Non-Ergodicity and Emergent Hilbert-Space Fragmentation in Tilted Fermi-Hubbard Chains

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Well-controlled synthetic quantum systems, such as ultracold atoms in optical lattices, offer intriguing possibilities to study complex many-body problems relevant to a variety of research areas. In particular, out-of-equilibrium phenomena constitute natural applications of quantum simulators, which have already successfully demonstrated simulations in regimes that are beyond reach using state-of-the-art numerical techniques. While generic models are expected to thermalize according to the eigenstate thermalization hypothesis (ETH), violation of ETH is believed to occur mainly in two types of systems: integrable models and many-body localized systems (MBL). In between these two extreme limits there is, however, a whole range of models that exhibit more complex dynamics.

The 1D tilted Fermi-Hubbard model has emerged as a versatile platform to study a rich variety of weak ergodic-breaking phenomena in a clean system without disorder. We have realized this model with fermionic K-atoms and observed a surprisingly robust memory of the initial state over a wide range of parameters [1], which we explain via emergent kinetic constraints. Our measurements were performed in systems of about 290 lattice sites for up to 700 tunneling times - a regime that is currently not accessible with state-of-the-art numerical techniques. We have used these results to benchmark a novel more efficient numerical technique [2]. Moreover, in the large-tilt regime the observed non-ergodic behavior is explained by an emergent fragmentation of the many-body Hilbert space into an exponential number of dynamically disconnected subspaces [3]. The experimental realization of this regime paves the way for future studies at the interface of MBL and weak-ergodicity breaking phenomena in one- and two-dimensions.

References:

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[2] B. Hebbe Madhusudhana et al., PRX Quantum 2, 040325 (2021).
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