OSCAR[1] Reports–

an SFB/TR 185 quarterly magazine (1/2020)

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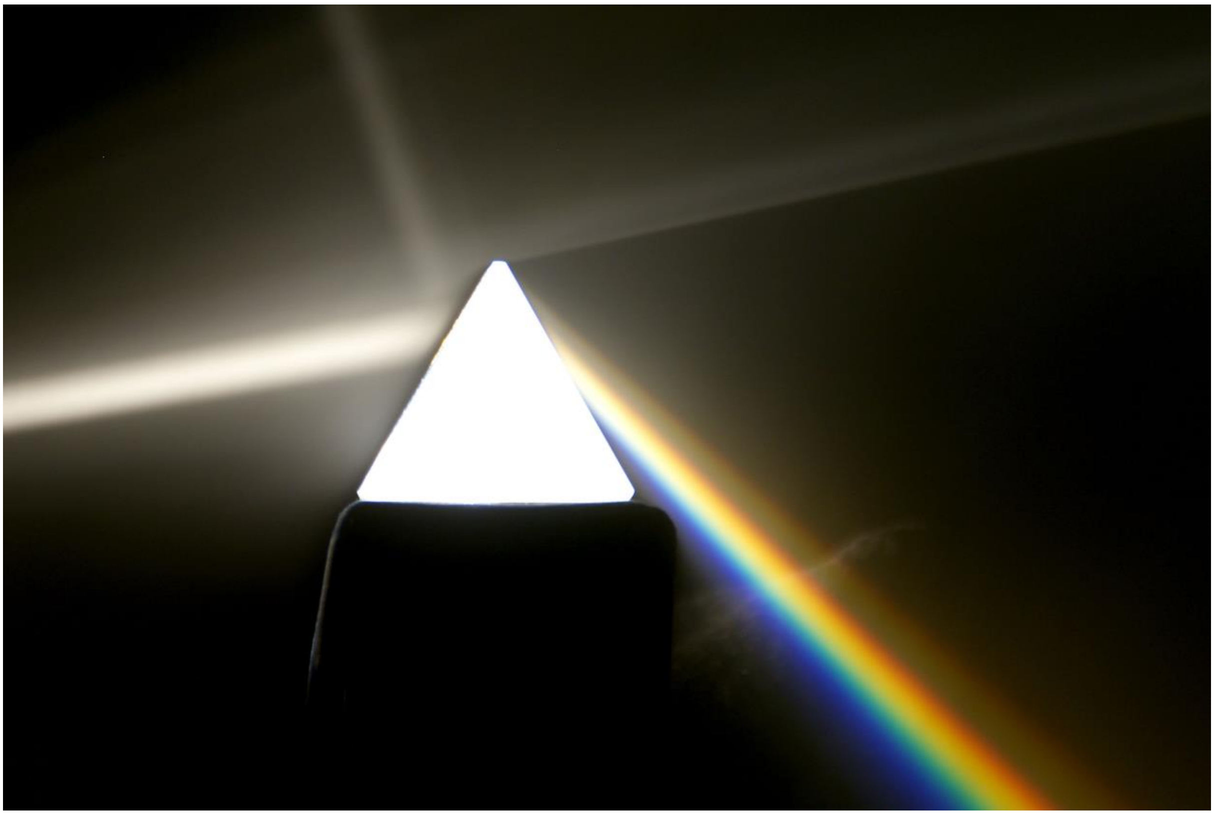

Photograph: Jan Heysel, U Bonn

[1] stands for **O**pen **S**ystem **C**ontrol of **A**tomic and Photonic Matte**R;** funded by the Deutsche Forschungsgemeinschaft since July 01, 2016

Single-Atom Quantum Probes for Ultracold Gases Boosted by Nonequilibrium Spin Dynamics

Immersing a single cesium atom into a rubidium cloud allows non-destructive temperature measurements with high sensitivity

Q. Bouton, J. Nettersheim, D. Adam, F. Schmidt, D. Mayer, T. Lausch, E. Tiemann, and A. Widera

Phys. Rev. X 10, 011018 (2020)

"Temperature is measured with a thermometer". In the macroscopic world this is realized by attaching a 'probe' to the sample, wait a little to achieve thermal equilibrium and then get the temperature from the probe using a well-defined mechanism. Traditionally, one uses mercury or alcohol in a tube, modern devices rely on the electrical resistance of a calibrated resistor or other sophisticated temperature-dependent mechanisms, but most methods in the end boil down to measuring the kinetic energy of the probe as detailed by the kinetic theory. This approach becomes problematic when we want to measure the temperature of a small system, as the probe is supposed to not alter the state of the system. Thus, miniaturizing the probe is required, and the ultimate probe is a single (quantum) particle as the probe. But then, a natural question occurs: Can we use the internal energetic structure of the quantum particle instead of its kinetic energy, and can we gain something from using a quantum particle?

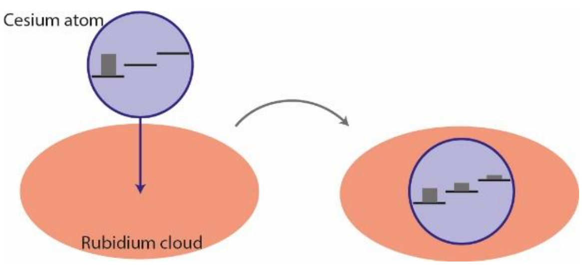

Fig. 1: A cesium atom is placed into a rubidium cloud, and by thermal contact the spin states equilibrate. For simplicity only 3 spin states are shown.

While both questions have been answered positive by theoreticians, experiments have been elusive up to now. One general problem is that the energy spacing of the probe energy levels should roughly match the thermal energy of the sample under investigation, and one should be able to address the probe. These problems have been tackled and solved by the group of Artur Widera: They use a single cesium atom to measure the temperature of a rubidium cloud by measuring the spin populations instead of the kinetic energy. A magnetic field is used to lift the energetic degeneracy of the spin states, and the contact of the cesium atom to the rubidium cloud equilibrates the spin population to the temperature of the cloud, allowing a spatially local and mostly non-invasive temperature measurement. As usual, there is a caveat: The thermometer needs a few seconds to equilibrate, a timescale that might be too long for many measurements. In the present experiment, a cesium atom is lost on average after 1.5 seconds, i.e. you displace your thermometer before you can read the temperature. However, in the present system a detour exists: When doing a model-dependent fit, one can extract the temperature after a time of only 350 - 400 milliseconds, after only 3 collisions between cesium and rubidium. Not only is this method faster, it also provides a sensitivity that beats the steady-state limit given by the Crámer-Rao bound.

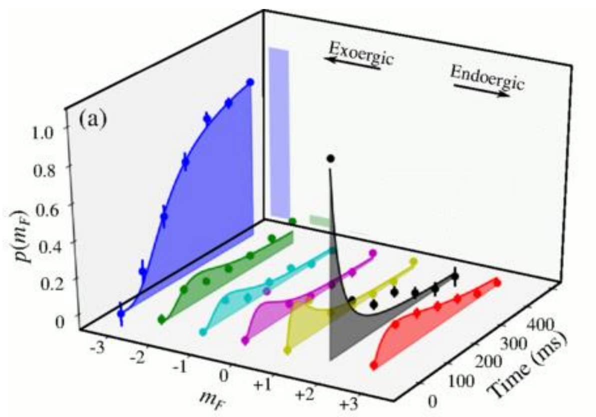

Fig. 2: Temporal evolution of the spin population of the single cesium atom.

The realization of this single-atom thermometer is a beautiful tool for further studies: Not only does it provide a non-destructive and minimally invasive method to measure the temperature, it also provides a spatially localized probe, which could give information on local temperatures in systems not in thermal equilibrium.

Simulating a Mott Insulator Using Attractive Interaction

Exploiting particle-hole symmetry opens a route for quantum simulations of strongly correlated systems

M. Gall, C. F. Chan, N. Wurz, and M. Köhl

Phys. Rev. Lett. 124, 010403 (2020)

Exploiting symmetries is often done in physics to find solutions to seemingly hard problems. Already in the introductory courses one uses symmetries to get rid of variables, or one finds the conservation law connected to a specific symmetry to find constants of motion. In quantum simulation, one uses symmetries to map experimentally "hard" problems to "easier" problems, where easier means that the corresponding observable (density, spin, …) or the interesting parameter range is accessible in a favorable way. It has been proposed to use particle-hole symmetry to study strongly correlated systems, for instance the putative d-wave superfluid phase of the repulsive Fermi-Hubbard model would relate to a d-wave antiferromagnetic phase in the attractive Fermi-Hubbard model.

The work done by Gall and coworkers shows that this mapping is indeed experimentally valid by studying fermionic potassium for both attractive and repulsive interactions. In their system, the Hamiltonian stays invariant when replacing one spin component by its hole, while simultaneously reversing the sign of the interaction (and a few details). Consequently, a singly occupied site is mapped to either an empty or a doubly occupied site, depending on its spin. This means that density is mapped to local magnetization, which in some circumstances simplifies measurements, as density correlations will be mapped to spin correlations and vice versa.

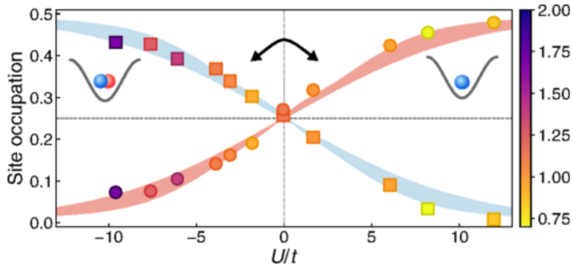

Fig. 2: When reversing the sign of the interaction U singly occupied sites (circles) with spin-up should be mapped to doubly occupied sites (squares). Particle-hole symmetry correspondingly here reflects in the mirror symmetry around the vertical line at U=0.

The Mott insulator phase has been studied before, and its properties are well known, correspondingly it can serve as a benchmark. Indeed, the results from the repulsive and attractive side agree extremely well, showing that exploiting particle-hole symmetry is a promising route to study highly correlated materials using ultracold atomic systems.

Floquet-induced superfluidity with periodically modulated interactions of two-species hardcore bosons in a one-dimensional optical lattice

Kicking bosons leads to the emergence of new and unconventional phases

T. Wang, S. Hu, S. Eggert, M. Fleischhauer, A. Pelster, and X.-F. Zhang

Phys. Rev. Research 2, 013275 (2020)

Phase transitions are studied in various fields, and usually we immediately associate them with a system close to equilibrium, where the system reacts by a strong change in a thermodynamic property as the result of a small change in an external parameter. To make use of a catchy example, consider a superconductor where the resistivity suddenly drops to zero when lowering the temperature.

Many interesting systems however are not in equilibrium, but coupled to an environment, be it via losses or external energy input, or a regular or irregular disturbance. To again invoke the superconductor, does the superconductivity survive when we attach leads at the end to supply or remove charge carriers? Thus, one natural question is to ask if a phase transition or a certain phase survives such a coupling to the environment, or if there are even phases which do not only survive, but only exist because of the disturbance.

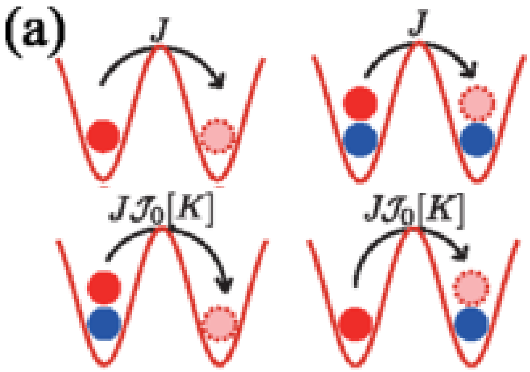

Fig. 3: Sketch of the system. Additional to the standard tunneling J a density dependent hopping term (with scaled strength K) emerges due to the Floquet drive. .$J_0[K]$ here is the Bessel function, depending on the strength of the modulation.

To address this question, the authors look at the experimentally realizable Bose-Hubbard model of two species of bosons in a one-dimensional lattice. Bosons are allowed to hop from site to site with a tunneling rate *J,* and they experience a species-independent on-site interaction U_L and an inter-species interaction U_F. For a deep lattice, the ground state of this system for half-integer filling (for each species) is a Mott insulator. But what happens if the system is now kicked periodically?

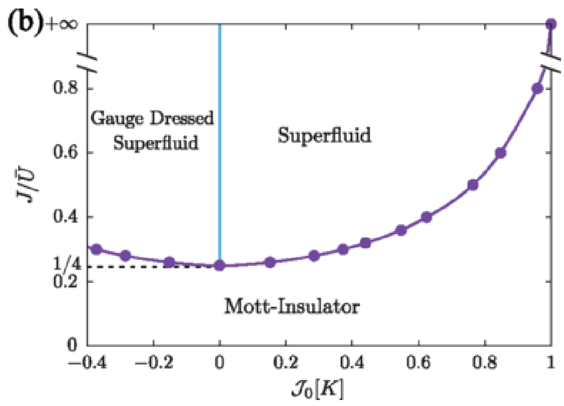

Fig. 4: Phase diagram of the kicked system. For strong kicks, corresponding to $J_0[K] < 0$, a novel superfluid phase emerges.

This Floquet drive introduces a density-dependent hopping term to the Hamiltonian, which can destroy the Mott insulator state: If you start to kick the system violently at some point something breaks, but as always things are not as simple. Indeed, the authors need a multitude of tools to study the Floquet system, namely DMRG (to e.g. find the superfluid density), iDMRG (to determine the entanglement entropy in the thermodynamic limit) and Quantum Monte Carlo (to find the compressibility). The results are intriguing: Not only does the kicking lead to the emergence of superfluidity, it actually leads to the emergence of two different types of superfluid states. For weak kicking, one enters a regime of "usual" superfluidity, but for stronger kicking (which corresponds to negative hopping) quasi-particles are responsible for the superfluid properties, a fact that can be seen in the strikingly different momentum distribution in both phases. This is an important aspect of his work: Not only do the authors describe a way to realize this system experimentally, the novel phase is accessible by measuring the momentum distribution, thus one can expect experimental results on this topic in the near future.