Quantum-atom optics using dissociation of molecular condensates

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The generation and detection of strongly correlated atomic ensembles is becoming one of the central themes in the study of ultracold quantum gases. Dissociation of a Bose-Einstein condensate of molecular dimers is among the most efficient processes to produce strong pair correlations between atoms of opposite momenta.

1. We have performed first-principles quantum simulations of the dissociation of a trapped, spatially inhomogeneous Bose-Einstein condensate of molecular dimers made of bosonic atoms [1]. Using stochastic positive-P simulations we have studied spatial pair correlations of atoms produced in dissociation after time of flight. We find that the observable correlations may significantly degrade in systems with spatial inhomogeneity compared to the predictions of idealized uniform models. We show how binning of the signal can enhance the detectable correlations and lead to the violation of the classical Cauchy-Schwartz inequality and relative number squeezing. Examples of observable correlation effects via shot-noise spectroscopy of absorption images are shown in Fig. 1.

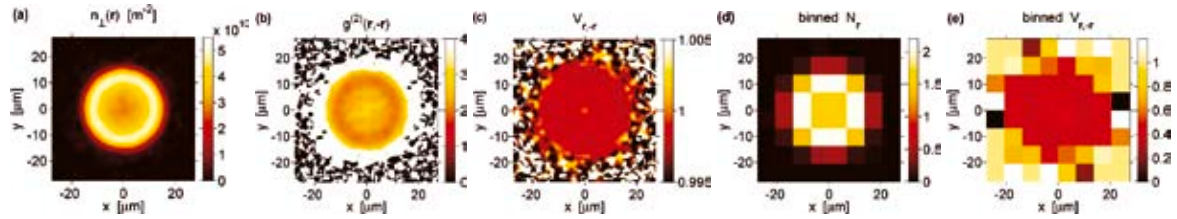

Figure 1: (a) Spatial column density of dissociated atoms $n_\perp(\mathbf{r}) = \langle \hat{n}_\perp(\mathbf{r}) \rangle$. (b) Pair correlation function in the absorption image at diametrically opposite locations, $g^{(2)}(\mathbf{r}, -\mathbf{r})$. (c) Relative atom number variance $V_{\mathbf{r},-\mathbf{r}}$ at diametrically opposite locations. (d) Binned atomic signal on the detection plane, for bins of size 32×32 pixels. (e) Relative atom number variance at opposite locations after binning, showing improved squeezing below the shot noise level $V_{\mathbf{r},-\mathbf{r}} < 1$.

2. We have developed a pairing mean-field theory of dissociation of a spatially uniform BEC of molecular dimers, including both bosonic and fermionic statistics for the constituent atoms. The details are given in the ACQAO Annual Report for 2006 (p. 30), and the results have been published in Ref. [2].

3. We are currently developing alternative theoretical approaches to treat spatial inhomogeneity of the molecular condensate and to address the role of mode-mixing on the strength of atom-atom correlations. The approaches include the Hartree-Fock-Bogoliubov (HFB) theory, undepleted molecular approximation for short time dynamics in the case of fermionic atoms, and first-principle simulations using Gaussian stochastic methods [3] which should allow us to extend the first-principle stochastic simulations to multi-mode fermionic systems. The HFB approach will allow us to understand the role of atom-atom s-wave scattering interactions in the long time limit, which is not possible using the positive-P stochastic method.

References

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