Quantum metrology: pushing the frontier with a cold-atom gyroscope

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Context: Inertial sensors with cold atoms offer many applications in fundamental physics geosciences and inertial navigation. The operation of these sensors is based on atomic interferometry taking advantage of superpositions between quantum states of different momentum of an atom. These superposition states are obtained by means of optical transitions with two (or more) photons communicating momentum to the atom and acting as beam splitters and mirrors for the matter waves. SYRTE is a pioneer laboratory of the field, recognized worldwide for its expertise in the metrology of these quantum sensors, their use for different applications, and their technological transfer. In particular, our cold atom gyroscope represents the state of the art in terms of sensitivity and stability.

Thesis work: The subject of this thesis is placed in the context of contribution to **the development of the cold atom gyroscope** currently operated at SYRTE. The experiment allows to implement and test new atom interferometry techniques. These improvements will allow to aim for a long-term stability below 10^{-10} rad.s^{-1}, providing an unprecedented resolution to **study systematic effects and opening up new possibilities for testing fundamental physics and for use in seismology**.

One part of the thesis will explore the possibility for **improving the sensitivity of cold-atom sensors** by increasing their scaling factor related to the space-time area of the interferometer and reducing the noise impact from vibrations. One sensor architecture that allows both is the atomic interferometer geometry using double diffraction. The two arms of the interferometer are then associated with the same internal state of the atom, which **cancels out some systematic effects** (notably the energy shift effects of the atomic levels). It should also improve our sensitivity by enabling a measurement setup with no dead time based on the use of two correlated interleaved interferometers. In this architecture, the vibration and rotation noises that limits the sensitivity should average **to achieve the detection noise, targeting the standard quantum projection noise**. Other possibilities for improving performance will be investigated, such as the **hybridization of the cold atom gyroscope with a fiber optic gyroscope** in order to benefit from the short-term sensitivity of the optical one. Finally, the thesis will explore the possibility of a **dual-axis cold atom gyroscope** by interleaving the measurements on the two horizontal axes.

Another aspect of the thesis work will focus on the **application of the cold-atom gyroscope in testing predictions of the Standard Model Extension** (SME), i.e. looking for possibly new interactions beyond those of the Standard Model. This matter waves gyroscope allows to explore a new parameter space of the SME in the co-called matter-gravity sector. Additionally, the atom interferometry techniques developed during the project will serve other experiments and notably the **future gravitational wave detectors involving cold atom interferometry** and which are currently in the construction phase. Finally, the research of this project will open applications of the cold atom gyroscope in **rotational seismology**, an emerging study of rotational motions induced by earthquakes and ambient vibrations, of interest to several seismology-related fields. Such applications require gyroscopes with scale factors that are stable over weeks and can be known with high accuracy (better than 100 ppm). The level of accuracy of the cold-atom gyroscope allows to foresee these applications, with major scientific and societal impacts.

References : R. Gautier et al, Science Advances (2022) ; R. Geiger et al, AVS Quantum Sci. 2, 024702 (2020) ; L. Sidorenkov et al, Phys. Rev. Lett. 125, 213201 (2020) ; D. Savoie et al, Science Advances, eaau7948 (2018).

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Key words: atom interferometry, quantum sensor, cold atoms, tests of fundamental physics.

Required skills: optics and lasers, instrumentation, atomic physics, data analysis; ability to work in a team.