QI 33: Quantum Materials and Many-Body Systems

Time: Thursday 14:30–16:30 Location: HS VIII

QI 33.1 Thu 14:30 HS VIII

Criteria for Matrix-Product Representations of Quantum Many-Particle States — •Lukas Pausch and Matthias Zimmermann — DLR e.V., Institut für Quantentechnologien, Ulm

Tensor networks [1] and in particular matrix-product states [2] have proven extremely useful for the investigation of quantum many-body states, such as, e.g., ground states of local many-body Hamiltonians. They provide an efficient description of these states, avoiding the exponential increase of Hilbert space with particle number at the cost of limiting the entanglement. In particular for matrix-product states, the relation between area laws of Rényi entanglement entropies and efficient simulability of quantum states is nowadays well understood [3]. However, it is not always clear a priori whether or not the relevant states of a given quantum system (e.g., its eigenstates) fulfil such an area law and can thus efficiently be represented by matrix-product states. By investigating specific states of relevance for many-body quantum dynamics, in particular symmetric states and Fock states, we here aim to derive criteria beyond the area law to assess for which quantum systems a description by matrix-product states or more general tensor networks is beneficial.

[1] S. Montangero, Introduction to Tensor Networks (Springer, Cham, 2018)

[2] J. I. Cirac, D. Pérez-García, N. Schuch, and F. Verstraete, Rev. Mod. Phys 93, 045003 (2021)

[3] N. Schuch, M. W. Wolf, F. Verstraete, and J. I. Cirac, Phys. Rev. Lett. 100, 030504 (2008)

QI 33.2 Thu 14:45 HS VIII

Quantum features from classical entropies — Yannick Deller[1], Martin Gärttner[2], •Tobias Haas[3], Markus K. Oberthaler[1], Moritz Reh[1,2], and Helmut Strobel[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg — [2]Institut für Festkörpertheorie und Optik, Friedrich-Schiller-Universität Jena — [3]Centre for Quantum Information and Communication, Université libre de Bruxelles

Local quantum entropies are of utmost interest in characterizing quantum fields, many-body systems, and gravity. Despite their importance, being nonlinear functionals of the underlying quantum state often hinder their theoretical as well as experimental accessibility. Here, we show that suitably chosen classical entropies of standard measurement distributions capture the very same features as their quantum analogs while remaining accessible even in high-dimensional Hilbert spaces.

We demonstrate the presence of the celebrated area law for classical entropies for typical states, such as ground and excited states of a scalar quantum field. Further, we consider the post-quench dynamics of a multi-well spin-1 Bose-Einstein condensate from an initial product state, in which case we observe the dynamical build-up of quantum correlations signaled by the area law, as well as local thermalization revealed by a transition to a volume law, both in regimes characterized by non-Gaussian quantum states and small sample numbers.

arXiv:2404.12320, 2404.12321, 2404.12323.

QI 33.3 Thu 15:00 HS VIII

Quantum-critical interplay between continuous-symmetry breaking and topological order in the long-range interacting spin-one Heisenberg chain — •Patrick Adelhardt[1,2], Sean R. Muleady[2], Alexey V. Gorshkov[2], and Kai P. Schmidt[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Joint Quantum Institute and Joint Center for Quantum Information and Computer Science, University of Maryland and National Institute of Standards and Technology, College Park, Maryland, USA

Recent experiments with AMO quantum simulators have demonstrated continuous symmetry breaking (CSB) in low-dimensional systems with long-range interactions, circumventing the constraint imposed by the Mermin-Wagner theorem in their short-ranged counterparts. Simultaneously, these platforms have enabled the investigations of symmetry-protected topological (SPT) phases in one-dimensional spin systems. Motivated by these experimental developments, we study the quantum phase diagram of the spin-one Heisenberg chain with staggered long-range interactions and single-ion anisotropy using matrix product states (MPS) techniques. Our study reveals the emergence of a multicritical point at the intersection of the SPT phase and CSB phases. We investigate the critical behavior along the various phase boundaries and at the multicritical point extracting critical exponents and elucidating their quantum-critical properties.

QI 33.4 Thu 15:15 HS VIII

Fracton and topological order in the XY checkerboard toric code — Max Vieweg and •Kai Phillip Schmidt — Frichdrich-Alexander Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany

Topological and fraction phases are of great importance in current research due to their fascinating physical properties like entangled ground states, exotic excitations with non-trivial particle statistics or restricted mobility as well as potential applications in quantum technologies. The 2D toric code is the most paradigmatic, simplest, and exactly solvable model displaying topological order, which has been proposed as quantum memory and is relevant for quantum error correction. Consequently, the toric code plays an important role in several domains of research covering condensed matter physics, quantum optics, and quantum information.

However, the toric code has so far not been linked to the field of fracton physics. Here we introduce the XY checkerboard toric code (XYTC) connecting for the first time topological and fracton order in two dimensions within the same model. The XYTC represents a generalization of the conventional toric code with two types of star operators and two anisotropic star sublattices forming a checkerboard lattice. The quantum phase diagram is deduced exactly by a duality transformation displaying topological and type-I fracton phases.

QI 33.5 Thu 15:30 HS VIII

Threetangle in the XY-model class with a non-integrable field background — •Andreas Osterloh[1] and Jörg Neveling[2] — [1]TII Abu Dhabi, UAE — [2]Software Engineering, Konecranes GmbH, Düsseldorf, Germany.

The square root of the threetangle is calculated for the transverse XY-model with an integrability-breaking in-plane field component. To be in a regime of quasi-solvability of the convex roof, here we concentrate here on a 4-site model Hamiltonian. In general, the field and hence a mixing of the odd/even sectors, has a detrimental effect on the threetangle, as expected. Only in a particular spot of models with no or weak inhomogeneity γ does a finite value of the tangle prevail in a broad maximum region of the field strength $h \approx 0.3 \pm 0.1$. There, the threetangle is basically independent of the non-zero angle α. This system could be experimentally used as a quasi-pure source of threetangled states or as an entanglement triggered switch depending on the experimental error in the field orientation.

QI 33.6 Thu 15:45 HS VIII

Efficient optimization and conceptual barriers with projected entangled-pair states — •Erik Weerda[1], Daniel Alcalde[1,2], Konrad Schröder[1], and Matteo Rizzi[1,2] — [1]University of Cologne, Cologne, Germany — [2]Forschungszentrum Jülich

Finite projected entangled-pair states (PEPS) are becoming a widely used tool in the computational study of strongly correlated systems. However, no standard set of computational tools has yet emerged to exploit the power of this approach. In this work we investigate a promising approach to ground state search with PEPS based on sampling methods. Along with presenting strategies for more efficient optimisation, we also discuss conceptual barriers associated with this approach. A benchmark illustrates the power of these tools in the study of ground states of frustrated magnetic models.

QI 33.7 Thu 16:00 HS VIII

Post-measurement Quantum Monte Carlo — •Kriti Baweja[1], David Luitz[1], and Samuel Garratt[2] — [1]Institute of Physics, University of Bonn, Nußallee 12, 53115 Bonn, Germany — [2]Department of Physics, University of California, Berkeley, CA 94720, USA

We study the effects of extensive measurements on many-body quantum ground and thermal states using Quantum Monte Carlo (QMC). Measurements generate density matrices composed of products of local non-unitary operators, which we expand into operator strings via a generalised stochastic series expansion (SSE). This 'post-measurement

SSE' employs importance sampling of operator strings contributing to a measured thermal density matrix. Our algorithm is applied to the spin-1/2 Heisenberg antiferromagnet on a square lattice. Thermal states of this system exhibit SU(2) symmetry, which is preserved through SU(2)-symmetric measurements. We identify two classes of post-measurement states: one where correlations can be efficiently computed using deterministic loop updates, and another where SU(2)-symmetric measurements induce a QMC sign problem in any site-local basis. Using this approach, we demonstrate measurement-induced phenomena, including the creation of long-range Bell pairs, symmetry-protected topological order, and enhanced antiferromagnetic correlations. This method offers a scalable way to simulate measurement-induced collective effects, providing numerical insights to complement experimental studies. Our work opens the door to exploring how measurements influence many-body quantum systems, enabling deeper understanding of their dynamics. [1] arXiv:2410.13844

QI 33.8 Thu 16:15 HS VIII

Symmetry-Resolved Out-of-Time-Order Correlators with Projected Matrix Product Operators — •Martina Gisti, David Luitz, and Maxime Debertolis — Institute of Physics, University of Bonn, Nußallee 12, 53115 Bonn, Germany

Out-of-Time-Order Correlators (OTOCs) are key measures of quantum many-body chaos and information spreading. We systematically analyse OTOCs as a function of particle number for interacting spinless fermions in one dimension. With the concept of generalized operator charge, we develop a formalism for the time evolution of symmetry-projected matrix product operators, which we use to resolve the scrambling behaviour by particle number sector. Our results reveal a crossover from ballistic to diffusive dynamics at early times and a saturation regime at late times.