Kyoto Workshop on Quantum Thermodynamics and Stochastic Thermodynamics 2025

Monday, 8 December 2025 - Friday, 12 December 2025

Yukawa Institute for Theoretical Physics

Kyoto University

Book of Abstracts

YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

Transformative research area (B): Quantum Energy Innovation

Scope

Recent advances in physics have increasingly highlighted the need to understand energy conversion at microscopic scales—a regime where quantum phenomena and statistical fluctuations coexist. On one hand, quantum thermodynamics seeks to extend concepts in thermodynamics into the quantum realm, grappling with effects such as coherence, entanglement, and quantum fluctuations. On the other hand, stochastic thermodynamics provides a framework to analyze energy processes in systems where random thermal fluctuations dominate, especially in small-scale or nonequilibrium settings. With the integration of these two approaches, quantum stochastic thermodynamics is rapidly emerging.

At the heart of this emerging intersection lies a fundamental question: How do quantum effects modify the limits of thermodynamic or informational devices? To answer this question, a wealth of insights—including resource theory, non-Markovianity, and optimal transport theory—is currently flowing into quantum stochastic thermodynamics.

This conference aims to bring together leading experts in quantum stochastic thermodynamics and foster interactions that will accelerate progress in this new frontier. The conference will be held in person to enhance active interactions. We look forward to seeing you in Kyoto in December 2025.

https://indico.yukawa.kyoto-u.ac.jp/event/68/

About this workshop

This workshop is "YITP International Workshop Led by Young Researchers" supported by YITP. It is also co-organized by the Grant-in-Aid for Transformative Research Area (B) “Quantum Energy Innovation.”

Acknowledgement

If your research was benefitted from discussions/talks/new collaborations during this workshop, please acknowledge YITP, as it will help organizing workshops in the future.

Example:

The authors thank Yukawa Institute for Theoretical Physics at Kyoto University, where this work was initiated [completed] during "Kyoto Workshop on Quantum Thermodynamics and Stochastic Thermodynamics 2025" (YITP-I-25-03).

Organizing Committee

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MEXT Grant-in-Aid for Transformative Research Areas（B）

Pioneering and realizing innovative methods to improve the efficiency of energy generation/utilization through quantum effects website: https://tajima-qi.lab.kyushu-u.ac.jp/qe-innovation/en/

Kyoto Workshop on Quantum Thermodynamics and Stochastic Thermodynamics 2025

Timetable

2025/12/8(Mon)			2025/12/9(Tue)			2025/12/10(Wed)			2025/12/11(Thu)			2025/12/12(Fri)		
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9:30 - 9:40	Opening													
9:40 - 10:30	Invited	Keiji Saito	9:30 - 10:20	Invited	Yoshihiko Hasegawa	9:30 - 10:20	Invited	Kihwan Kim	9:30 - 10:20	Invited	Eric Lutz	9:30 - 10:20	Invited	Géraldine Haack
10:30 - 11:20	Long	Ken Funo	10:20 - 11:10	Long	Hiroyasu Tajima	10:20 - 11:10	Long	Atsushi Noguchi	10:20 - 11:10	Long	Andreas Dechant	10:20 - 11:10	Long	Tan Van Vu
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14:20 - 14:40	Short	Shion Yamashika	14:20 - 15:10	Long	Sosuke Ito	14:20 - 14:40	Short	Koji Yamaguchi	14:20 - 15:10	Long	Kiyoshi Kanazawa	14:20 - 14:40	Short	Jihui Pei
14:40 - 15:00	Short	Hisao Hayakawa				14:40 - 15:00	Short	Tomohiro Shitara				14:40 - 15:00	Short	Guohua Xu
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CONTENTS

DECEMBER 8, 9:40 – 10:30

Keiji Saito, "Inverse thermodynamic uncertainty relation and entropy production"

Nonequilibrium current fluctuations represent one of the central topics in nonequilibrium physics. The thermodynamic uncertainty relation (TUR) is widely acclaimed for rigorously establishing a lower bound on current fluctuations, expressed in terms of the entropy production rate and the average current. In this study, we focus on an upper bound for the fluctuations, referred to as the inverse thermodynamic uncertainty relation (iTUR). We derive a universal iTUR expression in terms of the entropy production rate for continuous-variable systems governed by over-damped Langevin equations, as well as for discrete-variable systems described by Markov jump processes. The iTUR establishes a no-go theorem prohibiting perpetual superdiffusion in systems with a finite entropy production rate and a finite spectral gap. The divergence of the variance of any current becomes possible only when the spectral gap vanishes or the entropy production rate diverges. As a relevant experimental scenario, we apply the iTUR to the phenomenon of giant diffusion, emphasizing the pivotal roles of the spectral gap and entropy production.

Ref. Vo, Dechant, KS, Phys. Rev. Lett. (2025)

DECEMBER 8, 10:30 – 11:20

Ken Funo, "Thermodynamic approach to cooling limit of Gaussian feedback"

Feedback cooling plays a critical role in stabilizing quantum systems and achieving low temperatures, where a key question is to determine the fundamental thermodynamic limits on cooling performance. In this talk, we discuss a fundamental bound on quantum feedback cooling in Gaussian systems, by deriving a generalized second law of thermodynamics involving the kinetic temperatures of the system and a measure of quantum information flow obtained by continuous measurement. In contrast to previously known bounds, the obtained bound can be saturated by experimentally feasible situations using the quantum Kalman filter with a large feedback gain, where the cooling efficiency approaches its maximum. We further analyze the attainability of maximum cooling efficiency at finite cooling power by deriving a thermodynamic uncertainty relation (TUR) for feedback cooling in classical underdamped systems. From the obtained TUR, we find that divergence of the fluctuation of the reversible local mean velocity (i.e., taking a sufficiently large feedback gain) is the key to achieve such situations. Our theory provides a general framework for understanding the cooling limit from the perspectives of information thermodynamics.

DECEMBER 8, 11:20 – 11:40

Gentaro Watanabe, “Fast Charging of Quantum Batteries via Dephasing and Their Asymptotic Freedom”

Quantum batteries---energy storage devices based on quantum systems---have recently attracted significant attention as promising candidates for achieving fast and efficient charging by exploiting quantum effects. In this talk, we present our recent theoretical results showing that controlled decoherence, typically considered detrimental to quantum devices, can instead be harnessed as a universal resource for enhancing the charging performance of quantum batteries [1].
Specifically, we analyze a star-configuration model in which an ensemble of N qubits (the battery) is charged by a driven qubit (the charger) subject to pure dephasing noise. By carefully tuning the dephasing rate, one can balance coherent oscillatory energy exchange with quantum Zeno suppression, thereby realizing an optimal regime of fast and robust energy transfer. This mechanism is universal, applying to batteries modeled by either two-level systems or harmonic oscillators, and remains resilient against detuning of system frequencies.
Furthermore, we uncover an "asymptotic freedom"-like behavior: in the large-N limit, the ratio of extractable work (ergotropy) to stored energy approaches unity as 1-O(1/N), even though the steady state of the battery remains mixed [2]. This remarkable feature originates from the emergence of approximate ground-state degeneracy in the collective battery system. Finally, we discuss the scaling behavior of the charging time with N and the experimental feasibility of implementing our proposal with existing quantum platforms such as superconducting qubits and NMR systems.

[1] R. Shastri, C. Jiang, G.-H. Xu, B. P. Venkatesh, and G. Watanabe, npj Quantum Inf. 11, 9 (2025).
[2] C. Purkait, B. P. Venkatesh, and G. Watanabe, arXiv:2508.13497 [quant-ph] (2025).

DECEMBER 8, 13:30 – 14:20

Artemy Kolchinsky, “A variational approach to nonequilibrium thermodynamics”

I will discuss our recent work based on an information-theoretic variational principle for entropy production, closely related to the Donsker–Varadhan formula from large deviations theory. This principle can be applied to many types of systems (continuous and discrete, stochastic and deterministic, linear and nonlinear, classical and quantum), and it provides a unified way to approach many problems in nonequilibrium thermodynamics. As illustrative applications, I will discuss three topics: (1) decomposition of dissipation into conservative ("excess") and nonconservative ("housekeeping") parts, (2) derivation of thermodynamic uncertainty relations and thermodynamic speed limits, and (3) thermodynamic inference in many-body systems, such as nonequilibrium spin glasses. I will also mention some questions and open problems raised by this approach.

DECEMBER 8, 14:20 – 14:40

Shion Yamashika, "Quantum Fisher Information as a measure of symmetry breaking in quantum many-body systems"

Symmetry breaking underlies diverse phenomena from phase transitions in condensed matter to fundamental interactions in gauge theories. Despite many proposed indicators, a general quantification of symmetry breaking that is faithful, computable, and valid in the thermodynamic limit has remained elusive. Here, within quantum resource theory, we propose the quantum Fisher information (QFI) as such a measure. We demonstrate its utility by computing QFI for paradigmatic models: in the BCS superconductor, the QFI counts the number of Cooper pairs; in the transverse-field XY spin chains, it captures topological phase transition that has no local order parameter; and in quantum quench dynamics, it allows us to exactly derive the microscopic origin and conditions of the quantum Mpemba effect in terms of excitation propagation, including in the thermodynamic limit--beyond the reach of previous analyses. Our results show that the QFI, which is a complete resource monotone in the resource theory of asymmetry that plays the role of entanglement entropy in entanglement theory, faithfully captures symmetry breaking in condensed-matter systems. These results highlight the QFI as a universal and physically meaningful diagnostic of symmetry breaking in both equilibrium and non-equilibrium quantum many-body systems.

arXiv:2509.07468

DECEMBER 8, 14:40 – 15:00

Hisao Hayakawa, "Mpemba effect in bistable continuous potentials"

The Mpemba effect is a counterintuitive phenomenon in which an initially hot material cools down faster than an initially warm material.

After the confirmation of this effect in an experiment in 2020, it became a hot subject in non-equilibrium thermodynamics.

In this talk, I will present an exact solution of the heat relaxation of a particle in a one-dimensional double-well potential. I will also extend this analysis to a particle in a two-dimensional double-well potential, if I have time.

DECEMBER 9, 9:30 – 10:20

Yoshihiko Hasegawa, "Fundamental Precision Limits in Finite-Dimensional Quantum Thermal Machines"

Enhancing the precision of a thermodynamic process inevitably comes with a thermodynamic cost. This idea was recently formalized as the thermodynamic uncertainty relation, which states that the lower bound on the relative variance of thermodynamic currents decreases as entropy production increases. From another perspective, this relation suggests that if entropy production could become infinitely large, the lower bound on the relative variance could approach zero. However, achieving infinite entropy production is clearly impossible in practice. This implies that physical constraints impose fundamental limits on precision, independent of the system's dynamics. In this work, we derive such fundamental precision limits for open quantum thermal machines with finite-dimensional systems and environments. Crucially, these bounds depend only on the initial configuration and not on the dynamics. Using a quantum battery as a case study, we show that these fundamental limits reveal a trade-off between the amount of stored energy and the charging precision.

DECEMBER 9, 10:20 – 11:10

Hiroyasu Tajima, "Universal tradeoff relations between resource cost and irreversibility of channels: General-resource Wigner-Araki-Yanase theorems and beyond"

Quantum technologies offer exceptional -- sometimes almost magical -- speed and performance, yet every quantum process costs physical resources. Designing next-generation quantum devices, therefore, depends on solving the following question: which resources, and in what amount, are required to implement a desired quantum process? Casting the problem in the language of quantum resource theories, we prove a universal cost-irreversibility tradeoff: the lower the irreversibility of a quantum process, the greater the required resource cost for its realization [1]. The trade-off law holds for a broad range of resources -- energy, magic, asymmetry, coherence, athermality, and others -- yielding lower bounds on resource cost of any quantum channel. Its broad scope positions this result as a foundation for deriving the following key results: (1) we show a universal relation between the energetic cost and the irreversibility for arbitrary channels, encompassing the energy-error tradeoff for any measurement or unitary gate; (2) we extend the energy-error tradeoff to free energy and work costs; (3) we extend the Wigner-Araki-Yanase theorem [2], which is the universal limitation on measurements under conservation laws, to a wide class of resource theories: the probability of failure in distinguishing resourceful states via a measurement is inversely proportional to its resource cost; (4) we prove that infinitely many resource-non-increasing operations in fact require an infinite implementation cost as a generalization of the results on the cost-diverging Gibbs-preserving operations [3]. These results can be regarded as a generalization of the earlier work on asymmetry [4,5], and we also discuss their relation to those studies.

[1]H. Tajima, K. Yamaguchi, R. Takagi and Y. Kuramochi, arXiv:2507.23760 (2025) (QIP2026)

[2]H. Araki and M. M. Yanase Phys. Rev. 120 622 (1960).

[3]H. Tajima, R. Takagi, Phys. Rev. Lett. 134, 170201, 2025 (QIP2025)

[4]H. Tajima, N. Shiraishi, K. Saito Phys. Rev. Lett. 121, 110403 (2018) (QIP2020)

[5]H. Tajima, R. Takagi, Y. Kuramochi arXiv:2206.11086 (2022) (QIP2023)

DECEMBER 9, 11:10 – 11:30

Olga Movilla Miangolarra, "Quantum Schrödinger bridges: Large deviations and time-symmetric ensembles"

Quantum counterparts of Schrödinger's classical bridge problem have been around for the better part of half a century. During that time, several quantum approaches to this multifaceted classical problem have been introduced. In this presentation, we will show how to unify, extend, and interpret several such approaches through a classical large-deviations perspective. To this end, we consider time-symmetric ensembles that are pre- and postselected before and after a Markovian experiment is performed. Then, the Schrödinger bridge problem is that of finding the most likely joint distribution of initial and final outcomes that is consistent with the obtained endpoint results. The derived distribution provides quantum Markovian dynamics that bridge the observed endpoint states in the form of density matrices. The solution retains its classical structure in that density matrices can be expressed as the product of forward-evolving and backward-evolving matrices. In addition, the quantum Schrödinger bridge allows inference of the most likely distribution of outcomes of an intervening measurement with unknown results. This distribution may be written as a product of forward- and backward-evolving expressions, in close analogy to the classical setting, and in a time-symmetric way.
https://journals.aps.org/pra/abstract/10.1103/k35b-rkct

DECEMBER 9, 13:30 – 14:20

Sarah Loos, "Moving with minimum effort – Optimal work protocols for systems with memory and activity"

We discuss thermodynamically optimal driving protocols for systems with hidden degrees of freedom. As a paradigmatic case, we consider the finite-time transport of a particle in a harmonic trap through a medium with minimum average work input. For passive particles in viscous fluids, the optimal protocol features two symmetric jumps at the beginning and end of the trajectory [1]. We analytically show—and experimentally confirm using colloids in optical tweezers—that this structure originates from an intrinsic time-reversal symmetry of the optimal control problem [2]. Remarkably, this symmetry is universal for systems governed by a linear generalized Langevin equation, independent of the specific memory kernel or noise correlations, and thus also applies to glassy, granular, or active systems. Our findings establish a general criterion for identifying thermodynamically optimal protocols and provide a practical framework for constructing them. We further address the role of information thermodynamics in closed-loop control of active particles [3].

[1] Schmiedl, Seifert, PRL 98, 108301 (2007).

[2] Loos, Monter, Ginot, and Bechinger, PRX 14, 021032 (2024).

[3] Garcia-Millan, Schüttler, Cates, and Loos, PRL 135, 088301 (2025); PRE 112, 024119 (2025).

DECEMBER 9, 14:20 – 15:10

Sosuke Ito, “Thermodynamics based on optimal transport”

Over the last two decades, the relationship between optimal transport theory and stochastic thermodynamics in the context of classical diffusion systems has been widely discussed. It is well known, for example, that state evolution with minimal dissipation over a finite time period is described by optimal transport protocols. In optimal transport theory, a notable of the metric is the 2-Wasserstein distance between the initial and final distributions, which represents this minimal dissipation. This expression of minimal dissipation also leads to dissipation being decomposed into conservative and non-conservative components.

In this talk, we will present various recent findings on this subject and discuss their applications to classical systems and quantum extensions.

DECEMBER 10, 9:30 – 10:20

Kihwan Kim, "A Single-Ion Information Engine for Charging Quantum Battery"

In this talk, I will present an implementation of a microscopic information engine in a trapped-ion system, where quantized mechanical motion plays the role of a quantum battery. Information engines convert measurement and feedback into useful work, but a central challenge is how to store the extracted work in a controllable and reusable way. Our experiment addresses this by repeatedly charging the motional mode of a single trapped ion through measurement-based feedback, enabled by a fast, high-fidelity state-discrimination scheme that strongly suppresses measurement back-action on the motion. We achieve an information-to-ergotropy conversion efficiency of up to about 67% of the theoretical limit at an optimal reservoir temperature, and a maximum information-to-work conversion efficiency of 70%. These results show that trapped ions provide a powerful platform for studying information thermodynamics at the quantum level and for realizing microscopic information engines. If time allows, I will also briefly discuss our related efforts on scaling up to larger qubit numbers using two-dimensional ion crystals. This talk is based on our recent work, Phys. Rev. Lett. 135, 140403 (2025).

DECEMBER 10, 10:20 – 11:10

Atsushi Noguchi, "Toward quantum engines with high-performance superconducting circuits"

The performance of the superconducting quantum circuits has been improved for decades, and several kinds of quantum manipulation have been demonstrated with superconducting circuits. In addition to unitary operations, over-coupled superconducting resonators can function as a Markov bath, allowing us to engineer the environment of superconducting quantum circuits. These technologies provide us the one of the best quantum hardware platforms to investigate experimental demonstrations of quantum thermodynamic experiments, such as quantum engines. Quantum coherence and entanglement can enhance the performance of the engines and overcome the limitations of the thermal engine on classical dynamics. In this talk, I will talk about the improvement of the performance of our superconducting circuits and trials for the demonstration of the quantum engines.

DECEMBER 10, 11:10 – 11:30

Kohei Yoshimura, “Quasiprobability thermodynamic uncertainty relation”

I present a quantum extension of the thermodynamic uncertainty relation (TUR) where dynamical fluctuations are quantified by the Terletsky-Margenau-Hill quasiprobability, a quantum generalization of the classical joint probability.
I will explain that the obtained inequality plays a complementary role to existing quantum TURs, focusing on observables' change rather than exchange of charges through jumps and respecting initial coherence.
I also discuss how the quasiprobability TUR enables us to explore a quantum anomalous phenomenon, dissipationless current, recently studied in [Tajima & Funo, PRL (2021)], from the viewpoint of the quasiprobability's non-classicality, without relying on a specific eigenbasis.
arXiv:2508.14354

DECEMBER 10, 13:30 – 14:20

Nelly NG Huei Ying, “Thermal operations from informational equilibrium”

Thermal operations are quantum channels that have taken a prominent role in deriving fundamental thermodynamic limitations in quantum systems. We show that these channels are uniquely characterized by a purely quantum information theoretic property: They admit a dilation into a unitary process that leaves the environment invariant when applied to the equilibrium state. In other words, they are the only channels that preserve equilibrium between system and environment. Extending this perspective, we explore an information theoretic idealization of heat bath behavior, by considering channels where the environment remains locally invariant for every initial state of the system. These are known as catalytic channels. We show that catalytic channels provide a refined hierarchy of Gibbs-preserving maps for fully-degenerate Hamiltonians, and are closely related to dual unitary quantum circuits.

DECEMBER 10, 14:20 – 14:40

Koji Yamaguchi, “Quantum geometric tensor determines the i.i.d. conversion rate in the resource theory of asymmetry for any compact Lie group”

Quantifying physical concepts in terms of the ultimate performance of a given task has been central to theoretical progress, as illustrated by thermodynamic entropy and entanglement entropy, which respectively quantify irreversibility and quantum correlations. Symmetry breaking is equally universal, yet lacks such an operational quantification. While an operational characterization of symmetry breaking through asymptotic state-conversion efficiency is a central goal of the resource theory of asymmetry (RTA), such a characterization has so far been completed only for the $U(1)$ group among continuous symmetries. Here, we identify the complete measure of symmetry breaking for a general continuous symmetry described by any compact Lie group. Specifically, we show that the asymptotic conversion rate between many copies of pure states in RTA is determined by the quantum geometric tensor, thereby establishing it as the complete measure of symmetry breaking. As an immediate consequence of our conversion rate formula, we also resolve the Marvian-Spekkens conjecture on conditions for reversible conversion in RTA, which has remained unproven for over a decade. By applying our analysis to a standard setup in quantum thermodynamics, we show that asymptotic state conversion under thermal operations generally requires macroscopic coherence in the thermodynamic limit.

arXiv:2411.04766 [quant-ph] (https://arxiv.org/abs/2411.04766)

DECEMBER 10, 14:40 – 15:00

Tomohiro Shitara, "The i.i.d. State Convertibility in the Resource Theory of Asymmetry for Finite Groups"

We derive both the exact and approximate conversion rates between i.i.d. pure states under covariant operations in the resource theory of asymmetry for symmetries described by finite groups. We derive the formula for the exact conversion rate and thereby identify the relevant set of resource measures. The exact conversion is in general irreversible due to multiple independent resource measures, but we also find the condition for reversibility. On the other hand, we show that the approximate conversion rate either diverges or equals zero, which implies that the asymmetry can be amplified infinitely if we allow a vanishingly small error. We reveal the underlying mechanism of such a counterintuitive phenomenon, by showing the existence of maximally uniform states that act as a catalysis.

https://arxiv.org/abs/2312.15758

DECEMBER 11, 9:30 – 10:20

Eric Lutz, "Combining energy efficiency and quantum advantage in cyclic machines"

Energy efficiency and quantum advantage are two important features of quantum devices. I will present an experimental realization that combines both features in a quantum engine coupled to a quantum battery that stores the produced work, using a single ion in a linear Paul trap. The quantum nature of the device is first established by observing nonclassical work oscillations with the number of cycles as verified by energy measurements of the battery. In addition, shortcut-to-adiabaticity techniques are applied to suppress quantum friction and improve work production. While the average energy cost of the shortcut protocol is only about 3%, the work output is enhanced by up to approximately 33%, making the machine significantly more energy efficient. I will finally show that the quantum engine consistently outperforms its classical counterpart in this regime.

DECEMBER 11, 10:20 – 11:10

Andreas Dechant, "Thermodynamics and embedding of generalized Langevin equations"

For Markovian dynamics, stochastic thermodynamics provides a consistent framework relating macroscopic thermodynamic properties to the properties of individual trajectories under time-reversal. By contrast, for non-Markovian dynamics, where the evolution depends on the history of the process, the definition of time-reversal is ambiguous and there is no established framework of stochastic thermodynamics. In this talk, I will explore the possibility of defining the thermodynamics of non-Markovian dynamics based on Markovian embedding. Focusing on linear (or semi-linear) generalized Langevin equations, I will clarify the conditions under which such equations can be represented by higher-dimensional Markovian Langevin equations. In particular, I will discuss the invariance of entropy production under the embedding representation, which allows for a unique identification of the entropy production of a non-Markovian system based on its Markovian representation.

DECEMBER 11, 11:10 – 11:30

Ryuna Nagayama, "Duality between dissipation-coherence trade-off and thermodynamic speed limit for noisy oscillations"

We derive two fundamental trade-offs for general stochastic limit cycles in the weak-noise limit based on the thermodynamic uncertainty relation. The first is the dissipation-coherence trade-off, which was numerically conjectured and partially proved by Santolin and Falasco [Phys. Rev. Lett. 135, 057101 (2025)]. This trade-off bounds the entropy production required for one oscillatory period using the number of oscillations that occur before steady-state correlations are disrupted. The second is the thermodynamic speed limit, which bounds the entropy production with the Euclidean length of the limit cycle. These trade-offs are obtained by substituting mutually dual observables, derived from the stability of the limit cycle, into the thermodynamic uncertainty relation. This fact allows us to regard the dissipation-coherence trade-off as the dual of the thermodynamic speed limit.

R. Nagayama, and S. Ito. "Duality between dissipation-coherence trade-off and thermodynamic speed limit based on thermodynamic uncertainty relation for stochastic limit cycles in the weak-noise limit" arXiv:2509.06421

DECEMBER 11, 13:30 – 14:20

Shingo Kono, "Scalable superconducting circuit optomechanics with millisecond quantum coherence"

Superconducting circuit optomechanics based on vacuum-gap capacitors offers a versatile platform for controlling mechanical oscillators in the quantum regime, yet achieving long coherence and scalability has remained a major challenge. We address these limitations by developing a silicon-etched-trench fabrication technique that reproducibly forms vacuum-gap capacitors incorporating high-stress, high-Q superconducting membranes with strong optomechanical coupling. Using this platform, we achieve mechanical quality factors exceeding 40 million, corresponding to mechanical quantum coherence times beyond 10 milliseconds. We further demonstrate multimode optomechanical lattices with more than 20 sites, which not only exhibit basic optomechanical operation but also enable on-site optomechanical interactions to map microwave mode distributions in the lattices. Finally, we observe collective ground-state motion among degenerate mechanical modes, confirming access to the quantum regime in multimode optomechanical systems. These results establish a new regime of long-lived, controllable, and scalable optomechanics, opening new opportunities for studying quantum thermodynamics with mechanical oscillators.

DECEMBER 11, 14:20 – 15:10

Kiyoshi Kanazawa, "Stochastic thermodynamics for classical non-Markov jump processes based on the Fourier embedding"

Stochastic thermodynamics explores the thermodynamic structure of small systems based on stochastic processes. However, conventional stochastic thermodynamics has relied on the Markov assumption---the assumption that the system's history dependence is negligible---except for a few specific non-Markov models. Since many real physical phenomena have history dependence, it is important to develop stochastic thermodynamics for more general non-Markov processes with memory effects. In this talk, we present stochastic thermodynamics for non-Markov jump processes. We develop the Fourier embedding and derive the master equation for general non-Markov jump processes as a new tool to formulate the time-reversal symmetry. We show the first and second laws for non-Markov jump processes. Finally, we present two new non-Markov models that can be investigated by our framework from thermodynamic viewpoints.

DECEMBER 12, 9:30 – 10:20

Géraldine Haack, “Quantum Kinetic Uncertainty Relations in Mesoscopic Conductors at Strong Coupling”

Kinetic Uncertainty Relations (KURs) establish quantum transport precision limits by linking signal-to-noise ratio (SNR) to the system's dynamical activity, valid in the weak-coupling regime where particle-like transport dominates. At strong coupling, quantum coherence challenges the validity of KURs and questions the concept of activity itself.

In this work, we achieve two distinct, yet complementary main results. First, we introduce a general definition of dynamical activity valid at arbitrary coupling, which reveals the breakdown of standard KURs at strong coupling. Second, we prove a novel uncertainty relation valid at arbitrary coupling strength, which we denote Quantum KUR (QKUR). This QKUR corresponds to a nontrivial quantum extension of KUR, involving fundamental contributions of the generalized dynamical activity. These two achievements provide a general framework for out-of-equilibrium quantum transport precision analysis.

Explicit steady-state expressions are obtained within Green's-function and Landauer-Büttiker formalisms. We illustrate these concepts for paradigmatic quantum-coherent mesoscopic devices: a single quantum channel pinched by a quantum point contact and open single- and double-quantum dot systems.

Reference:Blasi, Rodriguez, Moskalets, Lopez, Haack, arXiv:2505.13200 (2025).

DECEMBER 12, 10:20 – 11:10

Tan Van Vu, “Thermodynamics of Precision in Open Quantum Systems”

In this talk, I will present recent progress on the thermodynamics of precision in open quantum systems, spanning both Markovian and non-Markovian regimes. For Markovian dynamics, quantum extensions of thermokinetic uncertainty relations reveal how coherence can relax classical bounds, allowing enhanced precision at reduced thermodynamic cost [1]. Going beyond the weak-coupling and memoryless limit, I will introduce universal precision bounds valid for general open quantum systems subjected to two-point measurements [2]. These bounds demonstrate that the relative fluctuations of time-antisymmetric currents are limited not only by entropy production but also by a forward-backward asymmetry term, which reflects the time-reversal symmetry breaking caused by dynamical factors such as quantum coherence and quantum entanglement. For generic observables, precision is instead constrained by a generalized activity term, which quantifies changes in the environment.

[1] T. Van Vu, PRX Quantum 6, 010343 (2025).

[2] T. Van Vu, R. Honma, and K. Saito, arXiv:2508.21567.

DECEMBER 12, 11:10 – 11:30

Yue Liu, "Optimally Fast Qubit Reset"

In practice, qubit reset must be operated in an extremely short time, which incurs a thermodynamic cost within multiple orders of magnitude above the Landauer bound. We present a general framework to determine the minimal thermodynamic cost and the corresponding optimal protocol for memory erasure under arbitrary erasure speeds. Our study reveals the divergent behavior of minimal entropy production in the short-time limit depends on the convergence and divergence of the jump operator. There is an inherent trade-off between the minimal required time and the set error probability for the convergent class. Moreover, we find the optimal protocol exhibits general features in the fast-driving regime. To illustrate these findings, we employ fermionic and bosonic baths as examples. Our results suggest that the superOhmic bosonic heat bath is suitable for qubit reset.

Y. Liu, C. Huang, X. Zhang and D. He, Phys. Rev. Lett. 134, 100401(2025)

DECEMBER 12, 13:30 – 14:20

Kay Brandner, "Weak-Memory Dynamics in Discrete Time "

Dynamical memory induced by hidden degrees of freedom is ubiquitous in small-scale systems. While current efforts to systematically characterize this phenomenon focus almost exclusively on continuous-time settings, discrete-time models are emerging as powerful tools to understand the dynamics of coarse-grained systems, and to derive their effective evolution equations from first principles. To help bridge this gap, we develop a universal theory of discrete dynamics with weak memory. By establishing rigorous conditions for the existence and general methods for the construction of accurate time-local approximations, we provide a versatile framework for analyzing moderate memory effects without assuming a strong separation of time scales.

DECEMBER 12, 14:20 – 14:40

Jihui Pei, "Promoting Fluctuation Theorems into Covariant Forms"

The principle of covariance, a cornerstone of modern physics, asserts the equivalence of all inertial frames of reference. Fluctuation theorems, as extensions of the second law of thermodynamics, establish universal connections between irreversibility and fluctuation in terms of stochastic thermodynamic quantities. However, these relations typically assume that both the thermodynamic system and the heat bath are at rest with respect to the observer, thereby failing to satisfy the principle of covariance. In this Letter, by introducing covariant work and heat that incorporate both energy-related and momentum-related components, we promote fluctuation theorems into covariant forms applicable to moving thermodynamic systems and moving heat baths. We illustrate this framework with two examples: the work statistics of a relativistic stochastic field and the heat statistics of a relativistic Brownian motion. Although our Letter is carried out in the context of special relativity, the results can be extended to the nonrelativistic limit. Our Letter combines the principle of covariance and fluctuation theorems into a coherent framework and may have applications in the study of thermodynamics relevant to cosmic microwave background as well as the radiative heat transfer and noncontact friction between relatively moving bodies.

Phys. Rev. Lett. 134, 237102 (2025)

DECEMBER 12, 14:40 – 15:00

Guohua Xu, "Thermodynamic Geometric Constraint on the Spectrum of Markov Rate Matrices"

The spectrum of Markov generators encodes physical information beyond simple decay and oscillation, which reflects irreversibility and governs the structure of correlation functions. In this work, we prove an ellipse theorem that provides a universal thermodynamic geometric constraint on the spectrum of Markov rate matrices. The theorem states that all eigenvalues lie within a specific ellipse in the complex plane. In particular, the imaginary parts of the spectrum, which indicate oscillatory modes, are bounded by the maximum thermodynamic force associated with individual transitions. This spectral bound further constrains the possible values of correlation functions of two arbitrary observables. We compare our result with a previously proposed conjecture, which remains an open problem and warrants further investigation.

arXiv:2507.08938

POSTER SESSION

Odd-numbered posters will be in “Session A,” and even-numbered posters will be in “Session B.”

<table>
<tr><th colspan="2">2025/12/8 (Mon)</th><th colspan="2">2025/12/9 (Tue)</th><th colspan="2">2025/12/10 (Wed)</th><th colspan="2">2025/12/11 (Thu)</th></tr>
<tr><td>15:30-16:00</td><td>Poster preview for session A</td><td>15:40-16:10</td><td>Poster preview for session B</td><td rowspan="2">15:30-17:00</td><td rowspan="2">Poster session A</td><td rowspan="2">15:40-17:00</td><td rowspan="2">Poster session B</td></tr>
<tr><td>16:00-17:00</td><td>Poster session A</td><td>16:10-17:00</td><td>Poster session B</td></tr>
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Posters No. 1 to 14 will be displayed in Room Y206 on the 2nd floor.

No	Session	Name	Title
1	A	Akihiko Sonoda	Analysis of entropy production in finitely slow processes between nonequilibrium steady states
2	B	Asad Ali	Quantum Mpemba Effect in One Dimensional Dirty Boson Model under Stark Potential
3	A	Guilherme Fiusa	Thermodynamics of counting observables in stochastic excursions
4	B	Hiroshi Murakami	Non-equilibrium Bose-Einstein condensation in nanoscale systems: terahertz vibrational condensation of interfacial water in reverse micelles
5	A	Honoe Kandabashi	States Minimizing Entropy Production and Its Rate in Classical Markov Processes
6	B	Hyun-Myung Chun	Fluctuation-response inequalities for nonequilibrium steady states
7	A	Isaac Layton	Preserving the thermal state in mixed classical-quantum systems
8	B	Jann van der Meer	Thermodynamic bounds and error correction for faulty coarse graining
9	A	Kaito Tojo	Thermodynamic uncertainty relation under continuous measurement and feedback with quantum-classical-transfer entropy
10	B	Yuto Nakajima	Categorical Approach to the Statistical Mechanics of Many-Anyon Systems
11	A	Kotaro Sekiguchi	Improvement of Speed Limits: Quantum Effect on the Speed in Open Quantum Systems
12	B	Masaaki Tokieda	Minimal work protocols in driven-dissipative quantum systems: An impulse ansatz approach
13	A	Ruicheng Bao	A random coarse-graining framework with applications to thermodynamic inference
14	B	Ruoyu Yin	Preparation of cat states in many-body eigenbasis via non-local measurement

Posters No. 15 to 28 will be displayed in Room Y306 on the 3rd floor.

No	Session	Name	Title
15	A	Ryogo Hara	Dynamics of entanglement asymmetry for space-inversion symmetry of free fermions on honeycomb lattices
16	B	Ryotaro Honma	Information flow and thermodynamic uncertainty relation for interacting quantum systems
17	A	Shanhe Su	Geometric bounds on the trade-off relation in quantum tricycles
18	B	Shiling Liang	Exact Identities and Universal Bounds for Nonequilibrium Nonlinear Responses
19	A	Shozo Yamada	Many-body burst in isolated quantum systems
20	B	Shuta Kobayashi	Deep reinforcement learning for feedback cooling
21	A	Steven Blaber	Nonequilibrium Thermodynamics of Amorphous Solids: from Gravitational Wave Detectors to Superconducting Qubits
22	B	Taiki Ishiyama	Exact current fluctuations in a tight-binding chain with dephasing noise
23	A	Takano Taira	Markovianity and non-Markovianity of Particle Bath with Dirac Dispersion Relation
24	B	Tingzhang Shi	Four-vector work distribution and covariant Jarzynski's equality in relativistic piston model
25	A	Yoh Maekawa	Information-thermodynamic speed limits based on optimal transport theory
26	B	Yoshiaki Horiike	Performance bound of quantum annealing
27	A	Yoshiteru Yonetani	Exciton quantum dynamics in molecular logic gates: A spin-boson model study
28	B	Yosuke Mitsuhashi	Unitary Designs of Symmetric Local Random Circuits

1

Akihiko Sonoda, "Analysis of entropy production in finitely slow processes between nonequilibrium steady states"

We investigate entropy production in finitely slow transitions between nonequilibrium steady states in Markov jump processes using the improved adiabatic approximation method, which has a close relationship with the slow driving perturbation. This method provides systematic improvement of the adiabatic approximation on infinitely slow transitions from which we obtain nonadiabatic corrections. We analyze two types of excess entropy production and confirm that the leading adiabatic contribution reproduces known results, and then obtain nonadiabatic corrections written in terms of thermodynamic metrics defined in protocol parameter spaces. We also numerically study the resulting excess entropy production in a two-state system.

Phys. Rev. E 106, 064119

2

Asad Ali, "Quantum Mpemba Effect in One Dimensional Dirty Boson Model under Stark Potential"

We investigated the quantum Mpemba effect (QME) in a one-dimensional Bose-Hubbard model across clean and disordered regimes using the exact numerical technique of a four-site lattice under Lindblad dynamics with local dephasing noise. By systematically varying hopping strength, onsite interactions, Stark potentials, and random disorder, we probe relaxation dynamics toward a common steady state using trace distance, relative entropy, entanglement asymmetry, and $¥ell_1$ norm coherence metrics. Our results reveal that QME emerges prominently in the clean-interacting regime, where many-body correlations drive nonlinear relaxation pathways, enabling initially distant states to overtake closer ones. In contrast, non-interacting systems exhibit conventional thermalization, whereas Stark potentials and random disorder suppress QME by inducing localization barriers, with disorder causing milder delays compared to the pronounced effects of Stark fields. Entanglement asymmetry proves to be particularly sensitive to the symmetry restoration dynamics underlying QME. These findings elucidate the critical role of interactions in anomalous relaxation and provide insights for controlling quantum thermalization in experimental platforms such as ultra-cold atomic systems.

3

Guilherme Fiusa, "Thermodynamics of counting observables in stochastic excursions"

Understanding thermodynamics beyond steady-state is crucial for characterizing current fluctuations and dissipation. We introduce stochastic excursions as a framework for analyzing thermodynamic processes that alternate between two phases, labelled inactive and active; an excursion starts with a transition into the active phase and ends upon returning to inactivity. By incorporating counting observables, our approach extends beyond full counting statistics (FCS), enabling the study of finite-time fluctuations and trajectory-level thermodynamics. We show that excursion statistics recover FCS results and uncover a fundamental relation between fluctuations of counting observables at the single-excursion level and the steady-state noise. To illustrate these ideas, we apply our framework to two models: a three-qubit quantum absorption refrigerator and a double quantum dot. Those models demonstrate how excursions distinguish heating, cooling, and idle cycles—elucidating trade-offs between cooling capacity, precision, and transport. Our results offer new insights into the non-equilibrium thermodynamics of trajectories and provide tools for optimizing heat engines and control strategies. https://arxiv.org/abs/2505.06208 and https://arxiv.org/abs/2506.05160

4

Hiroshi Murakami, "Non-equilibrium Bose-Einstein condensation in nanoscale systems: terahertz vibrational condensation of interfacial water in reverse micelles"

Fröhlich demonstrated that the population number of the lowest-frequency mode of the terahertz (THz) vibrational band becomes macroscopic, which is called vibrational condensation, when the energy-input rate exceeds a threshold (Fröhlich, Nature 1970). Moreover, he proposed that this condensation occurs by metabolic energy in cells and facilitates their functions. The following theoretical studies have supported a phenomenon of this non-equilibrium Bose-Einstein condensation (Zhang et al. Phys. Rev. Lett. 2019). However, there are no experimental studies that observe the spectral transition due to this condensation. We have observed it (H.M. Sci. Rep. 2023; J. Phys. Chem. B 2024; J. Phys. Chem. Lett. 2025). For nanoscale reverse micelles under microwave energy input at 2.45 GHz, the amplitude of a sub-THz vibration band is remarkably enhanced, accompanied by spectral narrowing and a shift to lower frequencies above a certain microwave intensity, compared to the spectrum in thermal equilibrium. This spectral narrowing was observed during the observation time of a few tens of minutes, indicating that the coherent vibration persists for a very long time. Furthermore, it is considered that this condensation occurs in heat flow resulting from an inhomogeneous temperature distribution in the sample solution induced by microwave irradiation.

5

Honoe Kandabashi, "States Minimizing Entropy Production and Its Rate in Classical Markov Processes"

Entropy is a key physical quantity that characterizes the efficiency and irreversibility of energy conversion. The larger the entropy production—the total entropy increase of a system and its environment—the less efficient and more irreversible the process becomes.

While states minimizing entropy production or its rate are well studied near equilibrium, their properties under strongly nonequilibrium conditions remain unclear.

Here, we investigate classical systems described by continuous-time, discrete-state Markov processes with fixed transition matrices. We analyze (i) the states that minimize the entropy production rate and (ii) the initial conditions that minimize the total entropy production from
$t=0$ to ∞, providing both general arguments and numerical results for simple models.

6

Hyun-Myung Chun, “Fluctuation-response inequalities for nonequilibrium steady states”

We present a unified framework of fluctuation–response inequalities (FRIs) for Markov jump processes, derived from the Cramér–Rao bound. The framework generalizes recently developed fluctuation–response relations by connecting the fluctuations of a broad class of observables to the system’s response under transition-rate perturbations. Known results arise as limiting cases, placing them within a single overarching structure. We further extend the framework to open quantum systems described by Lindblad dynamics, leading to a quantum FRI in which dynamical activity constrains the response. Numerical examples in both classical and quantum settings highlight the robustness of the inequalities across system topologies and observation times.

7

Isaac Layton, “Preserving the thermal state in mixed classical-quantum systems”

Despite the huge advances of both classical and quantum non-equilibrium thermodynamics in recent years, much less is understood about thermodynamics at their intersection. This is important for the many paradigms involving interacting classical and quantum variables in physics and chemistry, such as measurement-based feedback, non-adiabatic molecular dynamics and semi-classical black hole physics.

In this talk I will show how a basic first question in classical-quantum thermodynamics – is there dynamics that preserves the thermal state? – may be answered in the affirmative. In doing so, I will describe how to construct measurement-based feedback where the entire system of quantum system + classical controller obeys detailed balance, and provide methods for molecular dynamics that obey the second law over both classical nuclei and quantum electrons. These results will be illustrated using two simple toy models: an analytically solvable model of a qubit coupled to an overdamped classical system, and an underdamped quantum-classical oscillator model that exhibits thermalisation.

https://arxiv.org/abs/2504.10587

8

Jann van der Meer, “Thermodynamic bounds and error correction for faulty coarse graining”

At the nanoscale, random effects govern not only the dynamics of a physical system but may also affect its observation. This work introduces a novel paradigm for coarse graining that eschews the assignment of a unique coarse-grained trajectory to a microscopic one. Instead, observations are not only coarse-grained but are also accompanied by a small chance of error. Formulating the problem in terms of path weights, we identify a condition on the structure of errors that ensures that the observed entropy production does not increase. As a result, the framework of stochastic thermodynamics for estimating entropy production can be extended to this broader class of systems. As an application, we consider Markov networks in which individual transitions can be observed but may be mistaken for each other. We motivate, derive, and illustrate thermodynamic bounds that relate the error sensitivity of the observed entropy production to the strength of the driving and are valid for arbitrary network topologies. If sufficiently many transitions in the network can be observed, redundancies in the coarse-grained trajectories can be used to detect and correct errors, which potentially improves naive estimates of entropy production. We conclude with an outlook on subsequent research on thermodynamic bounds for erroneous coarse graining.

https://arxiv.org/abs/2507.02463

9

Kaito Tojo, “Thermodynamic uncertainty relation under continuous measurement and feedback with quantum-classical-transfer entropy”

Quantum feedback control plays a crucial role in stabilizing quantum systems subject to external noise[1]. We extend quantum thermodynamic uncertainty relation by incorporating QC-transfer entropy[2], which enables its applicability to non-Markovian

quantum feedback control. Our results are expected to clarify fundamental thermodynamic constraints underlying continuous quantum control.

[1] J. Zhang, et al , Phys. Rep. 679, 1 (2017). [2] T. Yada, et al , Phys. Rev. Lett. 128, 170601 (2022).

10

Yuto Nakajima, “Categorical Approach to the Statistical Mechanics of Many-Anyon Systems

Anyonic excitations from the topologically ordered ground states have been attracting interests from both the condensed matter and high-energy communities.
Due to their fractional charges and inherently interacting nature, standard statistical mechanics requires modifications when dealing with a macroscopic number of anyons. The framework of unitary modular tensor categories (UMTCs) offers a powerful description, where the Verlinde formula in the thermodynamic limit provides a natural modification to obtain the thermal partition function of the dynamical anyons. This perspective generalizes the ""quantum singlet condition"" in the Chern-Simons matter (CSM) theories on $S^1 ¥times S^2$, which are the TQFTs of the fractional quantum Hall system, and motivates us to revisit the Haldane-Wu fractional statistics.
In this poster session, we will explore the connection between Haldane-Wu statistics and UMTCs, and demonstrate how the statistics in the CSM can be generalized to arbitrary UMTCs.
arXiv:2508.14961[cond-mat.str-el]

11

Kotaro Sekiguchi, “Improvement of Speed Limits: Quantum Effect on the Speed in Open Quantum Systems”

In the context of quantum speed limits, it has been shown that the minimum time required to cause a desired state conversion via the open quantum dynamics can be estimated using the entropy production.
However, the established entropy-based bounds tend to be loose, making it difficult to accurately estimate the minimum time for evolution.
In this research, we have combined the knowledge of the entropy-based speed limits with that of the resource theory of asymmetry (RTA) and provided much stricter inequalities.
Our results show that the limitation on the change rate of states and expectation values can be divided into two parts: quantum coherence for energy (i.e., asymmetry) contributed by the system and the heat bath and the classical entropy-increasing effect from the bath.
As a result, our inequalities demonstrate that the difference in the speed of evolution between classical and quantum open systems, i.e., the quantum enhancement in speed, is determined by the quantum Fisher information, which measures quantum fluctuations of energy and serves as a standard resource measure in the resource theory of asymmetry.
We further show that a similar relation holds for the rate of change of expectation values of physical quantities.
arXiv:2410.11604

12

Masaaki Tokieda, “Minimal work protocols in driven-dissipative quantum systems: An impulse ansatz approach”

The second law of thermodynamics sets a lower bound on the work performed to the system during a transition between two thermal equilibrium states, with equality achieved only in the quasi-static limit. For processes completed in finite time, part of the extractable work is inevitably dissipated, motivating the search for optimal driving protocols. While this problem has been extensively studied within classical stochastic thermodynamics [1], quantum analyses remain comparatively scarce and are often restricted to approximate treatments of dissipation, such as the widely used Lindblad master equation [2]. In this work, we investigate minimal work protocols for a driven qubit coupled to a harmonic oscillator bath, described by the Caldeira-Leggett model [3]. We employ the hierarchical equations of motion [4] to identify optimal protocols beyond the reach of standard Lindblad treatments. We find that the protocol previously established for underdamped Brownian motion [5]—featuring delta functional impulses at the boundaries—remains nearly optimal in the quantum, non-Markovian regime. Furthermore, we identify situations where the Lindblad equation fails to capture high-temperature behavior, underscoring the necessity of fully quantum treatments of dissipative work processes.

[1] T. Schmiedl and U. Seifert, Phys. Rev. Lett. 98, 108301 (2007); E. Aurell, C. M-Monasterio, and P. M-Ginanneschi, ibid 106, 250601 (2011).

[2] V. Gorini, A. Kossakowski, and E. C. G. Sudarshan, J. Math. Phys. 17, 821 (1976); G. Lindblad, Commun. Math. Phys. 48, 119 (1976).

[3] A. O Caldeira and A. J Leggett, Ann. Phys. 149,374 (1983).

[4] Y. Tanimura and R. Kubo, J. Phys. Soc. Jpn. 58, 101 (1989).

[5] A. Gomez-Marin, T. Schmiedl, and U. Seifert, J. Chem. Phys. 129, 024114 (2008).

13

Ruicheng Bao, “A random coarse-graining framework with applications to thermodynamic inference”

Understanding and quantifying thermodynamic irreversibility is central to nonequilibrium statistical physics, yet its direct experimental assessment remains difficult, especially in large or interacting systems. We present a random coarse-graining framework that enables robust inference of irreversibility from minimal experimental data. The method exploits asymmetries in cross-correlations of coarse-grained observables, providing rigorous lower bounds on entropy production without requiring knowledge of microscopic dynamics. For many-particle systems, we propose a practical implementation in which real space is partitioned into virtual cells and only particle numbers within each cell are counted. This approach can be realized with standard video microscopy, eliminating the need for single-particle tracking or trajectory reconstruction. Because of its generality and low data requirements, the random coarse-graining framework

offers a versatile tool for probing nonequilibrium thermodynamics in a broad range of experimental settings.
https://arxiv.org/abs/2508.11586v1

14

Ruoyu Yin, "Preparation of cat states in many-body eigenbasis via non-local measurement"

Engineered dissipation offers a promising route to prepare correlated quantum many-body states that are otherwise difficult to access using purely unitary protocols. However, creating superpositions of multiple many-body eigenstates with tunable properties remains a major challenge. We propose to periodically interrupt the many-body evolution by precisely removing a given many-body Fock state through a non-local post-selected measurement protocol. Upon tuning the measurement period, we show that a dark state manifold survives the removal, allowing us to filter the system and generate a coherent superposition within this manifold at long times. As a testbed, we study a non-integrable spin-1 XY chain featuring a solvable family of eigenstates that can differ macroscopically in quasiparticle excitations. Our protocol generates tunable superpositions of these eigenstates, including the spin-1 Greenberger–Horne–Zeilinger state and a generalized variant with tunable spatiotemporal order. Under perturbations, the system exhibits an exceptionally long-lived metastable regime where the engineered superpositions remain robust. Our work provides new insight into quantum state preparation via non-local measurements using tools available in current quantum simulators.
arXiv:2507.00199

15

Ryogo Hara, "Dynamics of entanglement asymmetry for space-inversion symmetry of free fermions on honeycomb lattices"

While symmetry breaking is a central concept in modern physics, its faithful quantification in quantum-many body systems remains challenging. In this context, entanglement asymmetry (EA) has been proposed as a novel quantity grounded in resource theories, providing a powerful framework to quantify symmetry breaking beyond conventional approaches. To date, however, EA has been applied only to symmetries of Lie groups and their subgroups. Here, we extend the notion of EA to space-inversion symmetry and apply it to free fermions on honeycomb lattices, where space-inversion symmetry plays a crucial role in the system's topological properties. In particular, we analytically calculate the EA for local subsystems both in and out of equilibrium, and find that the extent of space-inversion symmetry breaking at the subsystem level qualitatively depends on the edge geometry of the subsystem—an effect that cannot be captured by conventional order parameters.

16

Ryotaro Honma, “Information flow and thermodynamic uncertainty relation for interacting quantum systems”

In recent years, various thermodynamic bounds have been investigated within the framework of nonequilibrium thermodynamics. One prominent example is the thermodynamic uncertainty relation (TUR), which characterizes a trade-off between the relative fluctuations of currents and entropy production. TUR has been studied in both classical and quantum systems. When two systems interact, information flow arises between them, which contributes to the second law of thermodynamics for subsystems. In classical bipartite systems, it has been shown that not only entropy production but also information flow can relax the lower bound on current fluctuations. However, it has remained unclear how TUR is modified in interacting quantum systems and how quantum effects contribute to the precision of currents. In this work, we derive a subsystem TUR for interacting quantum systems described by the GKSL master equation. We show that, similarly to classical systems, information flow relaxes the lower bound on current fluctuations, and furthermore, quantum effects contribute as correction terms. This work provides a new perspective on fundamental precision limits in information-thermodynamic machines with quantum coherence and quantum clocks.

17

Shanhe Su, “Geometric bounds on the trade-off relation in quantum tricycles”

We establish a finite-time quantum tricycle driven by an external field and investigate its thermodynamic performance in the slow-driving regime. By developing a perturbative expansion of heat with respect to operation time, we capture the dynamics of heat exchange processes beyond the quasistatic limit. Within a geometric framework, we derive fundamental bounds on trade-off between the cooling rate and coefficient of performance, governed by the thermodynamic length and trajectory geometry in control space. Our findings unveil intrinsic limits to the performance of quantum thermal machines and highlight the role of geometry in shaping finite-time thermodynamics. This work advances the fundamental understanding of quantum thermodynamic processes and offers guiding principles for the new design of quantum technologies.

18

Shiling Liang, “Exact Identities and Universal Bounds for Nonequilibrium Nonlinear Responses”

Understanding how systems respond to external perturbations is fundamental to statistical physics. For systems far from equilibrium, a general framework for response remains elusive. While progress has been made on the linear response of nonequilibrium systems, a theory for the nonlinear regime under finite perturbations has been lacking. Here, building on a novel connection between response and mean first-passage times in continuous-time Markov chains, we derive a comprehensive theory for the nonlinear response to archetypal local perturbations. We establish an exact identity that universally connects the nonlinear response of any observable to its linear counterpart via a simple scaling factor. This identity directly yields universal bounds on the response magnitude. Furthermore, we establish a universal bound on response resolution — an inequality that constrains an observable's change by its intrinsic fluctuations — thereby setting a fundamental limit on the signal-to-noise ratio. These results provide a rigorous and general framework for analyzing nonlinear response far from equilibrium, which we illustrate with an application to transcriptional regulation.

Bao, R. and Liang, S. , 2024. Nonlinear Response Identities and Bounds for Nonequilibrium Steady States. arXiv preprint, arXiv:2412.19602.

19

Shozo Yamada, “Many-body burst in isolated quantum systems”

The approach to thermal equilibrium in isolated quantum many-body systems is among the central issues concerning the foundation of statistical mechanics. The eigenstate thermalization hypothesis (ETH) [1], which is widely believed to hold in chaotic systems, ensures that a system eventually reaches thermal equilibrium starting from an arbitrary initial state. Nevertheless, the ETH does not describe the thermalization process itself. In fact, it is theoretically possible to envisage an initial state that causes the expectation value of an observable to ``burst’’—or to suddenly deviate significantly from its equilibrium value—at a specific later time even for a chaotic system. However, whether or not this phenomenon can be realized with experimentally accessible states remains elusive.

In this presentation, we focus on matrix product states (MPSs) as a proxy for such states, given their efficiency in representing lowly entangled states such as ground states of local Hamiltonians [2]. We conduct a numerical simulation to identify the initial state causing a burst by employing the density matrix renormalization group method [3]. We find that an initial MPS with a bond dimension (which characterizes entanglement) independent of the system size is sufficient to generate a burst of a prescribed amplitude for a given observable if the time of the burst is small enough. This is compatible with the analytical argument by local random quantum circuits. These results altogether suggest that a burst phenomenon can arise from a properly chosen initial state with low entanglement, that can be prepared as a ground state of a local Hamiltonian.

[1] M. Srednicki, J. Phys. A Math. Gen. 32, 1163 (1999).

[2] F. Verstraete and J. I. Cirac, Phys. Rev. B 73, 094423 (2006).

[3] S. R. White, Phys. Rev. Lett. 69, 2863 (1992).

20

Shuta Kobayashi, “Deep reinforcement learning for feedback cooling”

The study of feedback cooling, a process that removes thermal fluctuations from the environment and maintains particles in low-energy states, holds significant importance for practical applications. Feedback cooling has been extensively investigated within the framework of information thermodynamics.

Concurrently, the use of machine learning to address physical problems has gained considerable attention in recent years, particularly for its potential to resolve nonlinear problems that are analytically intractable.

In feedback systems, the manipulator—commonly referred to as the ""demon""—acquires information about the system and performs optimal control.

This functionality can be implemented using deep reinforcement learning.

In this study, we designed a reinforcement learning capable of sequentially acquiring system information and applying feedback control to decrease the kinetic tempeature in a Langevin system."

21

Steven Blaber, “Nonequilibrium Thermodynamics of Amorphous Solids: from Gravitational Wave Detectors to Superconducting Qubits”

A major limiting factor to the precision of next generation gravitational wave detectors (GWDs) is the mechanical loss from Brownian thermal noise in the mirror coatings. Concomitantly, dielectric loss of amorphous solids remains a major source of decoherence in modern superconducting qubits. For over 50 years, the two-level system (TLS) model has stood as the prevailing description of both mechanical and dielectric loss in amorphous solids. Our atomistic modeling shows that TLS are not independent as typically assumed, but form a sparse, interconnected network. I explore the dissipation of driven stochastic networks, demonstrating the impact of network topology and energy distribution. Our model for the mechanical loss of amorphous solids provides a major advance beyond the quintessential two-level system model and reveals new avenues for the study of amorphous materials.

https://doi.org/10.48550/arXiv.2406.17978

22

Taiki Ishiyama, “Exact current fluctuations in a tight-binding chain with dephasing noise”

Motivated recent interest in current fluctuations in quantum many-body systems, we theoretically study the impact of dissipation on current fluctuations [1,2]. Focusing on a tight-binding chain with dephasing noise, we obtain an exact Fredholm determinant formula for the moment generating function of the integrated current. This exact solution enables us to derive the large-deviation function of the current in the long-time limit, revealing that the presence of any finite dephasing destroys ballistic fluctuations and leads to diffusive ones.

Furthermore, we show that there is a crossover from ballistic to diffusive behavior in the weak dephasing regimes. The derivation is based on the duality and integrability of the system and employs techniques similar to those successfully applied to stochastic interacting systems.

[1] T. Ishiyama, K. Fujimoto, T. Sasamoto, arXiv:2504.06989.

[2] T. Ishiyama, K. Fujimoto, T. Sasamoto, in preparation.

23

Takano Taira, “Markovianity and non-Markovianity of Particle Bath with Dirac Dispersion Relation”

An open quantum system is the study of the dynamics of a quantum system coupled to an environment. When the coupling is weak and the environment evolves on a much slower timescale than the system, the dynamics can be described by a Markovian master equation, also known as the Gorini–Kossakowski–Sudarshan–Lindblad (GKSL) equation [1,2]. However, this description breaks down in both the short-time [3] and long-time regimes [4], often requiring resorting to numerical methods. To analyze these regimes analytically, we introduce a minimal model [5], in which a two-level system is coupled to a one-dimensional particle bath characterized by a Dirac dispersion relation. We show that the short- and long-time dynamics are governed by the high- and low-energy features of the spectral density: a high-energy cutoff controls the short-time behavior, while the low-energy structure—such as the spectral Dirac gap—determines the long-time decay. By examining the wave function of the system, we find that a bound state emerges when a spectral Dirac gap opens, while the scattering state exhibits exponential growth up to a finite spatial range before rapidly decaying to zero in the large-space limit, showing resonant-state behavior. Finally, we propose an experimental realization of our model using an optical waveguide array in the Su–Schrieffer–Heeger (SSH) configuration. We show that the relevant features of the model—such as the Dirac gap—can be engineered using current photonic technologies, enabling direct observation of the predicted Markovian-to-non-Markovian crossover in realistic parameter regimes.

[1] Gorini, V., Kossakowski, A., & Sudarshan, E. C. G. (1976). J. Math. Phys., 17(5), 821–825.

[2] Lindblad, G. (1976). Commun. Math. Phys., 48, 119–130.

[3] Chiu, C. B., Sudarshan, E. C. G., & Misra, B. (1977). Phys. Rev. D, 16(2), 520.

[4] Khalfin, L. A. (1958). Sov. Phys. JETP, 6(6), 1053–1063.

[5] Taira, T., Hatano, N., & Nishino, A. (2024). arXiv preprint arXiv:2406.17436.
https://arxiv.org/abs/2406.17436

24

Tingzhang Shi, “Four-vector work distribution and covariant Jarzynski's equality in relativistic piston model”

We investigate the non-equilibrium four-vector work in an expanding relativistic piston. By deriving the exact work distribution, we verify the covariant form of Jarzynski’s equality. In the non-relativistic limit, our results consistently reproduce the non-relativistic results of Lua and Grosberg [J. Phys. Chem. B 109, 6805 (2005)]. We further demonstrate that the momentum component of four-vector work remains significant in both the special-relativistic and Galilean-relativistic frameworks. In addition, we introduce a novel geometrical technique for analyzing the dynamics of relativistic collision processes, which can be naturally extended to three-dimensional piston models.

25

Yoh Maekawa, “Information-thermodynamic speed limits based on optimal transport theory”

A geometric understanding of non-equilibrium thermodynamics based on optimal transport theory has been advanced since the 2010s.
The connection between optimal transport theory and non-equilibrium thermodynamics is represented by thermodynamic speed limits, which are geometric inequalities that provide lower bounds on entropy production.
In this presentation, we introduce information-thermodynamic speed limits for bipartite systems subject to Markov jump processes based on optimal transport theory. Using insights from graph theory, we define the Wasserstein distance for subsystems and derive geometric inequalities that provide lower bounds on the subsystem's partial excess entropy production. The partial excess entropy production can then be decomposed into two quantities: a thermodynamic quantity, ""the sum of the change in Shannon entropy of the subsystem and excess thermal dissipation,"" and an information-theoretic quantity, ""the change in mutual information induced by the subsystem."" Thus, the resulting speed limits can be interpreted as information-thermodynamic speed limits.

26

Yoshiaki Horiike, “Performance bound of quantum annealing”

In simulated annealing, the system is gradually cooled and led to the ground state. This heuristic approach solves the optimization problem where the ground state is mapped to a low-cost state. Quantum annealing employs quantum fluctuation rather than thermal fluctuation to solve the optimization problem, and both experiment and simulation have shown that quantum annealing guides the system to the ground state faster than thermal fluctuation. Despite those differences, the difference between quantum and thermal fluctuation is obscure. In our poster session, we discuss the difference between quantum and thermal fluctuation from the perspective of the performance bound. Our analysis is based on stochastic thermodynamics and extends it to the quantum regime to reveal the difference.

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Yoshiteru Yonetani, "Exciton quantum dynamics in molecular logic gates: A spin-boson model study"

Exciton-based molecular logic gates, in which exciton flow is precisely controlled, could enable molecular-scale computing even within the quantum regime. However, it remains unclear whether such an implementation is practically feasible. In this study [Yonetani, Chem. Phys. 570, 111860 (2023)], we investigated feasibility of realizing exciton-based quantum gates, specifically the NOT and Hadamard gates, using a path-integral semiclassical approach. The system was modeled by a spin-boson Hamiltonian consisting of the logic gate and an environmental bath represented by harmonic oscillators. Our results indicate that a strong excitonic coupling ($J > 1000$ cm−1) is required to achieve high-fidelity computation ($F > 0.98$). Lower temperatures and smaller reorganization energies further improve the fidelity. Nevertheless, moderate temperature and reorganization energy can yield acceptable performance if the system has a sufficiently large coupling. Possible molecular systems satisfying these conditions are also discussed.

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Yosuke Mitsuhashi, "Unitary Designs of Symmetric Local Random Circuits"

We have established the method of characterizing the unitary design generated by a symmetric local random circuit. Concretely, we have shown that the necessary and sufficient condiiton for the circuit asymptotically forming a t-design is given by simple integer optimization for general symmetry and locality. By using the result, we explicitly give the maximal order of unitary design under the Z_2, U(1), and SU(2) symmetries for general locality. This work reveals the relation between the fundamental notions of symmetry and locality in terms of randomness.

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