PASQuanS

## People behind PASQuanS

*"Demonstrating a practical quantum advantage for problems beyond basic science is a very important next step. It will require the breadth of expertise that PASQuanS has brought together – across theory and experiment in academia, with industrial technology and end-use partners to take the critical next steps towards this challenge."*

**Andrew Daley**
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PI, Theorist

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

Our group is one of the five theory teams within PASQuanS, and we focus on developing new ways to control and engineer the behaviour of the PASQuanS experimental platforms, together with potential applications ranging from basic science to end-user problems. We make detailed models of the quantum simulators and analyse their potential for demonstrating a practical quantum advantage for different application areas. I am also the theory coordinator within the Executive Team of the project.

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

We have developed a number of theoretical building blocks that will help extend the the experimental platforms to new application areas, and allow for better benchmarking of their capabilities. For example, we have developed new control techniques for neutral atoms in Rydberg arrays, showing how highly entangled states can be prepared in few steps by shuffling the atoms in optical tweezers, as is possible in PASQuanS platforms. We have also separately worked with our experimental colleagues in Heidelberg to measure and benchmark entanglement for indistinguishable particles. The next milestones on our side will be particularly exciting as well look at more detailed quantification of where these platforms exhibit a practical quantum advantage for relevant problems, as well as developing further means to clearly verify this in ongoing experiments. As the project develops through this final year, we will see important steps in basic science coming together more clearly with the technological impacts of our work, helping us to identify new areas in which these technologies are relevant to computational challenges beyond basic science.

**For you personally, what has been most fascinating about the project so far and how do you think PASQuanS will impact future research and developments in this field?**

The great thing about being part of PASQuanS is that it brings together world-leading teams from theory and experiment in academia, as well as world-leading industrial technology and end-user partners to work towards a common goal of advancing these technologies. Part of the reason for the rapid development in our field has been the regular sharing ideas between leading academic groups from different countries and different technical backgrounds. PASQuanS extends this further by bringing on board the interaction with industry, not only bringing technical expertise, but also introducing us to a range of end-user problems that we as physicists seldom encounter. In this sense, I think and hope that the lasting impact of PASQuanS reaches beyond the development in science and technology, in setting up a common language and exchange between industry and academia in this area.

**What are the biggest challenges for quantum researchers and engineers – and how do you think projects like PASQuanS can help to overcome them?**

There are a lot of technical steps to in develop and improve these technologies, but perhaps the biggest challenges are (1) in identifying the areas where quantum simulation can have the largest impact, and (2) developing a common language and dialogue between scientists, engineers, and broader industry players with expertise on the computational challenges in their sector. We are very excited about the potential for quantum simulation and quantum computing, but both will require a lot of small steps, and expertise from many sides before we reach the point where – beyond basic science – we can solve a range of computational problems faster or more precisely than we can with classical computers. It requires both technological input on developing the platforms, and – more challenging still – identifying the most promising use cases, and determining how we can apply quantum devices to solve them. The starting point of a common language between the developers of the platforms and the end users is already often difficult to establish.

Projects like PASQuanS directly address these key challenges, by bringing together leading experts from this area, and allow a collaborative project to draw on international expertise to work on a common set of technological challenges. The focus around specific platforms and challenges is the ideal environment to develop new ways to work together, and the learn from different sides. The project is at the same time the ideal learning environment for postdocs and PhD students, who will be the next generation of leaders in academia and industry.

**You work in both quantum computing and simulation. Which one is your favourite and how can you benefit from your cross-linked expertise in PASQuanS?**

Because we work a lot on the architecture of experimental platforms, our theoretical work in quantum computing and simulation are strongly interlinked. One particularly interesting development, is the way that these areas are moving towards each other to identify near-term applications.  In quantum computing we often talk about variational algorithms for near-term applications on Noisy, Intermediate-Scale Quantum (NISQ) Devices. In a sense, many interesting applications of Quantum Simulation might come from taking a similar approach, but making use of the full analogue controllability of an experimental platform, rather than restricting the set of operations as is done in digital quantum computing (to set the stage for fault-tolerance, which we don’t have in on NISQ devices).

**Which of the five theoretical teams within PASQuanS do you work with and how is it linked to the experimental side of the project?**

We benefit greatly from regular exchanges with all of the theory partners on PASQuanS – for example, we have ongoing discussions with Padua on numerical methods for 2D systems, Julich on quantum control and controllability, ATOS on emulation and end-user applications, Berlin on benchmarking techniques, and with Innsbruck on verification of quantum advantage for specific applications. Several of these are likely to lead to joint publications, and all give important additions to our understanding, and how we orient the research we do. Our work focusses on the architectures of the experimental partners – we already have a joint paper with Heidelberg, and have ongoing discussions with each of the other partners.

**In your own words, what is the "Quantum Advantage" and where do we stand on our way to "Quantum Supremacy"?**

Achieving a practical quantum advantage is one of the big aims in quantum computing and simulation. For me, it entails (1) being able to show that our quantum devices are capable of solving a computational problem better or faster than any known classical algorithm, and which is relevant beyond just testing the quantum device, and (2) being able to verify that the solution is reliable. "Quantum Supremacy" is a much-debated term, which perhaps doesn't properly reflect its own meaning, and implies that a quantum device is able to solve some problem (which might not be relevant as a computational challenge beyond testing the device) better or faster than is possible with a classical algorithm. With analogue quantum simulation platforms and for problems relevant to science, we can already demonstrably reach regimes that are beyond the capabilities of existing classical simulation, and we're close to being able to quantitatively verify that this is the case. Demonstrating a practical quantum advantage for problems beyond basic science is a very important next step. It will require the breadth of expertise that PASQuanS has brought together – across theory and experiment in academia, with industrial technology and end-use partners to take the critical next steps towards this challenge.