M2 internship : Large momentum transfer for differential quantum gravimetry

Laboratory: Laboratoire Temps Espace – Observatoire de Paris, 77 avenue Denfert-Rochereau, 75014 Paris, France
Supervisors: Leonid Sidorenkov (leonid.sidorenkov@obspm.fr); Franck Pereira dos Santos (franck.pereira@obspm.fr)
Website: https://syrte.obspm.fr/spip/science/iaci/stages/
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Summary: The Atom Interferometry and Inertial Sensors Group (IACI) of LTE offers a M2 internship dedicated to the development of enabling technologies for quantum inertial sensors. The intern will implement and validate a high-power laser system for large momentum transfer (LMT) atomic beam splitters, aimed at enhancing the sensitivity of an atomic gravi-gradiometer.

Context:

A significant improvement in the sensitivity of ***atomic inertial sensors*** is linked to the deployment of architectures based on differential measurements, such as atomic ***gradiometers*** sensing the gradient of the Earth's gravitational acceleration, which allow rejecting the *common-mode vibrational and laser phase noise*. This feature enables the measurements at the quantum projection noise limit and provides an ideal testbed for exploring cutting-edge techniques (advanced atom sources, LMT beam splitting, hybridization with other sensors, etc.) to boost sensitivity and accuracy. Moreover, the ***simultaneous access to g and ∇g*** values discriminates the position and the mass of the gravitational source, opening intriguing perspectives in geoscience (natural resource exploration, civil engineering) and navigation [1].

The gravi-gradiometer of LTE ([2], see Figure, right) employs dual cold-atom source and a sensitive three-pulse (Mach-Zehnder like) interferometric sequence. The atom-optics elements (beam-splitters and mirrors) are implemented using short pulses of counter-propagating laser beams that Bragg-diffract the atomic wave packets. Ongoing work explores methods of quantum optimal control to enhance the efficiency of low-order ($n \leq 3$, $2n\hbar k$ photon transfer) ***multi-photon Bragg diffraction*** (see Figure, left), in combination with advanced optical beam shaping.

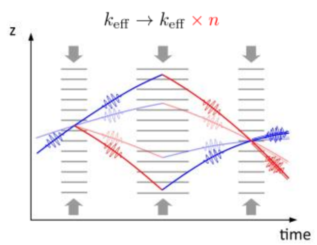
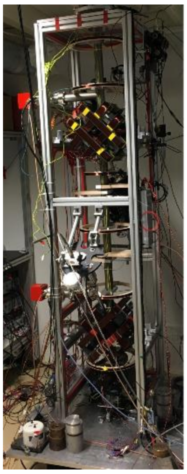


Figure: Scheme of the n-fold enhancement of interferometric area via LMT atomic beam splitter (left) and photo of laboratory atomic gravi-gradiometer of SYRTE (right)



Internship project:

To increase the separation of atomic wave packets - and thus interferometric area and sensitivity - we have recently developed a new higher-power laser system (fiber lasers and amplifiers, frequency-doubling stages, optical components and electronics for laser frequency, phase and power control) that should allow addressing $n > 3$ LMT transitions. The specific tasks of the internship will include:

- Improving the long-term stability of the new laser system and validating its performance via gravity gradient measurements in a conventional Bragg interferometer ($2\hbar k$ atom optics)
- Demonstrating LMT atom optics of $n > 3$ diffraction orders

The intern will perform experimental work requiring a good understanding of optics, laser physics, atom-light interaction and atomic physics, as well as scientific rigor and methodology. The skills in basic lab instrumentation, electronics, data analysis and physical modelling are a plus. The intern will join a team of three permanent researchers, postdoc and two PhD students, starting in spring 2026 for a period of up to 6 months, potentially followed by the PhD-thesis. The presentation of results at an internal group meeting is expected at the end of the internship.

[1] R. Caldani, et al., PRA **99**, 033601 (2019), R. Piccon, et al., PRA **106**, 013303 (2022)
[2] R. Geiger et al., AVS Quantum Sci. **2**, 024702 (2020)