Rydberg atom based quantum sensors

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Rydberg atoms, which are atoms with a large principal quantum number *n*, are one of the most versatile quantum systems: their unique sensing properties can be enhanced and controlled by the selection of the states and the application of external electromagnetic fields. The large size of these atoms (proportional to n^2), and therefore a potentially high dipole moment, raised primarily fundamental interest: it enabled numerous pioneering demonstrations in quantum physics, including those of Serge Haroche who won the Nobel Prize in 2012 [1]. More recently, Rydberg atoms have been at the heart of the quantum technology revolution: if the strong interactions between these atoms makes them very interesting for quantum information, we are here interested in exploiting their extreme sensitivity at very low field levels for possible applications in the field of detection and processing of RF signals [2,3].
Most of the schemes proposed for the detection of microwave fields are based on the use of electromagnetically induced transparency (EIT) in a ladder system [2]: if we scan the frequency of a laser probe around an optical transition, we will have an absorption resonance centered on the frequency of the atomic transition, but if another electromagnetic field couples the upper level with a higher Rydberg level, a transparency window appears in the center of the absorption line, when the optical detunings of both lasers are equal. Indeed, a two-photon transition excites the atom in a superposition of states, which can no longer absorb the probe laser. Nevertheless, the EIT phenomenon can be perturbed by an RF field, which makes the Rydberg level experience the Autler-Townes effect and gives rise to two resonances instead of a single one, allowing to detect the microwave field.

One of the most obvious limitations is indeed imposed by the discrete nature of the involved Rydberg levels, which limits the frequency agility and the bandwidth of the device. A second issue concerns the instantaneous measurement bandwidth, which is poorly understood today, as shown by the disagreements between experimental measurements and theoretical models. Finally, the detection of the phase of the electric field currently requires the addition of a transmitting antenna of a local oscillator which can for example disrupt the operation of an antenna.

The objective of this PhD proposal is therefore to develop original architectures in order to be able to adjust the RF detection bandwidth of the system and to measure not only the power of the detected RF radiation, but also its phase. It is therefore a question of ultimately making it possible to respond to the application challenges of this study, whether for the metrology of radiation from transmitting antennas or for radar or war type applications. This project will be carried out in the framework of our joint lab with Thales Research and Technology, a company specialized in applications of RF to radars, electronic warfare and communication systems.

The PhD student can also be partly involved in another project on spin noise spectroscopy, in collaboration with Antoine Browaeys from the Institute of Optics (see the PhD subject *Spin noise spectroscopy in gases* proposed by the same group).

[1] S. Haroche, Nobel lecture, Rev. Mod. Phys. 85, 1083 (2013)
[2] J. A. Sedlacek, A. Schwettmann, H. Kübler, R. Löw, T. Pfau et J. Shaffer, Nature Phys., 8, 819 (2012).
[3] L. A. Downes, A. R. MacKellar, D. J. Whiting, C. Bourgenot, C. S. Adams et K. J. Weatherhill, Phys. Rev. X 10, 011027 (2020).