Direct Measurement of the Third Order Correlation Function for Ultracold Quantum Gases

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One of the seminal advances in quantum optics was the understanding that a quantised description of ensembles of photons could be characterised by first, second and higher order correlations. These properties correspond to single photon density, two-photon coincidence (bunching or anti-bunching), three-photon coincidence and so on.

Correlations are also a fundamental property of matter waves, and the single wavefunction that describes a Bose-Einstein condensate (BEC) is in principle characterised by long range coherence to all orders (i.e. a universal correlation value of unity). By their very nature higher order correlations are difficult to measure, due to the vast amounts of data required. Higher order correlations have been shown for photons [1], but only first order [2] and second order [3] correlations have been directly measured for matter waves, even though the effect of third order correlations on 3-body loss rates has been shown to be important [4].

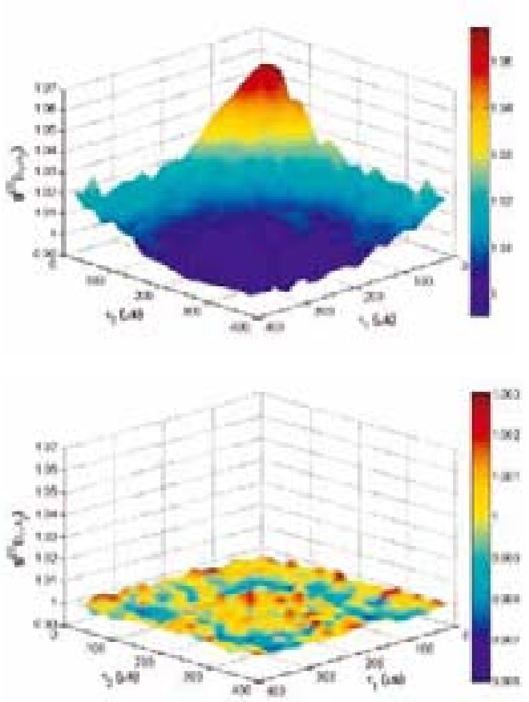

Figure 1: Third order correlation function for (upper) an ultracold thermal gas and (lower) a BEC.

In this experiment we demonstrate the first direct measurement of third order coherence for matter waves [5] (Fig. 1). Further, we show that the ratio of the second order to third order coherence for zero delay between the particle arrival times is consistent with theoretical predictions.

We exploit the unique single particle detection capabilities of metastable helium (He*) atoms made possible by our novel experimental process to study the correlation properties of ultracold atomic gases above and below the BEC critical temperature. Above condensation, where the atomic cloud behaves like an ensemble of incoherent sources, we observe bunching behaviour for both second order g(2)(τ_1) and third order g(3)(τ_1,τ_2) particle correlation functions. Below the critical temperature, the two correlation functions are both unity for all values of the delay between the particle arrival times, as expected for the long range coherence that characterises a BEC, see Fig. 1 (lower).

The ratio of the amplitude for thermal atoms of g(2)(0) and g(3)(0,0), which we measured to be 2.95 +/- 0.1, provides an absolute test of the higher order coherence properties.

References

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[4] E. A. Burt et al., Phys. Rev. Lett. **79**, 337 (1997).
[5] S. S. Hodgman *et al.*, Science **331**, 6020 (2011).