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Bragg Interferometers with Interacting Bose-Einstein Condensates

Francesco Minardi
Istituto Nazionale di Ottica, CNR-INO, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy

LENS and Dipartimento di Fisica e Astronomia, Università di Firenze, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy

Dipartimento di Fisica e Astronomia, Università di Bologna, Via C. Berti-Pichat 6/2, 40127 Bologna, Italy
francesco.minardi@ino.cnr.it

Alessia Burchianti
Istituto Nazionale di Ottica, CNR-INO, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy

LENS and Dipartimento di Fisica e Astronomia, Università di Firenze, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy
alessia.burchianti@ino.cnr.it

Chiara D'Errico
Istituto per la Protezione Sostenibile delle Piante, CNRIPSP, Strade delle Cacce 73, 10135 Torino, Italy

LENS and Dipartimento di Fisica e Astronomia, Università di Firenze, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy
chiara.derrico@cnr.it

Lorenzo Marconi
Istituto Nazionale di Ottica, CNR-INO, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy
lorenzo.marconi@ino.cnr.it

Michele Modugno
Depto. de Fisíca Teórica e Hist. de la Ciencia, Universidad del Pais Vasco UPV/EHU, Apdo. 644, 48080 Bilbao, Spain

IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Spain
michele.modugno@ehu.eus

Chiara Fort
LENS and Dipartimento di Fisica e Astronomia, Università di Firenze, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy

Istituto Nazionale di Ottica, CNR-INO, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy
chiara.fort@unifi.it

Abstract:
In search of non-classical correlations between momentum components of a Bose-Einstein condensate (BEC), we have investigated atom interferometers of trapped and free-falling BEC, obtaining a quantitative description of the spacing of interference fringes observed at output ports.

1. Main Text

Quantum cascade lasers (QCLs) are relatively novel sources that can be designed to emit at arbitrary infrared and THz frequencies in the range $\lambda \simeq 3$ to 300μm [1]. Since 2012, QCL frequency combs are also available [2] and their design and fabrication are rapidly progressing. Among the important questions still open is the quantum nature of the light emitted by QCL frequency combs, and more precisely whether non-classical correlations are present among the comb frequency components, the "comb teeth". Under the framework of the EU Flagship initiative on Quantum Technologies, project QOMBS aims, among other things, to elucidate the *quantum-ness* of the QCL comb teeth. For this purpose, quantum simulations with atomic samples have been proposed to get insight into the generation of quantum correlations. In this framework, QCL combs are emulated by a set of coeherently generated Bose-Einstein condensates with momenta evenly spaced, as integer multiples of a unit momentum. The analogy is due to the fact that the contact interaction hamiltonian of the atomic system, responsible for redistributing indivudual atoms among the different momentum components, is similar to the $\chi^{(3)}$ Kerr non-linearity redistributing photons among the frequency components, in four-wave mixing (FWM) processes. Energy conservation in photons FWM corresponds to the total momentum conservation in the atomic interactions.

Atom interferometry provides sensitive and accurate measurements of accelerations and rotations [3]; it can also be used to test non-classical properties of an atomic ensamble, such as atom number squeezing [4]. For this reason, we have started the investigation of interferometric schemes of trapped and free-falling Bose-Einstein condensates of ^{87}Rb atoms.

We use a time-dependent, pulsed, one dimensional optical lattice to generate multiple momentum components out of a parent Bose-Einstein condensate of approximately 1.5×10^5 atoms. Our lattice potential $V_0 \cos^2(k_L + \phi)$ can be adjusted in amplitude by controlling the intensity of the two laser beams generating the lattice; the wavevector $k_L \simeq 2\pi/0.6\,\mu\mathrm{m}^{-1}$ is set, but the phase ϕ is proportional to the optical path difference between the two beams. The lattice potential realizes the atom-interferometer beamsplitter. Differently from ordinary two ports beamsplitters, the lattice is intrinsecally multimode, as it couples a state of momentum p to two states of momentum $p \pm 2\hbar k_L$. Depending on the time duration of the beamsplitter, we can either work in a "Kapitza-Dirac" regime, where components of different kinetic energy are generated, or in the "Bragg" regime, where only two components with equal kinetic energy are coupled.

For simplicity, we chose to start with the Bragg interferometer. We set the parent condensate in motion with velocity $v_R = \hbar k_L \simeq 3.8$ mm/s and then we operate the interferometric sequence, in trap and in free fall. Both interferometric pulses redistribute atoms between the two momentum components $+\hbar k_L = m v_R$ and $-\hbar k_L$; the two output ports are distinguished by letting the opposite momentum components spatially separate for a sufficiently long time-of-flight, 32ms.

In each interferometric port, we observe a condensate with density interference fringes. We analyzed the fring spacing and observed the effect of interactions. In particular, we find that the spacing becomes larger when the density increases. The observed results are well reproduced by means of Gross-Pitaevskii numerical simulations.

We have also investigated the effect of interactions upon the interferometric phase, we will report the results and discuss their relevance to the quantum simulations of QCL combs.

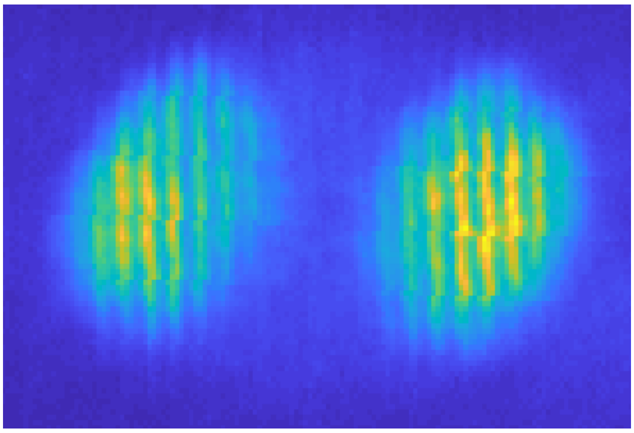

Fig. 1. Interference fringes as observed at the two output ports of the interferometer.

References

1. J. Faist, F. Capasso, D. L. Sivco, C. Sirtori, A. L. Hutchinson, and A. Y. Cho, Science **264**, 553 (1994)
2. A. Hugi, G. Villares, S. Blaser, H. C. Liu, J. Faist, Nature **492**, 229233 (2012).
3. A. D. Cronin, J. Schmiedmayer, and D. E. Pritchard, Rev. Mod. Phys. **81**, 1051-1129 (2009).
4. M. F. Riedel, P. Böhi, Yun Li, T. W. Hänsch, A. Sinatra, and P. Treutlein, Nature **464**, 1170–1173 (2010).