Quantum noise and entanglement in Bose-Einstein condensates

M. J. Davis[1], M. K. Olsen[1], A. J. Ferris[1], E. G. Cavalcanti[1,2], A. S. Bradley[1,3] S. Wüster[4], B. J. Dąbrowska-Wüster[5]
[1] *ACQAO, School of Mathematics and Physics, University of Queensland, Australia.*
[2] *Centre for Quantum Dynamics, Griffith University, Australia.*
[3] *Jack Dodd Centre for Quantum Technologies, University of Otago, New Zealand.*
[4] *Max Planck Institute for the Physics of Complex Systems, Dresden, Germany*
[4] *Centre of Theoretical Chemistry and Physicsk, Massey University, New Zealand*

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 truncated Wigner method for solving the quantum evolution of a Bose-condensed gas [1]. The inclusion of quantum noise in the intial conditions means that the technique can incorporate quantum corrections to the classical field dynamics.

1. We have analysed an experiment that observed the formation of multiple 3D bright solitary waves (BSWs) in the collapse of a BEC when the interaction strength was switched from being positive to negative [2]. Mean-field theory predicts that the solitary waves should form with the same phase, but the experimental results suggest that in fact they have repulsive phase relations. We have found that quantum noise can result in effective repulsive interactions between solitons in one dimension, but not in three dimensions [3].

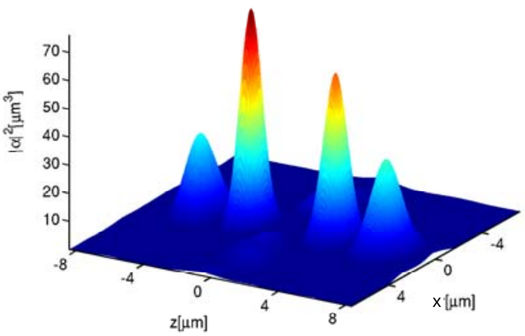

Fig. 1: Bright solitary waves formed in BEC collapse.

2. We have investigated the creation of entangled matter-wave packets in the degenerate four-wave mixing of a BEC in a moving 1D optical lattice. In this process atoms from a mother condensate form two entangled daughter condensates with differing momenta. Phase-sensitive homodyne measurements of the atomic fields are necessary in order to prove entanglement between the atomic pulses. This requirement has lead us to develop three new entanglement criteria for use with non-classical local oscillators [4]. We have made use of this scheme in simulating a 1D version of degenerate four wave mixing and developed and analysed an experimental measurement scheme to demonstrate both inseparability and the EPR paradox [5].

3. We have simulated and analysed the stirring and formation of a vortex lattice from a zero temperature 2D BEC in the presence of quantum noise. In contrast to previous findings, we demonstrated that it is not necessary to break the system symmetry by hand or by numerical integration error in order to realise vortex lattice formation [6].

4. Our earlier work on dynamical instabilities in a BEC in an optical lattice was published [7].

References

[1] M. J. Steel *et al.*, Phys. Rev. A **58**, 4824 (1998).
[2] S. L. Cornish, S. T. Thompson and C. E. Wieman, Phys. Rev. Lett. **96**, 170401 (2006).
[3] B. J. Dąbrowska-Wüster, S. Wüster and M. J. Davis, arXiv:0812.0493.
[4] A. J. Ferris, M. K. Olsen, E. G. Cavalcanti and M. J. Davis, Phys. Rev. A **78**, 060104(R) (2008).
[5] A. J. Ferris, M. K. Olsen and M. J. Davis, in preparation.
[6] T. M. Wright, *et al.* Phys. Rev. A **78**, 063601 (2008).
[7] A. J. Ferris, M. J. Davis, R W. Geursen, P. B. Blakie and A. C. Wilson, Phys. Rev. A **77**, 012712 (2008).