Transverse Mode profile of Guided Matter Waves

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Recently, the guiding of atom laser beams output-coupled from BECs has been achieved using optical waveguides to confine ^{87}Rb atoms released from magnetic [1] and optical trapping fields [2]. In both cases the output-coupled atoms were confined by far-red-detuned, focused laser beams aligned horizontally with respect to the condensate. The significance of these experiments is that the output-coupling mechanism allows the population of just a few transverse modes, with 50% [1] and 14% [2] in the transverse ground state.

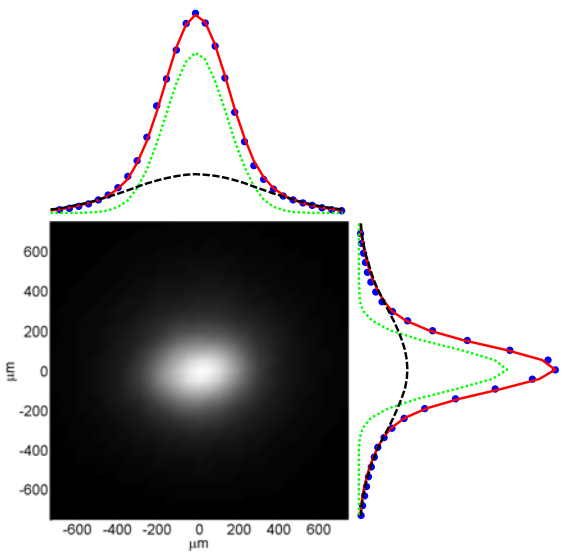

Fig. 1: Experimental image of the transverse mode of a guided atom laser. Both axes fit well to a double Gaussian, the narrowest being the lowest order mode of the guide.

In the experiments reported here, we are able to directly image - for the first time - the transverse mode structure of the guided matter waves by taking advantage of the high detection efficiency which is characteristic of metastable helium (He*) atoms. We are able to observe end-on to the guiding structure the transverse spatial profile of the atoms as they strike our detector, thereby allowing direct measurement of the guided matter wave mode structure.

The mode profile of a freely propagating atom laser beam is far from an ideal Gaussian, this is due to mean field interactions that generate 'caustics' and interference fringes. In comparison, the mode profile from our single moded, guided atom laser, shown in Fig. 1, is spatially smaller resulting in an increase in flux of more than two orders of magnitude compared to the unguided beam. Moreover, the guided atom laser spatial profile approaches a Gaussian.

In Fig. 1, a least squares fit to the guided atom laser mode profile is shown. The fitting function comprises two Gaussians, the narrower of which represents the lowest order mode and the wider one representing the sum of the many higher order modes. This is analogous to fitting the condensate and thermal background for a trapped gas. In addition, since at finite temperatures a thermal component is always present in the source condensate, it is therefore expected that some thermal modes will also be populated in the guided atom laser.

In summary, we have taken the first images of the transverse profile of a guided atom laser, demonstrating an atom waveguide in which atoms are guided predominately (65 %) in the fundamental mode. We have shown that guiding the atom laser beam maintains the near perfect Gaussian mode profile by avoiding the formation caustics and interference fringes that are normally present in atom laser beams.

References

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[2] Couvert, A., Jeppesen, M., Kawale, T., Reinaudi, G., Mathevet, R. and Guery-Odelin, D., Europhysics Letters **83**, 50001 (2008).