ÉCOLE DOCTORALE GALILÉE
Université Sorbonne Paris Nord

Contrat doctoral – ED Galilée

<u>Titre du sujet :</u> Quantum sensing of THz metamaterials with Rydberg atoms

- Unité de recherche : Laboratoire de Physique des Lasers
- Discipline : Physique
- Direction de thèse : Athanasios Laliotis
- Contact : Athanasios Laliotis (laliotis@univ-paris13.fr)
- Domaine de recherche : Physique et technologies quantiques
- Mots clés : Capteurs quantiques, Interactions Casimir-Polder, nanophotonique

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Atomic vapors confined in cells are convenient platforms for the realization of compact quantum sensors, providing ultra-sensitive sensing of magnetic and electric fields. In particular, microwave and RF quantum sensors based on Rydberg atoms have been developed in a number of universities but also quantum-technology start-ups. More recently Rydberg sensing has been extended to the THz range, exploiting the conversion of absorbed far-field THz radiation into scattered photons in the visible range.

Fabricating efficient THz sensors is crucial, as it offers potential for real-world applications, including wireless communications and gas sensing. The best way for creating THz devices is metamaterials, consisting of arrays of metallic resonators deposited on dielectric substrates. THz metamaterials are commonly characterized by far-field spectroscopy, which is limited by diffraction and cannot provide mapping of the electric field in the vicinity of the resonators. A possible route for overcoming such limitations is to extend Rydberg electrometry to the near-field and use atoms as local quantum probes of the THz near-field.

The proposed project has the following pioneering goals:

1) <u>Interface Rydberg atoms with metamaterials</u>
Fabricating cesium vapor cells that integrate metallic nanofabricated resonators, submerged into an atomic gas whose density is controlled by temperature. The metamaterials will be deposited and characterized by far-field time domain spectroscopy by the ODIN group of C2N.
2) <u>Perform near-field characterization of the metamaterials using Rydberg probes:</u>
When excited by an external THZ source, the resonators generate an intense electromagnetic response in the near-field. This will induce dipole transitions on the surrounding resonant Rydberg atoms transferring population to adjacent energy levels from which they will decay by fluorescing visible photons. Visible light can be detected by ultra-sensitive cameras providing a mapping of the electric field in the vicinity of the resonators with a resolution that beats the diffraction limit by 2-3 orders of magnitude. This will constitute a quantum technique for performing near-field optical microscopy.
3) <u>Probe the Casimir-Polder interaction between Rydbergs and metamaterials:</u>
Beyond quantum optical microscopy, the coupling of THz resonators and Rydberg atoms can allow us to study the fundamental Casimir-Polder interaction between atoms and metamaterials. THz resonators modify the local density of states of the electromagnetic field, suggesting that a resonant coupling between Rydberg atoms and THz metamaterials could be used to tune Casimir-Polder interactions. To probe Rydberg-metamaterial interactions, we will use selective reflection spectroscopy, developed by the SAI group to probe atoms at ~100nm) above the active region of the resonator.

<u>Perspectives:</u>
Rydberg-metamaterial coupling offers fascinating possibilities for near-filed quantum sensing. Additionally, fast tuning of the metamaterial properties can provide a unique tool to probe dynamical Casimir effects.

We are looking for a PhD student with good background in quantum physics, to work on both experiment and theory and participate in the exchanges between the SAI group and its collaborators: Rostock (Germany), NTU (Singapor).