Out-of-equilibrium dynamics in strongly correlated one-dimensional quantum many-body systems

PhD Thesis Summary

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Due to the rapidly growing experimental tools to probe their dynamics, strongly correlated low-dimensional quantum many-body systems became the cornerstone of contemporary condensed matter physics.

As a first agenda, I focused on the weak integrability breaking in the spin-1/2 XXZ spin chain. Recently, it turned out that perturbing an integrable spin chain by one of its generalised conserved currents breaks integrability at higher-than-first order in perturbation theory in the integrability-breaking coupling parameter. The phenomenon is dubbed *weak* integrability breaking, as opposed to the usual *strong* integrability breaking where the breakdown of integrability already occurs at first order in perturbation theory. Applying numerical exact diagonalisation and computing the level spacing statistics for the perturbed system, I directly compared the effects of current perturbation and next-to-nearest neighbour interaction (known to break integrability at first order). By studying the finite size scaling of the crossover coupling, I found that the level spacing statistics captures the effects of weak integrability breaking of the current perturbation.

Secondly, I determined the range of validity of two popular semi-classical methods for computing non-equilibrium dynamics in interacting quantum field theories: the self-consistent Hartree-Fock approximation (SCA or mean field) and the truncated Wigner approach (TWA). Serving as a platform for validation, I simulated quantum quenches in the (1+1)d φ^4 model using a version of the truncated Hamiltonian approach (THA), a well-controlled numerical method providing very precise time evolution. As expected, both the SCA and the TWA fail to reproduce the exact time evolution when the interactions grow too large. In the latter, large values of the coupling result in an artefact consisting of the appearance of a classical symmetry-broken steady state whenever the bare mass in the TWA equations of motion becomes negative, rendering the TWA unreliable.

Motivated by the success of the THA, I simulated the real-time decay of the false vacuum following quantum quenches in the (1+1)d φ^4 theory. Preparing the system close to the false vacuum, the exponential decay of the order parameter can be identified, allowing the numerical extraction of the decay parameter. The numerical results for the decay rate follow the analytical predictions for a wide range of coupling parameters up to a numerical normalisation factor that only depends on the coupling.

Finally, I performed quantum quenches in the sine-Gordon model, which provides a partial description of an experimental system consisting of two coupled one-dimensional bosonic quasi-condensates. Using a novel version of the THA built upon a mini-superspace treatment of the zero mode, I studied the non-equilibrium time evolution of the system in various quench protocols and compared the results to the TWA simulations. We clarified the roles of the phononic degrees of freedom and found that the MSTHA successfully reproduces the exact evolution when the injected energy density is sufficiently small. In contrast, the TWA performs very well even for stronger quenches in the experimentally available weakly interacting parameter range, suggesting that a semi-classical description can approximate the dynamics in the experiments well.