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Non-equilibrium dynamics, heating, and thermalization of cold atoms in optical lattices

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In recent years, out of equilibrium many-body dynamics have become accessible in a controlled way in experiments with ultracold quantum gases. Time-dependent processes in these systems are not only intrinsically interesting, but also extremely important for understanding many-body state preparation, heating, and thermalization as they arise in experiments. They also offer new connections to phenomena studied in solid-state systems. This interest has been complemented by the development of a range of numerical methods, including time-dependent density matrix renormalization group (t-DMRG) methods and matrix product state approaches, which have been applied to study dynamics in 1D lattice systems and spin chains. We have extended and applied these methods to study the non-equilibrium dynamics of cold atoms in optical lattices arising from different heating mechanisms, especially due to spontaneous emissions from incoherent scattering of the lattice light, or via classical noise on the optical potential. Understanding how these heating mechanisms affect the properties of different many-body states is crucial in addressing current experimental challenges in the preparation of interesting quantum phases at low temperatures. The resulting non-equilibrium dynamics typically depend strongly on the properties of the many-body state, with different states being more or less sensitive to different heating mechanisms. Moreover, there is often a separation of timescales between some excitations that thermalize rapidly, and some that do not properly thermalize in the duration of an experimental run, which can strongly modify, and even reduce the overall effects of the heating processes. Part of this work involves the treatment of open many-body quantum systems, where we derive many-body master equations to describe the dynamics and solve these numerically by combining t-DMRG methods with quantum trajectory techniques from quantum optics.