Eigenstate thermalization to non-Gibbs states in strongly-interacting chaotic lattice gases

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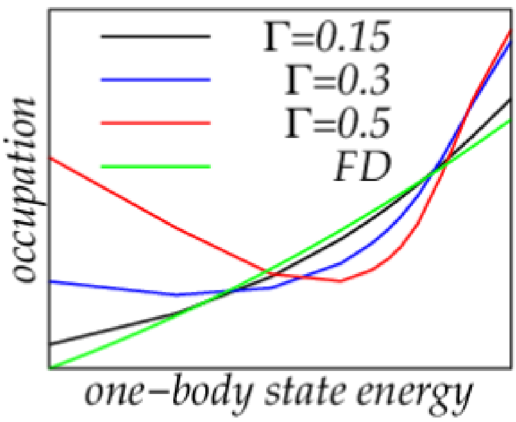
The eigenstate thermalization hypothesis (ETH) states that eigenstate expectation values are approximately equal to their microcanonical means. However, ETH does not specify the properties of these expectation values. We use exact diagonalization calculations [1] for two lattice systems: the two-dimensional Fermi-Hubbard model with 6 particles in the 6×5 lattice and the one-dimensional Bose-Hubbard one with 10 particles in 8 sites. In both cases, the Hilbert space dimension is about 20000. For sufficiently strong interactions, both models exhibit Wigner-Dyson statistics of energy spectra and demonstrate eigenstate thermalization. This is confirmed by the suppression of eigenstate-to-eigenstate fluctuations of the observable expectation values and by the large number of principal components (NPC). In this regime, the microcanonical distributions of the one-body (1B) orbital occupations for interacting and noninteracting particles are very close (the average expectation values of interactions are subtracted from the interacting particle Hamiltonians). Both distributions differ from the Fermi-Dirac (FD) and Bose-Einstein (BE) distributions due to the small system size.

In contrast, when the interaction is increased, the microcanonical distributions for interacting particles deviate substantially from the noninteracting ones. Unlike in the weak-interaction case, the interaction-energy shift does not capture the deviation, nor does any other energy shift, as the interacting and noninteracting distributions have different curvatures and are thus qualitatively different. In the systems considered, where the energy spectrum is bounded both from below and above, noninteracting distributions can have various shapes, being either increasing or decreasing functions of the 1B orbital energy. The eigenstates of the interacting system are superpositions of the noninteracting-system eigenstates with probabilities determined by the Wigner spectral function, or local density of states (LDOS). The LDOS width Γ increases with the interaction strength. If Γ exceeds the energy scale over which the noninteracting distributions vary, the interacting system's occupation distribution can mix noninteracting distributions of different shapes and differ from any individual noninteracting microcanonical distribution.

For large numbers of particles, noninteracting distributions are precisely given by the FD or BE distributions. While finding the exact LDOS by direct diagonalization is not possible for large systems, in the case of strong interactions, it can be approximated by the Gaussian shape. The obtained distributions (see figure) for the interacting system have clearly pronounced minima for Γ spanning eigenstates corresponding to both decreasing and increasing FD or BE distributions, or, respectively, to positive and negative temperatures. This occurs in the regime of quantum ergodicity, when NPC becomes comparable to the Hilbert space dimension. The proposed effects may be observed in experiments with cold atoms in optical lattices.



1. Vladimir A. Yurovsky and Amichay Vardi, Phys. Rev. Res. 7, 043354 (2025)