DY 40: Stochastic Thermodynamics

Time: Thursday 10:00–12:30 Location: ZEU 250

DY 40.1 Thu 10:00 ZEU 250

Optimized Work Protocols for the Higgs RNA-Model — •Peter Werner and Alexander K. Hartmann — Institute of Physics, University of Oldenburg, Germany

When a system is driven from one state to another in a *finite* amount of time $t \in [0, \dots, \tau]$ by changing an external control parameter according to a protocol $\lambda(t)$, some work W is performed. Here $\langle W \rangle \geq \Delta F$ holds, where ΔF is the equilibrium free energy difference between initial and final states. The protocol $\lambda^*(t)$ minimizing the average amount of work is of interest, since it tightens the upper bound to ΔF. The optimum protocols of simple Brownian-particle systems exhibit distinct jumps especially at the beginning and end of the process [1,2] and it was speculated that these are a generic feature for arbitrary systems.

Here the *many-particle* Higgs RNA model [3] is considered, where work is performed by stretching the RNA through changing an external force. For this model, an exact calculation of the free-energy differences ΔF and the sampling of the equilibrium initial state can be performed in polynomial time. The work processes are realized by means of non-equilibrium Monte-Carlo simulations [4]. The optimum protocols are obtained numerically with the parallel-tempering approach. Also for this complex system, the optimum protocols exhibit distinct jumps at the beginning and end.

[1] T. Schmiedl and U. Seifert, Phys. Rev. Lett., **98**, 108301 (2007)
[2] H. Then and A. Engel, Phys. Rev. E **77**, 041105 (2008)
[3] P. G. Higgs, Phys. Rev. Lett., **76**, 704 (1996)
[4] P. Werner and A. K. Hartmann, Phys. Rev. E **104**, 034407 (2021)

DY 40.2 Thu 10:15 ZEU 250

Coherence of oscillations in the weak-noise limit — •Benedikt Remlein, Volker Weissmann, and Udo Seifert — II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

In a noisy environment, oscillations lose their coherence, which can be characterized by a quality factor. We determine this quality factor for oscillations arising from a driven Fokker-Planck dynamics along a periodic one-dimensional potential analytically in the weak-noise limit. With this expression, we can prove for this continuum model the analog of an upper bound that has been conjectured for the coherence of oscillations in discrete Markov network models. We show that our approach can also be adapted to motion along a noisy two-dimensional limit cycle. Specifically, we apply our scheme to the noisy Stuart-Landau oscillator and the thermodynamically consistent Brusselator as a simple model for a chemical clock. Our approach thus complements the fairly sophisticated extant general framework based on techniques from Hamilton-Jacobi theory with which we compare our results numerically [1].

[1] B. Remlein, V. Weissmann, and U. Seifert, Phys. Rev. E 105, 064101 (2022)

DY 40.3 Thu 10:30 ZEU 250

Work extraction potential for a single spin in equilibrium with a non-isotropic environment — •Felix Hartmann[1] and Janet Anders[1,2] — [1]Institut für Physik und Astronomie, University of Potsdam, 14476 Potsdam, Germany — [2]Department of Physics and Astronomy, University of Exeter, Stocker Road, Exeter EX4 4QL, UK

Thermal equilibrium properties of nanoscale systems deviate from standard macroscopic predictions due to a non-negligible coupling to the environment. For non-isotropic three-dimensional materials, we derive the mean force corrections to the equilibrium state of a single classical spin vector. The result is valid at arbitrary coupling strength.

Specifically, we consider cubic, orthorhombic, and monoclinic symmetries, and compare differences in their spin expectation values as a function of temperature. We underpin the correctness of the mean force state by evidencing its match to the steady state of the simulated non-Markovian spin dynamics. Our results show an explicit dependence on the symmetry of the material in which the spin is confined.

Further, we quantify how the mean force-generated inhomogeneities in the energy shells lead to a work extraction potential. Such inhomogeneities constitute a classical equivalent to quantum coherences.

DY 40.4 Thu 10:45 ZEU 250

Time-resolved statistics of snippets as general framework for model-free entropy estimators — •Jann van der Meer, Julius Degünther, and Udo Seifert — II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart

Irreversibility is commonly quantified by entropy production. An external observer can estimate it through measuring an observable that is antisymmetric under time-reversal like a current. We introduce a general framework that, inter alia, allows us to infer a lower bound on entropy production through measuring the time-resolved statistics of events with any symmetry under time-reversal, in particular, time-symmetric instantaneous events. We emphasize Markovianity as a property of certain events rather than of the full system and introduce an operationally accessible criterion for this weakened Markov property. Conceptually, the approach is based on snippets as particular sections of trajectories, for which a generalized detailed balance relation is discussed.

DY 40.5 Thu 11:00 ZEU 250

Anomalous relaxation from a non-equilibrium steady state: An isothermal analog of the Mpemba effect — •Julius Degünther and Udo Seifert — II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

The Mpemba effect denotes an anomalous relaxation phenomenon where a system initially at a hot temperature cools faster than a system that starts at a less elevated temperature. We introduce an isothermal analog of this effect for a system prepared in a non-equilibrium steady state that then relaxes towards equilibrium. Here, the driving strength, which determines the initial non-equilibrium steady state, takes the role of the temperature in the original version. As a paradigm, we consider a particle initially driven by a non-conservative force along a one-dimensional periodic potential. We show that for an asymmetric potential relaxation from a strongly driven initial state is faster than from a more weakly driven one at least for one of the two possible directions of driving. These results are first obtained through perturbation theory in the strength of the potential and then extended to potentials of arbitrary strength through topological arguments.

[1] Julius Degünther and Udo Seifert, EPL, 139 4 (2022) 41002

15 min. break

DY 40.6 Thu 11:30 ZEU 250

Measurement phase transitions in the no-click limit as quantum phase transitions of a non-hermitean vacuum. — •Caterina Zerba[1,2,3] and Alessandro Silva[2] — [1]Technical University of Munich, 85748 Garching, Germany — [2]International School for Advanced Studies (SISSA), via Bonomea 265, 34136 Trieste, Italy — [3]Università degli Studi di Trieste, via Alfonso Valerio 2, 34127 Trieste, Italy

We study dynamical phase transitions occurring in the stationary state of the dynamics of integrable many-body non-hermitian Hamiltonians, which can be either realized as a no-click limit of a stochastic Schrödinger equation or using spacetime duality of quantum circuits. In two specific models, the Transverse Field Ising Chain and the Long Range Kitaev Chain, we observe that the entanglement phase transitions occurring in the stationary state have the same nature as that occurring in the vacuum of the non-hermitian Hamiltonian: an area law phase when the imaginary part of the quasi-particle spectrum is gapped and a logarithmic growth for gapless imaginary spectrum. This observation suggests the possibility to generalize the area-law theorem to non-Hermitian Hamiltonians

DY 40.7 Thu 11:45 ZEU 250

Thermodynamics of growth in chemical reaction networks — •Shesha Gopal Marehalli Srinivas, Francesco Avanzini, and Massimiliano Esposito — Complex Systems and Statistical Mechanics, Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg

Open chemical reaction networks show a variety of complex dynamical behaviour such as chemical waves, oscillations, chaotic dynamics, multistability, and so on. Progress in stochastic thermodynamics has enabled us to identify the energetic costs of these phenomena. However, very little attention has been paid to chemical growth. We will identify the necessary conditions under which open homogeneous

CRNs evolving with mass action kinetics show asymptotic growth. Our main results show that growth with nonequilibrium abundances requires nonlinear CRNs with the influx of at least one species from the surrounding. Linear CRNs, on the other hand, can only grow with equilibrium abundances. Our results illustrate the important interplay between topology and the chemostatting procedure in determining the asymptotic dynamics of CRNs.

DY 40.8 Thu 12:00 ZEU 250

Irreversible fluctuations herald dynamical phases in non-Hermitian phase-field models — •Thomas Suchanek[1], Klaus Kroy[1], and Sarah Loos[2] — [1]Institut für Theoretische Physik, Universität Leipzig, Leipzig, Germany — [2]DAMTP, University of Cambridge, Cambridge, United Kingdom

We study the time-reversal symmetry (TRS) breaking of fluctuations in phase-field models that exhibit dynamical phases. We focus on two typical scenarios in which dynamical phases can be born, namely, oscillatory instabilities and the recently uncovered $\mathcal{PT}$-symmetry breaking transitions in non-Hermitian systems [1] that are accompanied by Exceptional Points. Quantifying the TRS breaking by the informatic entropy production rate [2] and analytically investigating the zero noise limit, we find divergent behavior at both transitions. We discuss an example model of two nonreciprocally coupled Chan-Hilliard fields, and offer interpretations of the TRS breaking in terms of interface dynamics, the $\mathcal{PT}$-symmetry breaking and the amplification of dissipative noise near Exceptional Point transitions.

[1] M. Fruchart, R. Hanai, P. B. Littlewood, and V. Vitelli, Nonreciprocal phase transitions, Nature 592, 363-369 (2021).

[2] C.Nardini, E. Fodor, E. Tjhung, F. van Wijland, J. Tailleur, and M. E. Cates, Entropy production in field theories without time-reversal symmetry: Quantifying the non-equilibrium character of active matter, Phys. Rev. X 7, 021007 (2017).

DY 40.9 Thu 12:15 ZEU 250

Large deviations theory for noisy non-linear electronics — •Ashwin Gopal, Massimiliano Esposito, and Nahuel Freitas — University of Luxembourg, L-1511 Luxembourg, Luxembourg

The latest generations of transistors are nanoscale devices whose performance and reliability are limited by thermal noise in low-power applications. Therefore, developing efficient methods to compute the voltage and current fluctuations in such non-linear electronic circuits is essential. In this presentation, I will describe the large deviations approach to compute these fluctuations using the stochastic thermodynamic description of CMOS-based electronics (Phys. Rev. B 106, 155303). Starting from the thermodynamically consistent description of the charge transfer at a single electron level, I will then consider the macroscopic limit. This corresponds to scaling up the transistor's physical dimensions, resulting in an increase in the number of electrons on the conductors. In this limit, the thermal fluctuations satisfy a Large Deviations Principle which I will show is also remarkably precise in settings involving only a few tens of electrons, by comparing our results with Gillespie simulations and spectral methods. Traditional approaches, using the stationary Gaussian white noise, are recovered by resorting to an ad hoc diffusive approximation revealing their inconsistencies. To illustrate these findings, I will use the case study of the low-power CMOS inverter, or NOT gate, which is a basic primitive in electronic design. Finally, I will briefly comment on thermodynamic uncertainty (TUR) relations and information processing, in the context of such electronic circuits.