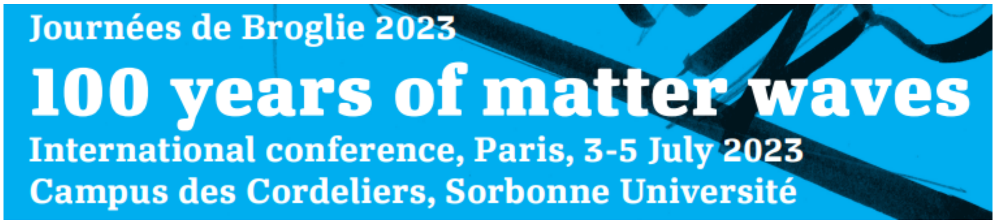


# Stern-Gerlach Splitting and Wave-Particle Duality, Recombined

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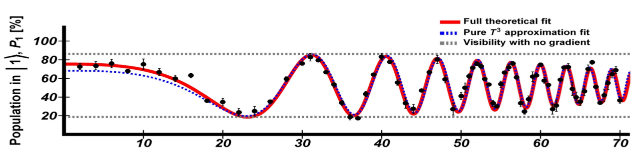
In this talk I will present in detail how De-Broglie's Particle-Wave Duality plays a key role in Stern-Gerlach (SG) interferometry. The Stern-Gerlach effect, found a century ago, has become a paradigm of quantum mechanics. Unexpectedly, until recently, there has been little evidence that the original scheme with freely propagating atoms exposed to gradients from macroscopic magnets is a fully coherent quantum process, or in other words, that the atoms indeed behave as waves which can be in a state of spatial superposition. Several theoretical studies have explained why coherence in a Stern-Gerlach interferometer is a formidable challenge. Here, we provide a detailed account of the realization of a half- [1-3] and full- [4-5] loop Stern-Gerlach interferometer for single atoms [6] and use the acquired understanding to show how this setup may be used to realize an interferometer for macroscopic objects doped with a single spin [5], namely, to show that even rocks may be shown to be waves. I will also describe unique decoherence channels such as those relating to phonons [7,8] and rotation [9], which must be considered in such a challenging experiment. The realization of such an experiment would open the door to a new era of fundamental probes, including the realization of previously inaccessible tests of the foundations of quantum theory and the interface of quantum mechanics and gravity, including the probing of exotic theories such as the Diosi-Penrose gravitationally induced collapse. Time permitting, I will also briefly present our recent work on Bohmian mechanics, which is an extension of De-Broglie's ideas concerning the pilot wave [10].

Fig 1. Spin population oscillations due to interference in a full-loop Stern-Gerlach interferometer at BGU [4].



[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., An experimental test of the geodesic rule proposition for the non-cyclic geometric phase, Science advances 6, eaay8345 (2020).

[4] O. Amit et al., $T^3$ Stern-Gerlach matter-wave interferometer, Phys. Rev. Lett. 123, 083601 (2019).

[5] Y. Margalit et al., Realization of a complete Stern-Gerlach interferometer: Towards a test of quantum gravity, Science advances 7, eabg2879 (2021).

[6] M. Keil et al., Stern-Gerlach interferometry with the atom chip, Book in honor of Otto Stern, Springer (2021).

[7] C. Henkel and R. Folman, Internal decoherence in nano-object interferometry due to phonons, AVS Quantum Sci. 4, 025602 (2022) – invited paper for a special issue in honor of Roger Penrose.

[8] C. Henkel and R. Folman, Universal limit on quantum spatial superpositions with massive objects due to phonons, https://arxiv.org/abs/2305.15230 (2023).

[9] Y. Japha and R. Folman, Role of rotations in Stern-Gerlach interferometry with massive objects, Phys. Rev. Lett. 130, 113602 (2023).

[10] G. Amit et al., Countering a fundamental law of attraction with quantum wave-packet engineering, Phys. Rev. Res. 5, 013150 (2023).