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Talk title: Atoms at their quantum speed limit

Abstract: How fast can a quantum system evolve between two states? This question is not only important for its basic nature, but it also has far-reaching implications on future quantum technologies. There are two well-known limits on the maximum evolution rate, named after their discoverers—Mandelstam–Tamm and Margolus–Levitin. Despite their fundamental character, only the Mandelstam–Tamm limit has been so far investigated and exclusively in effective two-level systems.

In this talk, I will report on a recent experimental study [1] where we test both limits in a multi-level system by following the motion of a single atom in an optical trap using fast matter wave interferometry. Our measurements reveal a crossover between the two quantum speed limits, depending on the energy distribution of the quantum state. We find a striking difference between a two-level and a multi-level system—excitations of a multi-level system do not saturate the speed limit but, unexpectedly, produce a small, universal deviation from it.

In the second part of my talk, I will address the related question, what is the fastest route—the quantum brachistochrone—to transport an atom between distant states. We demonstrate [2] coherent transport of an atomic wave packet over a distance of 15 times its size in the shortest possible time. Because of the large separation between the two sites, ours is a paradigmatic example of a quantum process where the Mandelstam-Tamm and Margolus-Levitin speed limits fail to capture the relevant time scale. In contrast, we show that quantum optimal control provides us with solutions to the quantum brachistochrone problem.

Our results, establishing quantum speed limits beyond the simple two-level system, are important to understand the ultimate performance of quantum computing devices and related advanced quantum technologies such as atomtronics.

[1] G. Ness, M. R. Lam, W. Alt, D. Meschede, Y. Sagi, and A. Alberti, “Observing quantum-speed-limit crossover with matter wave interferometry,” (2021), arXiv:2104.05638 [quant-ph]

[2] M. R. Lam, N. Peter, T. Groh, W. Alt, C. Robens, D. Meschede, A. Negretti, S. Montangero, T. Calarco, and A. Alberti, “Demonstration of Quantum Brachistochrones between Distant States of an Atom,” Phys. Rev. X 11, 011035 (2021)