THU 7: Entanglement and Complexity: Contributed Session to Symposium II

Time: Thursday 14:15–16:00 Location: ZHG008

THU 7.1 Thu 14:15 ZHG008

Complexity-driven ground state estimation in the Agassi model — •Sönke Momme Hengstenberg[1] and Caroline Robin[1,2] — [1]Fakultät für Physik, Universität Bielefeld, D-33615, Bielefeld, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany

I will discuss entanglement and non-stabilizerness (also referred to as magic) in ground states of the Agassi model. This model describes a non-trivial quantum many-body system exhibiting both superfluid pairing and collective deformation phases. We present multi-partite entanglement measures and stabilizer Rényi entropies to characterize the quantum complexity of the system. Based on this knowledge, we provide techniques to accelerate the estimation of ground states of this model in different regimes. I conclude with a short outlook on how to generalize this method to more complex quantum many-body systems.

THU 7.2 Thu 14:30 ZHG008

Complexity transitions in chaotic quantum systems — Gopal Chandra Santra[1,2,3], •Alex Windey[1,2], Soumik Bandyopadhyay[1,2], Andrea Legramandi[1,2], and Philipp Hauke[1,2] — [1]Pitaevskii BEC Center, INO-CNR and Department of Physics, University of Trento, Via Sommarive 14, I-38123 Trento, Italy — [2]INFN-TIFPA, Trento Institute for Fundamental Physics and Applications, Via Sommarive 14, I-38123 Trento, Italy — [3]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Complex quantum systems—composed of many interacting particles—are intrinsically hard to model. In the presence of disorder, such systems transition into non-ergodic and localized regimes, reducing relevant basis states. Whether these transitions also reflect abrupt complexity changes remains open. We study such transition in the power-law random banded matrix, Rosenzweig-Porter, and hybrid SYK+Ising models, comparing three complexity markers: fractal dimension, entanglement entropy, and stabilizer Rényi entropy. All markers show sharp transitions between high- and low-complexity phases, though at distinct critical points. Thus, while markers align in ergodic and localized regimes, they diverge in an intermediate fractal phase. The stabilizer Rényi entropy is sensitive to many-body symmetries such as fermion parity and time reversal. Our findings show different markers capture complementary facets of complexity, requiring their combination for a comprehensive diagnosis of phase transitions and revealing implications for classical simulability of chaotic systems.

THU 7.3 Thu 14:45 ZHG008

Communication Complexity Bounds using Information Causality — •Prabhav Jain[1], Nikolai Miklin[2], and Mariami Gachechiladze[1] — [1]Technische Universität Darmstadt — [2]Technische Universität Hamburg

In a distributed computing scenario, two parties (say Alice and Bob) aim to compute a given function with as minimum communication as possible. The communication cost or the complexity depends not only on the function itself but the shared resources to which both parties have access to such as public randomness or entangled Bell pairs. In this work, we aim to study communication complexity in theories satisfying the information causality principle. The principle essentially states that the information potentially available to Bob about Alice's data cannot be higher than the amount of information Alice sends to Bob. We formulate an extension of the information causality principle which is valid for any distributed computation scenario and apply it to several well known functions. We show a reduction for some of these problems to known functions and hence derive one-way communication complexity bounds in a theory independent manner. Finally, we prove that the information causality principle is at least as strong as the principle of non-trivial communication complexity.

THU 7.4 Thu 15:00 ZHG008

Splitting and interconnecting atomic singlets in dynamical superlattices — •Yann Kiefer, Zijie Zhu, Lars Fischer, Konrad Viebahn, and Tilman Esslinger — ETH Zürich, Zürich, Switzerland

The transport of atoms, electrons or entanglement in general in large many-body systems is becoming an increasingly important task for quantum applications. Often, long-distance qubit connectivity relies on the transport of particles, which leads to unwanted excitations and heating and ultimately the loss of information. To circumvent this, we present a ground-state preserving transportation scheme based on periodic modulation of an optical lattice potential.

In detail, we leverage topological pumping in a periodically modulated one-dimensional optical superlattice to realise the transport of coherent fermionic two-particle states over large distances. Furthermore, we use the access of the optical lattice potential to implement gate operations by engineering the local superexchange coupling J. More specifically, when two particles meet in a double well of the optical lattice, we can control J using two different methods, such that two-particle (SWAP)^n gates are implemented while preserving the motional many-body ground state of the system. We reveal the successful implementation of such gates by observing multi frequency singlet-triplet oscillations (STOs) as a direct signature of entanglement between fermions distributed over tens of lattice sites.

THU 7.5 Thu 15:15 ZHG008

Measurable Krylov spaces and eigenenergy count in quantum state dynamics — •Saud Čindrak, Lina Jaurigue, and Kathy Lüdge — Technische Universität Ilmenau, Ilmenau, Germany

Krylov complexity is defined on the Krylov space, which consists of the powers of the Hamiltonian acting on the initial state. We prove that an equivalent space can be constructed by taking time-evolved states as a basis, which is also quantum-mechanically measurable. The Krylov complexities computed with respect to both spaces exhibit almost identical behavior, thus enabling the use of Krylov complexity for systems where the Hamiltonian is unknown or in experimental settings. This is particularly relevant for quantum machine learning, where the system is described by unitaries and the Hamiltonian is not explicitly known. We then use this newly defined Krylov space to introduce the effective dimension, which captures the extent to which the state has evolved in the Krylov basis. This measure is upper-bounded by the number of pairwise distinct eigenvalues of the Hamiltonian, thereby providing a method to experimentally determine the number of eigenenergies.

[1] S. Čindrak, L. Jaurigue, K.Lüdge, J. High Energ. Phys 2024, 83

THU 7.6 Thu 15:30 ZHG008

Hamiltonian many-body model for strong vibrational coupling — •Mathis Noell, Jakob Kullmann, and Carsten Henkel — Universität Potsdam, Institut für Physik und Astronomie, Germany

Molecular vibrations may be strongly coupled to infrared micro cavities, and controversial results have been reported regarding changes in chemical reactions in and out of resonance. We study a simple many-body Hamiltonian that permits to retrieve strong-coupling conditions without recourse to damping. The cavity modes are represented as a dense continuum in an obvious extension of the Tavis-Cummings model. Depending on the scaling of the coupling constants (molecular oscillator strength) with the number of cavity modes and molecules, we find different regimes: the spectrum changes from a collective polariton mode to a photonic band with an anti-crossing. In between these limits, multiple scattering seems to generate spatially complex field patterns. We also consider an interaction including anti-rotating terms and estimate the energy shift of the collective ground state. This bridges polariton and Casimir physics.

THU 7.7 Thu 15:45 ZHG008

Impact of boundary conditions on a topological quantum kicked rotor — •Victoria Motsch[1], Nikolai Bolik[1], and Sandro Wimberger[2,3] — [1]Institut für Theoretische Physik, Universität Heidelberg — [2]Department of Mathematical, Physical and Computer Sciences, Parma University — [3]INFN, Sezione Milano-Bicocca, Parma group

We investigate the on-resonance Spin-1/2 Double Kicked Rotor under the influence of open (hard wall) and periodic boundary conditions. This system shows topological phases which could be observed in Bose-Einstein condensate experiments [1]. The Mean Chiral Displacement (MCD) as the proposed observable displays a strong dependence on the chosen boundary conditions. The spectrum under open boundary conditions displays edge states that can be shown to localize at the edge of the momentum basis. While the bulk observable MCD is sensitive to the boundary conditions as soon as the evolution touches the boundaries, the edge states could still act as indicators for topological transitions.

[1] N. Bolik *et. al.*, Phys. Rev. A 106, 043318 (2022)