Non-local spatial pair correlations in a 1D Bose gas

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The study of two-body and higher-order correlations is an important theme in the physics of ultracold quantum gases. Correlation functions are observables that provide information about quantum many-body wave functions beyond the simple measurement of density profiles. They are of particular importance for the understanding of low dimensional and strongly correlated systems, atomic gases with exotic phases, and systems with multiple order parameters. We have addressed the problem of nonlocal two-particle correlations in a uniform 1D Bose gas with repulsive δ-function interaction. The 1D Bose gas model is one of the simplest paradigms we have of a strongly interacting quantum fluid, owing to its exact integrability [1]. It also holds relevance to an experimentally accessible system, in which the motion of atoms in the gas is confined to the transverse ground-state of a highly anisotropic trapping potential.

We have calculated [2] the spatial second-order correlation function $g^{(2)}(r)$ for the uniform 1D Bose gas in the parameter space characterised by the dimensionless interaction parameter γ and the reduced temperature τ (see Fig. 1). The results span the entire range of physical regimes – from ideal gas ($\gamma \to 0$) to strongly interacting ($\gamma \gg 1$) and from low temperature ($\tau \ll 1$) to high temperature ($\tau \gg 1$) gases. We present the results of perturbative analytic methods available at strong and weak couplings, as well as first-principles numerical results using imaginary time simulations with the gauge-P representation in regimes where perturbative methods are invalid (see Fig. 2). In all regimes, we identify the profound role of interactions and find that under certain conditions the pair correlation may develop a global maximum at a finite interparticle separation due to the competition between repulsive interactions and thermal effects.

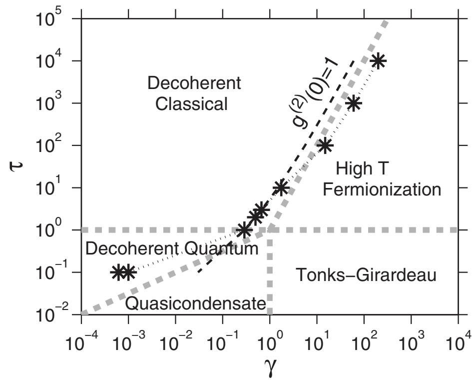

Figure 1. Phase diagram of different regimes in a uniform 1D Bose gas. The asterisks indicate the lowest τ and highest γ accessible using the numerical gauge-P method.

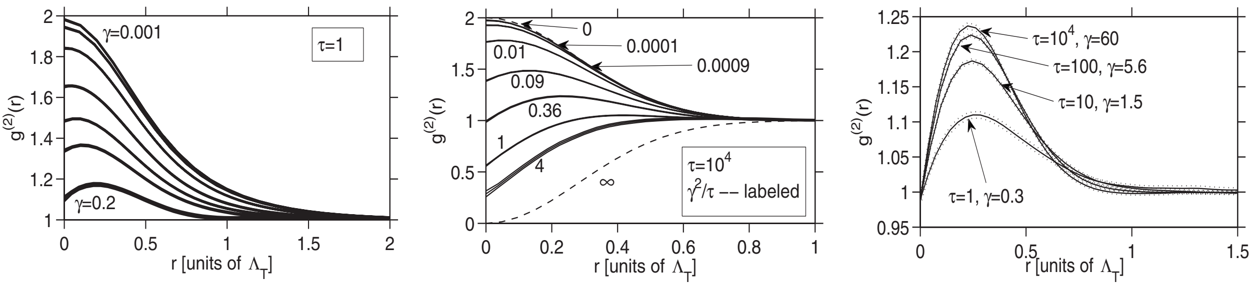

Figure 2. Examples of the pair correlation $g^{(2)}(r)$ as a function of the relative distance r in units of the thermal de Broglie wavelength Λ_T.

References

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