Project A3

Dynamical Arrest of Ultracold Lattice Fermions

We have theoretically calculated [1] the thermodynamics of interacting two-component fermions in an optical lattice. The trapping present in the lattice system causes fermionic gases to possess a particular cloud size, as shown in a recent experiment [2]. Depending on the interaction, entropy, particle number and trap size, we can calculate the cloud size by using dynamical mean-field theory (DMFT).

We find that the cloud size increases with strong repulsive interactions as expected, but also shows an anomalous increase for strongly attractive interactions. This is due to adiabatic heating originating from a reduced phase space available. The experiment [2], which also operated at fixed entropy, demonstrated the same behaviour. However, as the experimental lattice is ramped up, we have shown that dynamical arrest takes place at a critical lattice depth which depends on the interaction. This dynamical arrest describes the inhibited motion of the atoms due to the interactions and prevents introduces non-adiabaticity.

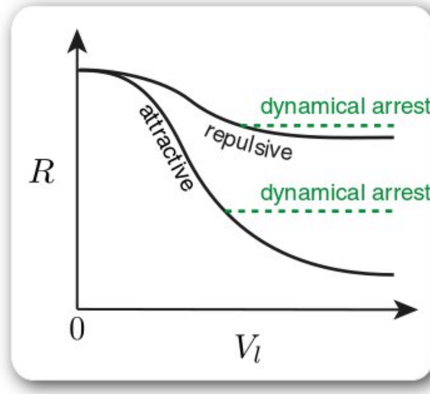

Figure 1: Cloud radius as a function of trap depth, showing the onset of dynamical arrest.

[1] B. Schmidt et al., Phys. Rev. Lett. 110, 075302 (2013).

[2] L. Hackermüller et al., Science 327, 1621 (2010).

Bosonic Dynamical Mean-Field Theory: Pomeranchuk Effect and Anisotropic Magnetism

In our group, we have developed the formalism to simulate bosonic ultracold gases with dynamical mean-field theory (BDMFT). This formalism allows us to go beyond weak-coupling approaches and simulate non-trivial phases such as supersolid order or anistropic magnetic order. In particular we have used this approach to investigate spin-gradient cooling [1], map out the phase diagram with anistropic interaction [2], and consider pair-superfluidity [3] of a two-component Bose-Bose mixture in a cubic lattice.

There are five different parameters possible within a two-component bosonic system, two of which govern the repulsion or attraction between same-spin species and one which governs the inter-spin interaction and two hopping parameters. We have shown [2] that many different phases can be found, such as the unordered Mott-insulator and superfluid phases of the spinless system, or more exotic phases such as XF-ferromagnet, anti-ferromagnet and single-component superfluid. Furthermore, we obtain regimes in which a super-solid can be found, i.e. a phase that includes both superfluidity and a spatial density profile.

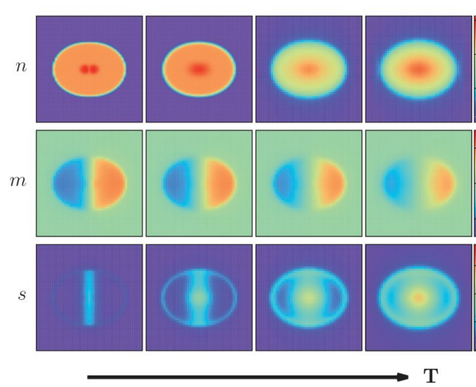

Figure 2: Real-space profiles of the density, magnetization and entropy with a magnetic field gradient.

The same homogeneous system, can be shown to exhibit a transition from the superfluid phase to a Mott-insulator phase upon heating, in a similar fashion to the Pomeranchuk effect in helium-3. With the inclusion of a trap and a magnetic field gradient that is slowly turned off in time, we observe spin-gradient cooling, in which the entropy of the system is carried mostly by the spin degrees of freedom.

[1] Y. Li et al., Phys. Rev. A 85, 023624 (2012).

[2] Y. Li et al., Phys. Rev. B 84, 144411 (2011).

[3] Y. Li et al., arXiv:1203.4262 (2012).

Dissipative Dynamical Bosonic Systems in 3D Optical Lattices

In the group of Herwig Ott (project A9), an experimental setup [1] that includes an electron beam provides the perfect opportunity to investigate dissipative dynamics in a lattice system. In Frankfurt, we have been theoretically investigating two different regimes for such a system. The first is the propagation of defects, resulting from a carefully prepared system. The way that these defects evolve in time tell us much about the competition between local interaction, lattice hopping and trapping effects. The second regime is the continuously dissipative regime, in which the electron beam may move across, or oscillate in, the lattice.

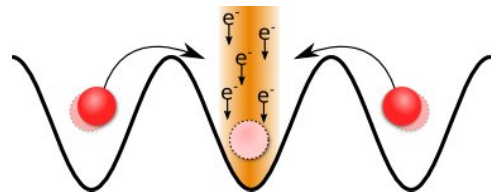

Figure 3: Illustration of the loss process induced by the electron beam.

We aim to investigate physics such as the quantum Zeno effect, the interplay between insulating and superfluid phases in the lattice and the characterisation of systems through dissipation. To this end, we use a combination of bosonic Gutzwiller calculations, dissipative master equations and exact diagonalization methods.

[1] P. Würtz, et al., Phys. Rev. Lett. 103, 080404 (2009).

1 Artificial Gauge Fields in Optical Lattices

Artificial gauge fields have arisen as a new and exciting field of study in ultracold gases. Previously, quantum simulators made from ultracold gases lacked the ability to model the Lorentz force as felt by an electron in a magnetic field, because the neutral atoms do not react in the same way. However, recent experiments have demonstrably produced artificial magnetic fields, by effecting the identical phase as would be expected from an electronic system. For example, vortices have been observed in Bose-Einstein condensates [1].

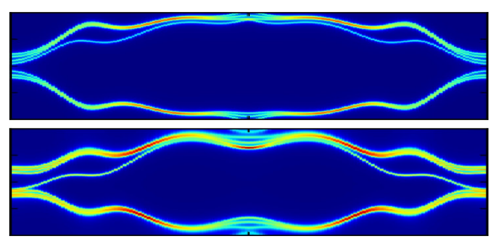

Figure 4: Spectrum at low (upper) and high (lower) interaction, showing the appearance of an edge state.

We are investigating the properties of artificial gauge fields in combination with optical lattice systems. Previous work within the group has looked at the effect of interactions in fermonic systems in the realization of the quantum (spin) Hall effect. Our current work, however, focuses on bosonic lattice systems which exhibit additional interesting features. While much is already known about the single-particle physics of these systems, the behavior of collective excitations in the presence of interactions is of great interest. Within the SFB project, in Frankfurt, we theoretically address typical excitation spectra of these phases and their dynamical response to external perturbations.

[1] Y. Lin et al., Nature 462, 7273 (2009).