Entanglement Dynamics and Scrambling in a Trapped Ion Quantum Magnet

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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. In this talk I will report on our current effort to develop protocols that can quantify the build-up of quantum correlations and storage of quantum information in a planar crystal of trapped ions. Using a pair of lasers, we couple the spins to the vibrational modes (phonons) of the crystal. The phonons mediate interactions between the spins which we use to generate entanglement starting from easily prepared uncorrelated states. We can operate in two different regimes. In one regime, phonons do not play an active role in the many-body dynamics and instead are used to mediate spin-spin coupling between ions. In the other regime, phonons actively participate and we use them to simulate the Dicke model an iconic model in quantum optics which describes the coupling of a (large) spin to an oscillator. The Dicke model is known to exhibit rich and interesting phenomena. For instance, it features a quantum critical point, and displays classical chaotic behavior. I will also discuss a new measurement scheme, implemented by using a manybody echo sequence that reverses the Hamiltonian dynamics, which can give experimental access to a type of out-of-time-order correlations (OTOCs) which have caught great deal of interest in the recent years. The reason is that those correlations can measure the scrambling of quantum information across the systems many-body degrees of freedom. Measuring OTOCs in controllable atomic laboratories can not only have a great impact on quantum information processing and quantum enhanced metrology, but also opens a path for future tests of the holographic duality between quantum and gravitational systems.