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Towards Simulating the Transverse Ising Model in a 2D Array of Trapped Ions[1]

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Two-dimensional Coulomb crystals provide a useful platform for large-scale quantum simulation. Penning traps enable confinement of large numbers of ions (>100) and allow for the tunable-range spin-spin interactions demonstrated in linear ion strings [1], facilitating simulation of quantum magnetism at a scale that is currently intractable on classical computers. We readily confine hundreds of Doppler laser-cooled $^9Be^+$ within a Penning trap, producing a planar array of ions with self-assembled triangular order. The transverse "drumhead" modes of our 2D crystal along with the valence electron spin of Be^+ serve as a resource for generating spin-motion and spin-spin entanglement. Applying a spin-dependent optical dipole force (ODF) to the ion array, we perform spectroscopy and thermometry of individual drumhead modes [2]. This ODF also allows us to engineer long-range Ising spin couplings of either ferromagnetic or anti-ferromagnetic character whose approximate power-law scaling with inter-ion distance, d, may be varied continuously from $1/d^0$ to $1/d^3$ [3]. An effective transverse magnetic field is applied via microwave radiation at the ~124-GHz spin-flip frequency, and ground states of the effective Ising Hamiltonian may in principle be prepared adiabatically by slowly decreasing this transverse field in the presence of the induced Ising coupling. Long-range anti-ferromagnetic interactions are of particular interest due to their inherent spin frustration and resulting large, near-degenerate manifold of ground states.

[1] R. Islam et al., Nat. Commun. **2**, 377 (2011).
[2] B. C. Sawyer et al., Phys. Rev. Lett. **108**, 213003 (2012).
[3] J. W. Britton et al., Nature **404**, 489 (2012).

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