Observing quantum-speed-limit crossover with matter-wave interferometry

G. Ness[*1], **M. R. Lam** [2], **W. Alt** [2], **D. Meschede** [2], **Y. Sagi** [1], **A. Alberti** [2]
1. Physics Department, Technion – Israel Institute of Technology, 32000 Haifa, Israel
2. Institut für Angewandte Physik, Universität Bonn, 53115 Bonn, Germany

Quantum mechanics sets fundamental limits on the speed at which quantum states can be transformed in time. Two well-known quantum speed limits are the Mandelstam–Tamm and the Margolus–Levitin bounds, which relate the maximum rate of evolution to the system's energy uncertainty and mean energy, respectively. We perform fast matter-wave interferometry experiments and track the motion of a single atom in a spin-dependent lattice. This setup constitutes a multi-level quantum system in which we concurrently test both speed limits. Our data reveal two different regimes: one where the Mandelstam–Tamm limit constrains the evolution at all times, and a second where a crossover between the two limits occurs at longer times. We take a geometric approach to quantify the deviation from the speed limit, measuring how far the matter-wave's quantum evolution deviates from the geodesic trajectory in the Hilbert space of the multi-level system. Our results [1], establishing quantum speed limits beyond the simple two-level system, are crucial to understand the ultimate performance of quantum computing devices and related advanced quantum technologies.

References

[1] G. Ness, M. R. Lam, W. Alt, D. Meschede, Y. Sagi, A. Alberti, *Observing crossover between quantum speed limits*, Sci. Adv., in press (2021). Preprint available on *arXiv*:2104.05638.

[*]Corresponding author: gn@technion.ac.il