challenging to interpret. We present a combined experimental and theoretical characterization of the 3S and 3D Rydberg series of ^{87}Sr in the range $n \sim 38 - 99$.

*Supported by the NSF, the Welch foundation, the AFOSR, and the FWF (Austria).

11:06

V04 4 Ion friction in dual species ultracold plasma expansion* TUCKER SPRENKLE, *Brigham Young Univ - Provo* ROSS SPENCER, SCOTT BERGESON, *Brigham Young University* We create a dual-species ultracold neutral plasma (UNP) by photo-ionizing Yb and Ca atoms in a dual-species magneto-optical trap. Unlike single-species UNP expansion, these plasmas are well outside of the collisionless (Vlasov) approximation. We observe the mutual interaction of the Yb and Ca ions by measuring the rms expansion velocity for each ion species separately. We model the expansion using a fluid code including ion-ion friction.

*National Science Foundation Grant No. PHY=1500376.

11:18

V04 5 Impact of Hydrodynamic Expansion on Laser Cooling of an Ultracold Neutral Plasma* THOMAS LANGIN, GRANT GORMAN, THOMAS KILLIAN, *Rice University* High temperatures and various heat sources make laser-cooling of typical neutral plasmas impractical. However, ultracold neutral plasmas (UNPs), created by photoionizing an ultracold neutral gas, have typical ion temperatures of $\sim$ 1K and minimal heating sources, making them amenable to laser cooling. Using a UNP of $^{88}Sr^{+}$ we have demonstrated the first application of laser cooling in a neutral plasma. After photoionization, UNPs expand hydrodynamically into vacuum over a time $\tau_{exp} \sim 100\mu$s, resulting in the development of an ion expansion velocity field increasing with both time and distance from the plasma center, with typical average terminal expansion velocity of $v_E \sim$ 40m/s. The expansion creates an environment that differs significantly from other systems that have been laser cooled. For example, the Doppler shift resulting from the high value of v_T can limit laser cooling to the central region of the plasma, where expansion velocity is minimal. The expansion dynamics depend primarily on the initial plasma size and the detuning of the cooling laser; for judicious choices of these parameters, the plasma expansion can be nearly halted by laser cooling forces, opening new possibilities of neutral plasma confinement and manipulation.

*Supported by NSF and DoE (PHY-0714603) and the Air Force Office of Scientific Research (FA9550- 12-1-0267).

11:30

V04 6 Demonstration of an on-demand single-photon source based on Rydberg blockade in a thermal vapor cell FABIAN RIPKA, FLORIAN CHRISTALLER, ANNIKA BELZ, HAO ZHANG, HARALD KUEBLER, ROBERT LOEW, TILMAN PFAU, *5th Institute of Physics, University of Stuttgart* Photonic quantum devices based on atomic vapors at room temperature are intrinsically reproducible as well as scalable and integrable. Besides quantum memories for single photons one key device in the field of quantum information processing are on-demand single-photon sources. A promising candidate for realization relies on the combination of four-wave mixing and the Rydberg blockade effect, as was demonstrated for ultracold atoms [1]. Coherent dynamics to Rydberg states [2] have already been demonstrated in thermal vapors, as well as sufficient Rydberg interaction strengths [3] and lifetimes of the collective Rydberg excitations [4]. Here we report on a significant decrease of photon coincidences for photons at 780 nm when the size of the atomic ensemble is reduced to 1 μm i.e. below the Rydberg blockade radius. The normalized photon pair correlation shows a clear signature for anti-bunched photon statistics and a strong evidence for the observation of a cooperative quantum effect in a thermal atomic ensemble. Future directions beyond this proof of principle will be discussed.

[1]Dudin *et al.*, Science **336**, 6083 (2012).
[2]Huber *et al.*, PRL **107**, 243001 (2011).
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[4]Ripka *et al.*, Phys. Rev. A053429 (2016).

11:42

V04 7 Charged impurities immersed in a Bose-Einstein condensate FLORIAN MEINERT, KATHRIN KLEINBACH, FELIX ENGEL, THOMAS DIETERLE, ROBERT LOEW, TILMAN PFAU, *5. Physikalisches Institut, University of Stuttgart* Giant Rydberg atoms immersed in a Bose-Einstein condensate provide an exquisite platform to study the interaction of charged impurities with neutral atoms at ultralow temperatures. Typically, the low-energy scattering of the Rydberg electron with neutral perturber atoms residing within the Rydberg orbit constitutes the dominant interaction process, which manifests in density-dependent spectral line shifts and broadening of the Rydberg excitation. Using a tightly focused optical tweezer we access a previously unexplored parameter regime for which the Rydberg electron orbit largely exceeds the spatial extent of the condensate. This reduces the contribution of electron-neutral interaction with increasing principal quantum number in the observed excitation spectrum. Consequently, the interaction of the condensate atoms with the Rydberg ionic core is expected to actively shape the spectral response. I will report on our endeavor to explore this appealing route to study atom-ion interaction in a Bose-Einstein condensate.

11:54

V04 8 Quantum-optical spectroscopy for plasma electric field measurements and diagnostics* DAVID ANDERSON, *Rydberg Technologies* GEORG RAITHEL, *Rydberg Technologies, University of Michigan* MATTHEW SIMONS, CHRISTOPHER HOLLOWAY, *National Institute of Standards and Technology* Measurements of plasma electric fields are essential to the advancement of plasma science and applications. Methods for non-invasive in situ measurements of plasma fields on sub-millimeter length scales with high sensitivity over a large field range remain an outstanding challenge. Here, we introduce and demonstrate a method for plasma electric field measurements and diagnostics that employs electromagnetically induced transparency as a high-resolution quantum-optical probe for the Stark energy level shifts of plasma-embedded Rydberg atoms, which serve as highly-sensitive field sensors with a large dynamic range. The method is applied in diagnostics of plasmas photo-excited out of a cesium vapor. The plasma electric fields are extracted from spatially-resolved measurements of field-induced shape changes and shifts of Rydberg resonances in rubidium tracer atoms. Measurement capabilities over a range of plasma densities and temperatures are exploited to characterize plasmas in applied magnetic fields and to image electric-field distributions in cyclotron-heated plasmas.

*This work was supported by Rydberg Technologies, the NSF (IIP-1624368 and PHY-1506093), and NIST through the Embedded Standards program.

12:06

V04 9 Theory of long range interactions for Rydberg states attached to hyperfine split cores* FRANCIS ROBICHEAUX, *Purdue University* DONALD BOOTH, MARK SAFFMAN, *University* *of Wisconsin* Theory for one and two atom interactions is developed for the case when the atoms have a Rydberg electron attached to a hyperfine split core state, a situation relevant for some rare earth and some alkaline earth atoms proposed for experiments on Rydberg-Rydberg interactions. For the rare earth atoms, the core electrons can have a very substantial total angular momentum, J, and a non-zero nuclear spin, I. For alkaline earth atoms there is a single, s, core electron whose spin can couple to a non-zero nuclear spin for odd isotopes. The hyperfine splitting of the core state can lead to substantial mixing between the Rydberg series attached to different thresholds. Compared to the unperturbed Rydberg series of the alkali atoms, series perturbations and near degeneracies from the different parity states could lead to qualitatively different behavior for single atom Rydberg properties (polarizability, Zeeman mixing and splitting, etc) as well as Rydberg-Rydberg interactions (C5 and C6 matrices).

*This work was supported by the National Science Foundation under Award No.1404419-PHY (FR) and award No.1707854-PHY (DWB and MS).

12:18

V04 10 Cs 62D_J Rydberg-atom macrodimers formed by long-range multipole interaction* JIANMING ZHAO, *Shanxi University, Taiyuan* GEORG RAITHEL, *University of Michigan, Ann Arbor, and Shanxi University, Taiyuan* We report on long-range macrodimers formed by D-state cesium Rydberg atoms. Cesium $[62D_J]_2$ Rydberg-atom macrodimers, bonded via long-range multipole interaction, are prepared by two-color photo-association in a cesium atom trap. The first color (pulse A) resonantly excites seed Rydberg atoms, while the second (pulse B, detuned by the molecular binding energy) resonantly excites the Rydberg-atom macrodimers below the $[62D_J]_2$ asymptotes. The molecules are measured by extraction of auto-ionization products and Rydberg-atom electric-field ionization, and ion detection. Molecular spectra are compared with calculations of adiabatic molecular potentials. Initial lifetime estimates are presented.

*Supported by the National Key R&D Program of China, Grant No. 2017YFA0304203, NNSF Grants No. 61475090, 61675123 and 61775124, NSF Grant No. PHY-1506093, and BAIREN plan of Shanxi.

SESSION V05: ATOMS, MOLECULES, AND CLUSTERS IN STRONG FIELDS

Friday Morning, 1 June 2018
Room: Grand E at 10:30
Li Fang, University of Texas, Austin, presiding

Contributed Papers

10:30

V05 1 Frustrated tunnel ionization in the few-cycle regime* R.D. GLOVER, D. CHETTY, A.J. PALMER, *Centre for Quantum Dynamics, Griffith University, Australia* B.A. DEHARAK, *Illinois Wesleyan University, USA* J.L. HOLDSWORTH, *School of Mathematical and Physical Sciences, University of Newcastle, Australia* M.A. DAKKA, A.N. LUITEN, P.S. LIGHT, *Institute for Photonics and Advanced Sensing and School of Physical Sciences, The University of Adelaide, Australia* I.V. LITVINYUK, R.T. SANG, *Centre for Quantum Dynamics, Griffith University, Australia* Frustrated Tunnel Ionization (FTI) is a strong-field phenomenon where an ultrashort laser pulse excites a target atom, leaving it in a Rydberg state [1]. This occurs after a tunneling ionization event when the dominant ionization channel is 'frustrated' by the atomic Coulomb potential. Studying the mechanism behind FTI facilitates our understanding of atomic and molecular strong-field dynamics; e.g. FTI is observed in time-resolved ionization dynamics [2] and delayed ionization [], and the fragmentation of molecules [4]. Here we compare our experimental and theoretical FTI yields for few- and multi-cycle pulses. We find that for the same pulse energy more FTI is generated with few-cycle pulses.

*This project is supported under the ARC Linkage Infrastructure, Equipment and Facilities scheme (project LE160100027). B.d. is funded by the US NSF (Grants No. PHY-1402899 and PHY-1708108). D.C. is supported by an Australian Government RTP Scholarship.

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[2]M. Sabbar *et al.*, Nat. Phys. **13**, 472 (2017).
[3]S. Larimian *et al.*, Phys. Rev. A **94**, (2016).
[4]B. Manschwetus *et al.*, Phys. Rev. Lett. **102**, 113002 (2009).

10:42

V05 2 Impact of atomic Rydberg state excitation on the radiation spectrum generated in short intense laser pulses* JOEL VENZKE, RAN REIFF, ZETONG XUE, AGNIESZKA JARON-BECKER, ANDREAS BECKER, *JILA and Department of Physics, University of Colorado, Boulder* The impact of highly excited (Rydberg) states on strong-field induced high harmonic generation and ionization has been of recent interest. Utilizing *ab initio* simulations of the Time Dependent Schrödinger Equation and systematically selecting laser intensities and frequencies, the distribution across the angular momentum states is analyzed for resonant absorption of odd and even number of photons. Furthermore, signatures of the population in the excited states in the radiation spectrum generated during the pulse and after the pulse are identified.

*This work is supported by DOE-BES (Award No. DE-SC0001771), NSF JILA Physics Frontier Center (Grant No. PHY1734006) and AFOSR MURI (Grant No. FA9550-16-1-0121).

10:54

V05 3 Resonant Enhancement of Strong Field Inner Orbital Ionization of Molecular Iodine* GEORGE GIBSON, DALE SMITH, *University of Connecticut* We present a wavelength study of the strong field single electron ionization of molecular iodine near its one-photon B-state resonance at 530 nm which shows a remarkably strong wavelength dependence. We have previously identified two ionization channels (PRA 95, 013410): ionization of the high lying molecular orbitals and ionization of the deep orbitals in I_2. We find a resonant enhancement of both channels, although the peak enhancement occurs at different wavelengths for the different channels. Moreover, the branching ratio of the ionization of the deep orbitals shows a dispersion-like function, with the branching ratio of the deep orbitals reaching over 98% at 519 nm. Finally, the branching ratio of double ionization into an excited state of I_2^{2+} as a function of wavelength closely matches the branching ratio of the single ionization of deep orbitals, implying that excitation of molecular ions generally comes about through inner orbital ionization.

*Supported by the NSF under award NSF-PHYS-1707542.

11:06

V05 4 Atomic single-active-electron potential and application to intense field processes* RAN REIFF, TENNESSE JOYCE, MICHELLE MILLER, EREZ SHANI, AGNIESZKA JARON-BECKER, ANDREAS BECKER, *Univ of Colorado - Boulder* Simulations of interaction of multielectron atoms with intense laser