Dynamics of Rydberg atoms via CMFT under partial-translational invariance.

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I. MATHEMATICAL DESCRIPTION OF THE SYSTEM

We consider the hamiltonian that governs the dynamics of the Rydberg system with $S = 1$ to be given by:

$$\hat{H} = \Omega_c \hat{S}_x + \frac{1}{2} \sum_{ij} V_{ij} \hat{n}_{\mathrm{ee}}^{(i)} \hat{n}_{\mathrm{ee}}^{(j)}, \tag{1}$$

$$\Omega_c = 2\pi \times 250 \text{ Hz}, \tag{2}$$

$$V_{ij} = \frac{C_6}{r_{ij}^6}, \text{with } r_{ij} \text{ in units of near-neighbor distance}, \tag{3}$$

$$C_6 = 2\pi \times 4.758 \text{ GHz}, \tag{4}$$

$$\hat{s}_x^{(i)} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}, \tag{5}$$

$$\hat{S}_x = \sum_i \hat{s}_x^{(i)}, \tag{6}$$

$$\hat{n}_{\mathrm{ee}}^{(i)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \tag{7}$$

$$|\psi(0)\rangle = \bigotimes_i \left(\frac{|e\rangle_i + |g\rangle_i}{\sqrt{2}} \right). \tag{8}$$

This hamiltonian can be mapped back to the hamiltonian from [1] up to a factor in the driving due to the normalization of the operator basis.

II. PARTIAL-TRANSLATIONAL INVARIANCE

The way in which we can separate our system such that we can create a partition of the systems of atoms and exploit it for constructing properly the dynamics in the cluster approach is to define a division of the lattice that depends of the distance of the elements respect to the geometric center of the lattice. In particular, for a odd and even lattice size we can observe the separation as:

In general, for simulating exactly a system of size L^2, where L is the number of atoms per

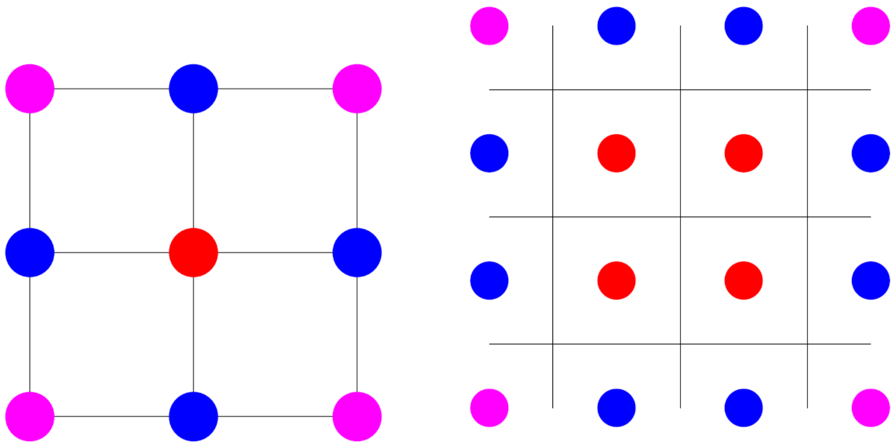

Figure 1: (Left) 3×3 and (Right) 4×4 lattice divided by equivalent elements in terms of distance to the geometrical center of the lattice that keep unchanged the interactions V_{ij}.

side, it is required to consider $O(L)$ partitions, which implies a reduction of the complexity of the algorithm.

III. SINGLE-PARTICLE OBSERVABLE ANALYSIS

At first we study the convergence and consistence of the cluster method for estimating the single particle observables. In particular, we will evaluate the dynamics of the operators $\hat{S}_x$, $\hat{S}_y$ and $\hat{S}_z$. For the hamiltonian and parameters shown previously we consider at first a 5-particles system.

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[1] arXiv:2303.08078 William J. Eckner, et al (2023)