DY 54: Focus Session: Many-Body Interference and Quantum Statistical Physics (joint session DY/TT)

Fascinating experimental progress in controlling and monitoring quantum many-body systems has triggered broad activities to better understand quantum coherent many-body phenomena, in particular from the perspective of dynamics and many-particle interference in Fock space. In this focus session, both in experimental and theory talks, light is shed on many-particle interference phenomena, for bosonic and fermionic (massive) particles as well as for photons, and their implications for modern quantum statistical physics. [Organizers: Klaus Richter (Universität Regensburg) and Andreas Buchleitner (Universität Freiburg; Chairperson DPG-Section SAMOP)]

Time: Thursday 15:00–17:45 Location: H20

Invited Talk DY 54.1 Thu 15:00 H20

Between Localization and Ergodicity in Quantum Systems — •Boris Altshuler — Columbia University, New York

Strictly speaking the laws of the conventional Statistical Physics, in particular the Equipartition Postulate, apply only in the presence of a thermostat. For a long time this restriction did not look crucial for realistic systems. Recently there appeared two classes of quantum many-body systems with the coupling to the outside world that is (or is hoped to be) negligible: (1) cold quantum gases and (2) systems of qubits, which enjoy a continuous progress in their disentanglement from the environment. To describe such systems properly one should revisit the very foundations of the Statistical Mechanics. The first step in this direction was the development of the concept of Many-Body Localization (MBL) [1]: the states of a many-body system can be localized in the Hilbert space resembling the celebrated Anderson Localization of single particle states in a random potential. Moreover, one-particle localization of the eigenfunctions of the Anderson tight-binding model (on-site disorder) on regular random graphs (RRG) strongly resembles a generic MBL. MBL implies that the state of the system decoupled from the thermostat depends on the initial conditions: the time averaging does not result in equipartition distribution, the entropy never reaches its thermodynamic value i.e. the ergodicity is violated. Variations of e.g. temperature can delocalize many body states. However, the recovery of the equipartition is not likely to follow the delocalization immediately: numerical analysis of the RRG problem suggests that the extended states are multi-fractal at any finite disorder [2]. Moreover, regular (no disorder!) Josephson junction arrays (JJA) under the conditions that are feasible to implement and control experimentally demonstrate both MBL and non-ergodic behavior [3].

[1] D. Basko, I. Aleiner, and B. Altshuler, Ann. Phys. 321, 1126 (2006). [2] A. De Luca, B.L. Altshuler, V.E. Kravtsov, & A. Scardicchio, PRL 113, 046806, (2014) [3] M. Pino, B.L. Altshuler and L.B. Ioffe, arXiv:1501.03853, PNAS to be published.

Invited Talk DY 54.2 Thu 15:30 H20

Canonical description of short-range interacting few-body quantum systems — •Quirin Hummel, Benjamin Geiger, Juan Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

The theoretical study of quantum few-body systems poses a fundamental challenge since the absence of a large number of particles makes the usually simplifying description within the grand canonical formalism invalid. We analytically address the fundamental interplay between indistinguishability, interactions and many-body interference in bosonic and fermionic systems with strictly fixed total particle number; quantum statistics is treated exactly and interparticle forces are described non-perturbatively. We perform calculations for thermodynamic and spectral quantities by expanding the canonical partition function in terms of Ursell operators in the short-time approximation where the discreteness of many-body spectra is neglected. This approach is specially suitable for the few-body case as it generates thermodynamic and spectral properties in terms of a finite set of permutation and interaction events thus overcoming the inappropriate use of virial expansions.

For 1D systems with short-range interactions we present analytical expressions applicable to both integrable prototypical systems such as the Lieb-Liniger and Gaudin-Yang models as well as realistic non-integrable models with harmonic confinement.

Invited Talk DY 54.3 Thu 16:00 H20

One, Two, Three, Many: Manipulating Quantum Systems One Atom at a Time — •Selim Jochim — Physikalisches Institut, Universität Heidelberg, Germany

Experiments with ultracold gases have been extremely successful in studying many body systems, such as Bose Einstein condensates or fermionic superfluids. These are deep in the regime of statistical physics, where adding or removing an individual particle does not matter. For a few-body system this can be dramatically different. This is apparent for example in nuclear physics, where adding a single neutron to a magic nucleus dramatically changes its properties. In our work we deterministically prepare generic model systems containing up to ten ultracold fermionic atoms with tunable short range interaction. In our bottom-up approach, we have started the exploration of such few-body systems with a two-particle system that can be described with an analytic theory. Adding more particles one by one we enter a regime in which an exact theoretical description of the system is exceedingly difficult, until the particle number becomes large enough such that many-body theories provide an adequate approximation.

Our vision is to use our deterministically prepared tunable few-body systems as microscopic building blocks to assemble model systems that might help to gain insight into complex many-body systems.

15 min. break

Invited Talk DY 54.4 Thu 16:45 H20

Statistical Signatures of Many-Particle Interference — •Mattia Walschaers — Physikalisches Institut, Albert-Ludwigs-Universitat Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany — Instituut voor Theoretische Fysica, University of Leuven, Celestijnenlaan 200D, B-3001 Heverlee, Belgium

The complexity of a quantum system drastically increases with the number of its constituents, which gives rise to several difficulties, often associated with the interactions between particles. Nevertheless, already the indistinguishability of particles alone can lead to dynamical interference effects which go well beyond mere quantum statistics, even in the absence of interactions. Recently, these many-particle interferences became the centrepiece of the debate on boson sampling, connecting them to quantum simulation. As a core message, it was explicitly stressed that such interference patterns are computationally intractable. As a consequence, we are confronted with apparent difficulties for the certification of many-particle interferometers. However, from a complex systems perspective, the intractability of the deterministic behaviour of a physical system is common place, and motivates a statistical treatment. In this contribution, we present statistical signatures of different types of many-particle interference by studying correlation functions combined with techniques from random matrix theory [1]. We also show how these signatures are altered by varying the degree of indistinguishability of the particles.

[1] M. Walschaers, J. Kuipers, J.-D. Urbina, K. Mayer, M. C. Tichy, K. Richter, and A. Buchleitner, arXiv:1410.8547 (2014).

Invited Talk DY 54.5 Thu 17:15 H20

Boson sampling with integrated quantum photonics — •Fabio Sciarrino — Dipartimento Sapienza, Università di Roma, Roma, Italy

Boson sampling is a computational task strongly believed to be hard for classical computers, but efficiently solvable by orchestrated bosonic interference in a specialized quantum computer. Current experimental schemes, however, are still insufficient for a convincing demonstration of the advantage of quantum over classical computation. A new variation of this task, scattershot boson sampling, leads to an exponential increase in speed of the quantum device, using a larger number of photon sources based on parametric down-conversion. This is achieved by having multiple heralded single photons being sent, shot by shot, into different random input ports of the interferometer. We report the first scattershot boson sampling experiments, where six different photon-pair sources are coupled to integrated photonic circuits. We use recently proposed statistical tools to analyze our experimental data, providing strong evidence that our photonic quantum simulator works as expected. This approach represents an important leap toward a convincing experimental demonstration of the quantum computational supremacy.