

Master 2: *International Centre for Fundamental Physics*

INTERNSHIP PROPOSAL

Laboratory name: [Laboratoire de Physique des Lasers](#)
CNRS identification code: UMR7538
Internship director's surname: Darquié
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Internship location: Laboratoire de Physique des Lasers
99 avenue Jean-Baptiste Clément, 93430, Villetaneuse
Thesis possibility after internship: YES
Funding: YES If YES, which type of funding: team's contracts/grant from Ecole Doctorale

Precision Measurements and tests of fundamental physics with cold molecules

Summary: An internship position is available to develop a new-generation molecular clock for precision vibrational spectroscopy (around 10 μm) of cold molecules in the gas phase. The proposed technology is at the forefront of cold molecule research and frequency metrology, and opens possibilities for using polyatomic molecules to perform tests of fundamental physics and explore the limits of the standard model. The apparatus will be used in the first place for measuring the electroweak-interactions-induced tiny energy difference between enantiomers of a chiral species, a signature of parity (left-right symmetry) violation, and a sensitive probe of dark matter.

Compared to atoms, molecular systems, owing to their numerous degrees of freedom, offer promising perspectives for improving tests of fundamental physics and precision measurements in general. Molecules are increasingly being used internationally for instance to test fundamental symmetries¹, to measure fundamental constants² or their variation in time³, to search for dark matter⁴, ... Many of these experiments can be cast as measurements of resonance frequencies of molecular transitions highlighting the importance of frequency metrology. They also require advanced manipulation techniques already standard for atoms: individual states addressing, high detection rates, long coherence times, cooling of internal and external degrees of freedom.

The student will participate in various aspects of the development of the experiment constituting major steps in providing such techniques for molecules (depending on his taste and the status of the project):

- development of an intense source of cold and slow polyatomic molecules, produced in a cryogenic chamber, called a buffer-gas-cooled beam; this is one of the latest cold molecule technology that has so far mostly been implemented on simple species;
- precise probing of these cold molecules with high-purity mid-infrared quantum cascade lasers (QCLs) calibrated against primary frequency standards using saturated absorption spectroscopy and Ramsey interferometry, the same quantum optics method as used in the world's best atomic clocks;
- implementation of a high-sensitivity microwave detector, for the detection of individual internal quantum states populations of cold molecules;
- development of advanced manipulation techniques combining ultrastable RF, microwave and optical fields to obtain individual state addressing, high detection rates, long coherence times, cooling of various degrees of freedom, ...

¹Andreev *et al*, *Nature* **562**, 355 (2018). ²Alighanbari *et al*, *Nature* **581**, 152 (2020). ³Bagdonaitė *et al*, *Science* **339**, 46 (2013). ⁴Gaul *et al*, *Phys. Rev. Lett.* **125**, 123004 (2020).

Keywords: frequency metrology, Ramsey interferometry, Doppler-free methods, precision measurements, parity violation, chiral molecules, molecular beams, buffer-gas cooling, cold molecules, frequency comb lasers, quantum cascade lasers, molecular physics, quantum physics, optics and lasers, vacuum techniques, electronics, programming and simulation

Relevant publications from the team:

Santagata *et al*, [Optica](#) **6**, 411 (2019); Cournol *et al*, *Quantum Electron.* **49**, 288 (2019); Tokunaga *et al*, *New J. Phys.* **19**, 053006 (2017), [arXiv](#); Argence *et al*, *Nature Photon.* **9**, 456 (2015), [arXiv](#)

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics:	YES	Soft Matter and Biological Physics:	YES
Quantum Physics:	YES	Theoretical Physics:	YES