# QI 9: Quantum Entanglement II

Time: Tuesday 11:00–12:30 Location: HS IX

QI 9.1 Tue 11:00 HS IX

**Full classification of Pauli Lie algebras** — •Gerard Aguilar, Simon Cichy, Jens Eisert, and Lennart Bittel — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

Lie groups, and therefore Lie algebras, are fundamental structures in quantum physics that determine the space of possible trajectories of evolving systems. However, their classification and characterization often becomes impractical for large systems. This work provides a comprehensive classification of Lie algebras generated by an arbitrary set of Pauli operators, from which an efficient method to characterize them follows. Mapping the problem to a graph setting, we identify a reduced set of equivalence classes for connected graphs: the free-fermionic Lie algebra, the set of all anti-symmetric Paulis, the Lie algebra of symplectic Paulis, and the space of all Pauli operators on n qubits, as well as controlled versions thereof. Out of these, we distinguish 6 Clifford inequivalent cases, for which we give a physical interpretation of their dynamics. We then extend this result to general graphs with arbitrarily many connected components. Our findings reveal a no-go result for the existence of small Lie algebras beyond the free-fermionic case in the Pauli setting and offer efficiently computable criteria for universality and extendibility of gate sets. These results bear significant impact in ideas in a number of fields like quantum control, quantum machine learning, or classical simulation of quantum circuits

QI 9.2 Tue 11:15 HS IX

**Closed-Form Expressions for Two- and Three-Colorable States** — •Konstantinos-Rafail Revis[1,2], Hrachya Zakaryan[1,2], and Zahra Raissi[1,2] — [1]Department of Computer Science, Paderborn University, Paderborn, Germany — [2]Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Paderborn, Germany

Graph states are a class of multi-partite entangled quantum states, where colorability, a property rooted in their mathematical foundation, has significant implications for quantum information processing. In this talk, we investigate the properties of graph states, focusing mainly on two-colorable and three-colorable graphs, but results for any colorability will be also discussed. A closed-form expression for all two-colorable graphs is presented. This result is tightly connected with the so-called orthogonal arrays and the minimum value of the Schmidt measure. Furthermore, we extend our analysis to every three-colorable graph state, revealing that they are equivalent via local operators to quantum orthogonal arrays, with a minimal number of Schmidt measure. The aforementioned results are extended to an arbitrary number of colors.

https://www.arxiv.org/abs/2408.09515

QI 9.3 Tue 11:30 HS IX

**The exact convex roof for GHZ-W mixtures for three qubits and beyond** — •Andreas Osterloh — TII, QRC, Abu Dhabi, UAE

I present an exact solution for the convex roof of the square root of the threetangle of GHZ-W mixtures for all states within the Bloch sphere. The key to the exact solution is the characteristic pattern for the pure states on the Bloch sphere surface that take part in the optimal decomposition. The method used here can be applied to arbitrary SL-invariant tangles of degree 2d specifically to their d-th root.

QI 9.4 Tue 11:45 HS IX

**Super-activation and incompressibility of genuine multipartite entanglement** — •Lisa T. Weinbrenner[1], Klára Baksová[2], Sophia Denker[1], Simon Morelli[3], Xiao-Dong Yu[4], Nicolai Friis[2], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Germany — [2]Atominstitut, TU Wien, Vienna, Austria — [3]Basque Center for Applied Mathematics (BCAM), Bilbao, Spain — [4]Department of Physics, Shandong University, Jinan 250100, China

Quantum correlations in the form of entanglement, quantum steering or Bell non-locality are resources for various information-processing tasks, but their detailed quantification and characterization remains complicated. One counter-intuitive effect is the phenomenon of super-activation of correlations, meaning that two copies of a quantum state may exhibit forms of correlations which are absent on the single-copy level.

In this contribution, we develop a systematic approach towards a full understanding of this phenomenon using the paradigm of genuine multipartite entanglement [1]. We introduce systematic methods for studying super-activation of entanglement based on symmetries and generalized notions of multipartite distillability. With this, we present novel criteria for super-activation as well as a quantitative theory of it. Moreover, we uncover forms of incompressible entanglement on multi-copy systems, which cannot be reduced to the single-copy level.

[1] Yamasaki et al., Quantum 6, 695 (2022); Palazuelos & de Vicente, Quantum 6, 735, (2022)

QI 9.5 Tue 12:00 HS IX

**Non-symmetric GHZ states; weighted hypergraph and controlled-unitary graph representations** — •Hrachya Zakaryan[1,2], Konstantinos-Rafail Revis[1,2], and Zahra Raissi[1,2] — [1]Department of Computer Science, Paderborn University, Paderborn, Germany — [2]Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Paderborn, Germany

Non-symmetric GHZ states, represent a significant yet underexplored class of multipartite entangled states with potential applications in quantum information. Despite their importance, the lack of a well-defined stabilizer formalism and corresponding graph representation has hindered their comprehensive study. We address this gap by introducing two novel graph formalisms and stabilizers for non-symmetric GHZ states. We provide a weighted hypergraph representation and demonstrate that non-symmetric GHZ states are local unitary (LU) equivalent to fully connected weighted hypergraphs. We provide stabilizers using local operations, and an ancilla. We further extend this framework to qudits, offering a specific form for non-symmetric qudit GHZ states and their LU equivalent weighted qudit hypergraphs. Lastly, we propose a graph formalism using controlled-unitary (CU) operations, showing that non-symmetric qudit GHZ states can be described using star-shaped CU graphs.

https://arxiv.org/abs/2408.02740

QI 9.6 Tue 12:15 HS IX

**Beating the Optimal Verification of Entangled States via Collective Strategies** — •Ye-chao Liu[1] and Jiangwei Shang[2] — [1]Zuse-Institut Berlin, Takustraße 7, 14195 Berlin, Germany — [2]Key Laboratory of Advanced Optoelectronic Quantum Architecture and Measurement (MOE), School of Physics, Beijing Institute of Technology, Beijing 100081, China

In the realm of quantum information processing, the efficient characterization of entangled states poses an overwhelming challenge, rendering the traditional methods including quantum tomography unfeasible and impractical. To tackle this problem, we propose a new verification scheme using collective strategies, showcasing arbitrarily high efficiency that beats the optimal verification with global measurements. Our collective scheme can be implemented in various experimental platforms and scalable for large systems with a linear scaling on hardware requirement, and distributed operations are allowed. More importantly, the approach consumes only a few copies of the entangled states, while ensuring the preservation of unmeasured ones, and even boosting their fidelity for any subsequent tasks. Furthermore, our protocol provides additional insight into the specific types of noise affecting the system, thereby facilitating potential targeted improvements. These advancements hold promise for a wide range of applications, offering a pathway towards more robust and efficient quantum information processing.