In physics, particles are excitations of fields for which we may write often simple propagation equations such as the famous Schrödinger equation. This equation allows us to treat the problem in which the particles appear using few-body physics approaches. Such an approach allows for solutions of problems in which otherwise complex quantum fields would persistently appear and require much more complicated approach. For few-body problems however, we may resort to only looking at simple correlation functions. This becomes particularly apparent for the case of quasi-particles, which are distinguished from elementary particles by the fact that they are excitations of complex quantum systems. In such a case, the quasi-particle may be treated as a certain kind of “guess” for a solution of a problem for which the treatment of few-particle interactions becomes feasible.

The quasi-particles we will treat within this project are called polaritons, and they are superpositions, that is, a combination, of a photon, a particle of light, and a select kind of material excitation. Polaritons appear across a range of physics problems, from condensed matter physics to atomic physics. In our case, we will work with polaritons emerging in an atomic system where photons interact by optical transitions with atoms. These atoms will be excited to very high-lying states, also known as Rydberg states. In those states, strong interactions between adjacent atoms may be observed. In a polaritonic system, the atoms can thus mediate the interaction between polaritons, allowing for the creation of polaritonic molecules, even of more than two polaritons, and more complex effects, such as polaritonic condensates.

In atomic physics, all of the previous experiments tackled the polaritons in zero or one dimension, greatly reducing the complexity of the problem, which was necessary at the time, but also reducing the richness of the underlying physics. The advances in spatial light detection made in our lab will allow for the treatment of polaritons in two and three dimensions. We will combine our exquisite control of the interaction in the atomic ensemble and the photon detection system to unravel physical processes governing the polaritonic system in its full glory, that is, in more than one dimension. Clearly, every system may “fit” more particles, and thus our experiment is an important step to study many-body physics with polaritons.

During the planned project, we plan to observe bound states of polaritons in 3D, which is a form of quasi-chemistry via forming molecules of quasi-particles. Applications of our research will help study new advanced materials thanks to analogies with condensed matter physics and the inherent ability to control the dispersion structure and interactions in our system. This system itself may be applied directly in quantum technologies related to very precise metrology, imaging, and potentially quantum information processing.