Universal adiabatic dynamics across a quantum critical point

Author: Anatoli Polkovnikov

and

Dynamics of a Quantum Phase Transition,

Authors: Wojciech H. Zurek, Uwe Dorner, and Peter Zoller

Recent experimental studies of ultracold atoms trapped in optical lattices have opened new frontiers in the studies of highly correlated quantum states. The characteristic microscopic time scales of the atomic systems are often long enough that they can become comparable to the scales over which the environmental parameters of the optical lattice can be changed. Such systems can be easily driven out of equilibrium, but there is little existing theoretical work in such situations. Studies of correlated systems as they initially fall out of equilibrium therefore seem ripe for theoretical investigation. Such studies would also appear to be a pre-requisite for the far more ambitious goal of using the correlated atomic states for applications in quantum computing, which clearly require states very far from equilibrium.

The two papers noted here make simple but important observations on non-equilibrium dynamics near second order quantum phase transitions. Imagine tuning a system across the quantum phase transition at the rate R. Because of critical slowing down, no matter how small R is, this rate will become faster than the intrinsic time scale of the quantum dynamics close enough to the quantum critical point, and so the system will fall out of equilibrium. By analogy with the Kibble-Zurek picture of the nucleation of defects in the early universe, we can characterize the out of equilibrium system by a density of defects (vortices or domain walls) that appear above an ordered ground state. A scaling argument shows that this density is of order $R^{(\nu d/(1+z\nu))}$, where ν is the correlation length exponent, d is the spatial dimensionality and z is the dynamic critical exponent. The papers present a number of explicit analytical and numerical computations on simple model system which support the scaling result. This result could turn out to be a useful tool for determining critical exponents in experiments.

Complementary to these ideas are studies in which a system parameter is changed instantaneously across a quantum phase transition. This typically leads to quantum oscillations: a recent comparison between theory and experiment for this case is in cond-mat/0504762.