Quantum Networks of Ions

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Trapped atomic ions are standards in quantum science, and one of the central challenges in this field is the scaling to larger numbers of interacting ions for quantum simulations of intractable models, large-scale quantum computation, and long-distance quantum communication. Local entanglement, provided through spin-dependent dipole forces and mediated by the Coulomb interaction, has allowed the quantum simulation of fully-connected Ising models with up to 18 trapped ion spins, including observations of ferromagnetic and antiferromagnetic ground state order, frustration, and coherent manybody dynamics. The use of mode-locked pulsed lasers also permits Coulomb gates to be performed much faster than the characteristic trap period, holding promise for gate speeds that could eclipse that typical in solid state quantum platforms. An alternative scaling strategy maps trapped ion qubits onto photons for the probabilistic (not post-selected) entanglement over remote distances, with the first experiments dealing with the entanglement of two remotely-located atomic ion qubits. While the probabilistic photonic link is generally much slower than the deterministic local operations, the significant advantages of distance-independent entanglement operations point to a juxtaposing both local (Coulombic) and remote (photonic) entanglement schemes for a modular quantum architecture capable of approaching very large numbers of qubits for useful quantum computation.