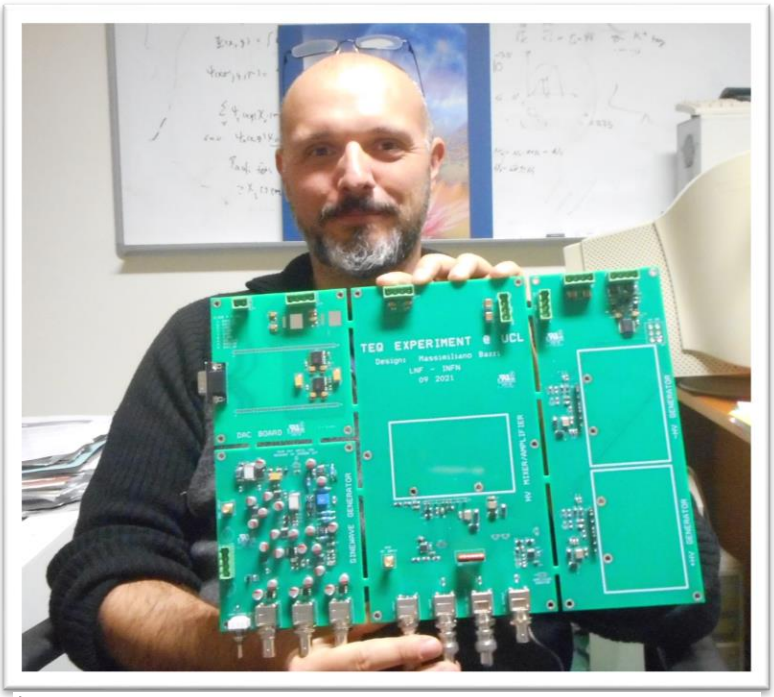
NEWSLETTER N.15, December 2021



A MEMBER OF THE LNF-INFN GROUP SHOWS THE LOW-NOISE ELECTRONICS PROTOTYPE. CREDITS: INFN

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HIGHLIGHT

TEQ extended by 6 months

The project has been granted a 6-month extension by the European Commission (EISMEA) as per request of the project Steering Committee to make up for the time lost because of Covid-19-related delays in the labs.
The project partners are satisfied with the outcome of the amendment procedure to the Grant Agreement and would like to thank the Project Officer for the fruitful collaboration during the process. The TEQ project will end in June 2022.

UPDATE OF WORK DONE

In the research on quantum information, **UNITS** investigated how quantum computers are affected by external noises, which may have an environmental or fundamental origin. In particular, UNITS studied how superconducting qubits are influenced by collapse models, showing that the collapse noise perturbs the highly sensitive superconducting materials inside these devices, leading the qubits to decohere. Furthermore, UNITS developed a scheme called Noise gates that models the effect of generic noises on quantum gates while these are performing their computations. This approach has the computational advantage of working with state vectors instead of density matrices, allowing for faster classical simulation. In the context of gravitational decoherence, UNITS worked on models based on the assumption that space-time metric has classical fluctuations, investigating how these fluctuations affect the dynamics of systems, and how such models can be tested through non-interferometric experiments. UNITS further worked on finding the precise connection between the spectrum of gravitational waves and the stochastic perturbation of relevant decoherence models. The goal is to study how the different setups designed for measuring gravitational waves can set bound on such stochastic perturbations.

The **Vienna node** proposed a strategy to determine the dynamics of objects in the presence of mass configurations in superposition, and hence an indefinite spacetime metric, using quantum reference frame (QRF) transformations. Specifically, they showed that as long as mass configurations in the different branches are related via isometries, it is possible to use an extension of the current framework of QRFs to "quantum isometries" to change to a frame in which the mass configuration becomes definite. Assuming covariance of dynamical laws under quantum coordinate transformations, this allows us to use known physics to determine the dynamics. The group applied this procedure to determine the motion of a test particle and the behaviour of clocks near the mass configuration, and thus found the time dilation caused by a gravitating object in superposition.

Experimental partners have been meeting every week to focus all partner's effort for the ultimate TEQ experiment at UoS and at low temperature (300 mK):

1. <u>The electronics boards from INFN to provide low-noise AC and DC power supplies for the TeQ Paul trap specifications.</u>
   Part of the **LNF-INFN** group activity was dedicated to continue to support the UCL staff for the use of the low-noise electronics prototype developed by LNF, which is presently in use at UCL. This activity was realised via online meetings and virtual work with UCL colleagues, and was focused on reducing the electronic noise on the overall setup. After the successful

test of the low-noise and low-distortion signal generator prototype at fixed frequency with possibility to vary the amplitude, the LNF-INFN group developed a unique electronic block which puts together the power supply, signal generator, amplification and signal mixing functions. During the reporting period 10 boards started to be realized, five of which were fully assembled and tested. All devices are on a single PCB board to avoid noise coupling into connection lines. 4 PCB boards have passed the quality check and have been shipped to UCL, where they will be assembled into an electronics box with in- and outputs. One more board is required (we need 5 in total) to be completed by INFN, and then shipped to UCL. The defined TEQ noise levels for the electronics have been achieved in a long, detailed and collaborative approach between INFN, UCL and Aarhus.

2. Configuration of Paul blade trap at UCL with low-noise electronic, at UHV conditions and at room temperature.
   The blade trap has been tested at UCL at room temperature. A silica particle has been trapped in the Paul trap and optically detected by the camera method. The temperature of the centre of mass motion has been measured for x,y,z – directions at vacuum down to 1e-6 mbar (HV). This experiment has already resulted in setting new bounds on CSL for levitated particles (1e-7 Hz @ 1e-7 m), but still short of the defined TEQ objective (1e-11 Hz @ 1e-7 m), but it is clear that if the same experiment can be repeated at 300 mK the TEQ objective will be research.

   The Paul trap is now re-assembled to be tested with the new low noise electronics from INFN and in a condition which can then be mounted in the cryostat at UoS.

3. Preparation of the cryostat at UoS to receive the Paul trap in early February 2022 and to conduct low temperature experiments.
   A design for mounting the Paul trap in the cryo at UoS has been completed in discussion with all TEQ partners. The Paul trap will be mounted inside the UHV chamber and attached to the 300 mK plate, a vibration damper to work at trap frequency (100 Hz to 1 kHz) has been designed and is manufactured at the moment at Southampton (planned to be completed by end of January 2022). The loading of the trap will be done by a laser ablation technique (LIAD), which is now used by a number of groups in the community (Innsbruck, Vienna, KCL). The ablation laser (Yag, 2nd harmonic at 532 nm) has been purchased and delivered at UoS in December 2021. A project student has built a setup to test the LIAD technique to load a particle trap (loading tests will be conducted in January 2022). The particle in the Paul trap will be detected optically by using a parabolic mirror.

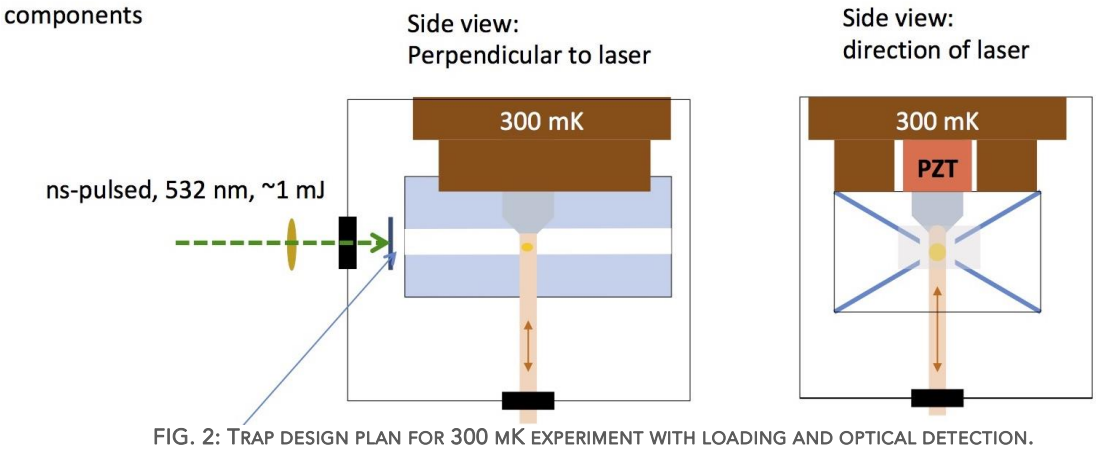


FIG. 2: TRAP DESIGN PLAN FOR 300 MK EXPERIMENT WITH LOADING AND OPTICAL DETECTION.

4. Magnetic levitation experiments at UoS to reach the TEQ objective to test CSL.
   Magnetic levitation experiment at UoS are underway. A new particle loading mechanism has been used to launch sub 60 micron particles based on the PIEZO. In order to achieve the TEQ objective (1e-11 Hz @ 1e-7m) we need to launch a particle of about 10 microns in diameter. This has not been achieved yet and to overcome surface forces is the main challenge. The plan is to use magnetic forces generated by currents through wires at the bottom of the trap, in addition to the mechanical PIEZO loader. This will be done in January 2022 and the following months.

5. Develop and apply to data a single trajectory based detection scheme for the TEQ experiment to avoid the long timescales of thermalization of the particle motion to the environment by QUB.
   A model is under development to describe the single trajectory detection technique and to then simulate the detection at experimental parameters. This has been discussed between experimentalists and theoreticians from QUB, Aarhus, UCL and UoS. The model is based on earlier work by some of the TEQ members and are published in: Setter et al., Phys. Rev. **A 97**, 033822 (2018) and McMillen et al., Phys. Rev. A. **95**, 012132 (2017). Different operation modes will be investigated to reduce the measurement time and to efficiently extract the noise level to search for the CSL effect. Possibilities include to generate a large number of fast measurements (~1 s) after initialisation of the particle motion out of equilibrium and during the much slower relaxation or for quick re-initialisation to allow for a sample set at the exact same initial conditions. The model is planned to be completed in December 2021 and tested with real data in January 2022.

6. In addition, at **TUDelft**, the synthesis of Yb:YLF nanocrystals (NCs) has been investigated on a molecular level, to understand the formation of these crystals better. This will help to synthesize the highest quality NCs and furthermore tells us how to separate the NCs from any formed byproducts. Large steps have been taken to understand the quenching mechanisms that hamper optical refrigeration. Soon it might be possible to compare TUD's ensemble measurements with UCL's single particle measurements to conclude whether or not the samples are stable enough to be measured for long times, or possibly show optical refrigeration in the set-up.

PUBLICATIONS

Authors	Title	Journal	Volume	Pages	Year
Barbado, Luis, Ana L. Baez-Camargo, and Ivette Fuentes	Evolution of confined quantum scalar fields in curved spacetime. Part II	The European Physical Journal C	81	953	2021
Mikusch, Marion, Luis C. Barbado, and Časlav Brukner	Transformation of spin in quantum reference frames	Phys. Rev. Research	3	043138	2021
Rubino, Giulia, Gonzalo Manzano, and Časlav Brukner	Quantum superposition of thermodynamic evolutions with opposing time's arrows	Communications Physics	4	251	2021
Renner, Martin J., and Časlav Brukner	Reassessing the computational advantage of quantum-controlled ordering of gates	Phys. Rev. Research	3	043012	2021
Ferialdi, L., and L. Diósi	General Wick's theorem for bosonic and fermionic operators	Phys. Rev. A	104	052209	2021
Di Bartolomeo, Giovanni, Matteo Carlesso, and Angelo Bassi	Gravity as a classical channel and its dissipative generalization	Phys. Rev. D	104	104027	2021
Timberlake, Chris, Andrea Vinante, Francesco Shankar, Andrea Lapi, and Hendrik Ulbricht	Probing modified gravity with magnetically levitated resonators	Phys. Rev. D	104	L101101	2021
Vinante, Andrea, and Hendrik Ulbricht	Gravity-related collapse of the wave function and spontaneous heating: Revisiting the experimental bounds	AVS Quantum Sci.	3	045602	2021

To explore the latest publications, visit Publications | TeQuantum.

DISSEMINATION ACTIVITIES

In the last 4 years (since the beginning of the project in January 2018), the dissemination activities held were a total of 358, addressing 39 000 people in 30 different countries.

Here below a highlight of some outstanding dissemination activities during 2020 per partner:
- **OEAW (Caslav Brukner)**: "Quantum reference frames for space and space-time" at the Conference "Quantizing Time", June 2021, Perimeter Institute, Waterloo, Canada;
- **UoS (Hendrik Ulbricht)**: "Probing new physics by levitated mechanical systems", at the 90th birthday of Roger Penrose event, August 2021, UK;
- **QUB (Marta Maria Marchese)**: "Quantum Hypothesis Test for Collapse Models", at the Theory Coffee talks, June 2021, Institute of Photonics and Quantum Sciences;
- **TUDelft (Arjan Houtepen)**: "Finding the weakest link – surface electrochemistry of nanomaterials" at the CHAIN conference, December 2021, the Netherlands;
- **UniTs (Angelo Bassi)**: "Present and future precision tests of spontaneous wave function collapse models" at the "Statistical and Quantum Mechanics: reconsidering their foundations in the light of new cutting edge experiments" workshop, September 2021, L'Aquila (IT);
- **INFN (Catalina Curceanu)**: "Quantum mechanics tests in the Gran Sasso undergroud laboratory: collapse models and spin-statistics" at the 16th Marcel Grossmann Meeting, July 2021, Rome.

A detailed list of all talks can be found at Talks | TeQuantum.

ANY OTHER RELEVANT INFORMATION

TEQ partners win an EIC Pathfinder grant

As TEQ project has come to its final phase, some of the partners have picked up research results and have put efforts in designing new potential projects.
The University of Southampton, the Queen's University Belfast and the University of Trieste have come together with a new Consortium to present to the European Commission a new project proposal in the frame of the HORIZON-EIC-2021-PATHFINDEROPEN-01-01 call. Together with the University of Leiden, Leiden Cryogenics S BV and Leiden Spin Imaging, the consortium consists of two experimentalists, two theorists, and two SMEs.
The project, named QuCoM, was submitted to the Commission back in May this year and has received a positive evaluation.
The main objective of QuCoM is to demonstrate the proof of concept (TRL 1) of a levitated acceleration sensor and its ability detecting gravity of small masses in the quantum controlled regime. Toward this objective the Consortium will explore the interplay between quantum mechanics and gravity in a parameter range accessible for cost-effective table-top experiments. Also, partners will investigate quantum superpositions in which these masses are delocalized and address some of the most popular theoretical proposals combining quantum physics and gravity in a nonstandard fashion. The proposed experiments will assess their limits of validity and/or further constrain the values of their parameters.
The experiments in question will be performed with optically and magnetically trapped micro/nano-particles based on the experimental expertise of partners in the consortium. Levitated mechanics experiments at Southampton have been already picked up by the EU Innovation Radar within the

TEQ project. The state preparation, control and analysis schemes are based on the expertise of the theory partners.
QuCoM will also have a high technological impact and will play a big role in innovation. High-tech SMEs will contribute in optimizing the experimental apparatus for fulfilment of the targeted objectives, which will in turn put them in a position to offer their improved products in sub mK, low vibration cryogenic equipment to market. In particular, the LSI will explore, together with University of Leiden, the feasibility of implementing our technology into a micro-satellite platform for space-based metrology and Earth Exploration utilizing gravitational detection.
With a total grant amount of 2 753 179,00 Euros, the project will last 3 years.

One quantum at a time

With the aim of making quantum mechanics more accessible to the larger public, the Trieste node has published a set of short video lessons.
Angelo Bassi, professor of quantum mechanics at the University of Trieste and PI of TEQ, takes the audience on a virtual educational trip from the beginning of modern quantum mechanics, through the challenges of the present theories, to the future perspectives. The lessons are 3-4 minutes short and, with the help of drawings and graphics, are targeting the Italian general public.
The lessons are accessible on the YouTube channel of the university of Trieste: (2) UN QUANTO ALLA VOLTA - YouTube and on the TEQ Youtube channel (with English subtitles): One quantum at a time - Trailer - YouTube

TEQ on Italian newspaper La Repubblica

TEQ was featured in a long article on the Italian Newspaper La Repubblica, written by the deputy director Mr Gianluca Di Feo. The article appeared in its online version on Thursday 21st October and in the Sunday paper edition on 24th October. The article covers some of the most known principles and problems on quantum mechanics through the work of TEQ's PI Prof. Angelo Bassi. Moreover, the article explores some of the latest technological outcomes of the quantum mechanics studies such as quantum computers and sensors and quantum encrypted communication.
With 3.705.000 unique users per day on the website (January 2021) and 112.500 paper copies per month sold[1] , La Repubblica is the first online newspaper in Italy. This article represents a big success for the TEQ project as its scientific efforts are translated into a science popularization language and delivered to a very large general audience.
Link to the article: Oltre i confini della fisica: lo scienziato ribelle Angelo Bassi - la Repubblica

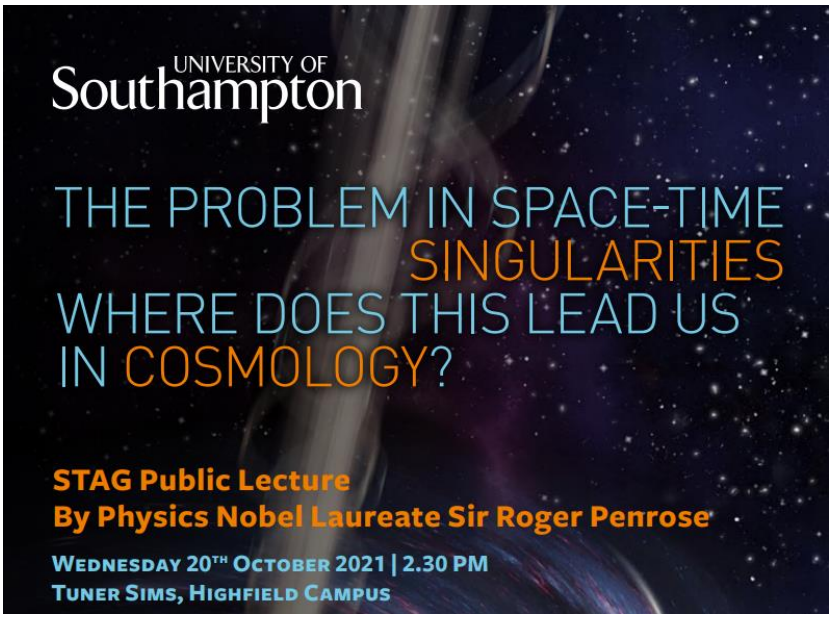
Paper by Vienna node reaches high ranking on Communications Physics

The paper "Quantum superposition of thermodynamic evolutions with opposing time's arrows?" published by Communications Physics on November 26, 2021 has fast reached 20k accesses and is now ranked 2nd of the 254 tracked articles of a similar age in Communications Physics.
The paper can be viewed here: Quantum superposition of thermodynamic evolutions with opposing time's arrows | Communications Physics

Co-organization of European Conference of Trapped Ions

The leader of TEQ's Aarhus University node has co-organized of the biannual major European conference of trapped ions (ECTI) with nearly 500 participants in the hybrid Physical/online event (November 22-26).
The conference brought together the European and international ion trapping communities and covered topics in quantum computing and quantum simulations, quantum networks, precision measurements and optical clocks, molecular ions and atom-ion mixtures, non-neutral plasmas, novel approaches, and more.

Co-organization of STAG Public Lecture by Physics Nobel Laureate Sir Roger Penrose



Leader of the TEQ's node at University of Southampton, Hendrik Ulbricht, has co-organized, in the frame of the STAG Research Centre, a public Lecture by Physics Nobel Laureate Sir Roger Penrose. The STAG Research Center brings together world- leading academics from three research groups – Particle Physics, Astrophysics and Gravitation – to explore issues of fundamental physics and astronomy.
The singularity theorems of the 1960s showed that not only are the space-time singularities of gravitational collapse generic expectations of classical general relativity, but so also is the big bang singularity a generic phenomenon (work largely by Stephen Hawking) for a rapidly expanding early universe. Whereas the mathematical arguments are time-symmetric in this way, our physical expectations (profoundly related to the 2nd Law of thermodynamics) are very different for the two types of singularity. The common view is that the resolution of the singularity problem must be through quantum gravity, but this cannot resolve this gross and fundamental time-asymmetry problem.
Conformal geometry provides a completely different outlook, which not only resolves this issue, but leads to observational implications that appear to be strongly confirmed in recent analyses of the cosmic microwave background radiation.

Cover story on the New Scientist

Hendrik Ulbricht, TEQ member at the University of Southampton, has been interviewed for a cover story in the New Scientist on 'Is reality real?' by Thomas Lewton, 6 November 2021. The article tells how new tests are being designed to tell us if quantum weirdness persists in macroscopic objects while interviewing different scientists on the issue.
Read more here.