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Measurements of Quantum correlations, and characterization of quantum thermalization, in a dipolar interacting spin system

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We experimentally study quantum magnetism using interacting spin systems made of lattice trapped magnetic atoms. The dipolar interactions between spins frozen on lattice sites gives rise to a beyond mean field spin dynamics, after excitation in an out of equilibrium initial state. This dynamic leads to a steady state compatible with the ETH scenario of quantum thermalization, in which the isolated spin system evolves towards a thermal-like state, due to the growth of quantum correlations hence of entanglement, while keeping its energy constant [1].
Experimental detection of the growth of quantum correlations in our spin system is obtained from collective measurements, by tracking the evolution of the norm of the collective spin [2], and by direct measurements of the two-body correlator associated with magnetization [3]. This latter work has required measuring spin fluctuations at the level of the standard quantum noise, which is very challenging for large ensemble of large spin atoms.
Besides, we have implemented an experimental bipartition technique, yielding two spin subfamilies, which is well adapted for revealing bipartite correlations as it relies on next neighbor separation inside the lattice. Our results show a complex structure of correlations, with positive intra-families and negative inter-families correlations. We attribute such structure to the anisotropic nature of our system.
Our experiment thus provides a platform for quantum simulations well adapted for studying the subtle process of quantum thermalization of mesoscopic spin systems.

[3] Measuring Correlations from the Collective Spin Fluctuations of a Large Ensemble of Lattice-Trapped Dipolar Spin-3 Atoms
Youssef Aziz Alaoui, Bihui Zhu, Sean Robert Muleady, William Dubosclard, Tommaso Roscilde, Ana Maria Rey, Bruno Laburthe-Tolra, and Laurent Vernac
Phys. Rev. Lett. 129, 023401 (2022)

[2] Relaxation of the collective magnetization of a dense 3D array of interacting dipolar S=3 atoms
Lucas Gabardos, Bihui Zhu, Steven Lepoutre, Ana Maria Rey, Bruno Laburthe-Tolra and Laurent Vernac
Phys. Rev. Lett. 125, 143401 (2020)

[1] Out-of-equilibrium quantum magnetism and thermalization in a spin-3 many-body dipolar lattice system
S. Lepoutre, J. Schachenmayer, L. Gabardos, B. Zhu, B. Naylor, E. Maréchal, O. Gorceix, A. M. Rey, L. Vernac and B. Laburthe-Tolra
Nature Communications 10, 1714 (2019)

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