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To cite this article: J D Whalen *et al* 2020 *J. Phys.: Conf. Ser.* **1412** 122004

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Measurements of spatial correlations in quantum gases using ultralong-range strontium Rydberg molecules

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Synopsis The photoexcitation of ultralong-range Rydberg molecules is demonstrated as a probe of spatial correlations in a quantum gas on previously inaccessible length scales of $1400\text{--}3200 a_0$. Measurements using cold ($\sim 1 \text{ K}$) (fermionic) ^{87}Sr and (bosonic) ^{84}Sr reveal the effects of quantum statistics on the pair correlation function $g^{(2)}(R)$.

The understanding of quantum gases can be enhanced by *in situ* measurements of spatial correlations. Here we demonstrate that photoexcitation of ultralong-range Rydberg molecules can provide a novel probe of nonlocal pair correlations. Rydberg dimer molecules [1] comprise a ground-state atom bound to a Rydberg atom by scattering of the Rydberg electron. The outer regions of the resulting molecular potential are shown in Fig. 1 for different n values together with the wavefunctions for the ground $\bullet = 0$ molecular dimer states which are strongly localized near the electron outer classical turning point at $R_n \sim 2n^2$. Thus, the molecular formation rate is governed by the probability of finding atom pairs with separation R_n .

Here we use non-degenerate quantum gases of (spin-polarized) fermionic ^{87}Sr ($I = 9/2$) and bosonic ^{84}Sr ($I = 0$) to measure the effects of quantum statistics on the molecular excitation rate. To extract the pair-correlation function $g^{(2)}(R)$ we compare excitation rates in the (polarized) Fermi- or Bose-gas to an unpolarized sample of ^{87}Sr where the tenfold-degenerate ground state provides a good approximation to a gas of uncorrelated particles. Figure 1 shows the dependence of the measured molecular production rate, normalized to that seen for an unpolarized sample, on R_n . As n , i.e., R_n , decreases, suppression of the excitation rate in the spin-polarized ^{87}Sr gas due to Pauli exclusion (anti-bunching), and the enhancement for the ^{84}Sr gas due to bunching are clearly evident. Figure 1 also includes the expected behavior of the pair correlation function $g^{(2)}(R)$ for non-degenerate gases of

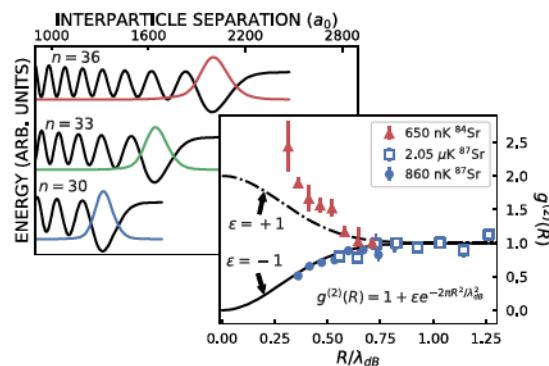


Figure 1 - Left: Black lines, molecular potentials for $5s\text{ns } ^3\text{S}_1 + 5s^2 \text{ } ^1\text{S}_0$ pairs (not to scale); colored lines, the radial wavefunction of the corresponding highly localized ground $\bullet = 0$ molecular state. Right: Extracted values of the pair-correlation function from comparing boson/spin-polarized fermion molecular excitation rates to unpolarized excitation rates plotted versus $R_n \sim 2n^2$ scaled by the thermal de Broglie wavelength $\lambda_{dB} = \hbar/\sqrt{2\pi m k_B T}$ (see text). The lines show the calculated values of $g^{(2)}(R)$.

non-interacting bosons and fermions. The measurements mirror well this behavior demonstrating that Rydberg molecule formation can provide a novel probe of pair correlations in cold gases that is suitable for use as a diagnostic in many other studies.

Research supported by the AFOSR, NSF, Robert A. Welch Foundation and FWF (Austria).

References

[1] DeSalvo B J *et al* 2015 *Phys. Rev. A* **92** 031403(R)

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