DY 32: Nonlinear Stochastic Systems

Time: Thursday 9:30–11:15 Location: H43

Invited Talk DY 32.1 Thu 9:30 H43

Fluctuation-Response Relations for Non-equilibrium Systems — •Benjamin Lindner — Institut für Physik, Humboldt-Universität Berlin

The fluctuations and the response of stochastic systems are related by fluctuation-dissipation theorems or, equivalently, fluctuation-response relations (FRRs). Originally introduced for systems in thermodynamic equilibrium, generalizations of such relations for non-equilibrium situations have been discussed since the 1970's and are particularly appealing for biological systems. FRRs may be used to e.g. (i) prove that a system is outside of equilibrium, (ii) prove that it does not follow Markovian dynamics, (iii) extract statistics of intrinsic noise sources. In my talk I report several FRRs in systems far from equilibrium. I discuss a nonlinear FRR for systems that can be perturbed by a step stimulus, which can be used as an efficient test of Markovianity. I present a universal description for stochastic oscillators, that results in a simple FRR in terms of a new complex-valued transform of the original oscillator variables. Last but not least, I derive a new class of FRRs for spiking neurons that relate the pronounced fluctuations of spontaneous neural firing to their average response to sensory stimuli, i.e. to the processing of sensory information that is the raison d'etre of neural systems.

Refs.: B. Lindner 129, 198101 Phys. Rev. Lett. (2022); A. Perez-Cervera et al. PNAS 120, e2303222120 (2023); K. Engbring et al. Phys. Rev. X 13, 021034(2023); J. Stubenrauch & B. Lindner Phys. Rev. X 14, 041047 (2024)

DY 32.2 Thu 10:00 H43

Oscillations and self-generated noise in a nonreciprocal single-species XY-model — •Thomas Suchanek[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 low temperature dynamics of an XY-model with random nonreciprocal couplings. Upon increasing average nonreciprocity, we observe a transition from a state of coherent oscillations to a chaotic stationary state. For a randomly selected degree of freedom, we derive an effective description of the dynamics in terms of a stochastic differential equation. This allows us to analyze the properties of the stochastic motion as well as the response of the system to perturbations.

DY 32.3 Thu 10:15 H43

Cross-correlation-response relations for systems driven by shot noise — •Jakob Stubenrauch and Benjamin Lindner — BCCN Berlin and Physics Department HU Berlin, Germany

In the analysis of stochastic dynamics, the Furutsu-Novikov [1,2] theorem (FNT), linking the input-output cross-correlation of a system driven by Gaussian noise to the response function of the system, has proven important in various applications.

In several situations, such as photon-detectors or neurons, it is inaccurate to model the input process as Gaussian noise; in the two examples the input is instead a sequence of pulses at random times (shot noise). Here, we present recently discovered analogues of the FNT for systems driven by shot noise [3]. Specifically, we show that the input-output cross-correlation of any system driven by Poissonian shot noise is linearly related to the linear response of the system to modulations of the intensity of input shots. We further present extensions for colored shot noise and for shot noise with random amplitudes.

To illustrate the wide applicability of our general result, we further present a fluctuation-response relation of a leaky integrate-and-fire neuron: Building on previous work [4], we show how the spontaneous output fluctuations of a spike-driven neuron are related to its susceptibility. Lastly, as teasers, we present applications to single-photon-detection, remote control in neural networks, and synaptic plasticity.

[1] Furutsu, J. Res. Natl. Bur. Stand. (1963) [2] Novikov, J. Exp. Theor. Phys. (1965) [3] Stubenrauch and Lindner, Phys. Rev. X (2024), [4] Lindner, Phys. Rev. Lett. (2022)

DY 32.4 Thu 10:30 H43

A Framework for Sparse Kinetic Monte-Carlo Models — •Bat-Amgalan Bat-Erdene, Roya Ebrahimi Viand, Karsten Reuter, and Sebastian Matera — Fritz-Haber-Institut der MPG, Berlin

The long-time dynamics of many problems in condensed matter physics are controlled by the interplay of rare events, e.g. chemical kinetics or crystal growth. Such problems are typically formulated as discrete-state Markov jump processes and can be simulated by kinetic Monte Carlo (kMC) methods. We are developing a software framework for implementing efficient kMC simulation models for arbitrary such processes. The key ingredients are i) a code generator for an optimized C++ skeleton where the user specifies the problem via a Python interface, and ii) the possible formulation as a sparse kMC model. Prototypical examples for sparsity appear in spatially extended models, where in each step the state changes only locally and interactions are only short ranged. This can then be exploited to achieve near-constant computational complexity per kMC time step. We evaluate the framework's efficiency on a dynamical Ising and a CO oxidation model on regular lattices. We find that our framework achieves a similar performance as specialized state-of-the-art kMC software for lattice kMC. Moreover, our framework offers a much larger flexibility, which we demonstrate on an implementation of Coupled Finite Differences for parameter sensitivity.

DY 32.5 Thu 10:45 H43

Dynamic instability in dissipative self-assembly: common principles in single and multi-filament polymers — •Seeralan Sarvaharman and Aljaž Godec — Max Planck Insitute for Multidisciplinary Sciences, Göttingen, Germany

Dissipative self-assembly underpins the formation of complex biological structures by breaking time-reversal symmetry. Microtubules, essential cytoskeletal polymers, exemplify this through "dynamic instability", where the growth and shrinkage of the polymer are governed by the instantaneous composition of the constituent filaments. The microtubule length, the observable most commonly used to quantify this behaviour, obscures the many-body physics involved. As such, the principles underpinning this instability have remained elusive.

Here, we address this challenge by modelling the dynamics using a three-state Potts framework with thermodynamically consistent driving, capturing the stochastic interactions within and between filaments. By employing a pair approximation and local equilibrium reasoning, we derive a chemical master equation that describes the system's probabilistic evolution in terms of the length and composition. To uncover the macroscopic dynamics, we apply WKB analysis and use Filippov theory to analyse the resultant piecewise continuous ODEs that describe the evolution of the most probable paths. This analysis allows us to construct a dynamical phase diagram, revealing distinct regimes of behaviour, including dissipative limit cycles that underlie the observed macroscopic fluctuations in microtubule length.

DY 32.6 Thu 11:00 H43

The effect of noise on the breather solutions of the discrete nonlinear schrödinger equation — •Mahdieh Ebrahimi[1], Barbara Drossel[1], and Wolfram Just[2] — [1]Institute of Condensed Matter Physics, Technical University of Darmstadt, Hochschulstr. 6, 64289 Darmstadt, Germany — [2]Institute of Mathematics, University of Rostock, D-18057 Rostock Germany

The Discrete Nonlinear Schrödinger Equation (DNSE) finds applications across diverse scientific fields, including physics, chemistry, and biology. This dynamical equation is characterized by localized solutions known as breathers. Gaining insights into the processes governing discrete systems is crucial for understanding phenomena such as excitations in crystal lattices and molecular chains, light propagation in waveguide arrays, and the dynamics of Bose-condensate droplets. In this study, we treat the DNSE as an effective macroscopic equation for a quantum many-particle system and investigate the impact of two types of noise (additive and multiplicative noise) on its Hamiltonian equations of motion using symplectic integration. Our findings reveal that the system's normalization increases linearly with time under additive noise, leading to unbounded energy. Conversely, multiplicative noise preserves normalization but causes the system to heat up, ultimately destabilizing the breather in the presence of noise. Our results vividly illustrate the relevance of conserved quantities for the stochastic dynamics in Hamiltonian systems.