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Quantum simulation of many-body physics with neutral atoms, molecules, and ions

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The achievement of quantum degeneracy in alkali vapors has enabled the simulation of iconic condensed-matter models. However, ultracold alkali atoms are not yet cold enough to simulate the most interesting and poorly understood low-temperature properties of those models. In this talk, I will emphasize how the rich internal structure of alkaline earth atoms, ions, and molecules can be leveraged to simulate complex many-body physics in presently accessible experimental settings. I will begin by examining how alkaline earth atoms can be used to simulate the physics of so-called heavy fermion materials, and will show how the exotic groundstate properties of those materials manifests in non-equilibrium dynamics at relatively warm temperatures. Not surprisingly, the rich structure of alkaline earth atoms and molecules comes with a price, in many cases increasing the susceptibility of these systems to decoherence. A particularly troubling feature common to alkaline earth atoms and many molecules is the possibility of two-body loss. However, I will show that such loss can be harnessed to drive optically excited alkaline earth atoms and reactive molecules into highly-entangled non-equilibrium steady states, which could be used in the near future to improve the accuracy of high precision atomic clocks operated with alkaline earth atoms. The fate of interacting quantum systems in the presence of decoherence is of interest much more broadly, and I will conclude by describing how trapped ion systems provide a natural platform for addressing this issue. In particular, I will describe an exact solution of the dissipative Ising models that govern trapped ion systems, which affords both a qualitative and quantitative understanding of the effects of decoherence on these large-scale quantum simulators.