Spatial Quantum Noise Interferometry in Expanding Ultracold Atom Clouds.

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Recommended with a Commentary by Jason Ho, Ohio State University.

This is a simple and elegant experiment which is likely to have a wide impact on future experiments on cold atoms in optical lattices. One of the most widely used methods for studying the properties of cold atom systems is absorption imaging. The system is allowed to expand for some time after the trapping potential is suddenly turned off, and a photograph (absorption image) of the expanded cloud is taken. In this way, the density $n(\vec{r}) = < \psi^{+}(\vec{r})\psi(\vec{r}) >$ of the expanded cloud, a one-body correlation function, is measured. In contrast, there are very few studies of two-body correlation functions. In the recent paper of Folling et.al., a general method is introduced to study two-body correlation functions which proves to be very successful.

The experiment by Folling et.al studies the particle correlations in a bosonic Mott insulator in an optical lattice with about one atom per site. Absorption image on an expanded cloud is taken as shown in figure 1. Each pixel on the screen records the number of atoms in a column through the cloud normal to the screen. In this way, the column density $\bar{n}(\vec{r}) = \int n(\vec{r},z)dz$, $\vec{r} = (x,y)$, is measured. By averaging over 30 samples, the authors find that a smooth average density $< \bar{n}(\vec{r}) >$ as shown in figure 2. The lack of features of this density simply reflects the absence of long range phase coherence between bosons prior to expansion. Should the initial state be a superfluid, the phase coherence between bosons would lead to an absorption image sharply peaked along directions perpendicular the Bragg planes. However, when the same sample averaging is performed on correlations of between the column densities,

$C(\vec{d}) = \frac{\int < \bar{n}(\vec{r} + \vec{d}/2)\bar{n}(\vec{r} - \vec{d}/2) > d^2 r}{\int < \bar{n}(\vec{r} + \vec{d}/2) >< \bar{n}(\vec{r} - \vec{d}/2) > d^2 r}$, where < .. > means averaging over samples, a regular array of sharp peaks is revealed. (See figure 3). The function $C(\vec{d})$ is constructed so that it is unity when the particles are totally uncorrelated. The origin of these sharp peaks can be traced back to the positional order of the bosons in the Mott phase prior to expansion. In other words, even though the positional order in the Mott phase cannot be identified in the average column density $< \bar{n}(\vec{r}) >$, it shows up prominently in the correlation $C(\vec{d})$. The physics for the formation of sharp peaks is similar to the Hanbury Brown and Twiss effects in quantum optics, where statistics tends to produce bunching of particles. While it comes with no surprise that bosons in the Mott phase have long range positional order, the important point is that two particle correlations can now be measured with high accuracy. It is conceivable that new types of correlation (or noise) measurements can be invented to explore more intricate orders, including those “exotic” ones that fascinate many condensed matter physicists.

Figure 1: From the number of photons collected in each pixel, the number of bosons in each column through the cloud can be deduced.
Figure 2: Absorption image on the expanded cloud after averaging over 30 samples. A smooth and featureless column density is found.

Figure 3: The column densities function separated by $C(\vec{d})$ shows an array of sharp peaks, reflecting the long range positional order of bosons in the Mott phase prior to expansion.

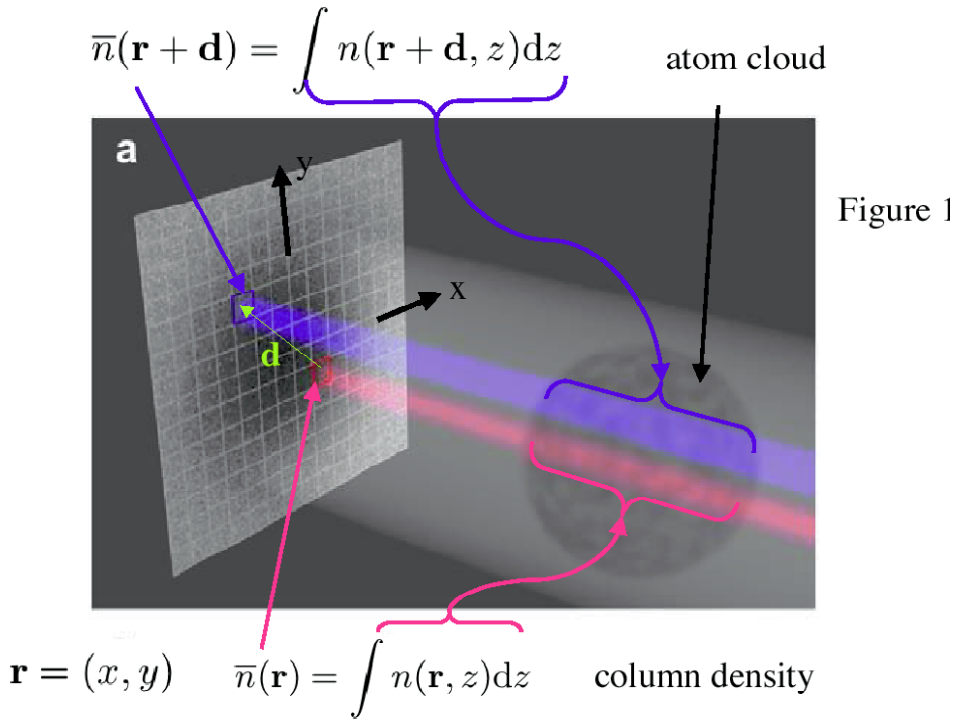

Figure 1

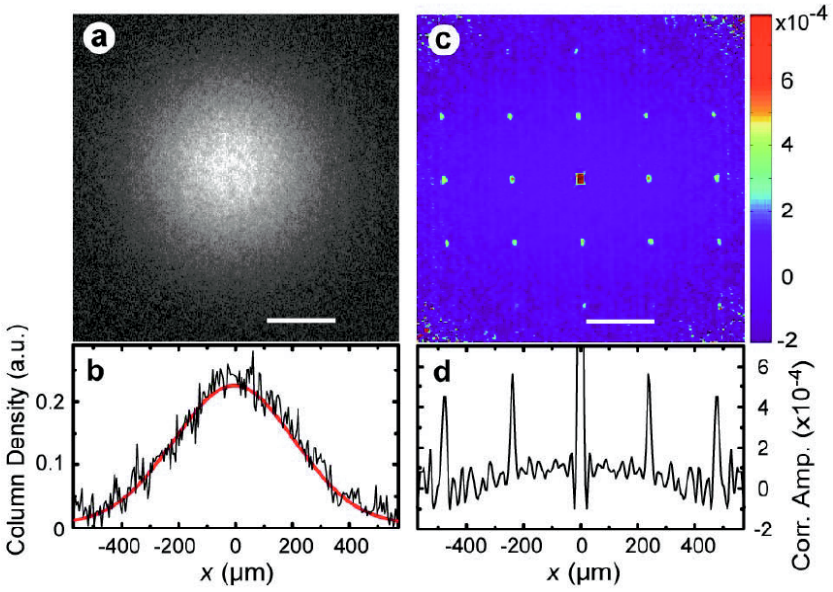

Figure 2 Figure 3