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Internship Title

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 symmetries[1], to measure fundamental constants[2] or their variation in time[3], to search for dark matter[4], … 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, such as (depending on his taste and on 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, …

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

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:1607.08741; Argence *et al*, Nature Photon. **9**, 456 (2015), arXiv:1412.2207

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

Requirements: good knowledge of basic physics, a good expertise in experimental physics (in particular in experimental optics) and/or in programming and simulation would be welcome, curiosity and creativity.

Possibility of a PhD? yes
Financial support for a PhD? team's own contracts / grant from Ecole Doctorale