Characterising the linewidth of an atom laser

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One of the most important properties of a laser is its linewidth, with a narrow linewidth essential for applications such as interferometry and spectroscopy. This is the case for both optical and atom lasers, making it vital to understand what can affect the linewidth and what the lower limit to linewidth is in a variety of regimes.

We have characterised the linewidth of an atom laser for a variety of cases, using both a semiclassical model [1] and a quantum field theory model [2]. Our semiclassical calculations demonstrate that for short times the linewidth of an atom laser can approach the Fourier limit. For longer times, however, the source condensate becomes depleted, leading to an energy drift, or "chirp", in the laser, broadening the linewidth. We have demonstrated a scheme using a time-dependent detuning to compensate for this effect, enabling us to recover the Fourier limit, leading the linewith to be bounded by the drain time of the condensate. Figure 1 shows effect of the compensation scheme on the linewidth of a typical atom laser. This semiclassical analysis suggests that there is no lower limit on the linewidth, provided outcoupling is arbitrarily weak.

Our fully quantum analysis, however, demonstrates that this is not necessarily the case. Our calculations show that the fundamental number uncertainty in the condensate gives rise to an energy uncertainty through the atomic nonlinear interactions. This in turn leads to a hard lower limit on the energy spread of the atom laser beam, that is, a lower bound on the linewidth. This behaviour is shown in Figure 2: at short times the quantum model agrees with the semiclassical model, but at longer times the linewidth of the quantum model hits a lower bound, while the semiclassical model allows the linewith to decrease without limit. The red horizontal line is the limit predicted by our analytic single mode quantum model; the slight reduction below this in our stochastic simulations is due to multimode effects. As futher confirmation of our model, we also simulated an atom laser sourced from a number squeezed condensate, and obtained a reduction in the lowest linewidth that could be achieved.

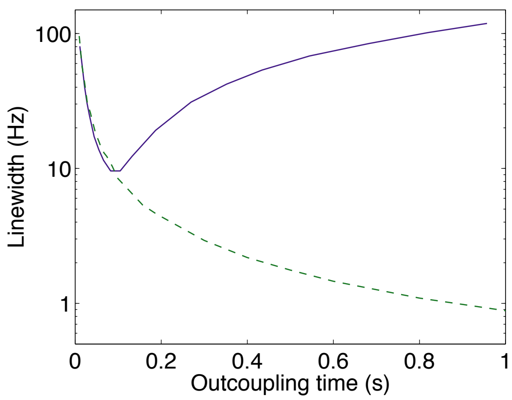

Figure 1: Linewidth of an atom laser with (dashed) and without (solid) chirp compensation.

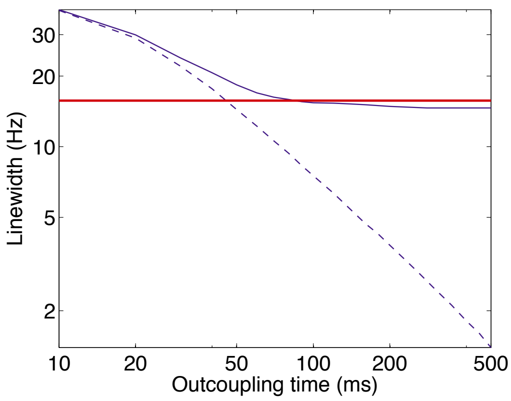

Figure 2: Atom laser linewidth for fully quantum (solid) and semiclassical (dashed) models.

References

[1] M.T. Johnsson, S.A. Haine, J.J. Hope, N. P. Robins, C. Figl, M. Jeppesen, J. Dugué and J. Close, Phys. Rev. A **75**, 043618 (2007).

[2] M.T. Johnsson and J.J. Hope, Phys. Rev. A **75**, 043619 (2007).