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Programmable Interactions and Emergent Geometries in an Atomic Array

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Interactions form the basis for the experimental generation of entanglement between quantum objects. Typical quantum simulation platforms such as atomic systems or trapped ions feature local interactions which decay as a function of distance. The spatial entanglement structure that can be generated is thus inherently connected to the physical geometry of the system. In this talk, I will present the recent results of our experiment where we use an optical cavity to mediate programmable long-range interactions between a 1D array of atomic ensembles. By tailoring the frequency spectrum of a drive field we achieve arbitrary control over the distance dependence of the interactions as well as their relative sign. This allows us to implement dynamics in various effective geometries which are entirely distinct from the physical arrangement of the atoms, including frustrated 2D lattices and an emergent tree-like geometry inspired by holographic models of quantum gravity. We demonstrate this by directly reconstructing the geometry from the measured spin correlations. In the realm of quantum information, these new capabilities pave the way towards engineering quantum states with specific spatial entanglement structure for quantum sensing and quantum computation.

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