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Quantum dynamics of interacting spins mediated by phonons and photons

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Techniques that enable robust, controllable interactions among quantum particles are now being actively explored. They constitute a key ingredient for quantum information processing and quantum simulations. We describe two atom-based platforms to experimentally realize and study quantum dynamics with controllable, long-range spin-spin interactions. Using trapped atomic ions, we implemented tunable spin-spin interactions mediated by optical dipole forces, which represent a new approach to study quantum magnetism. This platform has enabled sophisticated manipulations of more than 10 spins, and realization of quantum simulations of integer-spin chains. In a separate set of experiments we realized a hybrid system in which single photons, confined to sub-wavelength dimensions with a photonic crystal cavity, are coupled to single trapped neutral atoms. Extending this architecture to multiple atoms enables photon-induced quantum gates, and tunable spin-spin interactions, between distant atoms.