Il Colle di Galileo

Inventing new quantum technologies for understanding fundamental physics at GGI

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Abstract. We report on a recent GGI workshop, focused on the application of quantum-technology-based approaches to study fundamental physics, with an emphasis on studying gauge fields and gauge theories with ultracold atomic systems. Several topics at the frontier of contemporary research, ranging from the development of new experimental quantum simulators to quantum-information-based numerical techniques, were discussed in a very stimulating and multidisciplinary environment.

Keywords. Gauge fields, ultracold atoms, quantum simulation.

Experimental and theoretical physicists from all over the world gathered in Arcetri at the GGI Galileo Galilei Institute for Theoretical Physics, from 22/05/17 to 23/06/17, for the workshop "From static to dynamic gauge fields with ultracold atoms". The topic of the workshop was the discussion of new approaches to the study of strongly correlated quantum systems emerging in the presence of gauge fields. The notion of "gauge field" in Physics is quite general and plays a fundamental role in our understanding of a multitude of natural phenomena. As a matter of fact, dynamical gauge fields, being the mathematical tools that are used by physicists to describe the nature of fundamental interactions, are the paradigm upon which the entire Standard Model is built. In other contexts, "static" gauge fields, in the form of magnetic fields or spin-orbit couplings, are responsible for the peculiar properties of several solid-state systems, e.g. in the quantum Hall effect or in other newly discovered topological states of matter.

Over the last few years, the development of new quantum technologies has pro-

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vided physicists with novel investigation tools, both theoretical and experimental, for the study of strongly correlated quantum systems from new and quite different viewpoints. One of these is the experimental approach of "quantum simulation" with ultracold atomic systems, where gauge fields can be "synthesized" in the laboratory by controlling the interactions between atoms with quantum-optics techniques, and their effect on the matter field can be characterized in an experimental measurement. Then there are the novel numerical techniques inspired by quantum-information approaches, which are emerging as complementary methods to access regimes where other consolidated computational techniques (e.g. Monte Carlo simulations) reveal intrinsic limits. The primary aim of the workshop was to elaborate new strategies in the development of these novel quantum technologies, by promoting the interaction between researchers from very different fields of research, ranging from Atomic Physics to High-Energy Physics, from Condensed-Matter Physics to Computational Physics, in a joint effort.

During the five weeks of the workshop, GGI hosted approx. 150 visitors – students, postdocs and senior researchers – who contributed with 60 talks, distributed among the various events of the programme (see Fig. 1 for a group photo of some of the participants). A key element to the success of this initiative was really its multidisciplinary character. Physicists from very different backgrounds gathered at the GGI and placed their different skills and expertise at the disposal of the common aim of creating new connections between different fields of research, motivated by the challenge to develop a shared research platform. This was a very exciting intellectual challenge and a genuine stimulus to overcome the barriers of scientific culture and language which, all too often, are raised between specific areas of Physics. *A posteriori*, we can say that this challenge has been overcome

Figure 1. Group picture of some of the participants in the courtyard of the GGI.

very successfully. Many new ideas were developed during the workshop, with the launch of numerous scientific collaborations, which have already resulted in the publication of several scientific papers.

During the programme, two "focus weeks" were devoted to specific aspects of this new-born direction of research. The first focus week on "Advances in gauge field implementations in atomic systems" (22/05/17 – 26/06/17) was devoted to the discussion of the experimental techniques for the implementation of gauge fields in ultracold atomic platforms: experts in these techniques discussed the state of the art in the production of static gauge fields and suggested new directions for the implementation of dynamical fields. The second focus week on "Tensor networks for lattice gauge theories" (05/06/17 – 09/06/17) was devoted to the recent theoretical advances in the development of "tensor networks" algorithms for the solution of gauge theories.

The various topics of the workshop were then synthesised in the conference "Quantum science approaches to strongly correlated systems: from ultracold atoms to high-energy and condensed matter physics" (29/05/17 – 02/06/17). During the conference, leading international exponents presented their latest results in a busy schedule of invited and contributed talks (Fig. 2). The conference was complemented with a very successful poster session in the courtyard of the GGI, where younger participants presented the results of their research on a lovely sunny late-spring Florentine day.

The workshop was attended by many top-level scientists. Among them, we would like to thank the two long-term visitors of the workshop, Prof. Tin-Lun Ho (Ohio State University, USA) and Prof. Carlos Sa De Melo (Georgia Institute of Technology, USA), who were both supported by the Simons Foundation for the whole duration of the workshop. They both made a substantial contribution to the success of the

Figure 2. Conference participants in the lecture hall.

programme, assisting the organizers in the scientific management of the event and constantly promoting the scientific discussion. Furthermore, the last week of the workshop was honoured by the participation of Nobel prize winner Prof. Wolfgang Ketterle (Fig. 3), also supported by the Simons Foundation, who presented the latest results of his research work at MIT on the topic of spin-orbit-coupled ultracold quantum gases, which led to the recent observation of a new supersolid quantum phase.

In addition to the "official" schedule of talks and discussion sessions, many informal initiatives promoted by the participants meant that the atmosphere of the event was always active and stimulating.

We would like to express our gratitude to the Director and Scientific Board of the GGI for having invested in the success of the event, to the local co-organizer, Andrea Cappelli, for his very useful advice (and for sharing his knowledge about Galileo Galilei's life during a much-appreciated excursion to Villa Il Gioiello), and to the entire technical/administrative staff of the GGI, who were simply perfect in their assistance of the organizers and the participants during their stay in Florence.

The feedback from the participants was really enthusiastic and we have already received several requests to repeat the experience in the future. Indeed, it will be interesting to meet again in a few years (hopefully again at the GGI!) to discuss how far the ideas developed during this event will have taken us.

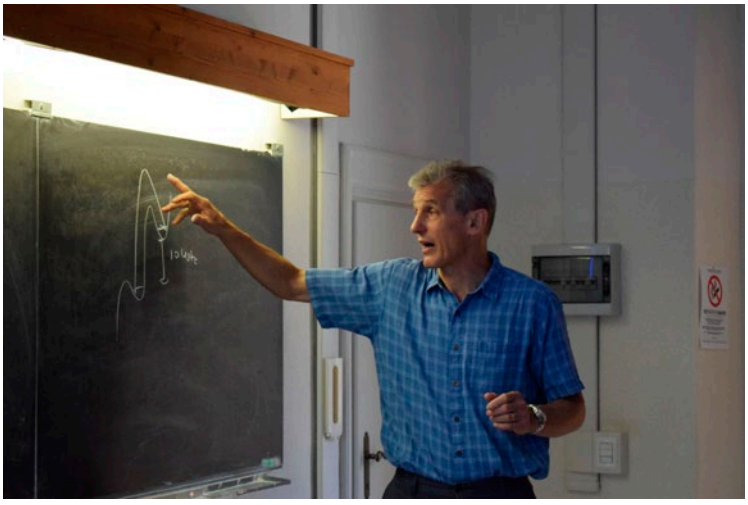

Figure 3. Wolfgang Ketterle during his talk at the workshop.