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Research Statement

Highly excited atoms (Rydberg atoms) are intrinsically quantum mechanical objects enlarged to a macroscopic scale. This tangibility makes them a very interesting undergraduate teaching tool.

With an orbital radius scaling as n^2, Rydberg atoms swell beyond the angstrom size scale of ground state atoms to micron-sized objects often describable using classical Keplerian dynamics[1]. They are weakly bound and therefore highly sensitive to external perturbations[2]. Their quantum nature gives rise to interesting laboratory astrophysics, quantum computing, and fundamental physics, such as Bohr wave-packets[3], long-range Rydberg "trilobite" molecules[4, 5], Schrödinger cat states[6], and quantum logical gates[7].

My interest lies in the interaction of Rydberg atoms and microwave radiation, a subject of much theoretical research[8–11] with open experimental endeavors. These systems provide insight into both the properties of Rydberg atoms and how we view the microwave field they interact with[12]. At the low frequency limit, microwave ionization can be viewed as a simple field ionization process[13]. In between the low frequency regime and the point where one microwave photon is enough for ionization lies a system ripe for experimental investigation, incorporating advanced topics such as multichannel quantum defect theory[14], localization[15, 16], and adiabatic rapid passage[17, 18]. I have been collaborating with Andreas Buchleitner at the University of Freiburg in order to complement my experimental interest with more advanced theoretical simulations[15].

There remain many open questions in microwave ionization of Rydberg atoms that I would address in my future research and that are of interest to a wide audience. These include probing the influence of electric and magnetic fields, the final state distribution of high-lying non-ionized states, and the importance of electron angular momentum on ionization. Using a system of nanosecond pulsed dye lasers, one can easily create a large number of low angular momentum alkali Rydberg states[19]. However, optically exciting Rydberg states to beyond $\ell \gtrsim 5$ is experimentally difficult[20]. This hurdle can be overcome by creating a low angular momentum Rydberg state and then altering the angular momentum of the electron, either via precession in an electric and/or magnetic field[21, 22], or by a slow phase shift of an applied non-ionizing microwave field[3]. State-selective field ionization provides an easy technique for analysis of the system, and should create a wealth of publishable data through projects accessible to undergraduate students.

My choice in post-doctoral fellowship was motivated by a desire to gain atom cooling and trapping experience. Long term, I would like to conduct ultra-cold Rydberg physics experiments. Laser-cooled ultra-cold Rydberg atoms in a magneto-optical trap provide a fascinating system for probing a wide range of topics from a unique atomic physics perspective. A cold gas of Rydberg atoms is essentially frozen over the relevant experimental time scale, and can be considered as a explorable solid that is highly sensitive to external perturbations[23]. These frozen Rydberg gases exhibit interesting properties such as Rydberg-Rydberg dipole[24] and van der Waals interaction[25], spontaneous evolution to a cold plasma[26], and "blockade" of the excitation of neighboring atoms[27]. These frozen Rydberg gases span the fields from AMO to condensed matter physics and quantum chemistry, and provide a rich system for long-term scientific exploration.

Similar groups in the field, both large research labs and small colleges, have succeeded in securing external funding for their work. I expect my projects to appeal to and be competitive for National Science Foundation grants, as well as Department of Energy and Air Force Office of Scientific Research grants.

As a teaching tool, Rydberg atoms are pedagogically beneficial in that they lie at the interface of classical and quantum mechanical physics. These systems provide accessible undergraduate research for students spanning the entire four year curriculum, from straightforward classical dynamics to deep quantum theory. Each component of this research can be quantized into semester-long undergraduate projects. These experiments are accessible in a small college environment and budget (as I have witnessed first-hand at Wesleyan), while introducing students to a wide variety of experimental tools and techniques, including laser physics, vacuum science, digital and analog electronics, computational modeling, and data acquisition and analysis.

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