Testing the quantum vs classical nature of gravity measuring diffusion

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Abstract: We show that if gravity is fundamentally classical, it necessarily induces wavefunction collapse and diffusion in space, even for localized systems. This provides a new experimental route to test gravity without preparing large-mass spatial superpositions.

The quest to unify quantum theory and gravity is still ongoing. The standard and by far the most widely studied approach consists in quantizing gravity. However, we still do not know whether gravity is fundamentally quantum or whether, for example, it could be fundamentally classical. Recently, several schemes have been proposed to address this question experimentally. One of the most prominent is the Bose–Marletto–Vedral (BMV) proposal [1, 2], in which two masses are prepared in spatial superposition and one checks whether gravitationally mediated entanglement is generated: if it is, gravity must be quantum; if it is not, gravity is classical (in the sense of being an LOCC). However, this scheme is not easily implementable, because creating spatial superpositions of masses large enough to produce non-negligible gravitational effects is extremely challenging.

Here, we propose an alternative approach [3]. We show that, if gravity is classical, it must necessarily induce wave function collapse in space, accompanied by unavoidable diffusive effects. These effects are always present, even for well-localized systems, so there is no need to generate macroscopic superpositions. For the proposed scheme shown in Fig. 1, where both the Newtonian interaction and the dissipative effects can be linearized, we derive a lower bound on the diffusion induced by classical gravity and discuss possible experimental scenarios for detecting it. Crucially, this result opens a new route to probing the quantum versus classical nature of gravity without the need to create large-mass quantum superpositions.

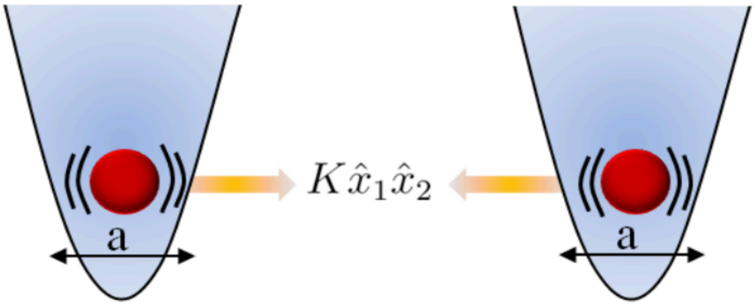

Fig. 1 Scheme of the proposed setup: two masses confined in harmonic traps interact gravitationally. We focus on the regime in which the distance between the oscillators is much larger than their spatial extent, so that both the gravitational interaction and the dissipative effects can be linearized. Then, if gravity is classical, in addition to the standard gravitational attraction, unavoidable diffusive effects must also arise.

References

[1] S. Bose,et al., “Spin entanglement witness for quantum gravity”. Phys. Rev. Lett. **119(24)**, 240401 (2017).

[2] C. Marletto and V. Vedral. “Gravitationally induced entanglement between two massive particles is sufficient evidence of quantum effects in gravity”. Phys. Rev. Lett., **119(24)**, 240402 (2017).

[3] O. Angeli, S. Donadi, G. Di Bartolomeo, J. L. Gaona-Reyes, A. Vinante, A. Bassi, “Probing the Quantum Nature of Gravity through Classical Diffusion” , ArXiv: 2501.13030.