Q 45: Mechanical, Macroscopic, and Continuous-variable Quantum Systems (joint session QI/Q)

Time: Wednesday 14:30–16:15 Location: HS IX

Invited Talk Q 45.1 Wed 14:30 HS IX

Wave-Function Expansion with Optically Levitated Nanoparticles — •Martin Frimmer — ETH Zürich, Zürich, Switzerland

Optomechanical systems provide testbeds for applications ranging from quantum information processing to fundamental searches for potential limitations of quantum theory with increasingly large masses. All quantum optomechanical protocols require purification of the motional state of the mass under scrutiny. Staying in the realm of Gaussian states, the only pure state of motion of a harmonic oscillator is the quantum ground state. Accordingly, ground-state cooling has been the main aim of the opto-mechanics community. It has been achieved with the help of laser cooling and, for the vast majority of experiments, of cryogenic cooling. Only recently, first systems have demonstrated quantum optomechanics at room temperature. A promising experimental platform in this context are optically levitated nanoparticles. Their center-of-mass motion and also their orientation (in case of optically anisotropic particles) resemble harmonic-oscillator degrees of freedom of mechanical motion. In our work, we prepare the highest-purity opto-mechanical oscillator to date. By coupling the rotational degree of freedom of an optically levitated nano-cluster to an optical cavity, we cool the libration mode to a phonon occupation of 0.04 quanta. Notably, we set this purity record in a room-temperature experiment, opening the door towards high-purity quantum optomechanics without the need for cryogenic cooling.

Q 45.2 Wed 15:00 HS IX

Macroscopic quantum sizes of mechanical systems — •Benjamin Yadin[1] and Matteo Fadel[2] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]Department of Physics, ETH Zürich, 8093 Zürich, Switzerland

Whether quantum theory holds true in the macroscopic realm – or breaks down at some size scale – is unknown. Many experimental platforms are probing this question by creating quantum states of ever-increasing size, for example with high masses or involving entanglement between many particles. Measures of 'macroscopicity' are designed to quantify the extent to which a system displays quantum behaviour at a large scale; however, these are often difficult to clearly interpret or fail to apply to a large variety of systems and states.

Here, we propose two measures corresponding to properties originally identified as crucial by Leggett: the 'extensive size', measuring the spread of quantum coherence over a physical size scale; and the 'entangled size', quantifying many-body entanglement between constituent parts of the system. These measures are mathematically well-defined for any state and lower bounds are readily obtainable from experimental data. We demonstrate this through application to mechanical systems – using data from mechanical oscillators and molecular interferometers. As part of this, we show the dependence on temperature of many-body entanglement between atoms in an oscillator.

Q 45.3 Wed 15:15 HS IX

How non-classical is a quantum state? — •Martina Jung and Martin Gärttner — Friedrich-Schiller-Universität Jena, Germany

Non-classicality, defined in the sense of quantum optics, is a resource: If a non-classical state is superimposed with vacuum in a beamsplitter, the resulting state will be entangled. Hence, quantifying the non-classicality of a quantum state is crucial to gauge its potential for quantum advantage - for instance in a Boson Sampler. However, conventional non-classicality measures often fail as a practical tool in experimental setups.

Here, we implement a data-driven, devise-specific approach which quantifies the non-classicality of a state by the ability of a neural network to distinguish the state from a classical one. In this approach, snapshots from photon-number measurements are input to a permutation invariant Vision Transformer. By studying the model's attention map, our goal is to identify signatures of non-classical states that might uncover yet unknown non-classicality witnesses.

Q 45.4 Wed 15:30 HS IX

Learning quantum states of continuous-variable systems — Francesco Mele[1], Antonio Mele[2], •Lennart Bittel[2], Jens Eisert[2], Vittorio Giovannetti[1], Ludovico Lami[3], Lorenzo Leone[2], and Salvatore Oliviero[1] — [1]NEST, Scuola Normale Superiore and Istituto Nanoscienze, Piazza dei Cavalieri 7, IT-56126 Pisa, Italy — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [3]Institute for Theoretical Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, the Netherlands

Quantum state tomography, aimed at deriving a classical description of an unknown state from measurement data, is a fundamental task in quantum physics. In this work, we analyse the ultimate achievable performance of tomography of continuous-variable systems, such as bosonic and quantum optical systems. We prove that tomography of these systems is extremely inefficient in terms of time resources. On a more positive note, we prove that tomography of Gaussian states is efficient. To accomplish this, we answer a fundamental question for the field of continuous-variable quantum information: if we know with a certain error the first and second moments of an unknown Gaussian state, what is the resulting trace-distance error that we make on the state? Lastly, we demonstrate that tomography of non-Gaussian states prepared through Gaussian unitaries and a few local non-Gaussian evolutions is efficient and experimentally feasible.

Q 45.5 Wed 15:45 HS IX

Entanglement detection in continuous-variable systems using two states — •Elena Callus[1], Tobias Haas[2], and Martin Gärttner[1] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-Universität Jena, Germany — [2]Centre for Quantum Information and Communication, Université Libre de Bruxelles, Belgium

The Shchukin-Vogel hierarchy gives necessary conditions for the separability of continuous-variable systems in terms of moments of the mode operators. However, higher-order moments, which are essential for non-Gaussian entanglement detection, are hard to extract efficiently. While recent work has shown the general usefulness of multiple state copies for entanglement witnessing in this regard, the therein proposed measurement schemes require at least three copies that would need to be phase-matched and interfered simultaneously. In this work, we demonstrate the capabilities from using only two states that are interfered on a beam-splitter with variable phase and photon-number detectors. This allows us to access certain classes of moments of the mode operators up to arbitrarily high orders. With their associated separability criteria, we witness entanglement in non-Gaussian classes of N00N states, with arbitrarily large N, and two-mode Schrödinger cat states.

Q 45.6 Wed 16:00 HS IX

Detecting genuine non-Gaussian entanglement — •Serge Deside, Tobi Haas, and Nicolas Cerf — ULB, Brussels, Belgium

Efficiently certifying non-Gaussian entanglement in continuous-variable quantum systems is a central challenge for advancing quantum information processing, photonic quantum computing, and metrology. Here, we put forward continuous-variable extensions of the recently introduced entanglement criteria based on moments of the partially transposed state, together with simple readout schemes that require only passive linear optics and local particle number measurements over a handful of state replicas. Our method enables the detection of genuine non-Gaussian entanglement for relevant state families overlooked by all standard approaches, which includes the entire class of NOON states. Further, it is robust against realistic experimental constraints (losses, imperfect copies, and finite statistics), which we demonstrate by an in-depth simulation.