QI 7: Quantum Thermodynamics

Time: Tuesday 9:30–11:00 Location: BEY/0E17

QI 7.1 Tue 9:30 BEY/0E17

Probes of Full Eigenstate Thermalization in Ergodicity-Breaking Quantum Circuits — •Gabriel O. Alves, Felix Fritzsch, and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany

The eigenstate thermalization hypothesis (ETH) is the leading interpretation in our current understanding of quantum thermalization. Recent results uncovered strong connections between quantum correlations in thermalizing systems and the structure of free probability theory, leading to the notion of full ETH. However, most studies have been performed for ergodic systems and it is still unclear whether or how full ETH manifests in ergodicity-breaking models. We fill this gap by studying standard probes of full ETH in ergodicity-breaking quantum circuits, presenting numerical and analytical results for interacting integrable systems. These probes can display distinct behavior and undergo a different scaling than the ones observed in ergodic systems. For the analytical results we consider an interacting integrable dual-unitary model and present the exact eigenstates, allowing us to analytically express common probes for full ETH. We discuss the underlying mechanisms responsible for these differences and show how the presence of solitons dictates the behavior of ETH-related quantities in the dual-unitary model. We show numerical evidence that this behavior is sufficiently generic away from dual-unitarity when restricted to the appropriate symmetry sectors.

QI 7.2 Tue 9:45 BEY/0E17

Exploring Noisy Quantum Thermodynamical Processes via Global Depolarizing Approximation — Jian Li[1], Xiaoyang Wang[2], Marcus Huber[1], Nicolai Friis[1], and •Pharnam Bakhshinezhad[1] — [1]Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria — [2]RIKEN Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS), Wako 351-0198, Japan

Noise is an unavoidable challenge for quantum thermodynamical protocols in deep circuits [1]. To overcome the difficulty of analytically characterizing cumulative, gate-dependent errors, we introduce the Global Depolarizing Approximation (GDA), a scalable framework. The GDA approximates complex local noise channels with a single, system-wide depolarizing channel, requiring only a moderate circuit depth that approximates a unitary 2-design [2].

Applying the GDA to the Two-Sort Algorithmic Cooling (TSAC) protocol [3], we derive a novel analytical expression for its asymptotic cooling limit under realistic noise. This analysis reveals a fundamental noise-induced trade-off: the ideal exponential gain from increasing the qubit number is counteracted by an exponential increase in noise accumulation, which dictates an optimal qubit number and a sharp upper bound on the achievable cooling performance. We validate the GDA's accuracy against detailed physical noise simulations for both TSAC and Dynamic Cooling (DC) protocols [4]. Our framework offers a powerful tool for quantifying the thermodynamic cost of imperfect control in noisy quantum systems.

QI 7.3 Tue 10:00 BEY/0E17

Exact heat currents for multi-bath open quantum systems — •Matteo Garbellini[1], Valentin Link[2], and Walter Strunz[1] — [1]Institut für Theoretische Physik, Technische Universität Dresden, Dresden, Germany — [2]Technische Universität Berlin, Berlin, Germany

I present a numerically exact method for computing stationary heat currents in small quantum systems coupled to multiple bosonic reservoirs at different temperatures. Our approach leverages the recently introduced uniTEMPO method [1], which efficiently generates compressed auxiliary environments for non-Markovian Gaussian baths. Building upon this, we are able to efficiently compute heat currents into the reservoirs in both transient and steady-state regimes.

We apply our method to a single qubit strongly coupled to two baths and analyze how different coupling operators and the structure of the environments affect heat transport. Finally, we apply the method to quantum refrigeration. For a three-level system coupled to two reservoirs, we find that although autonomous global refrigeration does not occur, a frequency-resolved analysis reveals local cooling of specific environmental modes, suggesting a route to exploiting this localized effect with additional weakly coupled modes.

[1] V. Link, H.-H. Tu, and W. T. Strunz, Phys. Rev. Lett. 132, 200403 (2024)

QI 7.4 Tue 10:15 BEY/0E17

Local energy assignment for two interacting quantum thermal reservoirs — •Alessandra Colla[1,2], Bassano Vacchini[2], and Andrea Smirne[2] — [1]Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Dipartimento di Fisica "Aldo Pontremoli", Università degli Studi di Milano, Via Celoria 16, I-20133 Milan, Italy

Understanding how to assign internal energy, heat, and work in quantum systems beyond weak coupling remains a central problem in quantum thermodynamics, particularly as the difference between competing definitions becomes increasingly relevant. In this work [1], we identify two common sets of definitions for first law quantities that are used in the literature to describe the thermodynamics of quantum systems coupled to thermal environments. Both are conceptually non-symmetric, treating one part of the bipartition (the "system") differently from the other (the "bath"). We analyze these in a setting where such roles are not easily assigned, namely two large sets of thermal harmonic oscillators interacting with each other. We further compare them with a third set of definitions based on a local, conceptually symmetric open-system approach ("minimal dissipation") and discuss their quantitative and structural differences. We observe that all three sets of definitions differ substantially even in the dispersive regime, and that the minimal dissipation approach features distinct work peaks that increase with coupling strength.

[1] A. Colla, B. Vacchini and A. Smirne, New Journal of Physics 10.1088/1367-2630/ae24a0 (2025)

QI 7.5 Tue 10:30 BEY/0E17

Symmetry-Aware Cooling Protocols for High-Fidelity Initialization of Many-Body Spin Networks — •Durga Dasari[1], Saikat Sur[2], and Gershon Kurizki[3] — [1]3. Physics Institute, University of Stuttgart, Stuttgart, GERMANY — [2]Institute of Mathematical Sciences, Chennai, India — [3]Weizmann Institute of Science, Israel

Interacting quantum spin networks are central to many-body quantum simulations, sensing, and quantum computation, all of which demand a highly polarized initial state. However, cooling such networks to their ground state is impeded by interaction-induced correlations and symmetry-protected subspaces. Resetting a mixed many-body state to the computational-zero state thus remains an open challenge. We present a universal cooling strategy that couples the network collectively to an ancilla spin that periodically dumps entropy into an ultracold bath. Using graph-theoretic analysis of the network*capturing connectivity, symmetry sectors, and correlation flow*we bypass the intractability of full quantum dynamics. This analysis reveals a unique coherent control sequence that deliberately breaks graph-imposed symmetry constraints and unlocks otherwise inaccessible cooling pathways. The resulting protocol provides a general and experimentally realistic route to high-fidelity purification of complex spin networks.

QI 7.6 Tue 10:45 BEY/0E17

Local and global thermodynamics of pure decoherence processes — •Irene Ada Picatoste[1], Alessandra Colla[2], and Heinz-Peter Breuer[1] — [1]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Dipartimento di Fisica Aldo Pontremoli, Università degli Studi di Milano, via Celoria 16, I-20133 Milan, Italy

We study the thermodynamics of pure decoherence processes in open quantum systems coupled to a thermal reservoir. We perform a comparison between two viewpoints: a local approach [1] which is based on the system's degrees of freedom alone, and global approaches [2, 3] which require knowledge about the degrees of freedom of the bath. We also employ a specific model and, in calculating entropy production, internal energy, heat and work, we find substantial differences between the formulations. Concretely, in the global approaches we observe a large heat exchange, that refers in this particular case to the rearranging of the energy in the degrees of freedom of the reservoir, rather than to energy entering or leaving the system [4].

[1] A. Colla and H.-P. Breuer, Phys. Rev. A 105, 052216 (2022).

[2] M. Esposito, K. Lindenberg, and C. V. den Broeck, New J. Phys. 12, 013013 (2010).
[3] G. T. Landi and M. Paternostro, Rev. Mod. Phys. 93, 035008 (2021).
[4] I. A. Picatoste, A. Colla, and H.-P. Breuer, Phys. Rev. A 112, 022210 (2025).