Contribution ID: **58** Type: **Talk**

Quantum light-matter interaction with a dielectric sphere: theory and applications

Friday, 5 May 2023 11:30 (30 minutes)

A major driving force of the field of levitodynamics —the levitation and control of microobjects in vacuum —is the possibility of generating macroscopic quantum states of the center-of-mass motion of a levitated nanoparticle. Not only can these states help address questions about the interplay between gravity of quantum physics or the nature of wavefunction collapse, but their mere existence would prove the validity of quantum mechanics at regimes of mass 4 orders of magnitude higher than the current record. Recent demonstrations of ground-state motional cooling and quantum control along one motional direction (1D) show that such quantum regime of levitated nanoparticles is within experimental reach. Still, the generation and certification of macroscopic quantum states requires to answer crucial fundamental questions, for instance: can one break the seemingly fundamental limitation which allows to only feedback-cool efficiently one of the three motional degrees of freedom? How to protect motional quantum states from decoherence? and how to generate the strong nonlinearity needed to observe purely quantum (Wigner-negative) states?

In my talk, I will discuss our team's theoretical effort to answer these questions. I will introduce our recently developed theoretical formalism describing the quantum interaction between light and a trapped dielectric sphere of arbitrary size. I will show how we quantitatively predict that (i) 3D ground-state feedback cooling is possible for particles beyond the point-dipole approximation (ii) laser-induced motional decoherence can be fully suppressed by using squeezed light and (iii) shifting from harmonic to double-well potentials allows to generate detectable Wigner negativities within the motional coherence lifetime. Our work sets the theoretical basis of 3D levitated optomechanics and provides the tools to design future macroscopic quantum physics experiments.

Abstract category

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