Reaching an unprecedented accuracy with an ultracold atom gravimeter

Laboratory name: SYRTE
CNRS identification code: UMR 8630
PhD supervizors: Pereira dos Santos Franck/Sébastien Merlet
e-mail: franck.pereira@obspm.fr Phone number: 0140512386
e-mail: sebastien.merlet@obspm.fr Phone number: 0140512393
Web page: https://syrte.obspm.fr/spip/science/iaci/
Location:
Observatoire de Paris, 61 avenue de l'Observatoire, 75014 PARIS
LNE, Trappes

We have developed at SYRTE a cold atom gravimeter, whose principle of operation lies on atom interferometry techniques. It uses free-falling ^{87}Rb cold atoms, which experience a sequence of Raman pulses driven by counter-propagating vertical lasers. This creates an atom interferometer, whose phase shift is proportional to g, the Earth gravity acceleration. Our instrument measures g with a sensitivity better than conventional state of the art absolute gravimeters, with a record sensitivity of 5.7 10^{-9}g at 1s, limited by residual vibrations. After averaging, we typically reach statistical uncertainties in the low 10^{-10}g range. Its accuracy was until recently of 4 10^{-9}g, limited by Coriolis acceleration and wavefront distortions of the Raman lasers. These two effects are related to the motion of the atoms in the horizontal plane. They can thus be reduced drastically by performing the interferometer with colder atoms, such as obtained using more advanced cooling methods than the ones we have used so far, which rely on laser cooling.

We have thus recently implemented on the setup a crossed dipole trap with a high power fiber laser at 1.5 µm, in which we have produced via evaporative cooling samples of ultracold atoms, with temperature down to 50 nK (and with much higher densities). Gravity measurements performed at such low temperatures allowed to evaluate the bias due to wavefront aberrations with a record uncertainty for such an instrument, and to reconstruct a modelled laser wavefront, thus using the atoms as direct probe of optical aberrations.

In this PhD project, this laser will be upgraded for a more powerful and reliable fiber laser at 1µm, in order to speed up the production of ultracold atoms, and eventually prepare Bose Einstein condensates. This will also allow us to further improve the performance of the sensor, with a target uncertainty of 10^{-9}g or below, which will make our sensor a standard in absolute gravimetry with unrivaled performances. The PhD student will also evaluate the effect of interatomic interactions, which, at the high atomic density we will operate, can impart small biases to the measurement. Finally, modifications will be implemented to the setup in order to improve the long term stability below 10^{-10}g, with laser cooling beams stabilized in polarization and intensity and a new retroreflecting optics setup based on an ultraflat tip-tilted mirror for compensating Coriolis acceleration.