

CONTRATS DOCTORAUX 2024 PROJET QUANTEDU

Sujet de thèse – Laboratoire de Physique des Lasers

Title: **Precision thin cell spectroscopy of Casimir-Polder molecule-surface interactions**

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Thin cells filled with atomic vapors, whose thickness can be as small as a few tens of nanometers, represent simple and easy-to use platforms that interface atoms with the solid state and can easily be integrated with photonic devices [1]. These platforms can be used for fundamental measurements but are also promising in the emerging field of quantum technologies. In particular, thin cells (thickness comparable to the wavelength) have been used as single photon sources [2], exploiting collective effects between Rydberg atoms and as efficient magnetic field or electric field sensors making efficient conversion of THz to optical photons [3]. Nevertheless, placing quantum emitters (atoms or molecules) in proximity to solid surfaces requires good knowledge of the fundamental Casimir-Polder (CP) interactions, due to the existence of quantum fluctuations of the electromagnetic field in the vacuum [4]. CP interactions are also paramount for our understanding of the quantum vacuum, the cohesion of matter and play an important role in fundamental precision measurements. CP interactions become significant in the near field, typically at nanometric distances, with an energy that depends on the inverse cube of the particle-surface distance.

The SAI group specializes in the spectroscopy of atoms confined inside nanocells (typical thickness between 50-1000 nm) and has already developed thin cell spectroscopy as a major technique for probing CP interactions with excited or even highly excited atoms. Since 2017 the group has turned its attention to molecules demonstrating rovibrational spectroscopy of confined gases in the near and mid infrared [5]. However, these experiments were not sensitive to molecule-surface potentials because the gases were probed in the micrometric regime, where Casimir-Polder interactions are small.

To explore Casimir-Polder interactions with molecules the group has fabricated nanocells (with nanometric thickness) that can be filled with molecular gases. We now propose to use these platforms to perform thin-cell spectroscopy of HF in order to measure the Casimir-Polder molecule-surface interaction and study its anisotropic component. HF is an excellent candidate for these experiments, as it provides a large spectroscopic signal, according to the HITRAN molecular database. The study of HF requires building an experimental machine operating at 2.5 μ m to probe the R(0) transition of the HF stretching vibration. Although this is a challenging and unusual region of the electromagnetic spectrum, the group has already assured the necessary funding to obtain a DFB laser emitting at this wavelength and dedicated optics. These experiments will provide the first precision measurements of CP interaction with molecules and could constitute a stepping stone towards hybridization of gas phase polar molecules with photonic devices.

We also plan to perform precise theoretical calculations of molecule-surface interactions (beyond rough estimates), with emphasis on the effects of Casimir-Polder anisotropy. This objective will be pursued in collaboration with S. Scheel's group in the University of Rostock (Germany). In our approach, we will need to take account the quantum nature of the probed rovibrational states with different orientation relative to the surface, going beyond a classical description of the molecule. The ultimate goal of the project will be to compare our theoretical calculations of the HF-surface interaction with the results of our experiment.

We are looking for a PhD student with good background in quantum physics, atomic or molecular physics and light-matter interactions to work on both experimental and theoretical aspects of this project and participate in the exchanges with the German group of theorists.

References

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3. L. A. Downes, *et al.*, 'Full-Field Terahertz Imaging at Kilohertz Frame Rates Using Atomic Vapor', *Phys. Rev. X*, **10**, 011027, (2020).
4. A. Laliotis *et al.*, 'Atom-surface physics: A review', *AVS Quantum Science* **3**, 043501 (2021).
5. J. Lukusa Mudiayi *et al.*, 'Linear Probing of Molecules at Micrometric Distances from a Surface with Sub-Doppler Frequency Resolution', *Phys. Rev. Lett.*, **127**, p. 043201, (2021).