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High precision optical spectroscopy and quantum state selected photodissociation of ultracold $^{88}Sr_2$ molecules in an optical lattice

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Over the past several decades, rapid progress has been made toward the accurate characterization and control of atoms, epitomized by the ever-increasing accuracy and precision of optical atomic lattice clocks. Extending this progress to molecules will have exciting implications for chemistry, condensed matter physics, and precision tests of physics beyond the Standard Model. My thesis describes work performed over the past six years to establish the state of the art in manipulation and quantum control of ultracold molecules. We describe a thorough set of measurements characterizing the rovibrational structure of weakly bound $^{88}Sr_2$ molecules from several different perspectives, including determinations of binding energies; linear, quadratic, and higher order Zeeman shifts; transition strengths between bound states; and lifetimes of narrow subradiant states. Finally, we discuss measurements of photofragment angular distributions produced by photodissociation of molecules in single quantum states, leading to an exploration of quantum-state-resolved ultracold chemistry. The images of exploding photofragments produced in these studies exhibit dramatic interference effects and strongly violate semiclassical predictions, instead requiring a fully quantum mechanical description.