Scaling multipartite entanglement in the real world

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The realization of multipartite entangled states with an entanglement depth scaling with the number of degrees of freedom is one of the central challenges of quantum science. It is vital to fundamental studies on quantum behavior at increasingly large scales; and to technological tasks, such as quantum metrology beating the standard quantum limit. Two-dimensional qubit networks, as those realized by Rydberg atoms with dipolar interactions, offer most effective routes towards scalable entanglement, in the form of scalable spin squeezing in quench dynamics [1, 2]; as well via quasi-adiabatic dynamics, which can reach the fastest possible (i.e. Heisenberg) scaling [3].

Yet the practical scalability of entanglement in any current platform is confronted with experimental imperfections, the most destructive being the loss of qubits. In this work, we investigate two strategies to cope with atom losses as well as other environmental effects.

The first strategy consists in being “faster than the environment”, by speeding the entanglement dynamics up to the ultimate speed. This corresponds to exponential onset of correlations, which — as we show — can be achieved in two-dimensional dipolar networks via the so-called twist-and-turn dynamics, combining the one-axis-twisting dynamics with a Larmor precession around an applied field. Heisenberg scaling of entanglement can be reached in times scaling logarithmically with system size, and can be detected metrologically by measuring the rotation of the spin parity [4].

A second strategy consists instead in probing how robust entanglement is to losses. Including atom losses explicitly in the quasi-adiabatic spin squeezing dynamics, we show that scalability resists a sizable loss rate, and that losses lead to a renormalization of the scaling exponent of the squeezing parameter.

Our results pave the way towards the achievement of scalable multipartite entanglement in experiments on Rydberg-atom platforms, going beyond the first observation of scalable squeezing [5].

References

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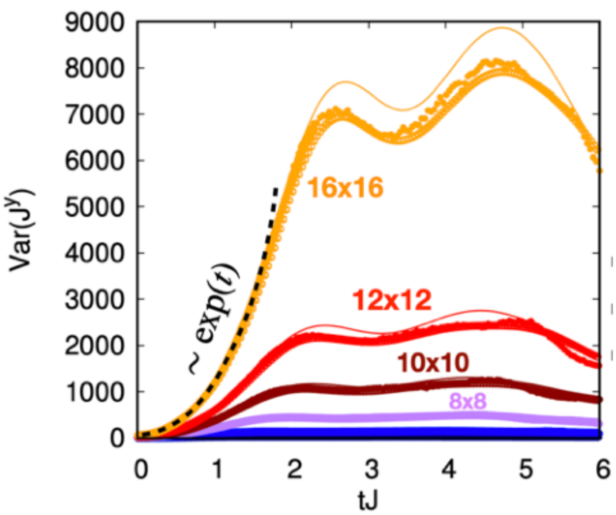

Figures

Figure 1: Exponential build up of quantum correlations in the 2d dipolar twist-and-turn dynamics, showing quantitative agreement between three independent theoretical predictions.