Contribution ID: **220** Type: **Talk**

Control, sensing and gravitational coupling of milligram pendulums: towards interfacing quantum and gravity

Tuesday, 24 June 2025 15:25 (15 minutes)

Can we test the quantum mechanical nature of gravitational fields? Milligram-scale optomechanical experiments present a frontier for bridging quantum mechanics and gravitational physics by aiming to strike a balance between 1) making gravitational couplings of the controlled objects dominant and 2) making the motions of these objects quantum noise dominated. Required systems necessitate low-frequency dynamics that is typically considered quantum-unfriendly, but seems to be needed to achieve a large figure-of-merit in the problem, quantifying the ability to generate quantum entanglement gravitationally. In this talk, I will first focus on our 1-milligram suspended torsional pendulum operating at 18 Hz, and the successful laser cooling of its motion to 240~microkelvins. I will elucidate the resulting boost in the quantum coherence length of this pendulum, benchmarking a state-of-the-art quantum-gravity figure-of-merit with a vast improvement potential [1]. I will outline a realistic path to enter a regime where gravitational entanglement could be generated utilizing our zig-zag optical cavities [2] to boost the interactions of light and torsional pendulums. I will conclude with the ongoing effort of achieving gravitationally-limited coupling between two free running ~1 milligram pendulums –aiming to push observable inter-particle gravitational couplings down by 3 orders of magnitude relative to current state of the art. [1] "1-milligram torsional pendulum for experiments at the quantum-gravity interface", S. Agafonova, P. Rossello, M. Mekonnen, O. Hosten, arXiv:2408.09445 (2024). [2] "A zigzag optical cavity for sensing and controlling torsional motion", S. Agafonova, U. Mishra , F. Diorico , and O. Hosten, Phys. Rev. Research 6, 013141. (2024)

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Session Classification: Tuesday Parallel Session F