High visibility gravimetry with a Bose-Einstein condensate

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A Bose-Einstein condensate (BEC) is frequently described as the matter-wave analog of an optical laser – the preferred source for optical interferometry. In this project, we have demonstrated an atom interferometer-based gravimeter using a ^{87}Rb Bose-condensed source [1]. Our data represent the highest fringe visibility yet achieved in such a device (Fig. 1), for both standard, and large-momentum-transfer (LMT) beamsplitting using Bloch oscillations [2, 3], leading to a precision of 17 ppm. Furthermore, we have shown explicitly that replacing a thermal source with a BEC leads to a significant increase in visibility (Fig. 1).

Our atomic gravimeter uses nth-order Bragg transitions [4] along gravity as the atom-optic beamsplitters and mirrors in a Mach-Zehnder configuration [5, 6]. This leads to an interferometric phase of $\Phi = 2n\,\vec{k}\cdot\vec{g}T^2$, where $\vec{k}$ is the wave vector of the beamsplitter, n an integer, and T is the time between coupling pulses. By scanning Φ one obtains probability fringes $P = \frac{1}{2}(A+V\cos\Phi)$, where we define V as the visibility and A the fringe offset. For small shifts $\Delta\Phi$ one obtains a signal of $\Delta P = Vn\vec{k}\cdot\Delta\vec{g}T^2$ when sitting at mid-fringe. High signal gain thus requires having a high visibility and a large enclosed space-time area ($\propto 2nkT^2$). Both of these parameters can benefit from the use of a BEC due to its very narrow momentum width $\Delta p \ll \hbar k$.

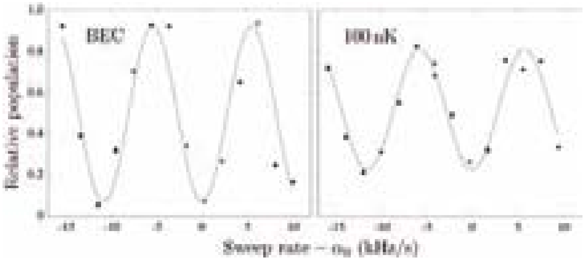

Fig. 1: Fringe comparison of a BEC source and a thermal source, for an $n = 1$, $T = 3$ ms gravimeter.

Comparing a 100 nK thermal atom-cloud with a BEC in our gravimeter under identical conditions, we found that a BEC leads to a significant improvement in visibility from 55% to 85%. A one-dimensional simulation of the interferometer produces no difference in visibility, and we conclude that the lower visibility is the result of technical effects, to which the thermal state is more susceptible. This can be likened to optical interferometry, where laser sources are preferred to white-light sources for practical reasons.

By increasing the enclosed space-time area to $n = 3$ using LMT, we achieve a precision of 17 ppm. Using Bloch-based LMT, a significant improvement in visibility to 24% is observed compared with previous work [3]. Crucially, we found that an imposed number variation of over 300% produced no measurable effect on fringe quality or sensor precision, provided the BEC had reached the ballistic expansion regime; this is in contrast to a common view that BEC is unsuitable for interferometry due to atom-atom interactions. The outcomes of this project suggest that, if combined with state-of-the-art BEC production and interferometer design, BEC sources can provide avenues to increase the best sensitivity realised so far with an atomic gravimeter [6].

References

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