Thermalization in a 1D Rydberg gas: validity of the microcanonical ensemble hypothesis

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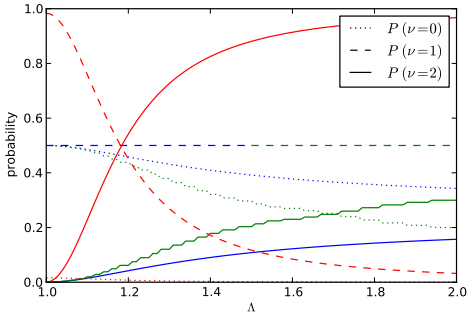
An atomic ensemble optically driven on a transition towards a Rydberg level exhibits complex many-body dynamics, due to the induced strong dipole-dipole interactions. In particular, these interactions prevent two atoms from being simultaneously excited to their Rydberg state when located close to each other. This phenomenon, the Rydberg blockade, is a key ingredient in many atomic quantum-information proposals [1].

This blockade induces a spatial structuration of Rydberg excitations in the atomic sample. The exact computation of this structure is impossible, and two approximations are often used in theoretical analyses: *1. sharp blockade radius:* the Rydberg blockade is assumed to forbid the simultaneous excitation of two atoms if they are closer than a given distance (the Rydberg radius R_b), while it has no influence at longer distances; *2. thermalization:* after a long enough time, even without any dissipative dynamics [2, 3], the system approximately ends up in a quasi-thermal state and observable tends to stationary values by the microcanonical ensemble assuming the eigenstate thermalization hypothesis [4].

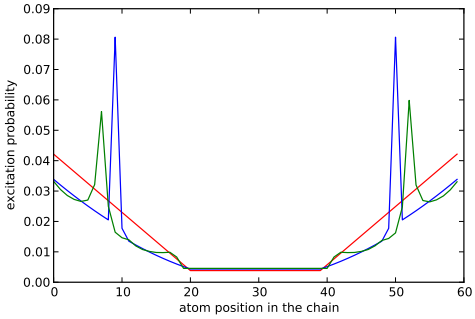
In this work, we keep the first assumption (sharp blockade radius) to study the dynamics of a dense 1D few-R_b-long atomic chain and test the validity of the second approximation (thermalization). We provide an analytical description of the emergent excitation lattice in the thermalization framework, giving the number $\mathcal{N}(\nu) = \frac{N^\nu}{\nu!}\left[1 - \frac{\nu-1}{\Lambda}\right]_+^\nu$ of configurations with ν excitations for N atoms along a line of length ΛR_b, as well as their spatial distribution. It agrees closely to previous results obtained through a Monte Carlo approach [3].

A numerical diagonalization of our system's Hamiltonian ($N = 100$), however, allows us to show noticeable differences in the excitation number probability as well as the spatial distribution of Rydberg excitations compared to the thermalization hypothesis. A 5-dimensional analytical model of the system confirms that these differences are not a numerical artifact.

This suggests that thermalization assumption should be considered with great care.



Probability to have ν excitations for $1 \leq \Lambda \leq 2$ with (red) and without (numerics:green, toy-model: blue) thermalization.



Spatial distribution of excitations for $\Lambda = 1.5$ with (red) and without (numerics:green, toy-model: blue) thermalization.

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[3] S. Bettelli, D. Maxwell, T. Fernholz, C. S. Adams, I. Lesanovsky, C. Ates, "Exciton dynamics in emergent Rydberg Lattices", Phys. Rev. A **88**, 043436 (2013).

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