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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 1400-3200 a_0. Measurements using cold (~1 • 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 • = 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 (antibunching), 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

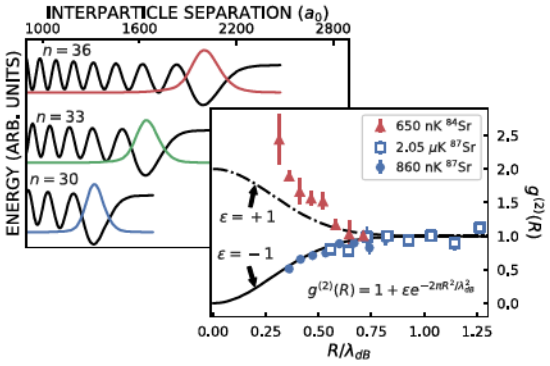

Figure 1 - Left: Black lines, molecular potentials for $5sns\ ^3S_1 + 5s^2\ ^1S_0$ pairs (not to scale); colored lines, the radial wavefunction of the corresponding highly localized ground • = 0 molecular state. Right: Extracted values of the pair-correlation function from comparing boson/spin-polarized fermion molecular excitation rates to unpolarized excitation rates plotted versus $R_n \sim 2n^2$ scaled by the thermal de Broglie wavelength $\lambda_{dB} = h/\sqrt{2\pi m k_B T}$ (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.

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References

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

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