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Probing Quantum Statistics and Spatial Correlations with Ultralong-Range Rydberg Molecules[1]

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Ultralong-range Rydberg molecules (ULRRMs) provide a sensitive and versatile probe of quantum statistics and spatial correlations in quantum gases. In ULRRMs, one or more ground-state atoms are bound to an atom in a highly excited Rydberg state through atom-electron scattering. Background atoms experience a potential that is given by the shape of the Rydberg-electron probability distribution, and the photo-excitation rate is proportional to the probability of finding atoms in the original ultracold gas with appropriate atomic configurations. In the low-density, few-body regime, ULRRMs can be created with well-defined internuclear spacing, set by the radius of the outer lobe of the Rydberg electron wavefunction. For the most-deeply bound dimer molecular state in particular, the excitation rate is proportional to the pair-correlation function, $g^{(2)}(R)$ of the initial sample, and R can be scanned by varying the principal quantum number of the target Rydberg state. We demonstrate this with ultracold, non-degenerate strontium gases and pair-separation length scales from $R = 1000 - 3000$ a_0, which is on the order of the thermal de Broglie wavelength for temperatures around 1 μK. Quantum statistics results in bunching for a single-component Bose gas of ^{84}Sr and Pauli exclusion for a polarized Fermi gas of ^{87}Sr. In the many-body regime the Rydberg atom is dressed by many background atoms, and for fermions the shape of the excitation spectrum can be explained in terms of Pauli blocking in the filled molecular orbitals of the final state.

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