

Project A11

1 Non-equilibrium dynamics and thermalization in closed quantum systems

Experiments on cold atomic gases allow to investigate fundamental questions of statistical physics in almost isolated and well-controlled quantum systems. In particular, microscopic parameters of the system can be changed in a so-called quantum quench and the ensuing non-equilibrium dynamics can be studied. Fundamental questions which can be addressed are the relaxation dynamics after the quench as well as a possible thermalization at long times. Much of the interest in recent years has been focussed on quasi one-dimensional systems where additional conserved or almost conserved charges can strongly affect the dynamics and prevent the system from thermalizing [1].

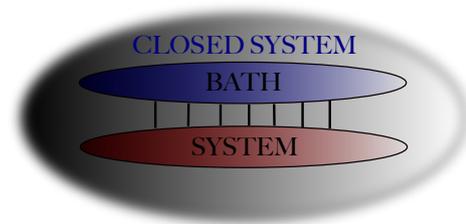


Fig.1: A closed quantum system can act as an effective bath for any of its subsystems leading to a thermalization of observables in the subsystem.

We have developed a numerical algorithm which allows to simulate very efficiently the dynamics following a quench by making use of the Lieb-Robinson bounds which set a maximum speed at which information can spread in a quantum lattice model [2]. We have then used similar algorithms as well as analytical methods to study the dynamics in a model system consisting of a chain coupled to a microscopically specified bath [3]. Furthermore, we have derived a necessary and sufficient condition for the thermalization of a quantum system based on the identification of its local and non-local conserved charges and shown the usefulness of this condition for numerical studies of specific lattice models [4]. One particular simple observable after a quantum quench is the Loschmidt echo which can be measured in nuclear magnetic resonance experiments. We have recently shown that non-analyticities in the Loschmidt echo are related to the crossing of eigenvalues in a boundary transfer matrix, an observation which will help to analyze and classify such dynamical transitions in the future [5].

[1] T. Kinoshita, T. Wenger, and D. S. Weiss, *Nature* **440**, 900 (2006).

[2] T. Enss and J. Sirker, *New J. Phys.* **14**, 023008 (2012).

[3] N. Sedlmayr, J. Ren, F. Gebhard, and J. Sirker, *Phys. Rev. Lett.* **110**, 100406 (2013).

[4] J. Sirker, N. P. Konstantinidis, F. Andraschko, and N. Sedlmayr, arXiv: 1303.3064 (2013).

[5] F. Andraschko and J. Sirker, arXiv: 1312.4165 (2013).

2 Dissipative quantum dynamics

In the group of Herwig Ott (project A9) an electron beam is used to remove bosons from selected sites of an optical lattice [6,7]. The ensuing dynamics in the three-dimensional case is investigated in the group of Walter Hofstetter (project A3).

We are interested in the one-dimensional case which can also be realized using optical lattices and are planning to extend the numerical method [1] (see above) to open quantum systems. As a first step,

we will investigate the dynamics after the removal or addition of a single boson at one particular lattice site. Here we are, in particular, interested in the different dynamics in the superfluid and the Mott insulating phases. As a second step, we will simulate a Lindblad equation for a continuous loss process as realized in project A9. We are interested in the quantum Zeno effect [8], the steady states which form at long times, the correlations in the steady state, and the dynamical phase transitions between different steady states.

[6] P. Würtz, T. Langen, T. Gericke, A. Koglbauer, and H. Ott, Phys. Rev. Lett. **103**, 080404 (2009).

[7] G. Barontini *et al.*, Phys. Rev. Lett. **110**, 035302 (2013).

[8] P. Barmettler, C. Kollath, Phys. Rev. A **84**, 041606(R) (2011).

3 Thermodynamics of frustrated magnetic systems

Geometrical frustration of magnetic interactions can possibly lead to new states of matter including spin liquid phases. In recent years, a large number of new compounds have been synthesized where frustration is present. One of these compounds is $\text{Cs}_2\text{CuCl}_{4-x}\text{Br}_x$ which has been synthesized in project B4 (Ritter/Abmus), experimentally investigated in project B1 (Wolf/Lang) [9], while band-structure calculations have been performed in project B2 (Jeschke/Valenti). $\text{Cs}_2\text{CuCl}_{4-x}\text{Br}_x$ consists of one-dimensional chains which are coupled through a frustrating interchain coupling which can be tuned by varying the Bromium content [10].

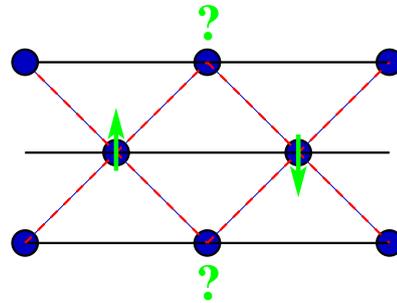


Fig. 2: $\text{Cs}_2\text{CuCl}_{4-x}\text{Br}_x$ consists of chains coupled by weaker interchain couplings along the triangles inducing magnetic frustration.

Since experiments are done at finite temperatures it is important to calculate the thermodynamic properties of appropriate minimal models for such frustrated magnetic compounds. We have started such an investigation by considering a two-leg ladder taken from the $\text{Cs}_2\text{CuCl}_{4-x}\text{Br}_x$ lattice. Such a two-leg ladder system is interesting in its own right because it describes materials such as LiCuVO_4 and LiCu_2O_2 which show multiferroic behavior, i.e., an intricate coupling between the magnetization and an electric polarization. By calculating thermodynamic quantities like the susceptibility, the specific heat, as well as the spin-structure factor we have confirmed the minimal model required to describe these compounds and obtained the magnetic exchange constants [11,12]. We are now planning to extend our studies to multi-leg ladders and to the two-dimensional lattice in order to obtain results which can be directly compared with the experiments on $\text{Cs}_2\text{CuCl}_{4-x}\text{Br}_x$ in project B1 (Wolf/Lang).

[9] P. T. Cong *et al.*, Phys. Rev. B **83**, 064425 (2011).

[10] K. Foyevtsova, I. Opahle, Y. Zhang, H. O. Jeschke, R. Valenti, Phys. Rev. B **83**, 125126 (2011).

[11] J. Ren and J. Sirker, Phys. Rev. B **85**, 140410(R) (2012).

[12] J. Sirker, Phys. Rev. B **81**, 014419 (2010).