

Characterizing Atom Sources with Quantum Coherence

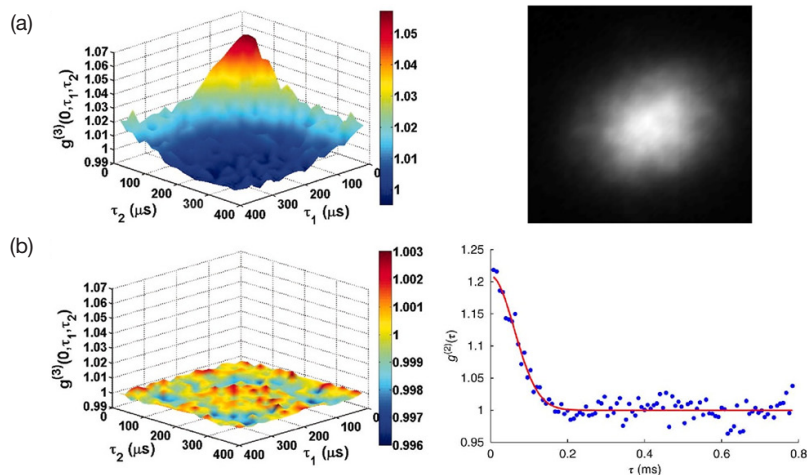
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Researchers can characterize atom sources by coherence properties, viewed by a wave or particle picture, by using quantum optics as an analogy. For example, first-order coherence measures amplitude fluctuations related to fringe visibility in an interferometer. Second-order coherence measures intensity variations as manifested in laser light speckle.

Hanbury Brown and Twiss (HBT) demonstrated that incoherent sources are characterized by photon bunching in the particle picture, whereby the second-order correlation function exceeds unity for short arrival times between pairs of photons (coherence time).¹ In contrast, a coherent source—e.g., a laser—has a correlation function value of unity for all times; and per Glauber’s quantum theory, this is expected to be true to all orders of the correlation function.²

Previous experiments by this group of researchers observed atom bunching for thermal (incoherent) sources of bosonic atoms (anti-bunching for fermions), and a second-order correlation function unity value, i.e., an equal probability for all arrival times, for Bose-Einstein condensates (BECs) by analogy with coherent optical sources.

We have used a new approach to measure the temporal third-order correlation function for both thermal and BEC ensembles of atoms. Our results demonstrate atom bunching for ultracold metastable helium atoms sourced from a 1 μ K thermal ensemble, where the observed 6 percent bunching enhancement is less than the theoretical maximum ($n!$ for n th order coherence) due to the finite resolution of the detector. By contrast, we measured a unity (within 0.1 percent) third-order correlation value for the BEC, thereby demonstrating that a BEC is coherent to a higher order and confirming Glauber’s hypothesis.³



(Left) Third-order correlation function for thermal atoms, 6 percent bunching enhancement (a) and a Bose-Einstein condensate, unity value, within 0.1 percent (b). (Right) Image of atomic speckle (top) and second-order correlation function (bottom) for multimode guided atoms, 21 percent bunching enhancement.

We have extended these quantum statistical measurements to atomic de Broglie waves guided within a red-detuned laser beam. The waveguide is capable of supporting the lowest-order mode (BEC, yielding a gaussian transverse spatial profile) or several low-order modes that we are able to selectively control.⁴ For multimode guiding, the transverse spatial profile exhibits a structure corresponding to atomic speckle. By adding the speckle images over multiple realizations of the experiment, the spatial profile yields an expected smooth average for independent thermal sources.

To further test the speckle hypothesis, we measured the second-order correlation function for the guided atoms. We detected HBT atom bunching, indicating that multimode guiding is associated with matter-wave speckle.⁵ When a BEC is loaded into the guide with up to 65 percent of atoms in the lowest order mode, the atom bunching disappears, a

finding that is consistent with the propagation of a coherent matter wave in the lowest-order mode of the guide.

These experiments demonstrate the usefulness of the quantum statistical properties of matter waves as a diagnostic for atomic source coherence properties. By being able to determine the transverse mode occupancy and spatial structure (speckle) for atoms guided by an optical potential, researchers can characterize de Broglie wave fronts for use in atom optics applications such as a matter-wave interferometry. \blacktriangle

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References

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