ENS DE LYON

Lab PHYS ENS de LYON

Academic year 2021-2022

Elementary excitations of quantum many-body systems and their non-equilibrium image

M2 internship => PhD Thesis — Quantum many-body physics, quantum simulation

Supervisor: **Tommaso ROSCILDE** (Laboratoire de Physique, ENS Lyon)
e-mail: tommaso.roscilde@ens-lyon.fr
URL: sites.google.com/site/roscilde/

Quantum simulators [1] — based on neutral atoms trapped in optical lattices, Rydberg atoms trapped by optical tweezers, ions in Paul/Penning traps, superconducting circuits, etc. — allow one to study quantum many-body phenomena in the most controlled way developed to date. Among most relevant phenomena demonstrated in quantum simulators one can cite superfluidity, superconductivity, and magnetic order; and their quantum or thermal transitions to normal/disordered phases.

In solid state physics, quantum many-body systems are generally prepared in equilibrium conditions at low temperatures in contact with a heat bath; and their thermodynamics, spectral functions etc. are studied by coupling them to probes minimally altering the equilibrium state. In a nicely complementary way to solid-state physics, the most natural conditions under which the above phenomena are investigated by quantum simulators are in a time-dependent framework, in which a fiducial initial state is let to evolve either adiabatically — targeting the low-energy state of a strongly interacting Hamiltonian; or abruptly via a so-called quantum quench — giving access to the dynamics of entanglement and correlations under the effect of the Hamiltonian in question. In this context, the nature of the dynamics under sudden or adiabatic transformation of the Hamiltonian is fundamentally influenced by the nature of the *elementary excitations* of the system. This observation suggests in turn that characteristics of the elementary excitations, and in particular their dispersion relation, can be quantitatively reconstructed via an analysis of the non-equilibrium dynamics. This is the principle of *quench spectroscopy* [2,3,4], which represents the most natural spectroscopic approach for quantum simulators undergoing coherent quantum dynamics away from equilibrium.

The goals of this project is to apply the quench spectroscopy program — namely the Fourier analysis of the spatio-temporal pattern of correlations developing after a quantum quench — to a broad variety of non-equilibrium evolutions of quantum many-body systems. Possible systems of interest will be: 1) quantum gases trapped in optical lattices, made either of spinless or spinful bosons/fermions, with particular interest in the dispersion relation of excitations in the Bose/Fermi-Hubbard model, and of models of spinor Bose gases on a lattice; 2) quantum spin models inspired by the capabilities of Rydberg-atom quantum simulators, with particular emphasis on the potential implementation of frustrated systems possessing fractionalized elementary excitations (namely excitations whose quantum numbers are fractions of the elementary quantum numbers that one can transfer physically to the system).

This large variety of models can be studied using time-dependent variational Ansätze, mostly of Gaussian type (modified spin-wave theory, Hartree-Fock-Bogolyubov theory, etc.) as well as their generalizations; a more advanced possibility will be the use of time-dependent variational Monte Carlo applied to highly correlated Ansätze, which has proved already very successful in analyzing the non-equilibrium physics of quantum many-body system [5].

The theoretical work is framed within a close collaboration with Fabio Mezzacapo (ENS de Lyon) on the development of variational Ansätze for strongly correlated systems. Moreover this project is framed within a theory-experiment collaboration (funded by a French and a European project) with a network of experimental and theory teams including the Laboratoire de Physique des Lasers, Paris XIII; the Center for Ultracold Atoms and Quantum Gases, University of Innsbruck (Austria); the 5th Institute of Physics of the University of Stuttgart (Germany); the CNR-INO in Pisa (Italy); the Institute for Photonic Sciences (Spain); and the Institute of Physics of the Polish Academy of Sciences (Poland).

[1] I. M. Georgescu et al., Rev. Mod. Phys. **86**, 153 (2014).
[2] I. Frérot, P. Naldesi and T. Roscilde, Phys. Rev. Lett. **120**, 050401 (2018).
[3] R. Menu and T. Roscilde, Phys. Rev. B **98**, 205145 (2018).
[4] L. Villa et al., Phys. Rev. A **100**, 063632 (2019).
[5] T. Comparin, F. Mezzacapo and T. Roscilde, arXiv:2103.07354 (2021).