Quantum state transfer in a Raman atom laser system

A. S. Bradley[1], M. K. Olsen[1], S. A. Haine[1] and J. J. Hope[2]
[1]*ACQAO, School of Physical Sciences, University of Queensland, Australia*
[2]*ACQAO, Department of Physics, Australian National University, Australia*

The ability to measure and manipulate the quantum state of an optical laser has allowed for the testing of some fundamental aspects of quantum mechanics, such as Bell's inequality, the Einstein-Podolsky-Rosen paradox, and quantum teleportation, for the first time. This theoretical research focusses on developing techniques which will allow similar breakthroughs in the field of *atom* optics. We have previously shown that atom laser beams which display exotic quantum properties, such as squeezing and entanglement, can be generated with existing experimental techniques [1]. However, measurement of the quantum state of a matterwave is an unresolved challenge. This is because techniques such as homodyne detection are much more difficult in matterwave systems than optical systems, due to the difficulty of obtaining the matterwave analogue of a mode-matched local oscillator, and efficient atom detection. We have developed a scheme for measuring the quadrature statistics of an atom laser beam using existing optical homodyning and Raman atom laser techniques. A reversal of the normal Raman atom laser outcoupling scheme is used to map the quantum statistics of an incoupled atomic beam to an optical probe beam, where the standard techniques of optical homodyne detection can be implemented. A multimode model of the spatial propagation dynamics shows that the Raman incoupler gives a clear signal of de Broglie wave quadrature squeezing for both pulsed and continuous inputs. We have shown that experimental realisations of the scheme may be tested with existing methods via measurements of Glauber's intensity correlation function [2].

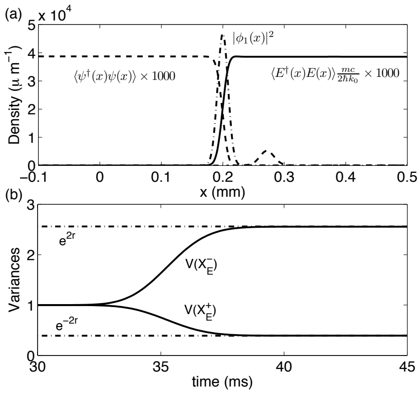

Figure 1: (a) A squeezed atomic beam is coupled into the condensate. (b) Variance of the quadratures of the emitted optical field.

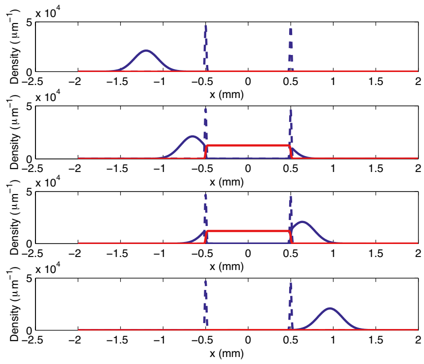

Figure 2: A pulse of atoms enters a condensate, which causes the stimulated emission of an optical beam containing the quantum statistics of the original atomic pulse. The atomic pulse is retrieved when the optical field enters a second condensate.

We have developed a scheme for the disembodied transport of a macroscopic matterwave over large distances at the speed of light. By combining the Raman incoupler scheme with the Raman outcoupler scheme [1], we have shown that a pulse of approximately 5000 atoms can be transported over a large distance by encoding their quantum statistics onto an optical field by using the atomic stimulated transition of the atoms into a condensate, and then retrieving this pulse at a second condensate in a separate location [3]. In practice, the efficiency of this disembodied transport may be much higher than is possible in alternate schemes such as quantum teleportation, as the fidelity of quantum teleportation is limited by the quality of the available entanglement resource.

References

[1] S.A. Haine, M.K. Olsen and J.J. Hope, Phys. Rev. Lett. **96**, 1336-1 (2006).
[2] A.S. Bradley, M.K. Olsen, S.A. Haine, J.J. Hope, Phys. Rev. A **76**, 033603 (2007).
[3] A.S. Bradley, M.K. Olsen, S.A. Haine, J.J. Hope, arXiv:0706.0062v1 (2007).