# Non-equilibrium phase transitions and quench dynamics in dissipative Rydberg gases

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Cold atomic gases are a versatile platform for the study of quantum many-body phenomena. Especially atoms excited to highly-lying electronic states — so-called Rydberg atoms — offer rather intriguing possibilities for the exploration of strongly correlated dynamics of interacting spin systems.

The out-of-equilibrium behaviour of Rydberg gases is governed by emergent kinetic constraints [1]. In soft-matter physics these are often used to mimic dynamical arrest or excluded volume effects in idealised models of glass forming substances. The strong interactions among Rydberg atoms moreover leads to a remarkably rich physics including non-equilibrium phase transitions and localisation phenomena. Rydberg gases thus offer intriguing opportunities for the systematic exploration of emerging collective non-equilibrium effects. Beyond that they highlight a route towards a systematic generalisation of classical non-equilibrium processes into the quantum domain (see Fig. 1). This permits for example the experimental study of quantum absorbing-state phase transitions [2] and the implementation of quantum generalisations of population dynamics [3]. In this talk I will give an overview over our recent results on this research direction.

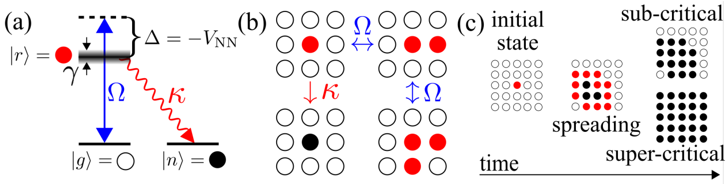

**Figure 1.** (a) Atoms are coherently excited from the ground state $|g\rangle$ to a Rydberg state $|r\rangle$ with a laser with Rabi frequency $\Omega$. External noise broadens the state $|r\rangle$ (width $\gamma$) which decays to a third state $|n\rangle$ at rate $\kappa$. The laser is off-resonant with a detuning $\Delta$ that compensates the nearest-neighbor interaction $V_{\rm NN}$ ($V_{\rm NN} - \Delta = 0$). (b) The dominant processes are facilitation (top row and right column) and decay (left column). (c) An initial seed leads to the formation of clusters of Rydberg states (infected sites) which can either be converted to ground state atoms (healthy sites) or decay to the immune state $|n\rangle$. The relative strength of the dephasing rate $\gamma$ with respect to $\Omega$ determines the nature of the transition. At fixed $\gamma$, depending on the ratio $\Omega/\kappa$ the stationary state is either an ever-expanding infection leaving a macroscopic fraction of immune sites (super-critical) or an infection that dies leaving the lattice partially filled (sub-critical).

[1] M. M. Valado *et al.*, Experimental observation of controllable kinetic constraints in a cold atomic gas, Physical Review A **93**, 040701 (2016).

[2] M. Marcuzzi *et al.*, Absorbing state phase transition with competing quantum and classical fluctuations, Physical Review Letters **116**, 245701 (2016).

[3] C. Pérez-Espigares *et al.*, Epidemic dynamics in open quantum spin systems, arXiv:1705.06994.