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Radiofrequency-assisted Förster resonances and Jaynes-Cummings dynamics in mesoscopic ensembles of the interacting Rydberg atoms

Long-range interactions between cold Rydberg atoms are being investigated for neutral-atom quantum computing, quantum simulations, phase transitions in cold Rydberg gases and other important applications. These applications often require fine tuning of the interaction strength. It can be implemented using Förster resonances between Rydberg atoms controlled by a dc, microwave or radiofrequency (rf) electric field. We have observed and studied experimentally the highly resolved rf-assisted Förster resonances between 2-5 cold Rb Rydberg atoms [1]. They correspond to an efficient transition from the van der Waals to dipole-dipole interactions due to Floquet sidebands of Rydberg levels appearing in the rf-field. Experiments were performed with cold ^{85}Rb atoms in a magneto-optical trap. The rf-field of appropriate frequency and amplitude induced single- and multiphoton rf-transitions between collective states of a Rydberg quasimolecule formed by the interacting Rydberg atoms. We have shown that in the presence of the dc electric field they can be induced both for the "accessible" Förster resonances which can be tuned by the dc field and for those which cannot be tuned and are "inaccessible". The van der Waals interaction of almost arbitrary high Rydberg states can thus be efficiently converted to resonant dipole-dipole interaction using the rf-field with frequencies below 1 GHz. Mesoscopic ensembles of interacting ultracold atoms are created by loading the atoms into optical dipole traps or optical lattices. Long-range interactions between Rydberg atoms in the ensemble lead to the effect of Rydberg blockade when not more than one atom could be excited into a Rydberg state by a narrow-band laser radiation. In general, the number of atoms in optical traps is random and is commonly described by the Poissonian statistics. We have shown theoretically that strongly interacting mesoscopic Rydberg ensembles with random and unknown number of atoms, which are coupled to a classical electromagnetic field, display the Jaynes-Cummings-type dynamics of single-atom laser excitation [2]. The collapses and revivals of collective Rabi oscillations between Dicke states of the atomic ensemble result from the $\sqrt{N}$ dependence of collective Rabi frequency of single-atom excitation in the regime of Rydberg blockade. The interference of Rabi oscillations with different frequencies occurs due to the random loading of optical dipole traps or optical lattices. We have studied the effects of finite interaction strengths and finite laser line width on the visibility of the revivals. An experimental observation of this effect can be used as a signature of perfect Rydberg blockade without the need to measure the actual number of detected Rydberg atoms.

[1] D.B.Tretyakov, V.M.Entin, E.A.Yakshina, I.I.Beterov, C.Andreeva, and I.I.Ryabtsev, Phys. Rev. A 90, 041403(R) (2014). [2] I.I.Beterov, T.Andrijauskas, D.B.Tretyakov, V.M.Entin, E.A.Yakshina, I.I.Ryabtsev, and S.Bergamini, Phys. Rev. A 90, 043413 (2014).

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