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Time-resolved observation of thermalization in an isolated quantum system

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Starting from which size can a closed quantum system feature thermailization, how can we reveal and interpret the related microscopic dynamics? We want to discuss our experimental study based on linear chains of up to five trapped ions using two different isotopes of magnesium to realize a single spin with tunable coupling to a resizable bosonic environment. By that we extend our trapped-ion system including its engineered phonon environment up to relevant Hilbert space dimensions. We measure time averages and fluctuations of spin observables and exploit an effective dimension to study their dependence on the size of the system. We find time averages of spin observables becoming indistinguishable from microcanonical ensemble averages, and amplitudes of time fluctuations decaying as we increase the effective system size. Simultaneously, we monitor the coherent dynamics, revealing the importance of initial and transient time scales by direct observation of the evolution towards thermal equilibrium. We interpret this behaviour as the emergence of statistical mechanics in a near-perfectly-isolated quantum system, despite its seemingly small size. In general, trapped-ion are well suited to study quantum dynamics at a fundamental level, featuring unique control in preparation, manipulation, and detection of electronic and motional degrees of freedom. Their Coulomb interaction of long range permits tuning from weak to strong coupling to the environment and controlling non-linear contributions. Additionally, systems can be scaled bottom up to the mesoscopic size of interest to investigate many-body physics. We aim to discuss future prospects, such as, generating a multitude of initial conditions, choosing different system and environment states, and preparing initial correlations. The system allows measuring a variety of observables. Applying those techniques, we can study, e.g., non-Markovianity of the dynamics, which is evidenced already by revivals in the evolution.