LASER COOLING MOLECULES FOR FUNDAMENTAL PHYSICS AND QUANTUM SCIENCE

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Ultracold molecules have a wide range of potential applications spanning from fundamental physics to quantum simulation and computation. Motivated by potential discoveries in these areas, significant advances in controlling molecules at the single-quantum-state level have occurred over the past decade. Progress in direct laser-cooling of molecules has led to the first molecular magneto-optical traps, which have allowed for optical trapping of ultracold molecules. Optical tweezer arrays have allowed both high-fidelity readout as well as quantum control of individual molecules. In this talk, we will discuss using optical tweezer arrays of CaF molecules to study ultracold collisions and quantum bits based on rotational states. We show greatly improved rotational coherence times for molecular qubits in optical tweezer traps, which parametrizes the potential performance of polar-molecule-based quantum simulators or computers. Finally, we show progress towards realizing the goal of high-fidelity molecular qubits by demonstrating dipolar interactions and entanglement between CaF molecules.

Extending the tools of quantum control beyond the rich structure of diatomic molecules to polyatomic molecules leads to powerful new scientific avenues. Notably, polyatomic molecules generically possess low-lying, closely spaced energy levels of opposite parity. This results in long-lived, fully polarizable quantum states with minimal sensitivity to external perturbations suitable for a broad range of scientific applications. Here we present results on laser-cooling and optical trapping of the polyatomic molecule CaOH. We establish coherent control of individual quantum states in CaOH and demonstrate a roadmap experiment for future searches for physics beyond the Standard Model with trapped polyatomic molecules. Finally, we realize single particle control by loading CaOH molecules into optical tweezer arrays.