Quantum simulations of Bose-Einstein condensates.

M. J. Davis[1], A. S. Bradley[1], M. K. Olsen[1], A. J. Ferris[1], P. B. Blakie[2], J. J. Hope[3],
C. M. Savage[3], S. Wüster[3], E. A. Ostrovskaya[4], B. J. Dąbrowska[4], and D. C. Roberts[5]
[1]*ACQAO, School of Physical Sciences, University of Queensland, Australia.*
[2]*Department of Physics, University of Otago, Dunedin, New Zealand.*
[3]*ACQAO, Department of Physics, The Australian National University, Australia.*
[4]*ACQAO, RSPhysSE, The Australian National University, Australia.*
[5]*Los Alamos National Laboratory, New Mexico, USA.*

This project considers situations in which beyond mean-field effects are important in the dynamics of Bose gases even at zero temperature. Typically we make use of the the truncated Wigner method for solving the quantum evolution of a Bose-condensed gas [1]. The inclusion of initial quantum noise means the technique can represent quantum corrections to the classical field equations of motion.

We have studied the effect of quantum and thermal fluctuations in the well-known “Bosenova” experiment [2], where the scattering length a ^{85}Rb BEC was switched to negative values for controlled periods using a Feshbach resonance, and the time evolution of the condensate studied. While GPE studies incorporating three body recombination have qualitatively agreed with the experimental results, there is a lack of quantitative agreement [3]. We found that although there were some differences from the GPE treatment, there were not sufficient to describe the experimental data [4].

Motivated by an experiment performed by the Otago group, we have studied the loading of a BEC into the band edge of a 1D optical lattice plus magnetic trap. Interactions cause a rapid loss of coherence and thermalisation in the Rabi cycling between momentum states that is observed, and we have quantitatively modelled this with results in reasonable quantitative agreement with the data. A paper written with the Otago group is currently being finalised.

The process of degenerate four-wave mixing of a BEC in a moving 1D optical lattice has also been studied, where atoms from a mother condensate form two entangled daughter condensates with differing momenta. A simplified three-mode model showed that significant continuous variable entanglement could be generated [5], and current works aims to determine whether this persists in more detailed 1D calculations. We have also developed a proposal for and experimental scheme to measure atomic quadratures and prove such entanglement.

We have been simulating the loading of a trapped BEC into an optical lattice which is then accelerated towards the band edge, similar to the experiments performed by De Sarlo *et al.* [6]. We have shown that quantum fluctuations determine the time scale for dynamical instability leading to the formation of soliton trains at random positions and a thermal component. We have also shown that phase-imprinting can fix the locations of the trains [7].

Recent analytic work has suggested that quantum fluctuations in BECs in an infinite system can cause a non-zero drag force on an object in a flow at all velocities [8], in contradiction with our conventional understanding of superfluidity . We have recently begun calculations aimed at conclusively demonstrating this force in a finite system.

References

[1] M. J. Steel *et al.*, Phys. Rev. A **58**, 4824 (1998).
[2] E. A. Donley *et al.*, Nature **412**, 295 (2001).
[3] C. M. Savage, N. P. Robins and J. J. Hope, Phys. Rev. A **76**, 014304 (2003).
[4] S. Wüster, B. J. Dabrowska-W”uster, A. S. Bradley, M. J. Davis *et al.*, cond-mat/0609417.
[5] M. K. Olsen and M. J. Davis, Phys. Rev. A **73**, 063618 (2006).
[6] L. De Sarlo *et al.*, Phys. Rev. A **72**, 013603 (2005).
[7] B. J. Dabrowska-Wüster, S. Wüster, A. S. Bradley, M. J. Davis and E. A. Ostrovskaya, cond-mat/0607332.
[8] D. C. Roberts and Y. Pomeau, Phys. Rev. Lett. **95**, 145303 (2006).