

Exploiting Rydberg blockade to probe strongly-coupled Rydberg atom pairs

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Synopsis Rydberg blockade at very-high- n , $n \sim 300$, is examined using strontium n^1F_3 Rydberg atoms excited in a small volume defined by two crossed tightly-focused laser beams. Strong but not complete blockade is observed and discussed with the aid of quantum calculations using a two-active-electron model. Nonetheless, the probability for creating one, and only one, Rydberg atom is large, >0.6 , sufficient to enable study of strongly-coupled Rydberg atom pairs.

The goal of the present program is to produce pairs of high- n , $n \sim 300$, Rydberg atoms with well-defined initial separations and then control and manipulate their interactions by exciting them to higher n states using techniques developed explicitly for high- n atoms that employ carefully-tailored sequences of one, or more, short electric field pulses [1]. If the atoms are initially well separated their interactions will be weak and they will evolve independently. Their interactions can be dramatically increased by transferring them to higher n levels using pulsed fields. Since both atoms are subject to the same pulses this enables creation of well-defined strongly-correlated two-electron wavepackets whose dynamics can be monitored by application of further probe fields. A necessary first step towards such studies is creation of single high- n Rydberg atoms at well-defined initial locations. We explore here the use of Rydberg blockade to accomplish this.

In the present experiments strontium atoms in a collimated beam are excited to n^1F_3 states by three-photon excitation via the $5s5p\ ^1P_1$ and $5s5d\ ^1D_2$ intermediate states using radiation at 461, 767, and 893 nm. The crossed 767 and 893 nm beams are strongly focused resulting in a localized excitation volume of $\sim 2 \times 10^{-7} \text{ cm}^3$. Measurements are conducted in a pulsed mode. The output of the 461 nm laser, which is not focused, is chopped into a series of ~ 100 ns-long pulses. Following excitation the number of Rydberg atoms created is determined by field ionization.

Figure 1 shows Rydberg atom number distributions typical of those obtained under optimal conditions. The distributions are strongly sub-Poissonian, pointing to sizeable blockade effects. Blockade, however, is not complete which, theory suggests, results because interactions between nF states are anisotropic. For certain relative atomic orientations interactions

are strong, introducing pronounced blockade effects, for others interactions are weak and blockade effects minimal.

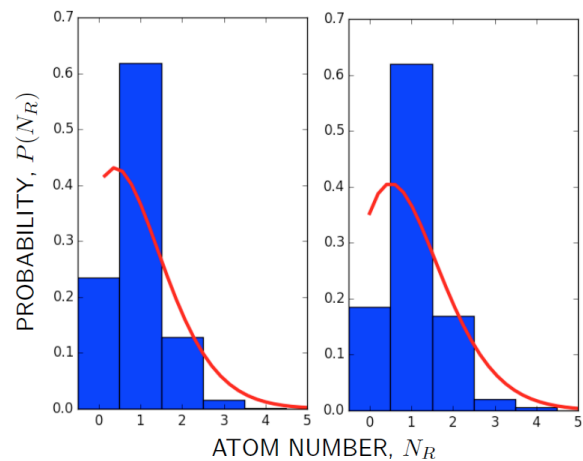


Figure 1. Measured Rydberg atom number distributions when the average number of Rydberg atoms created, \bar{N}_R , ~ 1 . The curves show Poissonian distributions for the same \bar{N}_R .

Nonetheless, the probability for creating a single Rydberg atom is large, ~ 0.62 . Thus, when using two excitation volumes the probability of producing a single Rydberg atom in each is sizeable, ~ 0.38 , much larger than for forming two Rydberg atoms in a single volume, ~ 0.06 . Since, with efficient Rydberg detection, it should be possible to discriminate against cases in which fewer than, or more than, two Rydberg atoms are created, study of Rydberg-Rydberg interactions under carefully controlled conditions becomes possible.

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References

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