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Sorbonne Université/China Scholarship Council program 2021

Thesis proposal

Title of the research project: High Sensitivity Quantum Gradiometer for ground and space applications

Keywords: Cold atoms, atom interferometry, quantum control………….

Joint supervision: yes (Merlet/Sébastien)

Joint PhD (cotutelle): no

Thesis supervisor: Pereira dos Santos Franck……………………………….

Email address of the thesis supervisor: franck.pereira@obspm.fr………………………………

Institution: Sorbonne Université…………………………………

Doctoral school (N°+name): ED 564 Physique de l'Ile de France…. ……………………………………….

Research laboratory: SYRTE…………………….

Address of the laboratory: 61 avenue de l'Observatoire, 75014 PARIS

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Name of the laboratory director: Landragin Arnaud…………………………………………….

Email address of the laboratory director: arnaud.landragin@obspm.fr……………………………………

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Subject description (2 pages max):

1) Study context

Our team at SYRTE develops inertial sensors (gyrometers, accelerometers…) based on atom interferometry technics. The development of this technology is linked to the use of cold atoms and laser beamsplitters, easy to implement and efficient, namely two photon transitions and more specifically stimulated Raman transitions. These methods allow now for the development of commercial products with applications in geophysics on the field, and of onboard instruments in ships or planes for inertial navigation and geoscience. Increasing significantly the performances of such instruments remains possible, in particular if using large multiphoton transitions, which increases the separation between the two arms of the interferometer and thus the sensitivity to inertial forces.

2) Details of the proposal

We are carrying on a new project of an atomic gradiometer based on these new technics. In this instrument, that measures the Earth gravity gradient, two ultracold atomic clouds will be prepared on atom chip traps, and launched upwards thanks to an accelerated lattice. During their free fall, they undergo a sequence of laser pulses which creates two simultaneous interferometers. The detection of the atomic state at the output of the interferometers allows to measure the difference of the interferometer phase shifts, which is proportional to the difference in the accelerations felt by the two atomic clouds.

The experimental setup is now operational and we are currently optimizing its key subsystems: atom launching in atomic fountains using Bloch elevators, LMT beamsplitting based on high order Bragg diffraction, and atomic detection.

The tasks of the PhD student will be:

- to implement ultracold atom sources prepared via evaporative cooling methods on atom chips. This will comprise a validation phase of the atom chips produced at the Paris Observatory in a dedicated test setup prior to their installation in the main setup.
- to optimize the measurement sensitivity of the interferometer. For that, the PhD student will have to optimize the beamsplitter efficiency and the interferometer contrast, which tend to decrease when the momentum transferred to the atoms by the Bragg lasers increases. He will work on improving our control of the frequency and phases of the Bragg lasers, so as to be able to tailor optimized phase and intensity profiles in order to increase the fidelity of the laser pulses using quantum control methods. He will also work on reducing the impact of the differential phase noise on the interferometer noise, using

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optimized phase lock loop techniques.

- to realize gravity gradient measurements using original measurement methods we have recently demonstrated [1,2] and assess the accuracy of the measurements by carefully evaluating the different systematic effects that may bias the interferometer phase
- to carry on long term continuous gravity measurements with the sensor so as to assess its long term stability
- to develop a dedicated model of the instrument, based on a Monte Carlo simulation of the complete experiment, and to compare experimental findings (in terms of contrast, noise and systematics) with the results of the numerical simulations.

The outcomes of this project, which is partly funded by CNES, the French Space agency, will also have a direct impact on the metrological characterization and modelling of quantum sensors for space gravimetry. The PhD student will thus have the opportunity to also contribute to on-going studies on this subject, into which our team is strongly involved, in collaboration with other groups in France and Europe [3,4].

3) References

[1] M. Langlois, R. Caldani, A. Trimeche, S. Merlet, F. Pereira Dos Santos, "Differential phase extraction in dual interferometers exploiting the correlation between classical and quantum sensors", Phys. Rev. A 96, 053624 (2017)

[2] R. Caldani, K. Weng, S. Merlet, F. Pereira dos Santos, "Simultaneous accurate determination of both gravity and its vertical gradient", Phys. Rev. A 99, 033601 (2019)

[3] K. Douch, H. Wu, C. Schubert, J. Müller, F. Pereira dos Santos, "Simulation-based evaluation of a cold atom interferometry gradiometer concept for gravity field recovery", Advances in Space Research 61, 1307-1323 (2018)

[4] A. Trimeche, B. Battelier, D. Becker, A. Bertoldi, P. Bouyer, C. Braxmaier, E. Charron, R. Corgier, M. Cornelius, K. Douch, N. Gaaloul, S. Herrmann, J. Müller, E. Rasel, C. Schubert, H. Wu, F. Pereira dos Santos, "Concept study and preliminary design of a cold atom interferometer for space gravity gradiometry", Classical and Quantum Gravity 36, 215004 (2019)

4°) Profile of the Applicant (skills/diploma…)

A good educational background in quantum and atomic physics.

General skills in experimental physics, and in particular in atomic and laser physics.
Any previous experience in cold atom physics or in atom interferometry will be a clear asset.

Proficiency in English.

Good communication skills.

Contacts:

Thesis supervisor

Franck Pereira dos Santos……………………………………………

Email address of the thesis supervisor:
franck.pereira@obspm.fr……………………………………………..