Spin entanglement of hot atoms in an optical tweezer

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The last decades have seen the emergence of ultracold atom experiments as powerful platforms for quantum simulation of complex many-body systems, owing to their ability to probe large ensembles of particles in a well-characterized, tunable, and isolated environment.

Among the various quantum many-body problems within reach of atom-based quantum simulators, interacting fermionic systems play a special role. While they constitute a cornerstone of quantum matter covering a broad fundamental and technological scope, their understanding however still represents a major challenge for existing theoretical approaches, which are widely plagued by the infamous sign-problem.

In this talk, I will present our recent work on quantum gas microscopy of fermionic many-body systems in continuous space, and how we can characterize them at previously inaccessible levels of resolution and control. Our approach offers radically new possibilities for the exploration of strongly interacting Fermi gases at the single-atom level. One of the great challenges of atomic physics is to accurately prepare, manipulate and measure the quantum-mechanical state of a physical system. One particular property of multi-particles quantum states is entanglement. This property is of high interest for performing non-classical calculations for the use in quantum information or for sensitivity enhanced measurements. Spin entangled states of many body atomic ensembles have been engineered and validated. Isolating a single atomic pair thanks to optical tweezers allows to deeply investigate spin-changing collision at the particle level and the entangled state. So far, the spin entanglement of an atomic pair has been successful for groundstate- cooled atoms. Being able to maintain it at a higher temperature would be a step forward to robust measurements into real-world field implementations.

Here, we study hot spin-exchange collision as a route to entanglement. In previous works, we observed the population dynamics of the magnetic sublevels of an atomic

pair of 85Rb prepared separately in two microtraps undergoing a collision in an optical tweezer. The spin-changing collision of two thermal atoms initially prepared in a $m = 0$ state leads to strong spin pair correlations between the magnetic states $m = 1$ and $m = -1$. To probe the entanglement of the pair, a Raman transition pulse couple the two magnetic sublevels, leading to a destructive interference when the pair is entangled. Our measurements and a simulation taking into account the full level structure of the atom while applying the Raman pulse, show that the spin exchange collision successfully create an entangled pair from two thermal atoms. Applying a magnetic gradient that the atomic pair experiences, introduces a bias between the two magnetic states and therefore destroy the entanglement of the pair. As a proof of principle, we show that this resulting entanglement could be useful for magnetic fields measurements beyond the standard quantum limit.