Quantum enhancement of atomic sensors with atom-light entanglement and information recycling

Simon Haine
School of Mathematics and Physics
University of Queensland
Brisbane, Australia
e-mail: haine@physics.uq.edu.au

Abstract

In recent years there has been much interest in atom-interferometry with sensitivity greater than the standard quantum limit (SQL). Due to the linear nature of atomic beam splitters, almost all atom interferometers demonstrated so far operate with uncorrelated atoms in each arm. This puts a limit on the sensitivity of $\Delta\phi = 1/\sqrt{N}$, where N is the number of detected atoms, which is commonly referred to as the *standard quantum limit* (SQL).

There have recently been proof-of-principle experiments demonstrating BEC atom-interferometry with sub-SQL sensitivity. All of these experiments used atom-atom interactions to create non-classical atom-atom correlations, in order to increase the sensitivity beyond the SQL. However, all of these schemes require large inter-atomic interactions, small atom number, and give little control over the motional atomic state. These are the *opposite* conditions required for precision inertial sensors based on atom interferometry: high-flux, large momentum transfer, and weak atomic interactions.

We propose a scheme for surpassing the SQL via a different approach. Instead of using a nonlinear atomic process to create entanglement between two atomic modes which are subsequently use as the input to an interferometer, we use the beam-splitting process itself to create atom-light entanglement. By making appropriate measurements on the optical beam, a correction to the atomic signal is obtained, leading to sensitivity better than the SQL. We refer to this technique as *information recycling* [1]. The benefit of these schemes is that it does not rely on atomic interactions to create the correlations, so can operate in a dilute regime where the detrimental effects of phase-diffusion and multimode excitations due to atomic interactions will be negligible.

We also consider several schemes involving the use of *quantum state transfer* (QST) between non-classical light and ultracold atoms. Importantly, we consider the case of imperfect QST, and show that by using information recycling, a significant enhancement can be achieved even when the QST efficiency is low [2].

Finally, we present two surprising results. The first result is that, in some circumstances, it is *better* to work in a regime of low QST efficiency, providing information recycling is implemented. The second result is that when a Heisenberg limited input state is used, the Heisenberg limit can be achieved *regardless* of the QST efficiency and the form of the QST coupling process, even in the presence of certain types of decoherence. This result may have significant implications in fields outside atom-interferometry, such as cavity-based optical interferometry.

Keywords: QUANTUM SQUEEZING, ATOM INTERFEROMETRY

References

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