Circular Rydberg atom - exotic magnetic impurity in ultracold quantum environment

Abstract for the general public

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I. MOTIVATION

The quantum impurities, which drastically change the properties of the systems, are well-known in condensed matter physics. The physical phenomena caused by them, like the Kondo effect or superconductivity in heavy-fermion materials, are heavily investigated in experiments and theoretical studies. The development of ultracold physics has unlocked new possibilities for the simulation and study of many-body systems, including systems with impurities. The unique control over the system's parameters and complete quantum picture gives unprecedented possibilities beyond the reach of standard solid-state methods. The magnetic impurities immersed in the polar environment are especially interesting due to the anisotropic and long-range nature of the dipolar interactions. Moreover, they are not well understood due to the complexity of the mathematical description of the impurity with an angular momentum strongly interacting with the bath of the particles.

II. RESEARCH PROJECT GOAL

In this project, we will study the effect of magnetic impurities in many-body environments, especially in dipolar spinor gases. Although the general formalism of mathematical description for spin-impurities is known, it has not yet been applied to dipolar impurities surrounded by the ultracold magnetic environment. Moreover, we will propose a novel type of impurity, in the form of the Rydberg atom in the circular state in which the valance electron possesses high orbital angular momentum that results in a huge magnetic moment of the atom, reaching an even ten times higher value than of the most magnetic ground-state atoms. Therefore, the combination of the unprecedentedly strong dipole-dipole interaction between the impurity and the bath and the Rydberg polaron physics could lead to new, exotic many-body effects that are at the heart of this project. The research project will be partially realized in collaboration with leading theoretical and experimental groups from Austria, Japan, and Germany. The project's realization will provide new scientific results about the yet uninvestigated quantum systems, guide potential experimental work in the field of the quantum simulations of the impurity problems and Rydberg atoms, and provide a better understatement of the magnetic impurities crucial for the development of new materials.

III. WORK PLAN

We will use and develop state-of-art molecular and condensed matter physics techniques. We will study the model of the single circular Rydberg impurity immersed in the polar spinor gas. We will develop the mathematical method to adequately describe the novel impurity type and investigate this system's many-body physics. We will study the magnetization of the system, spin dynamics, and many-body effects like localization, pattern formation in the array systems or deformation of condensate, the emergence of the self-organized structures like droplets or patterns, and topological excitations like vortices in a quantum gas.