Application for a Master 2 internship with possibility to pursue a PhD thesis

M2 internship (6 months, starting in February or March 2022):

Novel real-time control methods of the atomic phase for a cold-atom gyroscope

Laboratory : SYRTE - Observatoire de Paris, 77 avenue Denfert Rochereau, 75014 Paris, France

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Context: Inertial sensors with cold atoms offer many applications in fundamental physics (tests of the laws of gravitation, gravitational astronomy), geosciences (measurements of the gravity field or of Earth rotation) and inertial navigation (inertial units). 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.

The aim of this project (master and then possibly PhD thesis) is to contribute to the development of the cold atom gyroscope currently operated at SYRTE. The SYRTE cold-atom gyroscope represents the state of the art in terms of sensitivity and stability, and has proven to be a useful instrument for testing fundamental physics and use in seismology. The experiment also allows to implement and test new atom interferometry techniques that are of interest for future gravitational wave detectors based on cold-atom technologies.

Master thesis work

One possibility for improving the sensitivity of cold-atom sensors is to increase their scaling factor related to the space-time area of the interferometer. This area can be increased by using so-called "multi-photon" splitters for atomic waves, where the momentum of several photons is transferred to the atom. One sensor architecture that allows this increase in area while minimizing the introduction of spurious systematic effects is the atomic interferometer geometry using double diffraction. Moreover, it should also improve our record sensitivity to be at the standard quantum limit by enabling a measurement setup with no dead time. In this geometry, an atom interacts symmetrically with two pairs of counter-propagating laser beams inducing stimulated Raman transitions in two opposite directions. In this configuration, the two arms of the interferometer are associated with the same internal state of the atom, which cancels out some systematic effects (notably the energy shift effects of the atomic levels). This advantage is accompanied by a disadvantage: it becomes impossible to use the phase difference between the two Raman lasers to control the phase of the atom interferometer. This project aims to overcome this problem by implementing a method for controlling the phase of a double diffraction interferometer. In particular, two methods will be implemented and compared: varying precisely the frequency of the Raman lasers and using a high resolution piezo-mirror to scan the laser equi-phases.

In practice, the master thesis will involve

- Atomic physics calculation to estimate the Rabi frequencies, expected light shifts and optimize diffraction efficiencies;
- Laser physics and control electronics to upgrade the servo loop between two lasers;
- Test of the real-time control by frequency jumps or by movements of the piezo-mirror.

Continuation in PhD thesis

In the case of a continuation as a PhD student, the thesis work will focus on the **development of the cold-atom gyroscope for applications in testing predictions of the Standard Model Extension** (SME), i.e. looking for possibly new interactions beyond those of the Standard Model. The cold-atom gyroscope, which involves matter waves, 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 waves** 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, explosions, 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);

Possibility to pursue a PhD after the internship: YES. (Funding is available)

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

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