Creation of Rydberg Polarons in a Bose Gas

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Synopsis We report spectroscopic observation of Rydberg polarons in a Bose gas. Polarons are created by excitation of Rydberg atoms in a strontium Bose-Einstein condensate, and they are distinguished by occupation of bound molecular states that arise from scattering between the loosely bound Rydberg electron and ground state atoms.

The interaction between an impurity and a deformable medium can lead to a collective response and formation of a quasi-particle known as a polaron, consisting of the impurity dressed by excitations of the background medium. Polarons play important roles in conduction in ionic crystals and polar semiconductors, spin-current transport in organic semiconductors, and collective excitations in strongly interacting fermionic and bosonic ultracold gases [1, 2, 3]. Here, we report spectroscopic observation of polarons formed through excitation of Sr($5sns\,{}^3S_1$) Rydberg atoms in a strontium Bose-Einstein condensate (BEC). Theoretical calculations [4] accurately reproduce spectral features arising from few-body molecular states (dimers, trimers, etc.) and many-body dressing from the macroscopic occupation of molecular states. Rydberg polarons represent a new class of impurity states beyond those typically seen in condensed matter settings.

The interaction between a Rydberg atom and a bosonic medium arises from zero-range scattering of the Rydberg electron with background atoms [5, 6, 7]. The resulting Born-Oppenheimer potential for a ground-state atom at a distance $\mathbf{r}$ from the Rydberg impurity, $V(\mathbf{r})$, is shown schematically in Fig. 1, which illustrates the formation of a Rydberg polaron. Laser excitation of an atom in the BEC creates a Rydberg impurity and projects the system into a superposition state involving both bound and scattering states $|\beta_i\rangle$.

The cross-over from few-body bound molecular oligomers to many-body polaron features is described with a functional determinant theory that solves an extended Fröhlich Hamiltonian for an impurity in a Bose gas. Detailed analysis of the red-detuned tail of the excitation spectrum, which describes the contribution from the region of highest density in the condensate, provides a clear signature for the Rydberg polarons.

Rydberg-excitation experiments have been carried out previously using a Rb BEC [8, 9]. For Rb, however, the excitation spectrum is perturbed by a triplet p-wave shape resonance for e-Rb scattering, making identification of polaron features challenging.

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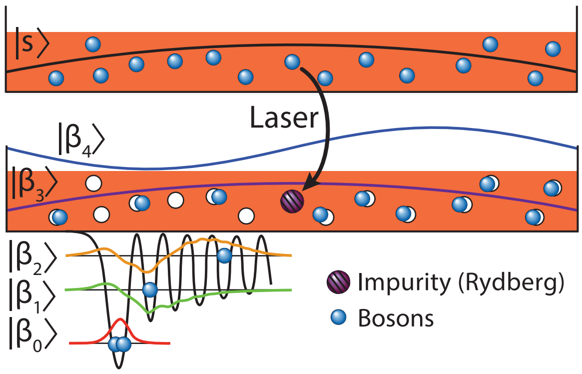

Figure 1. Schematic of the excitation of a Rydberg polaron in a uniform-density BEC. Laser excitation projects the system into final configurations involving atoms in bound and scattering states $|\beta_i\rangle$ that satisfy energy conservation. Bound states are confined in the Rydberg potential $V(\mathbf{r})$.

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