Correlations between bosonic atoms dissociated from a Bose-Einstein condensate of molecular dimers

C. M. Savage1, P. Schwenn2, and K. V. Kheruntsyan2

1ACQAO, Department of Physics, The Australian National University, Australia.

2ACQAO, School of Physical Sciences, University of Queensland, Australia.

Dissociation of a molecular dimer produces two quantum mechanically entangled atoms with equal and opposite momenta in the molecule’s rest frame. These atoms have Einstein-Podolsky-Rosen type correlations, and hence are of fundamental interest. It is possible to produce Bose-Einstein condensates (BECs) of molecules, and then to dissociate them as in Ref. [1], so that these correlations may be explored experimentally [2] in the regime of large number of particles.

In this project [3] we use quantum field simulations to investigate the conditions under which the atomic correlations may be observed. We use stochastic methods based on the the positive-P representation. This allows us to extend the analytical results which are known for the case of a spatially uniform system and undepleted, classical molecular field [4]. Important limitations on our method are that it is restricted to bosonic atoms, and that the positive-P simulations eventually fail as the simulation time increases, particularly when two-body scattering is included.

Since our simulations are three-dimensional (3D) we can both investigate the full spatial structure of the atoms and their correlations, and simulate experimental measurement methods, including time-of-flight expansion in free space and absorption imaging. In particular, we integrate along the propagation direction (z) of the imaging laser and obtain atomic (2D) column densities. We find that these images may then be correlated to reveal non-local density-density correlations, which we quantify via

\[ g^{(2)}_{zz}(r, r') = \frac{\langle \hat{n}_z(r) \hat{n}_z(r') \rangle}{\langle \hat{n}_z(r) \rangle \langle \hat{n}_z(r') \rangle}, \]

where \( \hat{n}_z(r) = \int dz \hat{\Psi}^\dagger(x) \hat{\Psi}(x) \) is the column density operator, and \( \hat{\Psi}(x) \) is the atomic field operator [\( x = (x, y, z), r = (x, y) \)]. We analyse these correlations as a function of the size and geometry of the initial molecular condensate, with examples shown in the figures.

Figures. (Left) Slice plot of atomic 3D density after dissociation and time-of-flight expansion, starting from a spherical molecular BEC. Values in all plots are indicated by a color scale. The density is in units of \( 10^{-5} n_0 \), where \( n_0 \) is the peak density of the initial molecular condensate. (Centre) Atomic column density \( \langle \hat{n}_z(r) \rangle \) as a function of \( r \); the scale is in units of \( (10^{-3} n_0) m \), i.e. in inverse area units. (Right) Second-order correlation function for column densities after expansion at diametrically opposite locations, \( g^{(2)}_{zz}(r, -r) \). This particular correlation is the strongest among all other non-local correlations, reflecting the intrinsic momentum correlations of dissociated atoms before expansion.

References


[4] K. V. Kheruntsyan, cond-mat/0509505 (see also the report on “Quantum atom optics with fermions”).