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Non-equilibrium dynamics of one-dimensional Bose gases

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ABSTRACT

Understanding the non-equilibrium dynamics of isolated quantum many-body systems is an open problem on vastly different energy, length, and time scales. Examples range from the dynamics of the early universe and heavy-ion collisions to the subtle coherence and transport properties in condensed matter physics. However, realizations of such quantum many-body systems, which are both well isolated from the environment and accessible to exerperimental study are scarce.

This thesis presents a series of experiments with ultra-cold one-dimensional Bose gases. These gases combine a nearly perfect isolation from the environment with many well-established methods to manipulate and probe their quantum states. This makes them an ideal model system to explore the physics of quantum many-body systems out of equilibrium.

In the experiments, a well-defined non-equilibrium state is created by splitting a single one-dimensional gas coherently into two parts. The relaxation of this state is probed using matter-wave interferometry. The observations reveal the emergence of a pre-thermalized steady state which differs strongly from thermal equilibrium. Such thermal-like states had previously been predicted for a large variety of systems, but never been observed directly.

Studying the relaxation process in further detail shows that the thermal correlations of the prethermalized state emerge locally in their final form and propagate through the system in a light-cone-like evolution. This provides first experimental evidence for the local relaxation conjecture, which links relaxation processes in quantum many-body systems to the propagation of correlations. Furthermore, enigneering the initial state of the evolution demonstrates that the prethermalized state is described by a generalized Gibbs ensemble, an observation which substantiates the importance of this ensemble as an extension of standard statistical mechanics. Finally, an experiment is presented, where pairs of gases with an atom number difference appear to have thermalized while they still remain in a non thermal state.

The results presented in this thesis demonstrate both the wide range of phenomena that can occur in non-euqilibrium quantum many-body systems, and the great potential of one-dimensional Bose gases to explore these phenomena. This paves the way for the further study of a universal framework for non-equilibrium dynamics.