# DY 27: Statistical Physics: Far From Equilibrium I

Time: Wednesday 9:30–13:00 Location: ZEU 250

Invited Talk DY 27.1 Wed 9:30 ZEU 250

**Evolution in changing environments and driven disordered systems** — •Joachim Krug, Suman Das, and Muhittin Mungan — Institute for Biological Physics, University of Cologne, Köln, Germany

Biological evolution is governed by the fitness landscape, a map from the genetic sequence of an organism to its fitness. A fitness landscape depends on the organism's environment, and evolution in changing environments is still poorly understood. After introducing the concept of fitness landscapes and their mathematical description, the talk will focus on a particular model of antibiotic resistance evolution in bacteria [1]. Tradeoffs between adaptation to low and high concentration lead to a rugged landscape with an exponentially large number of fitness peaks. With evolutionary dynamics that follow fitness gradients, resistance evolution under slowly changing antibiotic concentration maps to the zero temperature dynamics of a disordered spin system [2]. Specifically, the set of genetic sequences that form a fitness peak at some concentration maps exactly to the metastable states in an equivalent Preisach system, a paradigmatic model of hysteresis in random magnets. Making use of the conceptual tool of state transition graphs developed in the context of driven disordered systems, we quantify the degree of genotypic and phenotypic reversibility in the response of the population to antibiotic concentration cycling.

[1] S.G. Das, S.O.L. Direito, B. Waclaw, R.J. Allen, J. Krug, eLife 9:e55155 (2020)

[2] S.G. Das, J. Krug, M. Mungan, Phys. Rev. X 12:031040 (2022)

DY 27.2 Wed 10:00 ZEU 250

**Anomalous relaxation of density waves in a ring-exchange system** — •Pranay Patil[1,2], Markus Heyl[1,3], and Fabien Alet[2] — [1]Max-Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Laboratoire de Physique Theorique, Universite de Toulouse, CNRS, UPS, France — [3]Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, 86135 Augsburg, Germany

We present the analysis of the slowing down exhibited by stochastic dynamics of a ring-exchange model on a square lattice, by means of numerical simulations. We find the preservation of coarse-grained memory of initial state of density-wave types for unexpectedly long times. This behavior is inconsistent with the prediction from a low frequency continuum theory developed by assuming a mean field solution. Through a detailed analysis of correlation functions of the dynamically active regions, we exhibit an unconventional transient long ranged structure formation in a direction which is featureless for the initial condition, and argue that its slow melting plays a crucial role in the slowing-down mechanism. We expect our results to be relevant also for the dynamics of quantum ring-exchange dynamics of hard-core bosons.

DY 27.3 Wed 10:15 ZEU 250

**Colloidal monolayers: bridging the gap between two and three spatial dimensions** — Johannes Bleibel[2], •Alvaro Domínguez[1], and Martin Oettel[2] — [1]Univ. Sevilla, Spain — [2]Univ. Tübingen

It is well established that, unlike for a three-dimensional fluid, particle interactions prevent the hydrodynamic transport coefficients from being defined for a two-dimensional fluid due to the notorious "long-time tail" feature of the velocity autocorrelation.

A colloidal monolayer formed at a fluid interface builds a bridge between these two limiting cases, and it provides insight on the transition from three down to two spatial dimensions: the particle positions are constrained to a plane and the colloid thus resembles a two-dimensional fluid. But the exchange of particle momentum takes place in three-dimensional space through hydrodynamic interactions in the ambient fluid.

Here we study the colloidal diffusivity starting from the Smoluchowski equation. We show that the diffusivity exhibits an intermediate behavior between purely two-dimensional and fully three-dimensional fluid: on the one hand, Fick's law, which pertains to *collective diffusion*, breaks down altogether, as confirmed experimentally. On the other hand, the coefficient of *self-diffusion* is finite, but the transitional nature of the monolayer shows up in a non-analytic dependence on the colloidal packing fraction, at odds with the case of a fully three-dimensional colloid.

DY 27.4 Wed 10:30 ZEU 250

**Nonequilibrium mixture dynamics: A model for mobilities and its consequences** — Maryam Akaberian, •Filipe Thewes, Peter Sollich, and Matthias Krüger — Institut für Theoretische Physik, Georg-August-Universität Göttingen, Göttingen, Germany

Extending the famous Model B for the time evolution of a liquid mixture, we develop an approximate approach for the mobility matrix that couples the different mixture components. This approach is based on a single component fluid with particles that are artificially grouped into colors and the relevant parameters can be determined from experiments or numerical simulations. We identify two distinct regimes, corresponding to collective motion and inter-diffusion, respectively, and show how they emerge from the microscopic properties of the fluid. As a test scenario, we study the dynamics after a thermal quench, providing a number insights from a Gaussian theory. Specifically, for systems with two or three components, analytical results for the time evolution of the equal time correlation function compare well to results of Monte Carlo simulations of a lattice gas. A rich behavior is observed, including the possibility of fractionation.

DY 27.5 Wed 10:45 ZEU 250

**Dynamical Renormalization Group Theory for Driven Systems** — •Nikos Papanikolaou and Thomas Speck — Institute of Theoretical Physics 4, University of Stuttgart, Stuttgart, Germany

Active matter describes nonequilibrium systems that are self-driven due to their microscopic dynamics. These systems pose a fundamental physics challenge by unveiling new phenomena, not present in equilibrium systems, such as the Motility Induced Phase Separation; formation of clusters in the absence of any attractive interactions. To study analytically nonequilibrium complex systems, the Renormalization Group (RG) theory has been successfully used to extract the phase diagram, to study its qualitative behavior, and to explore the critical properties in the different phases. In this project, we explore a variation of RG called Dynamical RG to study self-driven systems by directly applying the RG to dynamical field equations such as the KPZ equation or the Active Model B+ which describe the stochastic evolution of systems like the population of bacteria, interfaces, and neural networks.

DY 27.6 Wed 11:00 ZEU 250

**Metastability as a Mechanism for Yielding in Amorphous Solids under Cyclic Shear** — •Muhittin Mungan[1] and Srikanth Sastry[2] — [1]Institute of Biological Physics, University of Cologne, Cologne, Germany — [2]Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru, India

We consider the yielding behavior of amorphous solids under cyclic shear deformation and show that it can be mapped into a random walk in a confining potential with an absorbing boundary. The resulting dynamics is governed by the first passage time into the absorbing state and suffices to capture the essential qualitative features recently observed in atomistic simulations of amorphous solids. Our results provide insight into the mechanism underlying yielding and its robustness. When the possibility of activated escape from absorbing states is added, it leads to a unique determination of a threshold energy and yield strain, suggesting thereby an appealing approach to understanding fatigue failure [1].

[1] M. Mungan and S. Sastry, Phys. Rev. Lett. 127 (2021) 248002

**15 min. break**

DY 27.7 Wed 11:30 ZEU 250

**Tunable Brownian magneto heat pump** — •Iman Abdoli[1], René Wittmann[2], Joseph Brader[3], Jens-Uwe Sommer[1], Hartmut Löwen[2], and Abhinav Sharma[1] — [1]Leibniz-Institut für Polymerforschung Dresden, 01069 Dresden, Germany — [2]Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany — [3]Université de Fribourg, CH-1700 Fribourg, Switzerland

We propose a mesoscopic Brownian magneto heat pump made of a single charged Brownian particle that is steered by an external magnetic field. The particle is subjected to two thermal noises from two different heat sources. When confined, the particle performs gyrating motion around a potential energy minimum. We show that such a magneto-gyrator can be operated as both a heat engine and a refrigerator. The maximum power delivered by the engine and the performance of the refrigerator, namely the rate of heat transferred per unit external work, can be tuned and optimised by the applied magnetic field. Further tunability of the key properties of the engine, such as the direction of gyration and the torque exerted by the engine on the confining potential, is obtained by varying the strength and direction of the applied magnetic field. In principle, our predictions can be tested by experiments with colloidal particles and complex plasmas.

DY 27.8 Wed 11:45 ZEU 250

**Work fluctuations in the harmonic Active Ornstein-Uhlenbeck particle model** — •Giuseppe Gonnella — Università degli Studi di Bari, Bari, Italy — Istituto Nazionale di Fisica Nucleare, sezione di Bari

Over the past few years great interest arose in providing a thermodynamic description of Active Matter Systems and an important emphasis was put on the Active Work study. The distribution of such an observable has been object of recent research[1] as possible singularities signal the occurrence of Dynamical Phase Transitions (DPTs)[2,3], in turn related to peculiar trajectory realisations.

Here we focus on a single harmonically trapped Active Ornstein-Uhlenbeck Particle and provide the analytic expression for the scaled cumulant generating function (SCGF) of the Active Work. Interestingly, we find the SCGF to be non-steep in many physical situations and we provide insight on the effect of relevant system parameters, such as the Peclet number, on the SCGF steepness trough a phase diagram in the system parameter space. Through Legendre-Fenchel transform, the SCGF steepness is shown to lead to singular rate functions with linear tails, and ultimately to the occurrence of DPTs also in this system. We also investigate on the role of initial and final condition in producing the consequent anomalous trajectories.

[1] Semeraro M. et al, J Stat Mech, 2021
[2] Cagnetta F. et al., PRL, 2017
[3] Keta YE. et al., PRE, 2021

DY 27.9 Wed 12:00 ZEU 250

**Non-thermal fixed points of universal sine-Gordon coarsening dynamics** — Philipp Heinen[1], Aleksandr N. Mikheev[1,2], Christian-Marcel Schmied[1], and •Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg

We examine coarsening of field-excitation patterns of the sine-Gordon (SG) model, in two and three spatial dimensions, identifying it as universal dynamics near non-thermal fixed points. The focus is set on the non-relativistic limit, governed by a Schrödinger-type equation with Bessel-function nonlinearity. The results of our classical statistical simulations suggest that, in contrast to wave turbulent cascades, in which the transport is local in momentum space, the coarsening is dominated by rather non-local processes corresponding to a spatial containment in position space. The scaling analysis of a kinetic equation obtained with path-integral techniques corroborates this numerical observation and suggests that the non-locality is directly related to the slowness of the scaling in space and time. Our methods, which we expect to be applicable to more general types of models, could open a long-sought path to analytically describing universality classes behind domain coarsening and phase-ordering kinetics from first principles, which are usually modelled in a near-equilibrium setting by a phenomenological diffusion-type equation in combination with conservation laws.

DY 27.10 Wed 12:15 ZEU 250

**Nonequilibrium probability currents in optically-driven colloidal suspensions** — •Samudrajit Thapa[1,2], Daniel Zaretzky[3], Grzegorz Gradziuk[4], Chase Broedersz[4,5], Yair Shokef[1,2,6], and Yael Roichman[3,6,7] — [1]School of Mechanical Engineering, Tel Aviv University, Tel Aviv 69978, Israel — [2]Sackler Center for Computational Molecular and Materials Science, Tel Aviv University, Tel Aviv 69978, Israel — [3]School of Chemistry, Tel Aviv University, Tel Aviv 69978, Israel — [4]Arnold Sommerfeld Center for Theoretical Physics, Ludwig Maximilians Universitaet Muenchen, Theresienstr. 37, 80333 Munich, Germany — [5]Department of Physics and Astronomy, Vrije Universiteit Amsterdam, 1081 HV Amsterdam, The Netherlands — [6]Center for the Physics and Chemistry of Living Systems, Tel Aviv University, 69978, Tel Aviv, Israel — [7]School of Physics & Astronomy, Tel Aviv University, Tel Aviv 69978, Israel

In the absence of visible currents and prior knowledge, it is often hard to recognize athermal fluctuations. Probability currents provide such a measure in terms of the rate at which they enclose area in phase space. We measure this area enclosing rate for trapped colloidal particles, where only one particle is driven, and they interact hydrodynamically. By combining experiment, theory and simulation, we identify an optimal measurement protocol in terms of the relations between the different time scales in the system. Furthermore, we find that hydrodynamic interactions render the effect of athermal agitation more local than that of elastic interactions. This may have significant implications for the interpretation of fluctuations in biological systems.

DY 27.11 Wed 12:30 ZEU 250

**A nonlinear fluctuation-dissipation theorem for Markovian systems** — •Benjamin Lindner[1,2], Kirsten Engbring[2], Dima Boriskovsky[3], and Yael Roichman[3] — [1]Bernstein Center for Computational Neuroscience Berlin, Philippstr.\ 13, Haus 2, 10115 Berlin, Germany — [2]Physics Department of Humboldt University Berlin, Newtonstr.\ 15, 12489 Berlin, Germany — [3]The Raymond and Beverley School of Physics \& Astronomy and The Raymond and Beverley School of Chemistry, Tel Aviv University, Tel Aviv 6997801, Israel

Fluctuation-Dissipation-Theorems (FDT) connect the internal spontaneous fluctuations of a system with its response to an external perturbation. In this work we propose a new nonlinear fluctuation-dissipation theorem as a test for Markovianity. Previously suggested FDTs are based on linear response and require a significant amount of measurements. However, the nonlinear relation holds for systems out of equilibrium, and for strong perturbations requiring significantly less data than the standard linear relation. We verify the nonlinear theorem for two theoretical model systems: a Brownian particle in a tilted periodic potential, and a harmonically bound particle. In addition, we apply our formalism and test for Markovianity in an inherently out of equilibrium experimental system, based on self-propelled agents.

DY 27.12 Wed 12:45 ZEU 250

**Heat capacity for a driven array of semiclassical dots** — •Pritha Dolai and Christian Maes — Instituut voor Theoretische Fysica, KU Leuven, Belgium

We analyze thermal properties for particle transport along an array of two-level systems. More specifically, we obtain analytic and numerical results for the heat capacity of a system of particles subject to mutual exclusion and to birth and death, driven around a ring by an external field. We find a zero-temperature phase transition as a function of the chemical potential of the environment, as shown by the divergence of the heat capacity at zero temperature. The non-vanishing of the heat capacity at absolute zero, violating the extended Third Law, is caused by a localization and corresponding delay in relaxation of excess heat. We also derive a regime of negative heat capacity indicating an anticorrelation between the temperature-dependence of the stationary occupation and the excess heat.