Formation of a spin texture and emergence of metastability in a quantum gas coupled to a cavity

The phenomena that can be observed in quantum many-body systems are strongly governed by the nature of the interactions between its constituents. Hence, it is a long-term goal for experiments with quantum gases to realize and explore new types of interactions. In this context, cavities play a special role by inducing global-range atom-atoms interactions.

In the first part of my talk, I will describe our recent experiments where we observe cavity mediated spin-dependent interactions in an off-resonantly driven atomic Bose-Einstein condensate that is strongly coupled to an optical cavity. The cavity field mediates global-range interactions between all atoms whose strength can be controlled by tuning the relative frequency of the off-resonant drive and the cavity. These interactions become spin-dependent due to a strong opto-magnetic response of the system originating from the vectorial polarizability of the multi-level atoms. Applying a driving field with adjustable polarization, we determine the opto-magnetic response of the system by studying a cavity induced self-organization phase transition. Using a condensate of two internal states coupled to an optical cavity, we realize a spin texture arising from dominant spin-spin long-range interactions[1].

In a different set of experiments, we experimentally realize an extended Bose-Hubbard model with cavity-mediated density-density interactions. The presence of three competing energy scales-tunnelling, short-range interactions and global-range interactions gives rise to a rich phase diagram. We observe four different phases- a superfluid, a supersolid, a Mott insulator and a charge density wave[2]. We further experimentally study the formation of metastable states in the transition between the Mott-insulator and the charge density wave arising due to the existence of an energy barrier between these states. The existence of metastable states is confirmed by two experiments: a quench of global coupling strength where we observe that the system falls into two distinct final states; and a slow ramp of the global coupling where a hysteresis loop is observed between the two states. From the real time monitoring of the state of the system via the cavity output field, we find that during the transition between two insulating states, several thousand atoms tunnel to a neighboring site on the time scale of the single particle dynamics, which can be understood as an avalanche tunnelling process in the Mott-insulating state[3].

[1] Landini et al., arXiv:1803.01803 (2018)

[2] Landig et al., Nature **532**, 476 - 479 (2016)

[3] Hruby et al., pnas.1720415115 (2018)