CARAMEL: Capturing polARitonic quAntuM corrELations

Look around the room where you are right now: How many electronic devices can you spot? Surely, we don't have to look hard to find one. In fact, it might be possible that you are using one of them to read these words. Independently of their brand, size and purpose they all have one thing in common. Inside each of them, there is a so-called *microchip* or *processor*, that enables the device to fulfill its tasks. In a radio, the processor converts the information received by the antenna into vibrations of the speaker, which allows us to hear the news or music. In a digital camera, the microchip converts the light received by the sensor into a series of 0's and 1's, which then are used to tell each pixel of the screen which color to display. With our current technology, processors are made of small electronic switches (known as *transistors*) that allow to flip 0's into 1's and vice-versa. As the electronic devices become smaller and the computational power of processors increases, the size of transistors decreases. However, we will soon reach the point in which transistors will consist of one atom, and we will not be able to miniaturize them further.

The fundamental limit imposed by atomic transistors does not imply that there is a limit on the computational limit that can be achieved by a computer. It means, however, that we need to change the way in which we think about computers. In the early 1980's, Nobel laureate Richard Feynman suggested that to simulate our world with an increasing level of detail we would need to use a *quantum computer*, namely, a computer that uses the laws of quantum mechanics to process information. This is easier said than done, but after almost four decades of research we have witnessed the first leap towards the realization of a quantum computer: the research division of Google in 2019 and a group of Chinese scientists in 2020 independently shown that their processors, *Sycamore* and *Jiuzhang*, respectively, had reached the so-called *quantum supremacy*, namely, they showed that their quantum processors were able to perform a task that would take the best classical computer (that is, a computer with atomic transistors) up to 2.5 billion years or, equivalently, one fifth of the age of the Universe.

Currently, the most advanced quantum processor is *Jiuzhang*: it consists of 76 *qubits* (short for *quantum bits,* which are the unit of *quantum* information) and uses light to encode and transmit information. However, beams of light do not interact, they *interfere*, and therefore manipulating light requires complex optical setups. This will become a problem as the number of qubits of the processor is increased. A way to solve this issue is to replace the carriers of quantum information, and instead of using *photons* (the particles composing light) turning to *polaritons*. The latter are commonly known as "interacting photons", because they are the result of the combination of a photon with a charged particle, which can be manipulated through electrostatic forces. Polaritons are able to display and maintain quantum behavior, and therefore it is important to make a scientific effort into researching the potential that they have to be used as a platform for quantum computation. CARAMEL is a theoretical project and, specifically, its goal is to systematically determine the quantum states that polaritons can access, the quantum phenomena that they can display, the mechanisms through which quantum information can be encoded onto polaritons, and ultimately the overall adequacy of polaritons to be used as building blocks of the next generation of quantum computers.

The goal of CARAMEL will be reached by completing six steps. The first of them consists in analyzing the quantum states that polaritons can access. To do that, we will simulate scenarios in which the polariton sample receives the light emitted by a quantum object. Because of this excitation, polaritons will emit light with a certain structure: the behavior of photons depends on their color. Thus, the second step of the project is to characterize completely the structure of the light emitted by polaritons. Next, the third step of CARAMEL is to establish the mechanisms to encode quantum information on polariton, and to identify the best way of doing it. The fourth step is to assess the capability of polaritons to transfer quantum information. Such a transmission takes place by letting the polaritons go from the place where the information is encoded to the place where the information in retrieved. Thus, it is necessary to use a generalization of Schrödinger's equation that allows the adequate description of the journey of a group of few polaritons carrying quantum information. The fifth step consists in finding the mechanisms through which the quantum state of polaritons can be modified without damaging the encoded quantum information. Finally, the sixth step of CARAMEL is to consolidate all the findings and assess the capability of polaritons to perform quantum operations and to be the platform of quantum computers.

CARAMEL will provide results that are relevant for the field of quantum physics in general, and which can later be used to develop quantum technologies. Namely, the generalized Schrödinger equation has a wide applicability, as it can be used to describe every type of interacting particle moving in an environment through which energy can dissipate. Additionally, the project will provide a complete roadmap of the quantum states that polaritons can visit, along the with properties of the light emitted by polaritons occupying these quantum states, and the mechanisms to encode, transmit and manipulate quantum information with polaritons.