Theoretical atom laser dynamics

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The squeezed atom laser: We have theoretically investigated the possibility of creating an atom laser with non-classical output by outcoupling with squeezed light. We have developed a multimode quantum field model of an atom laser that takes into account the quantum nature of the optical and atomic fields, and the details of the outcoupling process. We have shown that under appropriate conditions, using a Raman transition to outcouple atoms from a BEC, it is possible to transfer almost completely the quantum statistics of an arbitrary optical state from one of the optical beams to the atom laser beam. This may be used to perform sub-shot noise measurements in atom interferometers, in the same way as optical squeezing allows more sensitive interferometric measurements. We have shown that two-mode optical squeezing as produced from an optical parametric oscillator can produce twin entangled atom laser beams propagating in different directions. We show that the fluctuations in the difference of the flux for our twin atom laser beams are suppressed by approximately a factor of eight compared to coherent atomic beams. This may prove to be an easy way to generate entangled atoms to test the behaviour of spatially separated, entangled massive particles.

Figure 1: Twin atom laser beams produced from outcoupling atoms from a BEC using two-mode squeezed light. Beam correlations can be highly sub-Poissonian.

Figure 2: Pumped atom laser system with trapped (left) and untrapped fields (right). Interaction strength and stability increase downwards.

Control and stability of continuously pumped atom lasers: We have performed a comprehensive study of stability of a pumped atom laser in the presence of the pumping, damping and outcoupling. Previous work showed that a pumped atom laser is unstable in particular parameter regimes [1]. We developed a theory that shows how feedback can be used to remove energy from a fluctuating condensate [2]. The model demonstrated efficient BEC cooling by controlling only basic trap parameters.

We included this feedback scheme into our atom laser model. We find that extreme long term stability is still largely determined by the spatial dependence of the pumping mechanism, and the interatomic interaction energy. While the feedback scheme is highly efficient in reducing condensate fluctuations, it usually does not alter the stability class of a particular set of pumping, damping and outcoupling parameters. Feedback schemes will still be of great utility in experiments, as they dramatically improve the modal stability of the atom laser output over any finite temporal window.

References