Master 2: *International Centre for Fundamental Physics*

INTERNSHIP PROPOSAL

Laboratory name: Laboratoire de Physique des Lasers
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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

Widely tunable ultra-stable and SI-traceable quantum cascade lasers for frequency metrology and mid-IR precise spectroscopy: application to space, atmospheric and fundamental physics

Summary: Ultra-high spectral resolution molecular spectroscopy is an interdisciplinary field with fascinating and far-reaching applications ranging from fundamental physics to astrophysics, earth sciences, remote sensing, metrology and quantum technologies. Among recent instrumental advances, the stabilization of quantum cascade lasers (QCLs) on commercial optical frequency combs with traceability to primary frequency standards, a method recently implemented in our team, is a breakthrough technology. It offers an unprecedented level of precision and resolution in the mid-IR, an essential region known as the molecular fingerprint region, which hosts a considerable number of intense vibrational signatures of molecules of various interests. While the need for ultimate frequency control is obvious for fundamental applications such as testing fundamental symmetries or measuring fundamental constants and their possible variations, other fields such as atmospheric monitoring have surprisingly the same requirement. Molecular remote sensing measurements are often limited by the quality of spectroscopic data, resulting from the limited resolution of traditional spectrometers. The limited accuracy obtained for parameters affecting the line profile, such as frequency shifts and widths, leads to systematic biases in the determination of atmospheric species abundances, which is a crucial information for environmental and human health issues.

The techniques developed at the Laboratoire de Physique des Lasers can be used to overcome this type of bottlenecks in atmospheric sciences for example, but they still suffer from certain limitations that allow only a limited number of relatively simple species to be studied over a reduced spectral window. The student will actively participate in the development and operation of a new generation spectrometer for precise mid-infrared vibrational spectroscopy based on QCLs calibrated on some of the world's best atomic clocks. She/he will be responsible for improving the device in terms of:
- tunability: development of a system allowing continuous tunability over ~10 GHz at record precision
- resolution & detection sensitivity: integration to the setup of a new 3-m long cavity of finesse ~200;
- spectral coverage: the student will try to cover part of the 9-11 µm band using QCLs available in the group, and will also explore the 17 µm region as we have at our disposal the wold's first 17 µm QCL.

The proposed technology is at the forefront of time-frequency metrology and will bring increasingly complex polyatomic molecular systems within reach of precision measurement experiments and frequency metrology. It will be used for spectroscopy at unprecedented levels of accuracy of species of various interests, from fundamental physics to astrophysics, Earth sciences and climate change research. Finally, this work also has strong applicative and industrial perspectives, for example in medical diagnosis, detection of pollutants, hazardous materials or quantum technologies.

Keywords: ultra-high resolution vibrational spectroscopy, mid-infrared, frequency metrology, Doppler-free methods, precision measurements, optical 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); Argence *et al*, Nature Photon. **9**, 456 (2015), arXiv:1412.2207

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