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Lattice induced resonance revealed by metastable spin helix

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Exact solutions for quantum many-body systems are rare but provide valuable insights for the description of universal phenomena. Recently, specific solutions of the Bethe ansatz equations for 1D anisotropic Heisenberg model were found that can carry macroscopic momentum yet no energy on top of the ferromagnetically "vacuum" state, dubbed phantom Bethe states. Consequently, spin helix at special wavelength becomes exact eigenstates of these systems.

With ultracold Li-7 atoms on optical lattices, we can simulate the anisotropic Heisenberg model, and tune the interaction anisotropy with Feshbach resonance. Here, we show experimentally that there exist special helical spin patterns in 1D chains which are long-lived, relaxing only very slowly in dynamics. The wave-vector of these special helices also shifts with the anisotropy parameter. These results confirm theoretical predictions.

As the wavelength of the spin helix is determined by the anisotropy parameter, we use these phantom spin helices to directly measure the interaction anisotropy at different magnetic fields around Feshbach resonances. The measured anisotropy agrees well with the perturbative prediction at moderate distance from the Feshbach resonance. On the other hand, very close to the resonance, this phenomenon allows us to measure the realized anisotropy and the underlying spin interaction. With this powerful tool, we experimentally observed an important effect of strongly interacting particles in lattices, the lattice-induced resonance. In such a resonance, the positive center-of-mass excitation of a pair cancels its binding energy and becomes degenerate with the background energy of separated atoms and can mix due to interaction driven tunneling process. Such a process dominates spin dynamics at strong interaction.

The two effects we observed opened a wide range of possibilities. The Bethe phantom can be generalized to systems with higher dimension and other spin number, where integrability is absent, and these stable states become examples of quantum many-body scar. The simple construction and stability of these states enable their use as the start point of adiabatic preparation of more complex quantum states. Understanding lattice induced resonance can enable more accurate and flexible engineering of quantum Hamiltonians. An adiabatic sweep to paired states through lattice induced resonances may create highly entangled final states.

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