Q 15: Optomechanics

Time: Tuesday 11:00–13:00 Location: HS 1015

Invited Talk Q 15.1 Tue 11:00 HS 1015

Levitated nanoparticles as testbeds for fundamental aspects of physics — •Julen S. Pedernales — University of Ulm, Ulm, Germany

Quantum mechanics has been enormously successful at describing the microscopic world, however, at scales that exceed the mass of a few thousand atoms, it remains largely unexplored. Recent progress in the quantum control of the mechanical degrees of freedom of solids suspended in a vacuum suggests that this situation might be changing in the near to mid-term future. Containing billions of atoms, levitated nanoparticles might be able to perform quantum experiments in an unprecedented mass regime, and thus, interrogate Nature about fundamental aspects of physics for which we do not have an answer: does the linearity of quantum mechanics hold at macroscopic scales? or, how does the gravitational field of a source in superposition look like?

In my talk, I will examine the opportunities and challenges that this nascent quantum platform presents to address these fascinating questions. First, I will present a collection of proposed techniques to extend the coherence times and shorten the duration of experiments aimed at realizing matter-wave interferometry with levitated solids. Secondly, I will discuss the prospects of observing gravitationally mediated entanglement between levitated solids–a route to explore the quantumness of gravity. Finally, I will introduce an alternative strategy for the detection of the quantumness of gravity which does not rely on the generation of entanglement.

Q 15.2 Tue 11:30 HS 1015

Levitated optomechanics in microgravity — •Govindarajan Prakash[1], Sven Herrmann[1], Claus Lämmerzahl[1], and Christian Vogt[2] — [1]ZARM (Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation), Universität Bremen — [2]BIAS (Bremer Institut für angewandte Strahltechnik GmbH)

Optomechanical levitation of nanoparticles provides a promising platform to perform tests with macroscopic particles on the interface between quantum and classical regimes. Schemes of such tests involve optical trapping, feedback cooling, and release and retrapping of nanoparticles. Here, we present how this allows us to perform force sensing of the order of attonewtons in microgravity conditions at the drop towers of ZARM in Bremen using silica nanoparticles. We present our progress thus far where we discuss first results from microgravity and hypergravity conditions.

Q 15.3 Tue 11:45 HS 1015

The First Levitated Optomechanics Experiment in Space — Jack Homans[1], Govindarajan Prakash[2], Chris Bridges[3], Peter Nisbet-Jones[4], Elliot Simcox[1], Simeon Modre[1], Tiberius Georgescu[1], •Christian Vogt[2,5], and Hendrik Ulbricht[1] — [1]School of Physics and Astronomy, University of Southampton, Southampton SO17 1BJ, UK — [2]ZARM, Center of Applied Space Technology and Microgravity, Uni Bremen — [3]Surrey Space Centre, OBDH Group, University of Surrey, Guildford, U.K. — [4]Twin Paradox Labs, London, U.K. — [5]BIAS, Institute of Applied Beam Technology, Bremen, Germany

Optically levitated nanospheres hold great promises for investigations of quantum behavior of large masses. In order to observe these, the particles must be isolated from sources of decoherence e.g. collisions with gas molecules or photons. The latter can hardly be suppressed in optical traps. One way to circumvent this problem is to switch off the trap and allow for a free evolution of the particles' wave packet as it can be done in space. A first demonstrator for this technology will be launched by the end of 2024 with the reentry capsule Nyx, by the company TEC. This talk we will focus on our payload design, the given boundary conditions and our mission goals.

Q 15.4 Tue 12:00 HS 1015

Testing Spontaneous Collapse Models with Levitated Naphthalene — •Marit O. E. Steiner, Julen S. Pedernales, and Martin B. Plenio — Institute of Theoretical Physics, Ulm University

Spontaneous collapse models aim to address the quantum-to-classical transition and the measurement problem through non-linear, stochastic modifications of the Schrödinger equation. A promising route to test the existence of these modifications is through matter-wave interference experiments of increasing mass and coherence length. In particular, the nascent field of levitated optomechanics, promises the ability to perform matter-wave interference at unprecedented scales.

In my presentation, I will advocate for an unconventional material in levitated optomechanics: pentacene-doped naphthalene. Leveraging photo-excited triplet states in pentacene, it is possible to achieve remarkable nuclear spin hyperpolarization, up to 80% polarization rates with relaxation times of T1=800 hours. These properties make it an ideal candidate for matter-wave interferometry. Stronger spin-dependent forces allow shorter interference times, reducing susceptibility to various noise sources. Additionally, the homogeneous spin distribution mitigates unwanted rotations in nanoparticles, an expected challenge in experiments with fewer spins.

I will introduce a novel experimental protocol leveraging these properties, as well as discuss the intricacies of the protocol and showcase its ability to impose bounds on the free parameters of the Continuous Spontaneous Localization model compared to existing methodologies.

Q 15.5 Tue 12:15 HS 1015

Classical phase-space model for gravity-mediated entanglement — •Marta Maria Marchese, Martin Plávala, Matthias Kleinmann, and Stefan Nimmrichter — Universität Siegen, Siegen, Germany

Whether gravity is fundamentally quantum or not is still a debated question. On one side, there are several well-established quantum-gravity theories, on the other, there are semi-classical descriptions that treat the gravity field as a classical measurement-feedback channel. The lack of experimental evidence leaves the problem still unresolved, but experiments with massive levitated particles have been proposed: witnessing entanglement generated by the gravitational interaction between two masses in a matter-wave interferometer is claimed to probe the quantum nature of the gravitational field. Here, we argue that such a scheme is not sufficient to rule out all possible classical descriptions of gravity. Indeed, one can achieve the same entanglement built up through a classical evolution of the Wigner function of the two gravitationally interacting masses, making use of a second-order approximation of the Newtonian potential. This suggests that alternative experimental schemes be developed to test the quantum nature of gravity.

Q 15.6 Tue 12:30 HS 1015

Dynamics of diamagnetically levitated superconducting ellipsoids — •Fynn Köller[1], Klaus Hornberger[1], and Benjamin A. Stickler[2] — [1]University of Duisburg-Essen, Faculty of Physics, Lotharstraße 1, 47058 Duisburg, Germany — [2]Ulm University, Institute for Complex Quantum Systems, Albert-Einstein-Allee 11, 89069 Ulm, Germany

Superconducting bodies can be diamagnetically levitated in magnetic quadrupole traps, where their dynamics are governed by the internal magnetization induced by the trapping field. We derive an analytical expression for the magnetization in ellipsoids, which is fully characterized by the induced dipole and quadrupole moments. These moments give rise to diamagnetic forces and torques as well as spin-rotation coupling due to the Einstein-de Haas and Barnett effects, enabling full three-dimensional alignment in the trap centre. We study the resulting dynamics and show that signatures of strong spin-rotational coupling will become observable in upcoming experiments with levitated micron-sized superconductors.

Q 15.7 Tue 12:45 HS 1015

Decoherence of dielectric rotors by thermal emission — •Jonas Schäfer[1], Benjamin A. Stickler[2], and Klaus Hornberger[1] — [1]Faculty of Physics, University of Duisburg-Essen — [2]Institute for Complex Quantum Systems, Ulm University

Levitated nanoparticles can be used for sensing applications and fundamental tests of quantum theory [1,2]. The center-of-mass motion has already been driven into the quantum ground state [1], while the full rotation dynamics are expected to enter the quantum regime soon [2,3,4,5]. This talk presents the master equation quantifying the impact of thermal emission on the ro-translational quantum state of an arbitrarily sized dielectric rigid rotor. It involves only the bulk permittivity, geometry, and temperature of the particle, and it accounts for internal photon scattering to all orders. We find the orientation state to decohere even for spheres in the point-particle limit, which can be understood a consequence of the vector character of the thermally driven polarization currents.

[1] Gonzalez-Ballestero, Aspelmeyer, Novotny, Quidant, and Romero-Isart, Science 374, eabg3027 (2021)

[2] Stickler, Hornberger, and Kim, Nat. Rev. Phys. 3, 589-597 (2021)

[3] Schäfer, Rudolph, Hornberger, and Stickler, PRL 126, 163603 (2021)

[4] Pontin, Fu, Toroš, Monteiro, and Barker, Nat. Phys. 19, 1003-1008 (2023)

[5] Kamba, Shimizu, and Aikawa, arXiv:2303.02831 (2023)