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Quantum magnetism in different AMO systems.[1]

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One of the most important goals of modern quantum sciences is to learn how to control and entangle many-body systems and use them to make powerful and improved quantum devices, materials and technologies. However, since performing full state tomography does not scale favorably with the number of particles, as the size of quantum systems grow, it becomes extremely challenging to identify, and quantify the buildup of quantum correlations and coherence. In this talk I will report on a protocol that we have developed and experimentally demonstrated in a trapped ion quantum magnet in a Penning trap, which can perform quantum simulations of Ising spin models [1,2]. In those experiments strong spin-spin interactions can be engineered through optical dipole forces that excite phonons of the crystals. The number of ions can be varied from tens to hundreds with high fidelity control. The protocol uses time reversal of the many-body dynamics, to measure out-of-time-order correlation functions (OTOCs). By measuring a family of OTOCs as a function of a tunable parameter we obtain fine-grained information about the state of the system encoded in the multiple quantum coherence spectrum, extract the quantum state purity, and demonstrate the build-up of up to 8-body correlations. We also use the protocol and comparisons to a full solution of the master equation to investigate the impact of spin-motion entanglement and decoherence in the quantum dynamics. Future applications of this protocol could enable studies of manybody localization, quantum phase transitions, and tests of the holographic duality between quantum and gravitational systems. [1] J. G. Bohnet, B. C. Sawyer, J.W. Britton, M. L. Wall, A. M. Rey, M. Foss-Feig, John J. Bollinger, Science 352, 1297 (2016). [2] M Gärttner, J G. Bohnet, A Safavi-Naini, M. L. Wall, J. J. Bollinger and A.M. Rey, arXiv:1608.08938

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