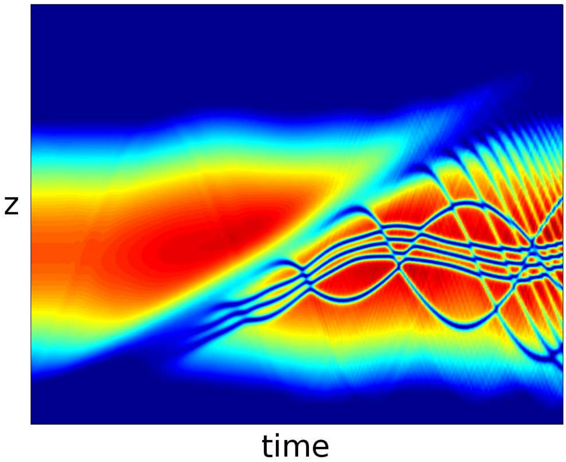
Superfluidity in dilute gas Bose-Einstein condensates

A. G. Sykes[1], C. Feng[1], D. C. Roberts[2], A. S. Bradley[3], B. P. Anderson[4], and M. J. Davis[1].
[1]*School of Mathematics and Physics, ACQAO, UQ*
[2]*Center for Nonlinear Studies, Los Alamos National Laboratory, New Mexico, USA*
[3]*Jack Dodd Centre for Quantum Technologies, University of Otago, Dunedin, New Zealand*
[4]*College of Optical Sciences, University of Arizona, Tucson, Arizona, USA*

It is generally accepted that dilute gas Bose-Einstein condensates (BECs) in three dimensions are superfluids — they can flow without resistance below a certain critical velocity, and may only rotate by forming quantised vortices. In the past twelve months we have been investigating a number of aspects of superfluidity in ultra-cold Bose gases.

1. A recent experiment by the Engels group at Washington State University has observed evidence for a superfluid critical velocity in dragging both attractive and repulsive obstacles through a harmonically trapped, cigar-shaped BEC [1]. In 2009 we have completed the modelling of these experiments using the 3D Gross-Pitaevskii equation and have found that it is highly likely that their data should not be interpreted as demonstrating a threshold velocity for the loss of superfluidity [2]. The image to the right is a plot of the average density in space and time of an obstacle being forced through a BEC showing soliton formation in its wake.



2. Recent experiments in the Anderson group at the University of Arizona have observed the formation of vortex dipoles by forcing a highly oblate BEC past a small Gaussian obstacle formed by a tightly-focussed blue-detuned laser beam. The dipole formation only occurs above a certain critical velocity, measured to be about 170 μm/s. At higher velocities multiply-charged dipoles are formed, which have not been predicted previously. We have simulated these experiments at zero and finite temperature and found good agreement with the observations [3].

3. Previous work using perturbation theory has suggested that quantum fluctuations in 3D BECs in an infinite system can cause a non-zero drag force on an object in a flow at all velocities [4], in contradiction with the conventional understanding of superfluidity. We have performed a mostly analytic calculation that finds a non-zero force acting on a delta-function impurity moving through a quasi-one-dimensional Bose-Einstein condensate at all subcritical velocities and at all temperatures. The force occurs due to an imbalance in the Doppler shifts of reflected quantum fluctuations from either side of the impurity [5]. It is feasible to numerically simulate this system, and we are continuing with quantum dynamical calculations aimed at conclusively demonstrating this force dynamically in a finite system.

References

[1] P. Engels and C. Atherton, Phys. Rev. Lett. **99**, 160405 (2007).
[2] C. Feng and M. J. Davis, in preparation.
[3] T. W. Neely, E. C. Samson, A. S. Bradley, M. J. Davis, and B. P. Anderson, arXiv:0912.3773 (2009).
[4] D. C. Roberts and Y. Pomeau, Phys. Rev. Lett. **95**, 145303 (2006).
[5] A. G. Sykes, M. J. Davis, and D. C. Roberts, Phys. Rev. Lett. **103**, 085302 (2009).