Nonlinear dynamics of Bose-Einstein condensates

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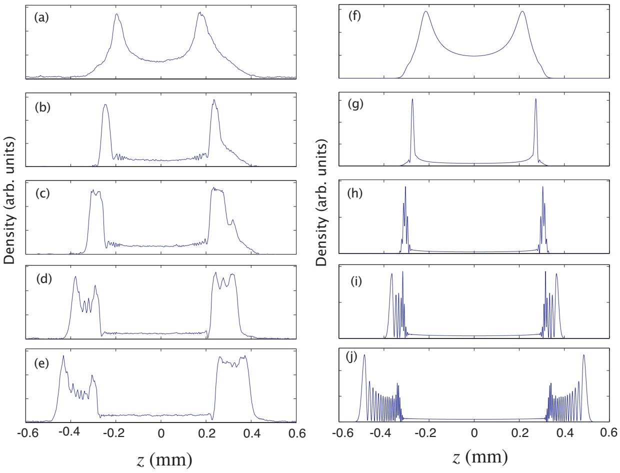
Over the past twelve months there have been two related projects concerning the nonlinear dynamics of Bose-Einstein condensates (BECs) as described by the Gross-Pitaevskii equation (GPE). This mean-field equation is the starting point for understanding many features of dilute gas Bose-Einstein condensates, so it is important to understand its capabilities and limitations.

1. Experiments were peformed in the group of Peter van der Straaten at Utrecht University in the Netherlands to generate shock waves in a large Bose-Einstein condensate in a cigar-shaped trap. They did this by suddenly turning on a blue-detuned laser sheet that intersected the condensate and repelled the atoms from the centre of the cigar. This resulted in density pulses that propagated along the cigar. Due to the condensate nonlinearity the pulses steepen, and as the front edge of the pulse becomes near vertical wave-breaking occurs. Due to the violence of the experiment it is unfeasible to perform a fully 3D GPE simulation of this experiment, even by making use of the cylindrical symmetry of the system. We modelled these experiments using the non-polynomical Schrödinger equation (NPSE) [1].

The NPSE is an effective 1D GPE that takes account of the width of the condensate in the radial direction to make a better model of what is really a 3D system. The simulations showed very good agreement with the density profiles measured in the lab [2]. This is another remarkable achievement for the GPE in a situation where it might otherwise be expected to be invalid. The figure on the right shows experimental density slices in the left column (a–e) and theoretical 1D GPE simulation density profiles in the right column (f–j) following 69 ms of expansion after evolving in the trap for up to 3.0 ms.



2. One of the approximations made in the derivation of the non-polynomial Schrödinger equation is that the radial width of the condensate adiabatically follows the axial density. We have been working at eliminating this approximation, and deriving an equation of motion for the radial width as a function of the axial position coupled to an effective 1D GPE-like equation [3]. This should not only be more accurate than the non-polynomial Schrödinger equation [1], but could also be used to simulate the expansion of a cigar-shaped BEC. This would be useful as BECs are often expanded before they are imaged, and sometimes the relationship between the measurement and the in-trap density is not clear.

References

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