Formation of topological defects in Bose-condensed gases

J. Sabbatini[1], G. M. Lee[1], M. C. Garrett[1], S. A. Haine[1],
A. S. Bradley[2], B. P. Anderson[3], W. H. Zurek[4], and M. J. Davis[1]
[1] *School of Mathematics and Physics, ACQAO, UQ*
[2] *Jack Dodd Centre for Quantum Technology, University of Otago, Dunedin, New Zealand*
[3] *College of Optical Sciences, University of Arizona, Tucson, Arizona, USA*
[4] *Theory Division, Los Alamos National Laboratory, New Mexico, USA*

Quenches of thermodynamic or Hamiltonian parameters in quantum degenerate Bose gases can result in the formation of topological defects such as solitons, vortices, or domain walls depending on the particular system. This project aims to simulate such quenches using the stochastic Gross-Pitaevskii formalism at finite temperature and the truncated Wigner method at zero temperature [1] in order to understand the formation and evolution of the defects [2].

1. Vortices have previously been observed to form in evaporatively cooled Bose-Einstein condensates [3]. Recently we have been simulating condensate formation in highly-oblate traps, and have found that up to ten vortices can be observed in a single condensate, in broad agreement with preliminary experimental results. Our current goal is to try to establish a Kibble-Zurek type scaling of the number of defects with the quench rate for experimentally realistic parameters [2].

2. Quench cooling and condensate formation experiments in prolate trapping potentials at Washington State University have observed what appear to be dark solitons in the resulting condensate images [4]. We have been simulating a one dimensional version of this experiment and have observed the formation of solitons during condensation. We have developed a robust algorithm for the detection of solitons, and can now track their evolution as the system relaxes towards thermal equilibrium [5]. Current data analysis is aimed at establishing if Kibble-Zurek scaling can be observed in this system.

3. We have been studying a quantum Kibble-Zurek scenario in a two-component BEC that is naturally immiscible [6]. By turning on a coupling between two hyperfine states of a BEC it is possible to load the system into a dressed state which is miscible. By quickly ramping off the coupling, the system returns to an excited immiscible state, with faster ramps resulting in more domain walls forming between the two components. We have demonstrated a power law scaling of the number of domain walls in a both a 1D homogeneous and 1D trapped system with different power-law exponents.

4. Recent experiments in the metastable helium BEC experiment at the Australian National University have observed that the system coherence takes longer to establish than the condensate density. We have been modelling this experiment using the stochastic GPE approach, but so far have yet to be able to reproduce this observation. Further work in this area is aimed at incorporating the non-equilibrium dynamics of the thermal cloud in the description of condensate formation. In particular this may explain some of the features of an earlier experiment at the University of Amsterdam in the hydrodynamic regime [7].

References

[1] P. B. Blakie *et al.*, Advances in Physics **57**, 363 (2008).
[2] W. H. Zurek, Physics Reports **276**, 177 (1996).
[3] C. N. Weiler *et al.*, Nature **455**, 948 (2008).
[4] P. Engels, private communication.
[5] G. M. Lee, S. A. Haine and M. J. Davis, in preparation.
[6] J. Sabbatini, W. H. Zurek and M. J. Davis, in preparation.
[7] I. Shvarchuck *et al.*, Phys. Rev. Lett. **89**, 270404 (2002).