Quantum control and simulation with large trapped-ion crystals†

John Bollinger
Time and Frequency Div., NIST, Boulder, CO

Trapped ions provide one of the best developed platforms for implementing numerous quantum technologies, including quantum computation, quantum simulation, and quantum sensing. Most demonstrations have employed the linear radio frequency (rf) trap to form very well controlled 1d crystals of up to ~50 ions in room temperature vacuum systems and even larger numbers in cryogenic systems. I will describe efforts that utilize a different type of ion trap, the Penning trap, to generate and control larger 2d and 3d ion crystals. This talk will focus on work with single-plane crystals of several hundred ions that are used for quantum simulation and sensing.

We isolate and control two internal levels or a “spin” degree of freedom in each ion with standard techniques. Long-range interactions between the ions are generated through the application of spin-dependent optical-dipole forces that couple the spin and motional degrees of freedom of the ions. When the frequency of the spin-dependent force is tuned to produce a coupling with a single motional mode (typically the center-of-mass mode), this system is described by the iconic Dicke model. Long-range Ising interactions and single-axis twisting are produced through this spin-motion coupling. To benchmark quantum dynamics, we measure spin-squeezing [1] and out-of-time-order correlations (OTOCs) [2] that quantify the build-up of correlations and the spread of quantum information. The OTOCs are measured with the multiple quantum coherence protocol invented in NMR that requires time reversal of the interactions.

We also employ spin-dependent optical dipole forces to sense center-of-mass motion that is small compared to the ground state zero-point fluctuations [3]. This enables the detection of weak electric fields, providing an opportunity to place limits on dark matter couplings due to particles such as axions and hidden photons that couple to ordinary matter through weak electric fields.

†In collaboration with E. Jordan, K. Gilmore, M. Affolter, A. Safavi-Naini, A. Shankar, R. Lewis-Swan, M. Holland, A.M. Rey