Atomic four-wave mixing via condensate collisions

A. Perrin[1], C. M. Savage[2], D. Boiron[1], V. Krachmalnicoff[1], C. I. Westbrook[1], and K. V. Kheruntsyan[3]
[1] *Laboratoire Charles Fabry de l'Institut d'Optique, CNRS, Univ Paris-Sud, Campus Polytechnique, France*
[2] *ACQAO, Department of Physics, Australian National University, Australia*
[3] *ACQAO, School of Physical Sciences, University of Queensland, Australia*

We perform a theoretical analysis of atomic four-wave mixing via a collision of two Bose-Einstein condensates of metastable helium atoms. The analysis is based on first-principles quantum simulations using the positive P-representation method and is aimed at modeling recent experiments at Orsay [2]. Using the actual experimental parameters, we calculate atom-atom pair correlations within the s-wave scattering halo produced spontaneously during the collision (see Fig. 1). Our results for the strength and the width of the correlation signal are consistent with the experimental observations. We also analyze relative atom number squeezing and the violation of the classical Causchy-Schwartz inequality.

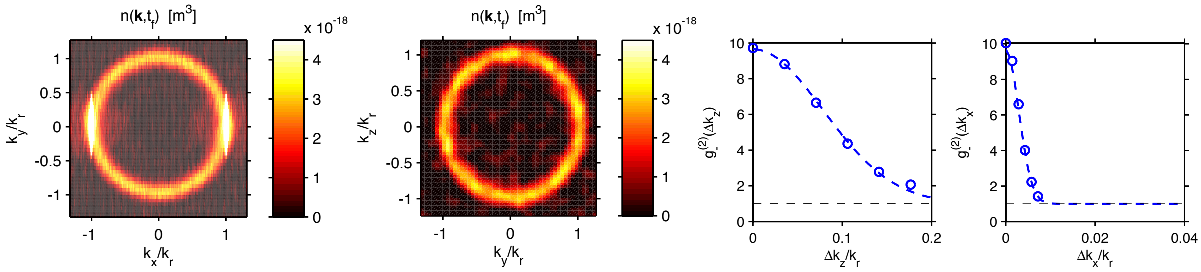

Figure 1: First and second panels: slices through $k_z = 0$ and $k_x = 0$ of the 3D atomic density distribution in momentum space $n(\mathbf{k}, t_f)$ after $t_f = 25\ \mu$s collision time. The scale is chosen to show the s-wave sphere of spontaneously scattered atoms and cuts off the colliding condensates (shown in white on the first panel) containing initially 10^5 atoms. Third and fourth panels: pair correlation of atoms on the opposite sides of the sphere as a function of the relative offset Δk_i, in units of the collision momentum k_r. The dots are the numerically calculated values; the dashed lines are simple Gaussian fits $\propto 1 + 9.7 \exp(k_i^2/2\sigma_i^2)$ to guide the eye, with $\sigma_z = 0.0785 k_r$ and $\sigma_x = 0.0029 k_r$.

Quantum dynamical simulations of this scale, i.e., corresponding to ensembles of large numbers of interacting particles in realistic parameter regimes, are becoming possible due to the advances in computational power and improvements in numerical algorithms (for recent examples, see Refs. [3, 4]). The importance of the present example with metastable helium is that the quantum correlations of interest have been both measured experimentally and calculated theoretically. In this sense, this work represents one of the first examples where the results of experimental measurements can be scrutinized to the level of *quantitative* theoretical understanding using first principles calculations. Our results can also serve as benchmarks for approximate theoretical methods to establish the range of their validity.

References

[1] A. Perrin, C.M. Savage, D. Boiron, V. Krachmalnicoff, C.I. Westbrook and K.V. Kheruntsyan, arXiv:0712.2145 (submitted to New J. Phys.).

[2] A. Perrin, H. Chang, V. Krachmalnicoff, M. Schellekens, D. Boiron, A. Aspect, and C.I. Westbrook, Phys. Rev. Lett. **99**, 150405 (2007).

[3] C.M. Savage, P.E. Schwenn, and K.V. Kheruntsyan, Phys. Rev. **74**, 033620 (2006).

[4] P. Deuar and P.D. Drummond, Phys. Rev. Lett. **98**, 120402 (2007).