

Experiments at the interface of general relativity and quantum mechanics

Ron Folman

Ben-Gurion University of the Negev, POB 653, Beer Sheva, Israel

The two pillars of modern physics are the theories of General Relativity (GR) and Quantum Mechanics (QM). After decades of theoretical attempts to unify these two pillars under one theoretical framework (often referred to as quantum-gravity), these pillars remain independent. To some this situation is so unnatural, that they claim it actually hints that at least one of the theories is wrong in some fundamental way. As technology in quantum-optics labs improves, new experiments - working at the interface of these two theories - can be realized. Such experiments will hopefully provide new insights.

In this talk, I will present three experiments conducted at this interface, two already realized and one planned. The first involves clock interferometry, in which a single clock in a spatial superposition experiences two different proper times due to gravitationally induced red shift [1-3]. The second involves the observation of the consistency of the Einsteinian equivalence principle in the quantum domain [4]. While the first two were realized with atoms, the third involves massive objects, specifically, nano-diamonds [5]. Leaping by ten orders of magnitude in mass relative to the atomic experiments, the third experiment makes use of so-called active mass, where not only the gravitational field of Earth needs to be taken into account.

The experiments are based on Stern-Gerlach interferometry [6]. Time permitting, I will be happy to also address more technical questions. For example, interesting issues concerning decoherence arise [7,8].

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- [1] Y. Margalit et al., A self-interfering clock as a “which path” witness, *Science* 349, 1205 (2015).
- [2] Zhifan Zhou et al., Quantum complementarity of clocks in the context of general relativity, *Classical and quantum gravity* 35, 185003 (2018).
- [3] Zhifan Zhou et al., Geometric phase amplification in a clock interferometer for enhanced metrology, *Science advances* 11, adr6893 (2025).
- [4] O. Dobkowski, B. Trok, P. Skakunenko, Y. Japha, D. Groswasser, M. Efremov, C. Marletto, I. Fuentes, R. Penrose, V. Vedral, W. P. Schleich, R. Folman, Observation of the quantum equivalence principle for matter-waves, *ArXiv:2502.14535* (2025).
- [5] Y. Margalit et al., Realization of a complete Stern-Gerlach interferometer: Towards a test of quantum gravity, *Science advances* 7, eabg2879 (2021).
- [6] O. Amit et al., T3 Stern-Gerlach matter-wave interferometer, *PRL* 123, 083601 (2019).
- [7] Y. Japha and R. Folman, Role of rotations in Stern-Gerlach interferometry with massive objects, *PRL* 130, 113602 (2023).

- [8] C. Henkel and R. Folman, Universal limit on quantum spatial superpositions with massive objects due to phonons, *Phys. Rev. A* 110, 042221 (2024) – Editor’s choice.