Measurement of density fluctuations as a new probe of the physics of quasi-1D Bose gases

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Measurements of atomic correlations and density fluctuations are becoming an increasingly important tool in the studies of ultracold quantum gases. Such measurements are able to probe quantum many-body states of interacting systems, often giving access to key quantities that characterize the system. This is particularly true for one-dimensional (1D) gases, where the effects of fluctuations are enhanced compared to 3D systems and govern the rich underlying physics.

Here we demonstrate that by measuring the density and atom number fluctuations (Fig. 1) in a highly elongated weakly interacting Bose gas we can map out the phase diagram (Fig. 2) of the transition from the ideal gas to a quasi-condensate regime throughout the dimensional crossover from a purely 1D to a 3D regime [1]. We show that the entire transition region and the dimensional crossover are described surprisingly well by the modified Yang-Yang model introduced in Ref. [2]. Furthermore, we find that at low temperatures the linear density at the quasi-condensate transition scales according to an interaction-driven scenario of a longitudinally uniform 1D Bose gas (n_t), whereas at high temperatures it scales according to the degeneracy-driven critical scenario of transverse condensation ($n_\perp$) of a 3D ideal gas.

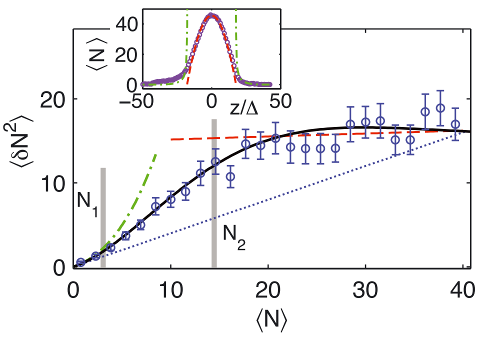

Figure 1. Atom number fluctuations $\langle \delta N^2 \rangle$ versus the mean $\langle N \rangle$ in a quasi-1D Bose gas: solid line – modified Yang-Yang model; dash-dotted – ideal Bose gas; dashed – quasi-condensate; dots – classical ideal gas. The positions of $\langle N_1 \rangle$ and $\langle N_2 \rangle$ correspond to 20% departures from the ideal gas and quasi-condensate regimes, respectively.

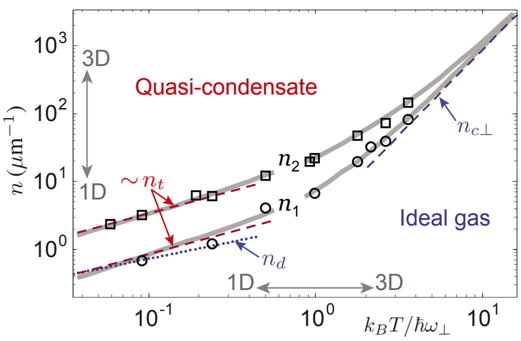

Figure 2. Phase diagram of different regimes in a uniform 1D Bose gas. The experimental data (circles and squares) are in excellent agreement with the modified Yang-Yang model (solid lines) for the linear densities $n_{1,2} = \langle N_{1,2} \rangle / \Delta$, where Δ is the length of a uniform segment in the gas.

In addition, we have measured the third moment $\langle \delta N^3 \rangle$ of atom number fluctuations in a quasi-1D Bose gas [3], which characterises the skewness of the atom number distribution. The skewness is linked to the third-order correlation function $g^{(3)}$, and our measurements demonstrate the presence of true three-body correlations in the gas. Apart from this, we show that the measured third moment is related to a thermodynamic relation that involves a second-order derivative of the equation of state of the gas, and therefore the technique can be used as a sensitive probe of the thermodynamics of a quantum gas.

References

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