Engineering the Kondo impurity problem with alkaline-earth atom arrays

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Abstract We explore quantum simulations of the Kondo problem using cold alkaline-earth(-like) atoms. We identify overlooked interaction terms spoiling Kondo physics and demonstrates its restoration using optical tweezers, enabling new direct insights into unconventional Kondo regimes.

We propose quantum simulation experiments of the Kondo impurity problem using cold alkaline-earth(-like) atoms in a combination of optical lattice and optical tweezer potentials. Leveraging on an ab-initio description of the atomic interactions in the optical lattice we identify additional terms not part of the textbook Kondo problem. These terms, mostly ignored in previous works, lead to a direct competition between spin and charge correlations—strongly suppressing Kondo physics. We show that the Kondo effect can be efficiently restored using locally controllable energy levels on the impurity site through an optical tweezer. Using numerical solution of small-scale systems at finite temperature, we analyze the hallmark signatures of the Kondo effect in a variety of observables accessible in cold-atom quantum simulators. This allows us to identify realistic parameter regimes and preparation protocols suited to current experiments with alkaline-earth(-like) atom arrays paving the way for novel quantum simulations of the Kondo problem and offering new insights on Kondo physics in unconventional regimes.