Sukinių suspaustos būsenos labai šaltųjų fermionų dujose

Spin-squeezed states with ultracold fermions

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Generation, storage, and utilisation of correlated many-body quantum states are crucial objectives of future quantum technologies and metrology. Such states can be generated by the spin-squeezing protocols. Systems composed of ultra-cold fermions in optical lattices have attracted a lot of attention currently in the context of the generation of such non-classical states.

In particular, in our recent work [1, 2], we have shown that in a lattice of strongly interacting ultra-cold fermionic atoms involving two internal states, it is possible to generate non-classical correlations when adding position-dependent atom-light coupling. The Fermi-Hubbard model describing the system under periodic boundary conditions (PBC) can be cast onto an isotropic spin-1/2 Heisenberg chain in a deep Mott regime, while the atom-light coupling can be considered as a position-dependent spin-flipping.

To generate spin squeezing the Ramsey-type spectroscopy scheme is considered, as illustrated in Fig. 1. As soon as the atoms are put in a coherent superposition of two internal states by an electromagnetic pulse, an additional weak atom-laser coupling is turned on. This coupling activates the general mechanism in PBC case: it induces excitation of a pair of spin waves with opposite quasi-momentum. These spin waves extend over the entire system allowing individual atoms to interact *effectively* and establish non-trivial quantum correlations. When the desired level of spin squeezing is established, the spin-flip coupling is turned off, but the quantum correlations survive and are stored deeply in the Mott insulating phase. We showed that the isotropic Heisenberg spin-1/2 chain with the weak position-dependent spin-flip coupling generates spin-squeezing dynamics given by the one-axis twisting model. Furthermore, we numerically observed that open boundary conditions (OBC) change the spin squeezing dynamics.

We provide a detailed analytical and numerical analysis of the impact of PBC and OBC on the spin squeezing dynamics in Heisenberg spin chains. For OBC the coupling leads to the excitation of a superposition of spin waves with different energies and amplitudes rather than a pair of spin waves with opposite quasi-momentum, as it is the case for PBC. This still allows individual atoms to correlate and generate squeezing.

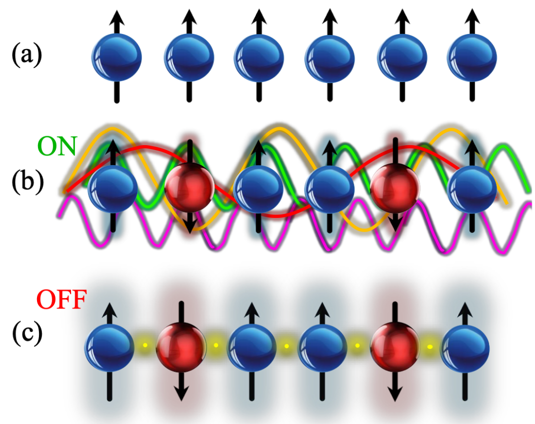

Fig. 1 pav. Illustration of the Ramsey-type spectroscopy scheme. (a) Preparation of the initial spin coherent state. (b) The excitation of spin waves states (different color lines) by the spin-flip coupling serves as an intermediate state to induce *effective* interaction and establish correlations between elementary spins. (c) Turning off the coupling freezes the dynamics, and the spin-squeezed states are stored in the Mott insulating phase. Panels (b) and (c) illustrate an example of a configuration of spins. Yet, the resulting state during and at the end of evolution is a superposition of various possible configurations including the initial one presented in (a).

The results obtained can be used in the current state-of-the-art experiments with ultra-cold atoms in optical lattices and tweezer arrays.

Keywords: optical lattices, cold atoms, quantum technologies, spin squeezing.

References

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