetic route was then extended to produce Yb doped $LiYF_4$ NC Samples having different doping levels. This was achivede by, simply, adding Yb_2O_3 to the reaction mixture in desired amounts. Yb-doped YLF samples were synthesized varying the doping level from 30% to 127% (expressed as Yb/Y * 100), as measured by our inductively coupled plasma elemental analysis. The resulting NCs have a rombohedral shape with a mean size of ~100nm (longest direction) and a very good size distribution. All the doped samples exhibited absorption peaks in 950-980nm range, which are typical of the Yb^{3+} ions inside the LiYF4 structure.

Eventually, in order to remove the ligands from the surface of YLF and Yb:YLF NC samples and to make them dispersible in Methanol, TUD employed either Triethyloxonium tetrafluoroborate ($NOBF_4$) or triethyloxonium tetrafluoroborate (Et_3OBF_4). Both reagents yielded good results: the size, shape, composition and crystal structure of the "striped" NCs were not altered upon the ligand removal procedure.

As part of the TEQ project, M Squared Lasers are supplying bespoke titanium sapphire ring laser systems to the Barker Group at University College London and the Ulbricht Group at the University of Southampton. The initial systems, which shipped in mid-June, will be used on the TEQ

experiments being setup at the two sites. The systems that were shipped are based on a number of proprietary technologies, to ensure the requisite performance for the planned work and focused on power at specific wavelengths, stability, noise performance and linewidth-narrowing capabilities. A system optimised for long wavelength operation of titanium sapphire was sent to University College London, whilst a unit with an additional frequency-doubling module known as an 'ECD-X', was sent to the University of Southampton.

CHANGES IN THE COMPOSITION OF THE CONSORTIUM

UniTs: The Administrative Officer Irene Spagnul of the TEQ Project joined the UniTs Partner.

UoS: PhD student Christopher Timberlake, and Drs Marko Toros and Muddassar Rashid became new TEQ team members.

QUB: PostDoc Dr. Oussama Houhou was contracted for a year to contribute to the work on TEQ.

UCL: Jonathan Gosling, a new PhD student, will begin working on laser refrigeration experiments on the TEQ project. Dr Antonio Pontin (Marie-Curie fellow at UCL) has become also part of the TEQ team.

PUBLICATIONS

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

Authors	Title	Journal	Volume	Pages	Year
Felix A. Pollock, César Rodríguez-Rosario, Thomas Frauenheim, Mauro Paternostro, and Kavan Modi	Operational Markov Condition for Quantum Processes	Phys. Rev. Lett.	120	040405	2018
Felix A. Pollock, César Rodríguez-Rosario, Thomas Frauenheim, Mauro Paternostro, and Kavan Modi	Non-Markovian quantum processes: Complete framework and efficient characterization	Phys. Rev. A	97	012127	2018
Setter, A., M. Toroš, J. F. Ralph, H. Ulbricht	Real-time Kalman filter: Cooling of an optically levitated nanoparticle	Phys. Rev. A	97	033822	2018
C. Curceanu, A. Bassi	A new FET Collaborative Project: Testing the	Nuclear Physics News	28	C.	2018

	Large-Scale Limit of Quantum Mechanics-TEQ				
Adler, Stephen L. and Vinante, Andrea	Bulk heating effects as tests for collapse models	Phys. Rev. A	97	052119	2018
Jader P. Santos, Alberto L. de Paula, Jr., Raphael Drumond, Gabriel T. Landi, and Mauro Paternostro	Irreversibility at zero temperature from the perspective of the environment	Phys. Rev. A	97	050101	2018

DISSEMINATION ACTIVITIES

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

In the first 6 months of TEQ, the dissemination activities held were a total of 35, divided in 6 types, and addressed a total of more than 3000 people. The audiences involved were academic, general public and high-school students. Typically, the academic audience is international while the others nationals.

a) Colloquia: 5 activities for 250 persons
b) Presentations: 11 activities for 1840 persons
c) Schools: 2 activities for 120 persons
d) Seminar: 1 activity for 50 persons
e) Talks: 10 activities for 680 persons
f) Workshops: 6 activities for 290 persons

ANY OTHER RELEVANT INFORMATION

UniTs organized the workshop "Trieste Junior Quantum Days", held on May 11th and 18th, 2018 at the University of Trieste, in collaboration with SISSA, CNR-IOM, INFN (Trieste, Italy) and LMU (Munich, Germany).

At **AU**, there is still an open postdoc position available, so if of interest contact Prof. Michael Drewsen. Moreover, the postdoc Dr. Cyrille Solaro connected to the project was in February awarded a Marie Curie Individual Fellowship.

Members of the TEQ consortium have met on June 22, at the University of Southampton (UK) to further discuss the design and realization of the TEQ experiment. In these regards, steps have been taken at a previous meeting at the University College London back in March when the participants defined preliminary experiments and manufacture of components.