Generating massively entangled states with Rydberg-atom arrays

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Rydberg-atom arrays are emerging as one of the most promising platforms for quantum computation and quantum simulation (1). In this work we theoretically show that the non-equilibrium dynamics in large planar arrays with resonant (dipolar) XY interaction can generate massively entangled states in a scalable way. This is due to a fundamental analogy existing between the dynamics of dipolar spins in two spatial dimensions and that of an array of spins with infinite-range interactions, realizing the paradigmatic one-axis-twisting Hamiltonian. Making use of state-of-the-art methods for the non-equilibrium evolution of quantum many-body systems, we theoretically show that dipolar Rydberg atoms can realize scalable spin squeezed states at short times (2); and, most prominently, they realize Schrödinger's cat states at times scaling linearly with the number of spins (3). We observe the formation of cat states with up to N=144 spins, being limited only by the computation time. Experimental imperfections (such as randomness in the atomic positions) are included in the analysis, showing that they lead to mild reductions of the macroscopic coherence in the cat state. The possibility of transferring the Rydberg excitations to low-lying states suggests to view these multipartite entangled states as a fundamental metrological resource, allowing one to reach the Heisenberg scaling.

References

1. A. Browaeys and T. Lahaye, Nature Phys. **16**, 132 (2020).
2. T. Comparin, F. Mezzacapo and T. Roscilde, Phys. Rev. A **105**, 022625 (2022).
3. T. Comparin, F. Mezzacapo and T. Roscilde, in preparation (2022).

Figures

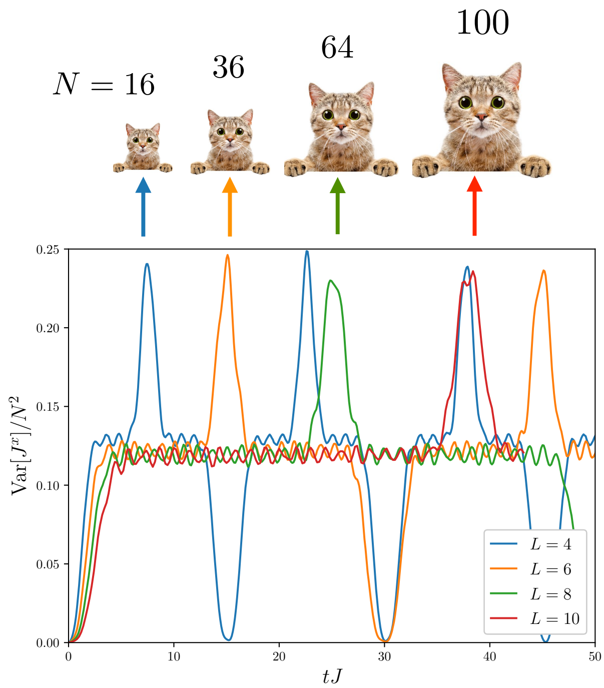

Figure 1: Scalable production of Schrödinger-cat states from the dynamics of dipolar XY spins on a *N=LxL* square lattice. The appearance of a cat state is signaled by the fact that the variance of the J^x collective-spin component, Var(J^x), acquires a value approaching the maximum allowed by quantum mechanics (namely $N^2/4$ for *N* spins).