Coherence of an Interacting Ultra-Cold Atomic Ensemble in a Trapped Matter-Wave Sensor

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The FORCA-G project aims to develop a quantum-sensor for probing short range forces, *i.e* forces at a length scale of typically few micrometers. The sensor relies on a trapped atom interferometer using an ultra-cold ensemble of ^{87}Rb trapped in a vertical optical lattice ($\lambda = 532$nm). For shallow depths of the lattice, stimulated Raman transitions are used to induce a coherent coupling between different lattice sites, allowing us to realize atom interferometers capable of probing with very high sensitivity and accuracy the local potential experienced by the atoms. By using a symmetrized Ramsey-Raman interferometer, our force quantum-sensor reaches a state-of-the-art relative sensitivity of 1.8×10^{-6} at 1 s on the Bloch frequency, and thus on the local gravitational field [1][2].

In a recent work [3], we studied the impact of atomic interactions arising from the use of a dense and small ultra-cold atomic ensemble as a source for our trapped interferometer. The purpose of using such an atomic source is to reduce inhomogeneous dephasing and to obtain better addressability of the lattice sites and ultimately to populate only one of them. At densities of typically 10^{12} atoms/cm^3, we observe an unexpected behavior of the contrast of Ramsey interferometers, when applying a π-pulse to symmetrize the interferometer. These results are interpreted as a competition between the spin-echo technique and a spin self-rephasing (SSR) mechanism based on the identical spin rotation effect (ISRE [4]), see Fig.1. Originating from particle indistinguishability, SSR has been observed in trapped atomic clocks, where it can enhance the clock's coherence up to several seconds [5][6]. The study of these mechanisms due to atomic interactions seems thus to be of great interest for metrology and for developing more compact quantum-sensors based on trapped atomic ensembles, and capable of probing the external fields experienced by the atoms with a spatial resolution better that 1μm.

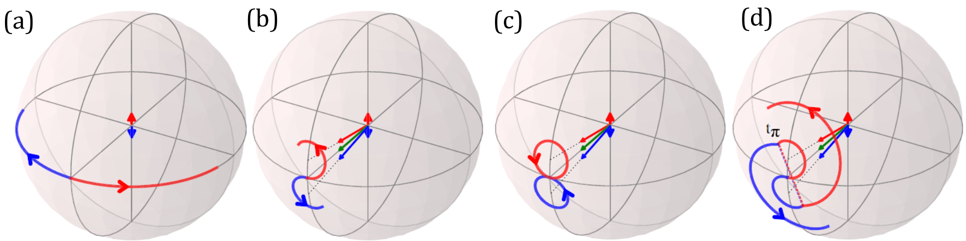

Fig. 1: *Competition between Spin Echo and Spin Self-Rephasing*. The atomic population is divided into two equal classes of hot (red) and cold (blue) atoms that are represented by their macrospins trajectories on the Bloch sphere. After the first $\pi/2$-pulse of the Ramsey sequence, the two macrospins are in the equatorial plane. (a) Inhomogeneous dephasing acts as a torque pointing in the vertical direction that is of opposite sign for the two classes of atoms (red and blue short arrows). (b) With the ISRE, the effective magnetic field seen by the atoms is the sum of the inhomogeneity and the exchange mean field proportional to the total spin (green arrow). As a consequence, the hot (cold) macrospin precesses around the red (blue) long arrow, so that if no π-pulse is applied they rephase at certain time T_{ex}: this is the SSR (c). If one applies a π-pulse when the two macrospins are out of the equatorial plane the rephasing is degraded (d).

References

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