Experimental signatures of an absorbing-state phase transition in a cold Rydberg gas

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Phase transitions in non-equilibrium systems have been extensively studied in recent years but continue to pose challenges. One example of such a phase transition is that between a non-fluctuating absorbing phase [1], e.g., an extinct population, and one in which the relevant order parameter, such as the population density, assumes a finite value. Here we report the observation of signatures of such a non-equilibrium phase transition in an open driven quantum system. In our experiment rubidium atoms in a quasi one-dimensional cold disordered gas are excited to Rydberg states under so-called facilitation conditions [2]. This conditional excitation process (which in the present work occurs in the incoherent regime and can thus be described by a rate equation) competes with spontaneous decay (see Fig. 1a) and leads to a crossover between a stationary state with no excitations and one with a finite number of Rydberg excitations. This crossover can be seen in the phase diagram of Fig. 1b, where the number of Rydberg excitations is plotted as a function of the driving strength and detuning from resonance for a system initially prepared in a state with a fixed number of seed excitations [3]. We relate the underlying physics to that of an absorbing state phase transition in the presence of a field which slightly offsets the system from criticality. We observe a characteristic power-law scaling of the Rydberg excitation density as well as increased fluctuations close to the transition point. Furthermore, we argue that the observed transition relies on the presence of atomic motion (due to the finite temperature of the atomic cloud) which introduces annealed disorder into the system and thus enables the formation of long-ranged correlations. Our study paves the road towards future investigations into the largely unexplored physics of non-equilibrium phase transitions in open many-body quantum systems. The experimental realization of such systems presented here promises to be a versatile platform for investigations both in the semi-classical (incoherent) and in the quantum (coherent) regime.

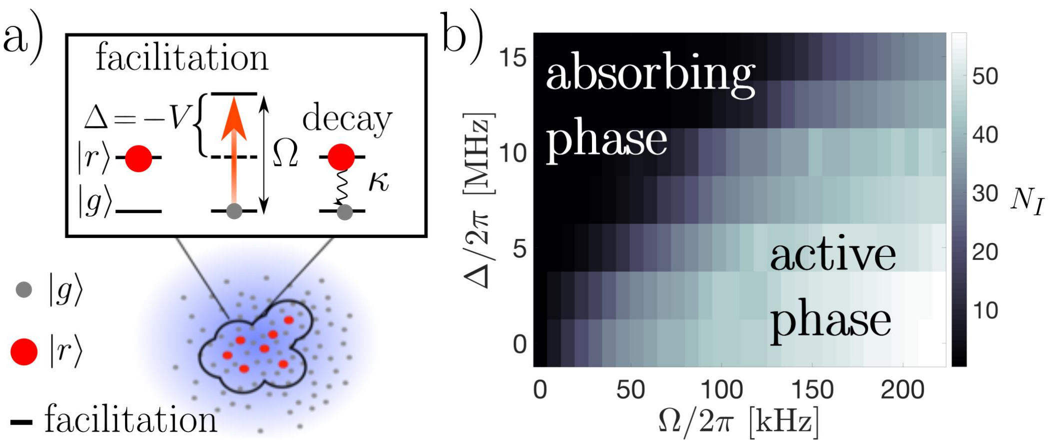

Fig. 1: (a) Microscopic processes leading to an absorbing state phase transition in a gas of cold Rydberg atoms with ground state $|g\rangle$ and excited state $|r\rangle$: facilitation (characterized by the van der Waals interaction $-V$ matching the detuning Δ for off-resonant excitation) and decay at rate κ. (b) Phase diagram of the experimental system: stationary number of Rydberg excitations N_I versus driving frequency Ω and detuning Δ.

References

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