Many-body dynamics of excitation holes in a dissipative spin chain of Rydberg superatoms

David Petrosyan[1], Fabian Letscher[2], Michael Fleischhauer[2]

[1] Institute of Electronic Structure and Laser, FORTH, GR-71110 Heraklion, Greece
[2] Department of Physics, University of Kaiserslautern, D-67663 Kaiserslautern, Germany

Strong dipole-dipole interactions between atoms in high-lying Rydberg states can suppress multiple Rydberg excitations within a micron-sized trapping volume and yield sizable Rydberg level shifts at larger distances. Ensembles of atoms in optical microtraps can then form Rydberg superatoms with collectively enhanced transition rates to the singly excited state. The superatoms can represent mesoscopic, strongly-interacting spins (Fig. 1(a)).

We study a regular array of such effective spins driven by a laser field tuned to compensate the interaction-induced level shifts between neighboring superatoms. During the initial transient, a few excited superatoms seed a cascade of resonantly facilitated excitation of large clusters of superatoms. Due to spontaneous decay, the system then relaxes to the steady state having nearly universal Rydberg excitation density $\rho_{\rm R} = 2/3$. This state is characterized by highly-nontrivial equilibrium dynamics of quasi-particles – excitation holes in the lattice of Rydberg excited superatoms.

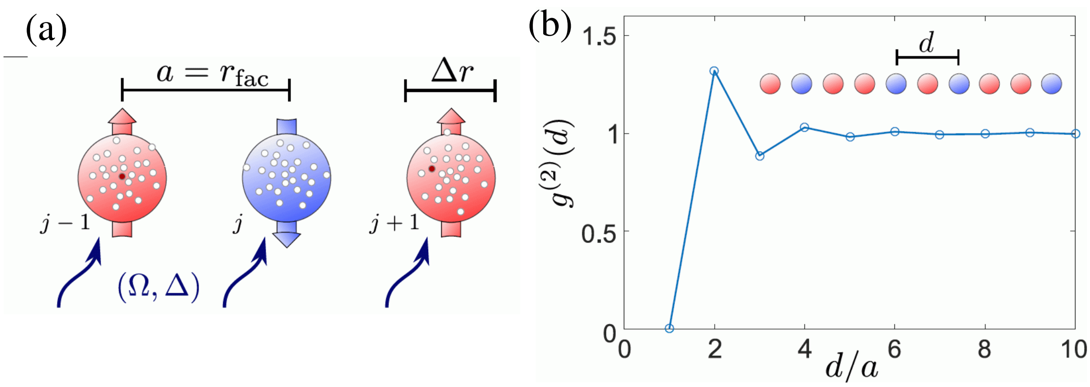

Figure 1. (a) A chain of effective spins is formed by Rydberg superatoms driven by a laser with Rabi frequency Ω and detuning Δ which facilitates excitation at distance $r_{\rm fac} = a$. (b) In the steady state, the typical two-particle correlation function $g^{(2)}(d)$ for the Rydberg excitation holes (blue circles) corresponds to a liquid of hard rods of length $2a$.

We derive an effective many-body model that accounts for hole mobility as well as continuous creation and annihilation of holes upon collisions with each other. Varying the parameters of the effective model, we find a cross-over from crystalline order of holes with period of three lattice sites to a nearly incompressible liquid of holes with density-density correlations peaked at the distance of two lattice periods (Fig. 1(b)). In both cases, the density of holes is $\rho_h \simeq 1/3$ (consistent with $\rho_{\rm R} = 2/3$) with highly suppressed number fluctuations.

[1] F. Letscher, D. Petrosyan, M. Fleischhauer, arXiv:1705.06532.