DY 12: Statistical Physics far from Thermal Equilibrium II

Time: Monday 15:00–17:00 Location: BH-N 334

DY 12.1 Mon 15:00 BH-N 334

Dynamic renormalization of active field theories — •Nikos Papanikolaou and Thomas Speck — Institute of Theoretical Physics 4, University of Stuttgart, Stuttgart, Germany

Conservative scalar field theories function as coarse-grained models that describe systems with conserved dynamics featuring a single order parameter, such as density, magnetization, or height. Notable examples include Model B (for liquid-gas separation), cKPZ (for surface growth with conserved dynamics), and Active Model B+ (AMB+) (for self-propelled particles with density-dependent speed). Dynamical renormalization is a powerful tool to study the critical behavior of these theories and to determine the relevant parameters dictating their large-scale dynamics. Here, we apply this technique to AMB+, a recent generalization of Model B involving non-potential terms. Analyzing such complex field theories poses a challenge due to its cumbersome calculations. To facilitate the analysis, we developed a symbolic computer algebra code to obtain the graphical corrections of the model parameters. Applying this framework to AMB+, we find that potentially relevant higher-order non-linear terms are generated, limiting the regime of the perturbative renormalization. We explore strategies to ameliorate this problem and provide evidence that no perturbative fixed points other than the Wilson-Fisher fixed point exist.

DY 12.2 Mon 15:15 BH-N 334

Time-reversal and PT symmetry breaking in non-Hermitian field theories — •Thomas Suchanek[1], Sarah Loos[2], and Klaus Kroy[1] — [1]Institut für Theoretische Physik, Universität Leipzig, Leipzig, Germany — [2]DAMTP, University of Cambridge, Cambridge, United Kingdom

We study time-reversal symmetry breaking in non-Hermitian fluctuating field theories with conserved dynamics, comprising the mesoscopic descriptions of a wide range of nonequilibrium phenomena [1]. They exhibit continuous parity-time (PT)-symmetry breaking phase transitions to dynamical phases. We introduce the (informatic) entropy rate as a method to quantify non-equilibrium dynamics emerging on the mesoscale. For two concrete transition scenarios, exclusive to non-Hermitian dynamics, namely oscillatory instabilities and critical exceptional points, a low-noise expansion exposes a pre-transitional surge of the entropy production, inside the static phases. For critical exceptional points, we identify the coupling of eigenmodes as the entropy-generating mechanism, causing a drastic noise amplification in the Goldstone mode. We illustrate our findings with a model of non-reciprocally coupled Cahn-Hilliard fields and an assembly of Brownian particles, interacting asymmetrically through chemotactic interactions.

[1] Suchanek, T., Kroy, K., & Loos, S. A. (2023). Irreversible mesoscale fluctuations herald the emergence of dynamical phases. arXiv preprint arXiv:2303.16701.

DY 12.3 Mon 15:30 BH-N 334

Pulsating with discrete symmetries: from microscopic dynamics to field theory — Massimiliano Esposito[1], Étienne Fodor[1], •Alessandro Manacorda[1], and Jan Meibohm[2] — [1]Department of Physics and Materials Science, University of Luxembourg — [2]Institute for Theoretical Physics, Technische Universität Berlin

Deformable active matter is a growing research field: it enables to model and analyze collective dynamics in dense systems where units have the ability to change their shape, such as epithelial or cardiac tissues.

Collective behavior emerges through the propagation of waves with intriguing patterns. The latter are intimately related with the symmetries of the system: the transition between arrest and wave propagation requires a symmetry breaking mechanism. Coarse-graining the microscopic dynamics in the complex Ginzburg-Landau approach (CGLE) leads to fluctuating hydrodynamics with predictive power.

Surprisingly, the presence of a discrete symmetry makes the CGLE approach unsuitable to describe the dynamics. We will show how one can build an active field theory with the prescribed symmetries, and how these affect the active phases and pattern formation at hydrodynamic level, opening the door to field theories of pulsating active matter.

DY 12.4 Mon 15:45 BH-N 334

Hydrodynamics of dense pulsating matter — •Tirthankar Banerjee[1], Jonas Ranft[2], Thibault Desaleux[3], and Etienne Fodor[1] — [1]Department of Physics and Materials Science, University of Luxembourg, Luxembourg — [2]Ecole Normale Superieure, Paris, France — [3]French Alternative Energies and Atomic Energy Commission (CEA), St-Paul-lez-Durance, France

Dense assemblies of deforming cells, e.g., in the heart, show rich behaviours from synchronized collective oscillation to various types of wave propagation. We propose a generic minimal hydrodynamic model of out-of-equilibrium pulsating (due to a global drive) particles in the presence of thermal fluctuations. Derived through a mechanistic approach, our model equations encode the coupled dynamics of two fields: a conserved density and a non-conserved phase variable that carries information on the size of deforming particles. We show that homogeneous arrested and cycling states can be separated by a sector of instabilities in the space of control parameters. Using a perturbative method, we show analytically how thermal fluctuations can modify these phase boundaries. Extensive numerical simulations on a two-dimensional lattice strongly corroborate the analytical phase diagrams and reveal that the instabilities grow into target wave patterns both in density and phase.

DY 12.5 Mon 16:00 BH-N 334

Hard sphere nucleation revisited: bringing simulation and experiment together — Sahana Kale and •Hans Joachim Schöpe — Universität Tübingen, Institut für angewandte Physik, Auf der Morgenstelle 10, 72076 Tübingen

Crystallization of a metastable melt is one of the most important non-equilibrium phenomena in classical physics. A milestone in crystal nucleation studies was the first prediction of absolute nucleation rate densities (NRDs) in hard sphere (HS) systems using the combination of computer simulations and classical nucleation theory (CNT), published in Nature in 2001. This work has been complemented in recent years by more advanced simulation work. However, a direct comparison of the experimental NRDs with those from the simulations shows a highly unsatisfactory result: the shape of the curves are qualitatively different and experimental and theoretical data diverge by up to 18 orders of magnitude!

Using laser-scanning confocal microscopy we study crystal nucleation in colloidal HS. We follow and characterise the formation of individual crystallites. Furthermore, we determine NRDs and critical radii in two different ways: 1) directly from the data without recourse to any model and 2) within the framework of CNT. The direct data analysis reproduces the existing experimental data sets from Bragg and small angle scattering, while the CNT-based analysis reproduces the simulation data. However, as mentioned above, the two data sets are incompatible. Accordingly, the cause of the huge discrepancy is due to shortcomings of the CNT and simulation techniques.

DY 12.6 Mon 16:15 BH-N 334

Sharp and soft metastable transitions under driving: A study with hard rods — •Miriam Klopotek[1], Martin Oettel[2], and Hans Joachim Schöpe[2] — [1]University of Stuttgart, Stuttgart Center for Simulation Science, SimTech Cluster of Excellence EXC 2075, Stuttgart, Germany — [2]University of Tübingen, Institute for Applied Physics, Tübingen, Germany

When external forces drive systems, states that are otherwise ephemeral in equilibrium can unfold. Metastability can imply a characteristic change in the dynamics for long periods and a blanketing of the whole system with new structures. The degree of (non-)stability depends on the time scale of the driving. In a model system of sticky hard rods on lattices confined to quasi-2D [1], we observe a crossover from “sharp” to “soft” metastable transitions in the evolution of order parameters. Static external potentials can “sharpen” and even potentially stabilize them thermodynamically. Their underlying nature is thus challenging to discern when observing the dynamical evolution alone. Implications include critically examining data from thin film growth experiments.

[1] M. Klopotek, H. J. Schöpe, and M. Oettel (2024), in preparation.

DY 12.7 Mon 16:30 BH-N 334

Phase behavior of particles with different temperatures — •Amir Abbasi and Roland R. Netz — Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

A well-known phenomenon in nonequilibrium thermodynamics is the phase separation in mixtures of hot and cold particles with purely repulsive interactions, coupled to heat baths at different temperatures [1-2]. Theoretical studies have explored this separation, often using the concept of an *effective* free energy, though its application is debatable due to the undefined temperature in such mixtures [3-4]. Our study aims to delineate the steady state of these particle mixtures using simulations and theoretical analysis of the extremal properties of the free entropy functional [5].

[1] S. N. Weber, C. A. Weber, and E. Frey, Phys. Rev. Lett. 116, 058301 (2016).
[2] S. S. N. Chari, C. Dasgupta, and P. K. Maiti, Soft Matter 15, 7275-7285 (2019).
[3] C. A. Weber, D. Zwicker, F. Jülicher, and C. F. Lee, Rep. Prog. Phys. 82, 064601 (2019).
[4] E. Ilker and J.-F. Joanny, Phys. Rev. Res. 2, 023200 (2020).
[5] R. R. Netz, Phys. Rev. E 101, 022120 (2020).

DY 12.8 Mon 16:45 BH-N 334

The spectral boundary of the Asymmetric Simple Exclusion Process (ASEP) - free fermions, Bethe ansatz and random matrix theory — •Goran Nakerst[1], Tomaz Prosen[2], and Masud Haque[1,3] — [1]Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany — [2]University of Ljubljana, Faculty for Mathematics and Physics, Jadranska 19, Ljubljana, Slovenia — [3]Max-Planck-Institut für Physik komplexer Systeme, D-01187 Dresden, Germany

The dynamical timescales of Markov processes are determined by the spectrum of their generator matrices. In this talk, we explore the spectral boundary characteristics of the generator matrix in a paradigmatic model: the 1D Asymmetric Simple Exclusion Process (ASEP) with both periodic and open boundary conditions. Our focus centers on the emergence of a distinctive spiky spectral boundary (SSB). We will illustrate how the ASEP generator is represented by an interacting fermion model, which, in its non-interacting variant, exhibits a pronounced SSB. Notably, the SSB persists upon the reintroduction of interactions, which revert to the conventional generator of ASEP. Furthermore, we will establish the universality of the SSB, illustrating its prevalence in random matrix ensembles characterized by particular trace correlations and, equivalently, in random graphs with specific cycle structures. This presentation aims to meld concepts from stochastic processes, quantum mechanics, and random matrix theory.