DY 41: Poster: Nonlinear Dynamics, Granular Matter, and Machine Learning

Time: Wednesday 15:00–18:00 Location: P5

DY 41.1 Wed 15:00 P5

Dynamics of Root Growth in Granular Media — Tianhui Liao[1,3], Jiayun Huang[1], Shihe Pan[1], Matthias Schroeter[1,4], and •Kai Huang[1,2] — [1]Collective Dynamics Lab, Division of Natural and Applied Sciences, Duke Kunshan University, 215306 Kunshan, Jiangsu, China — [2]Experimentalphysik V, Universität Bayreuth, 95440 Bayreuth, Germany — [3]Department of Physics, School of Science, Westlake University, Hangzhou, China — [4]Max-Planck-Institut für Dynamik und Selbstorganisation, Am Faßberg 17, 37077 Göttingen, Germany

Since the pioneering work of C. Darwin, the dynamics of growing plants and its interactions with the surrounding environment have been a topic of interest over centuries. As more frequent flooding and drought arise along with global climate change, it is essential to develop ecological models based on first principle understanding of the 'microscopic' interactions between plant roots and surrounding environment. Given the complex rheological behavior of granular media, it is intuitive to understand how plant roots navigate through granular media with heterogeneous stress distributions. By means of X-ray computer tomography, we measure the local packing density of individual 'soil' particles using (Set-)Voronoi tessellation, along with the morphological changes of plant roots. Our goal is to map temporal changes in packing fraction, displacement fields, and strain fields to reveal how roots actively adapt to the surrounding environment.

DY 41.2 Wed 15:00 P5

Diffusion in a Ferrogranular Pinball Machine — Ali Lakkis[1], Matthias Biersack[1], Oksana Bilous[2], Sofia Kantorovich[2], and •Richter Reinhard[1] — [1]Experimentalphysik 5, Universität Bayreuth — [2]Fakultät für Physik, Universität Wien

We experimentally investigate the diffusion of millimeter-sized glass and steel beads in a vessel under vertical vibration. At high amplitudes of an applied vertically oriented magnetic induction B, the magnetization of the steel beads aligns with the field direction. This causes the magnetized steel spheres to become nearly pinned in a hexagonal lattice due to dipole-dipole repulsion. As a result, they act as obstacles that hinder the diffusion of the glass beads, similar to the pins in a pinball machine. When B is reduced, the hexatic lattice of steel spheres becomes more fluid-like. We track both the glass and steel beads and estimate their mean square displacement (MSD) for different values of B. These results are compared to Molecular Dynamics simulations of a quasi-2D thermalized Stockmayer-glass mixture [1].

[1] O. Bilous, K. A. Okrugin, A. Lakkis, R. Richter, S. S. Kantorovich, *Self-diffusion in Ferrogranulates: Stockmayer Model Revisited*, J. Moll. Liquids, submitted (2025)

DY 41.3 Wed 15:00 P5

Analysis and optimization of power grid stability for rising feed-in of wind energy — •Jean-Luc Schnipper and Philipp Maass — Universität Osnabrück, Institut für Physik, Germany

On the basis of the swing equations for power flow in electricity grids and heterogeneous test grid structures, we analyse the impact of wind-power feed on grid stability. The stability is quantified by the exceedance, that is the fraction of time the network frequency exceeds thresholds triggering primary control measures. Wind farms are incorporated into test grids by replacing conventional generators. They are represented by stochastically driven single turbines with mean power output equal to that of the replaced conventional generator. We find that that the exceedance per unit of installed wind power can vary substantially depending on which generators are substituted and to which extent wind fluctuations are correlated at different locations of wind power injection. This offers strategies for maintaining best power grid stability by optimized spatial allocation of wind farms.

DY 41.4 Wed 15:00 P5

On Uncertainty Quantification in Parameter Estimation of Ordinary Differential Equation Initial Value Problems — •Oliver Strebel — Angelstr. 17, 75392 Deckenpfronn

Parameter estimation tasks for ordinary differential equation initial value problems (ODE-IVP) arise, when solution data for the ODE-IVP are given and for a given model the parameters and initial values are estimated. From the mathematical definition of the ODE-IVP it follows that uncertainty due to noise in the data and from a misfit of the model is reflected in the parameters and initial values alone. This uncertainty determines the uncertainty in the solution curves of the ODE-IVP. It is shown that simple Monte Carlo simulations, using the standard nonlinear regression measure, are well-suited for uncertainty quantification (UQ) in ODE-IVPs. This approach also uncovers practical identifiability issues related to the parameters and initial conditions. Additionally, the limitations of the method, such as its sensitivity to initial conditions and computational feasibility, are discussed.

DY 41.5 Wed 15:00 P5

Transition to Turbulence via Synchronization and Interacting Wakes — •Urantuya Batsuuri[1,2], Michael Hölling[1,2], Matthias Wächter[1,2], and Joachim Peinke[1,2] — [1]School of Mathematics and Science, Institute of Physics, Carl von Ossietzky Universität Oldenburg, 26129 Oldenburg, Germany — [2]ForWind - Center for Wind Energy Research, Küpkersweg 70, 26129 Oldenburg, Germany

The study investigates the dynamics of wake interactions under periodic perturbations using an active grid with two independently driven shafts, which are excited with different frequencies. Downstream velocity field is measured with constant-temperature anemometry to resolve the flow response.

For the single-shaft excitation case, a nonlinear synchronization effect is observed: the wake meandering synchronizes to the small-amplitude shaft motion, and this synchronized behavior grows downstream until it collapses into turbulence. Through this synchronization mechanism, the transition to turbulence appears to be accelerated.

For the two-shaft excitation case, an incipient interaction of the vortices leads to a low-dimensional quasi-periodic state. Further downstream, increasing nonlinear dynamics generate enhanced higher harmonics and interharmonics (mixing components). Eventually, the spectrum broadens into a fully turbulent state that follows the classical -5/3 power-law decay.

DY 41.6 Wed 15:00 P5

BHD In semi-chaotic phasespace — •Nico Fink — RPTU Kaiserslautern Landau; Kaiserslautern; Erwin Schrödinger Straße 46, Germany

The previous project showed a realisation of breaking of time reversal symmetry in a system with one degree of freedom, leading to the "rediscovery" of what was coined the Krystal-Neistadt-henrard-Theorem. This project extends the system to a nonlinear System with 1,5 degrees of freedom, displaying the rise of chaos around the separatrix widening and splitting of ensembles. Tje aim is to explore the macroscopic behaviour of ensembles by a bottom up approach.

DY 41.7 Wed 15:00 P5

Laminar chaos in systems with state-dependent delay — •David Müller-Bender — Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany

Laminar chaos, an extremely low-dimensional form of chaotic dynamics, was originally discovered in time-delay systems with large, periodically time-varying delays [Phys. Rev. Lett. 120, 084102 (2018)]. In contrast, the same systems with constant delay exhibit high-dimensional turbulent chaos. Laminar chaos therefore provides a clear example of how temporal modulation of the delay can drastically change the dynamics of a time-delay system. While turbulent chaos is characterized by strong high-frequency oscillations, laminar chaos shows nearly constant laminar phases, whose intensity levels follow the dynamics of a chaotic one-dimensional iterated map.

Following a bottom-up approach, we subsequently investigated systems with quasiperiodic [Phys. Rev. E 107, 014205 (2023)], random, and chaotically time-varying delays [Phys. Rev. E 112, 064203 (2025)], thereby stepwise increasing the generality of the delay variation and building on insights from the preceding cases. In the present work, we consider the case of state-dependent delays and present first results, demonstrating that laminar chaos can also be observed in such systems.

DY 41.8 Wed 15:00 P5

Mesoscopic interface laws in patterns formed by non-

equilibrium cell polarity models — •Tobias Alexander Roth[1], Henrik Weyer[2], and Erwin Frey[1,3] — [1]Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, Ludwig-Maximilians-Universität München — [2]Kavli Institute for Theoretical Physics, UCSB — [3]Max Planck School Matter to Life

Inspired by minimal models for protein-based polarization of living cells, we investigate the dynamics of interfaces in quasi-stationary patterns generated by two-component mass-conserving reaction-diffusion systems. These models describe two density fields that diffuse and interconvert through chemical reactions. Simulations reveal that for fast reactions sharp interfaces emerge, that separate high- and low density regions, which coarsen over time and eventually become a single patch. To quantitatively describe this process, we derive reduced descriptions for the motion of these interfaces, which are strikingly similar to what is found in crystal growth processes with dynamic heat deposition. Our derivation allows for a diffusio-chemical version of surface tension and kinetic drag and explains a cross-over in coarsening exponents. Taken together, we put non-equilibrium two-component models in context to classical thermodynamic models and give insight into biological self organization.

DY 41.9 Wed 15:00 P5

Nonlinear pulse dynamics in harmonic active mode-locking — •Shakiba Khajenooriranjbar[1], Elias R. Koch[1], Julien Javaloyes[2], and Svetlana V. Gurevich[1,2,3] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9, Münster 48149, Germany — [2]Departament de Física & IAC-3, Universitat de les Illes Balears, Cra. de Valldemossa, km 7.5. E-07122 Palma, Spain — [3]Center for Data Science and Complexity, Corrensstr. 2, 48149 Münster, Germany

Active mode-locking (AML) is a prominent technique for generating ultra-short laser pulses and frequency combs, finding applications in fields such as medicine and laser metrology. We employ a time-delayed model to study the multipulse dynamics in AML that is valid for large values of the round trip gain and losses. It allows us to access the typical regimes encountered in semiconductor lasers and to perform an extended bifurcation analysis. Close to the harmonic resonances and to the lasing threshold, we recover the Hermite-Gauss solutions. However, we also discover a global bifurcation scenario in which a single pulse can jump, over a slow time scale, between the different minima of the modulation potential. There, a periodic orbit terminates at an homoclinic limit point of the solution branch, where not all potential slots occupied with the pulses, forming a so-called time-crystal state. Next, we analyzed the interaction between pulses by analyzing their phase relations. Numerical path continuation reveals the existence of multistable splay states and the laser may wander between them under the influence of stochastic forces.

DY 41.10 Wed 15:00 P5

Dynamic Models for Two Nonreciprocally Coupled Fields: A Microscopic Derivation for Zero, One, and Two Conservation Laws — Kristian Blom[1], •Uwe Thiele[1], and Aljaz Godec[2] — [1]Institute of Theoretical Physics, University of Münster, Wilhelm-Klemm-Strasse 9, 48149 Münster, Germany — [2]Mathematical bioPhysics group, Max Planck Institute for Multidisciplinary Sciences, Am Faßberg 11, 37077 Göttingen, Germany

Dynamical field theories form a cornerstone of statistical and soft matter physics, providing continuum descriptions of complex systems through a coarse-grained order parameter field. These theories can be derived either by explicit coarse-graining of microscopic dynamics or by top-down symmetry and conservation arguments.

An intriguing class of such models are nonreciprocal field theories, including the nonreciprocal Allen-Cahn and Cahn-Hilliard models, which describe the spatiotemporal evolution of two fields coupled through interactions that violate Newton's third law. Depending on the underlying microscopic dynamics, two interacting fields may exhibit zero, one, or two conservation laws associated.

In this poster, we demonstrate how the evolution equations for each of these scenarios can be systematically derived from a single microscopic framework: the nonreciprocal Ising model. After obtaining the corresponding field-theoretic descriptions, we briefly discuss their linear and nonlinear behavior, and finally show how distinct combinations of kinetic modes give rise to a set of sixteen different nonreciprocal field theories.

DY 41.11 Wed 15:00 P5

Competing instabilities in electroferrofluids via non-variationally coupled Swift-Hohenberg equations — •Emil Stråka[1], Max Phillip Holl[1], Maria Sammalkorpi[1], and Mikko Haataja[2] — [1]Aalto University, Finland — [2]Princeton University, USA

Recent experiments in charged ferrofluids, so called electroferrofluids, have shown that they can exhibit Rosensweig-like patterns with non-equilibrium activity [1]. The observed activity rises from the competition of an magnetic and electric field induced instabilities. In this work, we study the phenomenon via two non-reciprocally coupled Swift-Hohenberg equations analytically and numerically [1,2]. In addition to the propagating patterns predicted by theory, the model equations reveal a wide range of dynamics, including irregular, active motions [2].

Our findings demonstrate how competing instabilities in a simplified model system can generate new, nontrivial pattern dynamics. These results suggest that similar active dynamics may arise broadly in complex fluids with competing instability mechanisms.

[1] Rigoni, C., Holl, M. P., Scacchi, A., Stråka, E., Sohrabi, F., Haataja, M. P., Sammalkorpi, M., & Timonen, J. V. I. (2025). Active Rosensweig Patterns. arXiv:2510.09099. https://arxiv.org/abs/2510.09099

[2] Stråka, E., Holl, M. P., Sammalkorpi, M. & Haataja, M. P., under preparation (2025). Competing instabilities in complex fluids via Swift-Hohenberg equations with non-variational coupling.

DY 41.12 Wed 15:00 P5

Mitigating Degradation in Anion Exchange Membrane Water Electrolysis: Repurposing Shutdowns to Probe Cell Health — •Limei Jin[1], Violeta Karyofylli[2], Karsten Reuter[1], and Christoph Scheurer[1,2] — [1]Fritz-Haber-Institut der MPG, Berlin — [2]IET-1, Forschungszentrum Jülich

The reliable integration of Anion Exchange Membrane Water Electrolysis (AEMWE) into renewable energy systems is hampered by rapid cell degradation, a challenge exacerbated by variable loads and frequent, safety-mandated shutdowns. This performance loss has been attributed to cell reversal: when the cell's potential drops below a critical inflection point, an acute negative current excursion occurs.

To address this challenge, we present an effect analysis of key shutdown parameters on the inflection point of the potential, using this operational signature as a critical indicator to correlate with long-term aging. We base the analysis on our comprehensive COMSOL multiphysics model to accurately simulate dynamical processes governing the shutdown and reversal phenomena in detail. Data generated from these simulations are integrated into an AI-driven optimization framework to identify ideal operating parameters. It will be used to design an optimal pulse sequence for an active online control to suppress reversal events and mitigate degradation.

DY 41.13 Wed 15:00 P5

TANGO and Machine Learning Enhanced Experimentation for Real Time Tracking of Actively Steered Magnetic Particles. — •Nikita Popkov[2,3], Nikolai Weidt[1,2], Yahya Shubbak[1,2], Rico Huhnstock[1,2], Kristina Dingel[2,3], Bernhard Sick[2,3], and Arno Ehresmann[1,2] — [1]Institute for Physics and CINSaT, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]AIM-ED, Joint Lab of Helmholtzzentrum für Materialien und Energie, Berlin (HZB) and University of Kassel, Hahn-Meitner-Platz 1, 14109, Berlin, Germany — [3]Intelligent Embedded Systems, University of Kassel, Wilhelmshöher Allee 71-73, 34121, Kassel, Germany

This work presents an AI-driven closed-loop framework for automating experimental tasks, demonstrated for the remote-controlled on-chip transport of magnetic particles. The system integrates machine learning models for particle detection, tracking, and classification, enabling dynamic feedback control during experiments. It autonomously adjusts experimental parameters to improve data quality and align outcomes with research objectives. The TANGO controls modular design allows adaptation to different experimental setups and hypotheses. Overall, it emphasizes how autonomous systems could iteratively optimize experiments, advancing the field of next-generation laboratory automation and, specifically for our experiments, the development of novel lab-on-a-chip devices.

DY 41.14 Wed 15:00 P5

Machine Learning of a Classical Density Functional for 2D Hard Rods — •Paul Bitzer, Jens Weimar, and Martin Oettel — Eberhard Karls University of Tübingen, Tübingen, Germany

Obtaining phase diagrams and density distributions via Grand canonical Monte Carlo simulations (GCMC) for classical fluids still requires substantial computational resources. Here, classical density functional theory (cDFT) is more efficient if the excess functional for the free energy is known. Recently, machine learning (ML) methods have become popular to learn such functionals (which are broadly applicable) from a limited amount of training data obtained in random, inhomogeneous external potentials [1]. We discuss an extension of an ML scheme to lattice fluids and apply it to the case of hard rods in two dimensions (2D). This model shows demixing between majority phases of vertically resp. horizontally oriented rods. This is typical of demixing in a binary, continumm fluid whose phase diagram has been learned recently in [2] employing only training data inhomogeneous in 1D. The use of explicit 2D training data allows applications to more general inhomogeneous situations [3].

[1] A. Simon and M. Oettel, Machine learning approaches to classical density functional theory (review), arXiv:2406.07345
[2] S. Robitschko et al, J. Chem. Phys. 163, 161101 (2025)
[3] F. Glitsch, J. Weimar and M. Oettel, Phys. Rev. E 111, 055305 (2025)

DY 41.15 Wed 15:00 P5

Neural-Network-Driven Sequential Quasi Monte Carlo Sampling for Bayesian Inference with Complex Posteriors — •Andreas Panagiotopoulos[1], Javed Mudassar[2], Jens-Uwe Repke[2], Georg Brösigke[2], and Sebastian Matera[1] — [1]Fritz-Haber-Institut der MPG, Berlin — [2]Technische Universität Berlin

Bayesian inference has seen an increasing popularity in recent years, because it overcomes some of the limitations of classical parameter fitting. The price is the need to sample the potentially high-dimensional parameter space, which can become computationally demanding for complex forward models. This is enhanced when faced with uninformative priors but accurate data in conjunction with highly sensitive and nonlinear models. Posteriors will be sharply localized and of complex nature resulting in challenging sampling problems. To address this, we have developed a sequential importance sampling approach which utilizes neural network normalizing flows to exploit the superior sampling properties of Quasi Monte Carlo (MC) techniques. An initial sampling from a simple distribution is employed to learn the first layer of the normalizing flow, i.e. a first coarse approximation of the posterior distribution. Using this flow to quasi MC sample from that distribution provides the data to learn the next layer and so on. As at early stages appropriate sampling of the posterior is intractable, a tempering strategy is employed to make this strategy more robust. We demonstrate the approach on a realistic problem with complex posteriors stemming from the field of chemical kinetics.

DY 41.16 Wed 15:00 P5

Computational modeling and design of self-stratifying colloidal materials — •Mayukh Kundu and Michael Howard — Auburn University, Auburn, United States

Mixtures of colloidal particles suspended in a solvent can spontaneously form layered structures during fast solvent drying. This process, called self-stratification, can be leveraged to fabricate multilayered colloidal materials in a single processing step. Existing models for simulating self-stratification are computationally expensive or inaccurate. I have developed a better model for simulating the phenomena using dynamic density functional theory (DDFT). DDFT is a continuum model that is systematically formulated from particle-level interactions and dynamics. As such, it incorporates physics that would be present in particle-based simulations but can access much larger length scales and longer time scales. DDFT has two key inputs: a thermodynamic model (free-energy functional) and a dynamics model (mobility tensor). DDFT model can be made faster using the simplest approximations of these inputs that give the desired accuracy. I systematically investigated approximations of both inputs to develop an accurate, efficient DDFT model for drying suspensions. I also coupled these drying simulations to an optimization strategy based on surrogate modeling to inverse design self-stratified coatings with targeted thickness and particle distribution. This work has the potential to reduce the time and resources required to create these novel materials in the laboratory.