# DY 42: Stochastic Thermodynamics

Time: Friday 9:30–11:15 Location: H43

DY 42.1 Fri 9:30 H43

**Stochastic Thermodynamics of the Interacting Nonreciprocal Particles and Fields** — •Atul Tanaji Mohite and Heiko Rieger — Saarland University, Saarbrücken, Germany

Non-reciprocal interactions that violate Newtons law 'actio=reactio' are ubiquitous in nature and are currently intensively investigated in active matter, chemical reaction networks, population dynamics and many other fields. An outstanding challenge is the thermodynamically consistent formulation of the underlying stochastic dynamics that obeys local detailed balance and allows for a rigorous analysis of the stochastic thermodynamics of non-reciprocally interacting particles. Here we present such a framework for a broad class of active systems and derive by systematic coarse-graining exact expressions for the macroscopic entropy production. Four independent contributions to the thermodynamic dissipation can be identified, among which the energy flux sustaining vorticity currents manifests the presence of non-reciprocal interactions. Then, Onsager's non-reciprocal relations, the fluctuation-response relation, the fluctuation relation and the thermodynamic uncertainty relations for non-reciprocal systems are derived. Finally, we demonstrate that our general framework is applicable to a plethora of active matter systems and chemical reaction networks and opens new paths to understand the stochastic thermodynamics of non-reciprocally interacting many-body systems.

DY 42.2 Fri 9:45 H43

**Staying on Time: Precision and Cost of a Controlled Clock** — •Till Welker and Patrick Pietzonka — School of Physics and Astronomy, University of Edinburgh, United Kingdom

The precision of an autonomous clock is associated with an entropic cost. In overdamped systems, the precision-cost tradeoff is bounded by the thermodynamic uncertainty relation (TUR). To avoid paying immense costs while staying accurate over an extended period, the clocks in our phones, radios, and computers adapt their dynamics according to a precise reference clock.

We study the minimal model of the two-state controlled clock with one state running slower and one state running faster than the reference clock. At a rate $R$, the controlled clock reads out the reference clock and adjusts its state accordingly. While the clock hand progresses, the offset reaches an analytically solvable steady state, and the clock's error remains bounded.

The combined cost of the controlled and reference clock obeys the TUR. However, the operator of the controlled clock only needs to pay a part of that cost, namely the driving of the controlled clock and the cost of state adjustment. We show that there is an $R$-dependent tradeoff between the controlled clock's cost and its total error, and we explore the Pareto front of optimal clocks.

DY 42.3 Fri 10:00 H43

**Active Brownian information engine: Self-propulsion induced colossal performance** — •Rafna Rafeek and Debasish Mondal — Department of Chemistry and Center for Molecular and Optical Sciences and Technologies, Indian Institute of Technology Tirupati, Yerpedu 517619, Andhra Pradesh, India

Many biological systems operating in athermal (active) environments, can be modeled as an information engine, with the key aspect of utilizing information on the fluctuation to extort work from the noisy environment. In this study, we propose a feedback-driven information engine operating in a Gaussian-correlated active reservoir with characteristic strength ($D_a$) and correlation time ($\tau_a$), which outperforms its thermal counterpart. We obtain the optimal functioning criteria for the enhanced performance of the active Brownian information engine (ABIE), reliant on the dispersion of the steady state, which is analogous to its passive analog. We notice that a weakly correlated active bath extracts colossal work due to the reduced relative loss of information in the relaxation process. In the limit of fractionally smaller correlation time ( $t_a/t_r \to 0, t_a$ is thermal relaxation time), the upper bound on colossal work extraction is $0.202(D + D_a)$. The excess amount of extracted work reduces and converges to its passive counterpart in the higher limit of correlation time ($t_a/t_r \to high$). Interestingly, when correlation time is equivalent to relaxation time ($t_a/t_r = 1$), half the upper bound of excess work is achieved irrespective of activity strength. This study provides a new insight into understanding and designing the information-energy exchange of biological submicrometer motors.

DY 42.4 Fri 10:15 H43

**Entropy estimation for partially accessible Markov networks based on imperfect observations: Role of finite resolution and finite statistics** — •Jonas H. Fritz, Benjamin Ertel, and Udo Seifert — II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

Estimating entropy production from real observation data can be difficult due to finite resolution in both space and time and finite measurement statistics. We characterize the statistical error introduced by finite sample size and compare the performance of three different entropy estimators under these limitations for two different paradigmatic systems, a four-state Markov network and an augmented Michaelis-Menten reaction scheme. We consider the thermodynamic uncertainty relation, a waiting-time based estimator for resolved transitions and a waiting-time based estimator for blurred transitions in imperfect observation scenarios. For perfect measurement statistics and finite temporal resolution, the estimator based on resolved transitions performs best in all considered scenarios. The thermodynamic uncertainty relation gives a better estimate than the estimator based on blurred transitions at low driving affinities, whereas the latter performs better at high driving affinities. Furthermore, we find that a higher temporal and spatial resolution leads to slower convergence of measurement statistics, implying that for short measurement times, a lower resolution may be beneficial. Additionally, we identify a self-averaging effect for the waiting-time based entropy estimators that can reduce their variance for observations with finite statistics.

DY 42.5 Fri 10:30 H43

**Stochastic Calculus Approach to Thermodynamic Bounds for Jump Processes** — •Lars Stutzer, Cai Dieball, and Aljaž Godec — Mathematical bioPhysics Group, Max Planck Institute for Multidisciplinary Sciences, 37077 Göttingen, Germany

Thermodynamic inequalities bound dissipation from below in terms of fluctuations of, and correlations between, observable currents and densities. They are at the heart of thermodynamic inference. By establishing a stochastic-calculus for functionals of Markov-jump dynamics, we allow for immediate extensions of results derived for overdamped diffusion to discrete state spaces, which expands the range of bounds available for jump processes. Moreover, we use the calculus to prove new bounds for jump-processes, including transient thermodynamic uncertainty relations, finite-time correlation bounds, and the recently established transport bounds. While it was expected for these results carry over to discrete spaces, the methodological advance establishes them as an inherent property of stochastic equations of motion. Our results put Langevin and Markov-jump dynamics on a common footing on the level of individual stochastic trajectories. We illustrate the results by means of biologically motivated examples.

DY 42.6 Fri 10:45 H43

**Is learning in Neural Networks just very high dimensional parameter fitting?** — •Ibrahim Talha Ersoy — Universität Potsdam, Institut für Astronomie und Physik, Potsdam, Deutschland

Neural Networks (NNs) are known for their highly non-convex loss landscapes, shaped by the data and the error function. Unlike in convex optimization, the model navigates regions of changing curvature to find the global minimum. We anticipate qualitative changes in the model occurring at points where new error basins are explored. In information bottleneck settings, Tishby et al. (2015) suggested that transitions between distinct loss regions are associated with phase transitions, a concept proven in L2 setups by Ziyin et al. (2023), where they examined the onset of learning when varying the L2 regularizer strength. We extend the findings of Ziyin et al. (2023), interpreting them from an information geometric perspective and demonstrate further phase transitions when model changes. By distinguishing between the loss and error landscapes, we provide a rigorous argument that extends the scope of our results beyond the L2 setup. This approach enables a better understanding of the limitations of the free energy interpretation of the L2 loss function and provides a more accurate depiction. Finally, our results suggest a clear distinction between learning, characterised by phase transitions at points of model change, and fitting, where the model remains qualitatively fixed, lacking phase transitions.

DY 42.7 Fri 11:00 H43

**Coherent effects in the semiclassical limit of quantum work**
— •Nicolás Torres-Domínguez[1], Carlos Viviescas[2], and JD Urbina[3] — [1]Chalmers tekniska högskola, Göteborg, Sweden — [2]Universidad Nacional de Colombia, Bogotá, Colombia — [3]Universität Regensburg, Institut für Theoretische Physik

Within the framework of quantum thermodynamics, the use of quasiprobabilities can provide a comprehensive approach to the work statistics of quantum systems. In this formulation the effects of coherences in the initial state of the system are accounted in a natural way for all protocols and are expected to be displayed in the quantum features of the chosen quasidistribution [1]; yet clear examples of this are scarce in the literature. In this work we consider the semiclassical limit of the quantum work distribution obtained using the Kirkwood-Dirac quasiprobability, highlighting the effects of initial coherences on the energetics of the system and on the quantum behavior of the quasidistribution. We illustrate our results in a study of the work distribution of a forced quantum harmonic oscillator [2] in the Weyl-Wigner representation in phase space.

[1] M. Lostaglio, A. Belenchia, A. Levy, S. Hernández-Gómez, N. Fabbri, and S. Gherardini, Quantum 7, 1128 (2023). [2] P. Talkner, P. S. Burada, and P. Hänggi, Phys. Rev. E 78, 011115 (2008).