Quantum-atom optics with molecular dissociation

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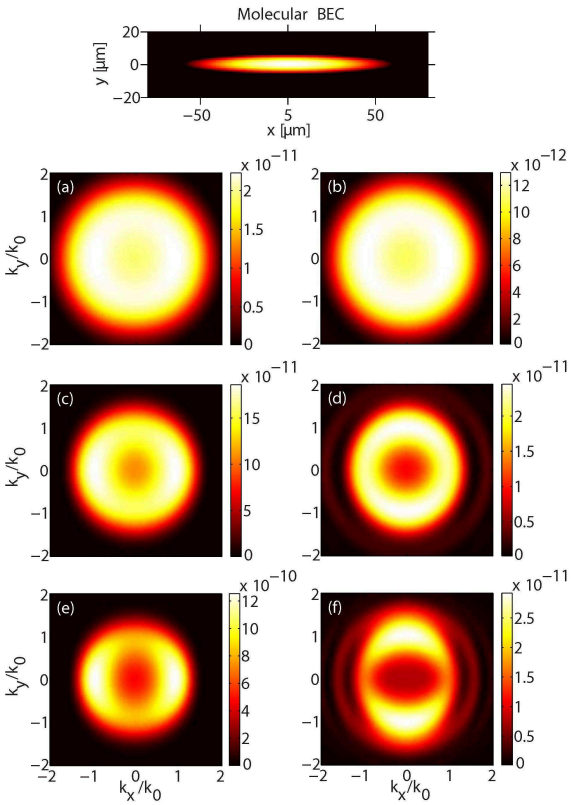
The dissociation of a Bose-Einstein condensate (BEC) of molecular dimers into pair-correlated atoms is a process analogous to parametric down-conversion in optics. Down-conversion with photons has been pivotal in the advancement of quantum optics by allowing for the generation of strongly entangled states. In the same way, molecular dissociation has emerged as an avenue for generating strongly entangled ensembles of atoms in the field of quantum-atom optics. This matter-wave analog is of additional interest, however, as it gives rise to the possibility of performing tests of quantum mechanics with mesoscopic or macroscopic numbers of massive particles rather than with massless photons. Also, the molecules in the BEC can be formed by either two bosonic or two fermionic atoms; the latter offers the possibility of a new paradigm of *fermionic* quantum-atom optics.

In Ref. [1] we have modeled the dissociation of two-dimensional, elongated molecular condensates (shown in the top panel of the figure) using the undepleted molecular approximation. For this geometry, the difference in quantum statistics of the constituent atoms (bosons or fermions) manifests as complementary geometric structures in the density profiles of the dissociated atomic clouds. Atomic bosons (with the momentum distributions shown in Figs. (a), (c) and (e) at three successive time instances) are preferentially emitted along the long axis of the molecular BEC, while atomic fermions (Figs. (b), (d) and (f)) are preferentially emitted along the short axis. This anisotropy provides a straightforward way to bin the atomic signal into two opposite bins (left-right for bosons, top-bottom for fermions) and potentially simplifies the measurement of relative atom number squeezing in the opposite bins. In addition to these numerical analysis, we have derived explicit analytic results [2], valid in the short time limit, for the shape and the strength of atom-atom pair correlations (see Annual Report for 2008).



In the regime of strong molecular depletion, we have analysed the relative performance of the Hartree-Fock-Bogoliubov (HFB), the truncated Wigner, and the positive-P methods for dissociation in 1D [3]. An important aspect of our analysis is the inclusion of atom-atom interactions, which can be problematic for the positive-P method. We find that the truncated Wigner method mostly agrees with the positive-P simulations, but can be simulated for significantly longer times. The HFB results diverge from the positive-P and Wigner methods after relatively short times.

References

[1] M. Ögren, C. M. Savage, and K. V. Kheruntsyan, Phys. Rev. A **79**, 043624 (2009).
[2] M. Ögren and K. V. Kheruntsyan, arXiv: 0905.0343 [see also: Phys. Rev. A **78**, 011602(R) (2008)].
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