Generating squeezing in an atom laser through self interaction

M. T. Johnsson and S. A. Haine
ACQAO, Department of Physics, Australian National University, Australia

The creation of the optical laser and the development of quantum optics has allowed tests of many fundamental properties of quantum mechanics. The ability to create quadrature squeezing is an important prerequisite for many of these tests as it allows the creation of continuous variable entanglement between the amplitude and phase of two spatially separated optical beams. With the advent of the atom laser, there has been much interest in creating a quadrature-squeezed atomic rather than optical beam as it allows us to revisit many of these tests using massive particles rather than photons. A squeezed atom laser also offers the possibility of beating the standard quantum shot-noise limit in atom interferometry.

The standard scheme to create a squeezed atom laser is to use a squeezed optical field to couple atoms out of a Bose-Einstein Condensate (BEC) and into the atom laser beam, attempting to transfer the quantum state of the light onto the atoms. Such a scheme is challenging, as it requires squeezed light at the relevant transition frequencies of the atomic species making up the BEC.

We have devised a scheme that allows the creation of a quadrature squeezed atom laser without requiring squeezed light as input, removing a significant source of complexity and cost. Our method utilizes the nonlinear interaction between atoms to generate squeezing via the Kerr effect.

To accomplish this we begin with a dense, tightly confined BEC in a strong magnetic trap. A beam of atoms is outcoupled from the BEC via either a Raman or RF transition, forming the laser beam. As the outcoupling process functions as a weak beam splitter, the atoms in the beam are initially in a coherent state and are not squeezed.

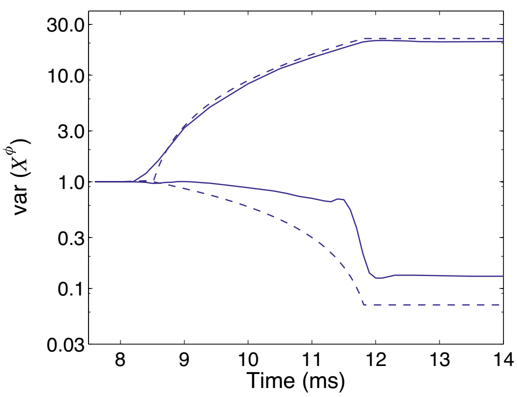

Figure 1: Quadrature squeezing (lower lines) and anti-squeezing (upper lines) of a Rb atom laser for a single-mode analytic (dashed lines) and a multimode stochastic (solid lines) model.

As the atoms fall under gravity, in the short time limit their nonlinear interactions result in a Kerr effect that transforms the coherent state into a quadrature squeezed state. If these interactions were to remain in effect indefinitely, the squeezing would begin to degrade. This is remedied, however, by the fact that as the atom beam falls under gravity it accelerates, reducing the density of the beam. As the Kerr effect is density dependent, the squeezing process ends after a certain fall distance, meaning the beam remains squeezed over its entire length.

We modelled a ^{87}Rb atom laser under our scheme using realistic parameters and quantified the degree of quadrature squeezing we obtained. The results are shown in Fig. 1, and indicate that significant quantities of squeezing can be obtained in realistic experiments, even if multimode effects are taken into account.

References

[1] M.T. Johnsson and S.A. Haine, Phys. Rev. Lett. **99**, 010401 (2007).