Testing of Quantum Gravity with ~kg scale acoustic resonators

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Historically, the development of quantum mechanics was driven largely by key experimental observations such as blackbody radiation, the photoelectric effect, and atomic spectra, that were at complete odds with predictions made by the (classical) theoretical understanding of the time. At present, one of the grandest challenges of physics is to unite its two most successful theories — quantum mechanics (QM) and general relativity (GR) — into a single unified mathematical framework. Attempting this unification has challenged theorists and mathematicians for several decades and numerous works have highlighted the seeming incompatibility between QM and GR. It was generally supposed that this requires energies at the Planck scale and so beyond the reach of current laboratory technology. However, in the relatively recent publication, I. Pikovsky et al. [1] proposed a new way of testing a set of quantum gravity (QG) theories by using witty interferometric measurement of an optomechanical system. The prediction of most of the QG theories (such as, string theory) and the physics of black holes lead to the existence of the minimum measurable length set by the Plank length. This results in the modification of the Heisenberg uncertainty principle and as consequence leads also to the modification of the fundamental commutator for harmonic oscillator [2]. The latter is equivalent to the non-linear modification of the Hamiltonian and results in the dependence of the oscillator resonance frequency on its energy [3]. The dynamics of the system can be described by a well-known Duffing oscillator model for which an amplitude dependence of the resonance frequency, i.e. so-called amplitude-frequency effect, is one of its distinctive features.

By implementing of this new method, we measure amplitude frequency effect for 0.3 kg ultra-high-Q sapphire split-bar mechanical resonator and for mg scale quartz bulk acoustic wave resonator. Our experiments with sapphire resonator have established the upper limit on quantum gravity correction constant of $\beta_0 < 5 \times 10^6$, which is factor of 6 better than previously measured [4]. The reasonable estimates of β_0 from experiments with quartz resonators yields even more stringent limit of $\beta_0 < 4 \times 10^4$. The heavier oscillators and more precise measurements will allow for the better determination of the correction strength. Therefore, the remarkable high-Q and frequency stability of state of the art quartz BAW resonators and SB sapphire resonator in conjunction with low acoustic non-linearities have a great potential for its further applications in precise tests of minimal length scale scenarios for the quantum gravity theories in the regime $\beta_0 \lesssim 1$.

[1] I. Pikovsky et al.,*Probing Planck-scale physics with quantum optics,* Nat. Phys. **8**, 393 (2012).
[2] S. Hossenfelder, *Experimental search for Quantum Gravity* (Springer, Cham 2018)
[3] M. Bawaj et al., *Probing deformed commutators with macroscopic harmonic oscillators,* Nat. Comm. **6**, 7503 (2015).
[4] P. Bushev et al., Testing of Quantum gravity with sub-kilogram acoustic oscillators, arXiv:1903.03346 (2019).