ÉCOLE DOCTORALE GALILÉE
Université Sorbonne Paris Nord

# Contrat doctoral – ED Galilée

**Titre du sujet :** Looking for potential variations of the proton-to-electron mass ratio and other tests of fundamental physics via precision measurements with molecules

- Unité de recherche : Laboratoire de Physique des lasers
- Discipline : Physique
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- Domaine : Fundamental physics, frequency metrology, mid-IR optics, molecular spectroscopy
- Mots clés : fundamental constants, standard model, precision measurements, ultra-high-resolution spectroscopy, frequency metrology, quantum cascade lasers, frequency comb lasers, cold molecules, molecular physics, quantum physics, astrophysics, optics & lasers, vacuum, electronics, programming & simulation.

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**Internship Description**:

The PhD student will participate in cutting-edge experiments aimed at ultra-precise measurements of rovibrational molecular transitions and dedicated to measuring/constraining the potential time variation of the proton-to-electron mass ratio (**μ**), a fundamental constant of the standard model (**SM**). Such variations, if detected, would be a signature of physics beyond the SM, providing insights into the nature of dark matter and dark energy. The idea here is to compare molecular spectra of cosmic objects with corresponding laboratory data. The experimental setup is based on quantum cascade lasers (**QCLs**) locked to optical frequency combs, with traceability to primary frequency standards, a breakthrough technology developed at Laboratoire de Physique des Lasers (**LPL**), allowing unprecedented spectroscopic precision in the mid-infrared range.

This PhD thesis will focus on measuring mid-infrared molecular transitions of **methanol** (**$CH_3OH$**), a molecule known for its enhanced sensitivity to changes in μ. The student will set up and stabilize a new QCL in a spectral region hosting particularly relevant transitions. The work will involve achieving sub-Doppler spectroscopic resolution to reach target laboratory frequency accuracies of ~100 Hz needed for **comparisons with astronomical observations**. This activity is part of the **ANR Ultiμos project**, a collaborative effort which seeks to refine current constraints on the possible variation of μ which involves leading research institutions, including **Laboratoire Kastler Brossel** (**LKB, L Hilico**) and **MONARIS** (**C Janssen**) at Sorbonne Université. The three partners of the Ultiμos consortium will collaborate to conduct measurements in methanol and other species such as ammonia ($NH_3$) in different spectral windows, to identify transitions as targets for future Earth/space comparison campaigns, which could further tighten constraints on variations of μ. Other collaborators, such as **Vrije Universiteit Amsterdam** and **Onsala Space Observatory**, will provide theoretical and observational/astronomical support to complement the experimental efforts.

The proposed laser technology is also crucial for the ongoing development at LPL of a **new-generation molecular clock** specifically designed for precision vibrational spectroscopy of **cold polyatomic molecules**. The PhD student may therefore be involved in first precise spectroscopic measurements on cold molecules produced at ~1 K in a novel cold molecule apparatus. Combining frequency metrology and cold molecule research as the potential to bring even more stringent constraints on a drifting-μ, and opens possibilities for using polyatomic molecules to perform other fundamental tests, including the measurement of the energy difference between enantiomers of a chiral molecule, a signature of **parity (left-right symmetry)** violation, and a sensitive probe of dark matter.

**Relevant publications from the team**:

Tran *et al*, arXiv:2502.08201 (2025); Manceau *et al*, arXiv:2310.16460 (2025), Tran *et al*, APL Photonics **9**, 030801 (2024); 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 applicant should be doing its master studies in a relevant area of experimental physics or chemical physics: atomic, molecular and optical physics, spectroscopy, lasers, quantum optics.