## Master (M1/M2) internship in Paris (LTE/Observatoire de Paris/LNE-OP) on

# *Vibrational properties of a pulse-tube cryostat for quantum metrology*

### Background

Time and frequency metrology is one of the most successful fields of high accuracy measurement today. Microwave and optical frequency standards now realize accuracies in terms of fractional frequency in the $10^{-16}$ range, ensuring a vast variety of applications from **practical day-to-day time keepi**ng (realization of SI second, atomic international time, satellite navigation systems, timing and synchronization at various geographical scales, etc…) to the **most demanding fundamental research experiments (measurement of the drift of fundamental constants, tests of relativity, detection of gravitational waves, …)**.

One of the key components in an optical atomic clock is an ultra-frequency-stable laser source, which is used to determine precisely the frequency of the atomic transition. Whereas standard high-finesse Fabry-Perot cavities, acceptable for many applications, provide a fairly good fractional frequency instability at a low $10^{-16}$ level between 0.1 s and 10 s averaging time at their thermal Brownian noise limit, further improvements are needed to meet the stringent requirement of quantum projection noise in optical lattice clocks, expected to reach $10^{-17}$ or below at 1 s. Among various technologies explored, low-vibration pulse-tube cryostats have emerged to become a key enabling technology, permitting to cool down both monocrystalline silicon cavities and rare-earth ion doped crystals to desired working temperatures, ranging from 124 K down to 100 mK. Whereas the choice of all-electric dry cryostats is motivated by the possibility of continuous operation without periodic cryogen refill, the vibration generated by the pulse-tube must be properly managed.

### Project

Various experimental means have been developed in the frequency metrology community to quantify the vibration level of the cryostats, using commercial mechanical sensors (accelerometers and seismometers), measuring the acceleration or the velocity in the inertial reference frame, and using optical interferometers to measure the position with respect to a reference plane. However, most mechanical sensors are cryo incompatible, limiting the accessible information. The optical interferometer, on the other hand, gives directly the information at the position of the object being cooled down, but it is difficult to access information at intermediate positions which are often not equipped with optical access.

A possibility to complement such effort in characterization of vibrational properties of a cryo-cooled object is to numerically simulate the mechanical properties of the cryostat, using a staged approach. The mechanical transfer function can be obtained by finite-element simulations once the architecture as well as material properties are known. Since there are different stages of thermal isolation, which is critical to the normal function of the cryostat, it is natural to break down the overall mechanical transfer function into that of each thermal isolation stage, reducing the complexity of the simulation.

The purpose of this internship is twofold. The candidate will first identify appropriate numerical tools and carry out simulations of various stages of thermal isolation to evaluate their mechanical transfer function. It is also necessary to identify potential resonances within the relevant frequency band that may strongly impact the final spectroscopy experiment. He/she will then compare with accelerometric measurements and possibly carry out new measurements at critical positions to feed the comparison process. Structural improvement could be identified in order to reduce the vibration level of the sample holder.

## Scope

The successful applicant will carry out the activities described above, while interacting with the rest of the team working on the experiment of rare-earth spectroscopy for laser frequency stabilization. The internship should span 2 months or more (duration negotiable). The start date is flexible.

## The applicant

Serious, motivated and professional, with a training in mechanical engineering. Some experience in vibration analysis and thermal analysis is useful, but not a strict requirement. Given the collaborative nature and international context of the overall research project, communication in English must be practiced.

## Application

Interested candidates should send a CV and a motivation letter to: Dr. Bess Fang-Sortais : bess.fang@obspm.fr. Interviews will be arranged once the documents are examined.