People behind PASQuanS

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Antoine Browaeys
Institut d'Optique, France
Coordinator, Experimentalist

Could you briefly describe your institutional and personal role within the PASQuanS project: Which specific project activities are you involved in?

I am a researcher at CNRS (the French national organisation for scientific research), working at the Institut d'Optique (Palaiseau, France). Together with Prof. Dr. I. Bloch from the Max Planck Institute for Quantum Optics, I coordinate the PASQuanS project. This implies in particular management tasks and reporting, as well as ensuring a smooth flow of information between the partners and the various Flagship projects. Besides, together with my colleague Thierry Lahaye and a team of post-docs and Phd students at the Institut d'Optique, we develop a quantum simulator based on arrays of atoms trapped in optical tweezers, that are made to interact by exciting them with laser beams. Our main tasks within PASQuanS consist in developing new technologies to trap the atoms, to improve the performances of each manipulation, as well as demonstrating that we can use this machine to solve open scientific questions related to magnetic properties of materials, out-of-equilibrium dynamics of quantum systems, etc., that are very hard to solve by any known numerical methods.

Which results have already been achieved on your end and what will be the next milestones?

Apart from important technological developments (new trapping techniques, laser systems with improved stability), we have recently demonstrated the quantum simulation of a two-dimensional antiferromagnetic material using up to 200 individual atoms. With the help of theory colleagues, we could compare our results with the predictions of some of the most advanced numerical methods available. These methods only work up to about 100 atoms, but showed that we had a good understanding of our platform and of the role of the residual imperfections. The next milestones would be to use our platform to investigate open questions related, for example, to an effect called “geometric frustration” when the atoms are placed on a triangular array as encountered in some magnetic compounds: the theoretical description of this system is very challenging and quantum simulation is a promising approach to tackle it. Before doing so however, we need to suppress some of the residual imperfections to be able to observe this phenomenon. We are also working towards increasing the number of atoms up to around 1,000 by trapping them in a cryogenic environment with the help of the company MyCryoFirm, which is a also partner in the project. These are our goals before the end of PASQuanS.

For you personally, what has been most fascinating about the project so far and how do you think PASQuanS will impact your future career?

I am very impressed by the experimental improvements that the various groups of PASQuanS have achieved. For example, for us, trapping and controlling 200 atoms as we have shown in 2020 was not something I was fully anticipating even 5 years ago, as it seemed quite out of reach back them. But our very driven students and post-docs made that work! At the end of the day, one has to remember the daily challenge that we face: we observe and control individual atoms that, when I was a student 25 years ago, I was told could not be seen! And these amazing developments are of course also happening in the other experimental groups of PASQuanS, and in many around the world.

The second thing that impresses me is the creativity of the theorists to come up with new approaches. For example, characterising the quantum correlations in our many-body systems is extremely challenging, but many theory colleagues from the consortium developed original methods that can be tried in the lab.

Last but not least, for me this was the first time that I have interacted strongly with people from the industry. I discovered their genuine interest for quantum technologies and the huge range of potential applications, from optimisation of processes, to quantum materials, low energy consumption, etc. For instance, we have started a collaboration with researchers at eDF (the main French electricity supplier) on the optimisation of the charging of a fleet of electrical vehicles, that may be solved efficiently on a quantum simulator. This exchange would not have happened without PASQuanS, as I would not have spontaneously thought of contacting them. This is just the beginning of a closer collaboration between academia and industry, and we are expecting a huge development in the years to come. In this respect, an important development for us at the Institut d’Optique was the creation of a start-up company (pasqal.io), now a full partner of PASQuanS, to further develop pre- industrial quantum simulators based on the technology we have demonstrated in our research laboratory. This start-up will be much better equipped than us as an academic group to meet the needs of the industry and to work with companies in the future.

How can quantum technologies impact our daily lives: Where do we stand now and what will be its future role in business and society?

This is a tough question. Quantum technologies are developing at the same time as the potential markets and their impact are not yet visible. Quantum technologies are still in their infancy, we are currently at the stage of proof-of-principle demonstrations to confirm their potential.

The promises are huge though and the fields of potential application manifold: more energy-efficient ways to perform computations, new approaches to hard optimisation problems such as finding the best way to load airplanes, trucks, the stabilisation of national or supranational electricity grids, the charging of fleets of electrical vehicles, the spatial arrangement of antennas for cell phones, or the development of new materials or new drugs, better solar cells. All these developments will have an impact on our societies when they are mature enough. An important aspect for the industry is also for them to learn about quantum technologies, their potential and what we can do today in order to invest wisely: knowing about the quantum is a competitive advantage. Quantum technologies will also create new ecosystems, with new job opportunities. As we develop this "quantum industry", we will need to develop dedicated curricula to train students and teach them the required know-how. This is already an ongoing process at the European level reflected in the definition and set-up of a core cursus to educate "quantum engineers".

Now, if the question is, whether we will all have a quantum laptop in our houses, I have to admit that I don't know. But if we ever do, this is not in the near-future.

Compared with other research endeavours and EU projects in the field of quantum simulation, what's unique about the aims and scope of PASQuanS?

PASQuanS gathers a unique combination of platforms and of skills with the consortium consisting of experimentalists and theorists from academia, partners from the industry who act as enablers , and potential end-users. Hence, we already have the full value chain represented in our consortium: from the fundamental demonstrations in the labs to the industry-driven applications via the suppliers of commercial technologies.

Scientifically, PASQuanS relies on neutral atoms in optical lattices or in arrays of optical tweezers, as well as on trapped ions. These are today the platforms with probably the highest potential for scaling up the number of qubits. Besides they are to a large extent programmable: one can engineer the interactions between the qubits and their connectivity by “simply” changing the parameters of the machine. Neutral atoms in optical lattices are very interesting as they allow the direct simulation of fermionic particles such as electrons in materials. No other platform can do that. Importantly, all of the PASQuanS platforms operate near or even deeply in the quantum advantage regime, and have already shown that they could challenge existing theory and numerical methods.

Besides, PASQuanS has a very strong theory component with experts in quantum information, condensed matter physics, quantum optics, etc. They all have strong links with the experimentalists, having worked with them for many years. In this way, ideas can be rapidly implemented on the various platforms of the consortium. Most of their effort is devoted to answering the crucial question of how to characterise large-scale quantum systems conceptually, and to develop experimentally feasible methods to do so, but also to assess, for specific problems, a potential quantum advantage (which often starts by assessing what can be done classically, an already surprisingly hard question).

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?

At the moment the most promising, near-term applications seem to relate to combinatorial optimisation problems that are encountered almost everywhere in industry and in finance. They could be solved by the quantum simulators developed within PASQuanS with a few more experimental improvements. However, today, we do not think that quantum simulation will offer a universal gain with respect to classical methods whatever the optimisation problem: we rather expect a “quantum advantage” for specific problems. This would already be an important development. Furthermore, even if quantum simulators would not present an advantage for some problems, it is likely that they will solve them with considerably less amount of energy than using high-performance-computing facilities. The quantum simulation approach would therefore have an important environmental impact.

Other potential applications often mentioned are quantum chemistry and the design of new materials as well as of new drugs. These are certainly very exciting perspectives, and the community is trying to assess what it would require in terms of hardware and resources. But one has to keep in mind that these are quite long-term goals.