People behind PASQuanS

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Clément Sayrin
Centre National de la Recherche Scientifique CNRS, France
Kastler Brossel Laboratory
Associate Professor, Experimentalist

Could you briefly describe your institutional and personal role within the PASQuanS project: Which specific project activities are you involved in?
I am an associate professor at Sorbonne University and, together with Michel Brune and Jean-Michel Raimond, I am leading the research activities of the **PASQuanS** team in Kastler Brossel Laboratory, in Collège de France, Paris. We are working towards the realization of a quantum simulator using giant atoms of a very special kind, so-called "circular Rydberg atoms". These atoms interact very strongly and live quite long, at least from an experimentalist point of view, namely few hundredths of a second. This combination of strong interaction and long lifetimes is ideal for the study of solid-state matter within a quantum simulator.

Which results have already been achieved on your end and what will be the next milestones?
Compared to other experimental platforms in **PASQuanS**, our quantum simulator is still at an early stage of development. Circular Rydberg atoms are more challenging to prepare and use than other (Rydberg) atoms used in the other platforms.

The atoms used in a quantum simulator need to be maintained at very specific positions, typically using laser beams, namely to be laser-trapped. Very recently, we have demonstrated in our cryogenic environment, running at -270°C, the first laser-trapping of circular Rydberg atoms. This is a decisive step towards the realization of a quantum simulator with circular Rydberg atoms.

In this work, the circular Rydberg atoms were trapped but unorganized, as the particle of a gas would do in a closed box. Our next goal is to laser trap several circular Rydberg atoms in so-called optical tweezers, so that the atoms are pin-pointed at very precise positions with a carefully tuned distance between them. This will immediately open proof-of-principle tests of our novel quantum simulator.

For you personally, what has been most fascinating about the project so far and how do you think PASQuanS will impact your future career?
Slightly more than 10 years ago, when I started my research career, scientists were still learning how to manipulate single atoms, single photons, how to make them interact together. The foundations of quantum mechanics were being tested, not to prove it wrong or true, but rather to demonstrate the high level of manipulation of those fragile quantum systems that was being reached. The results of the experiments were somehow known beforehand but the experiments themselves were for long believed to be too difficult to be realized.

This specific project, the studies performed within **PASQuanS** and the development of quantum technologies in general are fascinating as they reveal that we have bridged a gap: we can now use, and not only manipulate, those fragile quantum systems (atoms, ions, photons...) to actually do things, to solve problems, to study systems that are otherwise too complicated to apprehend. In other words, to now run experiments of which the outcomes are unknown, even by supercomputers. This will certainly modify the way quantum scientists will do research in the future, at the frontier between fundamental physics and technology.

Within PASQuanS, there are five experimental groups. Which one(s) are you involved in and how do they interrelate with the theoretical teams and the other experimental groups?
I am part of the experimental group of Laboratoire Kastler Brossel (CNRS, ENS, Sorbonne Université, Collège de France). Our (future) platform is very similar to the one originally developed in the experimental group of Institut d'Optique, where non-circular Rydberg atoms are used. While we need to adapt their set-up to the specificities of our experiment, and in particular make it compatible with cryogenic temperatures, we are in close contact with them in order to efficiently tackle problems they may have faced as well or that we both would simultaneously face. **PASQuanS** offers an excellent forum for this exchange. **PASQuanS** also

provides a great opportunity to interact and collaborate with theoretical teams. Of course, since our platform is still in the development stage, actual protocols or ideas that they may think of cannot be directly implemented in our setup and exchanges may not be as intense as with other experimental groups with running simulators. This motivates us all the more to fully and rapidly finish the construction of our own quantum simulator.

PASQuanS targets applications in material science, quantum chemistry, high-energy physics and optimisation. Which one of them do you expect to benefit from new simulation technologies first and why?
Many of the most advanced quantum simulators have been originally designed to study condensed matter systems. Many questions are left open in these systems and quantum simulators are believed to be good candidates to provide answers. Some experiments already run in regimes where supercomputers cannot compete anymore. Material science may therefore be one of the first to benefit from quantum simulators.

It is to be noted too that quantum simulators are almost per essence made to solve optimisation problems. The latter have indeed a very natural counterpart in the quantum world: finding the configuration of a system that requires minimal energy. Quantum simulators can efficiently answer those questions, leading to a growing interest in such an application. Optimisation in certainly another good candidate for being the first to benefit from quantum simulation technologies.

If you had to explain Rydberg atoms to a non-scientist in very few sentences, what would your explanation be?
By shining light of a carefully tuned colour on an atom, one can “excite” an atom, or more precisely one of the electrons that orbit its nucleus. In such an excited state, this electron is brought further away to the nucleus than he would normally be. When this new distance to the nucleus is very large, so large that the excited electron cannot distinguish the other non-excited electrons from the nucleus of the atom anymore, one says that the excited electron is in a Rydberg level, or that the atom is a Rydberg atom.

Rydberg atoms are gigantic atoms, thousand times bigger than “standard” non-excited atoms. Rydberg atoms can be as large as a bacterium. Such an extreme atom naturally comes with exaggerated properties. Most importantly, being so large, a Rydberg atom acts as a giant antenna that can feel the presence of another distant Rydberg atom, several microns away, while “standard” atoms generally need to collide to interact. The strong interaction between Rydberg atoms is the key property that make them so valuable for quantum simulations.