Contrat doctoral – ED Galilée

Titre du sujet : Ultra-High-Resolution Mid-Infrared Spectroscopy and Tests of Fundamental Physics with Cold Molecules

- Unité de recherche : Laboratoire de Physique des Lasers
- Discipline : Physique
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- Domaine de recherche : Experimental Molecular Physics
- Mots clés : ultra-high resolution vibrational spectroscopy, mid-infrared, frequency metrology, frequency comb lasers, quantum cascade lasers, Doppler-free spectroscopy, Ramsey interferometry, precision measurements, parity violation, chiral molecules, molecular beams, buffer-gas cooling, cold molecules, molecular physics, quantum physics, optics & lasers, vacuum, electronics, programming & simulation.

Overview:
The project focuses on ultra-high-resolution molecular spectroscopy, employing sub-Hz mid-infrared (MIR) quantum cascade lasers (QCLs) to perform tests of fundamental physics on cold polyatomic molecules. It is at the forefront of cold molecule research and frequency metrology.

Research Goals:
(1) Sub-Hz QCLs for Molecular Spectroscopy: Boost the use of widely tunable and ultra-stable QCLs for precise molecular spectroscopy. The PhD student will work on improving the signal-to-noise ratio and the accuracy of an existing cavity enhanced spectroscopy apparatus using sub-Hz 10 µm QCLs calibrated to some of the best atomic clocks and will extend this technology to new MIR spectral regions (from 6 to 17 µm) to bring an increasing variety of molecular species and rovibrational transitions within reach of precision spectroscopy. **(2) Cold Molecule Production and Analysis:** Implement advanced techniques for producing and analyzing cold molecules. This encompasses the development of sources of molecules cooled by collisions with a cryogenic buffer-gas, and integration of a highly sensitive microwave rotational population detector to this cryogenic setup, for a detailed examination of the cold molecules' internal quantum state. **(3) Precision Measurements and Fundamental Physics:** The project will exploit the source of cold molecules and the metrology-grade QCLs to conduct precision spectroscopy on a panel of complex species, including chiral organo-metallics and polycyclic aromatic hydrocarbons, using sub-Doppler techniques such as saturated absorption spectroscopy. The apparatus will be used to test the standard model an explore its limits, e.g. by measuring the electroweak-interactions-induced tiny energy difference between enantiomers of a chiral molecule, a signature of parity (left-right symmetry) violation, and a sensitive probe of dark matter. **(4) Interdisciplinary Applications:** Explore applications of this research in areas like atmospheric sciences and astrophysics. The project aims to also improve the current spectroscopic resolution limitations of these fields, leading to more accurate determinations of atmospheric/astrophysics species rovibrational frequencies and molecular constants.
This project will significantly advance the field of high-resolution molecular spectroscopy, MIR frequency metrology and cold molecule research. The candidate will contribute to a leading-edge field, gaining expertise in state-of-the-art technologies and methodologies.

Relevant publications from the team:
Tran *et al*, APL Photonics, 9, 030801 (2024); Manceau *et al*, arXiv:2310.16460 (2023); Fiechter *et al*,. J Phys Chem Lett **13**, 10011 (2022); Santagata *et al*, Optica **6**, 411 (2019); Cournol *et al*, Quantum Electron **49**, 288 (2019), arXiv:1912.06054; Tokunaga *et al*, New J Phys **19**, 053006 (2017), arXiv:1607.08741; Argence *et al*, Nature Photon **9**, 456 (2015), arXiv:1412.2207.

Requirements: The ideal candidate should have a strong foundation in physics or chemical physics, particularly in areas such as spectroscopy, laser physics, molecular physics, and quantum optics. Proficiency in experimental techniques, data analysis, and computational modelling is highly desirable. Creativity, problem-solving skills, and the ability to work both independently and collaboratively in an interdisciplinary environment are also key.