Kyoto Workshop on Quantum Thermodynamics and Stochastic Thermodynamics 2025

Report of Contributions

Contribution ID: **11** Type: **Invited Talk**

Inverse thermodynamic uncertainty relation and entropy production

Monday, 8 December 2025 09:40 (50 minutes)

"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)"

Presenter: SAITO, Kenji (Kyoto University)

Session Classification: Monday

Contribution ID: **12** Type: **Long Talk**

Thermodynamic approach to cooling limit of Gaussian feedback

Monday, 8 December 2025 10:30 (50 minutes)

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.

Presenter: FUNO, Ken (University of Tokyo)

Session Classification: Monday

Contribution ID: **13** Type: **Short Talk**

Fast Charging of Quantum Batteries via Dephasing and Their Asymptotic Freedom

Monday, 8 December 2025 11:20 (20 minutes)

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).

Presenter: WATANABE, Gentaro (Zhejiang University)

Session Classification: Monday

Contribution ID: **14** Type: **Invited Talk**

A variational approach to nonequilibrium thermodynamics

Monday, 8 December 2025 13:30 (50 minutes)

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.

Presenter: KOLCHINSKY, Artemy (Universitat Pompeu Fabra)

Session Classification: Monday

Contribution ID: **15** Type: **Short Talk**

Quantum Fisher Information as a measure of symmetry breaking in quantum many-body systems

Monday, 8 December 2025 14:20 (20 minutes)

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

Presenter: YAMASHIKA, Shion (The university of electro communications)

Session Classification: Monday

Contribution ID: **16** Type: **Short Talk**

Mpemba effect in bistable continuous potentials

Monday, 8 December 2025 14:40 (20 minutes)

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.

Presenter: HAYAKAWA, Hisao (Yukawa Institute for Theoretical Physics)

Session Classification: Monday

Contribution ID: **17** Type: **Invited Talk**

Fundamental Precision Limits in Finite-Dimensional Quantum Thermal Machines

Tuesday, 9 December 2025 09:30 (50 minutes)

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.

Presenter: HASEGAWA, Yoshihiko (University of Tokyo)

Session Classification: Tuesday

Contribution ID: **18** Type: **Long Talk**

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

Tuesday, 9 December 2025 10:20 (50 minutes)

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)

Presenter: TAJIMA, Hiroyasu (Kyushu university)

Session Classification: Tuesday

Contribution ID: **19** Type: **Short Talk**

Quantum Schrödinger bridges: Large deviations and time-symmetric ensembles

Tuesday, 9 December 2025 11:10 (20 minutes)

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

Presenter: MOVILLA MIANGOLARRA, Olga (University of La Laguna)

Session Classification: Tuesday

Contribution ID: **20** Type: **Invited Talk**

Moving with minimum effort –Optimal work protocols for systems with memory and activity

Tuesday, 9 December 2025 13:30 (50 minutes)

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).

Presenter: LOOS, Sarah (Max Planck Instutute for Dynamics and Self-Organizatio)

Session Classification: Tuesday

Contribution ID: **21** Type: **Long Talk**

Thermodynamics based on optimal transport

Tuesday, 9 December 2025 14:20 (50 minutes)

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.

Presenter: ITO, Sosuke (The University of Tokyo)

Session Classification: Tuesday

Contribution ID: **22** Type: **Invited Talk**

A Single-Ion Information Engine for Charging Quantum Battery

Wednesday, 10 December 2025 09:30 (50 minutes)

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).

Presenter: KIM, Kihwan (Tsinghua University)

Session Classification: Wednesday

Contribution ID: **23** Type: **Long Talk**

Toward quantum engines with high-performance superconducting circuits.

Wednesday, 10 December 2025 10:20 (50 minutes)

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.

Presenter: NOGUCHI, Atsushi (The University of Tokyo)

Session Classification: Wednesday

Contribution ID: **24** Type: **Short Talk**

Quasiprobability thermodynamic uncertainty relation

Wednesday, 10 December 2025 11:10 (20 minutes)

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

Presenter: YOSHIMURA, Kohei (RIKEN)

Session Classification: Wednesday

Contribution ID: **25** Type: **Invited Talk**

Thermal operations from informational equilibrium

Wednesday, 10 December 2025 13:30 (50 minutes)

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.

Presenter: NG HUEI YING, Nelly (Nanyang Technological University)

Session Classification: Wednesday

Contribution ID: **26** Type: **Short Talk**

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

Wednesday, 10 December 2025 14:20 (20 minutes)

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)

Presenter: YAMAGUCHI, Koji (Kyushu University)

Session Classification: Wednesday

Contribution ID: **27** Type: **Short Talk**

The i.i.d. State Convertibility in the Resource Theory of Asymmetry for Finite Groups

Wednesday, 10 December 2025 14:40 (20 minutes)

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

Presenter: TOMOHIRO SHITARA, Tomohiro Shitara (NTT)

Session Classification: Wednesday

Contribution ID: **28** Type: **Invited Talk**

Combining energy efficiency and quantum advantage in cyclic machines

Thursday, 11 December 2025 09:30 (50 minutes)

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.

Presenter: LUTZ, Eric (University of Stuttgart)

Session Classification: Thursday

Contribution ID: **29** Type: **Long Talk**

Thermodynamics and embedding of generalized Langevin equations

Thursday, 11 December 2025 10:20 (50 minutes)

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.

Presenter: DECHANT, Andreas (Kyoto University, Graduate School of Science, Department of Physics 1)

Session Classification: Thursday

Contribution ID: **30** Type: **Short Talk**

Duality between dissipation-coherence trade-off and thermodynamic speed limit for noisy oscillations

Thursday, 11 December 2025 11:10 (20 minutes)

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

Presenter: NAGAYAMA, Ryuna (The University of Tokyo)

Session Classification: Thursday

Contribution ID: **31** Type: **Invited Talk**

Scalable superconducting circuit optomechanics with millisecond quantum coherence

Thursday, 11 December 2025 13:30 (50 minutes)

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.

Presenter: KONO, Shingo (Niels Bohr Institute)

Session Classification: Thursday

Contribution ID: **32** Type: **Long Talk**

Stochastic thermodynamics for classical non-Markov jump processes based on the Fourier embedding

Thursday, 11 December 2025 14:20 (50 minutes)

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.

Presenter: KANAZAWA, Kiyoshi (Kyoto University)

Session Classification: Thursday

Contribution ID: **33** Type: **Invited Talk**

Quantum Kinetic Uncertainty Relations in Mesoscopic Conductors at Strong Coupling

Friday, 12 December 2025 09:30 (50 minutes)

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).

Presenter: HAACK, Géraldine (University of Geneva)

Session Classification: Friday

Contribution ID: **34** Type: **Long Talk**

Thermodynamics of Precision in Open Quantum Systems

Friday, 12 December 2025 10:20 (50 minutes)

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.

Presenter: Prof. VAN VU, Tan (Yukawa Institute for Theoretical Physics, Kyoto University)

Session Classification: Friday

Contribution ID: **35** Type: **Short Talk**

Optimally Fast Qubit Reset

Friday, 12 December 2025 11:10 (20 minutes)

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)

Presenter: LIU, Yue (Kyoto University)

Session Classification: Friday

Contribution ID: **36** Type: **Invited Talk**

Weak-Memory Dynamics in Discrete Time

Friday, 12 December 2025 13:30 (50 minutes)

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.

Presenter: BRANDNER, Kay (University of Nottingham)

Session Classification: Friday

Contribution ID: **37** Type: **Short Talk**

Promoting Fluctuation Theorems into Covariant Forms

Friday, 12 December 2025 14:20 (20 minutes)

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)

Presenter: PEI, Jihui (Peking University)

Session Classification: Friday

Contribution ID: **38** Type: **Short Talk**

Thermodynamic Geometric Constraint on the Spectrum of Markov Rate Matrices

Friday, 12 December 2025 14:40 (20 minutes)

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

Presenter: XU, Guohua (The University of Tokyo)

Session Classification: Friday