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The Dynamics and Statistical Physics Division covers theoretical and experimental activities in all areas of statistical physics, quantum dynamics and many-body systems, nonlinear dynamics and pattern formation, data analysis and machine learning as well as active matter, fluid physics, soft matter, and complex fluids. The DY section has strong links and joint sessions with the sections of Biological Physics (BP), Chemical Physics and Polymers (CPP), Socio- and Econophysics (SOE), and Low Temperatures (TT).

Overview of Invited Talks and Sessions

(Lecture halls H37, H43, and H47; Poster P3 and P4)

Invited Talks

DY 3.6	Mon	10:45–11:15	H37	**Collective behavior of photoactive macroscopic particles** — •Iker Zuriguel
DY 4.2	Mon	9:45–10:15	H43	**Physical application of infinite ergodic theory** — •Eli Barkai
DY 4.7	Mon	11:30–12:00	H43	**Modelling the movements of organisms: Movement ecology meets active particles and anomalous diffusion** — •Rainer Klages
DY 8.1	Mon	15:00–15:30	H43	**Spatio-temporal pattern formation in time-delayed optical systems** — •Svetlana Gurevich
DY 8.6	Mon	16:45–17:15	H43	**Nonlinear dynamics and time delays in metal cutting** — •Andreas Otto
DY 9.5	Mon	16:00–16:30	H47	**Large-deviation simulations of non-equilibrium stochastic processes** — •Alexander K. Hartmann
DY 14.1	Tue	9:30–10:00	H43	**Robust signal amplification and information integration via self-tuned proximity to bifurcation points** — •Isabella Graf
DY 14.7	Tue	11:30–12:00	H43	**Beyond the connectionist view: (De-)synchronizing neural networks via cell-intrinsic dynamics** — •Susanne Schreiber
DY 15.6	Tue	10:45–11:15	H47	**Beyond spheres - active matter in new shapes** — •Juliane Simmchen
DY 15.11	Tue	12:30–13:00	H47	**Emergent correlations and boundary fluctuations in epithelial cell sheets** — •Silke Henkes
DY 17.1	Tue	14:00–14:30	H43	**Mechanistic origins of temperature scaling in the early embryonic cell cycle** — •Lendert Gelens
DY 24.1	Wed	15:00–15:30	H43	**Dynamics of odd and chiral active systems** — •Hartmut Löwen
DY 24.7	Wed	16:45–17:15	H43	**Odd dynamics and universal flows of passive objects in a chiral active fluid** — •Cory Hargus, Federico Ghimenti, Julien Tailleur, Frédéric van Wijland
DY 24.11	Wed	18:00–18:30	H43	**How to model frictional contacts in sheared and active colloids** — •Friederike Schmid, Kay Hofmann, Kay-Robert Dormann, Benno Liebchen
DY 31.6	Thu	10:45–11:15	H37	**Strong coupling and coherence in quantum thermodynamics** — •Janet Anders, Federico Cerisola, James Cresser, et al
DY 32.1	Thu	9:30–10:00	H43	**Fluctuation-Response Relations for Non-equilibrium Systems** — •Benjamin Lindner
DY 36.1	Thu	15:00–15:30	H37	**Light-Driven Manipulation of Passive and Active Microparticles** — •Svetlana Santer

DY 44.1	Fri	9:30–10:00	H47	**From Cavitation in Soft Matter to Erosion on Hard Matter** — •Claus-Dieter Ohl
DY 46.1	Fri	11:30–12:00	H43	**Equilibrium and non-equilibrium dynamics of biological systems with memory** — •Roland Netz

Invited Talks of the joint Symposium Physics of Embryonic Development Across Scales: From DNA to Organisms (SYED)

See SYED for the full program of the symposium.

SYED 1.1	Mon	9:30–10:00	H1	**Emergent crystalline order in a developing epithelium** — Kartik Chhajed, Natalie Dye, Marko Popović, •Frank Jülicher
SYED 1.2	Mon	10:00–10:30	H1	**A tissue rigidity phase transition shapes morphogen gradients** — Camilla Autorino, Diana Khoromskaia, Bernat Corominas-Murtra, Zena Hadjivasiliou, •Nicoletta Petridou
SYED 1.3	Mon	10:30–11:00	H1	**Building quantitative dynamical landscapes of developmental cell fate decisions** — •David Rand
SYED 1.4	Mon	11:15–11:45	H1	**Control of lumen geometry and topology by the interplay between pressure and cell proliferation rate** — •Anne Grapin-Botton, Byung Ho Lee, Masaki Sano, Daniel Riveline, Kana Fuji, Tetsuya Hiraiwa
SYED 1.5	Mon	11:45–12:15	H1	**Chromosomes as active communication and memory machines** — •Leonid A. Mirny

Invited Talks of the joint SKM Dissertationspreis 2025 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	9:30–10:00	H2	**Nanoscale Chemical Analysis of Ferroic Materials and Phenomena** — •Kasper Aas Hunnestad
SYSD 1.2	Mon	10:00–10:30	H2	**Advanced Excitation Schemes for Semiconductor Quantum Dots** — •Yusuf Karli
SYSD 1.3	Mon	10:30–11:00	H2	**Aspects and Probes of Strongly Correlated Electrons in Two-Dimensional Semiconductors** — •Clemens Kuhlenkamp
SYSD 1.4	Mon	11:00–11:30	H2	**Mean back relaxation and mechanical fingerprints: simplifying the study of active intracellular mechanics** — •Till Münker
SYSD 1.5	Mon	11:30–12:00	H2	**Coherent Dynamics of Atomic Spins on a Surface** — •Lukas Veldman

Invited Talks of the joint Symposium AI in (Bio-)Physics (SYAI)

See SYAI for the full program of the symposium.

SYAI 1.1	Thu	9:30–10:00	H1	**Predicting interaction partners and generating new protein sequences using protein language models** — •Anne-Florence Bitbol
SYAI 1.2	Thu	10:00–10:30	H1	**Realizing Schrödinger's dream with AI-enabled molecular dynamics** — •Alexandre Tkatchenko
SYAI 1.3	Thu	10:30–11:00	H1	**Emergent behavior of artificial intelligence** — •Steffen Rulands
SYAI 1.4	Thu	11:15–11:45	H1	**AI in medical research - navigating complexity with AI** — •Daniel Truhn
SYAI 1.5	Thu	11:45–12:15	H1	**Computational Modelling of Morphogenesis** — •Dagmar Iber

Invited Talks of the joint Symposium Nonequilibrium Collective Behavior in Open Classical and Quantum Systems (SYQS)

See SYQS for the full program of the symposium.

SYQS 1.1	Thu	15:00–15:30	H1	**Active quantum flocks** — Reyhaneh Khasseh, Sascha Wald, Roderich Moessner, Christoph Weber, •Markus Heyl
SYQS 1.2	Thu	15:30–16:00	H1	**Robust dynamics and function in stochastic topological systems** — •Evelyn Tang
SYQS 1.3	Thu	16:00–16:30	H1	**Nonequilibrium Dynamics of Disorder-Driven Ultracold Fermi Gases** — •Artur Widera

SYQS 1.4	Thu	16:45–17:15	H1	**Topological classification of driven-dissipative nonlinear systems** — •Oded Zilberberg, Greta Villa, Kilian Seibold, Vincent Dumont, Gianluca Rastelli, Mateusz Michałek, Alexander Eichler, Javier del Pino
SYQS 1.5	Thu	17:15–17:45	H1	**Learning dynamical behaviors in physical systems** — •Vincenzo Vitelli

Sessions

DY 1.1–1.3	Sun	16:00–18:15	H2	**Hands-on Tutorial: AI Fundamentals for Research (joint session BP/TUT/DY/AKPIK)**
DY 2.1–2.11	Mon	9:30–12:30	H31	**Nonequilibrium Quantum Systems (joint session TT/DY)**
DY 3.1–3.11	Mon	9:30–12:45	H37	**Active Matter I (joint session DY/BP/CPP)**
DY 4.1–4.11	Mon	9:30–13:00	H43	**Focus Session: Nonlinear Dynamics and Stochastic Processes – Advances in Theory and Applications I**
DY 5.1–5.7	Mon	9:30–11:15	H47	**Statistical Physics: General**
DY 6.1–6.6	Mon	11:30–13:00	H47	**Critical Phenomena and Phase Transitions**
DY 7.1–7.7	Mon	15:00–17:00	H37	**Active Matter II (joint session BP/CPP/DY)**
DY 8.1–8.11	Mon	15:00–18:30	H43	**Focus Session: Nonlinear Dynamics and Stochastic Processes – Advances in Theory and Applications II**
DY 9.1–9.12	Mon	15:00–18:30	H47	**Statistical Physics far from Thermal Equilibrium**
DY 10.1–10.4	Mon	16:15–17:15	H34	**Wetting, Fluidics and Liquids at Interfaces and Surfaces I (joint session CPP/DY)**
DY 11.1–11.4	Mon	17:30–18:30	H34	**Wetting, Fluidics and Liquids at Interfaces and Surfaces II (joint session CPP/DY)**
DY 12.1–12.13	Tue	9:30–13:15	H31	**Quantum Coherence and Quantum Information Systems (joint session TT/DY)**
DY 13.1–13.13	Tue	9:30–13:00	H37	**Many-body Quantum Dynamics I (joint session DY/TT)**
DY 14.1–14.9	Tue	9:30–12:30	H43	**Focus Session: Nonlinear Dynamics in Biological Systems I (joint session DY/BP)**
DY 15.1–15.11	Tue	9:30–13:00	H47	**Active Matter III (joint session DY/BP/CPP)**
DY 16.1–16.6	Tue	14:00–15:30	H37	**Many-body Systems: Equilibration, Chaos, and Localization (joint session DY/TT)**
DY 17.1–17.4	Tue	14:00–15:15	H43	**Focus Session: Nonlinear Dynamics in Biological Systems II (joint session DY/BP)**
DY 18.1–18.6	Tue	14:00–15:30	H47	**Pattern Formation**
DY 19.1–19.5	Wed	9:30–12:15	H17	**Focus Session: Quantum Emission from Chaotic Microcavities (joint session HL/DY)**
DY 20.1–20.13	Wed	9:30–13:00	H37	**Many-body Quantum Dynamics II (joint session DY/TT)**
DY 21.1–21.8	Wed	9:30–11:30	H43	**Granular Matter**
DY 22.1–22.29	Wed	10:00–12:00	P3	**Poster: Statistical Physics**
DY 23.1–23.20	Wed	10:00–12:00	P3	**Poster: Active Matter, Soft Matter, Fluids (joint session DY/CPP)**
DY 24.1–24.11	Wed	15:00–18:30	H43	**Focus Session: Broken Symmetries in Statistical Physics - Dynamics of Odd Systems**
DY 25.1–25.10	Wed	15:00–18:00	H44	**Statistical Physics of Biological Systems I (joint session BP/DY)**
DY 26.1–26.9	Wed	15:00–17:30	H45	**Networks, From Topology to Dynamics (joint session SOE/BP/DY)**
DY 27.1–27.14	Wed	15:00–18:00	P4	**Poster: Nonlinear Dynamics, Pattern Formation, Granular Matter**
DY 28.1–28.7	Wed	15:00–18:00	P4	**Poster: Machine Learning, Data Science**
DY 29.1–29.9	Wed	15:00–18:00	P4	**Poster: Quantum Dynamics and Many-body Systems**
DY 30.1–30.12	Thu	9:30–12:45	H31	**Quantum-Critical Phenomena (joint session TT/DY)**
DY 31.1–31.11	Thu	9:30–12:45	H37	**Focus Session: Nonequilibrium Collective Behavior in Open Classical and Quantum Systems**
DY 32.1–32.6	Thu	9:30–11:15	H43	**Nonlinear Stochastic Systems**
DY 33.1–33.13	Thu	9:30–13:00	H47	**Machine Learning in Dynamics and Statistical Physics I**
DY 34.1–34.6	Thu	11:30–13:00	H43	**Nonlinear Dynamics, Synchronization, and Chaos**
DY 35.1–35.13	Thu	15:00–18:30	H31	**Fluctuations, Noise and Other Transport Topics (joint session TT/DY)**
DY 36.1–36.9	Thu	15:00–17:45	H37	**Microswimmers and Microfluidics (joint session DY/BP/CPP)**
DY 37.1–37.9	Thu	15:00–17:15	H43	**Brownian Motion and Anomalous Diffusion**

DY 38.1–38.11	Thu	15:00–18:00	H44	**Focus Session: Innovations in Research Software Engineering (joint session BP/DY)**
DY 39.1–39.6	Thu	15:00–16:30	H47	**Machine Learning in Dynamics and Statistical Physics II**
DY 40	Thu	18:00–19:00	H43	**Members' Assembly**
DY 41.1–41.7	Fri	9:30–11:15	H37	**Quantum Dynamics, Decoherence, and Quantum Information (joint session DY/TT)**
DY 42.1–42.7	Fri	9:30–11:15	H43	**Stochastic Thermodynamics**
DY 43.1–43.12	Fri	9:30–13:00	H44	**Active Matter IV (joint session BP/CPP/DY)**
DY 44.1–44.11	Fri	9:30–12:45	H47	**Droplets, Wetting, Complex Fluids, and Soft Matter (joint session DY/CPP)**
DY 45.1–45.6	Fri	11:30–13:00	H37	**Quantum Chaos (joint session DY/TT)**
DY 46.1–46.5	Fri	11:30–13:00	H43	**Statistical Physics of Biological Systems II (joint session DY/BP)**
DY 47.1–47.1	Fri	13:15–14:00	H2	**Closing Talk (joint session BP/CPP/DY)**

Members' Assembly of the Dynamics and Statistical Physics Division

Thursday 18:00–19:00 H43

DY 1: Hands-on Tutorial: AI Fundamentals for Research (joint session BP/TUT/DY/AKPIK)

Artificial intelligence (AI) has become an essential tool in modern physics, enabling new approaches to data analysis, modeling, and prediction. This hands-on tutorial provides an accessible introduction to key AI concepts, emphasizing their practical applications in physics research.

Please bring your laptop. There will be limited power outlets in the room, so come with a fully charged battery.

Materials will be made available from 10.03.2025, accessible via the following options:
GitHub repository:
https://github.com/RedMechanism/DPG-SKM-2025-Tutorial-AI-Fundamentals-for-Research
ZIP file download:
https://jlubox.uni-giessen.de/getlink/fiAGRzcGTiCL3GZxk8WAjom4/
Participants are encouraged to download them ahead of time.

Organized by Jan Bürger (Aachen), Janine Graser (Duisburg), Robin Msiska (Duisburg/Ghent), and Arash Rahimi-Iman (Gießen), with support from Stefan Klumpp (Göttingen) and Tim Ruhe (Dortmund).

Time: Sunday 16:00–18:15 Location: H2

Tutorial DY 1.1 Sun 16:00 H2
Introduction — Jan Bürger[1], •Janine Graser[2], Robin Msiska[2,3], and Arash Rahimi-Iman[4] — [1]ErUM-Data-Hub, RWTH Aachen University, Aachen, Germany — [2]Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Duisburg, Germany — [3]Department of Solid State Sciences, Ghent University, Ghent, Belgium — [4]I. Physikalisches Institut and Center for Materials Research, Justus-Liebig-University Gießen, Gießen, Germany

The session begins with an overview of essential AI concepts, including neural networks, training methodologies, and key distinctions between AI models. Participants will gain a foundational understanding of AI principles and how these tools can be leveraged for various research challenges.

5 min. break

Tutorial DY 1.2 Sun 16:40 H2
Hands-On Session 1 – Function Approximation — •Jan Bürger[1], Janine Graser[2], Robin Msiska[2,3], and Arash Rahimi-Iman[4] — [1]ErUM-Data-Hub, RWTH Aachen University, Aachen, Germany — [2]Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Duisburg, Germany — [3]Department of Solid State Sciences, Ghent University, Ghent, Belgium — [4]I. Physikalisches Institut and Center for Materials Research, Justus-Liebig-University Gießen, Gießen, Germany

In the first half of the interactive session, participants will work with Jupyter Notebooks to explore practical applications of machine learning. They will train simple neural networks to predict a mathematical function, gaining hands-on experience in tuning key parameters. Since neural networks can typically be considered universal function approximators, this concept is effectively illustrated using a one-dimensional function, making it easy to visualize and understand.

5 min. break

Tutorial DY 1.3 Sun 17:30 H2
Hands-On Session 2 – Classification and More — Jan Bürger[1], Janine Graser[2], •Robin Msiska[2,3], and Arash Rahimi-Iman[4] — [1]ErUM-Data-Hub, RWTH Aachen University, Aachen, Germany — [2]Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Duisburg, Germany — [3]Department of Solid State Sciences, Ghent University, Ghent, Belgium — [4]I. Physikalisches Institut and Center for Materials Research, Justus-Liebig-University Gießen, Gießen, Germany

The session demonstrates how pre-trained models can simplify tasks such as classification, making them readily applicable to research. Typical examples include recognizing handwritten digits, which showcase the power of pretrained models in solving common challenges. As a preview of advanced topics, the tutorial concludes with brief examples of large language models (LLMs) and generative AI.

DY 2: Nonequilibrium Quantum Systems (joint session TT/DY)

Time: Monday 9:30–12:30 Location: H31

DY 2.1 Mon 9:30 H31
Solving the nonequilibrium Dyson equation with quantics tensor trains — •Ken Inayoshi[1], Maksymilian Środa[2], Anna Kauch[3], Philipp Werner[2], and Hiroshi Shinaoka[1] — [1]Department of Physics, Saitama University, Saitama, Japan — [2]Department of Physics, University of Fribourg, Fribourg, Switzerland — [3]Institute of Solid State Physics, TU Wien, Vienna, Austria

The nonequilibrium Green's function (NEGF) method is a powerful tool to investigate dynamical phenomena in quantum many-body systems. However, the time-translational symmetry breaking of Green's functions (GFs) makes the simulation of long-time dynamics computationally and memory-intensive. To overcome these, various memory compression techniques have been proposed for the NEGF method [1,2]. Among these, quantics tensor trains (QTT) have been attracting a focus for its ability to exponentially compress the data size of GFs [3]. While a prototype NEGF method with QTT has been developed [4], its benchmarks were limited to the short-time dynamics due to technical challenges such as the slow convergence of self-consistent calculations. We propose an improved implementation to reach the longer time regions, using a variational method for solving the Dyson equation and a causality-based divide-and-conquer algorithm [5,6]. In this contribution, we benchmark our method in relevant test cases [6].
[1] J. Kaye and D. Golež, SciPost Phys. **10**, 091 (2021).
[2] M. Eckstein, arXiv:2410.19707.
[3] H. Shinaoka *et al.*, Phys. Rev. X **13**, 021015 (2023).
[4] M. Murray *et al.*, Phys. Rev. B **109**, 165135 (2024).
[5] M. Środa *et al.*, in preparation
[6] K. Inayoshi *et al.*, in preparation

DY 2.2 Mon 9:45 H31
Fractionalized prethermalization in the one-dimensional Hubbard model — •Anton Romen[1,2], Johannes Knolle[1,2,3], and Michael Knap[1,2] — [1]Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]Blackett Laboratory, Imperial College London, London, United Kingdom

Prethermalization phenomena in driven systems are generally understood via a local effective Floquet Hamiltonian. It turns out that this picture is insufficient for systems with fractionalized excitations. A first example is a driven Kitaev spin liquid which realizes a quasista-

tionary state with vastly different temperatures of the matter and flux sectors, a phenomenon dubbed fractionalized prethermalization. In our work we argue that similar heating dynamics also occur in driven 1D tJ-models. In the weak doping limit of this model, the electron fractionalizes into quasiparticles carrying charge and spin. We show that the nonequilibrium heating dynamics of this model feature a quasistationary state characterized by a low spin and high charge temperature. We argue that the lifetime of this quasistationary state is determined by two competing processes depending on the specific drive chosen: A Fermi Golden Rule that describes the lifetime of the quasiparticles and the exponential lifetime of a Floquet prethermal plateau. Using a time dependent variant of the Schrieffer-Wolff transformation we systematically analyze the different classes of drives emerging from the respective Hubbard model. Lastly, we discuss potential ways towards an experimental realization in cold atom experiments.

DY 2.3 Mon 10:00 H31

Computing the lifetime of spin-orbital excitations in TiOCl using Lanczos techniques — •Paul Fadler[1,2], Philipp Hansmann[1], Kai Phillip Schmidt[1], Angela Montanaro[1,3], Filippo Glerean[4], Enrico Maria Rigoni[1,3], Daniele Fausti[1,3], and Martin Eckstein[2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Universität Hamburg — [3]University of Trieste — [4]Harvard University, Cambridge

TiOCl is a spin-Peierls compound with optically active d-d-transitions at 0.7 eV and 1.5 eV. A pump-push-probe spectroscopy experiment on this system revealed a nonlinear signal asymmetric with respect to the order in which these transitions are pumped. This asymmetry could arise from differing lifetimes of the excitations due to multi-magnon and orbital-fission decay processes. To test this hypothesis we derive a spin-orbital Hamiltonian from ab-initio calculation. Within this description the pumped excitations are orbitons, i.e., hybrid spin-orbital quasiparticles, that can be understood as orbital excitations surrounded by a magnon cloud. We evaluate their lifetimes using Fermi's golden rule for all spin-orbital decay channels, which we compute on a large cluster using Lanczos techniques. Comparing the theoretical prediction to the asymmetry and absolute decay times of the nonlinear signal in the experiment we conclude, that multi-magnon and orbital-fission decay processes could be the dominant decay channels for the 0.7 eV excitation. On the other hand for the 1.5 eV excitation other types of processes such as phonon-assisted decays or nonlinearities in the double-pump scheme have to be taken into account.

DY 2.4 Mon 10:15 H31

Comprehensive analysis of electronic relaxation in one dimension Kondo lattice model — •Arturo Perez Romero, Mica Schwarm, and Fabian Heidrich-Meisner — Institut for Theoretical Physics, Georg-August-Universität Göttingen, D-37077 Göttingen, Germany

Recent advancements in laser technology have made it possible to create non-equilibrium conditions on timescales that outpace energy exchange across a wide range of degrees of freedom. The above represents a challenge not only for condensed matter experimental physicist, but also for theoretical physicist who are motivated to describe a great variety of far-from-equilibrium systems. In this paper, we study the real-time dynamics of two paradigmatic models: the Kondo lattice model (KLM) and Kondo-Heisenberg model (KHM) in one dimension. We analyze the role of exchange couplings for the relaxation of a single charge carrier via the time-dependent Lanczos method. We conduct a comprehensive study of the time evolution by evaluating the z-spin component of the conduction electron, the local spin-spin correlation between localized and conduction electron, the spin-spin correlation between localized spins, and the electronic momentum distribution momentum. The study includes a comparison with statistical mechanics predictions for steady state and a research of the effect of diagonal disorder.

This work was funded by the Deutsche Forschungsgemeinschaft (DPG, German Research Foundation) via CRC 1073

DY 2.5 Mon 10:30 H31

An attempt to extend the adiabatic theorem — •Sarah Damerow[1,2] and Stefan Kehrein[1] — [1]Institut für Theoretische Physik, Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen — [2]I. Institut für Theoretische Physik, Universität Hamburg, Notkestraße 9-11, 22607 Hamburg

A conjectured extension of the adiabatic theorem to quantum quenches, i.e., maximally non-adiabatic changes, is presented.The proposed extension is framed as follows: "as long as quenched states within the same magnetic phase are concerned, the overlap between the initial and final ground states is the largest possible." This conjecture is investigated analytically and is tested numerically using Exact Diagonalisation in two models: the Transverse Field Ising Model (TFIM) and the Axial Next Nearest Neighbour Ising Model (ANNNI).

DY 2.6 Mon 10:45 H31

Towards Floquet-GW: interacting electrons in time-periodic potentials — •Ayan Pal[1,2], Erik G. C. P. Van Loon[1,2], and Ferdi Aryasetiawan[1] — [1]Division of Mathematical Physics, Department of Physics, Lund University, Professorsgatan 1, 223 63, Lund, Sweden — [2]NanoLund, Lund University, Professorsgatan 1B, 223 63, Lund, Sweden

The Floquet theory of time-periodic systems provides a middle ground between equilibrium and completely non-equilibrium physics. Here, we study interacting electrons in time-periodic potentials using the combination of Floquet theory and many-body methods such as RPA and GW. We apply these techniques to the electron gas and to lattice models and study the electronic and dielectric properties, for example the appearance of side bands in the spectral functions. These methods have the potential to describe the impact of periodic laser pulses on the plasmonic and optical properties of (moderately) correlated materials.

15 min. break

DY 2.7 Mon 11:15 H31

Universal quench dynamics in Yukawa-Sachdev-Ye-Kitaev models — •Haixin Qiu and Stefan Kehrein — Institute for Theoretical Physics, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Understanding the non-equilibrium properties of non-Fermi liquids without quasiparticles is essential for exploring the dynamics of strongly correlated systems. Here we investigate the quantum quench of a non-Fermi liquid model, the Yukawa-Sachdev-Ye-Kitaev model with interactions involving one boson and q fermions and its lattice extensions. We compute various in and out of equilibrium quantities for general q within the large-N dynamical mean field scheme by integrating the Kadanoff-Baym equations. We find transient oscillations and relaxation dynamics are insensitive to the quench amplitudes deep inside the non-Fermi liquid phase. Notably, the relaxation dynamics involve two distinct transient temperatures and relaxation rates for bosonic and fermionic degrees of freedom, both of which show non-Fermi liquid or universal behaviors. Signatures of prethermalization are also found when quenching near the Fermi liquid phase.

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DY 2.8 Mon 11:30 H31

Long-range induced synchronization of Higgs oscillations in topological superconductors — Andreas Alexander Buchheit[1], Benedikt Fauseweh[2,3], and •Torsten Kessler[4] — [1]Saarland University, Department of Mathematics and Computer Science, Germany — [2]TU Dortmund University, Department of Physics, Germany — [3]German Aerospace Center (DLR), Cologne, Germany — [4]Eindhoven University of Technology, Department of Mechanical Engineering, Netherlands

We investigate the impact of long-range electron-electron interactions on the non-equilibrium dynamics of unconventional superconductors. Using recently developed mathematical tools for the efficient treatment of longe-range interactions on lattices, we simulate the time evolution of a triplet superconductor with arbitrary power law interaction. Owing to the long-range interaction, a chiral phase with d+p symmetry emerges. We find that the long-range interaction stabilizes the Higgs oscillation in this phase. While the d-wave's initial mode decays rapidly, it begins to mirror the stable Higgs oscillation of the p-wave condensate part. Eventually, the two parts oscillate with a joint frequency. We demonstrate that this behavior can also be observed in the optical conductivity resulting from an external probe pulse.

DY 2.9 Mon 11:45 H31

Tuning of slow dynamics in quantum East Hamiltonians motivated by Graph theory — •Heiko Georg Menzler[1], Mari Carmen Bañuls[2,3], and Fabian Heidrich-Meisner[1] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, D-37077 Göttingen, Germany — [2]Max-Planck-Institut für Quantenoptik, D-

85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schelling Strasse 4, D-80799 München

In-between fully ergodic/localized quantum system there exist many systems with atypical relaxation behaviors. One of these systems is the quantum East (QE) model. The classical East model is a central, exemplary model for glassy dynamics and kinetic constraints. Also its quantum counterpart features slow dynamics without conservation laws or disorder. However, the presence of slow dynamics has not yet been fully understood from a quantum perspective. Introducing an interpretation of constrained dynamics based on graph theory, we theoretically demonstrate control over the slow dynamics of QE models. As a general hypothesis, we propose that strong hierarchies between nodes on the Fock space graph are related to the presence of slow dynamics. To quantify hierarchical structures, we develop a measure of centrality for generic Hamiltonian matrices, reminiscent of established centrality measures from graph theory. Based on these ideas, we show how we can introduce detuning to alter the hierarchical structure in the QE model and acutely change the resulting constrained dynamics, evidenced by eigenstate structure in the detuned QE models.

Supported by DFG, German Research Foundation via FOR 5522

DY 2.10 Mon 12:00 H31

Optical signatures of dynamical excitonic condensates — •Alexander Osterkorn[1], Yuta Murakami[2], Tatsuya Kaneko[3], Zhiyuan Sun[4], Andrew J. Millis[5,6], and Denis Golež[1,7] — [1]Jožef Stefan Institute, Ljubljana, Slovenia — [2]RIKEN, Wako, Japan — [3]Osaka University, Toyonaka, Japan — [4]Tsinghua University, Beijing, P.R. China — [5]Columbia University, New York, USA — [6]Flatiron Institute, New York, USA — [7]University of Ljubljana, Ljubljana, Slovenia

Excitons, or bound electron-hole pairs, can condense into an excitonic insulator state, similarly to Cooper pairs in superconductors. A non-equilibrium carrier concentration, such as the one transiently induced by photo-doping or sustained by a tuneable bias voltage in bilayers, can create a dynamical excitonic insulator state, yet proving phase coherence in such setups remains challenging. We examine the condensate phase behavior theoretically and show that optical spectroscopy can distinguish between phase-trapped and phase-delocalized dynamical regimes. In the weak-bias regime, trapped phase dynamics result in an in-gap absorption peak nearly independent of bias voltage, while at higher biases its frequency increases approximately linearly. In the large bias regime, the response current grows strongly under the application of a weak electric probe leading to negative weight in the optical response, which we analyze relative to predictions from a minimal model for the phase. This work opens new avenues for experimentally probing coherence in excitonic condensates and the detection of their dynamical regimes.

DY 2.11 Mon 12:15 H31

Visualizing dynamics of charges and strings in (2+1)D lattice gauge theories — Tyler A. Cochran[1,2], •Bernhard Jobst[3,4], Eliott Rosenberg[1], Yuri D. Lensky[1], Adam Gammon-Smith[5], Michael Knap[3,4], Frank Pollmann[3,4], and Pedram Roushan[1] — [1]Google Research, CA, USA — [2]Princeton University, NJ, USA — [3]Technical University of Munich, 85748 Garching, Germany — [4]MCQST, 80799 München, Germany — [5]University of Nottingham, NG7 2RD, UK

Lattice gauge theories (LGTs) can be employed to understand a wide range of phenomena. Studying their dynamical properties can be challenging as it requires solving many-body problems that are generally beyond perturbative limits. We investigate the dynamics of local excitations in a $\mathbb{Z}_2$ LGT using a two-dimensional lattice of superconducting qubits. We first construct a simple variational circuit which prepares low-energy states that have a large overlap with the ground state; then we create particles with local gates and simulate their quantum dynamics via a discretized time evolution. As the effective magnetic field is increased, our measurements show signatures of transitioning from deconfined to confined dynamics. For confined excitations, the magnetic field induces a tension in the string connecting them. Our method allows us to experimentally image string dynamics in a (2+1)D LGT from which we uncover two distinct regimes inside the confining phase: for weak confinement the string fluctuates strongly in the transverse direction, while for strong confinement transverse fluctuations are effectively frozen.

DY 3: Active Matter I (joint session DY/BP/CPP)

Time: Monday 9:30–12:45 Location: H37

DY 3.1 Mon 9:30 H37

Odd dynamics and pattern formation in mixtures of magnetic spinners and passive colloids — •Dennis Schorn[1], Stijn van der Ham[2], Hanumantha Rao Vutukuri[2], and Benno Liebchen[1] — [1]Technische Universität Darmstadt, 64289 Darmstadt, Germany — [2]MESA+ Institute, University of Twente, 7500 AE Enschede, The Netherlands

Starfish embryos aggregate into chiral crystals exhibiting odd elasticity (Tan *et al.* Nature **607**, 287 (2022)). Similar structures have been recently observed in externally driven magnetic colloids. In this talk, I present experiments and simulations of binary mixtures of magnetic spinners and passive colloids. We develop a model to predict the phase diagram of the system, which comprises four distinct phases that can be systematically reproduced in experiments. In particular, our simulations and experiments show a phase where the passive particles form a gel-like network featuring significant holes filled with self-organized rotating chiral clusters made of spinners. This phase can be reversed by changing the system's composition and magnetic field strength, featuring a system spanning spinner phase with embedded counter-rotating chiral clusters made of passive colloids. Our system may open the route towards a new type of viscoelastic active chiral matter involving nonreciprocal interactions between both species.

DY 3.2 Mon 9:45 H37

Symmetry breaking in active non-reciprocal systems — •Kim L. Kreienkamp and Sabine H. L. Klapp — TU Berlin, Germany

Non-reciprocity significantly impacts the dynamical behavior in mixtures. One of its particularly striking consequences is the spontaneous emergence of time-dependent phases that break parity-time symmetry [1-3]. Here, we study a paradigmatic model of a non-reciprocal polar active mixture with completely symmetric repulsion [4,5]. Using a combination of field theory and particle-based simulations, we identify two qualitatively distinct regimes of non-reciprocity-induced dynamics. In the regime of weak intra-species alignment, non-reciprocity leads to asymmetric clustering in which only one of the two species forms clusters. Notably, the asymmetric density dynamics is driven alone by non-reciprocal orientational couplings [4,5]. In contrast, in the strongly coupled regime, the corresponding field theory exhibits exceptional points that have been associated with the emergence of chiral phases where the polarization direction rotates over time [2]. Our simulations confirm that spontaneous chirality arises at the particle level. In particular, we observe chimera-like states with coexisting locally synchronized and disordered regions. At the coupling strengths associated with exceptional points, the spontaneous chirality peaks.

[1] Z. You et al., PNAS 117, 19767 (2020).
[2] M. Fruchart et al., Nature 592, 363 (2021).
[3] K. L. Kreienkamp and S. H. L. Klapp, NJP 24, 123009 (2022).
[4] K. L. Kreienkamp and S. H. L. Klapp, to appear in PRE (2024).
[5] K. L. Kreienkamp and S. H. L. Klapp, to appear in PRL (2024).

DY 3.3 Mon 10:00 H37

Emergent phases in a discrete flocking model with non-reciprocal interaction — •Swarnajit Chatterjee, Matthieu Mangeat, and Heiko Rieger — Center for Biophysics & Department for Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany

Non-reciprocal interactions arise in systems that seemingly violate Newton's third law "actio=reactio". They are ubiquitous in active and living systems that break detailed balance at the microscale, from social forces to antagonistic interspecies interactions in bacteria. Non-reciprocity affects non-equilibrium phase transitions and pattern formation in active matter and represents a rapidly growing research focus in the field. In this work, we have undertaken a comprehensive study of the non-reciprocal two-species active Ising model (NRTSAIM), a

non-reciprocal discrete-symmetry flocking model. Our study uncovers a distinctive *run-and-chase* dynamical state that emerges under significant non-reciprocal frustration. In this state, A-particles chase B-particles to align with them, while B-particles avoid A-particles, resulting in B-particle accumulation at the opposite end of the advancing A-band. This run-and-chase state represents a non-reciprocal discrete-symmetry analog of the chiral phase seen in the non-reciprocal Vicsek model. Additionally, we find that self-propulsion destroys the oscillatory state obtained for the non-motile case, and all the NRTSAIM steady-states are metastable due to spontaneous droplet excitation and exhibit motility-induced interface pinning. A hydrodynamic theory supports our simulations and confirms the reported phase diagrams.

DY 3.4 Mon 10:15 H37

Emergent phases in a discrete flocking model with reciprocal interaction — •Matthieu Mangeat[1], Swarnajit Chatterjee[1], Jae Dong Noh[2], and Heiko Rieger[1] — [1]Saarland University, Saarbrücken, Germany — [2]University of Seoul, Seoul, Korea

We have undertaken a comprehensive study of the two-species active Ising model (TSAIM), a discrete-symmetry counterpart of the continuous-symmetry two-species Vicsek model, motivated by recent interest in the impact of complex and heterogeneous interactions on active matter systems. In the TSAIM, two species of self-propelled particles undergo biased diffusion in two dimensions, interacting via local intraspecies alignment and reciprocal interspecies anti-alignment, along with the possibility of species interconversion. We observe a liquid-gas phase transition, exhibiting macrophase-separated bands, and the emergence of a high-density parallel flocking state, a feature not seen in previous flocking models. With species interconversion (species-flip dynamics), the TSAIM corresponds to an active extension of the Ashkin-Teller model and exhibits a broader range of steady-state phases, including microphase-separated bands that further enrich the coexistence region. We also find that the system is metastable due to droplet excitation and exhibits spontaneous motility-induced interface pinning, preventing the system from reaching long-range order at sufficiently low noise. A hydrodynamic theory complements our computer simulations of the microscopic model and confirms the reported phase diagrams.

DY 3.5 Mon 10:30 H37

Emergent collective behavior from cohesion and alignment — •Jeanine Shea and Holger Stark — Technische Universität Berlin, Institut für Theoretische Physik, Hardenbergstr. 36, 10623 Berlin, Germany.

Collective behavior is all around us, from flocks of birds to schools of fish. These systems are immensely complex. To explore their basic characteristics, we introduce a minimal model for cohesive and aligning self-propelled particles in which group cohesion is established through additive, non-reciprocal torques [1]. These torques cause constituents to effectively turn towards one another, while an additional alignment torque competes in the same spatial range. By changing the strength and range of these torque interactions, we uncover six states which we distinguish via their static and dynamic properties. These states range from disperse particles to closely packed worm-like formations. A number of the states generated by this model exhibit collective dynamics which are reminiscent of those seen in nature.

[1] Knežević, M., Welker, T. and Stark, H. Collective motion of active particles exhibiting non-reciprocal orientational interactions. Sci Rep 12, 19437 (2022).

Invited Talk DY 3.6 Mon 10:45 H37

Collective behavior of photoactive macroscopic particles — •Iker Zuriguel — University of Navarra, Pamplona, Spain

Active matter refers to systems of interacting, self-propelled agents that convert energy into mechanical motion, representing a nice example of out-of-equilibrium systems. In this work, a novel type of active particles is introduced. These are active granular (i.e. they interact solely through physical contacts) and photoactive, meaning that they self-propel using energy from light. Therefore, by means of a programmable LED panel, we are able to change the illumination pattern and, consequently, the particle activity in space and time, allowing a precise exploration of a variety of scenarios related to collective behavior. This possibility has been exploited in microscopic systems but is genuinely new in macroscopic ones.

First, we will present the clustering behavior of these agents under homogeneous illumination. By varying the illumination intensities and changing the population size, we observed a power-law-like distribution for both the cluster sizes and durations. We identified a transition from unstable to stable clusters, as indicated by the divergence of average cluster durations. Higher particle activities and smaller populations led to the creation of small unstable clusters, while lower particle activities and larger populations result in big, stable clusters that persist over time. This transition is explained with the help of a simple model capturing the most important processes involved in cluster dynamics. In the last part of the talk, the collective behavior under inhomogeneous illumination patterns will be introduced.

15 min. break

DY 3.7 Mon 11:30 H37

Swarming model with minority interaction exhibits temporal and spatial scale-free correlations — •Simon Syga[1], Chandraniva Guha Ray[2,3,4], Josué Manik Nava Sedeño[5], Fernando Peruani[6,7], and Andreas Deutsch[1] — [1]Technische Universität Dresden — [2]Max Planck Institute for the Physics of Complex Systems — [3]Max Planck Institute of Molecular Cell Biology and Genetics — [4]Center for Systems Biology Dresden — [5]Universidad Nacional Autónoma de México — [6]Université Côte d'Azur, Nice — [7]CY Cergy Paris Université

Collective motion is a widespread phenomenon in social organisms, from bird flocks and fish schools to human crowds and cell groups. Swarms of birds and fish are particularly fascinating for their coordinated behavior and rapid escape maneuvers during predator attacks. Critical motion is hypothesized as an optimal trade-off between cohesive group behavior and responsiveness to well-informed individuals. However, traditional models only show criticality at the phase transition between ordered and unordered motion. Here, we extend the Vicsek model with a minority interaction, where individuals primarily follow neighbors but can switch to follow a defector moving against a well-aligned group. This triggers cascades of defections, leading to rich dynamics, including large-scale fluctuations, scale-free velocity distributions, and a scale-free return time distribution of the order parameter. Our model underscores the biological importance of minority interactions in swarming and their role in critical behavior.

DY 3.8 Mon 11:45 H37

'Predator-prey' driven swarmalator systems — •Ginger E. Lau, Mario U. Gaimann, and Miriam Klopotek — Stuttgart Center for Simulation Science (SimTech), Cluster of Excellence EXC 2075, University of Stuttgart, Germany

Swarmalators are an active matter system of oscillators which exhibit swarming and collective motion in physical space, as well as synchronization behavior in an additional phase variable space, originally introduced by O'Keeffe *et al.* (*Nat. Commun.* 8(1), 1504, 2017). Such systems with bidirectional couplings in space and phase can be observed in nature, such as in the chorusing behavior of Japanese tree frogs characterized by Aihara *et al.* (*Sci. Rep.* 4(1), 3891, 2014). The interplay between attraction, repulsion, and phase synchronization provides several distinct regimes of self-organizational behavior. Akin to biological swarm systems responding to predator interactions, swarmalators can respond collectively to external perturbations by a repulsive driver. In previous work, driving was realized with a mobile 'pacemaker' by Xu *et al.* (*Chaos* 34(11), 113103, 2024). The present study introduces a new 'predator-prey' driven swarmalator model showing rich adaptive behavior. This could have a wide variety of potential future applications, from biological physics to swarm robotics to nature-inspired learning algorithms and methods of inference.

DY 3.9 Mon 12:00 H37

Inertial active matter governed by Coulomb friction — •Alexander Antonov[1], Lorenzo Caprini[2], and Hartmut Löwen[1] — [1]Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany — [2]University of Rome La Sapenzia, Rome, Italy

Coulomb, or dry friction, is a common phenomenon that can be encountered in various systems, such as granular matter or Brownian motors. The Coulomb friction force resists the motion and, unlike the friction in wet systems, is almost independent of the relative velocity. We show that this characteristic feature of Coulomb friction leads to emergence of dynamical states when subjected to active, or self-propelled motion [1]. At low activity levels, the dynamics resembles Brownian motion, while at greater activity, a dynamic Stop &

Go regime emerges, marked by continuous switching between diffusion and accelerated motion. At even higher activity levels, a super-mobile regime arises, characterized by fully accelerated motion and an anomalous scaling of the diffusion coefficient with activity. Near the transition between the Stop & Go and super-mobile regimes, we reveal a novel activity-induced phase separation in collective behavior [2]. Our theoretical findings have been also demonstrated in experiments, where vibrobots on a horizontal surface are activated by vertical oscillations generated using an electromagnetic shaker.

[1] A.P. Antonov, L. Caprini, A. Ldov, C. Scholz, and H. Löwen, Phys. Rev. Lett. 133, 198301 (2024)

[2] A.P. Antonov et al., in preparation.

DY 3.10 Mon 12:15 H37

Active nematic turbulence with substrate friction — •Peter A. E. Hampshire[1,2] and Ricard Alert[1,2,3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Center for Systems Biology Dresden, Dresden, Germany — [3]Cluster of Excellence Physics of Life, Dresden, Germany

Active nematics with high activity exhibit turbulent-like flows, characterized by vortices, spatio-temporal chaos and power laws in the energy spectra [1-3]. Continuum models have been successfully used to predict the scaling of the energy spectra with the wavevector. Most theoretical work has focused on free-standing, active nematic films. However, in several experimental realisations, such as bacterial colonies and epithelial monolayers, the active nematic is in contact with a solid substrate. We generalised a 2D, incompressible active nematic model to include substrate friction, and studied its impact on the transition to turbulence and the energy spectra of the turbulent-like flows. We find a variety of dynamic states including flow in lanes, stable vortices and both isotropic and anisotropic turbulence. At high activity and moderate friction, we found a power-law scaling in the kinetic energy spectrum $E(q) \sim q^3$, where q is the wavevector, at low wavevectors. The exponent of 3 can be justified with a power-counting argument. Overall, we have developed a model for active nematic turbulence on a substrate that can be compared to biological systems. [1] L. Giomi, *Phys. Rev. X* **5**, 031003 (2015). [2] R. Alert, J.-F. Joanny, J. Casademunt, *Nat. Phys.* **16**, 682-688 (2020). [3] B. Martínez-Prat*, R. Alert*, et al., *Phys. Rev. X* **11**, 031065 (2021).

DY 3.11 Mon 12:30 H37

Self-sustained patchy turbulence in shear-thinning active fluids — •Henning Reinken and Andreas M. Menzel — Otto-von-Guericke-Universität Magdeburg

Bacterial suspensions and other active fluids are known to develop highly dynamical vortex states, denoted as active or mesoscale turbulence. We reveal the pronounced effect of non-Newtonian rheology of the carrier fluid on these turbulent states, concentrating on shear thinning. As a consequence, a self-sustained heterogeneous state of coexisting turbulent and quiescent areas develops, which results in anomalous velocity statistics. The heterogeneous state emerges in a hysteretic transition under varying activity. We provide an extensive numerical analysis and find indirect evidence for a directed percolation transition. Our results are important, for instance, when addressing active objects in biological media with complex rheological properties.

DY 4: Focus Session: Nonlinear Dynamics and Stochastic Processes – Advances in Theory and Applications I

Deterministic chaos and stochastic processes are often seen as opposites. However, not only do they share the aspect of being mechanisms for irregular temporal fluctuations, but more importantly, the theory of stochastic processes has helped to understand and quantify many aspects of chaos. Deterministic diffusion, intermittency, long-range temporal correlations can be generated by simple deterministic systems, but are conveniently characterized by concepts of stochastic processes. In both classes of systems, the inclusion of time delays in feedbacks through memory kernels has introduced additional phenomena, and more recently non-normalizable distributions have been found as causes of ageing. While a unified approach to chaos and stochastics is fascinating and satisfying from a theoretical point of view, it also has surprisingly strong application relevance. Examples include the study of turbulence, the nonlinear dynamics of wind turbines, industrial processes for metal milling and turning, laser dynamics, cardiac dynamics, and neuronal systems.

Organized by Robert Magerle (Chemnitz) and Holger Kantz (Dresden)

Time: Monday 9:30–13:00 Location: H43

DY 4.1 Mon 9:30 H43

Welcome and Remarks — •Robert Magerle[1], Holger Kantz[2], and Theo Geisel[3] — [1]Technische Universität Chemnitz, Institut für Physik, 09126 Chemnitz, Germany — [2]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [3]Max Planck Institute for Dynamics and Self-Organization, 37077 Göttingen, Germany

Welcome and introductory remarks.

Invited Talk DY 4.2 Mon 9:45 H43

Physical application of infinite ergodic theory — •Eli Barkai — Phys. Dept. Bar-Ilan University, Ramat-Gan, Israel

Norm conserving dynamical mappings, for example the Pomeau Manneville scenario for intermittency, exhibit either a normalized invariant density or an infinite (non-normalized) state, depending on the nonlinearity of the map. In the latter case infinite ergodic theory plays a key role in the description of time averages. We will present physical applications of infinite ergodic theory in the context of stochastic Langevin dynamics [1] where the normalizing partition function diverges, and for a gas of laser cooled atoms [2]. This allows for the construction of thermodynamical relations in a non-equilibrium setting, provided that the dynamics is recurrent.

[1.] E. Aghion, D. A. Kessler, and E. Barkai Phys. Rev. Lett. 122, 010601 (2019).

[2.] E. Barkai, G. Radons, and T. Akimoto Transitions in the ergodicity of subrecoil-laser-cooled gases Phys. Rev. Lett. 127, 140605 (2021).

DY 4.3 Mon 10:15 H43

Towards a model-free inference of hidden states and transition pathways — •Xizhu Zhao[1], Dmitrii E. Makarov[2], and Aljaž Godec[1] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]University of Texas at Austin, Austin, Texas, USA

Experiments on biophysical systems typically probe lower-dimensional observables, which are projections of high-dimensional dynamics. In order to infer a consistent model capturing the relevant dynamics of the system, it is important to detect and account for the memory in the dynamics. We develop a method to infer the presence of hidden states and transition pathways based on transition probabilities between observable states conditioned on history sequences for projected (i.e. observed) dynamics of Markov chains. The histograms conditioned on histories reveal information on the transition probabilities of hidden paths locally between any specific pair of states, including the duration of memory. The method can be used to test the local Markov property of observables. The information extracted is also helpful in inferring relevant hidden transitions which are not captured by a Markov-state model.

DY 4.4 Mon 10:30 H43

Interaction statistics in persistent Lotka-Volterra communities — •Joseph Baron[1], Thomas Jun Jewell[3], Christopher Ryder[4], and Tobias Galla[2] — [1]University of Bath, UK — [2]IFISC, Palma de Mallorca, Spain — [3]University of Oxford, UK — [4]University of Manchester, UK

One criticism that was levelled at Robert May's seminal ecological work, which posited random interactions to describe the stability of many-species ecological communities, was that such interactions may not arise naturally in any reasonable model of the ecosystem dynamics. In this talk, I discuss the kinds of interactions that arise between species in communities modelled by generalised Lotka-Volterra dynamics. Far from being iid random variables, there is an intricate structure of correlations between different species' interactions. These arise due to constraints on the species abundances that are imposed by the dynamics. I show that in order to correctly predict stability, one can no longer think of species as being statistically equivalent – a hierarchy amongst the species naturally emerges, even when the initial pool of species are statistically interchangeable. In a similar vein, I also show how the initial interaction network between species is warped by the Lotka-Volterra dynamics, changing the degree distribution, and introducing correlations between a species' connectivity and its interaction statistics. In the end, we see that the interactions in coexisting communities have non-trivial statistical interdependencies, and understanding this statistical structure can help us to understand which species are able to persist in a particular community.

DY 4.5 Mon 10:45 H43

Reduced order stochastic modeling of turbulent passive scalar mixing — Abhishek Joshi, Tommy Starick, •Marten Klein, and Heiko Schmidt — BTU Cottbus-Senftenberg, Cottbus, Germany

Turbulent mixing is composed of chaotic stirring (macromixing) and molecular diffusion (micromixing). The detailed numerical modeling of turbulent mixing has remained a challenge since all relevant flow scales have to be represented in a computationally feasible manner. Map-based stochastic modeling approaches address this challenge by a radical abstraction, which is accomplished by dimensional reduction and utilization of generalized baker's maps to model turbulent fluid motions. Dimensional reduction introduces limitations, but the modeling approach offers interpretability of the emerging complexity and, hence, further physical insight into turbulent mixing. In this contribution, the Hierarchical Parcel Swapping (HiPS) [Kerstein, J. Stat. Phys. 153, 142–161 (2013)] and the One-Dimensional Turbulence (ODT) [Kerstein, J. Fluid Mech. 392, 277–334 (1999)] models are used to study turbulent mixing of passive scalars. Both models aim to represent the state space of 3-D turbulent mixing by a 1-D computational domain. HiPS is a fully event-based mixing model with prescribed sampling from a turbulent cascade, whereas ODT employs an energy-based rejection sampling only for macromixing such that a turbulent cascade is the result of a prescribed physical forcing mechanism. Capabilities of both models are demonstrated for canonical single and multiple passive scalar mixing cases using standalone model formulations across diffusivities.

DY 4.6 Mon 11:00 H43

Which methods are best suited for predicting chaotic time series? — •Ulrich Parlitz — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Since the pioneering work in the 1980s on approximating the time evolution of dynamical systems using delay embedding, many methods for predicting univariate and multivariate chaotic time series have been proposed and published. Recently, the prediction of chaotic time evolution has also been used to demonstrate the performance of novel machine learning algorithms, but in many cases only low-dimensional chaos is considered, as generated by the classical Lorenz-63 system. In this talk, different prediction methods will be contrasted and compared in terms of their prediction power and complexity when applied to low- and high-dimensional chaotic time series.

15 min. break

Invited Talk DY 4.7 Mon 11:30 H43

Modelling the movements of organisms: Movement ecology meets active particles and anomalous diffusion — •Rainer Klages — Centre for Complex Systems, School of Mathematical Sciences, Queen Mary University of London

Organisms living at very different spatio-temporal scales, from migrating in the microworld to foraging at the surface of the earth, typically all display random-looking movement patterns. Understanding these complex patterns by constructing mathematical models from data provides a fundamental challenge. In this talk I first review fundamental stochastic models for understanding movement data, like random walks, Langevin equations and active Brownian particles. On this basis experimental data for the movement paths of foraging sea turtles, migrating cells and bumblee flights is analysed. For all three examples generalised overdamped Langevin equations are constructed from data revealing active and anomalous diffusive properties. I then put forward a generalised underdamped Langevin equation for modelling organismic movements, which blends key ingredients of the three fields of movement ecology, active particles and anomalous diffusion. I illustrate the application of this equation for constructing a stochastic model of bumblebee flights from experimental data and outline its theoretical foundation.

DY 4.8 Mon 12:00 H43

Self-diffusion anomalies of an odd tracer in soft-core media — Pietro Luigi Muzzeddu[1], •Erik Kalz[2], Andrea Gambassi[3,4], Abhinav Sharma[5,6], and Ralf Metzler[2] — [1]University of Geneva — [2]University of Potsdam — [3]SISSA, Trieste — [4]INFN, Trieste — [5]University of Augsburg — [6]IPF, Dresden

Odd-diffusive systems, characterised by broken time-reversal and/or parity symmetry, have recently displayed counterintuitive features such as interaction-enhanced dynamics in the dilute limit. Here we extend the investigation to the high-density limit of an odd tracer embedded in a soft Gaussian core medium (GCM) using a field-theoretic approach based on the Dean-Kawasaki equation. Our theory reveals that interactions can enhance the dynamics of an odd tracer even in dense systems. We demonstrate that oddness results in a complete reversal of the well-known self-diffusion (Ds) anomaly of the GCM. Ordinarily, Ds exhibits a non-monotonic trend with increasing density, approaching but remaining below the interaction-free diffusion, D0, (Ds $<$ D0) so that Ds approaches D0 at high densities from below. In contrast, for an odd tracer, self-diffusion is enhanced (Ds $>$ D0) and the GCM anomaly is inverted, such that Ds approaches D0 at high densities from above. The transition between the standard and reversed GCM anomaly is governed by the tracer's oddness, with a critical oddness value at which the tracer diffuses as a free particle (Ds = D0) across all densities. — arXiv:2411.15552

DY 4.9 Mon 12:15 H43

Memory effects and non-linear responses in colloidal depinning — Arthur V. Straube[1,2] and •Felix Höfling[2,1] — [1]Zuse-Institut Berlin — [2]Institut für Mathematik, Freie Universität Berlin

Particle transport in inhomogeneous environments is complex and typically exhibits non-Markovian responses. The latter can be quantified by a memory function within the framework of the linear generalised Langevin equation (GLE). Here, we exemplify the implications of steady driving on the memory of a colloidal model system for Brownian motion in a corrugated potential landscape, a prototypical set-up to study depinning and non-linear responses far from equilibrium [1,2]. Relying on exact solutions of the model, we show that the random force entering the GLE displays a bias far from equilibrium, which corroborates a recent more general prediction. Based on Brownian dynamics simulations, we show that already moderate driving accelerates the decay of the memory function by several orders of magnitude in time. Moreover in equilibrium, the memory persists much longer than suggested by the timescales of the mean-square displacement. Furthermore, the memory function changes from a monotonic decay to non-monotonic, damped oscillations, which can be understood from a competition of confined motion and depinning. The simulated transport process also is pronouncedly non-Gaussian, which questions the usual Gaussian approximation of the random force in the GLE.

[1] A. V. Straube & F. Höfling, J. Phys. A **57**, 295003 (2024).
[2] A. V. Straube & F. Höfling, Phys. Rev. E **110**, L06260x (2024).

DY 4.10 Mon 12:30 H43

Non-Gaussian random forces in the generalized Langevin equation — •Hélène A. Colinet and Roland R. Netz — Freie Universität Berlin

The generalized Langevin equation (GLE), derived by projection from a general many-body Hamiltonian, exactly describes the dynamics of an arbitrary coarse-grained variable in a complex environment. The complementary force term (typically called a random force) describes

the interaction with the environment, and is characterized by its second moment, linking it to the time-dependent friction memory kernel. For practical applications, this complementary force is commonly modeled as a Gaussian stochastic process, thus neglecting higher-order moments, which can become a bad approximation for non-linear systems. Leveraging advanced GLE extraction and simulation techniques, we explore the limitations of the Gaussian assumption and examine the role of non-Gaussian random forces in protein folding and conformational changes.

DY 4.11 Mon 12:45 H43

Chemo-mechanical motility modes of partially wetting liquid droplets — •Florian Voss[1] and Uwe Thiele[1,2] — [1]Institute for Theoretical Physics, University of Münster, Germany — [2]Center for Nonlinear Science, University of Münster, Germany

We consider a simple thermodynamically consistent model that captures the interplay between an autocatalytic reaction of chemical species on the free surface of a droplet, the solutal Marangoni effect and the physics of wetting in the presence of chemical fuel [1]. We find that a positive feedback loop between the local reactions and the Marangoni effect induces surface tension gradients, allowing for self-propelled droplets. Besides simple directional motion, we find crawling, shuttling and randomly moving droplets. We study the occurring dynamics and show how the observed states generically emerge from (global) bifurcations. We speculate that our results may also be relevant to the study of cell crawling [2] and self-propelled biomolecular condensates [3].

[1] Voss, F., Thiele, U., J. Eng. Math. 149, 2024

[2] Ziebert, F., Swaminatahan, S., Aranson, I., J. R. Soc. Interface 9, 2012

[3] Demarchi, L., Goychuk, A., Maryshev, I., Frey, E., Phys. Rev. Lett 130, 2024

DY 5: Statistical Physics: General

Time: Monday 9:30–11:15 Location: H47

DY 5.1 Mon 9:30 H47

The scaling behaviour of localised and extended states in one-dimensional tight-binding models with disorder — •Luca Schaefer and Barbara Drossel — Technische Universität Darmstadt, Hochschulstraße 6, 64289 Darmstadt

We investigate two one-dimensional tight-binding models with disorder that have extended states at zero energy. We use the eigenmodes of the Hamiltonian and the associated participation ratios, and the transfer-matrix method to determine the localisation length. The first model has no on-site disorder, but random couplings. While the participation ratio remains finite at zero energy, the localisation length diverges logarithmically as the energy goes to zero. We provide an intuitive derivation of this logarithmic divergence based on the weak coupling of the two sublattices. The second model has a conserved quantity as the row sums of the Hamiltonian are zero. This model can be represented as a harmonic chain with random couplings, or as a diffusion model on a lattice with random links. We find, in agreement with existing analytical calculations, that the number of system-spanning eigenmodes increases proportionally to the square root of the system size, and we related this power law to other power laws that characterise the scaling behaviour of the eigenmodes, the participation ratio, the localisation length, and their dependence on energy and system size. When disorder is so strong that the smallest hopping terms can be arbitrarily close to zero, all these power laws change, and we show a crossover between the two scaling regimes. All these results are explained by intuitive arguments based on scaling.

DY 5.2 Mon 9:45 H47

How hidden free energy landscapes imprint on the time-ordering of observed states — •Francesco Malcangi and Aljaz Godec — Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany

Single molecule experiments, such as FRET, Plasmon Ruler, or optical tweezers, probe low (often one-) dimensional projections of high dimensional dynamics. Unless the unobserved, hidden degrees of freedom relax much faster than the observable, the projection induces memory effects. By accessing the information encoded in the time-ordering of projected states, we show in our work that opportunely chosen functionals of observed paths, in particular their fluctuations and correlations, may be used to infer the presence of hidden free-energy barriers, multiple pathways, and even irreversible drifts. These hidden features are found to display common manifestations upon projection, which together with the comparison with manifestly Markovian dynamics in the free energy landscape may be used as a diagnostic tool. We demonstrate our findings with illustrative examples.

DY 5.3 Mon 10:00 H47

Long-term behavior of master equations on a countable system — •Bernd Michael Fernengel[1], Thilo Gross[1], and Wolfram Just[2] — [1]HIFMB, Oldenburg, Germany — [2]University of Rostock, Rostock, Germany

Master equations play a crucial role in natural science, as they describe the time evolution of probability distributions of all systems that can be modeled as directed, weighted graphs. Despite their essential role, computing a solution is often avoided and authors refer to numerical methods or approximation techniques instead.

We present both a mathematically sound framework for master equations on a discrete, countable configuration space as well as sufficient conditions the generator of the master equation must have for the time limit t -> infinity to converge, which is not guaranteed on an infinite dimensional space.

We discuss the assumptions for the possibility of interchanging the thermodynamic limit and the time limit. This makes it possible to obtain the long-term behavior of an infinite system from a thermodynamic limit of stationary solutions of corresponding finite subnetworks.

Our method is demonstrated by a few examples of master equations on linear, infinitely long chains, with one- and two open ends.

DY 5.4 Mon 10:15 H47

Density Fluctuations, Solvation Thermodynamics and Coexistence Curves in Grand Canonical Molecular Dynamics Simulations — •Mauricio Sevilla, Luis A. Baptista, Kurt Kremer, and Robinson Cortes-Huerto — Max Planck Institute for Polymer Research

The physics of externally driven systems is a challenge as the complexity of the amount of effects involved, yet crucial to be understood as it is present in many biological systems. Aiming to build a computational method to deal with such situations, it is first needed to reproduce correctly the equilibrium statistics of open systems. However, open-boundary computational methods are scarce and often do not satisfy all the conditions imposed by reality. The system of interest (SoI) must be at thermodynamic and chemical equilibrium with an infinite reservoir of particles. The fluctuations of the SoI in equilibrium should sample the grand canonical ensemble. The local solvation thermodynamics, extremely sensitive to finite-size effects due to particle depletion, should be correctly described. The method should be robust enough to deal with phase transitions and coexistence conditions that might occur in the SoI. In this context, the adaptive resolution method (AdResS), where the system's atomistic and ideal gas representations coexist at constant thermodynamic and chemical equilibrium, emerges as a promising alternative. Indeed, in this talk, we demonstrate with prototypical liquid systems that AdResS, coupled with particle insertion/deletion steps, satisfies all these requirements, and it is thus a suitable method to perform simulations of open systems.

DY 5.5 Mon 10:30 H47

Optimal control of fluid transitions in a Lennard-Jones like system — •William D. Pineros and Etienne Fodor — Department of Physics and Material Science, University of Luxembourg, 162a, avenue de la Faïencerie, L1511, Luxembourg

We study optimal control transitions in a system of Lennard-jones like fluid via a linear-response framework whose solutions correspond to minimum dissipation protocols in a thermodynamic space. In particular, we investigate fluid-fluid transitions via changes in particle size and attraction strength both in the homogenous and phase separated state. We compute the underlying friction tensor, representing the ease of parameter change in this space, directly from simulations and

compare against an analytical approximation for low density fluids at the continuum level.

DY 5.6 Mon 10:45 H47

Noether-constrained correlations and hyperforces in equilibrium liquids — •Sophie Hermann[1,2], Silas Robitschko[1], Florian Sammüller[1], and Matthias Schmidt[1] — [1]Universität Bayreuth, Bayreuth, Germany — [2]Sorbonne Université/CNRS, Paris, France

Noether's calculus of invariant variations in statistical mechanics yields exact identities ("sum rules") from functional symmetries. The invariance of spatial transformation of the underlying classical many-body Hamiltonian at first order in the transformation field Noether's theorem yields the local force balance. At second order three distinct two-body correlation functions emerge, namely the standard two-body density, the localized force-force correlation function, and the localized force gradient. An exact Noether sum rule interrelates these correlators. More generally exploiting invariance of a thermally averaged classical phase space functions results in hyperforce sum rules. These relate the mean gradient of a phase-space function to its negative mean product with the total force. As applications we investigate via computer simulations (including Lennard-Jones liquids, monatomic water and a colloidal gel former) the emerging one-body force fluctuation profiles in bulk and confined liquids. These local correlators quantify spatially inhomogeneous self-organization, demonstrate their fundamental role in the characterization of spatial structure and their measurement allows for the development of stringent convergence tests and enhanced sampling schemes in complex systems.

DY 5.7 Mon 11:00 H47

Hybrid particle-phase field model and renormalized surface tension in dilute suspensions of nanoparticles — •Alexandra Hardy, Abdallah Daddi-Moussa-Ider, and Elsen Tjhung — The Open University, Milton Keynes, UK

We present a two-phase field model and a hybrid particle-phase field model to simulate dilute colloidal sedimentation and flotation near a liquid-gas interface (or fluid-fluid interface in general). Both models are coupled to the incompressible Stokes equation, which is solved numerically using a combination of sine and regular Fourier transforms to account for the no-slip boundary conditions at the boundaries. The continuum two-phase field model allows us to analytically solve the equilibrium interfacial profile using a perturbative approach, demonstrating excellent agreement with numerical simulations. Notably, we show that strong coupling to particle dynamics can significantly alter the liquid-gas interface, thereby modifying the liquid-gas interfacial tension. In particular, we show that the renormalized surface tension is monotonically decreasing with increasing colloidal particle concentration and decreasing buoyant mass.

DY 6: Critical Phenomena and Phase Transitions

Time: Monday 11:30–13:00 Location: H47

DY 6.1 Mon 11:30 H47

The square lattice Ising model with quenched surface disorder — Luca Cervellera, Oliver Oing, Jan Büddefeld, and •Fred Hucht — Fakultät für Physik, Universität Duisburg-Essen

Using exact enumeration, the Casimir amplitude and the Casimir force are calculated for the square lattice Ising model with quenched surface disorder on one surface in cylinder geometry at criticality. The system shape is characterized by the aspect ratio $\rho = L/M$, where the cylinder length L can take arbitrary values, while the circumference M is varied from $M = 4$ to $M = 54$, resulting in up to 2^{54} numerically exact free energy calculations. A careful $M \to \infty$ extrapolation shows that quenched surface disorder is irrelevant in two dimensions, but gives rise to logarithmic corrections.

DY 6.2 Mon 11:45 H47

Partition Function Zeros of the Frustrated J_1-J_2 Ising Model on the Honeycomb Lattice — •Denis Gessert[1,2], Martin Weigel[3], and Wolfhard Janke[1] — [1]Institut für Theoretische Physik, Leipzig University, 04081 Leipzig, Germany — [2]Centre for Fluid and Complex Systems, Coventry University, Coventry CV1 5FB, United Kingdom — [3]Institut für Physik, Technische Universität Chemnitz, 09107 Chemnitz, Germany

We study the partition function zeros in the complex temperature plane (Fisher zeros) and in the complex external field plane (Lee-Yang zeros) of a frustrated Ising model with competing nearest-neighbor ($J_1 > 0$) and next-nearest-neighbor ($J_2 < 0$) interactions on the honeycomb lattice. We consider the finite-size scaling (FSS) of the leading Fisher and Lee-Yang zeros as determined from a cumulant method and compare it to a traditional scaling analysis based on the logarithmic derivative of the magnetization $\partial \ln\langle|M|\rangle/\partial\beta$ and the magnetic susceptibility χ. While for this model both FSS approaches are subject to strong corrections to scaling induced by the frustration, their behavior is rather different, in particular as the ratio $\mathcal{R} = J_2/J_1$ is varied. As a consequence, an analysis of the scaling of partition function zeros turns out to be a useful complement to a more traditional FSS analysis. The scaling of the zeros convincingly shows that the system remains in the Ising universality class for $\mathcal{R}$ as low as -0.22, where results from traditional FSS using the same simulation data are less conclusive. The approach hence provides a valuable additional tool for mapping out the phase diagram of models afflicted by strong corrections to scaling.

DY 6.3 Mon 12:00 H47

Cluster percolation in the three-dimensional $\pm J$ random-bond Ising model — •Lambert Muenster and Martin Weigel — Institut für Physik, TU Chemnitz, 09107 Chemnitz, Germany

We study the relation between cluster percolation and ordering phenomena in the three-dimensional $\pm J$ random-bond Ising model with different fraction of ferromagnetic bonds by performing Monte Carlos simulations. In particular a certain type of two-replica clusters is studied [1,2]. The density of these clusters can be linked to the overlap. We start the analysis with the pure ferromagnet and demonstrate that the percolation transition maps onto the ferromagnetic phase transition. Then, we continue our analysis with the frustrated disordered ferromagnet and finally consider the spin-glass system where half of all bonds are anti-ferromagnetic and point out differences as well as similarities between the cases.

[1] J. Machta, C. M. Newman, and D. L. Stein, *J. Stat. Phys.* **130**, 113 (2008).
[2] L. Münster and M. Weigel, *Phys. Rev. E* **107**, 054103 (2023).

DY 6.4 Mon 12:15 H47

Analysis of the Mpemba effect in magnetic systems — •Janett Prehl and Martin Weigel — Technische Universität Chemnitz, Chemnitz, Deutschland

The Mpemba effect, first discovered by Mpemba and Osborne for water [1], is observed when a hot sample cools faster than an initially colder one, when both are refrigerated in the same thermal reservoir. During the last years this effect has also been found to take place in the general context of magnetic phase transitions of different orders [2 – 4]. Here, we investigate and discuss the occurrence of this non-equilibrium process for different ferromagnetic models exhibiting a phase transition at a critical temperature T_c. We aim to analyze how different initial temperatures, structural properties or updating dynamics influence the time behavior of quantities such as energy per spin $\langle e\rangle$ or the average domain length ℓ for different system sizes L to get a deeper insight in the occurring mechanism of the Mpemba effect for the systems under consideration.

[1] E.B. Mpemba and D.G. Osborn, *Phys. Educ.* **4**:172 (1969)
[2] M. Baity-Jesi, et al., *PNAS*, **116**:15350 (2019)
[3] N. Vadakkayil, S.K. Das, *Phys. Chem. Chem. Phys.*, **23**:11186 (2021)
[4] A.K. Chatterjee, S. Takada, H. Hayakawa, *Phys. Rev. Lett.*, **131**:080402 (2023)

DY 6.5 Mon 12:30 H47

Relating phase transitions of confined materials and topology of pore network — Georgiy Baroncha[1], Rustem Valiullin[1], and •Eustathios Kikkinides[2] — [1]Leipzig University, Leipzig, Deutschland — [2]Aristotle University of Thessaloniki, Thessaloniki, Griechen-

land

Measuring adsorption/desorption and melting/freezing transitions in porous materials is a common route to obtain information about pore structure. To describe phase transition behavior we exploit statistical network models including cooperative effects. In this way, important properties such as pore size distribution can be deduced. By constructing statistically-disordered random-brunching Bethe lattices we show that the average pore connectivity can be assessed. However, phase transitions remain insensitive to fine details of pore network, namely its topology. Further we discuss the experimental approaches to probe pore network topology.

DY 6.6 Mon 12:45 H47

Study of the de Almeida-Thouless (AT) line in the one-dimensional diluted power-law XY spin glass — •Ramana Bharadwaj Vedula — IISER Bhopal, Bhopal, India

The behavior of finite-dimensional spin glasses at low temperatures has been debated for decades, with the replica symmetry breaking (RSB) and droplet pictures offering competing explanations. This work investigates the Almeida-Thouless (AT) line in the one-dimensional power-law diluted XY spin glass model, where interactions decay as $1/r^{2\sigma}$. Tuning σ emulates dimensional changes, bridging mean-field and non-mean-field regimes.

A novel heatbath algorithm was developed to efficiently equilibrate XY spins at low temperatures. Using this, we studied phase transitions for $\sigma = 0.6$ ($< 2/3$), where clear evidence for an AT line exists, and for $\sigma = 0.75,\ 0.85$ ($> 2/3$), where the evidence weakens. Interestingly, data for $\sigma = 0.75$ and $\sigma = 0.85$ suggest finite-size effects mimic RSB-like behavior, but analysis aligns with the droplet picture.

Unlike traditional approaches, we also varied the magnetic field at fixed temperature, providing unique insights into spin glass properties. Our results show that the AT line disappears as σ increases, favoring the droplet model for low-dimensional spin glasses.

DY 7: Active Matter II (joint session BP/CPP/DY)

Time: Monday 15:00–17:00 Location: H37

DY 7.1 Mon 15:00 H37

Emerging cellular dynamics from turbulent flows steered by active filaments — Mehrana Nejad[1,4], Julia Yeomans[2], and •Sumesh Thampi[2,3] — [1]Department of Physics, Harvard University, Cambridge, MA 02138 — [2]The Rudolf Peierls Centre for Theoretical Physics, Parks Road, Oxford OX1 3PU, UK — [3]Department of Chemical Engineering, Indian Institute of Technology, Madras, Chennai, India 600036 — [4]School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA

Describing the mechanics of cell collectives and tissues within the framework of active matter, without resorting to the details of biology is an exciting area. We develop a continuum theory to describe the dynamics of cellular collectives, discerning the cellular force-generating active filaments from cells shape. The theory shows that active flows and straining part of the active turbulence can elongate isotropic cells, which form nematic domains. This is important as cell morphology is not only an indicator of diseases but it can affect the nucleus morphology, gene expression and other biochemical processes inside the cells. Our theory highlights the importance of distinguishing the roles of active filaments from cell shape and explains outstanding experimental observations such as the origin of cell-filament alignment patches. Further, we reconcile how the contractile forces generated by the cytoskeletal network makes the cells to exhibit flow behaviours similar to that of extensile active systems. Revealing the crucial role of activity and rheology to describe the dynamics of cellular layers, our study is in consonance with a number of experimental observations.

DY 7.2 Mon 15:15 H37

Defects in active solids: self-propulsion without flow — •Fridtjof Brauns[1], Myles O'Leary[2], Arthur Hernandez[3], Mark Bowick[1], and Cristina Marchetti[4] — [1]Kavli Institute for Theoretical Physics, Santa Barbara, USA — [2]Princeton University, Princeton, USA — [3]Leiden University, Leiden, the Netherlands — [4]University of California Santa Barbara, Santa Barbara, California 93106, USA

Topological defects are a key feature of orientational order and act as organizing centers of orientation fields. Self-propulsion of $+1/2$ defects has been extensively studied in active nematic fluids, where the defects are advected with the fluid through the flow field they generate. Here, we propose a minimal model for defect self-propulsion in a nematic active solid: a linear elastic medium with an embedded nematic texture that generates active stress and in turn is coupled to elastic strain. We show that such coupling gives rise to self-propelled $+1/2$ defects that move relative to the elastic medium by local remodeling of the nematic texture. This mechanism is fundamentally different from the fluid case. We show that this mechanism can lead to unbinding of defect pairs and stabilize $+1$ defects. Our findings might help explain how orientational order, e.g. of muscle fibers, is reconfigured during morphogenesis in solid-like tissues. For instance, motility and merging of $+1/2$ defects play a crucial role in setting up the body axis during Hydra regeneration.

DY 7.3 Mon 15:30 H37

Isovolumetric dividing active matter — Samantha R. Lish[1], Lukas Hupe[1], Ramin Golestanian[1,2], and •Philip Bittihn[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

We introduce and theoretically investigate a minimal particle-based model for a new class of active matter where particles exhibit directional, volume-conserving division in confinement while interacting sterically, mimicking cells in early embryogenesis. We find that complex motion, synchronized within division cycles, displays strong collective effects and becomes self-similar in the long-time limit. Introducing the method of normalized retraced trajectories, we show that the transgenerational motion caused by cell division can be mapped to a time-inhomogenous random walk with an exponentially decreasing length scale. Analytical predictions for this stochastic process allow us to extract effective parameters, indicating unusual effects of crowding and absence of jamming. Robustness of our findings against desynchronized divisions, cell size dispersity, and variations in confinement hints at universal behavior. Our results establish an understanding of the complex dynamics exhibited by isovolumetric division over long timescales, paving the way for new bioengineering strategies and perspectives on living matter.

DY 7.4 Mon 15:45 H37

Tracking plankton-to-biofilm transition in phototrophic bacteria — •Anupam Sengupta — Physics of Living Matter Group, Department of Physics and Materials Science, University of Luxembourg, Luxembourg — Institute for Advanced Studies, University of Luxembourg, Luxembourg

Phototrophic bacteria commonly inhabit natural aquatic and marine ecosystems, exhibiting both motile and sessile lifestyles [1]. Yet, how and when they switch between the two states has remained unknown. Using quantitative imaging, AFM and mathematical modeling, we track the conditions and phenotypic changes across multiple generations in Chromatium okenii, a motile phototrophic purple sulfur bacterium [2]. Enhanced cell-surface adhesion together with changes in the cell shape and cellular mass distribution facilitate the motile-to-sessile shift. Our results, supported by cell mechanics model, establish a synergistic link between motility, mass distribution and surface attachment in promoting biofilm lifestyle. [1] T. Sommer et al., Geophys. Res. Lett. 44, 2017. [2] F. Di Nezio,.., & A. Sengupta, Plos one 19, e0310265, 2024.

15 min. break

DY 7.5 Mon 16:15 H37

How localized active noises influence the conformations and dynamics of semiflexible filaments — •Shashank Ravichandir[1], Jens-Uwe Sommer[1,2], and Abhinav Sharma[1,3] — [1]Leibniz-Institut für Polymerforschung, 01069 Dresden, Germany — [2]Technische Universität Dresden, 01069 Dresden, Germany — [3]Universität Augsburg, 86159 Augsburg, Germany

The structure and dynamics of active polymers have been recently studied in some detail. In these works all the monomers are considered to be active. However, in most biological systems non-equilibrium fluctuations manifest as activity only at isolated locations within the polymer. There have been only few studies of such polymers, in which the active monomers occur periodically along the polymer contour. We consider arbitrary active-passive copolymers and isolate the effects of the number and locations of active monomers on the conformational and dynamical properties of polymers. We use Langevin dynamics simulations to calculate the end-to-end distance, radius of gyration, and mean-squared displacement of such semiflexible filaments and classify the various states of these polymers based on their conformational properties. We also present preliminary results of polymers in which the location of active monomer moves dynamically along the chain contour. This is an idealized model of biopolymers such as DNA, during DNA transcription, and microtubules, which are driven by kinetic motors that traverse along its length.

DY 7.6 Mon 16:30 H37

Sequence-specific folding of partially active polymers — •Shibananda Das — Department of Physics, Indian Institute of Science, Bengaluru, India

Biological polymers like actin filaments and microtubules exhibit important physical properties due to their out-of-equilibrium behavior induced by ATP or GTP. In contrast, synthetic polymers rely on energy from their surrounding environment, often using local chemical, electrical, or thermal gradients to remain far from equilibrium. Theoretically, active polymers serve as minimal models for these systems, enabling systematic study of the competition between thermodynamic and active forces while they undergo conformational changes.

Using a combined analytical and numerical approach, we investigate an active polymeric chain composed of multiple self-avoiding units, representing good solvent condition in the absence of active forces. For partially active polymers without orientational constraints, we find that distribution of the active units in distinct sequences along the backbone can induce a significant collapse into folded, globular structures. Detailed analysis shows that this activity-dependent collapse is driven by a reduction in swim pressure of the monomers, linking the distribution of active forces along the polymer contour to its folded conformations.

DY 7.7 Mon 16:45 H37

Effect of interactions on the chemotactic response of active-passive chains — •Hossein Vahid[1], Jens-Uwe Sommer[1,2], and Abhinav Sharma[3] — [1]Leibniz-Institut für Polymerforschung, Dresden, Germany — [2]Technische Universität Dresden, Germany — [3]University of Augsburg, Augsburg, Germany

Living organisms, from single cells to populations, exhibit complex behaviors driven by the need to navigate toward favorable environments. These behaviors are often shaped by interactions within clusters or mixed populations, where collective dynamics play a crucial role in the characteristic properties of multicellular systems.

Chemotactic bacteria, found in diverse environments such as the gastrointestinal tract, plant surfaces, and aquatic ecosystems, demonstrate the significance of chemotaxis at the population level. While extensive research has focused on the properties of active polymers in spatially homogeneous activity fields, their behaviors in inhomogeneous fields remain less explored.

This study investigates the behavior of self-propelled polymers in activity gradients, emphasizing the effects of inter- and intra-chain interactions, such as steric and excluded volume effects, on chemotactic responses. These interactions give rise to distinct phases or collective behaviors that influence the stability and persistence of chemotaxis. Additionally, polymer density emerges as a critical factor impacting diffusion and the overall efficiency of chemotaxis. This work aims to study the dynamics of the active polymer populations in non-uniform environments systematically.

DY 8: Focus Session: Nonlinear Dynamics and Stochastic Processes – Advances in Theory and Applications II

Deterministic chaos and stochastic processes are often seen as opposites. However, not only do they share the aspect of being mechanisms for irregular temporal fluctuations, but more importantly, the theory of stochastic processes has helped to understand and quantify many aspects of chaos. Deterministic diffusion, intermittency, long-range temporal correlations can be generated by simple deterministic systems, but are conveniently characterized by concepts of stochastic processes. In both classes of systems, the inclusion of time delays in feedbacks through memory kernels has introduced additional phenomena, and more recently non-normalizable distributions have been found as causes of ageing. While a unified approach to chaos and stochastics is fascinating and satisfying from a theoretical point of view, it also has surprisingly strong application relevance. Examples include the study of turbulence, the nonlinear dynamics of wind turbines, industrial processes for metal milling and turning, laser dynamics, cardiac dynamics, and neuronal systems.

Organized by Robert Magerle (Chemnitz) and Holger Kantz (Dresden)

Time: Monday 15:00–18:30 Location: H43

Invited Talk DY 8.1 Mon 15:00 H43

Spatio-temporal pattern formation in time-delayed optical systems — •Svetlana Gurevich — Institute for Theoretical Physics, University of Münster, Germany

Control and engineering of complex spatio-temporal patterns in high-dimensional non-equilibrium systems has evolved as one of the central issues in applied nonlinear science. However, real-world complex systems can be strongly influenced by time delays due to unavoidable finite signal propagation speeds and time-delayed dynamical systems have proven to be a fertile framework for the modeling of nonlinear phenomena. Nonlinear laser dynamics is one of the fields where time-delayed system are frequently employed to model the arising complex dynamics. In this talk, we will explore time-delayed models to describe the behavior of ultrashort pulses in optical micro-cavities, highlighting their potential for the formation of spatio-temporal structures.

DY 8.2 Mon 15:30 H43

Thermo-optical excitations and mixed-mode oscillations in an injected Kerr microcavity — •Elias Koch[1], Julien Javaloyes[2], and Svetlana Gurevich[1,3] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9, 48149 Münster, Germany — [2]Departament de Fisica, Universitat de les Illes Balears & IAC-3, Cra. de Valldemossa, km 7.5, E-07122 Palma de Mallorca, Spain — [3]Center for Nonlinear Science (CeNoS), University of Münster, Corrensstraße 2, 48149 Münster, Germany

We study the dynamics of a vertically emitting micro-cavity containing a Kerr nonlinearity that is subjected to detuned optical injection. To this end, we present an extended model that allows investigation of the influence of cavity heating, which shifts the microcavity resonance and thus the detuning on a slow time scale. As a consequence of this scale separation, we uncover a canard scenario featuring dark and bright excitations, as well as mixed-mode oscillations that can be manipulated by tuning the injection amplitude and frequency. When the microcavity is coupled to a long external feedback loop, subjecting it to strong time-delayed optical feedback, we can examine the additional influence of the time delay on excitability dynamics, as well as

the impact of thermal effects on preliminary studies.

DY 8.3 Mon 15:45 H43

Back to the future: Fermi–Pasta–Ulam–Tsingou recurrence in a time-delayed system — •Jonas Mayer Martins[1], Elias Koch[1], Julien Javaloyes[2], and Svetlana V. Gurevich[1] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9 and Center for Nonlinear Science (CeNoS), University of Münster, Corrensstrasse 2, 48149 Münster, Germany — [2]Departament de Física and IAC-3, Universitat de les Illes Balears, C/ Valldemossa km 7.5, 07122 Palma de Mallorca, Spain

We demonstrate Fermi–Pasta–Ulam–Tsingou (FPUT) recurrence, a surprising quasi-periodicity of certain spatially extended systems, in a time-delayed system. Although the bi-Riccati system that we study is not integrable, we find in the long-delay limit that its normal form is a partial differential equation approximating the integrable Korteweg–de Vries (KdV) equation, prominently known to exhibit FPUT recurrence. Our results underscore the analogy between spatially extended and time-delayed systems.

DY 8.4 Mon 16:00 H43

Momentum space induced complex billiard dynamics — •Lukas Seemann, Jana Lukin, and Martina Hentschel — Institut für Physik, TU Chemnitz, Deutschland

While billiard models have always been a paradigm to study nonlinear dynamics, their class has been enriched by realistic models such as optical cavities, ballistic quantum dots, or graphene systems over the past decades. The originally hard billiard walls are replaced by confinement through total internal reflection of light or potential wells trapping electrons. They are well-known model systems in the field of mesoscopic physics, quantum chaos, and wave-ray correspondence exhibiting a broad range of dynamical behavior, ranging from regular and mixed to purely chaotic dynamics depending on their geometric shape. However, employing their material-specific properties allows one to influence and even control their complex dynamics in more ways. Using an anisotropy (as for electrons in bilayer graphene systems), one can induce chaotic motion even in a circularly shaped cavity [1]. We develop a ray tracing algorithm for anisotropic media and illustrate how anisotropy affects the billiards dynamics in real and phase space. In particular we show how deformation away from the circular shape in real and momentum space, changes the phase space structure and can be optimized to the formation of large stable island [2] that we quantify using Lyapunov exponents.

[1] L. Seemann, A. Knothe, M. Hentschel, Phys. Rev. B 107, 205404 (2023)

[2] L. Seemann, A. Knothe, M. Hentschel, NJP 26, 10 (2024)

DY 8.5 Mon 16:15 H43

Stochastic Properties of Musical Time Series: Measuring Musical Variability — Corentin Nelias and •Theo Geisel — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Music philosophers and psychologists have argued that emotions and meaning in music depend on an interplay of expectation and surprise. We aimed to quantify the variability of musical pieces empirically by considering them as correlated dynamical processes. Using a multitaper method we determined power spectral density (PSD) estimates for more than 550 classical compositions and jazz improvisations down to the smallest possible frequencies [1]. The PSDs typically follow inverse power laws ($1/f^{\beta}$-noise) with exponents near β=1 for classical compositions, yet only down to a cutoff frequency, where they end in a plateau. Correspondingly the pitch autocorrelation function exhibits slow power law decays only up to a cutoff time, beyond which the correlations vanish abruptly. We determined cutoff times between 4 and 100 quarter note units serving as a measure for the degree of persistence and predictability in music. They tend to be larger in Mozart's compositions than in Bach's, which implies that the anticipation and expectation of the musical progression tends to last longer in Mozart's than in Bach's compositions

[1] C. Nelias, T. Geisel, Nature Comm. 15, 9280 (2024)

15 min. break

Invited Talk DY 8.6 Mon 16:45 H43

Nonlinear dynamics and time delays in metal cutting — •Andreas Otto — Fraunhofer Institute for Machine Tools and Forming Technology IWU, Reichenhainer Str. 88, 09126 Chemnitz, Germany

Since products and consequently production processes in manufacturing industry becomes more and more individual, an agile and robust process design is important for minimizing costs while guaranteeing high product quality. A fundamental understanding of the underlying physics of the manufacturing processes is essential for finding sweet spots of high productivity with optimal quality of the produced part.

In this talk, we present some examples from metal cutting, where especially the complex behavior of mechanical vibrations also known as chatter lead to undesired noise, tool wear and scraped parts. We show that mechanical vibrations at machine tools can be described by nonlinear delay differential equations and in many situations the time delay is, in addition, distributed, time-varying or state-dependent. Some recent developments for the prediction of the stability of metal cutting processes with respect to chatter vibrations and applications for online chatter detection are presented.

DY 8.7 Mon 17:15 H43

Stability of power grids concerning strong perturbations - tropical cyclones and increasing resilience — •Jürgen Kurths — Potsdam Institute for Climate Impact Research, Telegraphenberg, 14473 Potsdam

The infrastructure of our modern society is efficient but also sensitive concerning strong perturbations, as terrorist attacks on the cybersystem or extreme climate events. An important part of modern infrastructure are power grids, which are characterized by multistability. For them, the strongly ongoing transition to distributed renewable energy sources leads to a proliferation of dynamical actors. The desynchronization of a few or even one of those would likely result in a substantial blackout. We discuss the concept of basin stability covering strong perturbations and identify most vulnerable motifs in power grids. To consider the vulnerability of power grids against extreme wind loads, we combine a detailed model of of extreme events, and a cascadable model of the transmission network to provide a holistic co-evolution model to consider wind-induced failures of transmission lines in the Texan electrical network.

DY 8.8 Mon 17:30 H43

Critical demand in a stochastic model of flows in supply networks — •Yannick Feld[1] and Marc Barthelemy[1,2] — [1]Université Paris-Saclay, CNRS, CEA, Institut de Physique Théorique, 91191 Gif-sur-Yvette, France — [2]Centre d'Analyse et de Mathématique Sociales (CNRS/EHESS) 54 Avenue de Raspail, 75006 Paris, France

Supply networks are essential to modern production, yet their critical properties remain understudied. This talk presents a stochastic model with random production capacities that allows us to investigate material flow to a root node, focusing on the network topology and buffer stocks. We examine the critical demand at the root, where unsatisfied demand diverges. Without stocks, minimal production governs behavior, and topology is mostly irrelevant. Buffer stocks introduce memory, significantly altering the dynamics. Now the topology is crucial, with local connectivity proving beneficial.

DY 8.9 Mon 17:45 H43

Generalizations of laminar chaos — •David Müller-Bender — Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany

Laminar chaos was originally discovered in scalar dynamical systems with a large periodically time-varying delay [Phys. Rev. Lett. 120, 084102 (2018)]. This demonstrated how drastically a temporal modulation of the delay can change the dynamics of a system as laminar chaos is an extremely low-dimensional dynamics compared to turbulent chaos, which is observed in such systems with constant delay. In this talk, I give an overview of recent generalizations of laminar chaos to systems with quasiperiodic [Phys. Rev. E 107, 014205 (2023)], random and chaotic delay time modulation. Using a connection to spatially disordered circle maps [Phys. Rev. E 106, L012202 (2022)], it is found that short-time correlated random and chaotic delays lead to low-dimensional generalized laminar chaos in almost the whole delay parameter space spanned by the mean delay and the delay amplitude. This is in stark contrast to the case of a constant delay, where only high-dimensional turbulent chaos is found. Finally, an outlook on laminar chaos in systems with state-dependent delay is given. I acknowledge the contributions of the late Günter Radons to these results.

DY 8.10 Mon 18:00 H43

Chaotic Diffusion in Systems with Delay — •Tony Albers, David Müller-Bender, and Lukas Hille — Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany

Chaotic Diffusion is a purely deterministic phenomenon occurring in nonlinear systems. While much is known about chaotic diffusion in low-dimensional dynamical systems such as iterated maps or Hamiltonian systems, there are only a few works dealing with chaotic diffusion in higher-dimensional systems. In this talk, we show that chaotic diffusion is also possible in dynamical systems with time delay, which raises the dimension of the problem formally to infinity. Moreover, we demonstrate that introducing a periodic modulation of the delay can increase the strength of the diffusion, as measured by the diffusion coefficient, by several orders of magnitude [1]. This phenomenon is counterintuitively related to a significant decrease of the Kaplan-Yorke dimension of the chaotic attractor due to the appearance of so-called laminar chaos [2], which is a recently discovered type of chaos that is not observed in systems with constant delay. We acknowledge the contributions of the late Günter Radons who initiated this work.

[1] Tony Albers, David Müller-Bender, Lukas Hille, and Günter Radons, Phys. Rev. Lett. **128**, 074101 (2022)

[2] David Müller, Andreas Otto, and Günter Radons, Phys. Rev. Lett. **120**, 084102 (2018)

DY 8.11 Mon 18:15 H43

Weak generalized synchronization in random neural networks and its impact on time series forecasting — •hiromichi suetani[1,2] and ulrich parlitz[3,4] — [1]Faculty of Science and Technology, Oita University, Oita, Japan — [2]International Research Center for Neurointelligence , The University of Tokyo, Tokyo, Japan — [3]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [4]Institute for the Dynamics of Complex Systems, Universität Göttingen, Göttingen, Germany

Time series forecasting is one of the important issues in data science, and approaches based on reservoir computing (RC), have been attracting attention. Previous studies have often suggested that the hyperparameter region at the so-called "edge of chaos," provides optimal performance in time series forecasting. But this concept is problematic because generally a reservoir is a non-autonomous dynamical system driven by external inputs, it should be referred to as the "edge of conditional stability" rather than the edge of chaos.

In this study, we argue that this is not just a matter of terminology, and that the edge of conditional stability does not provide optimal performance. For this purpose, we clarify the relevance of the concept of "weak generalized synchronization (W-GS)." This study demonstrates that random neural networks driven by chaotic inputs exhibit W-GS and shows that the fractal nature of the GS function affects forecasting ability. We quantitatively compare the relationship between the characteristics of GS and those of RC, such as the information processing capacity, to elucidate the role of GS in RC.

DY 9: Statistical Physics far from Thermal Equilibrium

Time: Monday 15:00–18:30 Location: H47

DY 9.1 Mon 15:00 H47

Shear-driven diffusion with stochastic resetting — •Iman Abdoli, Kristian Stølevik Olsen, and Hartmut Löwen — Institut für Theoretische Physik II - Weiche Materie, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Here, we explore the non-equilibrium dynamics that emerge from the interplay between linear shear flow and stochastic resetting. The particle diffuses with a constant diffusion coefficient while simultaneously experiencing linear shear and being stochastically returned to its initial position at a constant rate. We perturbatively derive the steady-state probability distribution that captures the effects of shear-induced anisotropy on the spatial structure of the distribution. We show that the dynamics, which initially spread diffusively, will at late times reach a steady state due to resetting. At intermediate timescales, the system approaches this steady state either by passing through a superdiffusive regime (in the shear-dominated case) or by exhibiting purely sub-diffusive behavior (in the resetting-dominated case). The steady state also gains cross correlations, a feature absent in simpler resetting systems. We also show that the skewness has a non-monotonic behavior when one passes from the shear-dominated to the resetting-dominated regime. We demonstrate that at small resetting rates, the energetic cost of maintaining the steady state becomes significantly higher due to the displacement caused by shear, a unique scaling not seen without shear. Surprisingly, if only the x-position is reset, the system can maintain a Brownian yet non-Gaussian diffusion pattern with non-trivial tails in the distribution.

DY 9.2 Mon 15:15 H47

Propulsion force and heat exchange for nonreciprocal nanoparticles — •Laila Henkes[1], Kiryl Asheichyk[2], and Matthias Krüger[1] — [1]Institute for Theoretical Physics, Georg-August-Universität — [2]Department of Theoretical Physics and Astrophysics, Belarusian State University

Nonreciprocity allows for interesting new phenomena in Casimir physics, such as propulsion forces pointing in translationally invariant directions, and persistent heat currents between objects of the same temperatures. To study these quantities, we derive general formulas for heat transfer and Casimir force involving a non-reciprocal point particle. These display how nonreciprocity of the particle couples to the nonreciprocity of the surrounding and also yield conditions for persistent heat current or propulsion force. Furthermore, we find a bound for the propulsion force acting on a point particle in terms of its heat exchange. This is, e.g., relevant for the efficiency of this arrangement when used as a heat engine.

DY 9.3 Mon 15:30 H47

Exponential change of relaxation rate by quenched disorder — •Jan Meibohm and Sabine H. L. Klapp — Technische Universität Berlin, Institut für Theoretische Physik, Hardenbergstraße 36, 10623 Berlin, Germany

We determine the asymptotic relaxation rate of a Brownian particle in a harmonic potential perturbed by quenched Gaussian disorder, a simplified model for rugged energy landscapes in complex systems. Depending on the properties of the disorder, we show that the mean and variance of the asymptotic relaxation rate are non-monotonous functions of the parameters for a broad class of disorders. In particular, the rate of relaxation may either increase or decrease exponentially compared to the unperturbed case, implying that the effect of disorder is stronger than that associated with other, well-studied anomalous-relaxation effects. In the limit of weak disorder, we derive the probability distribution of the asymptotic relaxation rate and show that it is Gaussian, with analytic expressions for the mean and variance that feature universal limits. Our findings indicate that controlled disorder may serve to tune the relaxation speed in complex systems.

DY 9.4 Mon 15:45 H47

Mean back relaxation for position, densities and others — •Gabriel Knotz and Matthias Krüger — Institute for theoretical physics, Göttingen, Germany

Recently, a so-called mean back relaxation (MBR) has been introduced, which correlates a scalar observable at three time points. The deviation of its long-time value from 1/2 has been shown to be a marker for breakage of time-reversal symmetry for observables with finite mean. We have extended the discussion by introducing a cut off length when evaluating the MBR from trajectories. For Gaussian systems we can derive a relation between MBR and the mean squared displacement and demonstrate that the MBR can be easily applied to stochastic observables like positions and densities. We discuss the application of the density MBR to multi-particle systems.

[1] Gabriel Knotz and Matthias Krüger, Mean back relaxation for position and densities, Phys. Rev. E 110, 044137 (2024)

[2] Till M. Muenker, Gabriel Knotz, Matthias Krüger and Timo Betz, Accessing activity and viscoelastic properties of artificial and living systems from passive measurement, Nature Materials 23, pages 1283*1291 (2024)

Invited Talk DY 9.5 Mon 16:00 H47

Large-deviation simulations of non-equilibrium stochastic processes — •Alexander K. Hartmann — University of Olden-

burg, Germany

Stochastic processes are investigated by obtaining the probability distributions $P(S)$ of relevant quantities S of interest. A full description is obtained, if $P(S)$ is known over its full range of support. Also the structure of the entities contributing to the different parts of $P(S)$ are of interest. Usually analytical calculations are not feasible, so most of the time one has to use numerical simulations. Unfortunately, most of the support, in particular in the tails, is not accessible by standard algorithms.

By applying special large-deviation algorithms, also the tails can be accessed, down to probabilities such as 10^{-200}, or even much smaller. Here, a very general *black-box* algorithm [1] is explained, which allows one to study rather arbitrary stochastic processes. Some application examples are shown, such as force-induced RNA unfolding [2], S being the physical work W; interface growth [3], S being the height H; fractional Brownian motion [4], S being the area A under the curve; or the spread of diseases [5], S being the number of infected.

[1] A.K. Hartmann, Phys. Rev. E **89**, 052103 (2014)
[2] P. Werner and A.K. Hartmann, Phys. Rev. E **104**, 034407 (2021)
[3] A.K. Hartmann, P. Le Doussal, S.N. Majumdar, A. Rosso and G. Schehr, Europhys. Lett. **121**, 67004 (2018)
[4] A.K. Hartmann and B. Meerson, Phys. Rev. E **109**, 014146 (2024)
[5] Y. Feld and A.K. Hartmann, Phys. Rev. E **105**, 034313 (2022)

15 min. break

DY 9.6 Mon 16:45 H47

Dissipation bounds precision of current response to kinetic perturbations — •Krzysztof Ptaszyński[1,2], Timur Aslyamov[1], and Massimiliano Esposito[1] — [1]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg City, Luxembourg — [2]Institute of Molecular Physics, Polish Academy of Sciences, Mariana Smoluchowskiego 17, 60-179 Poznań, Poland

The precision of currents in Markov networks is bounded by dissipation via the so-called thermodynamic uncertainty relation (TUR). We conjecture [1] and prove [2] a similar inequality that bounds the precision of the static current response to perturbations of kinetic barriers. Perturbations of such type, which affect only the system kinetics but not the thermodynamic forces, are highly important in biochemistry and nanoelectronics. Our inequality cannot be derived from the standard TUR, but rather implies it and provides an even tighter bound for dissipation. We also provide a procedure for obtaining the optimal response precision for a given model.

[1] Phys. Rev. Lett. 133, 227101 (2024)
[2] arXiv:2410.17140

DY 9.7 Mon 17:00 H47

Theory of Nonequilibrium Responses for Markov Jump Processes — •Timur Aslyamov[1] and Massimiliano Esposito[2] — [1]University of Luxembourg, Luxembourg — [2]University of Luxembourg, Luxembourg

The theory of nonequilibrium responses in complex systems to parameter perturbations is fundamental, spanning disciplines from ecology to metabolic control and the design of low-noise devices. The framework of Markov jump processes is one of the most popular approaches for studying a broad range of nonequilibrium phenomena across various fields.

In recent papers [1, 2], we formulated a theory of static response for Markov jump processes under arbitrary parameterizations. Leveraging stochastic thermodynamics, we developed a novel approach based on simple linear algebra, enabling us to extend beyond previously known results. Through our analysis, we uncovered a novel fundamental property of Markov processes: the responses are constrained by specific linear combinations, which we term the Summation and Cycles Response Relations.

[1] Aslyamov, T., and Esposito, M. (2024). Nonequilibrium Response for Markov Jump Processes: Exact Results and Tight Bounds. Physical Review Letters, 132(3), 037101.

[2] Aslyamov, T., and Esposito, M. (2024). General Theory of Static Response for Markov Jump Processes. Physical Review Letters, 133(10), 107103.

DY 9.8 Mon 17:15 H47

How topologically distinct non-equilibrium currents imprint on projected observables — •Felix Tippner and Aljaz Godec — Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany

Almost all measurements track only a limited subset of degrees of freedom simultaneously. Mathematically, the higher-dimensional stochastic process governing a physical system (e.g., the dynamics of protein conformation) is accessible only through observables of projected dynamics, which, in practice, are constrained by strict experimental limitations. These projections not only introduce or amplify non-Markovian effects but also obscure features such as irreversible currents (e.g., driven versus non-driven systems) or barriers in the underlying energy landscape. In our work we investigate how topological and geometric properties imprint on projected dynamics that appear similar (i.e., those exhibiting the same observed steady state), both in and out of equilibrium. This is achieved by examining path-wise observables, such as empirical densities and currents inferred from projected trajectories, through a detailed analysis of their fluctuations and (cross-)correlations.

DY 9.9 Mon 17:30 H47

Slow relaxation in a facilitated trap model — •Gregor Diezemann — Department Chemie, JGU Mainz

Trap models have successfully been applied to understand a number of relaxation features of simulated and real-world supercooled liquids. A common choice for the transition rates is that the system leaves a trap and chooses the destination trap at random. Depending on the form of the prior distribution of trap energies, a broad the relaxation spectrum results. Recently, a facilitated trap model (FTM) in which each transition is accomponied by a small change in the energies of all traps equivalent to a diffusion of trap energies has been implemented. It has been shown that a strong asymmetry of susceptibilities can be obtained with reasonable assumptions regarding the model parameters(1).

In the present contribution, we present the numerical solution of the master equation for the FTM and discuss the relaxation behavior of various one-time and two-time quantities, both in equilibrium and in the particular non-equilibrium situation encountered after temperature jumps, such as in typical aging experiments. Using a model of random rotational jumps for the reorientational motion, the linear dielectic susceptibility in thermal equlibrium is found to be given as a convolution of a Debye-like response originating from the energy drift inherent in the FTM and the response of the original trap model.

(1) C. Scalliet, B. Guiselin, and L. Berthier, J. Chem. Phys. 155, 064505 (2021).

DY 9.10 Mon 17:45 H47

Nonequilibrium shortcuts and anomalous thermal relaxations: the Mpemba effect — •Gianluca Teza[1], John Bechhoefer[2], Antonio Lasanta[3], Oren Raz[4], and Marija Vucelja[5] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Simon Fraser University, Burnaby, Canada — [3]Universidad de Granada, Ceuta, Spain — [4]Weizmann Institute of Science, Rehovot, Israel — [5]University of Virginia, Charlottesville, USA

Most of our intuition about the behavior of physical systems is shaped by observations at or near thermal equilibrium. However, even a phenomenon as basic as a thermal quench leads to states far from any thermal equilibrium, where counterintuitive effects can occur. A prime example of anomalous thermal relaxation is the Mpemba effect, a phenomenon in which a hot system cools down faster than an equivalent colder one. Although originally witnessed in water, perspectives towards the design of optimal heating/cooling protocols and observations in a variety of systems pushed the development of a high-level characterization in the framework of nonequilibrium statistical mechanics. In this talk, I will review the phenomenology of this and related anomalous relaxation effects, in which nonmonotonic relaxation times act as the common denominator. With a focus on Ising systems, I will provide insight on the physical mechanisms that enable their emergence. I will show how they can survive arbitrarily weak couplings, highlighting the role played by equilibrium and dynamical features, as well as experimental observation of these effects in quantum simulators.

DY 9.11 Mon 18:00 H47

Power-Efficiency Trade-offs in Finite-Time Thermodynamics: From Minimal Model to General Principle — •Shiling Liang[1,2,3,4], Yu-Han Ma[5,6], Daniel Maria Busiello[4], and Paolo De Los Rios[1] — [1]EPFL, Lausanne, Switzerland — [2]Okinawa Institute of Science and Technology, Okinawa, Japan — [3]Center for Systems Biology Dresden, Dresden, Germany — [4]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [5]Beijing Nor-

mal University, Beijing, China — [6]Graduate School of China Academy of Engineering Physics, Beijing, China

Thermodynamic systems operating in finite time face fundamental trade-offs between power output and efficiency. While conventional wisdom dictates that Carnot efficiency is only attainable in the quasi-static limit with vanishing power, we demonstrate theoretically that this constraint can be circumvented in finite-time operations. We present a minimal heat engine model incorporating intrinsic energy level degeneracy that achieves Carnot efficiency at maximum power in the thermodynamic limit. The enhanced performance originates from first-order phase transitions far from the linear response regime, enabled by collective effects in many-body systems. Our results reveal how collective advantages can fundamentally alter power-efficiency trade-offs and suggest new strategies for designing efficient heat engines operating at finite times far from equilibrium.

[1] Liang, S., Ma, Y. H., Busiello, D. M., & De Los Rios, P. (2023). A Minimal Model for Carnot Efficiency at Maximum Power. arXiv preprint arXiv:2312.02323.

DY 9.12 Mon 18:15 H47

Fluctuating diffusivity in living cells: Analog of Carnot engine — •Yuichi Itto — Aichi Institute of Technology, Japan — ICP, Universität Stuttgart, Germany

The diffusivity fluctuating over local areas of living cells is experimentally known to obey the exponential law for normal/anomalous diffusion. In Ref. [1], a formal analogy of the fluctuating diffusivity to thermodynamics has been studied. Remarkably, the exponential law is formally equivalent to the "canonical distribution": the diffusivity, which is proportional to local temperature of the cell in nonequilibrium stationary states [2], is identified with the analog of the system energy. Consequently, the analogs of the internal energy, the quantity of heat, work, and the Clausius inequality have been established.

Here, the analog of the heat engine is constructed for the fluctuating diffusivity [3]. This heat-like engine consists of processes realized by compression/expansion of the cell and the change of temperature, along which the average value of the diffusivity or local temperature is kept fixed. The efficiency of the engine in a cycle, which characterizes how much the diffusivity change as the analog of work is extracted, is found to formally take that of Carnot's. The result is expected to be useful, for example, for tuning the rates of biochemical reactions in cells, see, e.g., Ref. [4].

References [1] Y. Itto, Entropy, 23, 333 (2021). [2] Y. Itto and C. Beck, J. Royal Society Interface, 18, 20200927 (2021). [3] Y. Itto, in preparation. [4] N. Bellotto, J. Agudo-Canalejo, R. Colin, R. Golestanian, G. Malengo, and V. Sourjik, eLife, 11, e82654 (2022).

DY 10: Wetting, Fluidics and Liquids at Interfaces and Surfaces I (joint session CPP/DY)

Time: Monday 16:15–17:15 Location: H34

DY 10.1 Mon 16:15 H34

Beyond contact angle measurements of aerophilic surfaces — •Alexander Tesler[1], Wolfgang Goldmann[1], Anca Mazare[2], Ben Fabry[1], Stefan Kolle[3], Robin A.H. Ras[4], Heikki Nurmi[4], George Sarau[5], and Silke Christiansen[5] — [1]Biophysics Chair, Erlangen, Germany — [2]WW4-LKO, Erlangen, Germany — [3]UCSD, San Diego, USA — [4]Aalto University, Epsoo, Finland — [5]Fraunhofer Institute, Forchheim, Germany

Aerophilicity can provide surface resilience to the detrimental effects of wetting-related phenomena. However, the development of such superhydrophobic surfaces with a long-lasting entrapped air layer, called plastron, is hampered by the lack of evaluation criteria and methods that can unambiguously distinguish between stable and metastable Cassie-Baxter wetting regimes. The information to evaluate the stability of the wetting regime is missing from the commonly used contact angle goniometry. Therefore, it is necessary to determine which surface features can be used as a signature to identify thermodynamically stable plastron. Here, I describe a methodology for evaluating the thermodynamic underwater stability of the Cassie-Baxter wetting regime of superhydrophobic surfaces by measuring the surface roughness, solid-liquid area fraction, and Young's contact angle. The method allowed the prediction of passive plastron stability for over one year of continuous submersion,[1] impeding mussel and barnacle adhesion,[2] and inhibition of metal corrosion in seawater.[3] [1] Tesler et al., Commun. Mater. 2024, 5, 112. [2] Tesler et al., Nat. Mater. 2023, 22, 1548. [3] Prado et al., Adv. Funct. Mater. 2024, 35, 2407444.

DY 10.2 Mon 16:30 H34

Fluid flow inside slit-shaped nanopores: the role of molecular surface morphology — •Giorgia Marcelli[1], Tecla Bottinelli Montadon[1], Roya Ebrahimi Viand[1], and Felix Höfling[1,2] — [1]Institute of Mathematics, Freie Universität Berlin, Germany — [2]Zuse Institute Berlin, Germany

The boundary conditions of nanoscale flows near surfaces can deviate from the no-slip condition observed at macroscopic scales, and used in classical fluid mechanics. In this context, we investigate the influence of surface morphology on fluid flow inside slit-shaped nanopores [1]. Using non-equilibrium molecular dynamics (NEMD) simulations, we demonstrate that the surface morphology effectively controls the slip length, which approaches zero when the molecular structures of the pore wall and the fluid are matched. We examine two types of pore walls, mimicking a crystalline and an amorphous material, that exhibit markedly different surface resistances to flow. The resulting flow velocity profiles are consistent with Hagen–Poiseuille theory for incompressible, Newtonian fluids when adjusted for surface slip and effective viscosity; the latter is found to vary substantially with the pore width. Moreover, analysis of the hydrodynamic permeability shows that the simulated flows are in the Darcy regime. We further show that thermal isolation within the pore causes a linear increase in fluid temperature along the flow, which we relate to strong viscous dissipation and heat convection, utilizing the conservation laws of fluid mechanics.

[1] G. Marcelli, T. Bottinelli Montadon, R. Ebrahimi Viand, and F. Höfling, arXiv:2411.04882 [cond-mat.soft].

DY 10.3 Mon 16:45 H34

How do polymers of different architecture penetrate nanochannels? — •Panagiotis Kardasis[1] and George Floudas[2] — [1]Department of Physics, University of Ioannina, 45110 Ioannina, Greece — [2]Max Planck Institute for Polymer Research, 55128 Mainz, Germany

The way that polymers penetrate narrow pores is of both academic and technological importance. Capillary force can drag polymer chains into nanopores, a process called imbibition. Using in situ nanodielectric spectroscopy (nDS), we report the imbibition and following adsorption kinetics of star cis-1,4-polyisoprenes (SPI) and of bottlebrush polymers directly at the chain length scale by monitoring the evolution of the normal modes, during the flow within in alumina nanopores (AAO), as a function of chain architecture (vs linear), pore size, molar mass, and temperature. We demonstrate that the imbibition kinetics of SPIs proceeds via a slow adsorption mechanism, about 2 orders of magnitude slower than in linear polyisoprenes (PI). We further demonstrate that the bottlebrush topology results in slower adsorption in nanopores in comparison to linear counterpart, albeit, with different dependence. Additionally, bottlebrushes present weaker temperature dependence comparing to both linear and star polymers. Furthermore, we explore how symmetric star / linear and brush / linear blends penetrate the same nanopores and we demonstrate that differences in the imbibition and adsorption kinetics can be used to separate the homogeneous blend to its components, giving rise to *topology sorting*, based on the relative viscosities and pore diameter.

DY 10.4 Mon 17:00 H34

Removing particles from hydrophobic surfaces by single water drops — •Franziska Sabath, Stefanie Kirschner, and Doris Vollmer — Max Planck Institute for Polymer Research, 55128 Mainz, Germany

The accumulation of dust on surfaces is a well-known phenomenon in everyday life, for example on windows and solar panels. Both manual cleaning and self-cleaning of hydrophobic surfaces with water can restore the properties of soiled surfaces. However, it is not yet understood how particles are removed by a water drop and which forces play a role for successfully removing the particles. We investigated the removal of two or more particles from hydrophobic coatings by a single

water drop. For this purpose, we used a confocal microscope with a sliding drop setup. This implies that the particles was moved at constant velocity while the drop is hold in position by a blade. The sliding drop and the way in which the particles are picked up and pulled along by the water drop can be imaged. From the deflection of the blade, we can determine the force required to pull the particles along with the drop. Here, we focus on the removal of spherical model particles and the impact of drop volume, particles size and particle velocity on the particle removal. At low velocities the particles remain attached to the drop. With increasing velocity we observe that the particle detachment becomes more likely. In case of particle detachment, we observe a correlative effect: after the second particle has reached the rear side of the drop, both particles can detach together.

DY 11: Wetting, Fluidics and Liquids at Interfaces and Surfaces II (joint session CPP/DY)

Time: Monday 17:30–18:30 Location: H34

DY 11.1 Mon 17:30 H34

Vapor-mediated wetting and imbibition control on micropatterned surfaces — •Ze Xu and Stefan Karpitschka — Fachbereich Physik, Universität Konstanz, Konstanz, Germany

Wetting and evaporation of droplets on micropatterned surfaces are ubiquitous in nature and key to many technological applications, such as water/ice-proof coatings, spray cooling, inkjet printing, and semiconductor surface processing. The wettability of micropatterned surfaces is governed by surface chemistry and topography, and significant effort has been devoted to overcoming this intrinsic behavior, e.g. to dry or coat structures surfaces, by use of external stimuli like electromagnetic fields. However, these methods usually require specific materials, thus limiting their practical use. Here, we show that the spreading behavior of water droplets on hydrophilic surface patterns can be controlled and even temporarily inhibited by the presence of the vapor of a low surface tension liquid. We show that this delayed wicking arises from Marangoni forces due to vapor condensation at the droplet periphery that compete with the capillary wicking force of the surface topography. We further demonstrate how modulating the vapor concentration in space and time can be used to guide droplets across patterns and even extract liquid from fully imbibed films, devising new strategies for coating, cleaning and drying of functional surface designs.

DY 11.2 Mon 17:45 H34

Gradient dynamics model for volatile binary mixtures including Marangoni flows — •Jan Diekmann und Uwe Thiele — Universität Münster, Wilhelm-Klemm-Straße 9, 48149 Münster

We present a mesoscopic thin-film model in gradient dynamics form for binary liquid mixtures on solid substrates incorporating interface tension-induced flow, and volatility in a narrow gap. Thereby, we use and expand models established in [1-4] by accounting for the two substances in each of two bulk phases - liquid and gas - and for the enrichment of one component at the liquid-gas interface. We discuss the different contributions to the free energy, thereby employing Flory-Huggins theory of mixing for the condensed phase and assuming ideal gases for the vapor phase. The resulting five-field model is then analyzed with numerical time simulations focusing on the interplay of the drop dynamics with the developing lateral concentration gradients, and the resulting Marangoni flows. The results are compared to experimental findings [5].

[1] Thiele et al. Physical Review Fluids, 2016. doi: 10.1103/physrevfluids.1.083903.

[2] Xu et al. Journal of Physics: Condensed Matter, 2015. doi:10.1088/0953-8984/27/8/085005.

[3] Hartmann et al. Langmuir, 2024. doi: 10.1021/acs.langmuir.3c03313.

[4] Thiele et al. Physical Review Letters, 2013. doi: 10.1103/physrevlett.111.117801.

[5] Chao et al. Proceedings of the National Academy of Sciences, 2022. doi: 10.1073/pnas.2203510119.

DY 11.3 Mon 18:00 H34

Fast dynamics of PNIPAM microgels at fluid interfaces: insights from droplet bouncing and jetting — Atieh Razavi, Suvendu Mandal, Benno Liebchen, Regine von Klitzing, and •Amin Rahimzadeh — Technische Universität Darmstadt, Hochschulstrasse 8, 64289 Darmstadt, Germany

PNIPAM microgels, as cross-linked polymer networks, are known to adsorb at the air-water interface, reducing surface tension. The kinetics of their adsorption, and thus the dynamic surface tension, depend on their cross-linking density, which determines the stiffness of individual microgels. Under interfacial perturbations such as dilation, softer microgels restore surface tension more rapidly, creating interfaces with higher surface elastic moduli, as shown by interfacial rheology studies using profile analysis tensiometry (1-10 s timescales). However, the behavior of microgels under very rapid interfacial deformations (milliseconds) remains unclear. We address this question through experiments involving droplet bouncing and jetting, processes relevant to applications such as inkjet printing and needle-free drug delivery. Our results demonstrate that microgels rapidly respond to fast interfacial deformations, with softer microgels restoring surface tension more efficiently. This quicker response allows greater interfacial extension in the presence of softer microgels. Molecular dynamics simulations corroborate our experimental findings, providing further insight into the mechanisms at play. This study highlights the critical role of microgel stiffness in determining their interfacial dynamics across a wide range of timescales and deformation rates.

DY 11.4 Mon 18:15 H34

Soft dynamic wetting transition — •Christopher Henkel[1], Vincent Bertin[2], Jacco Snoeijer[2], and Uwe Thiele[1,3] — [1]Institut für Theoretische Physik, Universität Münster, Germany — [2]Physics of Fluids Group, Faculty of Science and Technology, Mesa+ Institute, University of Twente, The Netherlands — [3]Center for Nonlinear Science (CeNoS), Universität Münster, Germany

We investigate the forced receding and advancing dynamics of a three-phase contact line on a viscoelastic substrate, i.e., the wetting transition of a substrate from macroscopically dry to wet or vice versa. Thereby, we use the Landau-Levich (or dip-coating) geometry, where a solid viscoelastic plate is dragged out of or pushed into a liquid bath. We employ a mesoscopic hydrodynamic model in long-wave approximation, i.e. valid at small contact angle and plate inclination. The elastic response of the substrate follows the Winkler foundation with a Kelvin-Voigt relaxation. In particular, we investigate how the shape and stability of the meniscus changes with the plate velocity and the substrate softness. In this we compare numeric results with asymptotic analytic calculations. Finally, we explore whether the occurrence of stick-slip motion in the advancing case can be predicted, using simple scaling arguments.

DY 12: Quantum Coherence and Quantum Information Systems (joint session TT/DY)

Time: Tuesday 9:30–13:15 Location: H31

Invited Talk DY 12.1 Tue 9:30 H31

Solving Many-Body Problems on Quantum Computers — •Benedikt Fauseweh — TU Dortmund University, Otto-Hahn-Str 4, 44227 Dortmund

In this talk, I will provide an overview on the state-of-the art in digital quantum simulations (DQS) for many-body systems [1]. Modern quantum computers present challenges due to the noisy nature of these systems. Novel quantum algorithms, especially hybrid classical-quantum algorithms [2], have been developed to fit the specifications of such devices. For DQS, the prevailing question today is: What problems are amenable to be simulated on noisy quantum computers? I will discuss recent work on simulating quantum many-body dynamics [3], algorithmic advances to detect ground state phase transitions and the potential of stabilizing exotic non-equilibrium phases of matter, e.g., discrete time crystals [4], using quantum-classical feedback.

[1] B. Fauseweh, Nat. Comm. 15, 2123 (2024).
[2] B. Fauseweh and J.-X. Zhu, Quantum 7, 1063 (2023).
[3] B. Fauseweh and J.-X. Zhu, Quantum Inf. Process. 20, 138 (2021).
[4] G. Camacho and B. Fauseweh, Phys. Rev. Res. 6, 033092 (2024).

DY 12.2 Tue 10:00 H31

Fast Initialisation of Bell States in Kerr Cat Qubits — •Miriam Resch[1], Ciprian Padurariu[1], Björn Kubala[1,2], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Schrödinger cat states play an important role for applications in continuous variable quantum information technologies. As macroscopic superpositions they are inherently protected against certain types of noise making cat qubits a promising candidate for quantum computing [1]. It has been shown recently that cat states occur naturally in driven Kerr parametric oscillators (KPOs) as degenerate ground states with even and odd parity that are adiabatically connected to the respective Fock states by switching off the drive [2]. To perform operations with several cat qubits one crucial task is to create entanglement between them. This can be done by initializing the cats from entangled Fock states or by performing operations directly in cat space. Here we show efficient transformations of multi mode cat states through adiabatic and diabatic switching between Kerr-type Hamiltonians with degenerate ground state manifolds and show how those transformations can be used to directly initialize the cat states as entangled Bell states.

[1] Réglade et al., Nature 629, 778 (2024);
[2] Puri et al., npj Quantum Inf. 3, 18 (2017).

DY 12.3 Tue 10:15 H31

Impurity models in waveguide QED — •Adrian Paul Misselwitz[1,2,3], Jacquelin Luneau[1,2,3], and Peter Rabl[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

In this talk I will discuss photonic impurity models, which emerge from the coupling of two-level atoms to a 1D photonic waveguide in the presence of strong photon-photon interactions. Such models appear, for example, in the context of superconducting microwave circuits, where Josephson junctions give rise to strong Kerr-nonlinearities at the few-photon level. In this case, the resulting competition between photon-photon repulsion and the attractive atom-photon interaction leads to the formation of localized bound states with a well-defined photon number and, under certain conditions, the build-up of long-range, algebraically decaying correlations between the impurity sites. I will show how these strongly-correlated phases of light and matter can be simulated efficiently with the help of large-scale tensor network simulations and discuss a possible explanation of the observed long-range correlations in terms of a simpler, effective Bose-Hubbard model.

DY 12.4 Tue 10:30 H31

Voltage without current — Christina Koliofoti and •Roman-Pascal Riwar — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany

Superconductors famously give rise to equilibrium currents without voltages. But can the converse exist? We argue that voltage-dependent Josephson effects generically provide exactly such a classical time crystal behaviour – bringing with them known conceptual issues, such as discontinuous "brick-wall" trajectories, and ill-defined canonical quantization. With the example of quantum phase slip junctions in the presence of electro-motive forces, we resolve these lingering problems. Decoherence provokes a phase transition from a quantum Hamiltonian (non-Lagrangian) system with nonlinear Cooper-pair tunneling to a Lagrangian (non-Hamiltonian) classical time crystal. Our work illustrates that direct canonical quantization of low-energy theories may fail, and that the nonadiabaticity of brick-wall trajectories leads to a temporary break down of the classical theory even for strong decoherence.

DY 12.5 Tue 10:45 H31

Of gyrators and anyons I - Anyons — •Oleksiy Kashuba, Ram Mummadavarapu, and Roman-Pascal Riwar — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany

In recent years there have emerged various ideas to create and control topological excitations in superconducting devices. Notably, nontrivial Chern bands were predicted to exist in conventional multiterminal Josephson junctions, but the Chern number is yet to be experimentally verified, and the pathway towards feasible quantum hardware applications is unclear. In this talk, we show how generic multiterminal circuits can be expressed as gyrator networks with quantized gyration conductance, giving rise to anyonic excitations carrying q/p fractional fluxes (q, p integer), measurable via a fractional Aharonov-Casher phase. We further present concepts for error correction protocols, and quantum simulations of interacting fermionic (or generally anyonic) many-body systems—notably, introducing the possibility to mimic fractional quantum Hall physics or to implement local fermionic models that explicitly break the Wigner superselection rule. The latter indicates that a full understanding of multiterminal circuits will require grappling with a virtually unexplored class of parity-breaking quantum field theories.

DY 12.6 Tue 11:00 H31

Of gyrators and anyons II - Gyrators — •Ram Mummadavarapu, Oleksiy Kashuba, and Roman-Pascal Riwar — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany

In recent years, significant progress has been made in developing methods to create and control topological excitations in superconducting devices. Among these, the prediction of nontrivial Chern bands in conventional multiterminal Josephson junctions stands out as a particularly promising development. However, despite theoretical predictions, the experimental verification of the non-trivial Chern number remains an open challenge. Based on the realization that multiterminal junctions generically map on special gyrator networks hosting anyons (see also talk "Of gyrators and anyons I"), we here present circuit-specific band-engineering techniques to minimize parasitic anyon interactions. We show in particular how circular scattering in three-terminal quantum dot chains gives rise to a flat topological ground state, where disorder mitigates Chern number fluctuations and the quasiparticle continuum provides a work-around for known limitations to create nontrivial flat bands. Further band-engineering strategies are presented where the superconducting phase is scrambled either via parallelization or dissipative phase transitions.

15 min. break

DY 12.7 Tue 11:30 H31

Minimal SU(2) models for analog simulation in small-scale superconducting quantum devices — •Lucia Valor[1,2,3], Jacquelin Luneau[1,2,3], Klaus Liegener[1,2,3], Stefan Filipp[1,2,3], and Peter Rabl[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Lattice gauge theories (LGTs) are essential tools for studying fundamental interactions in particle physics and have broad applications in

condensed matter physics and quantum information. Quantum simulation of non-Abelian theories remains challenging. Recent research on the analog simulation of LGTs has focused on scalable atomic quantum platforms. In contrast, we propose minimal SU(2) LGT models for analog simulation, tailored for small-scale superconducting quantum hardware. By adopting concepts from quantum optics, our approach emphasises coarse-grained systems that capture internal degrees of freedom and relevant non-Abelian properties with just a few qubits, bypassing the scalability demands of fine-grained models. We explore unique features of these non-Abelian systems and provide a circuit design for their experimental realisation. This work advances the study of non-Abelian gauge theories and introduces a novel method for implementation of LGTs using superconducting qubits.

DY 12.8 Tue 11:45 H31

Secure squeezed state microwave quantum communication with spin ensembles (part 1) — •Florian Fesquet[1,2], Patricia Oehrl[1,2], Kedar E. Honasoge[1,2], Maria-Teresa Handschuh[1,2], Achim Marx[1], Rudolf Gross[1,2,3], Hans Huebl[1,2,3], and Kirill G. Fedorov[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Quantum key distribution (QKD) holds the promise of delivering unconditionally secure distribution of classical keys between remote parties. So far, its implementation in the microwave regime, which is frequency-compatible with superconducting quantum circuits, has been missing. Here, we present the realization of a continuous-variable QKD protocol using propagating squeezed microwave states and demonstrate a finite-size security. In order to store these states for quantum memory applications, we investigate a scheme based on the excitation of high-coherence spin ensembles by microwave quantum signals. Here, we focus on a phosphorus donor electron spin ensemble hosted in isotopically engineered silicon. Our measurements indicate a successful coupling of microwave squeezed states to the spin ensemble with an estimated efficiency of 36%.

DY 12.9 Tue 12:00 H31

Secure squeezed state microwave quantum communication with spin ensembles (part 2) — •Patricia Oehrl[1,2], Florian Fesquet[1,2], Tahereh Parvini[1,2,3], Maria-Teresa Handschuh[1,2], Kedar E. Honasoge[1,2], Achim Marx[1], Nadezhda Kukharchyk[1,2,3], Rudolf Gross[1,2,3], Kirill G. Fedorov[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Solid-state spin ensembles offer exceptional coherence times at low temperatures and transition frequencies in the GHz range, which makes them ideal for interfacing with superconducting quantum circuits. Moreover, they are promising candidates for the storage of microwave quantum states, providing great potential for quantum memory and quantum sensing applications. Here, we investigate a phosphorus donor electron spin ensemble hosted in silicon. It is coupled to a superconducting microwave resonator and probed at millikelvin temperatures as well as moderate magnetic fields. We investigate the efficiency of photon absorption for coherent and squeezed microwave signals. To this end, we use continuous wave and pulsed electron spin resonance protocols. We verify our results with an input-output model of our hybrid system and discuss the storage efficiency of microwave signals.

We acknowledge financial support from the Federal Ministry of Education and Research of Germany (project number 16KISQ036).

DY 12.10 Tue 12:15 H31

Quantum thermodynamics of non-Markovian Otto cycles using the principle of minimal dissipation — •Salvatore Gatto[1], Alessandra Colla[2], Heinz-Peter Breuer[1], and Michael Thoss[1] — [1]University of Freiburg — [2]Università degli Studi di Milano

A central challenge in quantum thermodynamics revolves around establishing a consistent and universally accepted definition for work, heat, and entropy production in open quantum systems subjected to thermal reservoirs. A recently developed approach, known as principle of minimal dissipation [1,2], leads to a unique decomposition of the quantum master equation into coherent and dissipative dynamics, allowing to identify uniquely the contributions describing work and heat. In this contribution, we apply this approach to investigate the thermodynamic characteristics of the quantum Otto cycle[3] of a single-impurity Anderson model, with a particular focus on memory effects and strong system-bath couplings. The study uses the hierarchical equations of motion approach (HEOM), which allows a numerically exact simulation of nonequilibrium transport in general open quantum systems involving multiple bosonic and fermionic environments [4].

[1] A.Colla and H.-P.Breuer, Phys Rev.A 105, 052216 (2022).
[2] S.Gatto,A.Colla,H.-P.Breuer,M.Thoss,Phys.Rev.A110,032210(2024)
[3] I.A.Picatoste,A.Colla,H.-P.Breuer, Phys.Rev.Res.6,013258 (2024).
[4] J.Bätge, Y.Ke, C.Kaspar, M.Thoss, Phys.Rev.B 103, 235413 (2021).

DY 12.11 Tue 12:30 H31

Non-Hermitian dynamics close to exceptional points — •Aisel Shiralieva, Grigorii Starkov, and Björn Trauzettel — University of Würzburg, Würzburg, Germany

Exceptional points (EPs), which are degeneracies occurring in both open classical and quantum systems, play a crucial role across numerous areas of physics. This work examines the behavior of dissipative systems with N levels, with a particular emphasis on non-Hermitian qubits and qutrits. These systems are of interest due to recent experimental studies involving a driven non-Hermitian superconducting qubit embedded within a three-level structure, where the ground state serves as an "effective bath". Although significant progress have been made in understanding EPs, the precise connection between their occurrences in non-Hermitian Hamiltonians and in the Lindblad formalism remains unclear, especially if quantum jumps are treated as perturbations. Our results reveal how EPs in these two frameworks relate to each other and illustrate how perturbations can either lift the degeneracy or eliminate the EPs entirely in the Lindblad formalism.

DY 12.12 Tue 12:45 H31

Post-measurement Quantum Monte Carlo — •Kriti Baweja[1], David Luitz[1], and Samuel Garratt[2] — [1]Institute of Physics, Nussalle 12 53115, Bonn, Germany — [2]Department of Physics, University of California, Berkeley, CA 94720, USA

We study the effects of extensive measurements on many-body quantum ground and thermal states using Quantum Monte Carlo (QMC). Measurements generate density matrices composed of products of local nonunitary operators, which we expand into operator strings via a generalized stochastic series expansion (SSE). This 'post-measurement SSE' employs importance sampling of operator strings contributing to a measured thermal density matrix. Our algorithm is applied to the spin-1/2 Heisenberg antiferromagnet on a square lattice. Thermal states of this system exhibit SU(2) symmetry, which is preserved through SU(2)-symmetric measurements. We identify two classes of post-measurement states: one where correlations can be efficiently computed using deterministic loop updates, and another where SU(2)-symmetric measurements induce a QMC sign problem in any site-local basis. Using this approach, we demonstrate measurement-induced phenomena, including the creation of long-range Bell pairs, symmetry-protected topological order, and enhanced antiferromagnetic correlations. This method offers a scalable way to simulate measurement-induced collective effects, providing numerical insights to complement experimental studies. Our work opens the door to exploring how measurements influence many-body quantum systems, enabling deeper understanding of their dynamics. [1] arXiv:2410.13844

DY 12.13 Tue 13:00 H31

Zero-temperature magnon-mediated long-range entanglement in Heisenberg chain with magnetic impurity — •Marius Melz and Jamal Berakdar — Martin-Luther-Universität Halle - Wittenberg

The understanding of many-body entanglement in solid-state systems is of interest both for fundamental and practical reasons. In this work, a spin-1/2 Heisenberg chain is coupled to a chiral magnetic impurity, acting as a magnon scatterer. The spatial entanglement structure of the ground state and its effect on the propagation of local magnons is characterized by the spatially resolved bipartition entropy and logarithmic negativity. The ground state exhibits an entanglement transition at a critical magnetic bias field. We find that magnon scattering generates steady-state long-range entanglement between two scattering regions. Furthermore, it is demonstrated that this effect is significantly amplified in the high-entanglement phase.

DY 13: Many-body Quantum Dynamics I (joint session DY/TT)

Time: Tuesday 9:30–13:00 Location: H37

DY 13.1 Tue 9:30 H37

Controlling Many-Body Quantum Chaos — •Lukas Beringer[1], Mathias Steinhuber[1], Juan Diego Urbina[1], Klaus Richter[1], and Steven Tomsovic[1,2] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]Department of Physics and Astronomy, Washington State University, Pullman, WA USA

Controlling chaos is a well-established technique that leverages the exponential sensitivity of classical chaotic systems for efficient control. This concept has been generalized to single-particle quantum systems [1] and, more recently, extended to bosonic many-body quantum systems described by the Bose-Hubbard model [2]. In direct analogy to the classical paradigm, a localized quantum state can be transported along a specific trajectory to a desired target state. In the latter context, this approach reduces to time-dependent control of the chemical potentials, making it suitable for implementation in optical lattice experiments. Highlighted potential applications are rapid, customizable state preparation and stabilization of quantum many-body scars in one-, two-, and three-dimensional lattices. Recent progress includes potential applications to large time-crystal platforms and preparation protocols for entangled states, such as cat-like states.

[1] S. Tomsovic, J. D. Urbina, and Klaus Richter, Controlling Quantum Chaos: Optimal Coherent Targeting, PRL 130.2 (2023): 020201.

[2] L. Beringer, M. Steinhuber, J. D. Urbina, K. Richter, S. Tomsovic, Controlling many-body quantum chaos: Bose-Hubbard systems, New J. Phys (2024): 26 073002.

DY 13.2 Tue 9:45 H37

Exact spectral function and nonequilibrium dynamics of the strongly interacting Hubbard model — Ovidiu I. Pâţu[1], •Andreas Klümper[2], and Angela Foerster[3] — [1]Institute for Space Sciences, Bucharest-Măgurele, R 077125, Romania — [2]Fakultät für Mathematik und Naturwissenschaften, Bergische Universität Wuppertal, 42097 Wuppertal, Germany — [3]Instituto de Física da UFRGS, Av. Bento Gonçalves 9500, Porto Alegre, RS, Brazil

Analytical results on the correlation functions of strongly correlated many-body systems are rare in the literature and their importance cannot be overstated. We present determinant representations for the space-, time-, and temperature-dependent correlation functions of the strongly interacting one-dimensional Hubbard model in the presence of an external trapping potential. These representations are exact and valid in both equilibrium and nonequilibrium scenarios like the ones initiated by a sudden change of the confinement potential. In addition, they can be implemented numerically very easily significantly outperforming other numerical approaches. As applications of our results we investigate the single particle spectral functions of systems with harmonic trapping and show that dynamical quasicondensation occurs for both fermionic and bosonic spin-1/2 systems released from a Mott insulator state.

DY 13.3 Tue 10:00 H37

Quantum many-body scars beyond the PXP model in Rydberg simulators — Aron Kerschbaumer[1], Marko Ljubotina[1,2,3], Maksym Serbyn[1], and •Jean-Yves Desaules[1] — [1]Institute of Science and Technology Austria, Klosterneuburg, Austria — [2]Technical University of Munich, Garching, Germany — [3]Munich Center for Quantum Science and Technology, Munich, Germany

Persistent revivals recently observed in Rydberg atom simulators have challenged our understanding of thermalization and attracted much interest to the concept of quantum many-body scars (QMBSs). QMBSs are non-thermal highly excited eigenstates that coexist with typical eigenstates in the spectrum of many-body Hamiltonians, and have since been reported in multiple theoretical models, including the so-called PXP model, approximately realized by Rydberg simulators. At the same time, questions of how common QMBSs are and in what models they are physically realized remain open.

In our work, we demonstrate that QMBSs exist in a broader family of models that includes and generalizes PXP to longer-range constraints and states with different periodicity. We show that in each model, multiple QMBS families can be found. Each of them relies on a different approximate su(2) algebra, leading to oscillatory dynamics in all cases. However, in contrast to the PXP model, their observation requires launching dynamics from weakly entangled initial states rather than from a product state. The new QMBSs we unveil may be experimentally probed using Rydberg atom simulator in the regime of longer-range Rydberg blockades.

DY 13.4 Tue 10:15 H37

Roughening dynamics of quantum interfaces — Wladislaw Krinitsin[1,2], •Niklas Tausendpfund[1,3], Matteo Rizzi[1,3], Markus Heyl[4], and Markus Schmitt[1,2] — [1]Institute of Quantum Control (PGI-8), Forschungszentrum Jülich, Jülich, Germany — [2]Faculty of Informatics and Data Science, University of Regensburg, Regensburg, Germany — [3]Institute for Theoretical Physics, University of Cologne, Köln, Germany — [4]Center for Electronic Correlations and Magnetism, University of Augsburg, Augsburg, Germany

The roughening transition, known from three-dimensional classical spin systems, describes how fluctuations of interfaces transition from being bounded to being extensive when crossing the characteristic roughening temperature. We explore signatures of such phenomena in the dynamics of domain walls in the two dimensional quantum Ising model, where we observe pre-thermal steady states in their evolution well beyond the perturbative limit using Tree Tensor Networks. We formulate an effective model of the interface, which captures qualitative features of a roughening transition. Most notably, it exhibits a Berezinskii Kosterlitz Thouless quantum phase transition from smooth to rough interfaces, whose signatures extend to finite temperatures. These findings can be related to the observed slow thermalization in the full model, opening the way to a better understanding of prethermalization effects in interface dynamics, which can be easily implemented and tested in experimental setups such as Rydberg atom experiments.

DY 13.5 Tue 10:30 H37

Semigroup Influence Functionals for the Dynamics of Quantum Impurity Models — •Michael Sonner[1], Valentin Link[2], and Dmitry Abanin[3,4] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, D-01187 Dresden, Germany — [2]Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany — [3]Department of Physics, Princeton University, Princeton, New Jersey 08544, USA — [4]Google Research, Brandschenkestrasse 150, 8002 Zürich, Switzerland

Quantum impurity models˜(QIM) consist of a local interacting impurity which is coupled to baths of free fermions. These models exhibit a range of non-trivial phenomena such as the Kondo effect. and play a central role in the dynamic mean field theory (DMFT) approach to correlated matter. However, despite their importance, computing the real time dynamics of QIM remains a challenge. Recently, approaches based on matrix product states (MPS) representation of influence functionals (IF) have been proven effective approaches to this problem. These method work by capturing the, generically non-markovian dynamical effects of the quantum environments on the local impurity in a multi time object, which then is compressed as MPS. Taking explicit advantage of time-translation invariance of the model, we find an infinite MPS or semigroup representation of the IF. I will demonstrate how these ideas can be used to predict QIM dynamics for very long times as well as give direct access to stationary non-equilibrium states.

DY 13.6 Tue 10:45 H37

Quantum Fisher information of monitored random circuits — •Arnau Lira Solanilla, Xhek Turkeshi, and Silvia Pappalardi — Universität zu Köln

We characterize the multipartite entanglement structure of monitored random quantum circuits using the quantum Fisher information. We show that, despite the known phase transition in bipartite correlations, the multipartiteness is bounded. On the other hand, we generate a phase with extensive multipartite entanglement under symmetry preserving random operations by introducing two-qubit measurements. We focus on the limit where no unitary operations are applied, but there is a competition between two noncommuting projective measurements. We exploit a map to bond percolation to precisely calculate the universal scaling of multipartite entanglement.

DY 13.7 Tue 11:00 H37

Entanglement in quantum circuits with SU(2) symmetry — •Tobias Dörstel and Michael Buchhold — Institute for Theoretical Physics, Cologne

Quantum circuits offer a robust framework for studying the out-of-equilibrium dynamics of quantum many-body systems. We investigate one-dimensional monitored quantum circuits with global SU(2) symmetry, serving as digital counterparts to the Heisenberg chain. These circuits consist of unitary qubit SWAPs and non-unitary SWAP-measurements. Entanglement in the chain is governed by the configuration of qubit singlet states, whose count is fixed by the symmetry sector. Varying the measurement rate, unitary operations, and singlet number reveals diverse entanglement behaviors, ranging from volume law to $\log^2(L)$ and $\log(L)$ scaling of half-chain entanglement. We explain these scaling regimes analytically using an SU(2)-symmetric "Page law" and a mapping to loop models with crossings.

15 min. break

DY 13.8 Tue 11:30 H37

Generalized dual-unitary circuits from biunitarity — •Michael A. Rampp, Suhail A. Rather, and Pieter W. Claeys — Max-Planck-Institut für Physik komplexer Systeme, Dresden

We present a general framework for constructing solvable lattice models of chaotic many-body quantum dynamics with multiple unitary directions using biunitary connections. We show that a network of biunitary connections on the Kagome lattice naturally defines a multi-unitary circuit, where three 'arrows of time' directly reflect the lattice symmetry. These models unify various constructions of hierarchical dual-unitary and triunitary gates and present new families of models with solvable correlations and entanglement dynamics. Using multilayer constructions of biunitary connections, we additionally introduce multilayer circuits with monoclinic symmetry and higher level hierarchical dual-unitary solvability and discuss their (non-)ergodicity. Our work demonstrates how different classes of solvable models can be understood as arising from different geometric structures in spacetime.

DY 13.9 Tue 11:45 H37

Magic spreading in doped Clifford circuits — •Jiangtian Yao and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems

We study the spreading of magic, or nonstabilizerness, in Clifford circuits with doping by non-Clifford gates. We characterize the spatial extent of magic in classes of Clifford circuits where the growth behavior of entanglement entropy and operator strings are known. The dynamics of magic spreading in such circuits is compared to that of entanglement entropy, and quantitative measures for longer-ranged magic are also explored.

DY 13.10 Tue 12:00 H37

One magnon magnetization dynamics for the kagome lattice antiferromagnet — Henrik Schlüter, •Jannis Eckseler, and Jürgen Schnack — Faculty of Physics, Bielefeld University, Bielefeld, Germany

We present aspects of the one-magnon dynamics of the antiferromagnetic kagome lattice as an example of flat-band dynamics extending the work of [1] to two dimensional systems. We illustrate how localized eigenstates also called localized magnons [2] influence the dynamics of excitations and possibly prevent the system from thermalization. To this end we introduce a $J_1 - J_2$-model for the kagome lattice which guarantees the stability of one out of three localized magnons and lets us distinguish the different flat bands.

[1] F. Johannesmann, J. Eckseler, H. Schlüter, and J. Schnack, Phys. Rev. B 108, 064304 (2023).

[2] J. Schnack, H.-J. Schmidt, J. Richter, and J. Schulenburg, Eur. Phys. J. B 24, 475 (2001).

DY 13.11 Tue 12:15 H37

Towards a Many-Body Generalization of the Wigner-Smith Time Delay — •Georg Maier[1], Carolyn Echter[2], Juan Diego Urbina[1], Caio Lewenkopf[3], and Klaus Richter[1] — [1]Institut für Theoretische Physik Universität Regensburg, Regensburg, Germany — [2]Mathematische Fakultät Universität Regensburg, Regensburg, Germany — [3]Instituto de Física Universidade Federal Fluminense, Niterói RJ, Brazil

Many body systems with a large number of degrees of freedom are usually described by statistical physics on the theoretical side while experiments usually relay on scattering (e.g. particle physics). Is it possible to relate scattering and statistical physics, or to measure scattering-related observables which directly relate to quantities of statistical physics? At least for single particle systems a close relation exists between the well known Wigner-Smith delay time in scattering theory and the density of states of the scattering system.

I will present a novel ansatz relating a many-body version of dwell-/Wigner-Smith delay time and many body density of states based on the famous Birman-Krein-Friedel-Loyd formula connecting scattering theory and statistical observables in the many-body context. Due to the flexibility of this ansatz it can be used to investigate a wide variety of MB systems. I will discuss interesting scaling behaviors for different systems, like the harmonic trap[1] or the free particle together with the different behavior of bosons, fermions and indistinguishable particles.

[1] C. Echter et. al 2409.08696

DY 13.12 Tue 12:30 H37

Subleading logarithmic behavior in the parquet formalism — •Marcel Gievers[1,2], Richard Schmidt[3], Jan von Delft[1], and Fabian B. Kugler[4] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Universität Heidelberg — [4]CCQ, Flatiron Institute, New York

The Fermi-edge singularity in x-ray absorption spectra of metals is a paradigmatic case of a logarithmically divergent perturbation series. Prior work has thoroughly analyzed the leading logarithmic terms. Here, we investigate the perturbation theory beyond leading logarithms and formulate self-consistent equations to incorporate all leading and next-to-leading logarithmic terms. This parquet solution of the Fermi-edge singularity goes beyond the previous first-order parquet solution and sheds new light on the parquet formalism regarding logarithmic behavior. We present numerical results in the Matsubara formalism and discuss the characteristic power laws. We also show that, within the single-boson exchange framework, multi-boson exchange diagrams are needed already at the leading logarithmic level.

DY 13.13 Tue 12:45 H37

Ballistic transport in a disordered, boundary-driven XXZ spin chain. — •Johannes S Hofmann[1], Adam McRoberts[2], and Roderich Moessner[1] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]International Centre for Theoretical Physics, Strada Costiera 11, 34151, Trieste, Italy

Recent experiments on Google's sycamore NISQ device on spin transport realised ballistic transport in a edge-driven XXZ chain without disorder; and theoretical works on the classical variant demonstrated the survival of ballistic regime in the easy-plane upon the introduction of bond disorder. Here, we consider various generalisations of this set-up.

DY 14: Focus Session: Nonlinear Dynamics in Biological Systems I (joint session DY/BP)

Nonlinear dynamics play a central role for biological systems to achieve remarkable complexity and adaptability. They underlie processes where small changes cascade into large effects, critical thresholds drive transitions, and feedback mechanisms maintain intricate balances. Biological systems are often far from equilibrium, exhibiting behaviors shaped by competing forces, stochastic fluctuations and emergent behavior. From the amplification of sensory signals near bifurcation points to the development of turbulence, concepts from nonlinear dynamics provide a unifying framework for studying patterns, stability, and collective behavior in living systems. This focus session explores the richness of nonlinear dynamics across biological scales, from molecular circuits to population-level phenomena, spanning vastly different fields from cardiac dynamics, embryogenesis and cell motility to active fluids, condensates and origin of life. Through theoretical models, experimental insights, and computational approaches, the talks illustrate how nonlinear-dynamics principles unravel the mechanisms driving function and complexity in biology, offering new perspectives across disciplines.

Organized by Philip Bittihn (Göttingen), Stefan Klumpp (Göttingen), and Carsten Beta (Potsdam)

Time: Tuesday 9:30–12:30 Location: H43

Invited Talk DY 14.1 Tue 9:30 H43

Robust signal amplification and information integration via self-tuned proximity to bifurcation points — •Isabella Graf — Developmental Biology Unit & Theory Transversal Theme, EMBL Heidelberg, Germany

Many living systems demonstrate exquisite sensitivity to small input signals. A tempting hypothesis is that these systems operate close to bifurcation or critical points, where the system's response exhibits a diverging susceptibility to the control parameter and small signals are amplified into a large collective response. A common concern, however, is that proximity to such points requires fine-tuning of parameters, which seems impossible for noisy biological systems. Based on several distinct sensory systems, we have investigated a feedback motif that robustly maintains these systems close to their respective bifurcation point. The key ingredient is that the collective response feeds back onto the control parameter. To illustrate this idea, I will mention several examples ranging from snake thermosensing to mammalian hearing and discuss the functional benefits associated with being near-critical.

DY 14.2 Tue 10:00 H43

Exceptional Points and Stability in Nonlinear Models of Population Dynamics having PT symmetry — •Alexander Felski — Max Planck Institute for the Science of Light, Erlangen, Germany

Nonlinearity and non-Hermiticity, for example due to environmental gain-loss processes, are a common occurrence throughout numerous areas of science. For the latter, parity-time-reflection (PT) symmetry has played an eminent role in understanding exceptional-point structures and phase transitions in these systems. Yet their interplay has remained by-and-large unexplored. We analyze models governed by the replicator equation of evolutionary game theory and related Lotka-Volterra systems of population dynamics. These foundational nonlinear models offer a broad platform for non-Hermitian theory beyond physics. In this context we study the emergence of exceptional points in two cases: (a) when the governing symmetry properties are tied to global properties of the models, and, in contrast, (b) when these symmetries emerge locally around stationary states–in which case the connection between the linear non-Hermitian model and an underlying nonlinear system becomes tenuous. We outline further that when the relevant symmetries are related to global properties, the location of exceptional points in the linearization around coexistence equilibria coincides with abrupt global changes in the stability of the nonlinear dynamics. Exceptional points may thus offer a new local characteristic for the understanding of these systems.

DY 14.3 Tue 10:15 H43

Pattern selection and the route to turbulence in polar active fluids — Henning Reinken[1], Sebastian Heidenreich[2], •Markus Bär[2,3], and Sabine Klapp[3] — [1]OVGU Magdeburg, Germany — [2]Physikalisch-Technische Bundesanstalt, Germany — [3]TU Berlin, Germany

Active fluids, such as suspensions of microswimmers, are well known to self-organize into complex spatio-temporal flow patterns. An intriguing example is mesoscale turbulence, a state of dynamic vortex structures exhibiting a characteristic length scale. Here, we employ a minimal model for the effective microswimmer velocity field to explore how the turbulent state develops from regular, stationary vortex patterns when activity is increased. First, we demonstrate analytically that the system develops a stationary square vortex lattice in the absence of nonlinear advection. Subsequently, we perform an extended stability analysis and uncover a linear instability, above which the square vortex lattice becomes unstable. In numerical simulations, we confirm that this instability is predictive for the unset of turbulence. In addition, an extended region of hysteresis where turbulence and a stable vortex lattice coexist, is found Reference: H. Reinken, S. Heidenreich, M. Bär, S. Klapp, New J. Phys. 26 063026 (2024).

DY 14.4 Tue 10:30 H43

Likelihood-based inference for heterogeneous motile particle ensembles — •Jan Albrecht[1], Cristina M. Torres[1], Carsten Beta[1], Manfred Opper[2,3,4], and Robert Grossmann[1] — [1]Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany — [2]Faculty of Electrical Engineering and Computer Science, Technische Universität Berlin, 10587 Berlin, Germany — [3]Centre for Systems Modelling and Quantitative Biomedicine, University of Birmingham, B15 2TT, United Kingdom — [4]Institute of Mathematics, University of Potsdam, 14476 Potsdam, Germany

The inherent complexity of biological agents often leads to motility behavior that appears to have random components. Robust stochastic inference methods are therefore required to understand and predict the motion patterns from time discrete trajectory data provided by experiments. In many cases second-order Langevin models are needed to adequately capture the motility. Additionally, population heterogeneity needs to be taken into account when analyzing data from multiple individual organisms. We present a maximum likelihood approach to infer stochastic models and, simultaneously, estimate the heterogeneity in a population of motile active particles from discretely sampled trajectories. To this end we propose a new method to approximate the likelihood for nonlinear second order Langevin models. We demonstrate that our approach outperforms alternative methods for heterogeneity estimation, especially for short trajectories, while also providing a measure of uncertainty for the estimates. We use the approach to investigate population heterogeneity in systems of ameboid cells.

DY 14.5 Tue 10:45 H43

Surviving the first "winter": Protocells with polymerization reactions protects against environmental fluctuations — •Xi Chen, Jens-Uwe Sommer, and Tyler Harmon — Leibniz Institute of Polymer Research, Dresden, Germany

The origin of life has been a long standing question with various hypotheses describing the emergence of the first protocells. Phase separated condensates are promising candidates for protocells because they are compartments that enrich specific polymers and host nonequilibrium reactions that leads to growth and division. However, the ability of protocells to survive in an environment that has large fluctuations, such as temperature and composition, is poorly understood. We show with a mean-field model that condensates formed by polymers which undergo nonequilibrium polymerization/depolymerization reactions exhibit significant robustness to large environmental fluctuations.

This robustness occurs when the nonequilibrium polymerization reactions are faster inside condensate phases than outside. The first

condensate does not form until environmental factors lead to strong enough reactions that polymers long enough to phase separate form. The effects of nonequilibrium polymerization is then fully realized because a condensate exists. From here, the condensate does not dissolve until the nonequilibrium reactions are diminished to significantly below when the condensate formed. Altogether, this forms a hysteretic loop with respect to the environmental factors that drive nonequilibrium reactions. We show this hysteretic loop prevents protocells from dying from environmental fluctuations.

DY 14.6 Tue 11:00 H43

How inter-particle interaction affects two species transport in nano-channels — •Wolfgang Bauer — Dept. of Internal Medicine I, UKW, Würzburg, Germany

Channel transport mechanisms of multiple species is essential for cell physiology and nanotechnology. Here, we present a model maintaining spatial correlations of two species, moving away from mean field approaches. The spatial occupations of the channel give the state space, where local flux and entropy production determine channel transport and its thermodynamic efficiency. Optimal transport coupling between species occurs in an attractive empty channel and strong repulsive forces between particles of the same species. This confines state space to a circular topology with concentration gradients of the two species acting as thermodynamic driving forces in series. For opposing gradients, the species with the stronger gradient produces positive entropy, while the other negative entropy. Attenuating the repulsive force within one species and maintaining that of the other adds a bypass path on the circular topology in state space. This enables a leak flow of the less repulsive species parallel to its gradient, generating local positive entropy on the bypass. For a certain range of opposing gradients, both species can produce positive overall entropy simultaneously. However, the rectifying potential of the concentration gradient of the species with bypass option is diminished, i.e. it cannot rectify flow of the other species above a threshold of the latter's opposing gradient. Vice versa the flow of the species with bypass option may always be rectified parallel to the concentration gradient of the other.

15 min. break

Invited Talk DY 14.7 Tue 11:30 H43

Beyond the connectionist view: (De-)synchronizing neural networks via cell-intrinsic dynamics — •Susanne Schreiber — Humboldt-Universität zu Berlin, Institute for Theoretical Biology, Berlin, Germany

Neural computation is thought to arise from the connectivity among neurons. Accordingly, we are often more than happy to ignore seemingly unimportant and potentially overwhelming biological detail, for example, related to the properties of the neurons themselves. In this talk, however, I will highlight how cell-intrinsic dynamics, namely the biophysics of action-potential generation, can have a decisive impact on network behaviour. Recent work of my lab shows that, among regularly firing neurons, the somewhat unattended homoclinic type (characterized by a spike onset via a saddle homoclinic orbit bifurcation) particularly stands out: First, spikes of this type foster specific network states - synchronisation in inhibitory and splayed-out/frustrated states in excitatory networks. Second, homoclinic spikes can be easily induced in by changes in a variety of physiological parameters (like temperature, extracellular potassium, or dendritic morphology). As a consequence, small changes in these parameters can suffice to induce drastic switches in network states. I will discuss functional consequences of homoclinic spikes for the design of pattern-generating motor circuits in Drosophila as well as for mammalian pathologies like febrile seizures. Our work predicts an interesting role for homoclinic action potentials as an integral part of brain dynamics in both health and disease.

DY 14.8 Tue 12:00 H43

Transient spatiotemporal chaos in cardiac excitable media — •Melvin Dix[1,2], Thomas Lilienkamp[1,3], Stefan Luther[1,4,5], and Ulrich Parlitz[1,2,5] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Institute for the Dynamics of Complex Systems, Georg-August-Universität Göttingen, Göttingen, Germany — [3]Faculty for Applied Mathematics, Physics, and General Science, Computational Physics for Life Science, Nuremberg Institute of Technology Georg Simon Ohm, Nürnberg, Germany — [4]Institute of Pharmacology and Toxicology, University Medical Center Göttingen, Göttingen, Germany — [5]German Center for Cardiovascular Research (DZHK), Partner Site Göttingen, Göttingen, Germany

Life-threatening cardiac arrythmia such as ventricular fibrillation have been linked to spatiotemporal chaotic dynamics governed by scroll or spiral waves. It has been observed in vivo and in vitro that these dynamics can be transient, e.g. abruptly stop. Using simulations with different numerical models we investigate the effects of factors such as heterogeneities, motivated by the complexity of the heart. We show that these perturbations can (significantly) prolong the duration of chaotic transients and may also lead to persistent chaos or stable periodic wave patterns [1].

[1] Melvin Dix et al. Physical Review E 110(4), 044207 (2024).

DY 14.9 Tue 12:15 H43

Nonlinear dynamics of heart and brain — •Irene Pellini[1,2], Simon Bauer[1], Johannes Zierenberg[1,3], Philip Bittihn[1,3], and Viola Priesemann[1,3] — [1]Max Planck Institute for Dynamics and Self Organisation, Göttingen, Germany — [2]Max Planck School Matter to Life, Heidelberg, Germany — [3]Institute for the Dynamics of Complex Systems, University of Göttingen, Germany

The core function of the heart and brain arises from the coordinated interaction of their cells. Both organs rely on excitable units – cardiomyocytes and neurons – that propagate electrical signals when a specific threshold is exceeded. Despite this similarity, the two organs exhibit opposed collective behavior due to marked differences in intercellular dynamics and network topology. In the heart, localized electrical connectivity through reciprocal gap junctions generates local synchronization and traveling waves, ensuring efficient pumping function with low entropy. In the brain, long-range connectivity via delayed, non-reciprocal chemical synapses promotes asynchronous dynamics with high entropy, supporting information processing.

Using coupled FitzHugh-Nagumo oscillators, we showcase that characteristic non-linear dynamics for the heart and brain can be related to the network structure, which places both systems on opposite sides of a synchronization phase transition. Crossing this phase transition would lead to pathological conditions, e.g., heart arrhythmia or brain seizures, quantifiable via entropy measures. Our joint view on heart and brain dynamics may foster new perspectives on the function and pathology of both organs.

DY 15: Active Matter III (joint session DY/BP/CPP)

Time: Tuesday 9:30–13:00 Location: H47

DY 15.1 Tue 9:30 H47

From micro to macro: systematic coarse-graining of active particle models and implications on phase separation — •Sumeja Burekovic[1], Filippo De Luca[2], Cesare Nardini[1,3], Ananyo Maitra[4,5], and Michael E. Cates[2] — [1]CEA, Paris-Saclay, France — [2]DAMTP, University of Cambridge, UK — [3]LPTMC, Sorbonne Université, France — [4]LPTM, CY Cergy Paris Université, France — [5]LJP, Sorbonne Université, France

Significant insights into collective phenomena of active systems, such as phase separation, have been obtained through minimal field theories developed in a top-down manner. In contrast, the bottom-up approach seeks to link these continuum models to the microscopic dynamics of active particles, often formulated as Langevin equations for their position and orientation. This connection is typically achieved via explicit coarse-graining and allows active field theories to be expressed in terms of physically meaningful parameters. A major challenge in coarse-graining is the consistent elimination of irrelevant fast degrees of freedom to derive closed equations for the hydrodynamic variables or order parameters, such as the density field. We propose a systematic extension of standard homogenization/projection-operator techniques. As we show in minimal examples with few degrees of freedoms, our technique allows to go beyond the state of the art of homogenization in the mathematical literature. We then discuss the predictions of our coarse-graining methods for the large-scale phenomenology of non-aligning active particles, including cases in which microphase separation - rather than full phase separation - emerges due to activity.

DY 15.2 Tue 9:45 H47

Active Quadrupolar Dumbbells — •Margaret Rosenberg[1], Marco Musacchio[1], Lorenzo Caprini[2], and Hartmut Löwen[1] — [1]Heinrich-Heine University Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf — [2]Università di Roma Sapienza, P.le Aldo Moro 2, 00185 Rome, Italy

The field of Active Matter has thrived in recent years, driven both by the insight that it underlies fundamental processes in nature, and by its vast potential for applications. Although the self-propulsion mechanisms of Active Matter allow us to consider and control a wide range of motions, there is - by default - no obvious control over the orientation and rotation of the particles. One approach to resolve this is the use of anisotropic particles and interactions. This contribution presents a computational study of a novel system composed of active, quadrupolar dumbbells, the phase behavior of which is determined by the competition between active motion and the orthogonal alignment favored by quadrupolar attraction. We explore the novel phase behavior unlocked by these anisotropic interactions, and discuss options for experimental realizations and applications.

DY 15.3 Tue 10:00 H47

Order by disorder in a swarm with obstacles — Pradeep Kumar[1], Sanjay Puri[1], and •Martin Weigel[2] — [1]School of Physical Sciences, Jawaharlal Nehru University, New Delhi – 110067, India — [2]Institut für Physik, Technische Universität Chemnitz, 09107 Chemnitz, Germany

Simple models of swarming and active matter such as the Vicsek model [1] have been studied in detail, and the phase diagram as a function of noise strength and particle density is by now well understood. Real active systems are usually affected by impurities and random disorder, however. The presence of a quenched distribution of disc-like obstacles in the domain of the Vicsek model is observed to have a dramatic effect on the ordering behavior [2]: in contrast to the model without obstacles, where the strongest alignment is observed for the lowest noise, as soon as obstacles are added only the presence of a certain amount of noise leads to a global alignment of particles. This order by disorder phenomenon for active systems is traced back to the interplay of multiple length scales in the system: the typical inter-obstacle distance, the typical cluster size, and the resulting mean-free-paths of cluster-obstacle and cluster-cluster collisions. We present scaling arguments explaining these connections and provide an outlook towards similar phenomena in related systems.

[1] T. Vicsek, Phys. Rev. Lett. 75, 1226 (1995).
[2] O. Chepizhko, E. G. Altmann, and F. Peruani, Phys. Rev. Lett. 110, 238101 (2013).

DY 15.4 Tue 10:15 H47

Autonomous navigation in synthetic microswimmers: solving mazes with chemical echolocation — •Aritra K. Mukhopadhyay[1], Linhui Fu[2], Kai Feng[2], Ran Niu[2], and Benno Liebchen[1] — [1]Technische Universität Darmstadt, Darmstadt, Germany. — [2]Huazhong University of Science and Technology, Wuhan, China.

Motile microorganisms like bacteria and algae combine self-propulsion, cooperation, and decision-making at the micron scale. Inspired by these biological systems, synthetic microswimmers are emerging as human-made counterparts capable of self-propulsion. Recent breakthroughs provide a platform to integrate additional functionalities, bridging the gap between biology and synthetic systems.

We propose and experimentally demonstrate a mechanism enabling synthetic microswimmers, such as autophoretic colloids, droplet swimmers, and ion-exchange-driven modular swimmers, to make autonomous navigational decisions. These swimmers generate chemohydrodynamic signals that interact with boundaries, creating echoes that carry structural information about the environment. Remarkably, these echoes invoke automatic responses, such as synthetic chemotaxis, enabling the swimmers to avoid dead ends and autonomously find paths through complex mazes.

Our findings illustrate how simple physical principles can endow synthetic systems with advanced navigation functionalities, which could be useful for developing self-navigating micromachines with potential applications in targeted drug delivery and environmental sensing.

DY 15.5 Tue 10:30 H47

Active Particles in Tunable Colloidal Environments — •Abhimanyu Nowbagh[1], Venkata M.S.G. Tanuku[2], Thomas Palberg[2], and Ivo Buttinoni[1] — [1]Institute of Experimental Colloidal Physics, Heinrich-Heine University, 40225 Düsseldorf — [2]Institute of Physics, Johannes-Gutenberg University, 55128 Mainz

Active colloids are microscopic particles which propel through aqueous media by converting the externally available energy into directed motion. Using non equilibrium thermodynamics to understand biological systems: interactions of active colloids with crowded systems, and emergent phenomena of ensembles of active particles, remain an important and open question.

In this work, we investigate the dynamics of active particles in crowded environments subjected to alternating-current (AC) electric fields. The AC electric field is used to control: i) the velocity of active particles and ii) the inter-particle interaction between passive colloids. As we increase electric field strength, the velocity of active particles increases and the inter-particle interaction between passive colloids becomes stronger. We study the behaviour of active particles as a function of: i) the frequency of the applied AC electric field, ii) the area fraction of the passive crowd, iii) the active to passive particle number ratio, and iv) the velocity of the active particles.

Our experimental findings show that the active particles reorient faster with an increasing electric field strength. With an increase in the active to passive particle ratio, we show that cluster formation is non-monotonically sensitive to the passive crowd density.

Invited Talk DY 15.6 Tue 10:45 H47

Beyond spheres - active matter in new shapes — •Juliane Simmchen — University of Strathclyde, Cathedral street 295, Glasgow UK

Surface minimisation for a given volume is energetically favourable on the small scale - this is why most colloidal particles are spherical. In active matter they have the added advantage of facilitating comparison between experiment and theory, one of the reasons why spherical Janus particles dominate the field.

However, broadening the range of materials has led to interesting discoveries - behaviour that would not have been observable in the spherical regime. This talk will give an overview of the intriguing behaviour of non-spherical active materials at the microscale - from plates to truncated bipyramids and rods.

15 min. break

DY 15.7 Tue 11:30 H47

Modeling Filamentous Cyanobacteria — •Elias Fischer and Holger Stark — Institute Of Theoretical Physics, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Filamentous cyanobacteria play an important role in many ecosystems and the carbon cycle of our planet, both in the present and the past. They triggered the great oxygenation event about 2.5 billion years ago, generating the atmospheric oxygen of our planet while contributing large parts of our fossil fuel record.

Filamentous cyanobacteria exhibit gliding motility when in contact with solid surfaces or each other. Despite their ecological relevance and increased use in biotech applications, the exact nature of the force-generating process remains not fully understood. Furthermore, the gliding of cyanobacteria is strongly affected by external cues, most importantly light. They aggregate in regions with the highest light intensity, which means best environmental conditions for photosynthesis.

Following recent advances in understanding the self-organization of cyanobacteria, we present a novel approach for modeling the mechanical and behavioral aspects of individual cyanobacteria filaments, including force synchronization and response to light. Each filament is modeled as a bead-spring chain in 3D with bending and torsional elasticity, as well as a hard-core repulsion between the filaments. Notably, the propulsion forces that drive the individual parts of the filament forward are only considered locally where the filament comes into contact with another surface. First results on the 3D bending and twisting motion of a filament and its reaction to light are presented.

DY 15.8 Tue 11:45 H47

Self-assembly and control of active and passive triblock Janus colloids — •Juri Franz Schubert, Salman Fariz Navas, and Sabine H. L. Klapp — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin

Triblock Janus colloids belong to the family of patchy particles, interacting with hydrophobic attraction at opposite poles and electrostatic repulsion in the equatorial region. They are known to self-assemble into a colloidal kagome crystal from experiments [1] and theory [2,3,4]. However, investigating the self-assembly of such systems via Brownian Dynamics can result in timescales inaccessible to brute force simulations, often requiring complex sampling techniques [3]. Recently, it has been shown that introducing self-propulsion can significantly accelerate self-assembly and enhance the Kagome yield [4]. Here, we study the model introduced in [4] and further investigate the self-assembled structures in active and passive systems. Using simple time-dependent activity protocols, we are able to sample a temperature-density state diagram of the passive system. Our results closely match with earlier studies [2,3], where different triblock models and sampling techniques were used.

[1] Q. Chen, S. C. Bae, S. Granick, Nature 469, 7330 (2011).
[2] F. Romano, F. Sciortino, Soft Matter 7, 12 (2011).
[3] K. Bahri, H. Eslami, and F. Müller-Plathe, JCTC 18, 1870 (2022).
[4] S. A. Mallory, A. Cacciuto, JACS 141, 6 (2019).

DY 15.9 Tue 12:00 H47

Enhanced Diffusion and Universal Rouse-like Scaling of an Active Polymer in Poor Solvent — Suman Majumder[1], Subhajit Paul[2], and •Wolfhard Janke[3] — [1]Amity Institute of Applied Sciences, Amity University Uttar Pradesh, Noida 201313, India — [2]Department of Physics and Astrophysics, University of Delhi, Delhi 110007, India — [3]Institut für Theoretische Physik, Universität Leipzig, IPF 231101, 04081 Leipzig, Germany

By means of Brownian dynamics simulations we study the steady-state dynamic properties of a flexible active polymer in a poor solvent condition. Our results show that the effective diffusion constant of the polymer D_{eff} gets significantly enhanced as activity increases, much like in active particles. The simulation data are in agreement with a theoretically constructed Rouse model of active polymer, demonstrating that irrespective of the strength of activity, the long-time dynamics of the polymer chain is characterized by a universal Rouse-like scaling $D_{\text{eff}} \sim N^{-1}$, where N is the chain length. We argue that the presence of hydrodynamic interactions will only have an insignificant effect on the observed scaling behavior.

DY 15.10 Tue 12:15 H47

A Pulsating Active Solid — •Umang A Dattani[1], Francesco Serafin[1], Jonas Ranft[2], and Etienne Fodor[1] — [1]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg City, Luxembourg — [2]Institut de Biologie de l ENS, Ecole Normale Superieure, CNRS

Active matter has garnered significant attention in recent decades due to its numerous parallels with biological systems. Inspired by recent studies of biological tissues, such as cardiac cells, where constituent cell sizes periodically vary, a new form of activity termed "pulsating active matter" has been introduced recently. We propose a model of a pulsating active solid, consisting of size-changing particles linked by a triangular spring network. Despite the fixed connectivity, our model exhibits a variety of patterns and topological phase defects, akin to previous studies. Additionally, we explore the elastic continuum limit, which successfully predicts several essential features of the microscopic model. We conclude by highlighting intriguing properties of this system and its different potential parallels.

Invited Talk DY 15.11 Tue 12:30 H47

Emergent correlations and boundary fluctuations in epithelial cell sheets — •Silke Henkes — Lorentz Institute, Leiden University, Leiden, The Netherlands

In soft active materials, the driving motion of individual constituents competes with their mechanical interactions, giving rise to active liquids, solids or glasses. An especially important example of this are epithelial cell sheets, which form a barrier function in the body and where the active crawling motion of cells over the substrate acts against cell-cell adhesion and repulsion.

I will show that a minimal model of cell sheets with uncorrelated activity, based on active Brownian dynamics and a vertex model, is a good quantitative match to data from two experiments on corneal and MDCK cell sheets. Its core feature is an emergent correlation length, arising from the diffusive spread of active forces through an elastic solid. This is a very general result that emerges in many active solids.

The boundary of such cell sheets exhibits a 'fingering instability' where the initially straight boundary develops large, spatiotemporally correlated fluctuations. Despite previous interpretations within many frameworks as an instability, I will show that it can be fully explained as arising from the active correlations of the cell sheets driving the boundary.

DY 16: Many-body Systems: Equilibration, Chaos, and Localization (joint session DY/TT)

Time: Tuesday 14:00–15:30 Location: H37

DY 16.1 Tue 14:00 H37

Power-law banded random matrices as models for quantum many-body Hamiltonians — •Wouter Buijsman[1], Masudul Haque[2,1], and Ivan M. Khaymovich[3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]TU Dresden, Institute of Theoretical Physics, Dresden, Germany — [3]Nordita, Stockholm, Sweden

Hamiltonians of one-dimensional, disordered single-particle sytems with long-range hoppings can naturally be modeled by power-law banded random matrices. In this picture, the phase diagram of power-law banded random matrices show an ergodic, weakly ergodic, and localized phase. Motivated by modern developments on ergodicity breaking and localization in interacting quantum many-body systems, we study many-body interpretations of such random matrices. We discuss a number of ways to label the basis states with many-body configurations, and compare the physical properties of the resulting Hamiltonians. Specifically, we study the scaling of the many-body entanglement entropy with system size for eigenstates at both the bulk and the edge of the spectra. Using a scaling analysis on the full sets of eigenstates, we subsequently provide a quantitative picture of the phase diagram. We elaborate on the physical relevance of this interpretation of random matrix models for quantum many-body systems.

DY 16.2 Tue 14:15 H37

Escaping the Krylov space during reorthogonalization — •Max Pieper, Jannis Eckseler, and Jürgen Schnack — Universität Bielefeld

Krylov complexity [1] is often used as a measure of complexity in quantum many-body-systems. During its calculation, the Lanzcos algorithm is used to construct an operator basis. Due to the poor orthogonality of the resulting basis reorthogonalization is often employed [2]. We investigate how using reorthogonalization causes the Lanczos algorithm to accumulate non-Krylov basis elements. We suspect this to negatively affect the Krylov algorithm.

[1] D. E. Parker et al. Phys. Rev. X 9, 041017 (2019)
[2] E. Rabinovici et al. JHEP 06, 062 (2021)

DY 16.3 Tue 14:30 H37

An estimate of the equilibration time based on the operator growth hypothesis — •Merlin Füllgraf, Jiaozi Wang, and Jochen Gemmer — Universität Osnabrück

We study the equilibration times T_{eq} of local observables in quantum chaotic systems by considering their auto-correlation functions. Based on the recursion method, we suggest a scheme to estimate T_{eq} from the corresponding Lanczos coefficients. We numerically find that, if an observable follows the *operator growth hypothesis*, a finite number of Lanczos coefficients is sufficient for a reasonable estimate of the equilibration time. This implies that equilibration occurs on a realistic time scale much shorter than the life of the universe. The numerical findings are further supported by analytical arguments.

DY 16.4 Tue 14:45 H37

Effects of chaos in Bose-Hubbard systems with few degrees of freedom. The smallest possible heat engine? — •Viviane Bauer, Nico Fink, and James Anglin — Physics Department and Research Center OSCAR, RPTU Kaiserslautern-Landau

Microscopic engines are a research focus in both biochemistry and nanotechnology. While other forms of engines besides heat engines are also being considered, the fully microscopic limit of a heat engine is a fundamentally important problem in physics. What happens to thermodynamics when not only the working fluid and mechanism of a heat engine, but even the hot and cold reservoirs are microscopic?

To realize such microscopic heat baths, we turn to the process of chaotic ergodization, studied in Bose-Hubbard dimers and trimers.

One realization we currently study is based on two Bose-Hubbard trimers, which allow energy and particle transport between them. The particle transport is furthermore coupled to a mass, so our engine works against a force to lift it. Moreover, we have identified a dynamic mechanism which can stabilize this lifting process. The result is a system which operates just like a heat engine, except for being fully microscopic. The structure of coupled chaotic subsystems both supports and requires an understanding of the fully microscopic heat engine in terms of open-system control.

DY 16.5 Tue 15:00 H37

Impurity coupled to the SYK bath — •Anastasia Enckell and Stefan Kehrein — Institute for Theoretical Physics, Georg-August-Universität Göttingen, Germany

System-plus-bath models play an important role in addressing fundamental questions in condensed matter physics. One challenging aspect is modelling the bath, which is often approached using free-particle or open quantum system frameworks. Here, we explore the Sachdev-Ye-Kitaev (SYK) model as a new kind of quantum bath with unique properties, including the absence of quasiparticles, maximal chaos, and non-integrability, which make it a valuable framework for studying system-plus-bath interactions. We study the time evolution of the occupation of an impurity coupled to the SYK bath following a quench. From the Kadanoff-Baym equations for a noninteracting impurity, we see that the only relevant property for the impurity occupation is a combination of hybridisation and density of states of the bath. These parameters can be adjusted in order to model the impurity coupled to any bath of interest. Using this approach, we can study the impurity dynamics coupled to the SYK bath by making suitable changes to the hybridisation in impurity plus Fermi bath setting, which significantly simplifies the task. We observe oscillatory dynamics of the impurity at zero temperature, with the oscillations decreasing as the temperature increases. This behaviour contrasts with that of a free-particle bath and suggests interesting underlying physics.

DY 16.6 Tue 15:15 H37

Thermal-relaxation asymmetry in fluctuating hydrodynamics — •Felipe Pereira-Alves and Aljaž Godec — Mathematical bioPhysics Group, Max Planck Institute for Multidisciplinary Sciences, 37077 Göttingen, Germany

It was theoretically predicted and recently experimentally confirmed that small systems, such as trapped colloidal particles quenched far from equilibrium, heat up faster than they cool down. The phenomenon was coined thermal-relaxation asymmetry. The proposed physical explanation of the asymmetry instigated intriguing questions about its existence in the thermodynamic limit. Here we investigate thermal relaxation dynamics in far-from-equilibrium temperature quenches on the level of fluctuating hydrodynamics of short- and long-range (logarithmically) interacting many-body systems. We prove the existence of a strict asymmetry for any temperature quench for both, short- and long-range interactions. Remarkably, in contrast to small systems, there is no "close-to-equilibrium" regime of quenches for which heating and cooling are symmetric. Notably, we find that relaxation is self-similar up to the relaxation time, and uncover intricate differences between short- and long-range interactions.

DY 17: Focus Session: Nonlinear Dynamics in Biological Systems II (joint session DY/BP)

Nonlinear dynamics play a central role for biological systems to achieve remarkable complexity and adaptability. They underlie processes where small changes cascade into large effects, critical thresholds drive transitions, and feedback mechanisms maintain intricate balances. Biological systems are often far from equilibrium, exhibiting behaviors shaped by competing forces, stochastic fluctuations and emergent behavior. From the amplification of sensory signals near bifurcation points to the development of turbulence, concepts from nonlinear dynamics provide a unifying framework for studying patterns, stability, and collective behavior in living systems. This focus session explores the richness of nonlinear dynamics across biological scales, from molecular circuits to population-level phenomena, spanning vastly different fields from cardiac dynamics, embryogenesis and cell motility to active fluids, condensates and origin of life. Through theoretical models, experimental insights, and computational approaches, the talks illustrate how nonlinear-dynamics principles unravel the mechanisms driving function and complexity in biology, offering new perspectives across disciplines.

Organized by Philip Bittihn (Göttingen), Stefan Klumpp (Göttingen), and Carsten Beta (Potsdam)

Time: Tuesday 14:00–15:15 Location: H43

Invited Talk DY 17.1 Tue 14:00 H43

Mechanistic origins of temperature scaling in the early embryonic cell cycle — •Lendert Gelens — Laboratory of Dynamics in Biological Systems, Department of Cellular and Molecular Medicine, KU Leuven, Herestraat, 49, Leuven, Belgium

Temperature profoundly impacts organismal physiology and ecological dynamics, particularly affecting ectothermic species and making them especially vulnerable to climate shifts. Even though complex physiological processes usually involve dozens of enzymes, empirically it is found that the rates of these processes often obey the Arrhenius equation, which was originally derived for single enzyme-catalyzed reactions. Here we have examined the temperature scaling of the early embryonic cell cycle, with the goal of understanding why the Arrhenius equation approximately holds, and why it breaks down at temperature extremes.

Using experimental data from different frog, fish, fly, and worm species, we find that the apparent activation energies for the early embryonic cell cycle for diverse ectotherms are all similar. Computational modeling and experiments with frog egg extracts show that the non-Arrhenius scaling can be accounted for by biphasic temperature scaling in critical individual components of the cell cycle oscillator circuit, in combination with imbalances in the activation energies for different partially rate-determining enzymes. These findings provide mechanistic insights into the dynamic interplay between temperature and complex biochemical processes, and into why biological systems fail at extreme temperatures.

DY 17.2 Tue 14:30 H43

Reshaping morphogen gradients through porous tissue architecture — •Diana Khoromskaia[1,2] and Zena Hadjivasiliou[1,2,3] — [1]Francis Crick Institute, London, United Kingdom — [2]University College London, London, United Kingdom — [3]London Centre for Nanotechnology, London, United Kingdom

The morphogenesis of tissues during embryonic development is controlled by concentration gradients of morphogens – signalling molecules whose readout determines cell fate decisions. How the spread of morphogens is affected in tissues with complex geometry and spatially heterogeneous architecture is not well understood. To address this question, we introduce a porous vertex model, by explicitly considering the network of extracellular spaces between the cells. Morphogens produced by source cells disperse through the tissue via three modes of transport: extracellular diffusion, membrane-bound diffusion, and cell-based transport through recycling. With this model we investigate numerically and analytically how cell-scale geometry, such as cell size, cell shape anisotropy, and cell distance, influences effective diffusion and degradation of morphogens at tissue-scale. We further show that a non-linear coupling between cell packing and morphogen concentration renders the morphogen gradient robust to perturbations, for instance by locally buffering fluctuations in the production. Our characterisation of tissues as active porous materials provides new insights into how morphogenesis and cell fate determination may interact during embryonic development.

DY 17.3 Tue 14:45 H43

Active viscoelastic condensates provide controllable mechanical anchor points — •Oliver Paulin[1], Luise Zieger[2,3], Júlia Garcia-Baucells[5], Alexander Dammermann[5], Sebastian Aland[2,3,4], and David Zwicker[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen — [2]TU Bergakademie Freiberg — [3]HTW Dresden — [4]Center for Systems Biology, Dresden — [5]Max Perutz Labs, University of Vienna

Many biological materials must couple mechanical strength with the ability to rapidly self-assemble at a specific location. In particular, biomolecular condensates readily self-assemble via phase separation, but may also need to anchor external forces to fulfil their function. Spatial localisation of condensate formation can be controlled by active cores that preferentially drive the production of condensate material at a particular point, while resistance to external forces can be facilitated by viscoelastic material properties. Here, we develop a continuum model of viscoelastic growth around an active core, and investigate the results in a spherically symmetric geometry. We find that viscoelastic stresses restrict condensate growth, but also impart resistance to deformation. We investigate the effect of varying different mechanical properties on condensate growth and strength, and also study how strain-dependent material incorporation may limit the maximum rate of growth. Finally, we compare the predictions of our model to experimental data from centrosomes in C. elegans embryos, identifying a parameter regime in which rapid growth can be combined with appropriate mechanical strength.

DY 17.4 Tue 15:00 H43

Modelling cell crawling on different substrate stiffness — Sohei Nakamura and •Mitsusuke Tarama — Kyushu University, Fukuoka, Japan

Crawling cells sense the mechanical properties of the underlying substrate and change their dynamics accordingly. This ability called durotaxis is of great importance in various biological processes including development and homeostasis. In order to understand how intracellular chemical reactions and cellular mechanics give rise to durotaxis, we constructed a simple model from reaction diffusion equations for intracellular chemical compounds and force balance equations for the intracellular mechanics including the effect of the substrate stiffness. We found that within the model, the cell speed and diffusion coefficient change non-monotonically with the substrate stiffness, indicating the existence of an optimal substrate stiffness for migration. This non-monotonic behavior of the cell speed is consistent with experimental observations and can be understood to be caused by the competition between substrate adhesion and cell shape deformation. We further discuss cell migration on a patterned substrate.

DY 18: Pattern Formation

Time: Tuesday 14:00–15:30 Location: H47

DY 18.1 Tue 14:00 H47

Amplitude and envelope equation for the conserved-Hopf bifurcation — •Daniel Greve[1] and Uwe Thiele[1,2] — [1]Institut für Theoretische Physik, Universität Münster, Münster, Germany — [2]Center for Nonlinear Science (CeNoS), Münster, Germany

Nonreciprocal interactions and conservation laws both play an important role in out-of-equilibrium pattern formation processes, e.g., in biochemical systems.[1,2] The generic large-scale oscillatory instability in such systems – the conserved-Hopf instability – is a central organizing element for such processes.[3,4] After classifying this instability within an extension of the Cross-Hohenberg[5] scheme, we use weakly nonlinear multi-scale analysis to obtain aclosed form (but nonlocal) slow time evolution equation for the spatiotemporal dynamics of the amplitude of fast time oscillations for thee example of two-species nonreciprocal Cahn-Hilliard models. Analytical results then reveal a universal coarsening suppression in oscillatory phase separation. Finally, we demonstrate the agreement of the two levels of description in a comparison of numerical results for the reduced and full model.

[1] A. Dinelli, J. O'Byrne, A. Curatolo, Y. Zhao, P. Sollich, and J. Tailleur, Nat. Commun. 14, 7035 (2023). [2] F. Brauns and M. C. Marchetti, Phys. Rev. X 14, 021014 (2024). [3] A. Förtsch and W. Zimmermann, (2023), talk, DPG Spring Meeting, Dresden, and A. Förtsch, Ph.D. thesis, Bayreuth (2023). [4] T. Frohoff-Hülsmann and U. Thiele, Phys. Rev. Lett. 131, 107201 (2023). [5] M. C. Cross and P. C. Hohenberg, Rev. Mod. Phys. 65, 851 (1993).

DY 18.2 Tue 14:15 H47

Wavelength selection mechanism for turbulent superstructures in Rayleigh Bénard convection — •Fabián Alvarez-Garrido and Michael Wilczek — University of Bayreuth, Bayreuth, Germany

Large-scale flow patterns coexist with small-scale turbulence in high-aspect-ratio Rayleigh-Bénard cells. These flow patterns, known as turbulent superstructures, are significantly larger than convection rolls that emerge at the onset of convection. Direct numerical simulations of the Oberbeck-Boussinesq equations reveal that the size of these structures increases with the Rayleigh number. However, the mechanism behind this increase has not been elucidated.

Small-scale turbulence plays an important role in the redistribution of heat across the system. Motivated by how the background temperature gradient profile varies between the boundary layers and the bulk, we formulate effective equations for the large scales introducing a height-dependent turbulent thermal diffusivity. A sharp increase in the diffusivity renders the boundary layers effectively thermally insulating boundaries, fundamentally modifying how the fluid exchanges heat with its surroundings. A linear stability analysis of our model shows that this change in boundary conditions goes along with a change of the type of instability, which then leads to an increased wavelength of the flow patterns. These findings provide a mechanism to understand the increasing size of turbulent superstructures.

DY 18.3 Tue 14:30 H47

Turbulence-like behavior of spot patterns mediated by defects in the context of the liquid crystal light valve experiment — •Simon Navia[1], Marcel Clerc[2], and Pedro Aguilera[2] — [1]University of Münster, Münster Germany — [2]University of Chile, Santiago, Chile

The liquid crystal light valve experiment (LCLV) with optical feedback consists of a liquid crystal cell stimulated by a voltage and a photodiode that is coupled to the intensity of the light reaching the cell, thereby creating the optical feedback loop. This experiment exhibits a variety of complex spatiotemporal phenomena. This talk presents the experimental results of the observed formation of aperiodic spatiotemporal patterns in a quasi-one-dimensional channel, characterized by power-law scaling in the temporal and spatial-spectral density of the measured light intensity, as well as in the pseudo-envelope and pseudo-phase. Moreover, theoretically, the system is locally described as being near nascent bistability and spatial instability, from which a simplified model could be derived. We performed numerical simulations of this simplified model which show chaotic spatiotemporal patterns and spectral densities with exponents similar to those observed in the experiment.

[1]Aguilera-Rojas PJ, Clerc MG, Navia S. Opt Lett. 2024 doi: 10.1364/OL.522830.

[2]Verschueren N, Bortolozzo U, Clerc MG, Residori S. Phys Rev Lett. 2013 doi: 10.1103/PhysRevLett.110.104101.

DY 18.4 Tue 14:45 H47

Efficient formation of Turing patterns using physical interactions — •Cathelijne ter Burg, Chengjie Luo, and David Zwicker — Max Planck Institute for Dynamics and Self-Organisation, Am Fassberg 17, Gottingen 37077, Germany

Turing patterns arise when an activating and an inhibitory component drive local activation and global inhibition of their production. Physical interactions between the components can facilitate such patterns. Using a thermodynamically-consistent version of such a model, we show that physical interactions lower the energetic requirements for forming patterns of a given length scale. Stronger physical interactions thus permit pattern formation for systems that are less active. However, we also found a dynamic regime where structures of well-defined length scales evolve chaotically for very strong physical interactions. This regime emerges from an interplay of coarsening and spinodal decomposition of bulk phases. We conclude that physical interactions of intermediate strength are energetically optimal for forming stationary patterns of a well-defined length scale.

DY 18.5 Tue 15:00 H47

Numerical and Experimental Analysis of Multi-Soliton Interactions in Ultrafast Lasers — •Julia Lang and Georg Herink — Universität Bayreuth

Ultrafast lasers are excellent platforms for experimentally observing multi-soliton solutions of the nonlinear Schrödinger equation in real-time. Interactions between solitons are often neglected in common pulse propagation models. However, they generate a variety of nonlinear dynamics, which manifest in distinct soliton trajectories observed via real-time spectral interferometry. Here, we report on soliton interactions in two different classes of widely established laser systems, namely Kerr-lens mode-locked Ti:sapphire [1] and SESAM mode-locked Er:fiber [2] lasers. Laser system-specific components result in virtually opposite behaviour, i.e., in soliton attraction, repulsion and/or binding. We discuss their representations in the generalized Schrödinger equation and present one-to-one correspondences between experiment and theory.

[1] A Völkel et al. Intracavity Raman scattering couples soliton molecules with terahertz phonons. Nat Commun. 2022;13(1):2066.

[2] J. A. Lang et al. Controlling intracavity dual-comb soliton motion in a single-fiber laser. Sci Adv. 2024;10(2):eadk2290.

DY 18.6 Tue 15:15 H47

Self-similarity in 1 and 2-dimensional cellular automata — •Jens Christian Claussen — University of Birmingham, UK

Cellular automata with a localized single seed initial condition can exhibit deterministic time series with power-law scaling, which led us numerically to the identification of two universality (sub)classes within the Wolfram class IV cellular automata [1], where rule 90 (Sierpinski) and rule 150 are representatives of these classes. The generated time series can be analytically described by a tensorial Fibonacci iteration [2]. An exploration of 2-dimensional outer-totalistic cellular automata showed that fractals with more general one- or two-step self-similarity may exist, including a rule providing a triple replication, and generating a 2-dim spatial Sierpinski pattern. Here we also consider the more general question what variety of universality classes can be found, eventually extending the dynamics to more general algebraic structures. We show that in the 1-dimensional ECA case of a mod 2 dynamics indeed only the two self-similarity cases represented by rule 90 and rule 150 exist.

[1] J. Nagler and J.C.Claussen (2005) $1/f^{\alpha}$ spectra in elementary cellular automata and fractal signals, Phys. Rev. E 71, 067103 (2005) [2] Time evolution of the rule 150 cellular automaton activity from a Fibonacci iteration, J. Math. Phys 49, 062701 (2008)

DY 19: Focus Session: Quantum Emission from Chaotic Microcavities (joint session HL/DY)

In this joint focused session of the divisions DY, HL, and TT, we bring together two dynamic areas of research: semiconductor quantum emitters and chaotic cavities. While quantum emitters in cavities represent an established building block for quantum information technologies, chaotic microcavities may promise novel design routes towards optimized cavity performance parameters. Experts from both fields will provide an overview of the current state of research, exploring the potential of chaotic and unconventional microcavities to enhance the emission of quantum states.

Organized by Sonja Barkhofen (University of Paderborn) and Christian Schneider (University of Oldenburg).

Time: Wednesday 9:30–12:15 Location: H17

Invited Talk DY 19.1 Wed 9:30 H17

From complex internal dynamics to emission characteristics control in quantum billiards — •Martina Hentschel — 1 Institute of Physics, Technische Universität Chemnitz, D-09107 Chemnitz, Germany

The field of mesoscopic physics has given access to new classes of fascinating model systems ranging from ballistic quantum dots via microcavity lasers to graphene billiards over the past decades. Their rich internal dynamics, subject to quantum chaos and often successfully accessed employing wave-particle correspondence in real and phase space, is directly related to their emission properties. Here, we illustrate this close connection for various examples and system classes. For optical microcavities, we vary the internal dynamics by changing the geometric shape of the resonator and explain how the far-field emission characteristics is determined by the underlying steady probability distribution and a possibility to achieve directional emission required for microlasing devices with the Limaçon geometry. Placing sources into the cavity will affect the internal dynamics of the cavity by, taking the particle point-of-view, effectively changing the set of initial conditions, as observed for optical cavities as well as for graphene billiards in the form of Dirac fermion optics. A further way to change the dynamics of a system is the existence of anisotropies that can either be intrinsically present such as in bilayer graphene in the form of trigonal warping [1], or can be induced to a given system by, for example, applying a mechanical strain. [1] L. Seemann, A. Knothe, and M. Hentschel, New J. Phys. 26, 103045 (2024).

Invited Talk DY 19.2 Wed 10:00 H17

Positioning of microcavities around single emitters — •Tobias Huber-Loyola — Technische Physik, Physikalisches Institut, Julius-Maximilians-Universität Würzburg, 97074 Würzburg, Germany

Single emitters in solids are great sources of single and entangled photons for usage in quantum information technologies. Many emitters possess high internal quantum efficiency, majority of the emission into the zero-phonon line and controllable single charge spins that can be used as quantum memories or as resource to generate chains of entangled photons. However, due to their solid-state host, which usually comes with a high refractive index, the outcoupling of photons requires the use of nanophotonic structures such as waveguides or microcavities. In this talk, I will show how we place microcavities around pre-registered quantum dots using hyperspectral imaging and e-beam lithography and I will give an overview of how placement accuracy has different effects on the emitted photons‘ properties based on the type of cavity.

Invited Talk DY 19.3 Wed 10:30 H17

Exploring Wave Chaos and Non-Hermitian Physics: Future Prospects for Quantum Emission from Chaotic Microcavities — •Jan Wiersig — Otto-von-Guericke-Universität Magdeburg, Germany

Optical microcavities play a fundamental role in many fields of basic and applied research in physics. A chaotic microcavity is a type of cavity where the light ray dynamics is (partially) chaotic [1]. This can occur in a microdisk cavity with a deformed boundary shape. Chaotic microcavities are ideal for studying ray-wave correspondence, or wave chaos, in open systems, allowing direct comparisons with experiments [2]. These cavities can also exhibit non-Hermitian phenomena such as reflectionless scattering modes [3] and exceptional points [4].

The light emission from chaotic microcavities has been studied exclusively within the classical domain. The effects of electromagnetic field quantization, including phenomena like entanglement, single-photon states, and squeezed light, remain unexplored in this context. In this talk, I will review my group's recent efforts to investigate classical emission from chaotic microcavities and quantum emission from semiconductor quantum dots embedded in conventional microcavities. Additionally, I will discuss the prospects for achieving genuine quantum emission from chaotic microcavities.

[1] H. Cao and J. Wiersig, Rev. Mod. Phys. 87, 61 (2015)
[2] X. Jiang et al., Science 358, 344 (2017)
[3] X. Jiang et al., Nat. Phys. 20, 109 (2023)
[4] C.-H. Yi et al., Phys. Rev. Lett. 120, 093902 (2018)

15 min. break

Invited Talk DY 19.4 Wed 11:15 H17

Correlations and statistics in cavity embedded quantum dot sources of quantum light — •Ana Predojevic — Stockholm University, Stockholm, Sweden

Single quantum dots coupled to photonic cavities are established emitters of single photons and entangled photon pairs. The cascaded generation of photon pairs intrinsically contains temporal correlations that negatively affect the ability of such sources to perform two-photon interference, hindering applications. I will show how such correlation interacts with decoherence and temporal postselection, and under what conditions temporal postselection could improve two-photon interference visibility. Our study identifies crucial parameters of the source and shows the way to achieve optimal performance. The single photons emitted by a quantum dot exhibit quantum statistics, which is usually verified in an autocorrelation measurement. Single photons can be subjected to more extensive tests of quantum nature, such as non-Gaussianity. However, there is little evidence that such a measurement can be made on pairs of photons. I will show that pairs of photons exhibit strongly non-classical properties that can be quantified. Our result is applicable to a wide range of quantum light sources and measurement methods.

Invited Talk DY 19.5 Wed 11:45 H17

Nonlinear Phenomena in Exciton-Polaritons from Bound States in the Continuum — •Dario Ballarini — CNR-NANOTEC, Lecce, Italy

Exciton-polaritons in semiconductor microcavities have demonstrated remarkable collective behaviors and nonlinear interactions. In this work, we introduce an alternative platform to study strong light-matter interactions within a waveguide configuration. Among other interesting phenomena and applications, such as dispersion engineering of waveguide exciton-polaritons or exciton tuning through the Stark effect [1,2], we highlight the demonstration of parametric nonlinearities, polariton lasing from bound-in-the-continuum (BIC) states, and the recent realization of polariton BICs operating at room temperature in 2D materials [3-5].

[1] Electrically controlled waveguide polariton laser, Optica 7, 1579 (2020). [2] Reconfigurable quantum fluid molecules of bound states in the continuum, Nature Physics 20, 61 (2024). [3] Polariton Bose-Einstein condensate from a bound state in the continuum, Nature 605, 447 (2022). [4] Emerging supersolidity from a polariton condensate in a photonic crystal waveguide, arXiv:2407.02373 (2024). [5] Strongly enhanced light-matter coupling of monolayer WS2 from a bound state in the continuum, Nature Materials 22, 964 (2023).

DY 20: Many-body Quantum Dynamics II (joint session DY/TT)

Time: Wednesday 9:30–13:00 Location: H37

DY 20.1 Wed 9:30 H37

The Sound of Entanglement — •Benjamin Orthner[1], Clemens Wenger[5], Johannes Kofler[2], Richard Küng[2], Enar de Dios Rodríguez[3], Martin Ringbauer[4], Alexander Ploier[2], and Philipp Haslinger[1] — [1]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Vienna, Austria — [2]Johannes Kepler University Linz, Austria — [3]Internationale Forschungszentrum Kulturwissenschaften, Kunstuniversität Linz, Austria — [4]University of Innsbruck, Austria — [5]Universität für Musik und darstellende Kunst Graz, Austria

This contribution presents *The Sound of Entanglement*, a project at the intersection of quantum physics, music, and visual art. At its core lies a Bell experiment setup, where polarization-entangled photon pairs are generated through spontaneous parametric down-conversion in a β-BBO crystal. The experiment acts as a quantum conductor, utilizing the quantum correlations between the photons to coordinate and influence the choices of live musicians in real-time, creating a performance guided by principles beyond classical physics.

This work seeks to make these abstract concepts more accessible and engaging to broader audiences by transforming them into tangible, sensory experiences. By combining live music with a dynamic light show, both controlled by the experiment, this project illustrates how advancements in technology, like those shaping the second quantum revolution, can redefine artistic expression and bridge the gap between science and art.

DY 20.2 Wed 9:45 H37

A Solvable Model for Full Eigenstate Thermalization — •Felix Fritzsch and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The Full Eigenstate Thermalization Hypothesis (Full ETH) aims to characterize thermalization in many-body quantum systems in terms of the dynamics of higher-order spatiotemporal correlation functions, going beyond the current standard ETH paradigm. In this talk, we introduce a solvable random matrix model for many-body quantum dynamics in which the asymptotic dynamics of generalized out-of-time-order correlation functions can be exactly obtained in the thermodynamic limit. The dynamics of this model naturally maps to dynamics on the lattice of non-crossing partitions, combinatorial structures underlying the mathematics of Free Probability and Full ETH. We demonstrate how local observables approach asymptotic freeness at late times and explicitly characterize all relevant time scales. We confirm our analytical results with numerical simulations performed directly in the thermodynamic limit.

DY 20.3 Wed 10:00 H37

Scrutinizing the Mori memory function for transport scenarios — •Scott Daniel Linz, Jiaozi Wang, Robin Steinigeweg, and Jochen Gemmer — Department of Mathematics/Computer Science/Physics, University of Osnabrück, D-49076 Osnabrück, Germany

Diffusion is a phenomenological hydrodynamic transport behavior that holds over a wide range of materials. Within condensed matter physics there is the opinion that as long as the area under the current-current correlation function converges in time, one has a criterion for diffusive behavior of the corresponding spatiotemporal density dynamics. Attempts to derive this statement are notoriously challenging. We will first demonstrate that it is possible to construct correlation functions of some local density, where the area under a current-current correlation function converges, but the system is not diffusive. After this is demonstrated, we shall introduce a method based on the recursion method and the Mori memory formalism, that yields insight into whether or not a process is truly diffusive. The only disadvantage of this strategy is that one would have to know the behavior infinitely many Lanczos coefficients, whereas in practice one can only calculate a finite number of them in most cases. In the cases examined in this talk, however, the convergence or lack thereof becomes apparent to the naked eye with the finite amount of coefficients that were calculated.

DY 20.4 Wed 10:15 H37

Long-time Freeness in the Kicked Top — •Elisa Vallini and Silvia Pappalardi — University of Cologne, Köln, Germany

Recent work highlighted the importance of higher-order correlations in quantum dynamics for a deeper understanding of quantum chaos and thermalization. The full Eigenstate Thermalization Hypothesis, the framework encompassing correlations, can be formalized using the language of Free Probability theory. In this context, chaotic dynamics at long times are proposed to lead to free independence or "freeness" of observables. We investigate these issues in a paradigmatic semiclassical model - the kicked top - which exhibits a transition from integrability to chaos. Despite its simplicity, we identify several non-trivial features. By numerically studying 2n-point out-of-time-order correlators, we show that in the fully chaotic regime, long-time freeness is reached exponentially fast. These considerations lead us to introduce a large deviation theory for freeness that enables us to define and analyze the associated time scale. The numerical results confirm the existence of a hierarchy of different time scales, indicating a multifractal approach to freeness in this model. Our findings provide novel insights into the long-time behavior of chaotic dynamics and may have broader implications for the study of many-body quantum dynamics.

DY 20.5 Wed 10:30 H37

Periodically and aperiodically Thue-Morse driven long-range systems: from dynamical localization to slow dynamics — •VATSANA TIWARI — Indian Institute of Science Education and Research Bhopal, Bhopal, India

In this talk, I will discuss the impact of time-periodic and aperiodic field on power-law random banded matrix (PLRBM) model where variation in the power-law exponent yields a delocalization-to-localization phase transition. We investigate the periodically driven PLRBM model with the help of the static measures such as level spacing ratio and generalized inverse participation ratio and report the drive-induced multifractal to localization transition. The transport study of the periodically driven system demonstrates the transition from diffusive to logarithmically slow relaxation at dynamical localization point. Extending our analysis to the aperiodic Thue-Morse driving, we find that specific driving parameters leads to the *exact dynamical localization* in a disordered-free long-range model regardless of the long-range parameter. In the disordered case, the localized phase exhibits a long prethermal plateau followed by diffusion to an infinite temperature state, while the delocalized phase shows immediate diffusion. Additionally, we compare this with a quasi-periodic model that also undergoes a localization-delocalization transition, noting that, unlike the delocalized side of the disordered long-range model, it features a prolonged plateau followed by diffusion to the infinite temperature state.

DY 20.6 Wed 10:45 H37

Symmetry-Resolved Out-of-Time-Order Correlators with Projected Matrix Product Operators — •Martina Gisti, David Luitz, and Maxime Debertolis — Institute of Physics, University of Bonn, Nußallee 12, 53115 Bonn, Germany

Out-of-Time-Order Correlators (OTOCs) are key measures of quantum many-body chaos and information spreading. We systematically analyse OTOCs as a function of particle number for interacting spinless fermions in one dimension. With the concept of generalized operator charge, we develop a formalism for the time evolution of symmetry-projected matrix product operators, which we use to resolve the scrambling behaviour by particle number sector. Our results reveal a crossover from ballistic to diffusive dynamics at early times and a saturation regime at late times.

DY 20.7 Wed 11:00 H37

Revealing ultrafast phonon mediated inter-valley scattering through transient absorption and high harmonic spectroscopies — •Kevin Lively[1], Shunsuke Sato[2,3], Guillermo Albareda[2,4], Angel Rubio[2], and Aaron Kelly[2] — [1]Deutsches Zentrum für Luft- und Raumfahrt — [2]Max Planck Institute for the Structure and Dynamics of Matter — [3]University of Tsukuba — [4]Ideaded

Processes involving ultrafast laser driven electron-phonon dynamics play a fundamental role in the response of quantum systems in a growing number of situations of interest, as evinced by phenomena such as strongly driven phase transitions and light driven engineering of material properties. To show how these processes can be captured from a computational perspective, we simulate the transient ab-

sorption spectra and high-harmonic generation signals associated with valley selective excitation and intraband charge-carrier relaxation in monolayer hexagonal boron nitride. We show that the multitrajectory Ehrenfest dynamics approach, implemented in combination with real-time time-dependent density-functional theory and tight-binding models, offers a simple, accurate, and efficient method to study ultrafast electron-phonon coupled phenomena in solids under diverse pump-probe regimes which can be easily incorporated into the majority of real-time ab initio software packages.

15 min. break

DY 20.8 Wed 11:30 H37

Chiral basis for qubits and decay of spin-helix states — •Frank Göhmann — Fakultät für Mathematik und Naturwissenschaften, Bergische Universität Wuppertal, 42097 Wuppertal, Germany

In a recent cold-atom experiment by the Ketterle group at MIT one-dimensional spin-helix states could be prepared and their time evolution induced by the XXZ Hamiltonian could be observed. The experiment allows to adjust the anisotropy parameter of the latter. For the special case of the XX model we describe the spatio-temporal decay of a transversal spin helix explicitly. The helix pattern stays stable in space, but has a non-trivial time-dependent decay amplitude which is of scaling form and is governed by a universal function that can be represented as a semi-infinite determinant related to the discrete Bessel kernel. This representation is valid for all times, is numerically utterly efficient and allows us to obtain the long-time asymptotics of the function. Our work is a rare example of a quench that has been experimentally realized and for which the full time dependence could be calculated exactly.

V. Popkov, X. Zhang, F. Göhmann and A. Klümper, *Chiral basis for qubits and spin helix decay*, Phys. Rev. Lett. **132** (2024) 220404 (5pp)

DY 20.9 Wed 11:45 H37

Towards the chaotic melting at low energies in large systems — •Mathias Steinhuber[1], Jonas Rigo[2], Juan Diego Urbina[1], Klaus Richter[1], and Markus Schmitt[1,2] — [1]University of Regensburg, Regensburg, Germany — [2]Forschungszentrum Jülich GmbH, Peter Grünberg Institute, Quantum Control (PGI-8), Jülich, Germany

Thinking in a classical phase space picture, a many-body ground state should be localized around the minimum of the classical mean-field energy landscape with stable integrable features. But here, we investigate many-body ground states on chaotic features, as the phase space picture is actually fragile if we increase the system size and keep the quantum scale (the effective Plank constant $\hbar_{\text{eff}}$) fixed. With the new degrees of freedom, we disturb the energy landscape in the classical limit more and more such that classical chaos is present even for low energies. We show this phenomenon, called 'chaotic melting' [1,2], is indeed happening in the Bose-Hubbard system with disorder. By using neural quantum states we can push quantum calculations for ground states to large systems and find signatures of chaos at the ground state. An intriguing application for these large systems is that the Bose-Hubbard Hamiltonian with disorder is an effective model for transmon arrays which are a prime candidate for quantum computer hardware. Therefore we also gain access to quantum states describing a possible quantum computer with chaotic features.

[1] S.-D. Börner, et al. Phys. Rev. Research 6, 033128 (2024)
[2] J. Chávez-Carlos, et al. arXiv: 2310.17698 (2024)

DY 20.10 Wed 12:00 H37

Period n-tupling in driven two level systems — •Dhruv Deshmukh and Joachim Ankerhold — Institute for complex quantum systems, Ulm University, Germany

This talk presents the necessary and sufficient conditions for realizing period n-tupling phenomena in periodically driven two-level systems. For the specific case of a two-level system driven linearly by a sinusoidal drive, we numerically identify the drive parameters that enable period n-tupling. Experimental results verifying period doubling in an NV centre driven by a microwave drive, are given. Further, we show that period quadrupling drives yield pulses which are much faster than the standard (Rabi) $\pi/2$ and π pulses built from weak drives. These stronger and faster pulses can be utilized for qubit manipulation, enabling faster gates and more efficient pulse sequences. Moreover, they inspire a new strategy for constructing efficient pulses using a Floquet theory approach to optimal control. Furthermore, the drive parameters could also be set to achieve period-1 (stroboscopic) dynamical freezing. The fragility of such phenomena can be exploited for sensing applications, as illustrated with an example in magnetometry.

DY 20.11 Wed 12:15 H37

Efficient computation of cumulant evolution and full counting statistics: application to infinite temperature quantum spin chains — •Angelo Valli[1,2], Cătălin Pascu Moca[2,3], Miklós Antal Werner[1,4], Márton Kormos[1,2], Žiga Krajnik[5], and Tomaž Prosen[6] — [1]Budapest University of Technology and Economics, Muegyetem rkp. 3., 1111 Budapest, Hungary — [2]HUN-REN BME Quantum Dynamics and Correlations Research Group — [3]University of Oradea, 410087, Oradea, Romania — [4]HUN-REN Wigner Research Centre for Physics, P.O. Box 49, 1525 Budapest, Hungary — [5]New York University, 726 Broadway, New York, NY 10003, USA — [6]University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia

We propose a numerical method to efficiently compute quantum generating functions (QGF) for a wide class of observables in one-dimensional quantum systems at high temperature. We obtain high-accuracy estimates for the cumulants and reconstruct full counting statistics from the QGF. We demonstrate its potential on spin S=1/2 anisotropic Heisenberg chain, where we can reach time scales hitherto inaccessible to state-of-the-art classical and quantum simulations. Our results are in excellent agreement with a recent Google Quantum AI experiment [2] and challenge the conjecture of the Kardar-Parisi-Zhang universality for isotropic integrable quantum spin chains.

[1] A. Valli et al. arXiv:2409.14442 (2024)
[2] E. Rozenberg et al. Science 384, 48-53 (2024)

DY 20.12 Wed 12:30 H37

Machine learning approach to study the properties of ground and excited states in the 1D Bose-Hubbard model — •Yilun Gao[1], Alberto Rodríguez González[2,3], and Rudolf A. Römer[1] — [1]Department of Physics, University of Warwick, Coventry, CV4 7AL — [2]Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain — [3]Instituto Universitario de Física Fundamental y Matemáticas (IUFFyM), Universidad de Salamanca, E-37008 Salamanca, Spain

Many-body quantum interacting systems continue to play a key role in theoretical developments of modern condensed matter physics. Various numerical techniques have been used to explore the features of these many-body systems. Exact diagonalization methods, which most results going beyond ground state properties are based on, can only deal with small system sizes $L \lesssim 15$ because the Hilbert dimensions grow exponentially in L. Recently, deep learning has emerged as a numerical technique that uses strategies of artificial intelligence to predict the physics of such systems. Here we focus on the Bose-Hubbard chain and use HubbardNet [1] to investigate the physics of ground and excited states. We show that the energies and wavefunctions predicted by HubbardNet agree well with the ones calculated by exact diagonalization over a broad range of interaction strengths. We investigate the properties of the eigenstates via their finite-size generalized fractal dimensions. [1] Ziyan Zhu, et al., HubbardNet: Efficient predictions of the Bose-Hubbard model spectrum with deep neural networks, Phys. Rev. Res., **5**, 043084 (2023)

DY 20.13 Wed 12:45 H37

Entanglement Transitions in Quantum Games through Reinforcement Learning — •Giovanni Cemin[1], Marin Bukov[1], and Markus Schmitt[2,3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]University of Regensburg, Regensburg, Germany — [3]Forschungszentrum Jülich, Institute of Quantum Control, Jülich, Germany

In this research, we investigate the dynamics of entanglement in Cliord circuits by employing a reinforcement learning (RL) algorithm in competition with a random agent. The RL agent is designed to strategically place gates that decrease entanglement, while the random agent aims to increase entanglement. This interaction between the two agents results in an entanglement transition, the nature of which is induced by the level of information accessible by the RL agent. By systematically varying the information provided to the RL agent, we analyze its impact on the transition characteristics. Our findings provide new insights into the interplay between entanglement manipulation and information constraints, shedding light on the fundamental mechanisms governing quantum circuit dynamics.

DY 21: Granular Matter

Time: Wednesday 9:30–11:30 Location: H43

DY 21.1 Wed 9:30 H43

Coarsening dynamics of ferrogranular networks for different granular temperatures — •Ali Lakkis[1], Matthias Biersack[1], Oksana Bilous[2], Pedro A. Sanchez[2], Sofia S. Kantorovich[2], and Reinhard Richter[1] — [1]University of Bayreuth, Experimental Physics 5, Universitätsstr. 30, 97440 Bayreuth, Germany — [2]University of Vienna, Faculty of Physics, Kolingasse 14-16, 1090 Vienna, Austria

We are exploring in experiments the aggregation process in a shaken granular mixture of glass and magnetized steel beads, filled in a horizontal vessel. After the shaking amplitude is suddenly decreased, the magnetized beads form a transient network that coarsens in time into compact clusters [1]. Recently it has been quantified how a homogeneous magnetic field B oriented in vertical direction impedes the emergence and growth of the networks [2,3], where the mean degree $\bar{k}$ of a node serves as an order parameter. Here we explore the impact of the acceleration amplitude Γ onto the velocity distribution of the particles, their granular temperature, and the coarsening dynamics of the network, i.e. $\bar{k}(\Gamma)$.

[1] A. Kögel, R. Maretzki, E. S. Pyanzina, P. A. Sánchez, S. S. Kantorovich, R. Richter *Soft Matter*, 14 (2018) 1001.

[2] M. Biersack, A. Lakkis, R. Richter, O. Bilous, P. A. Sánchez, S. S. Kantorovich *Phys. Rev. E*, 108 (2023) 054905.

[3] A. Lakkis, M. Biersack, O. Bilous, S. S. Kantorovich, R. Richter, *J. Magn. Magn. Mater* 589 (2024) 171620.

DY 21.2 Wed 9:45 H43

Decoding diffusion: insights into ferrogranulate dynamics under competing interactions — •Oksana Bilous[1], Kirill Okrugin[1], Pedro A. Sánchez[1], Ali Lakkis[2], Matthias Biersack[2], Reinhard Richter[2], and Sofia Kantorovich[1] — [1]Computational and Soft Matter Physics, University of Vienna, Vienna, Austria — [2]Experimental Physics 5, University of Bayreuth, Bayreuth, Germany

Granulates with magnetic and non-magnetic particles exhibit unique diffusion behaviors, challenging conventional models. Using experiments and Langevin dynamics simulations, we studied their dynamics under varying magnetic fields and particle compositions.

In steady states, entropic, dipolar, and field-induced forces create distinct distributions: single particles, cluster-bound particles, and migrating particles transitioning between these states. Sub-diffusion occurs exclusively in magnetic particles within clusters, independent of external fields or concentrations. Glass particles remain non-aggregated.

Velocity distributions in high-shaking experiments validate the use of Langevin dynamics, revealing an effective temperature that links structural separations to thermodynamic scaling laws. These findings deepen our understanding of diffusion and force interactions in complex granular systems.

DY 21.3 Wed 10:00 H43

Advances and challenges in experiments with granular gases of rod-like particles — •Dmitry Puzyrev[1], Torsten Trittel[2,1], Kirsten Harth[2,1], Mahdieh Mohammadi[2], Raul Cruz Hidalgo[3], and Ralf Stannarius[2,1] — [1]Otto von Guericke University, Magdeburg, Germany — [2]Brandenburg University of Applied Sciences, Brandenburg an der Havel, Germany — [3]Univerisity of Navarra, Pamplona, Spain

Granular gases, i.e., ensembles of free-moving macroscopic particles which collide inelastically, demonstrate fascinating dynamical effects like unusual cooling properties, violation of energy equipartition, clustering, and spontaneous collective movement. Our investigation is focused on 3D microgravity experiments with ensembles of rod-like particles [1] and their mixtures. With the help of machine learning methods, we have obtained various statistical properties for the mixture of thinner and thicker rods [2]. Kinetic energy partitions and collision numbers were extracted for both vibrational heating and homogeneous cooling regimes. The systems in question pose some conundrums, such as cooling rates larger that theoretically predicted or accumulation of kinetic energy in rotational DOF which is hard to observe in the experiment. Currently, the granular gas mixture of shorter and longer rods is under analysis. Our studies are funded within by the DLR projects VICKI, EVA-II, JACKS, and KORDYGA (50WM2252, 50WK2348, 50WM2340, and 50WM2242). [1] K. Harth et al., Rev. Lett., 120, 214301 (2018) [2] Puzyrev et al., npj Microgravity, 10, 36 (2024)

DY 21.4 Wed 10:15 H43

Force networks in granular experiments: From topology to dynamics — •Lou Kondic — Department of Mathematical Sciences, NJIT, Newark, NJ, USA

We will discuss force networks that spontaneously form in particulate-based systems. These networks, most commonly known as 'force chains' in granular systems, are dynamic structures of fundamental importance for revealing the underlying causes of many physical phenomena involved in the statics and dynamics of particulate-based systems. While these networks emerging from discrete element simulations have been analyzed extensively, the analysis of networks found in physical experiments is far less developed. The presentation will focus on applications of algebraic topology, particularly persistent homology (PH) to analysis of such networks. PH allows for a simplified representation of complex interaction fields in both two and three spatial dimensions in terms of persistent diagrams (PDs) that are essentially point clouds. These point clouds could be compared meaningfully, allowing for the analysis of the underlying systems' static and dynamic properties. The presentation will focus on applications of topological data analysis of such networks found in photoelastic experiments involving an intruder moving in a stick-slip fashion through a 2D granular domain. We will particularly focus on exploring the predictability potential of the considered topological measures.

DY 21.5 Wed 10:30 H43

Crystallization dynamics in a dense sphere system — •Frank Rietz and Matthias Schröter — Max Planck Institute for Dynamics and Self-Organization (MPIDS), Göttingen

When balls are thrown into a box and subsequently agitated, they tend to arrange themselves in a denser configuration, as observed in numerous experiments. However, a barrier is typically present at random close packing, which occupies approximately 64% of the available space. The spheres remain in their densest amorphous state and do not undergo a phase transition to a denser crystalline structure with a space-filling ratio of 74%. In our experiment, we successfully surmounted this barrier and observed the emergence of crystallization events from the disordered phase [1].

Initially, we observed the formation of groups of a few spheres that fluctuated between a disordered and a nucleated state. In rare instances when the balls remained in the ordered state, further investigation was conducted into their preceding conditions. This approach enables us to address the question of why the majority of precursors are not stable, while a few of them undergo growth to become part of the larger crystals of FCC and HCP structures that never dissolve.

[1] F. Rietz, C. Radin, H. L. Swinney, M. Schröter: Nucleation in sheared granular matter, Phys. Rev. Lett. 120, 055701 (2018)

DY 21.6 Wed 10:45 H43

Vibro-fluidized beds: A systematic dynamics study utilizing Diffusing Wave Spectroscopy — •Marlo Kunzner, Christopher Mayo, Matthias Sperl, and Jan Philipp Gabriel — Deutsches Zentrum für Luft- und Raumfahrt, Köln, Deutschland

Using a granular vibration fluidised bed, we demonstrate how our granular model system of polystyrene spheres becomes denser over time through different excitation amplitudes and how the heterogeneous dynamics of the system can be resolved with diffusing wave spectroscopy(DWS) measurements. We extract mean-square displacements from the DWS correlation functions of the sinusoidal excited system and model the excitation to extract the ballistic and diffusive time constants, as well as caging sizes, depending on applied acceleration and excitation time. At low excitations we observe a sub-diffusion power law behaviour of the MSD indicating potentially a glassy system.

DY 21.7 Wed 11:00 H43

Simulation of Spherical Particles as a Granular Gas in Microgravity: A Comparison with Experimental Results

— •Mahdieh Mohammadi[1], Torsten Trittel[1], Rau'l Cruz Hidalgo[2], Dmitry Puzyrev[3], Ralf Stannarius[1], and Kirsten Harth[1] — [1]Department of Engineering, Brandeburg University of Applied Sciences, Magdeburger Str. 50, 14770 Brandenburg an der Havel,Germany — [2]Departamento de Física y Matemática Aplicada, Facultad de Ciencias , Universidad de Navarra, Pamplona, Spain — [3]MTRM, Otto von Guericke University Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

Simulation of a Granular Gas of Frictional Spherical Particles in Microgravity: A Comparison with Experimental Results

We investigate dilute granular ensembles (granular gases) of rough spheres in Microgravity, both in experiment and simulation. The experiment examines the time scale (Haff time) for energy dissipation in an initially excited granular gas, the collision statistics, and the distribution of angular and translational velocities. We aim to determine how well the experimental results can be reproduced by a DEM simulation. A variety of criteria were tested, including different restitution coefficients. One goal of the simulation is to analyze the effect of different collision parameters on the statistical properties of a granular gas. Second, we aim demonstrate how the model can effectively replicate the experimental data, with a strong correlation between the translation energy in the model and experimental data.

We thank DLR for funding in grants 50WM2242 / 50WM2340.

DY 21.8 Wed 11:15 H43

Aerodynamic origin of aeolian mineral dust emission — Sandesh Kamath[1,2], Yaping Shao[2], and •Eric Parteli[1] — [1]Fakultät für Physik, Universität Duisburg-Essen — [2]Institut für Geophysik und Meteorologie, Universität zu Köln

Atmospheric dust aerosol particles exert a substantial impact on climate, radiation balance, and various other components of the Earth's system. However, state-of-the-art climate models rely on empiric parameterization schemes for the vertical dust flux at emission. While such schemes are derived from wind-tunnel simulations on flat granular beds, environmental soils are often characterized by a spatial distribution of non-erodible elements and crusts. Indeed, the vertical flux predicted by the various schemes often differs from observations by orders of magnitude. Here we develop a numerical tool for the particle-based simulation of wind-blown transport of granular particles in the atmospheric boundary layer. Our model accurately reproduces the observed minimal threshold wind shear velocity for direct fluid entrainment over the entire broad range of particle diameters from dust to gravel particles. However, we show that a topographic effect in polydisperse beds and soils with large non-erodible elements lowers the minimal threshold for dust entrainment substantially. This finding challenges our understanding that dust is mainly ejected at sand grain-bed collisions, rather than being directly entrained by wind. Our simulations show that dust can be emitted as single grains, as dust agglomerates, or coated on the surface of sand grains, depending on dust grain size.

DY 22: Poster: Statistical Physics

Time: Wednesday 10:00–12:00 Location: P3

DY 22.1 Wed 10:00 P3

Adaptive Quasi-Monte Carlo Quadrature for Concentrated Distributions in Bayesian Inference — •Jinyi Zhou and Sebastian Matera — Fritz-Haber-Institut der MPG, Berlin

By its probabilistic formulation, Bayesian inference cures many of the problems of the traditional parameter-fitting approach, such as potential ill-posedness and the lack of reliable uncertainty estimates. However, for highly nonlinear and sensitive models, the Bayesian posterior distribution can become complex and is often concentrated in a small fraction of the parameter space. This challenges established sampling approaches, which typically perform well only for smooth distributions. We address this challenge with a novel adaptive Quasi-Monte Carlo (aQMC) quadrature method. This approach combines the highly uniform coverage of Quasi-Monte Carlo with a greedy iterative subdivision algorithm, concentrating the sampling in subdomains where the quadrature error is expected to be largest. In addition to testing on benchmark functions, we demonstrate our approach on a kinetic model from the field of catalysis. In this field, concentrated distributions are expected because, even with the best priors derived from quantum chemical calculations, uncertainties can span several orders of magnitude for the predicted catalytic response, whereas experimental data is highly accurate in comparison.

DY 22.2 Wed 10:00 P3

A novel mathematical model for the coupled binary-fluid surfactant system — •Alexandra Hardy, Steven McDonald, Abdallah Daddi-Moussa-Ider, and Elsen Tjhung — The Open University, Milton Keynes, UK

We propose a new binary-fluid surfactant mathematical model derived from modeling the surfactant molecules as dumbbells. By explicitly taking into account the molecules alignment, we gain new field variable p(r,t); the average orientation of surfactants. Combined with standard phase-field theory for binary fluids gives the system equations, which we both solve numerically and analytically. We employ a hybrid finite difference (FDM) and spectral method for the simulations. Whereas regular perturbation theory is used for the equilibrium solutions, facilitated by assuming weak coupling between surfactant and fluid. Three investigations are presented, firstly we demonstrate excellent agreement between simulation and the analytical solutions for a planar water-oil interface. Second, we prove that our model accurately predicts the decrease in surface tension with increasing surfactant concentration, in line with experiments and related theory. Finally, we show that our model is capable of preventing surfactant-laden droplet coalescence due to the added polarization field p(r,t).

DY 22.3 Wed 10:00 P3

Nonequilibrium mixture dynamics: a model for mobilities and its consequences — •Maryam Akaberian[1], Filipe C Thewes[1,3], Peter Sollich[1,2], and Matthias Krüger[1] — [1]University of Goettingen — [2]King's College London — [3]Max plank institute

extending the famous model b for the time evolution of a liquid mixture, we derive an approximate expression 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 separate species labelled by "colors". The resulting mobility matrix depends on a single dimensionless parameter, which can be determined efficiently from experimental data or numerical simulations, and includes existing standard forms as special cases. we identify two distinct mobility regimes, corresponding to collective motion and interdiffusion, 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 of general relations and analytical 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 transient fractionation.

DY 22.4 Wed 10:00 P3

Transport in classical systems with fractionally charged excitations — •Jannis Waldmann, Malte Grunert, Max Grossmann, and Erich Runge — Theoretical Physics I, Institute of Physics, Technische Universität Ilmenau, 98693 Ilmenau, Germany

Interacting systems of charged particles can show fractionally charged excitations, as is well known from the Fractional Quantum Hall Effect of electrons in a magnetic field. Fractionally charged excitations in the absence of magnetic fields have also been predicted for certain lattices with geometric frustrations, e.g. for quantum mechanical models of spinless fermions on the criss-crossed checkerboard lattice [1,2]. Here, we present result on transport properties of classical particles with nearest-neighbor repulsion on a Kagome lattice. Using Monte Carlo simulations, we study the transition from classical hopping at high temperatures to transport dominated by half-charged quasi-particles for special filling factors at low temperatures. Furthermore, we provide evidence for a residual entropy at zero temperature and Andreev-like reflection at interfaces to 'normal', i.e. not frustrated systems.

[1] Fulde et al., Ann. Phys. (Leipzig) 11 (2002) 12, 892-900
[2] Pollmann et al., J. Magn. Magn. Mater. 310 (2007), 966-968

DY 22.5 Wed 10:00 P3

Diffusion and order in mixed lattice gas of hard squares — •Piotr Nowakowski[1], Niklas Raake[2], and Ana-Sunčana Smith[2,1] — [1]Institut Ruđer Bošković, Zagreb, Croatia — [2]Friedrich–Alexander–Universität Erlangen–Nürnberg, Erlangen, Germany

We study the diffusion in a crowded environment using a model system of a lattice gas composed of hard square particles of 1×1 and 2×2 size (measured in lattice constant units) undergoing a Brownian motion on a two-dimensional square lattice. For the whole range of concentrations of both types of particles, we numerically test the accuracy and efficiency of an approximation of the motion by a persistent random walk with one or two step memory. A good agreement is observed for very low and very high concentrations of particles.

Additionally, we look at the second order phase transition from a gas phase for low densities of 2×2 particles to a columnar phase. Surprisingly, it seems that the density of large particles at which the transition occurs is not affected by the presence of smaller particles. Moreover, in columnar phase the diffusion constant can be approximated by studying a one-dimensional system.

DY 22.6 Wed 10:00 P3

The bath *remembers*: how many time-scales can we probe through recoil? — •Rupayan Saha[1], Niloyendu Roy[2], Debankur Das[1], Clemens Bechinger[2], and Matthias Krüger[1] — [1]Institute for Theoretical Physics, Georg-August-Universität Göttingen, Göttingen 37073, Germany — [2]Fachbereich Physik, Universität Konstanz, Konstanz 78457, Germany

Recoil experiments, where one studies the transient dynamics of a colloidal particle after driving it externally, are of particular importance to gain insight into the non-Markovian properties prevalent in visoelastic solvents such as micellar suspensions. In an earlier experimental study by Félix Ginot et al. [*New J. Phys. 24.12 (2022): 123013*], the *translational* recoil was found to be governed by a small number of distinct time scales, reproduced by a microscopic model using a small number of so-called bath particles. In this contribution, we investigate *orientational* recoil of such a colloidal probe in a viscoelastic fluid, which, in contrast, appears to exhibit a large number of time scales. In collaboration with experiment, we develop microscopic models to account for such observations, and develop driving protocols to dissect the various time scales involved in this process.

DY 22.7 Wed 10:00 P3

Large-deviation simulation of the coupling time distribution for the CFTP method applied to the heat bath Ising process — •Mathis Groenhagen, Alexander K. Hartmann, and Peter Werner — Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany

Coupling from the past (CFTP), introduced by Propp and Wilson [1], is a version of the Markov-chain Monte Carlo method, which is capable of generating exact samples from a finite set with a particular distribution. The performance of the CFTP method for a given application can be characterized by the distribution of the CFTP method's random running time, the *coupling time* τ, for this application.

A large-deviation Monte Carlo algorithm, as described for example in [2], is used to sample these coupling times for the application of the CFTP method to a single-spin-update heat-bath process for the ferromagnetic two-dimensional square lattice Ising model without an external field. This yields the coupling time distributions over a wide range of coupling times τ down to probability densities of 10^{-80} for different lattice sizes L and temperatures T. These results give additional numerical evidence for the analytical results shown in [3].

[1] J. Propp, D. Willson, Random Struct. Algorithms **9**, 223-252 (1996).
[2] A. K. Hartmann, Phys. Rev. E **65**, 056102 (2002).
[3] A. Collevecchio, E.M. Elçi, T.M. Garoni et al., J Stat Phys **170**, 22-61 (2018).

DY 22.8 Wed 10:00 P3

Large-deviation simulations of non-equilibrium stochastic processes — •Chinmay Chandratre — Heinrichstr. 16, 26131 Oldenburg

For N non-interacting diffusing particles in a harmonic trap where the stiffness is switched randomly between μ_1 and μ_2, the joint distribution of particle positions has been exactly computed [1]. This allowed the computation, in the limit of $N\to\infty$, of the distribution of the position M_k of the k-th rightmost particle. It is governed by a universal scaling function with finite support and tunable shape. However, the behaviour for finite numbers of particles, where the large-deviation corrections become relevant, is analytically not known. Numerically, standard algorithms fail to access the majority of the support, particularly in the tails. Here, special large-deviation algorithms [2] are used to access the tails of the distribution, reaching probabilities as small as 10^{-200} or even smaller. This includes a highly general *black-box* algorithm suitable for studying a wide range of stochastic processes.

[1] Biroli, Marco and Kulkarni, Manas and Majumdar, Satya N. and Schehr, Grégory, Phys. Rev. E **109**, 032106 (2024)
[2] A.K. Hartmann, Phys. Rev. E **89**, 052103 (2014)

DY 22.9 Wed 10:00 P3

Residual entropy of ice: A study based on transfer matrices — •De-Zhang Li[1], Yu-Jie Cen[2], Xin Wang[3], and Xiao-Bao Yang[4] — [1]Quantum Science Center of Guangdong-Hong Kong-Macao Greater Bay Area — [2]Institute of Materials Chemistry, Vienna University of Technology — [3]Department of Physics, City University of Hong Kong — [4]Department of Physics, South China University of Technology

The residual entropy of ice systems has long been a significant and intriguing issue in condensed-matter physics and statistical mechanics. This study focuses on two typical realistic ice systems: hexagonal ice (ice Ih) and cubic ice (ice Ic). We present a transfer-matrix description of the number of ice-ruled configurations for these systems. A transfer matrix M is constructed for ice Ic, where each element represents the number of ice-ruled configurations of a hexagonal monolayer under certain conditions. The product of M and M^T corresponds to a bilayer unit in the ice Ih lattice, thus forming an exact transfer matrix for ice Ih. Utilizing this, we show that the residual entropy of ice Ih is not less than that of ice Ic in the thermodynamic limit, first proved by Onsager in the 1960s. Additionally, we introduce an alternative transfer matrix M' for ice Ih based on a monolayer periodic unit. Various interesting properties of M, MM^T and M' are analyzed, including the sum of all elements, the element in the first row and first column, and the trace. Each property corresponds to the residual entropy of a certain 2-d ice model. This work provides an effective description, based on transfer matrices, for the residual entropies of various 2-d ice models.

DY 22.10 Wed 10:00 P3

Beyond mean-field kinetic theory of nematic self-propelled particles — •Benjamin Kohler, Horst-Holger Boltz, and Thomas Ihle — Institute for Physics, University of Greifswald, 17489 Greifswald, Germany

We present Landau kinetic theory and direct simulation results for systems of self-propelled particles with alignment interactions of higher-order symmetry with a particular focus on nematic couplings. Systematically expanding the BBGKY-hierarchy approximation beyond the mean-field contributions, we employ the one-sided molecular chaos assumption and an diagrammatic approach to account for higher order correlations. Our calculations yield predictions with no free parameters that are in quantitative agreement with direct agent-based simulations without being restricted to low densities.

DY 22.11 Wed 10:00 P3

Barrier crossing and rare fluctuations of active Brownian particles — •Rafael Diaz Hernandez Rojas[1], Karthik Cheruvary[1,2], and Peter Sollich[1] — [1]University of Göttingen — [2]IISER Pune

Understanding noise-induced transitions is crucial for modelling complex systems where random fluctuations can affect both the local stability and the global behaviour of a system. Noise-activated escape processes are a key instance, and were solved by Kramers long ago for barrier crossing driven by thermal noise. A natural question is how different noise sources might change the picture, in particular those postulated in active matter models. Here we study the escape problem for the paradigmatic case of an Active Brownian Particle, where the direction of the self-propulsion velocity rotates randomly on a timescale known as persistence time. Using a path integral formalism in the weak thermal noise limit. We map the problem of finding the most likely escape trajectory to the minimisation of an appropriate action. We show that optimal trajectories always consist of an initial relaxation in a tilted potential, beyond which the escape becomes genuinely activated. We apply our approach to convex potentials (to study barrier climbing by rare fluctuations) as well as potentials with multiple minima (to analyse barrier crossing). We highlight the effects of directionality induced by the self-propulsion and its non-trivial interplay

with the shape of the potential. A key result is that, for potentials with a symmetry axis along the line between two minima, activity can generate optimal escape paths that break this symmetry.

DY 22.12 Wed 10:00 P3

Rarefied gas transport in a narrow channel induced by an asymmetric wall geometry — •Constantin Rein[1], Klaus Kroy[1], and Viktor Holubec[2] — [1]Brüderstr. 16, D-04103 Leipzig — [2]V Holešovičkách 747/2, Praha 8, Czech Republic

Since the work of Knudsen on gas transport in a narrow channel, it is known that gases in the dilute limit, where the mean free path is larger than the characteristic length scale, behave different as compared to the well known finite density regime[1]. So-called Knudsen pumps use temperature differences along channel walls to induce gas particle transport along the channel[2]. Inspired by the working principle of our recently introduced active Brownian ratchet[3], we investigate numerically and analytically the gas transport phenomenon appearing in a narrow channel with specular walls, except for a diffusively reflecting triangle that protrudes into the channel from one of the walls. Despite the absence of a variation in the wall temperature, a flow emerges. It arises solely from an asymmetry of the incoming and outgoing orientational distribution. The magnitude, direction and flow pattern of the induced transport is discussed.

[1] Knudsen, M. Eine revision der Gleichgewichtsbedingung der Gase, Thermische Molekularströmung. Ann. Phys. 336,205*229 (1909). [2] Wang, X., Su, T., Zhang, W., Zhang, Z. & Zhang, S. Knudsen pumps: a review. Microsyst Nanoeng 6, 26 (2020). [3] Rein, C., Kolář, M., Kroy, K. & Holubec, V. Force-free and autonomous active Brownian ratchets(a). EPL 142, 31001 (2023).

DY 22.13 Wed 10:00 P3

Dielectric response and fluctuation-dissipation-theorem for moving bodies — •Daniele Gamba, Philip Rauch, and Matthias Krüger — Georg-August University, Göttingen

Casimir forces operate at microscopic scales and are integral to phenomena such as gecko adhesion and functionality of nano-devices. Recent research has unveiled new effects, arising from thermal and mechanical non-equilibrium, such as levitation or propulsive forces capable to driving heat engines, or novel effects tied to optically nonreciprocal materials [1,2]. In this contribution we formulate scattering theory for objects in respective motion. Specifically, we find the dielectric response and the fluctuation-dissipation theorem for arbitrary moving bodies. The dielectric response of a moving body is found to be nonlocal in space, optically non-reciprocal, and can also appear as being active. Conversely, it is possible to design an active medium that appears optically passive when in motion. Finally, we derive closed expressions for Casimir forces and heat transfer between moving bodies using scattering theory.

1. Krüger et al., Physical Review B, 2012.
2. Gelbwaser-Klimovsky et al., Physical Review Letters, 2021.

DY 22.14 Wed 10:00 P3

Criticality in non-reciprocal spin modells — •Max Hässler and Martin Weigel — TU Chemnitz, Chemnitz, Deutschland

Equilibrium statistical physics is based on symmetric, Hamiltonian interactions fulfilling Newton*s Third Law. On the other hand, active matter like bacteria or other self-propelled particles such as bird flocks violates time-reversal symmetry and is often characterized by non-reciprocal interactions. Simple models are of interest for exploring fundamental features of such systems. We examine classical spin systems including the Ising model with non-reciprocal interactions, using Monte Carlo simulations to study criticality in such models. For several systems we determine critical exponents and compare the observed universality classes to those of the corresponding reciprocal, equilibrium models.

DY 22.15 Wed 10:00 P3

Harnessing finite-size effects to gauge aging in the $2D$ Ising model — •Dustin Warkotsch[1,2], Malte Henkel[2,3], and Wolfhard Janke[1] — [1]Institut für Theoretische Physik, Universität Leipzig, Leipzig, Germany — [2]Laboratoire de Physique et Chimie Théoriques (CNRS UMR 7019), Université de Lorraine, Nancy, France — [3]Centro de Física Teórica e Computacional, Universidade de Lisboa, Lisbon, Portugal

The finite-size effects in a $2D$ Ising model with nearest-neighbor interactions are investigated at low temperature with respect to the two-time autocorrelation function $C(t,s)$, where t is the observation and s the waiting time. Using a finite-size scaling ansatz established for the spherical model linking the resulting plateaus in $C(t,s)$ to waiting time s and lattice size L, a precise and reproducible estimation for the autocorrelation exponent λ and dynamical exponent z is developed.

DY 22.16 Wed 10:00 P3

Theoretical and Experimental Advances in Non-Equilibrium Statistical Physics — •Anton Zizenko — Bolshaya Semenovskaya 38

Research helps to understand how complex systems behave when they are far from equilibrium, such as in cases of anomalous transport or phase transitions. Main achievements: Relaxation and fluctuations: Describing the behavior of systems after external influence. Critical phenomena: Studying changes in systems out of equilibrium. Entropy production: Connection with energy loss processes and irreversibility. Applications: Development of materials with new properties, improvement of thermal conductivity, and optimization of processes in chemistry and biology.

DY 22.17 Wed 10:00 P3

Frustrated Self-Assembly — •Andrey Zelenskiy and Martin Lenz — Université Paris-Saclay, CNRS, LPTMS, 91405, Orsay, France

Biomolecular self-assembly lies at the very heart of the function of living cells, where it organizes individual components into functional biological machines. The macromolecular sub-units typically correspond to proteins, whose shapes have been optimized over millions of years of evolution to ensure a proper functionality of the self-assembled structures. However, in pathological cases, proteins fail to achieve the optimal folding, which often leads to complex ill-fitting shapes. This produces geometrical incompatibility, which leads to frustrated interactions between the sub-units. Surprisingly, despite a huge variability in protein structure, such misfolded units tend to robustly self-assemble into aggregates with well-defined morphologies. Interestingly, these structures display a clear preference for slimmer topologies, such as fiber aggregates. This emergent principle of dimensionality reduction suggests that the aggregation of irregular components derives from the generic physical principles, rather than the microscopic details of the interactions.

Inspired by this idea, we model the frustrated self-assembly of ill-shaped proteins as coarse-grained anisotropic particles, whose interactions depend on their relative orientations and positions in space. This simple model successfully reproduces a hierarchy of aggregate morphologies and gives pointers to the origins of dimensionality reduction.

DY 22.18 Wed 10:00 P3

Topological and thermodynamic inference in Markov networks with observed and hidden transitions — •Alexander M. Maier[1], Udo Seifert[1], and Jann van der Meer[2] — [1]II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany — [2]Kyoto University, Graduate School of Science, Division of Physics and Astronomy, Oiwakecho 145-10, Kyoto 606-8224, Japan

The number of observable degrees of freedom is typically limited in experiments. Here, we consider discrete Markov networks in which an observer has access to a few visible transitions. We present what information, locally and globally, of such a Markov network can be inferred from the observed data. In particular, we shed light on operationally accessible information about the topology of shortest paths between visible transitions in the underlying graph and show a rule that allows us to identify potential clusters of states or exclude their existence. Moreover, we show how to estimate entropy production along an observable, coarse-grained path. Combining this with further inferable information, we propose two strategies to reconstruct a graph that is compatible with the observations and part of the original graph underlying the Markov network. This approach highlights how much information waiting-time distributions contain while also paving the way to infer thermodynamically consistent models of observed partially accessible systems.

DY 22.19 Wed 10:00 P3

Stroboscopic measurements in Markov networks: Thermodynamic inference vs. exact generator reconstruction — •Malena Thea Bauer[1], Udo Seifert[1], and Jann van der Meer[2] — [1]II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany — [2]Kyoto University, Graduate School of Science, Division of Physics and Astronomy, Oiwakecho 145-10, Kyoto

606-8224, Japan

A major goal of stochastic thermodynamics is to estimate the inevitable dissipation that accompanies particular observable phenomena in an otherwise not fully accessible system. Quantitative results are often formulated as lower bounds on the total entropy production, which capture a part of the total dissipation that can be determined based on the available data alone. In this work, we discuss the case of a continuous-time dynamics on a Markov network that is observed stroboscopically, i.e., at discrete points in time in regular intervals. We compare the standard approach of deriving a lower bound on the entropy production rate in the steady state to the less common method of reconstructing the generator from the observed propagators by taking the matrix logarithm. Provided that the timescale of the stroboscopic measurements is smaller than a critical value that can be determined from the available data, this latter method is able to recover all thermodynamic quantities like entropy production or cycle affinities and is therefore superior to the usual approach of deriving lower bounds. We conclude the comparison of both methods with numerical illustrations and a discussion of the requirements and limitations of both methods.

DY 22.20 Wed 10:00 P3

Brownian particles for unconventional computing — •Alessandro Pignedoli, Atreya Majumdar, and Karin Everschor-Sitte — Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen

Brownian particles naturally explore a system's configuration space offering an energy efficient approach to optimisation problems [1]. We demonstrate that interacting Brownian particles can solve optimisation problems [2,3] more efficiently than individual particles acting alone. This collective efficiency arises from their local interactions, which mimic the principles of swarm intelligence, where the whole systems emergent behaviour outperforms the sum of its individual components [4].

[1] C. H. Bennett, Int. J. Theor. Phys. 21, 905 (1982); [2] German Patent Application DE 10 2023 131 171, K. Everschor-Sitte, A. Pignedoli, B. Dörschel (2023); [3] German Patent Application DE 10 2023 131 706, K. Everschor-Sitte, A. Pignedoli, B. Dörschel (2023); [4] Bonabeau, et al, Oxford University Press (1999).

DY 22.21 Wed 10:00 P3

Investigating hydrogen isotopologues at cryogenic temperature in the gas, liquid, and solid phase with the T2ApIR experiment — •Alexander Marsteller, Dominic Batzler, Beate Bornschein, Lutz Bornschein, Tobias Falke, Florian Hanss, Joshua Kohpeiss, Bennet Krasch, Simone Wadle, and Robin Grössle — Karlsruher Institut für Technologie, Karlsruhe, Deutschland

Cryogenic hydrogen is of interest for a wide range of research topics such as fundamental phyiscs of liquids, astrophysics or energy storage. Tritium, the radioactive isotope of hydrogen, is of particular use as an electron source for neutrino mass measurement, and also the most promising contender for fuel in nuclear fusion for power generation. In spite of this, literature on the material properties of tritium is sparse. To improve upon this, the Tritium Absorption InfraRed Spectroscopy 2 (T2ApIR) Experiment has been designed and built at the Tritium Laboratory Karlsruhe (TLK), and is currently in its scientific commissioning phase. The main focus of this experiment is to enable the investigation of the properties of all six hydrogen isotopologues and their mixtures in the gaseous, liquid, and solid phase. This is achieved using infrared absorption spectroscopy, a polariscope setup, Raman spectroscopy, as well as a temperature and pressure measurement. On this poster I will present the T2ApIR setup as well as some of the first measurements performed with it.

DY 22.22 Wed 10:00 P3

GEANT4 based design to measure the solubility of tritiated molecules in dual phase xenon — •J.R. Braun[1], V. Aures[2], D. Forck[1], R. Grössle[1], and M. Röllig[1] — [1]Tritium Laboratory Karlsruhe, Eggenstein-Leopoldshafen, Germany — [2]Technische Universität München, Garching bei München, Germany

Detection of trace amounts of tritium is a challenging task that can be tackled using scintillation. Liquid xenon is an excellent scintillator for this purpose. A fundamental property in designing analytical systems for tritium detection is the solubility of tritiated molecules. Trace detection of tritium is critical for experiments aimed at the detection of rare physical interactions, such as the direct detection of dark matter, where naturally occurring tritium background is a challenge to overcome. Consequently, systems for both detection and removal of tritium are required. The aim of the "Tritium in Xenon" (TriXe) experiment is to determine the Henry solubility and the diffusion constant of tritiated hydrogen, water and methanes in dual-phase xenon in thermal equilibrium. TriXe employs a dual-phase chamber in which the xenon is present at operating conditions of DARWIN. By detecting VUV scintillation light with photomultipliers, the concentration of the tritiated molecules in each phase can be determined, as the concentration is proportional to the counting rate. Together with the second diffusion law, the diffusion constant can be deduced from the change in the count rate over time. The results of TriXe can be used to make qualitative and quantitative suggestions for changes in background reduction and direct tritium monitoring by cryogenic distillation.

DY 22.23 Wed 10:00 P3

Precise Estimation of the Liquid-Gas Critical Point of Water — •Mayank Sharma and Peter Virnau — Institute of Physics, Johannes Gutenberg University Mainz

We perform Molecular Dynamics simulations to investigate the liquid-gas critical point for the TIP4P water model. In the canonical (NVT) ensemble, density fluctuations are quantified and analyzed using a recently developed method [1] based on cumulant crossings. Complementary simulations in the isothermal-isobaric (NPT) ensemble yield density and energy distributions, which are mapped onto the universal 3D Ising master curve via histogram reweighting. The critical points determined by the two approaches exhibit very good agreement, highlighting the robustness of this methodology. This work establishes a reliable framework for accurately locating the critical point which is applied to test the influence of ionic conditions on the latter.

[1] J.T. Siebert et al., Phys. Rev. E (R) 98, 030601 (2018).

DY 22.24 Wed 10:00 P3

Linking Local and Macroscopic Transport Properties in Confined Electrolyte Systems: Molecular Dynamics Simulations of Water Swollen Hectorite — •Bastian Füsser, Aqsa Nisar, and Michael Vogel — Technische Universität Darmstadt, Darmstadt, Germany

In this work, we study the structural and dynamic properties of water and ions in hectoriete slit confinements using molecular dynamics simulations. Our goal is to develop a detailed understanding of the relationship between local interactions and macroscopic ion transport.

This study is part of a collaboration aiming to bridge experimental observations and theoretical models. Initially, we simulate hectorite systems as realistically as possible to compare the simulation results with experimental results. Subsequently, we investigate artificial systems to systematically analyze the role of specific parameters, such as layer charge. In doing so, we vary the interlayer spacing, solvent composition, and ion concentration.

Our goal is to develop an understanding of the relation between local interactions and dynamics with the long-range transport in confined electrolyte systems. These insights provide valuable contributions to the development of more efficient electrochemical systems, e.g., devices for energy storage and conversion.

DY 22.25 Wed 10:00 P3

Phase transitions in mesoporous solids with structural disorder — •Ali Alzaidi[1], Georgiy Baroncha[1], Dirk Enke[1], Eustathius Kikkinides[2], and Rustem Valiullin[1] — [1]Leipzig University, Leipzig, Germany — [2]Aristotle University of Thessaloniki, Thessaloniki, Greece

Phase transitions within the pore spaces of structurally disordered porous solids exhibit complex behavior with many aspect remaining poorly understood. This complexity arises from cooperative effects emerging during first-order phase transitions in pore networks. Building on the microscopic mechanisms of phase transitions occurring in single pores and between neighboring pores, we propose a statistical thermodynamic model to describe phase transitions in pore networks driven by two competing mechanisms: invasion and nucleation. We solve this model for two types of statistically disordered pore networks, linear pore chains and Bethe lattices, and correlate the results with experimental data on gas-liquid and solid-liquid equilibria in disordered porous glasses.

DY 22.26 Wed 10:00 P3

Cluster Formation and Phase Transitions Induced by Non-Reciprocal Interactions — •Thomas Richard Ullmann and

Klaus Kroy — Institute for Theoretical Physics, Leipzig University, 04103 Leipzig, Germany

The emergence of cluster formation in a two-dimensional lattice spin system driven by non-reciprocal interactions (NRI) is investigated. The development of a novel phase, characterized by clusters distinct from the quasi-long-range order (QLRO) state of the conventional XY model, is unveiled through the use of a tunable non-reciprocal parameter. Cluster formation is shown to result from particular local spin alignment due to non-reciprocal coupling, which dynamically reshapes the stability landscape of defects and topological structures. The stability of the system is analyzed using nearest-neighbour interactions and stochastic dynamics, and critical points are identified indicating phase transitions associated with clustering. The stability and evolution of defects and structures within this regime are further examined, providing insights into the interplay between non-reciprocity and the dynamics of spin textures. Broader implications for understanding collective behaviour in non-equilibrium systems are suggested, offering a framework for exploring non-reciprocity-induced phases and their stability in both physical and biological contexts.

DY 22.27 Wed 10:00 P3

Criticality and Percolation in the Off-Lattice XY Model — •Manthan Chattopadhyay, Thomas Richard Ullmann, and Klaus Kroy — Institute for Theoretical Physics, Leipzig University, 04103 Leipzig, Germany

We investigate the critical behavior of the 2D XY model with quenched positional disorder by distributing spins randomly via a spatial Poisson point process. This off-lattice approach allows us to study how quenched disorder affects phase transitions and critical phenomena, with the primary focus being the critical power-law scaling between the Kosterlitz-Thouless transition temperature T_c and the mean spin density $\langle\rho\rangle$. Using both a homogeneous coarse-graining method and percolation theory, we derive predictions for the scaling $T_c \propto (\langle\rho\rangle - \langle\rho_c\rangle)^{\zeta}$. By considering the fractal nature of the spin network near the percolation threshold, characterized by the fractal dimension D_f, the exponent is estimated. Simulation results confirm the existence of a percolation threshold with an exponent obtained from simulations similar to those of our analytic work, aligning closely with theoretical prediction. The fractal nature of the spin network near $\langle\rho_c\rangle$ is validated through the box-counting method, which is consistent with the value for 2D percolation. At high densities well above the percolation threshold, critical exponents approach expected values of the XY universality class, and the magnetization exponent β conforms to empirical observations in ultrathin magnetic films.

DY 22.28 Wed 10:00 P3

The random-field Ising model and two-phase flow in disordered media — •Peter Henning and Martin Weigel — Institut für Physik, Technische Universität Chemnitz, 09107 Chemnitz, Germany

Two-phase flow in disordered media exhibits a rich phenomenology of behaviors with manifold applications for example in oil extraction [1]. A simplified model for such flows might be provided by the zero-temperature dynamics of the random-field Ising model (RFIM) that exhibits interfaces between the pure phases that propagate through avalanches and show a roughening transition as a function of disorder strength. In the present study we focus on several properties of the interface between the phases such as its fractal geometry which can be characterized by critical exponents [2]. Furthermore we investigate abrupt changes in the propagation of the interface also known as crackling noise. By applying the RFIM to this problem we hope to gain insights into the underlying mechanisms of two-phase flow in disordered media and to provide a framework for interpreting experimental observations.

[1] R. Holtzman, M. Dentz, R. Planet and J. Ortin, *Commun Phys.* **3**, 222 (2020).
[2] B. Drossel and K. Dahmen, *Eur. Phys. J. B* **3**, 485 (1998)

DY 22.29 Wed 10:00 P3

Relating Thermodynamics and Dynamics in a Trap-like Model of Supercooled Liquids — •Simon Kellers, Anshul D. S. Parmar, and Andreas Heuer — Institute of Physical Chemistry, University of Münster, Corrensstraße 28/30, 48149 Münster, Germany

Previous studies on 2D non-network glass formers utilized the million-fold acceleration of Swap Monte-Carlo and potential energy landscape (PEL) analysis to establish a connection between deviations from Gaussian behavior of the inherent structure (IS) density function, Fragile-to-Strong-Crossover [1] and a low-energy depletion regime. In recent work [2] a specific low-temperature behavior for thermodynamical (IS-energy) and dynamical (apparent activation energy) observables could be observed with basically the same onset temperature. To understand the physical background we investigate various model IS distributions in a trap-like picture and their derived dynamic and thermodynamic properties. Indeed, for different realizations of non-Gaussianity in the PEL strong correlations between the respective onset temperatures are observed as well, suggesting indeed a strong correlation between thermodynamics and dynamics. These results contribute to our understanding of the PEL picture of glass formers.

[1] A. Heuer, *J. Condens. Matter Phys.* **2008**, 20, 373101
[2] A. D. S. Parmar, A. Heuer, **2023** *arXiv preprint arXiv:2307.10143*

DY 23: Poster: Active Matter, Soft Matter, Fluids (joint session DY/CPP)

Time: Wednesday 10:00–12:00 Location: P3

DY 23.1 Wed 10:00 P3

Enhanced stability and chaotic condensates in multi-species non-reciprocal mixtures — •Laya Parkavousi[1], Navdeep Rana[1], Ramin Golestanian[1,2], and Suropriya Saha[1] — [1]Max Planck Institute for Dynamics and Self-Organization (MPI-DS), D-37077 Göttingen, Germany — [2]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

Random non-reciprocal interactions between a large number of conserved densities are shown to enhance the stability of the system towards pattern formation. The enhanced stability is an exact result when the number of species approaches infinity and is confirmed numerically by simulations of the multi-species non-reciprocal Cahn-Hilliard model. Furthermore, the diversity in dynamical patterns increases with increasing number of components and novel steady states such as pulsating or spatiotemporally chaotic condensates are observed. Our results may help to unravel the mechanisms by which living systems self-organise via metabolism.

DY 23.2 Wed 10:00 P3

Non-reciprocal Model B and the role of mobilities and non-reciprocal interfacial forces — •Bibhut Sahoo[1] and Peter Sollich[1,2] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, 37077 Göttingen — [2]Department of Mathematics, King's College London, London

Recently the effects of non-reciprocal interactions have been widely studied in the Cahn-Hilliard model for phase separation, which is based on a magnetic analogy. Here we explore the corresponding nonreciprocal model B, as the continuum theory for non-reciprocal particle mixture. We focus on the effect of mobility matrix on topology of the phase diagram and find that changing mobility can change stability of a homogeneous state, which for reciprocal interactions would be impossible. We study spinodal dynamics in regions of instability, where static or travelling spinodal patterns can occur. This aspect is as in non-reciprocal Cahn-Hilliard but, the transitions between these instabilities are novel: they occur not via exceptional points, but via first order transitions in the length scale of the dominant unstable modes. At transition, a static and a travelling spinodal pattern with two different scales coexist. We show that more complicated transitions involving coexistence of three length scales can also occur. We finally argue, based on a nonreciprocal version of Dean's equation, that coarse graining into a model B description should lead to non-reciprocal interface terms, rather than only in the bulk as assumed in theories to date. We show that such interfacial terms can significantly enlarge the travelling spinodal regions in the phase diagram.

DY 23.3 Wed 10:00 P3

Mixed active fluids of two kinds — •Astik Haldar — Universität des Saarlandes, Saarbrücken 66123, Germany

We explore here the polar active fluids of two types, characterizing by their different aligning and propulsion strengths. We example here the fluids as the collections of moving living creatures, which could fuel itself through chemical reactions in their body . We called this system as active system, and consider their brilliant interactions. We here try to model those through considering some parameters and physically observable quantities. We find the parameters region where they have their oriented flocking as parallel or antiparallel, ordered rotating phase coherently meaning chiral phase. Our study finds the transition between the phases as saddle node as well as pitchfork bifurcation in mean field theory scheme. We find different kind of pattern formed states appear through the analytical as well as numerical study.

DY 23.4 Wed 10:00 P3

Verification, efficiency analysis and extension of the kinetic Event-Chain Algorithm — •Nico Schaffrath, Tobias Kampmann, and Jan Kierfeld — TU Dortmund, Dortmund, Germany

The novel cluster kinetic Monte-Carlo algorithm, which is based on the event-chain Monte-Carlo method, is specifically designed to simulate systems of two-dimensional self-propelled hard particles. We verify this algorithm from scratch by analysing various single-, two- and many-body systems, as well as some algorithm-specific quantities. To gain insight about the applicability of the algorithm, we compare its performance to that of an Event-Driven Brownian-Dynamics simulation. Finally, we investigate the possibility to simulate particles with soft interaction energies as well as an extension to three-dimensional systems. Regarding the latter, the phase diagram of self-propelled hard spheres is calculated.

DY 23.5 Wed 10:00 P3

AMEP: Analyzing Active Matter Simulations in Python — Kay-Robert Dormann[1], Lukas Hecht[1], Kai Luca Spanheimer[2], Aritra K. Mukhopadhyay[1], Mahdieh Ebrahimi[1], Suvendu Mandal[1], and •Benno Liebchen[1] — [1]Institut für Physik kondensierter Materie, Technische Universität Darmstadt, Darmstadt, Germany — [2]Institut für Theoretische Physik II, Heinrich-Heine-Universität, Düsseldorf, Germany

The **A**ctive **M**atter **E**valuation **P**ackage (AMEP)[1] is an easy-to-use Python library for analysing simulation data of particle-based and continuum simulations. It provides a powerful interface for handling complex analysis of large data sets from different simulation software such as LAMMPS, HOOMD-blue, GROMACS and others. A plethora of methods to calculate observables and visualise results make AMEP suitable to calculate complex observables not only for beginners but also for advanced studies of active and soft matter. AMEP is written in pure Python and leverages powerful and well-known libraries such as NumPy, SciPy and Matplotlib. Computationally expensive methods are parallelized to run on laptops and workstations as well as high-performance computing clusters.

The methods range from order parameters, cluster methods, spatial and time correlation functions to thermodynamic properties and coarse-graining methods. More information and examples are available at https://amepproject.de. AMEP can be installed via conda and pip.

[1] L. Hecht et al., arXiv:2404.16533 [cond-mat.soft]

DY 23.6 Wed 10:00 P3

Fluctuation induced network patterns in spatially correlated noise — •Sebastian Fehlinger[1], Kai Cui[2], Arooj Sajjad[1], Heinz Koeppl[2], and Benno Liebchen[1] — [1]Technische Universität Darmstadt, Institut für Physik Kondensierter Materie, Hochschulstraße 8, 64289 Darmstadt — [2]Technische Universität Darmstadt, Selbstorganisierende Systeme, Merkstraße 25, 64283 Darmstadt

Fluctuations play an important role in many fields of physics, from quantum electrodynamics to statistical mechanics. In active matter physics, so far, most works have focused on active particles that are subject to thermal fluctuations caused by the surrounding solvent. Here, we explore the collective behaviour of active particles under the influence of spatially correlated noise, that can arise, e.g., from fluctuating external fields. Therefore, we introduce a minimal model which describes the dynamics of (chiral) active particles with alignment interactions in a time-dependent Gaussian random field, that features a characteristic spatial correlation length, but no temporal correlations. Using Brownian dynamics simulations, we find, that the active particles aggregate to system spanning, percolated networks. These structures are (i) fluctuation-induced, (ii) feature local alignment of the contained particles, but no global alignment, and (iii) hardly show any coarsening. We systematically characterize the emerging patterns with tools from topological data analysis (persistence diagrams, Vietoris-Rips complexes and Betty numbers).

DY 23.7 Wed 10:00 P3

Reconfiguring hydrodynamic flow fields of active particles by light — Lisa Rohde, Tom-Hannes Hemann, Gordei Anchutkin, and •Frank Cichos — Molecular Nanophotonics Group, Peter Debye Institute for Soft Matter Physics, University Leipzig, Leipzig, Germany

Microscopic active particles propel themselves via localized energy conversion, generating hydrodynamic flow fields that govern their boundary interactions and collective behaviour. The long-range behaviour of the flow patterns classifies them as either pushers, which expel fluid along their swimming axis, or pullers, which draw fluid inward. In nature, some microorganisms can adaptively switch between pusher and puller modes in response to their environment. However, synthetic active particles are currently limited to a fixed pusher or puller configuration during fabrication, constraining our ability to study their dynamic responses to environmental cues. Here, we present a self-thermophoretic active particle that can reconfigure its flow field on demand during the experiment. This is achieved by illuminating the particle with an inhomogeneous light field shaped by a spatial light modulator. The illumination patterns create surface temperature fields inducing thermo-osmotic flow fields that propel the particle and shape the hydrodynamic interactions. By using gold nanoparticles, we trace and characterize the hydrodynamic flow field of the active particle. The ability to dynamically alter the propulsion characteristics will enable us to investigate and control their interactions and collective dynamics.

DY 23.8 Wed 10:00 P3

Brainbots as smart autonomous active particles with programmable motion — •Isa Mammadli[1], Martial Noirhomme[2], Nathan Vanesse[2], Jayant Pande[3], Ana-Sunčana Smith[1], and Nicolas Vandewalle[2] — [1]PULS, Institute for Theoretical Physics, FAU Erlangen-Nürnberg, 91058, Erlangen, Germany — [2]GRASP, Institute of Physics B5a, University of Liege, B4000 Liege, Belgium — [3]Department of Physical and Natural Sciences, FLAME University, Pune, India

We introduce an innovative robotic device designed to enable controlled motion for the study of active matter. Motion is driven by an internal vibrator, powered by a compact rechargeable battery. The system integrates acoustic and magnetic sensors alongside a programmable microcontroller. Unlike conventional vibrobots, this device employs a motor that generates horizontal vibrations, producing cycloidal trajectories that have been thoroughly characterized and optimized. Specific segments of these trajectories can be harnessed to create tailored motion patterns. As a proof of concept, we demonstrate how this versatile system can be used to develop active particles exhibiting diverse dynamics, ranging from ballistic motion to run-and-tumble diffusive behavior. Based on experimental data, we provide a simulation routine capable of replicating these trajectories, enabling the generation of extended datasets and the exploration of various input velocity configurations. This approach facilitates the determination and prescription of optimized input parameters for applications such as enhanced search strategies and precise path following.

DY 23.9 Wed 10:00 P3

Fundamental Measure Theory for active hard discs — •Jonas Buba and Michael Schmiedeberg — Theoretical Physics: Lab for Emergent Phenomena, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

The behavior of active soft particles has been studied extensively and provides a good model for many active matter systems [1]. However, some systems might be described more accurately by considering hard particles instead. While active soft particles have been described with a Phase Field Crystal approach (e.g., in [2]), a similar description of active hard particles is still lacking. In our approach we use Fundamental Measure Theory [3] to model hard discs and add activity. We expect to gain further insight into the role that the particle type can play in dynamical pattern formation.

[1] Marchetti M C, Joanny J F, Ramaswamy S, Liverpool T B, Prost J, Rao M and Simha R A. Hydrodynamics of soft active matter. Rev. Mod. Phys. 85 1143, 2013. [2] Arold D and Schmiedeberg M. Mean field approach of dynamical pattern formation in underdamped active matter with short-ranged alignment and distant anti-alignment interactions. J. Phys.: Condens. Matter 32 315403, 2020. [3] Roth R, Mecke K, and Oettel M. Communication: Fundamental measure theory for hard disks: Fluid and solid. The Journal of Chemical Physics,

136(8):081101, 2012.

DY 23.10 Wed 10:00 P3

Many-Body Dynamics of actively rolling fibers — •Alex Arnhold[1], Falko Ziebert[1,2], and Igor M Kulic[3,4] — [1]Institute for Theoretical Physics, Heidelberg University, Philosophenweg 19, 69120 Heidelberg, Germany — [2]BioQuant, Heidelberg University, Im Neuenheimer Feld 267, 69120 Heidelberg, Germany — [3]Institut Charles Sadron UPR22-CNRS, 67034 Strasbourg, France — [4]Institute Theory of Polymers, Leibniz-Institute of Polymer Research, D-01069 Dresden, Germany

Fiberboids are active filaments, capable of self-propulsion, whose dynamics were recently described in [A. Bazir, A. Baumann, F. Ziebert, I. M. Kulić, Soft Matter 2020]. So far, only single and simple 2-body dynamics of fiberboids were described.

In this work we will take a first look at the many-body dynamics. Specifically, we analyze a system of multiple nylon-rods, which when heated from below display self-propelled rolling motion. Confining the rods to roll on a single axis only, implements a simple realization of an 1D active gas. We analyze the experiments concerning clustering and nonequilibrium fluctuations and rationalize the system by simple lattice models.

DY 23.11 Wed 10:00 P3

Pumping currents and formation of flocks in 1D Ising model — •Adrian Morais Cabral and Achim Rosch — Institute for Theoretical Physics, University of Cologne, Germany

Non equilibrium systems create phenomena that are not observed in equilibrium counterparts, such as long range order in two or less dimensions and breaking of detailed balance.

We use an effective description of coupled Langevin equations to study a 1D system where an Ising order parameter is coupled to a charge density. Our assumption is that the charge current has a contribution proportional to the order parameter for the driven system. The formation of domain walls leads to a source of dynamical frustration for the charge. Driving disallows the formation of domain walls and creates flocking blob like states in addition to constant ordered and disordered states and a non moving spike phase. These solutions are studied numerically in 1D for $T \geq 0$.

At $T = 0$, we characterize existing flocking solutions and compare analytical predictions to numerical simulations which agree well with only one fitting parameter.

At finite temperatures we find new dynamics for the flocking state such as reversals similar to the active Ising model and (quasi) crossings. However, we have not yet been able to answer whether the existing ordered phase is stable in 1D.

DY 23.12 Wed 10:00 P3

Statistical Field Theory for Vicsek-type models — •Carsten Littek, Falko Ziebert, and Matthias Bartelmann — Institut für Theoretische Physik, Universität Heidelberg, Germany

Dry, aligning, dilute active matter systems display a wide range of emergent phenomena such as collective, orientationally ordered motion and phase separation. The self-propelled particles in such systems undergo noisy aligning interactions with their neighbours, but they do not exchange momentum with their surrounding. While microscopic and hydrodynamic descriptions, whose connection involves approximations, exist, their predicted behaviour - such as scaling exponents - do not match.

Here we present a microscopic statistical field theory for active Brownian particles inspired by Mazenko (2010). In our formulation we interpret the particles' two-dimensional positions and their direction of motion as Martin-Siggia-Rose (MSR) fields to obtain a path integral representation of the N-particle partition function. The MSR action is augmented by a two-particle interaction that aligns particle directions either ferromagnetically as in the Vicsek model or nematically. Similar to quantum many-body theory the benefit of our field theoretic formulation of Vicsek-type models is that it allows for developing a self-consistent perturbation theory and using renormalization techniques. Our aim is the calculation of density and velocity correlation functions in the homogeneous ordered phase and the transition into the ordered phase.

DY 23.13 Wed 10:00 P3

Coupling reaction-diffusion and locomotion in vegetative cells — •Blaž Ivšić[1], Piotr Nowakowski[2], Igor Weber[2], and Ana Sunčana Smith[3,2] — [1]Institut za fiziku, Zagreb, Croatia — [2]Institut Ruđer Bošković, Zagreb, Croatia — [3]Friedrich-Alexander- Universität, Erlangen, Germany

Cellular locomotion involves the dynamic interplay between signaling molecules, cytoskeletal activity, and membrane deformation. We present a computational model coupling protein Rac1 reactiondiffusion dynamics to cell locomotion to study vegetative state of amoeba Dictyostelium discoideum. Rac1 regulates actin polymerization via effectors like WASP and Arp2/3, while GAP modulates its activity. The model captures Rac1 dynamics on a deforming membrane, reproducing experimentally observed spatiotemporal patterns.

Cell shape is modeled using a Level-set method to track membrane dynamics, driven by forces linked to Rac1 concentration. Specifically, surface tension and normal forces (due to interaction of the cell with the substrate) proportional to Rac1 concentration influence membrane movement. The dynamics are conveyed through a fluid velocity field obtained by solving a time-dependent Stokes equation.

Our model replicates Rac1 activity patterns seen in live-cell imaging and links these patterns to cell motility. By bridging Rac1 reactiondiffusion dynamics with membrane mechanics, the model provides insights into the mechanisms of actin-driven locomotion in vegetative cells.

DY 23.14 Wed 10:00 P3

Numerical Simulation of Microplastic Permeation in Soil: from Solutes to Particles — •Hao Liu[1], Yifan Lu[2], Christina Bogner[2], Martin Lörder[1], and Stephan Gekle[1] — [1]University of Bayreuth, Bayreuth, Germany — [2]University of Cologne, Cologne, Germany

Microplastics have become significant environmental pollutants, raising concerns about their accumulation and distribution across ecosystems. Although terrestrial environments, particularly soils, often exhibit high levels of microplastic contamination, they remain relatively understudied. Microplastic transport in soil involves complex interactions among particle properties, soil structure, and fluid dynamics. Understanding mechanisms such as permeation, aggregation, and degradation is essential for effective environmental risk assessments and strategies to control microplastic pollution.

This study aims to simulate and predict soil hydraulic conductivity in microplastic-laden flows. Challenges include modeling behaviors of microplastic particles as they transport in soil with complex porous structures. High-resolution μCT scans of soil samples will provide the necessary porous media data, and simulations will be conducted using FluidX3D software. The research progresses in two phases: first, disregarding particle size and shape to analyze solute transport mechanisms; second, incorporating detailed particle properties to study transport and accumulation in pores. The goal is to model microplastic dynamics for accurate predictions of microplastic distribution in soil systems.

DY 23.15 Wed 10:00 P3

Thermo-Osmotic Flows via Anti-Stokes Cooling — •akshay kallikkunnath[1], kamil bruchal[2], pawel karpinski[2], and frank cichos[1] — [1]Molecular Nanophotonics, Peter Debye Institute for Soft Matter Physics, Faculty of Physics and Earth System Sciences, Leipzig University, Germany — [2]Faculty of Chemistry, Institute of Advanced Materials, Wroclaw University of Science and Technology, Poland

Fluidic manipulation has gained huge interest over time especially with the studies on metal nanoparticles as optically controlled heat sources generating temperature gradients. With recent developments in the synthesis of lanthanide doped crystals which can be cooled by anti-stokes cooling, we try to bring laser cooling of microcrystals to the field of fluidics. In this work, we optically trap and cool ytterbium doped NaYF4 crystals by means of anti-stokes cooling. Temperature measurements for such microscale cooled crystals are done using a technique which utilizes the phase transition of liquid crystals. With such a thermal gradient created using cold sinks in liquid, we study and provide for the first time experimental and numerical results for flows generated at solid-liquid boundary, i.e., thermo-osmotic flows. The results will provide further scope for studying dipolar thermo-osmotic and corresponding thermo-electric fields in an electrolyte solution generated by arranging optically heated and cooled particles together. Our findings can have direct implications on the study of temperature-dependent biochemical processes which inhibit with lower temperature or on response of a biological specimen to low temperature stress or may even find application in local cryotherapy.

DY 23.16 Wed 10:00 P3

Thermodynamically consistent coarsening model of crossover placement in meiosis — •Marcel Ernst[1,2] and David Zwicker[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Universität Göttingen, Germany

Crossovers play an important role in meiosis, ensuring correct segregation of homologous chromosomes and increasing genetic variability. A recently proposed model suggests that crossover placement is determined by biomolecular condensates that coarsen by exchange and diffusion of a protein along chromosomes, consistent with experiments. We here present an extended model including exchange with the nucleoplasm based on thermodynamic principles. We study theoretically and numerically the initial protein loading onto the chromosome, the droplet growth regime, the coarsening regime, and the final equilibrium. We derive scaling laws for the number of crossovers analogous to Lifshitz-Slyozov-Wagner theory in different limits. Finally, we investigate the effect of protein exchange with the nucleoplasm on crossover placement and compare the results with empirical data from several species. In conclusion, our model allows us to explain key features of meiotic crossover placement in wild type and several mutants.

DY 23.17 Wed 10:00 P3

A lattice Boltzmann approach to electrolytic multiphase flows — •Alexander Reinauer and Christian Holm — Institute for Computational Physics, Stuttgart, Germany

Simulating electrolytic multiphase flow presents significant challenges, often requiring either the detailed modeling of large numbers of particles or solving complex, nonlinear partial differential equations, such as the Navier-Stokes and Nernst-Planck equations. While particle-based simulations provide molecular details, continuum-scale approaches, including the Navier-Stokes and Nernst-Planck equations, enable the study of larger systems relevant to applications in oil recovery, biological processes, and waste treatment.

In this work, we extend the Lattice Boltzmann Method using a Color-Gradient approach to simulate immiscible two-phase flow, coupled with a custom Nernst-Planck solver for the transport of dissolved charged species. This coupling allows to incorporate the preferential solubilities of chemical species.

Our implementation, based on the pystencils/lbmpy framework, generates highly optimized code for both CPU and GPU architectures. To validate the model, we performed simulations of freely suspended liquid droplets subjected to an external electric field. Additionally, we explored contact angle models and initiated studies on applying the approach to porous media under varying conditions.

DY 23.18 Wed 10:00 P3

Coarsening of chemically active droplets — •Stefan Köstler[1,2], Yicheng Qiang[1], and David Zwicker[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany — [2]University of Göttingen, Institute for the Dynamics of Complex Systems, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Droplets formed by phase separation play an important role in cellular organization and are widely used in the design of synthetic cells and lab-on-chip devices. Droplet emulsions typically coarsen due to surface tension and hydrodynamic effects, which generally prevents precise control over droplet sizes. While coarsening can be suppressed by active chemical reactions, it is unclear how these reactions affect the coarsening dynamics and control droplet sizes. To elucidate this, we numerically simulate a binary mixture that phase separates and undergoes reactions. We find three different dynamical regimes: Small droplets are dominated by coalescence due to hydrodynamic advection, then transition to an Ostwald ripening regime dominated by diffusion, and finally exhibit size control by active chemical reactions. We predict the transition from ripening to size control analytically, and we validate our analytical estimate of the final size using a numerical minimization of a surrogate equilibrium free energy. Our theory provides an improved understanding of coarsening mechanisms, allowing to achieve greater control of emulsions.

DY 23.19 Wed 10:00 P3

Zetapotential of Gold Surfaces in a Flow Cell — •Mattis Rasenat, Peter Vogel, Marcus Witt, and Thomas Palberg — Johannes gutenberg Universität Mainz

We present a case study on the zeta-potential of gold surfaces in a continuous flow cell. The charge of dielectric surfaces is of high interest for technological applications. Therefore, we measure the zeta potential of polymer particles in a custom-made electrokinetic flowthrough cell with exchangeable sidewall. The zeta potential is measured with a super-heterodyne light scattering setup.

DY 23.20 Wed 10:00 P3

Use of molecular CO_2 for surface charge regulation — Peter Vogel[1], Markus U. Witt[1], David Beyer[2], Christian Holm[2], Muhammad Navaz Qaisrani[3], Marialore Sulpizi[4], and •Thomas Palberg[1] — [1]Inst. of Physics, JGU, Mainz, Germany — [2]Inst. of Computational Physics (ICP), U Stuttgart, Stuttgart, Germany — [3]MPI for Polymer Research, Mainz, Germany — [4]Dept. of Physics, RU Bochum, Bochum, Germany

In deionized water CO_2 forms carbonic acid which partially dissociates. Such 'realistic' salt free systems contain a significant background electrolyte concentration and a pH of 5.5. Both lowers the effective charge of dielectric surfaces. Surprisingly, the remaining molecular CO_2 causes an additional drastic decharging effect, even to complete decharging in water equilibrated against pure CO_2. Molecular CO_2 acts directly on the degree of dissociation and thus lowers the bare charge, while effective charges merely follow suit. MD simulations show the formation of a diffusely adsorbed monolayer of CO_2, which locally lowers the dielectric constant. Based on this we suggested dielectric charge regulation as novel decharging mechanism. If then salts are added to the carbonized surfaces, one finds recharging by co-ion adsorption. This process is favoured by hydrophobicity, by co-ion size and, most important, also by the amount of adsorbed CO_2. Given the ubiquity of dielectric surfaces in contact with aqueous electrolytes, this very general charge regulation processes appear to be of great fundamental and practical importance.

DY 24: Focus Session: Broken Symmetries in Statistical Physics - Dynamics of Odd Systems

In recent years, the effect of broken microscopic symmetries on emergent mesoscopic and macroscopic behavior has gained significant attention in non-equilibrium statistical physics. For example, breaking Newton's third law leads to so-called "non-reciprocal interactions" among species and gives rise to odd transport coefficients. These are primarily investigated in active systems. However, even with Newton's third law valid, odd transport can emerge, and even in equilibrium systems. In both cases, many novel phenomena have been reported over the last years, such as asymmetric clustering, oscillatory phase behavior, crowding-enhanced diffusion in in- and out-of-equilibrium systems, as well as off-diagonal correlation functions, topologically protected edge flows, and many more. With this symposium, we bring together the communities working on odd transport systems in the context of (non)equilibrium statistical physics, to stimulate discussions about the physical background and implications of such broken symmetries in transport-related phenomena.

Organized by Erik Kalz (Potsdam), Ralf Metzler (Potsdam), and Abhinav Sharma (Augsburg)

Time: Wednesday 15:00–18:30 Location: H43

Invited Talk DY 24.1 Wed 15:00 H43

Dynamics of odd and chiral active systems — •Hartmut Löwen — Heinrich-Heine-Universität Düsseldorf

After a brief introduction into "odd" systems characterized by odd viscosity, odd elasticity or odd diffusivity, we focus on *odd diffusive dynamics*. For normal diffusive systems, repulsive interactions typically reduce the dynamics as signalled by a reduction of the long-time self-diffusion coefficient. Contrarily, in odd-diffusive systems, collisions can enhance the self-diffusion due to a mutual rolling effect. We further address *active chiral particles* which break the discrete left-right symmetry in their motion. Examples include spinners, circle swimmers and particles moving on helical trajectories. We explore phase separation, glassy dynamics as well as crystallization and polymerisation in these chiral systems. New phenomena absent for achiral objects are observed including active surfactants, rotating crystallites, self-wrapping of chiral polymers and a hammering effect in supercooled fluids. Also the realization of such odd systems in granular or colloidal experiments is discussed.

DY 24.2 Wed 15:30 H43

A route from force to velocity autocorrelation in over-damped odd dynamic and its applications to the study of diffusion — Filippo Faedi and •Abhinav Sharma — University of Augsburg, Augsburg, Germany

In this work we present a derivation of the relation between the velocity and force autocorrelation in over-damped dynamic starting from the underdamped Langevin equation. Time reversal symmetries are used to simplify the noise force autocorrelation and this procedure can be applied both in the presence and in the absence of magnetic field. Thanks to these relation we can prove that off diagonal element of the force autocorrelation matrix contribute to the self diffusion coefficient in the presence of a magnetic field. In addition the result is applied to study the dynamics of two odd dimers with same and opposite charges.

DY 24.3 Wed 15:45 H43

A model collective system made of spinning micro-disks: from fundamentals to microrobot swarms — •Gaurav Gardi — Max Planck Institute fort Intelligent Systems, Stuttgart, Germany

Collective systems such as bird flocks and fish schools in nature and colloidal and robotic artificial collectives, display order in their spatiotemporal patterns. Although they are inherently out-of-equilibrium systems, the order in their patterns may share similarities with well-understood phases of matter in equilibrium and thus may be characterized by similar metrics. These phases also contain information, which is embedded in their spatiotemporal structures and can be quantified by information entropy. Although order and information are connected fundamentally in thermodynamics, their relation in collective systems is seldom explored. Here we combine the approaches of statistical mechanics and information sciences to demonstrate the order and the information in the phases of a two-dimensional (2D) small-scale robotic collective system consisting of hundreds of spinning micro-disks at the air-water interface. We design and control the balances of local interaction forces between micro-disks so that distinct globally ordered phases emerge. We relate the order and information in the global phases using concepts from statistical physics and information theory. Lastly, we design experiments to demonstrate the diverse self-organised behaviours of our system and its ability to transition to non-reciprocal regime. Overall, this talk highlights our system's capability to act as an adaptable and versatile model system for dynamic self-organisation and for development of versatile microrobot collectives.

DY 24.4 Wed 16:00 H43

Active pattern formation emergent from single-species nonreciprocity — Zhi-Feng Huang[1], •Michael te Vrugt[2], Jonas Mayer Martins[3], Raphael Wittkowski[3,4], and Hartmut Löwen[5] — [1]Department of Physics and Astronomy, Wayne State University, Detroit, Michigan 48201, USA — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany — [3]Institut für Theoretische Physik, Universität Münster, 48149 Münster, Germany — [4]Center for Soft Nanoscience, Universität Münster, 48149 Münster, Germany — [5]Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany

Nonreciprocal interactions violating Newton's third law are common in a plethora of nonequilibrium situations ranging from predator-prey systems to the swarming of birds and effective colloidal interactions under flow. Here (arXiv:2404.10093), we systematically derive a field theory for the basic case of a single-component system breaking the *actio* and *reactio* equality of force within the same species from the microscopic particle dynamics, leading to a generic continuum model termed *Active Model N*. One particular new characteristic pattern found in this model is an interwoven self-knitting "yarn" structure with a unique feature of simultaneous development of micro- and bulk phase separations. The growth dynamics of a "ball-of-wool" active droplet towards these self-knitted yarn or branched states exhibits a crossover between different scaling behaviors.

DY 24.5 Wed 16:15 H43

Dance of odd-diffusive particles: A Fourier approach — •Amelie Langer[1], Abhinav Sharma[2,3], Ralf Metzler[4], and Erik Kalz[4] — [1]University of Heidelberg — [2]University of Augsburg — [3]IPF Dresden — [4]University of Potsdam

Odd-diffusive systems are characterized by transverse responses and exhibit unconventional behaviors in interacting systems. To address the dynamical interparticle rearrangements in a minimal system, we here exactly solve the problem of two hard disklike interacting odd-diffusing particles. We calculate the probability density function (PDF) of the interacting particles in the Fourier-Laplace domain and find that oddness rotates all modes except the zeroth, resembling a mutual rolling of interacting odd particles. We show that only the first Fourier mode of the PDF, the polarization, enters the calculation of the force autocorrelation function (FACF) for generic systems with central-force interactions. An analysis of the polarization as a function of time reveals that the relative rotation angle between interacting particles overshoots before relaxation, thereby rationalizing the recently observed oscillating FACF in odd-diffusive systems. — [Langer et al., Phys. Rev. Res. 6, 043036 (2024)]

DY 24.6 Wed 16:30 H43

Odd mobility in interacting particle systems — •Erik Kalz[1], Shashank Ravichandir[2], Johannes Birkenmeier[1], Ralf Metzler[1], and Abhinav Sharma[2,3] — [1]University of Potsdam —

[2]IPF, Dresden — [3]University of Augsburg

Colloidal mobility characterises the response of an overdamped particle to an external drift. We present a many-body theory where the diffusion of particles is modelled in the presence of interactions with other colloids. A tracer particle therefore can respond to its own applied force as well as to the external drift of the host particles, an effect transferred via particle-particle interactions. We examine these direct and transferred mobilities in the context of odd systems and show that they display qualitatively different behaviours. Odd systems are characterized by a transverse — Hall-like response which occurs in addition to the ordinary, parallel response. We show that both components, the parallel and transverse are drastically altered by particle-particle interactions up to a complete reversal for each component. Our findings are validated by Brownian dynamics simulations.

Invited Talk DY 24.7 Wed 16:45 H43

Odd dynamics and universal flows of passive objects in a chiral active fluid — •Cory Hargus[1], Federico Ghimenti[1,2], Julien Tailleur[1,3], and Frédéric van Wijland[1] — [1]Laboratoire Matière et Systèmes Complexes (MSC), Université Paris Cité & CNRS (UMR 7057), 75013 Paris, France — [2]Department of Applied Physics, Stanford University, 348 Via Pueblo, Stanford, CA 94305, United States of America — [3]Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, United States of America

A passive object submerged in a chiral active fluid is imbued with odd diffusivity, odd mobility, and rotational ratchet motion. We show how these different effects are interrelated, obtaining a Langevin equation for a sufficiently heavy object, and how they are determined by the symmetry properties of the object, as well as its size and mass. Finally, spontaneous flows of the chiral active fluid around the object are understood through a multipole expansion, and connected through odd diffusion to equations of state involving only bulk fluid properties.

DY 24.8 Wed 17:15 H43

Vortex formation and odd viscosity in a chiral active fluid — •Joscha Mecke[1,2], Yongxiang Gao[1], Gerhard Gompper[2], and Marisol Ripoll[2] — [1]Institute for Advanced Study, Shenzhen University, Shenzhen, PR China — [2]Institute of Advanced Simulation, Forschungszentrum Jülich, Germany

Materials consisting of active particles with an intrinsic rotation can be considered as chiral active matter. We study a colloidal chiral active system, consisting of magnetic microrotors of diameter 0.8 μm in an externally applied rotating magnetic field. The stabilised colloids synchronously rotate with the rotating field and solely interact via steric and hydrodynamic interactions, granting odd and active stresses already at low densities and large colloidal separations. We address the system by means of experiments as well as particle based hydrodynamics simulations (MPC) of the active colloidal suspension. The rotors' transverse, anti-symmetric, and non-reciprocal interactions lead to a pair-rotation about the centre of mass and subsequently to the formation of multiscale vortices. Energy is injected on the particle level and is transported to the largest scales in the system, unless it is dissipated at a hydrodynamic damping length, a process reminiscent of turbulence, even in the absence of dominant inertial contributions. The rich phenomenology of our system additionally includes odd diffusion and enhancement of effective diffusive transport by the introduction of obstruction, directed transport by virtue of symmetry breaking at confining walls, and correlations between vorticity and density which allow for a measurement of the system's odd viscosity.

DY 24.9 Wed 17:30 H43

Chirotactic response of microswimmers in 3D chiral active fluids with odd viscosity — •Yuto Hosaka[1], Michalis Chatzittofi[1], Ramin Golestanian[1,2], and Andrej Vilfan[1,3] — [1]Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Göttingen, Germany — [2]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom — [3]Jožef Stefan Institute, 1000 Ljubljana, Slovenia

Odd viscosity is a property of chiral active fluids with broken time-reversal and parity symmetries. We show that the flow of such a fluid around a rotating axisymmetric body is exactly solvable [1]. Using this solution and the generalized Lorentz reciprocal theorem [2], we determine the orientational dynamics of microswimmers with an arbitrary surface slip velocity. Swimmers with a force-dipole moment exhibit precession around the axis of the odd viscosity. In addition, pushers show *bimodal chirotaxis*, i.e., alignment parallel or antiparallel to the axis, while pullers orbit in a plane perpendicular to it. A chiral swimmer that itself has a broken parity symmetry can exhibit *unimodal chirotaxis* and always align in the same direction. Since the chirotactic response of microswimmers is prohibited in 2D fluids, our theoretical results highlight the critical role of three-dimensionality in transport phenomena in chiral active fluids.

[1] Y. Hosaka, M. Chatzittofi, R. Golestanian, and A. Vilfan, Phys. Rev. Research **6**, L032044 (2024).

[2] Y. Hosaka, R. Golestanian, and A. Vilfan, Phys. Rev. Lett. **131**, 178303 (2023).

DY 24.10 Wed 17:45 H43

Chirality and symmetry breaking in Dictyostelium Discoideum: Probing odd dynamics in cellular behavior — •Fereydoon Taheri — IMSEAM, Heidelberg University, Heidelberg, Germany

The interplay between chirality and symmetry breaking is a fundamental aspect of many biological systems, and Dictyostelium discoideum offers a unique model to explore these phenomena. This bacteria-guzzling amoeba that lives in soil, serves as a powerful model organism for studying fundamental cellular processes such as cell-cell signalling, collective movement, and self-organization in multicellular complexes. In this study, we present an in-depth investigation into the motility patterns of D. discoideum, with a focus on the inherent chirality observed during intercellular interactions. By analyzing the off-diagonal components of the diffusion tensor, we connect this chirality to asymmetries in the velocity correlation function. These off-diagonal terms capture the coupling between orthogonal velocity components, providing a quantitative measure of non-reciprocal motion and breaking of time-reversal symmetry. Our analysis reveals that these contributions are directly linked to chiral trajectories and it is not merely a byproduct of individual behavior but plays a functional role in mediating the efficiency and directionality of cell-cell communication influencing both individual and collective behaviors during aggregation and morphogenesis.

Invited Talk DY 24.11 Wed 18:00 H43

How to model frictional contacts in sheared and active colloids — •Friederike Schmid[1], Kay Hofmann[1], Kay-Robert Dormann[2], and Benno Liebchen[2] — [1]Johannes Gutenberg Universität Mainz — [2]Technische Universität Darmstadt

In simulations of colloidal matter, frictional contacts between particles are often neglected. For spherical colloids, such an approximation may have a significant impact on the results in certain situations (e.g., colloids under shear, chiral active matter), since frictional contacts induce a coupling between translational and orientational degrees of freedoms of particles which is otherwise absent. Models for implementing frictional contacts have been proposed in the granular matter community. Owing to the large size of granular particles, these models do not include thermal noise. On the colloidal scale, thermal fluctuations are important and should be incorporated in a thermodynamically consistent manner.

In the present talk, we show how to derive the correct fluctuation-dissipation relation for frictional contacts with arbitrary - linear or nonlinear - relation between the friction force and the relative velocity at the contact point, and how to implement the corresponding stochastic force terms. Among other this results in a new generalized class of dissipative particle dynamics (DPD) thermostats with rotation-translation coupling. Possible effects of frictional contact interactions are demonstrated using the example of Poiseuille flow and motility induced phase separation in active Langevin particles.

DY 25: Statistical Physics of Biological Systems I (joint session BP/DY)

Time: Wednesday 15:00–18:00 Location: H44

DY 25.1 Wed 15:00 H44

Separating bio-condensates with surfactant-like proteins — Jannik Kindermann and •Tyler Harmon — Leibniz Institute for Polymer Research, Dresden, Germany

Biocondensates are prevalent in cells as individual compartments that separate material and reactions in space. Many condensates share similar components and/or chemical interactions that drive their formation. This would suggest that the condensate:condensate interface would have a very low surface tension compared to the condensate:solvent interfaces. Supported by in vitro results, this leads to condensate-inside-condensate or dumbbell-like architectures which minimize the condensate:solvent interfaces. However, in vitro, condensates are most often isolated in space from each other. This could play important roles such as limiting the direct flow of material from one condensate to another. The mechanism in cells that separates droplets in space is unknown.

We show using simulations and theory that proteins or other biopolymers that have surfactant like molecular architectures can separate condensates in space. We show how robust this mechanism can be with respect to condensate specificity and the expression levels of surfactant-like molecules in cells.

DY 25.2 Wed 15:15 H44

Phase separation in membranes and compartments with binding reactions — •Riccardo Rossetto, Gerrit Wellecke, and David Zwicker — Max Planck Institute for Dynamics and Self-Organization

Biological cells exhibit a hierarchical spatial organization, where various compartments and membranes harbor condensates that form by phase separation. Cells can control the emergence of these condensates by affecting the physical interactions of the involved biomolecules, thus also tuning the binding affinity to the compartments. We describe this situation with a thermodynamically-consistent kinetic model considering passive and active binding reactions to elucidate their role in controlling the occurrence and timescales of phase separation in compartments. On the one hand, binding reactions can lead to the emergence of new equilibrium phenomena, such as re-entrant phase transitions and multistability. On the other hand, they can also affect the kinetics of phase separation. As a particular example, we consider protein droplets in cellular membranes when proteins can also unbind to the cellular bulk. For fast bulk diffusion, this leads to effective nonlocal transport, which fundamentally affects droplet dynamics. For instance, the seminal Lifshitz-Slyozov coarsening can be abolished. Furthermore, active binding reactions can both accelerate or fully suppress coarsening, leading to protein patterns on the membrane. The general conclusions from our model unveil fundamental mechanisms of phase separation in membranes and compartments, and will help us explain more biological observations in the future.

DY 25.3 Wed 15:30 H44

Reconciling conflicting selection pressures in the plant collaborative non-self recognition self-incompatibility system — Amit Jangid[1], Keren Erez[1], Ohad-Noy Feldheim[2], and •Tamar Friedlander[1] — [1]Faculty of Agriculture, food and environment, The Hebrew University of Jerusalem, Rehovot, Israel — [2]Einstein Institute for Mathematics, The Hebrew University of Jerusalem, Jerusalem, Israel

Complex biological systems should often reconcile conflicting selection pressures. Specifically, in systems relying on molecular recognition, molecules should recognize particular partners, but avoid others. Here we study how such selection pressures shape the evolution of the self-incompatibility system in plants. This system inhibits self-fertilization using specific molecular recognition between proteins, expressed in the plant female and male reproductive organs. We study the impact of these opposing selection pressures on the amino acid frequencies in these proteins' recognition domain. We construct a theoretical framework enabling promiscuous recognition between proteins and multiple partners each, as found empirically, and employ stochastic simulations. We find asymmetric responses to selection affecting mostly the female, but not the male protein composition. Using large deviations theory, we well-approximate the simulated frequencies and find agreement with genomic data. Our work offers a general theoretical framework to study the impact of multiple selection pressures, applicable to additional biological systems.

DY 25.4 Wed 15:45 H44

Learning the Equilibrium Free Energy from Non-Equilibrium Steady States with Denoising Diffusion Models — •Daniel Nagel and Tristan Bereau — Institute for Theoretical Physics, Heidelberg University, 69120 Heidelberg, Germany

Estimating accurate free energy profiles is crucial for predicting the behavior of complex molecular systems. While biased molecular dynamics simulations enhance the sampling of rare events, extracting reliable free energy landscapes from these simulations remains challenging. On the other hand, stochastic thermodynamics, i.e. the concept of entropy production, provides valuable insights into the dynamics of complex systems in non-equilibrium states. However, its computational complexity, due to dependence on time-dependent probability distributions, limits its application to smaller systems.

This work presents a novel approach that combines stochastic thermodynamics with the established machine learning technique of denoising diffusion models to efficiently estimate free energy profiles from biased non-equilibrium steady states. By linking the diffusion and simulation times, we show that the training objective, known as the score, can be decomposed into a non-trivial conservative contribution from the equilibrium potential and a trivial non-conservative part determined by external driving forces. To showcase the effectiveness of our approach and its ability to learn equilibrium free energy profiles, we apply it to a driven toy model and a Martini force field molecular dynamics simulation of a small molecule biased through a lipid bilayer.

DY 25.5 Wed 16:00 H44

Multiple Pareto-optimal solutions of the dissipation-adaptation trade-off — •Jorge Tabanera-Bravo and Aljaz Godec — Max Planck Institute for Multidisciplinary Sciences, Göttingen

Adaptation refers to the ability to recover and maintain "normal" function upon perturbations of internal or external conditions and is essential for sustaining life. Biological adaptation mechanisms are dissipative, i.e. they require a supply of energy such as the coupling to the hydrolysis of ATP. Via evolution the underlying biochemical machinery of living organisms evolved into highly optimized states. However, in the case of adaptation processes two quantities are optimized simultaneously, the adaptation speed or accuracy and the thermodynamic cost. In such cases one typically faces a trade-off, where improving one quantity implies worsening the other. The solution is no longer unique but rather a Pareto set—the set of all physically attainable protocols along which no quantity can be improved without worsening another. We investigate Pareto fronts in adaptation-dissipation trade-offs for a cellular thermostat and a minimal ATP-driven receptor-ligand reaction network. We find convex sections of Pareto fronts to be interrupted by concave regions, implying the existence of distinct optimization mechanisms. We discuss the implications of such "compromise-optimal" solutions and argue that they may endow biological systems with a superior flexibility to evolve, resist, and adapt to different nvironments.

15 min. break

Invited Talk DY 25.6 Wed 16:30 H44

Centrosome positioning in cell migration and immune response — •Heiko Rieger — Department of Physics and Center for Biophysics, Saarland University, Saarbrücken, Germany

Leukocytes are the key players of the immune system in eliminating pathogen-infected or tumorigenic cells. During these processes centrosome positioning plays a crucial role for establishing cell polarization and directed migration, targeted secretion of vesicles for T cell activation and cellular cytotoxicity as well as the maintenance of cell integrity. Here, we give an overview over microtubule organization and dynamics during immune processes and present models for centrosome repositioning during the formation of the immunological synapse and during cell migration. We focus particularly on actin-myosin crosstalk, which is involved in regulating the polarity and morphology of migrating cells and encompasses mechanical interactions, mediated by crosslinkers and molecular motors, as well as cytoskeletal

regulators. Based on recent experimental results we develop a computational whole-cell model involving dynamical microtubules that interact not only mechanically but also via signaling with an active cell boundary. A rich self-organized dynamical behavior emerges, comprising varying positions of the microtubule organizing center relative to the nucleus in the migration direction, varying migration characteristics and cell shapes, and complex migratory behavior in obstacle parks and microfluidic setups. Specific dependencies of these behaviors from parameters like the average microtubule length or the cell-boundary stiffness are predicted and compared with experimental observations.

DY 25.7 Wed 17:00 H44

Modelling neuron growth dynamics and role of extra-cellular matrix — •Pritha Dolai, Federica Furlanetto, Sven Falk, Marisa Karow, and Vasily Zaburdaev — Friedrich-Alexander-Universität (FAU) Erlangen-Nürnberg, Erlangen

Biological tissues are composed of cells embedded in extracellular matrix (ECM) and extracellular fluid. We study the role of cell-matrix interactions in the context of brain tissues and the mechanism of neuron growth through this matrix. We consider two modes for the neurite growth: linear growth by tip extension and growth by the traction force at the tip of the neurite with the ECM. In the second mechanism, growth happens solely due to the interaction of the growing appendages with the particles modeling the matrix. With an agent based model we recapitulate experimentally observed neuron growth patterns in healthy neurons and neurons with mutations corresponding to a disease state performed in organoid models. In experiments, neuron growth is quantified by the dynamics of the growing tips. Additionally we compare further growth characteristics such as track length and velocity of the tip, tortuosity, and angular correlation of growth direction. Our model provides mechanistic description of the neurite growth and can be useful in describing neuronal network formation during early development.

DY 25.8 Wed 17:15 H44

Cellular morphodynamics as quantifiers for functional states of resident tissue macrophages in vivo — •Miriam Schnitzerlein[1,2], Eric Greto[3,4], Anja Wegner[3,4], Anna Möller[3,4], Oliver Aust[3,4], Oumaima Ben Brahim[3,4], Stefan Uderhardt[3,4], and Vasily Zaburdaev[1,2] — [1]Department of Biology, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) — [2]Max-Planck-Zentrum für Physik und Medizin, Erlangen — [3]Department of Medicine 3 - Rheumatology and Immunology, FAU und Universitätsklinikum Erlangen — [4]Deutsches Zentrum für Immuntherapie, FAU

Resident tissue macrophages (RTMs) perform essential tasks such as clearing cellular debris to ensure tissue homeostasis. Such actions are accompanied by morphological changes in cell shape which reflect their functional states. Until now, RTMs were mostly studied *in vitro*, even though their dynamic behaviour *in vivo* is fundamentally different.

We employed a high-resolution, intravital imaging protocol to generate dynamic data of *in vivo* peritoneal RTMs of mice. Next we built a custom image processing pipeline to assess RTM morphodynamics via a set of human-interpretable cell shape and size features. Those features could quantitatively and also qualitatively differentiate between cells in different activation states. Furthermore, we showed that unperturbed RTMs exhibit a wide range of morphodynamical phenotypes, constituting a naive morphospace of behavioural motifs. Analysing cells challenged by chemical stimulations or due to aging gave us insights into how RTMs respond and adapt to inflammatory stimuli.

DY 25.9 Wed 17:30 H44

Slimming down through frustration — •Martin Lenz — Université Paris-Saclay, CNRS, LPTMS, 91405, Orsay, France — PMMH, CNRS, ESPCI Paris, PSL University, Sorbonne Université, Université Paris-Cité, F-75005, Paris, France

In many disease, proteins aggregate into fibers. Why? One could think of molecular reasons, but here we try something more general. We propose that when particles with complex shapes aggregate, geometrical frustration builds up and fibers generically appear. Such a rule could be very useful in designing artificial self-assembling systems.

DY 25.10 Wed 17:45 H44

RNA fitness prediction with sparse physics based models - A way to explore the sequence space — •Christian Faber[1], Francesco Calvanese[2], Alexander Schug[1], and Martin Weigt[3] — [1]Forschungszentrum Jülich, Jülich, Germany — [2]Sorbonne-Université, Paris, France — [3]CNRS, Paris, France

The field of medicine uses macromolecules as a means of therapeutic intervention. Consequently, the functional attributes of these novel molecules are assuming greater significance. To complement the wet-lab experiments, we have devised a series of statistical physics based models that are capable of predicting the fitness of RNA molecules based on one- and two-point mutation scans. The experimental data were employed as training data to fit models of increasing complexity, commencing with an additive model and concluding with a model that accounts for global and local epistasis. The models were validated using fitness data from scans with higher order mutations of the wild-type. In contrast to conventional AI algorithms, the parameters of our models were designed for direct interpretation. In examining more distant sequences, we can distinguish the corresponding RNA family from random sequences with a high degree of accuracy. Moreover, the models facilitate interpretations of evolutionary processes and the significance of epistatic terms. Our model can be used to create a fitness landscape far beyond the experimental sequence space, thus identifying promising RNA molecules. Furthermore, the extension to the entire sequence space can be used as a blueprint for other molecules, providing a novel avenue for questions in biomolecular design.

DY 26: Networks, From Topology to Dynamics (joint session SOE/BP/DY)

Time: Wednesday 15:00–17:30 Location: H45

DY 26.1 Wed 15:00 H45

Self-organized transport in noisy dynamic networks — •Frederic Folz[1], Joshua Rainer Ganz[1], Kurt Mehlhorn[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Algorithms and Complexity Group, Max-Planck-Institut für Informatik, Saarland Informatics Campus, 66123 Saarbrücken, Germany

We present a numerical study of multicommodity transport in a noisy, nonlinear network. The nonlinearity determines the dynamics of the edge capacities, which can be amplified or suppressed depending on the local current flowing across an edge. We consider network self-organization for three different nonlinear functions: For all three we identify parameter regimes where noise leads to self-organization into more robust topologies, that are not found by the sole noiseless dynamics. Moreover, the interplay between noise and specific functional behavior of the nonlinearity gives rise to different features, such as (i) continuous or discontinuous responses to the demand strength and (ii) either single or multistable solutions. Our study shows the crucial role of the activation function on noise-assisted phenomena.

DY 26.2 Wed 15:15 H45

Critical properties of Heider balance on multiplex networks — •Krishnadas Mohandas, Krzysztof Suchecki, and Janusz Hołyst — Faculty of Physics, Warsaw University of Technology, Koszykowa 75, PL-00-662 Warsaw, Poland

Heider's structural balance theory has proven invaluable in comprehending the dynamics of social groups characterized by both friendly and hostile relationships. Extending this understanding to multiplex networks, we investigate Heider balance dynamics in systems where agents exhibit correlated relations across multiple layers. In our model, intralayer interactions adhere to Heider dynamics, while interlayer correlations are governed by Ising interactions, using heat bath dynamics for link signs. This framework reveals a multifaceted equilibrium landscape, with distinct phases coexisting across layers. Starting from a paradise state with positive links in all layers, increasing temperature induces a discontinuous transition to disorder, similar to single-layer scenarios but with a higher critical temperature, as verified through extended mean-field analysis and agent-based simulations.

We extend this analysis to Erdös-Rényi random graphs in noisy environments. We predict a first-order transition with a critical temperature scaling as p^2 for monolayers and follow a more complex behav-

ior for bilayers. To replicate dynamics observed in complete graphs, intralayer Heider interaction strengths must scale as p^{-2}, while interlayer interaction strengths scale as p^{-1} in random graphs. Numerical simulations confirm these analytical predictions for dense graphs.

DY 26.3 Wed 15:30 H45

Functional Motifs in Food Webs and Networks — •Melanie Habermann[1,2,3], Ashkaan Fahimipour[4], Justin Yeakel[5,6], and Thilo Gross[1,2,3] — [1]Helmholtz Institute for Functional Marine Biodiversity (HIFMB), Oldenburg, GER — [2]Alfred-Wegener Institute (AWI), Helmholtz Center for Polar and Marine Research, Bremerhaven, GER — [3]Carl-von-Ossietzky University, Institute for Chemistry and Biology of the Marine Environment (ICBM), Oldenburg, GER — [4]Florida Atlantic University, Boca Raton, FL, USA — [5]University of California Merced, Merced, CA, USA — [6]The Santa Fe Institute, Santa Fe, NM, USA

It is interesting to ask when the presence of a small subgraph in a complex network is sufficient to impose constraints on system dynamics that are independent of the broader network structure. We refer to these subgraphs as functional motifs. A classic example can be found in ecology with the competitive exclusion motif in food webs, where two species compete for the same resource without regulation. The presence of this motif precludes any stable equilibrium for the entire system. However, examples of other motifs with similarly definitive implications for system stability are rare. But our usual notion of asymptotic stability is just one among many different concepts of stability. Another one, reactivity, captures a system's immediate response to small perturbations. In this talk, we explain why functional stability motifs are rare and show that every subgraph is a functional reactivity motif. This highlights reactivity as a promising concept for exploring a vast range of networked phenomena.

DY 26.4 Wed 15:45 H45

Infecting Apex Predators Could Lead to Their Extinction — •Fakhteh Ghanbarnejad[1] and Hooman Saveh[2] — [1]SRH University of Applied Sciences, Leipzig, Germany — [2]Sharif University of Technology, Tehran, Iran

Food webs have been extensively studied from both ecological and mathematical aspects. However, most of the models studied in this area do not capture the effects of infectious diseases simultaneously. Recently, the idea of including an infectious disease in a food web model has been investigated. We study and simulate a small food chain consisting of only prey, predators, and apex predators governed by the generalized Lotka-Volterra equations and we implement the Susceptible-Infected-Recovered (SIR) model on only one of the species at a time in the food chain. To study the effects of an infectious disease on the food chain, we introduce a new parameter that increases predation rate by a factor of w and decreases hunting rate by a factor of $1/w$ for infected species. When the infectious disease is in our predators we observe that predators do not extinct under any set of parameters, however, an oscillation in its population size occurs under some circumstances which we do not observe in ordinary SIR or the generalized Lotka-Volterra equations alone. When an infectious disease is present in apex predators, oscillations in the population size do not happen; but if the set of parameters is in a specific range the apex predators may extinct. Furthermore, the chance of survival of the community, known as community persistence, increases for the predators and decreases for the apex predators.

15 min. break

DY 26.5 Wed 16:15 H45

Behavioral Heterogeneity in Disease Spread: Contrasting Effects of Prevention Strategies and Social Mixing — •Fabio Sartori[1,2] and Michael Maes[1] — [1]Chair of Sociology and Computational Social Science, Karlsruhe Institute of Technology, Karlsruhe — [2]Max Planck Institute for Dynamics and Self Organisation, Göttingen, Germany

Despite mounting evidence of behavioral heterogeneity in response to disease threats, the majority of epidemiological models assume uniform behavior across populations for mathematical tractability. We analyze three distinct mechanisms of behavioral response to disease threat: susceptibility reduction (e.g., mask-wearing), active testing, and vaccination propensity. Through extensive numerical analysis, we demonstrate that the impact of behavioral heterogeneity strongly depends on the specific mechanism involved. While heterogeneous susceptibility-reducing behaviors generally decrease disease spread, heterogeneity in testing rates and vaccination propensity typically amplifies epidemic severity. Furthermore, we show that non-homogeneous mixing patterns, particularly when correlated with behavioral traits, exacerbate disease spread across all three mechanisms. These findings reveal fundamental principles about the interplay between behavioral heterogeneity and epidemic dynamics, challenging the conventional homogeneous assumption and providing important implications for public health interventions and policy design.

DY 26.6 Wed 16:30 H45

Modelling retweet cascades using multivariate Hawkes processes on sparse networks — Alexander Kreiss[1] and •Eckehard Olbrich[2] — [1]Leipzig University, Germany — [2]Max Planck Institute for Mathematics in the Sciences, Leipzig, Germany

We apply a model that considers vertices in a network who are able to cast events, e.g. users of the online social media platform Twitter. Furthermore, there is a directed edge from vertex A to vertex B if A takes note of the events cast by B and changes its own behavior accordingly. More precisely, the model assumes that the activity of B increases the activity of A and likewise its other neighbors. This is called peer effects. However, there might also be other information, which also influences the activity of the vertices, e.g. the time of the day for social media posts. This is called global effects. We use a Hawkes model that incorporates, both, peer and global effects. This allows for the estimation of the network, that is, the influence structure while controlling for network effects or the estimation of the global effects while controlling for peer effects. The estimation is based on a LASSO strategy, which respects sparsity in the network. We apply this model to retweets on Twitter in order to reconstruct potential retweet cascades and identify accounts that are influential in sharing information.

DY 26.7 Wed 16:45 H45

Influence, Incidence, Imitators and Individualists: Comparing social influence models of protective behavior in an epidemic — •Andreas Reitenbach — Karlsruhe Institute of Technology, Karlsruhe, Germany

To manage a pandemic, it is critical that citizens voluntarily engage in protective behavior (e.g. masking or vaccinating). Voluntary behavior is subject to complex dynamics of social influence, however. While various models couple social influence dynamics with disease spreading, assumptions about how individuals influence each other differ markedly. Models assuming herding implement that agents imitate their peers. On the contrary, rational agents (individualists) engage in protective behavior when their peers are not and vice versa, potentially free-riding on others' contributions to herd immunity.

Here, I study whether and why these competing behavior models translate into different disease dynamics. Following a recent call to abstract from psychological mechanisms underlying social influence, I translate the behavior theories into influence-response functions.

I find that individualists self-coordinate on a moderate level of protection and experience long-lasting but flat incidence curves. Herding, in contrast can result in rapid cycling through waves of high incidence and strong collective efforts to mitigate. Whether herders or individualists navigate an epidemic better can depend on the population's hospital capacity and disease parameters.

DY 26.8 Wed 17:00 H45

Formalism and Physical Principles of Human Mobility and Routine — •Marlli Zambrano[1], Ashish Thampi[2], Alejandra Rincon[2], Andrzej Jarynowski[1], Steven Schulz[2], and Vitaly Belik[1] — [1]Freie Universität Berlin, Germany — [2]Machine Learning Unit, NET CHECK GmbH, Berlin, Germany

The physical principles underlying human mobility have been extensively studied in recent years, enabled by the availability of large-scale mobile phone data. While significant progress has been made in understanding general mobility patterns, capturing the dynamics of individual trajectories, specifically how mobility varies from person to person and day to day, remains challenging due to the need for highly detailed and persistent data. This study addresses this challenge by examining sequences of individual daily mobility motifs, as defined by Schneider et al., from a stochastic process perspective. The analysis uses a persistent mobile phone user panel in Berlin, with high-frequency GPS data collected over four years. Twenty motifs were identified, covering 96% of all observations. The extent of inter- and intra individual variability is explored, focusing on how motifs change within individ-

uals over time and differ between individuals in various contexts (e.g., weekends, seasons). Additionally, sequences of motifs are modeled as a stochastic process, and properties such as transition probabilities are analyzed. These findings provide deeper insights into the variability and structure of human mobility, contributing to a better understanding of individual mobility dynamics.

DY 26.9 Wed 17:15 H45

The world air transportation network: import risk of diseases, pandemic potentials and passenger routes — •Pascal Klamser[1,2], Adrian Zachariae[1,2], Benjamin Maier[3], Olga Baranov[4], and Dirk Brockmann[1,2] — [1]Technische Universität Dresden, Dresden, Germany — [2]Robert Koch-Institute, Berlin, Germany — [3]University of Copenhagen, Copenhagen, Denmark — [4]LMU München, München, Germany

Disease propagation between countries strongly depends on their effective distance, a measure derived from the world air transportation network. It reduces the complex spreading patterns of a pandemic to a wave-like propagation from the outbreak country, establishing a linear relationship to the arrival time of the unmitigated spread of a disease. However, in the early stages of an outbreak, what concerns decision-makers in countries is understanding the relative risk of active cases arriving in their country*essentially, the likelihood that an active case boarding an airplane at the outbreak location will reach them. While there are data-fitted models available to estimate these risks, accurate mechanistic, parameter-free models are still lacking.

We (i) introduce the "import risk" model, which defines import probabilities using the effective-distance framework, (ii) show its application to estimate the pandemic potential of emerging variants of COVID-19 and (iii) show that the effective distance shortest path tree, on which the "import risk" model is based on, is an extremely accurate representation of true passenger routes.

DY 27: Poster: Nonlinear Dynamics, Pattern Formation, Granular Matter

Time: Wednesday 15:00–18:00 Location: P4

DY 27.1 Wed 15:00 P4

Statistical field theory of linear spatio-temporally extended systems with multiplicative noise — •Frederik Gareis, David Aderbauer, and Michael Wilczek — Theoretische Physik I, Universität Bayreuth, Universitätsstr. 30, 95447 Bayreuth

Linear systems with multiplicative stochastic noise commonly exhibit non-Gaussian behavior in both space and time. We consider a classic example from statistical hydrodynamics, the Kraichnan model for a passive scalar convected in a stochastic velocity field. Describing such systems via a characteristic functional elegantly encodes the full statistics of the fields. However, the analysis of the resulting functional differential equations remains challenging due to the mathematical intricacy of treating second-order functional derivatives. Here, we show that a broad variety of such problems permit a solution of the functional differential equations in the form of a superposition of Gaussian functionals, even if the noise is correlated in space and time. While the linear terms, excluding the multiplicative noise, are compatible with Gaussian solutions, averaging over the multiplicative advection term introduces non-Gaussian statistics. Our approach provides a starting point for various systematic approximations such as a perturbation theory in terms of small multiplicative noise strength. On a conceptual level, it allows us to gain insights into the emergence of non-Gaussianity and intermittency, which could be relevant beyond statistical hydrodynamics.

DY 27.2 Wed 15:00 P4

Identifying Change Points in Local Air Temperature Time Series — •Fatemeh Aghaei A., Ewan Thomas Phillips, and Holger Kantz — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Global air temperature reconstructions consistently reveal a warming trend beginning around 1975, with signs of earlier increases since the early 20th century. However, regional temperature variations display complex, heterogeneous patterns that warrant deeper exploration. Understanding local climate change is critical for effective adaptation in health, agriculture, water management, and infrastructure sectors. By analyzing change points in regional warming trends, this study aims to identify periods of intensified climate change, suggesting potential historical tipping events.

In this paper, we analyze 2-meter mean daily temperature data from the ERA5 reanalysis project to track warming trends across a 1x1 degree global grid. By removing seasonal cycles, we capture temperature anomalies that reveal significant regional warming variations, with standard deviations of 4-6K depending on location. Recognizing that local warming is rarely linear, we fit two linear slopes with a change point to each grid point to capture change in warming trends. This approach produces global maps indicating the timing and magnitude of trend changes, highlighting regions where local warming has intensified.

DY 27.3 Wed 15:00 P4

Causal inference in nonlinear Covid-19 time series — •Adrian Pelcaru and Dirk Brockmann — SynoSys/TU Dresden, Dresden, Germany

Covid-19 pandemic exemplifies a spatio-temporal dynamic system which can hardly be studied by controlled experiments with "laboratory settings". Advances of computational power and availability of large datasets, causal discovery frameworks enable one to gain insight into the dynamics and couplings between observables of the system. We employ an approach rooted in state space reconstruction called Convergent Cross-Mapping (CCM) and investigate time-lagged interactions between multiple observables (temperature, interventions, human mobility, reproduction rate) of Covid-19 in 114 countries and 38 regions in Germany. Central, is the interrelationship between human mobility and reproduction rate. We find evidence for time lagged feedback couplings between human mobility and reproduction rate and identify other drivers of the reproduction rate acting either directly or indirectly through human mobility. Furthermore, we detect latitudinal dependence of coupling strengths and clear segregation of coupling strengths between historic east and west Germany. Finally, we measure dynamic tipping points of strong unidirectional forcing between human mobility and reproduction rate leading to distinct periods with characteristic dynamics. While many causal discovery frameworks and previous studies related to Covid-19 a priori reject potential feedback mechanisms between observables of a system, this study, to our knowledge, shows their existence for the first time.

DY 27.4 Wed 15:00 P4

Numerical Differentiation by Integrated Series Expansion (NDBISE) in the Context of Ordinary Differential Equation Estimation Problems — •Oliver Strebel — Angelstr. 17, D-75392 Deckenpfronn

Parameter or model estimation of ordinary differential equations (ODE) involves nowadays frequently the numerical calculation of derivatives from noisy data. This article presents a novel differentiation method (NDBISE) for such calculations. The method is benchmarked against 57 differential equations and compared to other numerical differentiation methods. The hyperparameters of all these methods are optimized in order to get a reasonable comparison. The resilience against larger noise or fewer data points per time interval is examined. It turns out that the novel method is overall superior to the other methods.

The derivative for the 42 real world data points of the Hudson bay lynx hare data (years 1900-1920) is also calculated. The results match the derivative of a curve fit to the data points astonishingly close. Using a Savitsky-Golay filter the method can be leveraged to calculate second and third order derivatives, so that the results are close to the theoretically expected outcome.

Preprint: https://doi.org/10.21203/rs.3.rs-5465961/v1

DY 27.5 Wed 15:00 P4

Origin of Frequency Clusters in Globally Coupled Phase Oscillators — •Yannick Schöhs, Nicolas Thomé, and Katharina Krischer — Technische Universität München

Frequency clusters arise in a wide range of physical, technological, and biological systems, making them a topic of significant interest both

for their practical implications and for advancing the fundamental understanding of collective dynamics. Despite their importance, their origin remains relatively unexplored. In this study, we investigate the origin of frequency clusters using a model of globally coupled phase oscillators with adaptive coupling strength. By numerically solving the differential equations for a network of 100 oscillators, the formation of up to four distinct frequency clusters was confirmed. Additionally, we conducted a bifurcation analysis on a system of four oscillators. The reduced system size allowed for an analytical bifurcation analysis of the fixed points, while the bifurcation analysis of the limit cycles was performed numerically. The results reveal that the frequency clusters originate from a homoclinic bifurcation and lose their stability through a transcritical bifurcation.

DY 27.6 Wed 15:00 P4

Optimal Control of Fractional Bistable System — •Finn Biesterfeldt[1], Andreas Rauh[2], and Alexander K. Hartmann[1] — [1]Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany — [2]Department für Informatik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany

In this work, a classic bistable system in continuous time and space and described by an ordinary integer-order differential equation is generalized to fractional order using the principles of Fractional Calculus. This results in an intrinsic memory effect and the time evolution depends on the full history of its prior configurations. In numerical simulations we observe that depending on the initial conditions, the system drives towards one of two possible fixed points of the integer order system. Initializing the system with a non-constant history leads to a complex time evolution that is highly dependent on the fractional order. In this study, the non-constant history can be interpreted as an external influence or control input that drives the system from one fixed point to the other. Influenced by the fractional order, the system may converge back to the initial fixed point. The optimal control strategy for transitioning the system from one to the other fixed point is computed numerically, revealing a dependence on the fractional order of the system.

DY 27.7 Wed 15:00 P4

Phase separation with long-range interactions — •Filipe Thewes, Yicheng Qiang, Oliver Paulin, and David Zwicker — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

It is well known that long-range interactions affect phase separation. For instance, such interactions can suppress droplet coarsening, leading to microscopic pattern with selected length scales. This effect is widely exploited by nature – from structure formation in living cells to food engineering by humans. Although the details of the transition from macroscopic phase separation to microscopic pattern formation are understood for particular systems, the general conditions for the existence of such transition remain unclear.

We propose a general field theoretical model that combines Flory's theory of phase separation and a broad class of long-range interactions. We then show that the particular details of these interactions are not relevant to the transition from macro phase separation to micro pattern formation and the most important parameter is the length-scale associated with the long-range interactions. We uncover the possibility of both first-order and second-order transitions as this length-scale crosses a threshold value, and we show how two macro phases can coexist with patterned phases. Extending these results to multi-component mixtures reveals even richer physics with multiple coexisting patterns. Our results open the possibility of systematic control of droplet sizes via different pathways, and depending on the nature of the phase transition, allow for an intricate design of pattern formation.

DY 27.8 Wed 15:00 P4

Rapid Control of Soliton Dynamics in Dual-Comb Lasers via Intra-Cavity Modulation — Julia Lang[1], •Simeon Schmitt[1], Luca Nimmesgern[1], Sarah Hutter[2], Alfred Leitenstorfer[2], and Georg Herink[1] — [1]Universität Bayreuth, Germany — [2]Universität Konstanz, Germany

We present a novel approach for controlling the timing of solitons in ultrafast mode-locked lasers, enabling the programmable synthesis of ultrashort soliton pulse patterns. The approach utilizes intracavity acousto-optic modulation in a single, harmonically mode-locked Er:fiber laser. By employing single-pulse modulation, we induce precise timing shifts between the two temporally separated, interlaced soliton combs. Through external splitting and recombination, we obtain temporally overlaying ultrashort soliton pulse-sequences that can be rapidly tuned above kHz scanning rates. We present real-time spectral interferometry data based on the dispersive Fourier transformation and corresponding simulations that resolve the underlying intersoliton motion due to ultrafast nonlinearities and laser gain dynamics. [1]

[1] J. A. Lang, S. R. Hutter, A. Leitenstorfer, and G. Herink. 'Controlling Intracavity Dual-Comb Soliton Motion in a Single-Fiber Laser'. Science Advances 10 (2024)

DY 27.9 Wed 15:00 P4

Driven BHD - onset of chaos and extendet KNH-Theorem — •Nico Fink, Viviane Bauer, and James Anglin — Physics Department and Research Center OSCAR, RPTU Kaiserslautern-Landau

When we investigate physical systems the method of description changes in dependence of scale: mechanics for individual particles but statistical methods for many. Indeed the latter should derive from mechanics, but how exactly do they relate? In other words: how does an increse in degrees od freedom influences the behaviour of a system and what kind of effects appear? In a Bose-Hubbard-dimer as a modelsystem it has been shown, that the existence of an instable fixpoint - and thereby a separatrix - can give rise to irreversibility. This is realised by adiabatically varying the potentialdifference of the sites, causing the ensemble to split into two sub-ensembles when crossing the separatrix. If the consicered meanfield Bose-Hubbard-Dimer is extendet by periodic driving a chaotic band emerges in the neighbourhood of the separatrix. We investigate the onset of chaos and the characteristic behaviour of the system in general and under the change of potential as described above.

DY 27.10 Wed 15:00 P4

QH plateau and CMB- CR near nontrivial zeros of the zeta function — •Otto Ziep — 13089 Berlin, Am Wasserturm 19a

Chaotic one-dimensional period-doublings as iterated hyperelliptic-elliptic curves are used to derive n-dim Kepler- and Coulomb singularities. Millikan experiment, quantum Hall (QH) effect, atmospheric clouds and universe clouds are self-similar of mass ratio 10^20 in a fractal zeta universe (FZU) of ripped spacetime [1]. The cosmic microwave background (CMB) and cosmic rays (CR) are explained as bifurcating ripped spacetime tensile forces below and above first Sharkovsky cycles from the tree root up to third branch. At QH CMB emissions 1...1000 GHz are predicted by the iterated binary tree cloud which are possibly already detected [2]. An interaction-independent universal vacuum density allows to predict large area correlated CR in QH-experiments which would generate local nuclear disintegration stars, enhanced damage of layers and enhanced air ionization [1]. A 10^20 self-similarity between conductivity plateau and atmospheric cloud as a superfluid having two cycles of entropy and temperature allows us to conclude that CMB and CR correlations in atmospheric layer influence global temperature and climate.

[1] The poster is based on trilogy Nucleosynthesis in Thin Layers, Fractal zeta universe and cosmic-ray-charge-cloud superfluid, The sensitive balance by O. Ziep www.epubli.de in 03/24,11/24, 01/25

[2]R. Bisognin und others, Microwave photons emitted by fractionally charged quasiparticles Nat, Commun, 2019.

DY 27.11 Wed 15:00 P4

Detection and Analysis of Topological Defgnetic Systems via Enhanced Topological Data Analysisects in Ma — •Kyra Klos[1], Karin Everschor-Sitte[2], and Friederike Schmid[1] — [1]Insitute of Physics, Johannes Gutenberg-University Mainz, Mainz, Germany — [2]Faculty of Physics & Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, Duisburg, Germany

Complex data structures, marked by multi-dimensional correlations and noise, pose significant challenges in various fields like genetics and complex dynamical quantum systems. Topological Data Analysis (TDA) [1], rooted in Persistent Homology can address this, e.g. by effective characterizing phase transitions in dynamical systems [2], enhancing large genome data analysis [3] and preprocessing data for machine learning [1]. By introducing series of graph structures into data point clouds intrinsic topological information can be extracted. Focusing on magnetic systems with topological defects, localized perturbations in the ordering field, we propose using TDA to enhance their detection and analysis. By combing conventional persistence diagram analysis with geometrical, topological, and graph-based measures applied directly to the representative clustering, our approach can provide an additional insight into the topological landscape and multi-scale nature of topological defects in magnetic systems.

[1] F. Hensel et al., Frontiers in AI, vol. 4 (2021)
[2] E. Cheng et al., IOP, vol.57 [30] (2024)
[3] S. Yara et al, Journal of Biomedical Informatics, vol. 130 (2022)

DY 27.12 Wed 15:00 P4

Force enhancement in-between suszeptible dipolar hard spheres - measurement vs computation — Andree Smolla[1], Alexandros G. Sourais[2], Sofia S. Kantorovich[3], Andreas Boudouvis[2], and •Reinhard Richter[1] — [1]Experimentalphysik 5, Universität Bayreuth, 95447 Bayreuth, Germany — [2]School of Chemical Engineering, National Technical University of Athens, Zografu Campus, 15780 Athens, Greece — [3]Computational Physics, University of Vienna, 1090 Vienna, Austria

We measure the force acting in-between two magnetized steel spheres used previously in ferrogranular model experiments [1]. When reducing the mutual distance r of the spheres the force r exceeds considerably the scaling $\sim r^{-4}$ known from dipolar hard spheres (DHS). To elucidate this deviation we measure the magnetization curves $M(H)$ of both steel spheres by means of a vibrating sample magnetometer. Their magnetization curves show a remanent magnetization plus a contribution which depends on an outer magnetic field, i.e. we have suszeptible dipolar hard spheres (SDHS). Taking into account $M(H)$ we solve the governing equations with the finite element method using FEniCS and COMSOL [2], showing a peak of the magnetization in the contact zone. The estimated force captures the enhanced force measured before.

[1] M. Biersack, A. Lakkis, R. Richter, O. Bilous, P. A. Sánchez, S. S. Kantorovich *Phys. Rev. E*, 108 (2023) 054905.

[2] Alexandros G. Sourais, Solution of magnetostatics problems with the Finite Element method using FEniCS computational platform, Master Thesis, National Technical University of Athens (2021).

DY 27.13 Wed 15:00 P4

Athermal jamming as a Manna class transition with a deterministic protocol — •Thomas Axmann, Mishael Derla, and Michael Schmiedeberg — Theoretical Physics: Lab for Emergent Phenomena, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

Athermal jamming can be understood as the transition point of an overlap reducing dynamical protocol of soft particles, where the absorbing (non-overlapping) states become inaccessible during configuration space sampling when increasing the density above the transition. The properties of this transition appear to be of $d+1$ conserved directed percolation (Manna) universality, largely independent of the details of the dynamics implemented. To demonstrate this, we present a fully deterministic protocol that remains in the Manna class. The study was conducted numerically, but we further endeavor to illuminate the situation analytically, by exploring possibilities for relating athermal jamming to directed percolation in time. We aim to determine the transition density for systems with Random Organization and Jamming and conditions to be in the Manna class.

(Note: Thomas Axmann and Mishael Derla contributed equally and will present the poster together)

DY 27.14 Wed 15:00 P4

Self-assembly of Eiffel Towers out of a ferrogranular gas — •Matthias Biersack, Ali Lakkis, and Reinhard Richter — University of Bayreuth, Experimental Physics 5, Universitätsstr. 30, 97440 Bayreuth, Germany

We are exploring in experiments a shaken granular mixture of glass and magnetized steel beads, filled in a horizontal vessel [1]. For strong shaking amplitude ($\Gamma > 3g$) we observe a ferrogranular gas. By means of a Helmholtz-pair of coils we apply a homogeneous magnetic field oriented normal to the vessel. Then we observe the self-assembly of ferrogranular crests resembling miniatur Eiffel Towers. Our findings are compared with the normal field instability emerging in a ferrofluid [2].

[1] M. Biersack, A. Lakkis, R. Richter, O. Bilous, P. A. Sánchez, S. S. Kantorovich *Phys. Rev. E*, 108 (2023) 054905.

[2] M. Cowley, R. E. Rosensweig *J. Fluid Mech.* 30 (1967) 671.

DY 28: Poster: Machine Learning, Data Science

Time: Wednesday 15:00–18:00 Location: P4

DY 28.1 Wed 15:00 P4

Thermal Neural Quantum States — •Atiye Abedinnia and Annabelle Bohrdt — Institute of theoretical physics, University of Regensburg

Finite-temperature effects play an important role in the design and optimization of quantum devices, as decoherence and noise often originate from thermal fluctuations. At finite temperatures, quantum systems are described by a statistical ensemble of states rather than a single pure state. Simulating such thermal states requires constructing the thermal density matrix, which suffers from significant computational challenges due to the exponential growth of the Hilbert space with system size. So far, purification methods(thermofield) in the context of MPS and Minimally Entangled Typical Thermal States (METTS) approach have been developed in the context of tensor networks. In this work, we propose using neural quantum states (NQS), leveraging the expressivity and scalability of transformer-based architectures to address the challenges of thermal equilibrium density matrix representation.

DY 28.2 Wed 15:00 P4

Neural Networks for Phase Recognition on Lattice Systems — •Shashank Kallappara and Martin Weigel — Institut für Physik, Technische Universität Chemnitz, Chemnitz, Germany

The Ising model undergoes a phase transition in dimensions d > 1, with its magnetisation as the order parameter. Fully connected neural networks have been shown to learn the translational invariance of the Ising model when learning its phases. This requires only a single hidden layer; analytic solutions for the same exist for highly compact networks that are constructed to obey the translational invariance automatically. Here, we show this learning of the invariance in single-layer networks of different widths and compare the networks performance in classifying the phases. We also consider a highly compact network to study the gradient descent dynamics during training over its loss landscape; we suggest a few changes to this that greatly improve its performance while preserving interpretability. Another problem we consider is percolation on a square two-dimensional lattice. Here, we leverage convolutional neural networks to detect the phase transition by training on different properties of the systems and evaluate its effectiveness.

DY 28.3 Wed 15:00 P4

optimization of the algorithm of operation of a series-parallel combined power plant — •Malika Allakulyyeva — Moscow, Russia

Over the past 15 years, work on the creation of a combined power plant (CEP) of a car has become an independent direction of modern electromechanics, characterized by its scientific problems, the specifics of performing applied research, and the expanding field of practical use of developments. This article presents the results of experimental studies of series-parallel power plants on the educational laboratory stand of the CO3221-6X model *Cars with power plants and electric vehicles* and proposes an alternative algorithm for the operation of a combined power plant.

DY 28.4 Wed 15:00 P4

Stability of Machine-Learned Interatomic Potentials in Molecular Dynamics Simulations for Complex Organic Crystals — •Martin Tritthart, Florian Linder, Lukas Legenstein, Florian Unterkofler, Martin Klotz, and Egbert Zojer — Institute of Solid State Physics, Graz University of Technology, NAWI Graz, AUSTRIA

Understanding thermal conductivity and mechanical stability is crucial for several applications of organic semiconductors (OSCs) and metal-organic frameworks (MOFs). Molecular dynamics (MD) simulations are commonly used to deduce these properties, and in recent years, machine Learned interatomic potentials (MLIPs) have been employed to enhance accuracy compared to classical force fields. MLIPs are orders of magnitude faster than ab initio methods and can achieve close to

DFT accuracy. Their accuracy,however, heavily depends on the quality of the training data. Incorrect predictions of forces and energies for atomic configurations outside the training dataset can accumulate in the MD trajectory, potentially even leading to disintegration of the (molecular) building blocks. This, however, limits long-time simulations, which are necessary to investigate thermal transport properties. To mitigate these issues and to realize a robust MLIP, reliable uncertainty estimates are needed especially for atomic configurations outside the region of the phase space sampled during training. Structures characterized by high uncertainties can then be calculated by ab initio methods and incorporated into the training dataset. This approach is tested in my contribution for prototypical MOF and OSC materials.

DY 28.5 Wed 15:00 P4

Estimating parameters for a simple tipping model from complex Earth system model output — •Jonathan Krönke[1,2], Jonathan F. Donges[1], Johan Rockström[1], Nils Bochow[3], and Nico Wunderling[1,2] — [1]Earth Resilience Science Unit, Potsdam-Insitute for Climate Impact Research, Potsdam, Germany — [2]Center for Critical Computational Studies, Goethe University Frankfurt, Frankfurt am Main, Germany — [3]Department of Mathematics and Statistics, UiT - The Arctic University of Norway, Tromsø, Norway

The existence of large-scale tipping points - thresholds where small changes can trigger drastic, often irreversible shifts in the climate system - has been a major concern of climate science in the past two decades. The ability to evaluate tipping risks using computationally manageable models is crucial to assess the resilience of the climate system and also to identify safe global warming trajectories for tipping elements. Here, we present an approach to estimate parameters of a simple tipping model based on complex Earth system model output. We validate our results by reproducing simulations that have not been used in the training process and apply the model to major earth system tipping elements such as the Greenland Ice Sheet. A simple model that captures essential behaviour of complex earth system models provides an important step towards a tipping point emulator for extensive tipping risk analyses.

DY 28.6 Wed 15:00 P4

Advanced Framework for State of Health Estimation Using Equivalent Circuit Models and Machine Learning — •Limei Jin[1,2], Franz Bereck[2], Josef Granwehr[2], Rüdiger-A. Eichel[2], and Christoph Scheurer[1,2] — [1]Fritz-Haber-Institut der MPG, Berlin — [2]IET-1, Forschungszentrum Jülich

Traditional Electrochemical Impedance Spectroscopy (EIS) techniques for characterizing a battery's behavior face several limitations, including time-consuming data collection, assumptions of system linearity, and difficulties in accurately assessing State of Charge (SoC) and State of Health (SoH). To address these challenges, we developed a robust framework for estimating SoH within a low-dimensional latent space using an autoencoder applied to raw time-domain battery data. This methodology combines synthetic training data from equivalent circuit models with machine learning techniques, specifically utilizing Chebyshev-based parameter space expansion to vary models on the SoC and SoH scale. Thereby, our framework effectively captures dynamic aging patterns while ensuring efficient data generation with minimal experimental input. Additionally, we introduced a stochastic pulse load profile to the models, which overcomes limitations of conventional frequency-based EIS measurements to better reflect real-world battery usage. This approach was initially validated on coin cell batteries in the lab, requiring only three standard spectroscopy experiments to train the framework. It will be extended to larger batteries, such as LFP batteries commonly used in automotive applications, offering scalable solutions for real-time monitoring and enhanced longevity.

DY 28.7 Wed 15:00 P4

Parameter estimation and Bayesian comparison of Langevin models describing cell motility — •Yusuke Kato[1,2], Jan Albrecht[1], Hiroshi Kori[2], Robert Grossmann[1], and Carsten Beta[1] — [1]Institute of Physics and Astronomy, University of Potsdam, Germany — [2]Department of Complexity Science and Engineering, Graduate School of Frontier Sciences, The University of Tokyo, Kashiwa, Japan

In nature, motile bacteria and eukaryotic cells exhibit spontaneous movement. This cell motility plays an essential role in both maintaining homeostasis (such as the migration of immune cells to a wound site) and the pathogenesis of certain diseases (like the aggregation of cancer cells to other organs in metastasis). Various SDE-based Langevin models have been proposed to describe cell motility.

In this study, we adopt a Bayesian approach using the likelihood approximation technique introduced in Ref. [arxiv:2411.08692] to estimate parameters of tentative first- and second-order models. In order to compare the different models, we develop a framework that ranks them using Bayesian model comparison. We test and benchmark the approach using synthetic data and subsequently apply it to time-series data of ameboid cells in order to find the best model for their ameboid motility.

DY 29: Poster: Quantum Dynamics and Many-body Systems

Time: Wednesday 15:00–18:00 Location: P4

DY 29.1 Wed 15:00 P4

Prethermalization in Open Quantum Systems — •Saptarshi Saha[1] and Rangeet Bhattacharyya[2] — [1]Institute of Theoretical Physics, Technical University of Berlin Hardenbergstr. 36, Sekr. EW 7-1, 10623 Berlin, Germany. — [2]Department of Physical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur-741246, West Bengal, India

A nearly-integrable isolated quantum many-body system reaches a quasi-stationary prethermal state before a late thermalization. Here, we revisit a particular example in the settings of an open quantum system (OQS). We consider a collection of non-interacting atoms coupled to a spatially correlated bosonic bath characterized by a bath correlation length. Our result implies that the integrability of the system depends on such a correlation length. If this length is much larger than the distance between the atoms, such a system behaves as a nearly-integrable OQS. We study the properties of the emerging prethermal state for this case, i.e. the state's lifetime, the extensive number of existing quasi-conserved quantities, the emergence of the generalized Gibbs state, and the scaling of von Neumann entropy, etc. We find that for the prethermal state, the maximum growth of entropy is logarithmic with the number of atoms, whereas such growth is linear for the final steady state, which is the Gibbs state in this case.

DY 29.2 Wed 15:00 P4

Quantum Fluctuations Approach to Many-Body Systems for Weak and Strong Coupling — •Erik Schroedter, Jan-Philip Joost, Tim Kalsberger, and Michael Bonitz — CAU, Kiel, Germany

The theoretical description of correlated quantum many-body systems out of equilibrium is a significant challenge across many areas, including condensed matter, ultracold atoms, and dense plasmas. Standard approaches used for their description include the formalisms of reduced density matrices (RDM) and nonequilibrium Green functions (NEGF). However, all approaches suited for the description of nonequilibrium systems are limited in their applicability due to their accuracy or numerical scaling. Here, we present an alternative approach based on fluctuations of field operator products and their correlation functions[1,2]. It is closely related to NEGF and RDM theory and offers an alternative approach to the GW and T-matrix approximations while exhibiting interesting complementary features, such as the capability to simulate many-body effects using stochastic methods[3]. This significantly reduces numerical complexity while preserving accuracy and allows for the description of both weakly and strongly coupled systems. Additionally, this improves numerical stability and allows for direct access to spectral two-particle quantities, such as the density response function or dynamic structure factor.

[1] E. Schroedter, et al., Cond. Matt. Phys. 25, 23401 (2022)
[2] E. Schroedter, and M. Bonitz, CTPP 202400015 (2024)
[3] E. Schroedter, et al., Phys. Rev. B 108, 205109 (2023)

DY 29.3 Wed 15:00 P4

Dynamics of topological defects in non-equilibrium magnon condensates — •Alexander Wowchik and Achim Rosch — Institut für Theoretische Physik, Universität zu Köln, 50937 Cologne,

Germany

It has been demonstrated in the past that thin Yttrium Iron Garnet (YIG) films exhibit condensation of magnons in two degenerate minima of the band structure when driven with microwave radiation in the presence of an external magnetic field.

This creates a non-equilibrium many-body system at room temperature, which provides a framework to study the dynamics of self-propelling units that violate the conservation of energy, analogous to models of active matter.

We examine the behaviour of a single topological vortex defect in the magnon condensate after explicitly breaking the spatial inversion symmetry that restricts the dynamics of the ideal system. This is motivated by an asymmetric configuration in the typical experimental setup.

The study is performed by solving the driven-dissipative Gross-Pitaevskii equation for the emergent condensate degrees of freedom. It is derived from the semi-classical limit of an effective U(1) x O(2) symmetric Keldysh field theory.

The results are compared to micromagnetic simulations of the underlying ferromagnetic spin-Hamiltonian.

DY 29.4 Wed 15:00 P4

Wiedemann-Franz law violation domain for graphene and nonrelativistic systems — •Thandar Zaw Win, Cho Win Aung, Gaurav Khandal, and Sabyasachi Ghosh — Department of Physics, Indian Institute of Technology Bhilai, Kutelabhata, Durg 491002, India

Systematic and comparative research on Lorenz ratios for graphene and nonrelativistic systems has been studied to identify their Wiedemann-Franz law violation domain. Fermi energy and tem- perature are the main governing parameters for deciding the values of the Lorenz ratio, which is basically thermal conductivity divided by electrical conductivity times temperature times Lorenz number. Metals as three-dimensional nonrelativistic electron gas locate at higher Fermi energy by temperature domain, where Lorenz ratio remains one. Hence, they obey the Wiedemann-Franz law. By creating higher doping in a two-dimensional graphene system, one can again reach a higher Fermi energy by temperature domain and get a constant Lorenz ratio. For both graphene and nonrelativistic systems, the Lorenz ratio goes below one if we go lower Fermi energy by temperature domain, which is possible for the graphene system by decreasing the doping concentration. Experimentally observed greater than one Lorenz ratio in this lower Fermi energy by temperature domain or Dirac fluid domain indicates that non-fluid expressions of Lorenz ratio should be replaced by fluid-type expressions. We have noticed a divergent trend of Lorenz ratio in the Dirac fluid domain using its fluid-type expression, and it matches with the trend of experimental data.

DY 29.5 Wed 15:00 P4

Anisotropic Dicke model in the presence of periodic and quasiperiodic drive — •Pragna Das[1], Devendra Singh Bhakuni[2], Lea F. Santos[3], and Auditya Sharma[4] — [1]Department of Theoretical Physics, J. Stefan Institute, SI-1000 Ljubljana, Slovenia — [2]The Abdus Salam International Centre for Theoretical Physics (ICTP), Strada Costiera 11, 34151 Trieste, Italy — [3]Department of Physics, University of Connecticut, Storrs, Connecticut 06269, USA — [4]Indian Institute of Science Education and Research, Bhopal 462066, India

We analyze the anisotropic Dicke model in the presence of a periodic drive and under a quasiperiodic drive. We show that under a quasiperiodic Fibonacci (Thue-Morse) drive, the system features a prethermal plateau that increases as an exponential (stretched exponential) with the driving frequency before heating to an infinite-temperature state. In contrast, when the model is periodically driven, the dynamics reaches a plateau that is not followed by heating. In either case, the plateau value depends on the energy of the initial state and on the parameters of the undriven Hamiltonian. Surprisingly, this value does not always approach the infinitetemperature state monotonically as the frequency of the periodic drive decreases. We also show how the drive modifies the quantum critical point and discuss open questions associated with the analysis of level statistics at intermediate frequencies.

DY 29.6 Wed 15:00 P4

Enhancing quantum metric using periodic driving — •Dhruv Tiwari, Roderich Moessner, and Johannes S. Hofmann — Max Planck Institute for Physics of Complex Systems, Nöthnitzer Str., 01187, Dresden

The advent of periodically driven systems has revolutionized modern condensed matter physics by offering two transformative opportunities. First, they allow the realization of nonequilibrium analogs of well-established equilibrium phases under highly tunable conditions. Second, they facilitate the emergence of novel phases with no equilibrium counterparts. In this work, we focus on the former, leveraging the tunable parameters of periodically driven systems to enhance the quantum metric in flat-band systems. The quantum metric, a fundamental geometric property of the band structure, plays a critical role in the formation of superconductivity in flat-band systems with attaractive density interactions. Here, we present preliminary results demonstrating how the interplay between periodic driving and electron correlations can amplify the quantum metric, leading to enhanced physical properties compared to the equilibrium case. These findings pave the way for designing engineered quantum states and exploring the interplay of nonequilibrium dynamics and strong correlations in flat-band systems.

DY 29.7 Wed 15:00 P4

Phase-space correlations of resonances in chaotic scattering systems — •Florian Lorenz and Roland Ketzmerick — TU Dresden, Institute of Theoretical Physics, Dresden, Germany

Chaotic eigenfunctions in closed quantum systems show strong phase-space correlations along classical trajectories [1]. These correlations extend across the whole system size and persist in the semiclassical limit [1]. We here expand this analysis to open quantum maps and scattering systems, in particular the kicked rotor and a dielectric cavity. To this end, we generalize a time-dependent correlator suggested in [1] to the case of an open system using left- and right resonance states. For quantum maps we find similar results as for closed systems. For the dielectric cavity the correlations propagate as wave fronts through the system.

[1] H. Schanz, Phase-Space Correlations of Chaotic Eigenstates, Phys. Rev. Lett. **94**, 134101 (2005).

DY 29.8 Wed 15:00 P4

Generalizing Quantum Question Equalities: Measurement Order Effects in Cognitive Decision-Making — •Michael Schnabel — Vanderbilt University, Nashville, TN (USA)

The quantum question (QQ) equality, formulated by Wang and Busemeyer [1] provides a non-parametric prediction for the pairwise probabilities of binary questions represented by two non-commutative observables A and B and their associated projection operators P_A and P_B. The QQ equality has played a significant role in the development of the quantum cognition research program as it enabled testing whether the order effects observed in a representative dataset of questionnaires could be represented as quantum interference within a quantum probability framework, providing compelling evidence [2]. Here, I formulate QQ equalities that extend beyond pairwise comparisons and binary outcomes, accommodating situations with $N \geq 3$ questions under the assumption that measurements are represented by idempotent projection operators. These results may be applicable to low-dimensional discrete quantum systems, such as qubits and qtrits, and potentially provide a generalizable framework for understanding order effects in cognitive decision-making across various domains of questionnaire design and experimental psychology. [1] Wang and Busemeyer. *Top.Cogn.Sci.,* 5(4), (2013). [2] Wang, Solloway, Shiffrin, and Busemeyer.*PNAS,* 111(26), (2014).

DY 29.9 Wed 15:00 P4

Subordination approach for derivation of generalized quantum models in non-relativistic and relativistic cases — •Irina Petreska[1], Trifce Sandev[1,2,3], and Alexander Iomin[4,5] — [1]Ss. Cyril and Methodius University in Skopje, Macedonia — [2]Macedonian Academy of Sciences and Arts, Skopje, Macedonia — [3]Korea University, Seoul, Korea — [4]Solid State Institute, Technion, Haifa, Israel — [5]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The generalized Schrödinger equation and the generalized Klein-Gordon equation are derived by applying the subordination approach to conventional quantum mechanics. The special cases of the fractional Schrödinger equation and the fractional Klein-Gordon equation are adequately introduced. Additionally, the subordination approach is also applied to derive the special case of the generalized Dirac equation for spin 1/2 particles and the directions for future research are discussed.

It is evident that according to the subordination approach, the time fractional derivatives in quantum mechanics, including the relativistic one, can be related to the Lévy stable processes in time.

[1] T. Sandev, I. Petreska, A. Iomin, From standard to generalized Schrödinger and Klein-Gordon equations: Subordination approach, *submitted* (2024).

DY 30: Quantum-Critical Phenomena (joint session TT/DY)

Time: Thursday 9:30–12:45 Location: H31

DY 30.1 Thu 9:30 H31

Missing Spectral Weight in a Paramagnetic Heavy-Fermion System — •Debankit Priyadarshi[1], Jingwen Li[1], Chia-Jung Yang[1], Ulli Pohl[2], Oliver Stockert[3], Hilbert von Löhneysen[4], Shovon Pal[5], Manfred Fiebig[1], and Johann Kroha[2,6] — [1]ETH Zurich, Switzerland. — [2]University of Bonn, Germany — [3]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [4]Karlsruhe Institute of Technology, Germany — [5]NISER, HBNI, Jatni, India. — [6]University of St. Andrews, UK

Time-resolved terahertz spectroscopy (THz-TDS) has proven to be a powerful method to study the correlation dynamics in many-body systems, particularly heavy-fermions [1]. The competition between the Kondo screening effect and the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction in these materials drives a quantum phase transition (QPT) between a magnetically ordered and a liquid-like ground state of heavy Kondo quasiparticles. These quasiparticles disintegrate near a quantum critical point (QCP). Using THz-TDS, we report a suppression in the quasiparticle spectral weight in $CeCu_{6-x}Au_x$ on the antiferromagnetic side of the QPT at temperatures much higher than the Neel temperature, which has a different origin from the suppression at QCP [2]. We study the paramagnetic phase of $CeCu_{6-x}Au_x$ with x = 0.2, 0.3, and 0.5 samples, and show that the suppression results from a quantum frustration effect induced by the temperature-independent RKKY interaction, which may influence material properties at QCP.
[1] C. Wetli *et al.*, Nat. Phys. 14, 1103 (2018);
[2] J.Li *et al.*, arXiv:2408.07345 (2024).

DY 30.2 Thu 9:45 H31

Terahertz Crystal Electric Field Transitions in a Kondo-Lattice Antiferromagnet — •Payel Shee[1], Chia-Jung Yang[2], Shishir Kumar Pandey[3], Ashis Kumar Nandy[1], Ruta Kulkarni[4], Arumugam Thamizhavel[4], Manfred Fiebig[2], and Shovon Pal[1] — [1]NISER, HBNI, Jatni, India. — [2]ETH Zurich, Switzerland. — [3]Artificial Intelligence for Science Institute, Beijing, China. — [4]Tata Institute of Fundamental Research, Mumbai, India.

The interplay between the Kondo effect and Ruderman-Kittel-Kasuya-Yosida (RKKY) leads to the emergence of many intriguing phenomena in strongly correlated systems. Metallic materials doped with magnetic impurities are ideal for such studies. These impurities interact with the crystal electric field (CEF) produced by neighboring ions, lifting the degeneracy of their energy levels and creating CEF states. Given that CEF excitations occur in the millielectronvolt (meV) range, the terahertz (THz) frequency range is particularly suited for these investigations. Using time-domain THz reflection spectroscopy, we show the first direct evidence of two low-energy CEF transitions at 0.6 THz (2.5 meV) and 2.1 THz (8.7 meV) in $CeAg_2Ge_2$, a prototype Kondo-lattice antiferromagnet. In addition, we also observe that the lower CEF transition peak undergoes a blue-shift once the sample enters into the antiferromagnetic phase. The temporal spectral weights obtained directly from the THz time traces corroborate the corresponding CEF energy scales of the compound [2].
[1] S. Pal *et al.*, Phys. Rev. Lett. 122, 096401 (2019);
[2] P. Shee *et al.*, Phys. Rev. B 109, 075133 (2024).

DY 30.3 Thu 10:00 H31

Tuning a ferromagnetic quantum phase transition by interface engineering in artificial heterostructures — Robin Heumann[1], Robert Gruhl[1], Ludwig Scheuchenpflug[1], Leonard Schüler[2], Vasily Moshnyaga[2], and •Philipp Gegenwart[1] — [1]Lehrstuhl für Experimentalphysik VI, Universität Augsburg — [2]Erstes Physikalisches Institut, Georg-August-Universität-Göttingen

The substitution series $Sr_{1-x}Ca_xRuO_3$ between the itinerant ferromagnet $SrRuO_3$ (SRO) and the non-Fermi liquid paramagnetic metal $CaRuO_3$ (CRO) constitutes a broadly smeared quantum phase transition (QPT) between $x = 0.7$ and 1. To avoid the impact of structural disorder we explore the possibility of tuning ferromagnetism by confining SRO to thin layers placed in between those of CRO. Ordered epitaxial $[SRO_n/CRO_m]_K$ superlattices, with n ranging from 8 down to the monolayer limit, keeping $m/n = 2$ and 3 with $K = 32/n$, were grown on $SrTiO_3$ (100) substrates, characterized and investigated by electrical transport and Hall effect measurements. We observe stable ferromagnetism from SRO layers for $n \geq 3$ and fragile low-temperature ferromagnetism due to the SRO/CRO interfaces. The latter survives down to the monolayer limit $n = 1$, explaining the difficulty to cross a ferromagnetic QPT in $Sr_{1-x}Ca_xRuO_3$. We also find that the effective interface density $K/(n + m)$ is a new suitable control parameter and construct the T_C vs $K/(n + m)$ phase diagram.

DY 30.4 Thu 10:15 H31

Interplay of nematic fluctuations and transverse phonons near a nematic quantum critical point — •Morten H. Christensen[1], Michael Schütt[2], Avraham Klein[3], and Rafael M. Fernandes[4] — [1]Niels Bohr Institute, University of Copenhagen — [2]University of Minnesota — [3]Ariel University — [4]University of Illinois Urbana-Champaign

In an electronic fluid absent an atomic lattice, an electronic nematic transition can be described as a consequence of a Pomeranchuk instability of the Fermi surface with an associated critical nematic mode. As a coupling to an atomic lattice is introduced, the nematic transition is accompanied by a structural distortion of the lattice. Here, we study the fluctuation spectra near such a coupled nematic-structural transition driven primarily by the electronic nematic fluctuations. This requires coupling the nematic fluctuations to transverse phonons which implies that the transition is no longer accompanied by a critical nematic mode, but rather by the vanishing of the transverse phonon velocity along a certain direction. To understand how, e.g., superconductivity is affected by this, knowledge of the dynamic behaviour of the hybrid nematic/phonon soft excitation is crucial. The purpose of this presentation is to elucidate the properties of this mode. We find that the low-energy fluctuations are generally overdamped except near the soft lattice directions where they become underdamped. How the transition from overdamped to underdamped takes place depends on the proximity to the nematic quantum critical point.

DY 30.5 Thu 10:30 H31

Chiral Heisenberg Gross-Neveu-Yukawa criticality: Honeycomb vs. SLAC fermions — •Thomas C. Lang[1] and Andreas M. Läuchli[2,3] — [1]Institute for Theoretical Physics, University of Innsbruck, Austria — [2]Laboratory for Theoretical and Computational Physics, Paul Scherrer Institute, Switzerland — [3]Institute of Physics, École Polytechnique Féedérale de Lausanne, Switzerland

We perform large scale quantum Monte Carlo simulations of the Hubbard model at half filling with a single Dirac cone close to the critical point, which separates a Dirac semi-metal from an antiferromagnetically ordered phase where SU(2) spin rotational symmetry is spontaneously broken. We discuss the implementation of a single Dirac cone in the SLAC formulation for eight Dirac components and the influence of dynamically induced long-range super-exchange interactions. The finite size behavior of dimensionless ratios and the finite size scaling properties of the Hubbard model with a single Dirac cone are shown to be superior compared to the honeycomb lattice. We extract the critical exponents believed to belong to the chiral Heisenberg Gross-Neveu-Yukawa universality class which coincide for the two lattice types once honeycomb lattices of sufficient linear dimension are considered.

DY 30.6 Thu 10:45 H31

Fractionalized multicriticality in Kitaev spin-orbital liquids — •Max Fornoville[1,2] and Lukas Janssen[3] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]School of Natural Sciences, Technische Universität München, 85748 Garching, Germany — [3]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062

Dresden, Germany

Two-dimensional spin-orbital magnets with Kitaev-like exchange frustration realize spin-orbital liquid ground states that are characterized by the appearance of gapless Majorana fermions and a static $\mathbb{Z}_2$ gauge field. It has been shown that the introduction of an antiferromagnetic Heisenberg interaction between nearest-neighbor spin degrees of freedom facilitates a transition towards a partially ordered spin-orbital liquid state with a spontaneously broken spin-rotation symmetry. The associated quantum critical point belongs to the fractionalized fermionic Gross-Neveu-SO(3)* universality class and only partially gaps out the fermionic spectrum. Here, we consider an enlarged theory space, introducing an anisotropic XXZ interaction in the spin sector. The explicit breakdown of spin-rotation symmetry allows for two types of antiferromagnetic order, depending on the nature of the anisotropy. By means of Majorana mean-field theory and ε-expansion to leading order, we uncover the phase diagram of the model and characterize its multicritical behavior. Additionally, we present evidence for the appearance of a symmetry-enhanced first-order transition between the two ordered phases.

15 min. break

DY 30.7 Thu 11:15 H31

One-loop perturbative structure of a (2+1)D bosonized non-Fermi liquid — •Parasar R. Thulasiram[1,2], Chris Hooley[3], and Roderich Moessner[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [3]Centre for Fluid and Complex Systems, Coventry University, Coventry, United Kingdom

Non-Fermi liquids are a class of metals with no quasiparticle excitations often arising from the interaction of slow collective modes, such as an emergent critical boson, with a Fermi surface. Minimal models of this type are called Hertz-Millis-Moriya models and historically suffer from uncontrolled approximations in perturbation theory and patchy treatments of the Fermi surface, preventing the study of global-Fermi surface physics. Delacrétaz et al. (2022) recast Fermi liquid theory in any dimension via a bosonic field that parametrizes macroscopic particle-hole excitations about the whole Fermi surface. This bosonized field theory is suggested to reduce the order in perturbation theory necessary to calculate important quantities and is considerate of whole Fermi surface fluctuations, potentially providing the first robust results of a Hertz-Millis-Moriya theory when coupled to a critical boson. We present initial results of the one-loop critical boson self-energy in 2+1D for calculating the dynamical critical exponent and discuss the benefits and challenges of this theory.

DY 30.8 Thu 11:30 H31

Exotic quantum criticality in Luttinger semimetals — •David Moser and Lukas Janssen — TU Dresden, Deutschland

Luttinger semimetals are three-dimensional strongly-spin-orbit-coupled systems, in which valence and conduction bands touch quadratically at the Fermi level. They provide a rich playground for highly unconventional physics and serve as a parent state to a number of exotic states of matter, such as Weyl semimetals, topological insulators, or spin ice. Here, we discuss various quantum critical phenomena beyond standard quantum criticality, including quasiuniversality, fixed-point annihilation scenarios, and large-N aspects. Our results are relevant for the low-temperature behavior of rare-earth pyrochlore iridates, such as $Pr_2Ir_2O_7$ or $Nd_2Ir_2O_7$.

DY 30.9 Thu 11:45 H31

Examination of the antiferromagnetic superradiant intermediate phase and the effects of geometrical frustration in the Dicke-Ising model — •Jonas Leibig, Anja Langheld, Andreas Schellenberger, and Kai Phillip Schmidt — Chair for Theoretical Physics V, FAU Erlangen-Nürnberg, Germany

We map the Dicke-Ising model to a self-consistent matter Hamiltonian in the thermodynamic limit [1, 2] and solve it using a variety of methods, including exact diagonalization, perturbative and numerical linked-cluster expansions, and density matrix renormalization group. In one dimension, we explore the intermediate phase in the antiferromagnetic model and the multi-critical point in the ferromagnetic model, comparing our results with complementary quantum Monte Carlo simulations [2]. Additionally, we investigate the antiferromagnetic model on the frustrated geometry of the sawtooth chain. We employ high-order series expansions in the strong coupling limit, where the mapping to the self-consistent matter Hamiltonian is definitively valid. Independently, we analyze in greater detail whether the mapping also holds in the specific regime emerging from the frustrated Ising limit induced by an infinitesimal light-matter perturbation.
[1] K. Lenk, J. Li, P. Werner, M. Eckstein, arXiv:2205.05559;
[2] A. Langheld, M. Hörmann, K. P. Schmidt, arXiv:2409.15082.

DY 30.10 Thu 12:00 H31

Critical behavior of the 1d superconductor in the FLEX approximation — •Šimon Kos[1], Sunil D'Souza[1], Jan Gebel[1], Ján Minár[1], and Václav Janiš[2] — [1]University of West Bohemia, Univerzitní 8, CZ-301 00 Plzeň, Czech Republic — [2]Institute of Physics, The Czech Academy of Sciences, Na Slovance 2, CZ-18200 Praha 8, Czech Republic

The dynamical quantum fluctuations below the lower critical dimension push the superconducting critical point to zero temperature. We study the quantum critical behavior of the 1d superconductor with one-particle self-consistency provided by the FLEX approximation within the canonical Baym-Kadanoff scheme. We use the non-interacting singlet electron-electron bubble in the two-particle vertex of the Schwinger-Dyson equation, allowing for a qualitatively correct and tractable treatment of the low-energy critical behavior compatible with the Mermin-Wagner theorem. We use a polar approximation to transform the convolutive Schwinger-Dyson equation into an algebraic one that can be solved semi-analytically. We confirm the position of the critical point and assess the low-temperature behavior of the Hubbard model with attractive interaction.

DY 30.11 Thu 12:15 H31

Tunable criticality and pseudo-criticality in a quantum dissipative spin system — •Manuel Weber — Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

The study of competing orders in two-dimensional quantum magnets was strongly motivated by the prediction of non-Landau quantum phase transitions, but often we found symmetry-enhanced first-order transitions or pseudocriticality with a logarithmic drift of critical exponents. Here we present results for a (0+1) dimensional spin-boson model where all of these phenomena occur due to a fixed-point annihilation within the critical manifold. Our recently-developed wormhole quantum Monte Carlo method for retarded interactions allows us to study the critical properties of this model with unprecedented precision. We find a tunable transition between two ordered phases that can be continuous or first-order, and even becomes weakly first-order in an extended regime close to the fixed-point collision. We provide direct numerical evidence for pseudo-critical scaling on both sides of the collision manifesting in an extremely slow drift of critical exponents. We also find scaling behavior at the symmetry-enhanced first-order transition as described by a discontinuity fixed point. Our study motivates future work in higher-dimensional quantum dissipative spin systems.

DY 30.12 Thu 12:30 H31

Universality of the quantum Heisenberg model with sub-volume long-range couplings — •Daniel Resch and Thomas C. Lang — Institute for Theoretical Physics, University of Innsbruck, Austria

We investigate the critical properties of effective spin models which emerge from low energy band structures, or momentum space patches of strongly interacting fermions. As representative worst case scenario we present quantum Monte Carlo simulations of phase transitions in the major-axis coupled, long-range quantum Heisenberg model in two spatial dimensions at finite and zero temperature. We quantify the effects of sub-volume anisotropic long range spin-coupling with power-law form $1/r^{\alpha}$ on the critical exponents of the transitions where SU(2) spin symmetry is spontaneously broken for at low, finite temperatures in accordance with the Mermin Wagner Hohenberg theorem. Performing finite-size scaling analyses for different α we determine the extent of the regimes where the (quantum) phase transitions are represented by Gaussian fixed point, short-range Wilson-Fisher, or continuously varying long-range non-Gaussian critical exponents.

DY 31: Focus Session: Nonequilibrium Collective Behavior in Open Classical and Quantum Systems

Nonequilibrium classical and quantum systems coupled to thermal or (driven) non-equilibrium environments have recently been shown to exhibit rich collective phenomena and phase transitions without equilibrium counterparts. From the classical side, intriguing examples are flocking and phase separation in active matter, but also patterns and bifurcations in driven-diffusive systems and spontaneous parity-time symmetry breaking in systems involving nonreciprocal couplings. From the quantum side much interest has been devoted, e.g., to ordering and phase transitions in non-equilibrium steady states, the formation of time crystals, superradiance, as well as phase transitions or critical behavior in time. The symposium and the accompanying focus session is devoted to connections between the quantum and the classical realms, as they have been explored recently both in theory and experiment.

Organized by Sabine Klapp (TU Berlin) and André Eckhardt (TU Berlin)

Time: Thursday 9:30–12:45 Location: H37

DY 31.1 Thu 9:30 H37

Ultra-critical Fermi Surfaces, Quantum Oscillations, and Bosonic Metals — •Likun Shi and Inti Sodemann Villadiego — Institut für Theoretische Physik, Leipzig, Germany

Periodically driven quantum systems exhibit rich non-equilibrium phenomena that transcend equilibrium paradigms. We demonstrate the emergence of novel Fermi surface physics in particle-number-conserved fermionic and bosonic systems coupled to heat baths. In the fermionic case, we uncover "ultra-critical" Floquet non-Fermi liquid states characterized by persistent non-analyticities in momentum space occupation that remarkably retain their sharpness at finite temperature - a phenomenon without equilibrium analogues. These non-equilibrium Fermi surfaces manifest in quantum oscillation signatures and display power-law correlations immune to the finite-temperature bath. Extending beyond fermions, we discover analogous Fermi surface physics in bosonic systems, pointing to universal features in driven quantum systems that transcend particle statistics. Our findings open new avenues for realization of exotic non-equilibrium phases in driven quantum materials.

DY 31.2 Thu 9:45 H37

Giant Dynamical Paramagnetism in the driven pseudogap phase of YBa2Cu3O6+x — •Marios Michael[1], Duilio De Santis[2], Eugene Demler[3], and Patrick Lee[4] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Luruper Chausse 149, 22761 Hamburg, Germany — [2]Physics and Chemistry Dept., Interdisciplinary Theoretical Physics Group, Palermo University, 90128 Palermo, Italy — [3]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland — [4]Department of Physics, MIT, 77 Massachusetts Avenue, 02139 Cambridge, MA, USA

In this talk, I will discuss theory aimed at understanding recent experimental data on driven YBa2Cu3O6+x published recently in Nature: Fava, S., De Vecchi, G., Jotzu, G. et al. Magnetic field expulsion in optically driven YBa2Cu3O6+x Nature 632,75-80 (2024). Experiments on optically pumped YBa2Cu3O6+x in the pseudogap phase far above Tc have shown evidence of dynamical Meissner effect. In our effort to understand the new experimental signatures, we have uncovered a universal instability triggered in Josephson junctions under a magnetic field that are strongly driven with an AC field. The instability leads to the generation of giant paramagnetic currents at the edges of Josephson junctions. For strong enough drive such instabilities ultimately lead to a soliton ratchet after driving. I will focus on why this instability of a generic Josephson junction is applicable to the pseudogap YBa2Cu3O6+x far above Tc and how it matches the experimental observations.

DY 31.3 Thu 10:00 H37

entropy production in ultrafast quantum stochastic dynamics — •Yulong Qiao and Matthias Geilhufe — Department of Physics, Chalmers University of Technology, Gothenburg, Sweden

Thanks to advancements in femto- and atto-second laser technologies, thermodynamics has entered the ultrafast era. Ultrafast dynamics provides a unique way to probe the transient properties of materials. In [1], ultrafast stochastic thermodynamics was developed based on X-ray scattering experiments [2], and has been successfully applied to the study of entropy production in laser-excited phonons. However, how to develop a unifying theory for both classical and quantum systems remains an open challenge [3].

In the quantum realm, fluctuations arising from the uncertainty principle do not depend on temperature, meaning they are inevitable even in a vacuum. As a result, in the quantum analogues of the Langevin equations, classical stochastic forces are replaced by quantum noise operators. In this talk, I will discuss how to handle the quantum nosies in the frame of open quantum systems. I will also present the impact of quantum effects on the entropy production in the ultrafast processes.

[1] L. Caprini, H. Löwen, and R. M. Geilhufe, Nat. Commun. 15, 94 (2024).

[2] M. Kozina. et al., Nat. Phys. 15, 387 (2019).

[3] G.T. Landi and M. Paternostro, Rev. Mod. Phys. 93, 035008 (2021).

DY 31.4 Thu 10:15 H37

Cooling dynamics of the 2D Kitaev honeycomb model coupled to phonons — •Arkadeep Mitra, Francesco Piazza, and Markus Heyl — Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, 86135 Augsburg, Germany

The ground state of the Kitaev spin-1/2 model on a 2D honeycomb lattice hosts a quantum spin liquid (QSL) phase where excitations fractionalize into Majorana fermions. At high temperatures, however, it has recently been observed to enter a disorder-free localized phase, so that any experimental cooling of a Kitaev material has to cross this localized and associated phase transition. Motivated from this, we study theoretically the cooling dynamics upon coupling the Kitaev model to phonons. We envisage that signatures obtained from this dynamics could act as probes for QSL.

DY 31.5 Thu 10:30 H37

Hydrodynamic description of emergent long-range coherence in active quantum flocks — •Byjesh N Radhakrishnan[1,2], Thomas L. Schmidt[1], and Markus Heyl[2] — [1]Department of Physics and Material science, University of Luxembourg — [2]Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, D-86135 Augsburg, Germany

The quantum analog of classical active matter flocking has recently been reported in [arXiv:2308.01603]. The reported model introduces the concept of active quantum matter in a system of hard-core bosons in a one-dimensional lattice. The results provide both analytical and large-scale numerical evidence that these systems can give rise to quantum flocks due to the interplay of spin-flipping and alignment interactions. One of the key findings is that these flocks, unlike classical ones, exhibit distinct quantum properties by developing strong quantum coherence over long distances. Our work focuses mainly on developing a hydrodynamics description to study the origin and properties of this long-range quantum coherence. We systematically explore the relationship between long-range coherence and system parameters like alignment strength and quantum amplitude and compare our analytical results with large-scale numerical simulations.

Invited Talk DY 31.6 Thu 10:45 H37

Strong coupling and coherence in quantum thermodynamics — •Janet Anders[1,2], Federico Cerisola[2], James Cresser[2], and et al[2] — [1]Universität Potsdam, Germany — [2]Exeter University, UK

The interaction of nanoscale and quantum systems with their environment can be relatively strong, and alter the equilibrium state. For open quantum systems, explicit expressions of these so-called mean force (MF) equilibrium states have been missing. In this talk I will report on useful analytic expressions of these states, valid for a general quantum system in contact with a bosonic bath [1]. The results are illustrated with the well-known spin-boson model, for which we provide the first classification of coupling regimes, from weak to ultrastrong, and for both the quantum and classical setting [2].

In the second part of the talk, I will briefly comment on quantum signatures that arise in thermodynamic processes due to the presence of coherences. For example, the work distribution of time-varying quantum systems violates the corresponding classical fluctuation-dissipation relation for slowly driven processes [3]. A geometric framework is proposed to find optimal trade-offs between dissipation and fluctuations. Coherences also give rise to quantum irreversibility. We unravel how this irreversibility manifests itself in energetic exchanges that differ from those in the classical regime [4].

[1] PRL 127, 250601 (2021)
[2] NJP 26, 053032 (2024)
[3] PRL 123, 230603 (2019)
[4] Comm. Phys. 3, 1 (2020)

15 min. break

DY 31.7 Thu 11:30 H37

Ultrafast Dynamics Across the Phase Transition of the Charge Density Wave in $K_{0.3}MoO_3$ — •Rafael T. Winkler[1], Larissa Boie[1], Yunpei Deng[2], Matteo Savoini[1], Serhane Zerdane[2], Abhishek Nag[2], Sabina Gurung[1], Davide Soranzio[1], Tim Suter[1], Vladimir Ovuka[1], Janine Zemp[1], Elsa Abreu[1], Simone Biasco[1], Roman Mankowsky[2], Edwin J Divall[2], Alexander R. Oggenfuss[2], Mathias Sander[2], Christopher Arrell[2], Danylo Babich[2], Henrik T. Lemke[2], Paul Beaud[2], Urs Staub[2], Jure Demsar[3], and Steven L. Johnson[1,2] — [1]Institute for Quantum Electronics, Physics Department, ETH Zurich, Zurich, Switzerland — [2]SwissFEL, Paul Scherrer Institute, Villigen, Switzerland. — [3]Faculty - Institute of Physics, Johannes Gutenberg-University Mainz

Blue Bronze ($K_{0.3}MoO_3$) is a quasi 1D material exhibiting a charge density wave (CDW) with a periodic lattice distortion (PLD). In a time resolved x-ray experiment, we study the dynamics of the PLD by pumping $K_{0.3}MoO_3$ with short laser pulses and probing it using x-ray diffraction. We construct reciprocal space maps (RSM) of superlattice reflections at different delays. The RSMs indicate a transient inversion of the phase of the CDW. We attribute the suppression of the diffracted x-ray intensity after this phase inversion to a fast decoherence of the CDW driven by local pinning of the phase of the CDW in the material. These observations were confirmed by numerical simulations of the time dependent Ginzburg-Landau equations, extended by including defects which favor a particular phase of the CDW in combination with a temperature dependent coherence factor.

DY 31.8 Thu 11:45 H37

Optimal dynamical regimes for reservoir computing with soft matter — •Mario U. Gaimann and Miriam Klopotek — Stuttgart Center for Simulation Science (SimTech), Cluster of Excellence EXC 2075, University of Stuttgart, Germany

Reservoir computing with physical systems is a promising approach for next-generation and *in materio* computing. Recently, active matter systems for reservoir computing were introduced by Lymburn *et al.* (*Chaos* 31(3), 033121, 2021). However, the optimal properties of active matter systems for reservoir computing remain poorly understood. Here we show that viscoelastic, overdamped dynamics yield high predictive performances. This is remarkable since it was previously believed that optimal swarm dynamics are found at a gas-to-liquid phase transition. We relate predictive performance to correlations of agent velocities and their fluctuations. The optimal overdamped swarms show rich phenomenology: interface formation and breaking, local shear thinning, and self-healing. We show that the overdamped regime is optimal across a range of different chaotic attractors. Notably the optimal dynamics are already uncovered by studying reservoir computing with a single particle. Our results demonstrate the importance of tuning basic dynamical properties in physical reservoir substrates to generate optimal correlative effects. Reservoir computing with viscoelastic soft matter inspires novel mechanisms for computing in matter and novel computing devices based on these principles.

DY 31.9 Thu 12:00 H37

Universality in time-crystalline matter — •Carl Philipp Zelle, Romain Daviet, Achim Rosch, and Sebastian Diehl — University of Cologne

Dynamical phases of matter in which time translation symmetry is broken spontaneously are fascinating examples of phases that can only occur far from equilibrium. In this talk, we show that paradigmatic O(N) models display time-crystalline order once driven suitably out of equilibrium.

We employ dynamic RG techniques to determine the universal phenomena at the ensuing transitions as well as within the time-crystalline phase: The transition between an ordered phase and the time-crystal occurs through a critical exceptional point which we show cause a fluctuation-induced first order transition. The transition between a symmetric and a time-crystalline phase defines a new, genuinely non-thermal universality class. We show, that the Goldstone-modes within the dynamical phases are a realisation of the KPZ universality class and offer new generalisations of KPZ to larger symmetry groups.

Surprisingly, these phenomena can be realized by rather simple driving protocols, i.e. weakly irradiating a ferrimagnetic spin system. Furthermore, we connect our results to recent advances in nonreciprocal active matter.

Based on

1) Zelle, Daviet, Rosch, Diehl; Phys. Rev. X 14, 021052 (2024)
2) Daviet, Zelle, Rosch, Diehl; Phys. Rev. Lett. 132, 167102 (2024)
3) Zelle, Daviet, Asadollahi, Diehl; in preparation

DY 31.10 Thu 12:15 H37

Thermalizing Lindbladians for many-body systems — •Nico Albert[1], Shovan Dutta[2], and Masudul Haque[1] — [1]Technische Universität Dresden, Dresden, Germany — [2]Raman Research Institute, Bangalore, India

Thermalization is closely associated with the effect of a bath. For quantum systems, the most prominent type of bath is a Markovian bath, whose dynamics are governed by a Lindblad master equation. Therefore, it is important to understand Lindbladians that lead to a thermal (Gibbs) steady state. We will present some properties of thermalizing Lindbladians for many-body systems.

DY 31.11 Thu 12:30 H37

Signatures of Quantum Chaos and fermionization in the incoherent transport of bosonic carriers in the Bose-Hubbard chain — Pavel Muraev, Dmitri Maksimov, and •Andrey Kolovsky — Krasnoyarsk, Russia

We analyse the stationary current of Bose particles across the Bose-Hubbard chain connected to a battery, focusing on the effect of inter-particle interactions. It is shown that the current magnitude drastically decreases as the strength of inter-particle interactions exceeds the critical value which marks the transition to quantum chaos in the Bose-Hubbard Hamiltonian. We found that this transition is well reflected in the non-equilibrium many-body density matrix of the system. Namely, the level-spacing distribution for eigenvalues of the density matrix changes from Poisson to Wigner-Dyson distributions. With the further increase of the interaction strength, the Wigner-Dyson spectrum statistics changes back to the Poisson statistics which now marks fermionization of the Bose particles. With respect to the stationary current, this leads to the counter-intuitive dependence of the current magnitude on the particle number.

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.

DY 33: Machine Learning in Dynamics and Statistical Physics I

Time: Thursday 9:30–13:00 Location: H47

DY 33.1 Thu 9:30 H47

Learning Mechanisms of Neural Scaling Laws — •Konstantin Nikolaou[1], Samuel Tovey[1], Sven Krippendorf[2], and Christian Holm[1] — [1]Institute for Computational Physics, University of Stuttgart, Germany — [2]Cavendish Laboratory and DAMTP University of Cambridge, United Kingdom, CB3 0WA

Recent works have identified neural scaling laws, which describe the trade-off between neural network performance and computation cost. Understanding the underlying mechanisms leading to scaling behavior might be one of the most important questions in current machine-learning research.

We compare the behavior of neural networks for data and model scaling by analyzing the learning dynamics through the lens of the neural tangent kernel. We find similar performance scaling in both regimes but uncover fundamentally distinct internal model mechanisms underlying the scaling. Additionally, we investigate scaling towards the infinite-width limit of neural networks and identify a transition, we coin the Feature-Kernel Transition, separating two regimes: Below, a model refines features to resolve a task, while above the transition the refinement declines and the initial state becomes the dominant factor. We argue that the transition marks the trade-off between model size and maximum feature learning.

DY 33.2 Thu 9:45 H47

Finite integration time drives optimal dynamic range into subcritical regime — Sahel Azizpour[1,2], Viola Priesemann[3,4], •Johannes Zierenberg[3,4], and Anna Levina[1,2] — [1]Eberhard Karls University of Tübingen, Germany — [2]Max Planck Institute for Biological Cybernetics, Tübingen, Germany — [3]Max Planck Institute for Dynamics and Self Organisation, Göttingen, Germany — [4]Institute for the Dynamics of Complex Systems, University of Göttingen, Germany

Sensitivity to small changes in the environment is crucial for many real-world tasks, enabling living and artificial systems to make correct behavioral decisions. It has been shown that such sensitivity is maximized when a system operates near the critical point of a second-order phase transition. However, proximity to criticality introduces large fluctuations and diverging timescales. Hence, it would require impractically long integration periods to leverage the maximal sensitivity. Here, we analytically and computationally demonstrate how the optimal tuning of a recurrent neural network is determined given a finite integration time. Rather than maximizing the theoretically available sensitivity, we find networks to attain different sensitivity depending on the time available. Consequently, the optimal dynamic regime shifts from critical to subcritical when integration times are finite, highlighting the necessity of incorporating finite-time considerations into studies of information processing.

DY 33.3 Thu 10:00 H47

Self-Organizing Global Computation from Local Objective Functions Based on Partial Information Decomposition — Andreas C. Schneider[1,2], •Valentin Neuhaus[2,1], David A. Ehrlich[3], Abdullah Makkeh[3], Alexander S. Ecker[4,2], Viola Priesemann[2,1], and Michael Wibral[3] — [1]Institute for the Dynamics of Complex Systems, University of Göttingen, Germany — [2]Max Planck Institute for Dynamics and Self Organisation, Göttingen, German — [3]Campus Institute for Dynamics of Biological Networks, University of Göttingen — [4]Institute of Computer Science and Campus Institute Data Science, University of Göttingen

In modern deep neural networks, individual neuron learning dynamics are often obscure due to global optimization. In contrast, biological systems use self-organized, local learning to achieve robustness and efficiency with limited global information. We propose a method for achieving self-organization in artificial neurons by defining local learning goals based on information theory. These goals leverage Partial Information Decomposition (PID), which breaks down information from sources into unique, redundant, and synergistic contributions. Our framework enables neurons to locally determine how input classes contribute to the output, expressed as a weighted sum of PID terms derived from intuition or numerical optimization. This approach enhances task-relevant local information processing and neuron-level interpretability while maintaining strong performance, providing a principled foundation for local learning strategies.

DY 33.4 Thu 10:15 H47

Explaining Near-Zero Hessian Eigenvalues Through Approximate Symmetries in Neural Networks — •Marcel Kühn and Bernd Rosenow — Institute for Theoretical Physics, University of Leipzig, 04103 Leipzig, Germany

The Hessian matrix, representing the second derivative of the loss function, offers crucial insights into the loss landscape of neural networks and significantly influences optimization algorithms, model design, and generalization in deep learning. A common characteristic of the Hessian eigenspectrum is the presence of a few large eigenvalues alongside a bulk of near-zero eigenvalues. We propose that this bulk structure arises from approximate symmetries inherent in network architectures – an often overlooked aspect. First, we demonstrate that in deep, fully connected linear networks, exact continuous symmetries that leave the loss invariant lead to zero eigenvalues in the Hessian. These zero eigenvalues and their corresponding eigenvectors can be attributed to symmetries such as rotations between weight layers. Extending this concept, we suggest that in networks with nonlinear activation functions, approximate symmetries introduce a large number of small but finite eigenvalues, viewed as perturbations of the linear case. We illustrate this phenomenon in a two-layer ReLU student-teacher setup and in a multi-layer network trained on CIFAR-10, showing that eigenvectors with small eigenvalues predominantly align with symmetry directions. Finally, we apply our symmetry-based analysis to convolutional networks, demonstrating the generality of our approach in understanding the Hessian eigenspectrum across different architectures.

DY 33.5 Thu 10:30 H47

Efficient mapping of phase diagrams with conditional Boltzmann Generators — •Maximilian Schebek[1], Michele Invernizzi[2], Frank Noé[1,2,3,4], and Jutta Rogal[1,5] — [1]Fachbereich Physik, Freie Universität Berlin, 14195 Berlin — [2]Fachbereich Mathematik und Informatik, Freie Universität Berlin, 14195 Berlin — [3]Department of Chemistry, Rice University, Houston, 77005, Texas, USA — [4]AI4Science, Microsoft Research, 10178 Berlin — [5]Department of Chemistry, New York University, New York, NY 10003, USA

The accurate prediction of phase diagrams is of central importance for both fundamental and applied material sciences. However, the computational prediction of the relative stability between phases based on their free energy is a daunting task, as traditional free energy estimators require a large amount of uncorrelated equilibrium samples over a grid of thermodynamic states. In this work, we develop deep generative machine learning models based on the Boltzmann Generator approach for entire phase diagrams, employing normalizing flows conditioned on the thermodynamic states that they map to. By training a single model to transform the equilibrium distribution sampled at only one reference thermodynamic state to a wide range of target temperatures and pressures, we can efficiently generate equilibrium samples across the entire phase diagram. We demonstrate our approach by predicting the solid-liquid coexistence line for a Lennard-Jones system in excellent agreement with state-of-the-art free energy methods while significantly reducing the number of energy evaluations needed.

DY 33.6 Thu 10:45 H47

Sampling rare events with neural networks: Machine learning the density of states — •Moritz Riedel[1], Johannes Zierenberg[2], and Martin Weigel[1] — [1]Institute of Physics, Technische Universität Chemnitz, 09107 Chemnitz, Germany — [2]Max Planck Institute for Dynamics and Self-Organization, 37077 Göttingen, Germany

Neural networks can be trained to generate samples from the Boltzmann distribution of many-particle systems. If suitable architectures such as normalizing flows or variational autoregressive networks are chosen, exact generation weights are known and hence present biases can be corrected for. Still, such networks typically struggle to learn and reproduce configurations from the full range of configuration space since effects such as mode collapse occur. For the simulation of rare events and suppressed states accessible in generalized frameworks such as the multicanonical ensemble such broad exploration is crucial. Here, we show how a combination of variational autoregressive network and autoencoder allows for a systematic exploration of configuration space

in spin models, during which the network is able to learn the density of states. We demonstrate the efficacy of the approach in the Potts system in the strong first-order regime.

DY 33.7 Thu 11:00 H47

stable diffusion for microstructure: from microstructural properties to 2D-to-3D reconstruction — •Yixuan Zhang[1], Teng Long[2], Mian Dai[1], and Hongbin Zhang[1] — [1]TU Darmstadt, Darmstadt, Germany — [2]Shandong University, Jinan, China

We propose a novel framework that combines Stable Diffusion and ControlNet to generate microstructures tailored to specific properties, such as coercivity. By leveraging latent alignment techniques, our method enables direct reconstruction of 3D microstructures from 2D inputs, ensuring geometric and property consistency across dimensions. This approach not only facilitates accurate 2D-to-3D reconstruction but also opens possibilities for studying and predicting microstructural transformations during various manufacturing processes. By integrating generative AI with material design, this work provides a robust foundation for property-driven microstructure generation, offering a potential pathway to optimize materials for targeted applications.

15 min. break

DY 33.8 Thu 11:30 H47

Machine learning for prediction of dynamical clustering in granular gases — •Sai Preetham Sata[1], Dmitry Puzyrev[2,1], and Ralf Stannarius[3,2] — [1]AMS, Otto von Guericke University, Germany — [2]MTRM and MARS, Otto von Guericke University, Germany — [3]Department of Engineering, Brandenburg University of Applied Sciences, Germany

Granular gases are sparse ensembles of free-moving macroscopic particles that interact via inelastic collisions. One peculiar property of granular gas is dynamical clustering, i.e. spontaneous increase of local number density. To quantify this effect, microgravity experiments and simulations were performed [1-3] and two gas-cluster transition criteria were established:Kolmogorov-Smirnov test, and caging effect criterion [2]. We perform simulations based on the VIP-GRAN experiment [3] and test these criteria for various combinations of system parameters, revealing their advantages and drawbacks. In addition, we investigate additional criteria that can help to understand the dynamical properties of gas-cluster transition. Based on the simulation data, machine learning can be used to detect dynamical clusters and predict the state of the system for a given set of system parameters. This study is funded by the German Aerospace Center (DLR) within projects VICKI (50WM2252) and EVA II (50WK2348). References: [1] É. Falcon et al., Phys. Rev. Lett., 83:440, 1999. [2] E. Opsomer et al., Europhys. Lett., 99:40001, 2012. [3] S. Aumaître et al., Rev. Sci. Instr., 89:075103, 2018.

DY 33.9 Thu 11:45 H47

Automated construction of complex reaction networks — •Weiqi Wang[1], Xiangyue Liu[1], and Jesús Pérez Ríos[2] — [1]Fritz-Haber-Institut, Berlin — [2]Department of Physics and Astronomy, Stony Brook University, Stony Brook, New York 11794, USA

Kinetic models are essential for understanding chemical reaction mechanisms and estimating reaction rates. Typically, kinetic models are constructed based on transition state theory, using stable and intermediate species with zero-Kelvin energy calculations. However, they often fail to account for temperature effects and anharmonic influences, limiting their accuracy for real-world reactions.

This talk will discuss our method for automatically constructing reaction networks at finite temperatures using *ab initio* molecular dynamics simulations. Based on extensive sampling of configurational space, temperature-dependent free energies, and transition probabilities can be derived, enabling the construction of reaction networks to analyze temperature effects.

DY 33.10 Thu 12:00 H47

Data-Driven Sparse Identification with Adaptive Function Bases — •Gianmarco Ducci, Maryke Kouyate, Karsten Reuter, and Christoph Scheurer — Fritz-Haber-Institut der MPG, Berlin

Interpretable data-driven methods have proven viable for deriving kinetic equations directly from experimental data. However, such numerical methods are inherently susceptible to noise, which affects the sparsity in the resulting models. In order to promote such a sparsity condition, finding the optimal set of basis functions is a necessary prerequisite, but yet a challenging task to determine in advance.

We here present our in-house developed `ddmo` (Data-Driven Model Optimizer) software, which allows precise control over the space of candidate constituent terms. Such a complete framework comprises two main novel features. The first feature permits to include parametric functions in the library. The second feature is an adaptive library sizing routine that progressively adds or removes elements based on the learning from the dataset. We show a practical application of our algorithm tailored at identifying Langmuir-Hinshelwood mechanisms from experimental data.

DY 33.11 Thu 12:15 H47

Kalman filter enhanced adversarial Bayesian optimization for active sampling in inelastic neutron scattering — Yixuan Zhang[1], •Nihad Abuawwad[2], Samir Lounis[2], and Hongbin Zhang[1] — [1]TU Darmstadt, Darmstadt, Germany — [2]Peter Grünberg Institute (PGI), Jülich, Germany

Spin waves, or magnons, are fundamental excitations in magnetic materials that provide insights into their dynamic properties and interactions. Magnons are the building blocks of magnonics, which offer promising perspectives for data storage, quantum computing, and communication technologies. These excitations are typically measured through inelastic neutron or x-ray scattering techniques, which involve heavy and time-consuming measurements, data processing, and analysis based on various theoretical models. Here, we introduce a machine learning algorithm that integrates adaptive noise reduction and active learning sampling, which enables the restoration from minimal inelastic neutron scattering point data of spin wave information and the accurate extraction of magnetic parameters, including hidden interactions. Our findings, benchmarked against the magnon spectra of CrSBr, significantly enhance the efficiency and accuracy in addressing complex and noisy experimental measurements. This advancement offers a powerful machine learning tool for research in magnonics and spintronics, which can also be extended to other characterization techniques at large facilities.

DY 33.12 Thu 12:30 H47

Accelerating the Training and Improving the Reliability of Machine-Learned Interatomic Potentials for Strongly Anharmonic Materials through Active Learning — •Kisung Kang, Thomas A. R. Purcell, Christian Carbogno, and Matthias Scheffler — The NOMAD Laboratory at the FHI of the Max Planck Society

Machine-learned interatomic potentials (MLIP) can efficiently implement molecular dynamics (MD) simulations with large spatial and long time scales. However, immature training for rare dynamical events, such as defect creation, may happen due to their absence or insufficiency in training data or their fadeout during regularization, leading to the critical deterioration of MLIP predictions regarding dynamical properties like transport phenomena. To improve the MLIP's reliability and accelerate the whole training process, we adopt a sequential active learning ($\mathcal{AL}$) scheme via MD employing MLIP (MLIP-MD) and uncertainty estimates [1]. In each iterative step, MLIP-MD serves as an efficient exploration tool for configurational space to generate training data, while uncertainty estimates identify unfamiliar data to be sampled for subsequential MLIP models. The representative examples of CuI and $AgGaSe_2$ among 112 materials display erroneous MLIP predictions of missing and fictitious rare events. We demonstrate how $\mathcal{AL}$ addresses these issues, specifically correcting unfamiliar regions for the MLIP potential energy surface. At last, the over(under)estimation of their phonon lifetimes is rectified after the $\mathcal{AL}$ steps.
[1] K. Kang, T. A. R. Purcell, *et al.*, arXiv:2409.11808 (2024).

DY 33.13 Thu 12:45 H47

Molecular Dynamics of Endohedral CaX@C60 Fullerenes: Reproducing Correlated Movement Features Using Machine Learning Applications — •Mihaela Cosinschi[1,3], Amanda Teodora Preda[1,3], Calin Andrei Pantis Simut[1,3], Nicolae Filipoiu[1,3], Ioan Ghitiu[4], Mihnea Alexandru Dulea[3], Andrei Manolescu[5], and George Alexandru Nemnes[1,2,3] — [1]University of Bucharest, Faculty of Physics, Magurele, Romania — [2]Research Institute of the University of Bucharest, Bucharest, Romania — [3]Horia Hulubei National Institute for Physics and Nuclear Engineering, Magurele, Romania — [4]National Institute for Laser, Plasma and Radiation Physics, Magurele, Romania — [5]Department of Engineering, School of Technology, Reykjavik University, Reykjavik, Iceland

Fullerenes are allotropes of carbon with remarkable properties due to their high degree of symmetry, cage-like structures and ability to support addition of internal or external atoms. In the present work, we have conducted a molecular dynamics (MD) study on the C60 fullerene containing one to four encapsulated calcium atoms. All-atomistic ab initio DFT methods were employed to perform calculations through the Orca MD Module, albeit at a high computational cost. Results proved that the internal atoms adopt minimal-energy configurations and exhibit coupled motion, maintaining constant characteristics after a period of equilibration. Furthermore, we have built an artificial neural network (ANN) that can pick up the dynamics patterns and recreate trajectories to reasonable accuracy, allowing for MD calculations in significantly shorter times, even under small perturbations.

DY 34: Nonlinear Dynamics, Synchronization, and Chaos

Time: Thursday 11:30–13:00 Location: H43

DY 34.1 Thu 11:30 H43

Hierarchical Clustering in Mean-Field Coupled Stuart-Landau Oscillators — •Nicolas Thomé and Katharina Krischer — Technische Universität München

Coupled oscillator networks are fundamental in many physics, chemistry, and biology fields, representing a captivating subject of study in nonlinear science. A persistent challenge is understanding the transition from a coherent synchronous solution to a completely incoherent one. This work explores this transition using globally coupled Stuart-Landau oscillators under mean-field interactions. We show that a cascade of codimension-2 points, coined Type-II cluster singularities, organizes the transition from two- to three-cluster solutions. These Type-II cluster singularities naturally induce a hierarchal structure to the clustering behavior and pave the way for the formation of chimera and incoherent solutions. Based on numerical bifurcation and Floquet multiplier analyses, our findings offer new insights into intermediate synchronization states and their role in complex oscillator systems.

DY 34.2 Thu 11:45 H43

Synchronization in the Fully Disordered Kuramoto Model of Coupled Oscillators — •Axel Prüser, Sebastian Rosmej, and Andreas Engel — Carl von Ossietzky University Oldenburg, Institut für Physik, D26111 Oldenburg, Germany

We investigate the dynamics of phase oscillators in fully disordered Kuramoto networks with defined degree of asymmetry. Both disordered couplings and disordered phases are considered. Employing the dynamical cavity method, the mean-field dynamics is reduced to a self-consistent stochastic single-oscillator problem which we analyze perturbatively and by numerical simulations. We elucidate the influence of the disorder characteristics on the correlation and response function of the system, together with their impact on the distribution of the order parameter. The mechanism of the so-called volcano transition and its relation to the existence of an oscillator glass phase is clarified.

DY 34.3 Thu 12:00 H43

Training of neuromorphic systems based on coupled phase oscillators via equilibrium propagation: effects of network architecture — •Qingshan Wang[1], Clara Wanjura[1], and Florian Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstrasse 2, Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, 91058 Erlangen, Germany

The increasing scale and resource demands of machine learning applications have driven research into developing more efficient learning machines that align more closely with the fundamental laws of physics. A key question in this field is whether both inference and training can exploit physical dynamics to achieve greater parallelism and acceleration. Equilibrium propagation, a learning mechanism for energy-based models, has shown promising results in physical systems with energy functions more complex than Hopfield-like models.

In this study, we focus on equilibrium propagation training of coupled phase oscillator systems. We investigate the influence of different experimentally feasible network architectures on the training performance. We analyze lattice structures, convolutional networks, and autoencoders, examining the effects of network size and other hyperparameters. Our findings lay the ground work for future experimental implementations of energy-based neuromorphic systems for machine learning, encompassing systems such as coupled laser arrays, CMOS oscillators, Josephson junction arrays, coupled mechanical oscillators, and magnetic systems

DY 34.4 Thu 12:15 H43

Stability of Grid-Following Inverters Under Forced Oscillations and Sequential Load Switching — •Benedikt Grüger and Florian Steinke — Technical University of Darmstadt, Darmstadt, Germany

The growing integration of renewable energy sources has led to a proliferation of inverter technologies in modern distribution grids. This shift introduces new dynamic stability challenges, particularly during periodic fluctuations in demand or generation caused by equipment malfunctions or cyber-physical attacks. Our work investigates the dynamic stability of grid-following inverters subjected to periodic grid voltage fluctuations. While forced oscillations in high-voltage grids have been widely studied, related research at the low-voltage level has primarily focused on bifurcations in inverter dynamics (e.g., Ma et al., 2020) or the impact of current limits (Zhang et al. 2024). However, the behavior of inverter-dominated distribution grids under forced oscillations remains largely unexplored. Our study employs a dynamic grid model that includes control mechanisms operating on time scales comparable to load switching, such as direct voltage control and phase-locked loop. This approach results in a fourth-order differential-algebraic system, akin to that proposed by Ma et al. (2023). We show that periodic grid voltage fluctuations can destabilize controllers, leading to inverter failures. By varying internal controller time scales, we identify different stability regimes and destabilizing effects are characterized. In sum, these findings highlight dynamic vulnerabilities in inverters and point out cyber-physical risks in inverter-dominated grids.

DY 34.5 Thu 12:30 H43

Shrimp structure as a test bed for ordinal pattern measures — Yong Zou[1], Norbert Marwan[2,3], Xiujing Han[4], •Reik V. Donner[2,5], and Jürgen Kurths[2] — [1]East China Normal University, Shanghai, China — [2]Potsdam Institute for Climate Impact Research, Potsdam, Germany — [3]University of Potsdam, Germany — [4]Jiangsu University, Zhenjiang, China — [5]Magdeburg-Stendal University of Applied Sciences, Magdeburg, Germany

Identifying complex periodic windows surrounded by chaos in the two or higher dimensional parameter space of certain dynamical systems is a challenging task for time series analysis. This holds particularly true for the case of shrimp structures, where different bifurcations occur when crossing different domain boundaries. Here we propose to use ordinal pattern transition networks (OPTN) to characterize shrimp structures. Our results demonstrate that among different ordinal characteristics, the OPTN out-link transition entropy exhibits better classification accuracy between chaotic and periodic time series than other existing measures like permutation entropy. This improved performance results from the fact that the transition behavior between ordinal patterns encodes additional dynamical information that is not captured by traditional ordinal measures that are solely based on pattern occurrence frequencies. Ultimately, the new OPTN based entropy measure also outperforms previously used measures based on recurrences in phase space.

DY 34.6 Thu 12:45 H43

Designing Robust Edge Oscillations with Topological Protection in Nonlinear Coupled Systems — •Sayantan Nag Chowdhury and Hildegard Meyer-Ortmanns — School of Science, Constructor University, 28759 Bremen, Germany

Topological protection, a powerful concept in physics, ensures robust states across quantum and classical systems. While topological insulators exemplify its applications in quantum systems with electric currents protected along the edges, an example from classical physics is provided by topoelectrical circuits with stable signal transduction. However, the role of topological protection in the context of classical oscillatory systems has been much less explored. Our study applies

tools from band theory of condensed matter physics to systems with nonlinear dynamics to achieve robust edge oscillations. This means that oscillations are restricted to the edge of a two-dimensional grid, while those in the bulk settle into near-steady-state dynamics. This pattern is resilient to parameter mismatches, structural defects, and blockages. By calculating the Zak phase as topological characteristic for this phenomenon, we explain edge-localized oscillations through bulk-boundary correspondence. We further analyze the collective behavior by examining the limiting case of weak coupling strength in our directed network, which alternates between strong and weak values. We validate our findings for different prototypical oscillator models with possible applications in biochemical systems. Our findings establish a robust design for controlling the state of oscillation of units that are attached to a spatial grid.

DY 35: Fluctuations, Noise and Other Transport Topics (joint session TT/DY)

Time: Thursday 15:00–18:30 Location: H31

DY 35.1 Thu 15:00 H31

Noise and reliability characterization of ferroelectric field-effect transistors under cryogenic conditions — •Yannick Raffel[1], Shouzhuo Yang[1], Oliver Ostien[1], Maik Simon[1], Thomas Kämpfe[1], Konrad Seidel[1], Maximilian Lederer[1], and Johannes Heitmann[2] — [1]Fraunhofer Institute IPMS-CNT, Dresden, Germany — [2]TU Bergakademie Freiberg, Freiberg, Germany

This study explores the impact of defects in the ferroelectric (FE) hafnium oxide (HfO_2) layer on the low-frequency noise (LFN) characteristics of HfO_2-based ferroelectric field-effect transistors (FeFETs), which show great potential as memory devices for quantum computing applications under cryogenic conditions. The investigation focuses on device degradation and material-dependent changes under various temperature conditions, including cryogenic temperatures as low as 2 K. A clear link between device reliability and flicker noise was identified. Initially, the endurance of the devices was evaluated across a range of temperatures, including cryogenic conditions. Subsequently, their data retention behavior was characterized, revealing a notably prolonged electron detrapping time at 2 K. In addition, flicker noise trends were analyzed and discussed, shedding light on key factors influencing device optimization and reliability.

DY 35.2 Thu 15:15 H31

Charge dissipation in Josephson systems and its impact on phase diffusion — •Johannes Hauff, Joachim Ankerhold, and Dominik Maile — Institut für komplexe Quantensysteme, Universität Ulm

We theoretically investigate the dynamics of the Josephson phase for different quantum circuits in the presence of dissipative couplings. Thereby, we study the environmental assisted quantum tunneling of the superconducting phase in a current-biased Josephson junction and consider Ohmic resistors inducing dissipation both in the phase and in the charge of the quantum circuit. We find that the charge dissipation leads to an enhancement of the quantum escape rate, which is strongly dependent on the shape of the potential. This effect appears already in the low Ohmic regime and also occurs in the presence of phase dissipation that favors localization [1]. Inserting realistic circuit parameters, we address the question of its experimental observability, the impact of temperature and discuss suitable parameter spaces for the observation of the enhanced rate. Furthermore, we show how the interplay of thermal and quantum fluctuations in such nonlinear systems can lead to an interesting stochastic cooling process. In this context, we also discuss the relevance of dissipative couplings for quantum annealing procedures.

[1] D. Maile et al., Phys. Rev. B 106, 045408 (2022)

DY 35.3 Thu 15:30 H31

Thermodynamic and energetic constraints on out-of-equilibrium tunneling rates — Ludovico Tesser[1], •Matteo Acciai[2,1], Christian Spånslätt[3,1], Inès Safi[4], and Janine Splettstoesser[1] — [1]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Göteborg, Sweden — [2]Scuola Internazionale Superiore di Studi Avanzati, Trieste, Italy — [3]Department of Engineering and Physics, Karlstad University, Karlstad, Sweden — [4]Laboratoire de Physique des Solides, CNRS-Université Paris-Sud and Paris-Saclay, Orsay, France

We consider a bipartite quantum system, where the two parts are kept at different temperatures and are connected by a tunnel coupling. In this setup, we show that the out-of-equilibrium tunneling rates between the two subsystems (depending on the applied temperature bias) are bounded by two constraints. The derived bounds are related to the dissipated heat and the absorbed energy neede to establish and deplete the temperature bias, thus providing a thermodynamic and energetic constraint on the tunneling rates.

Except for the restriction to the tunneling regime, our results are valid for arbitrary Hamiltonians of the two subsystems, that can include generic many-body interactions. The derived bounds thus apply to a large class of systems, such as molecular junctions and coupled cavities, and can be tested by measuring the out-of-equilibrium tunneling current and its fluctuations.

Based on: arXiv:2409.00981

DY 35.4 Thu 15:45 H31

Colored noise Langevin equation for photon counting — •Steven Kim and Fabian Hassler — Institute for Quantum Information, RWTH Aachen, Germany

For open quantum systems, obtaining the photon counting statistics of the emitted radiation is central to obtain insights into phenomena such as entanglement and correlations, in particular super- and anti-bunching. Typically, these systems are described by a Lindblad master equation, which allows the counting statistics to be derived from normal-ordered number operators. However, the Lindblad equation relies on the rotating wave approximation (RWA), which assumes that the dissipation rate is much smaller than the characteristic photon frequency. While this requirement is always fulfilled at optical frequencies, microwave cavities can have broader linewidths, making the RWA inaccurate. Alternatively, such systems can be effectively described by an equivalent Langevin equation with correlated (colored) noise, which bypasses the need for the RWA. In this work, we derive the photon counting statistics directly from the Langevin equation, providing a broader framework for understanding photon emission in open quantum systems.

DY 35.5 Thu 16:00 H31

Quantum stochastic resonance in a periodically-driven quantum dot — •Johann Zöllner[1], Hendrik Mannel[1], Eric Kleinherbers[2], Marcel Zöllner[1], Nico Schwarz[1], Fabio Rimek[1], Andreas Wieck[3], Arne Ludwig[3], Axel Lorke[1], Martin Geller[1], and Jürgen König[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen — [2]Department of Physics and Astronomy, University of California, Los Angeles — [3]Faculty of Physics and Astronomy, Ruhr University Bochum

The combination of periodic driving and fluctuations in a system with an inherent noise source leads to stochastic resonance, where the synchronization of the system dynamics with the external drive leads to an enhanced signal-to-noise ratio. This phenomenon has been found in many different noisy systems in palaeoclimatology, biology, medicine and physics. The classical stochastic resonance with thermal noise has recently been experimentally extended to the quantum regime, where the fundamental randomness of individual quantum events is the noise source [1]. Here we demonstrate quantum stochastic resonance in the single-electron tunneling dynamics of a periodically driven single self-assembled quantum dot, tunnel-coupled to an electron reservoir [2]. We extend the statistical evaluation to factorial cumulants to gain a deeper understanding of the transition between stochastic and deterministic transport through the quantum dot.

[1] T. Wagner et al., Nat. Phys. 15, 330 (2019).
[2] A. Kurzmann et. al., Phys. Rev. Lett. 122, 247403 (2019).

DY 35.6 Thu 16:15 H31

Curvature-assisted high harmonic generation in strongly-driven superconductors — •Björn Niedzielski and Jamal Berakdar — Institut für Physik, Martin-Luther Universität Halle-Wittenberg, Halle/Saale 06099, Germany

Superconductors (SCs) under strong driving fields show inherently

nonlinear dynamics, offering potential for nonlinear optics and high harmonic generation. However, the weak coupling of SCs to homogeneous transverse fields limits their efficiency. Here, we show that introducing curvature to mesoscopic type-II SC structures enables enhanced coupling to strong THz fields. Applied transport currents further allow for controlled emission of even and odd-order harmonic light modes.

The enhanced coupling of SCs and light arises from geometric and finite-size effects steering supercurrents while preserving the coherence of the SC state. Using the time-dependent Ginzburg-Landau framework, we simulate the dynamics of the superconducting order parameter in nanostructures with large coherence lengths under near-gap driving frequencies. Our simulations reveal the time-dependent supercurrents and their contributions to dipole radiation and high harmonic generation.

Our results highlight the role of the SC geometry and finite-size effects for amplifying nonlinear optical responses, offering a new method to use SCs for nonlinear THz optics.

15 min. break

DY 35.7 Thu 16:45 H31

Quantum oscillations in magneto-thermoelectrical conductivities of 2DEG: The Keldysh field-theoretical approach — •Kitinan Pongsangangan — Mahidol University, Bangkok, Thailand

The purpose of this work is to formulate a kinetic theory describing transport properties of interacting electrons in a uniform magnetic field of arbitrary magnitude. Exposing an electronic system to a constant magnetic field quenches its energy bands into a series of discrete energy levels, known as Landau levels. Following Keldysh formalism, we derive the quantum kinetic equation with the Landau-level basis. The Landau-level states, exact solutions of the Schroedinger equation in a constant background magnetic field, are natural and suitable basis to use, especially, for the investigation of strong-magnetic-field phenomena. In the weak-field limit, the lowest order approximation of the quantum kinetic equation reduces to a Boltzmann equation into which the magnetic field enters as the Lorentz force. As an application of our quantum transport equation, we calculate magneto-thermoelectric coefficients of a disordered two-dimensional electron gas (2DEG) in the quantum hall regime interacting with acoustic phonons.

DY 35.8 Thu 17:00 H31

Typical medium theory for disordered electronic systems on simple lattices with Cauchy distribution of on-site potentials — Andreas Ostlin[1], Hanna Terletska[2], Dylan Jones[1], and •Liviu Chioncel[1,3] — [1]Institute of Physics, University of Augsburg, Augsburg, Germany — [2]Middle Tennessee State University, Murfreesboro, Tennessee, USA — [3]ACIT, University of Augsburg, Augsburg, Germany

Effective medium approaches using single-site averaging procedures of various kinds contributed substantially in understanding the density of states of electronically disordered systems in models and materials. The nature and the conditions for appearance of single-particle (Anderson) localization seems to be qualitatively understood, yet discussions concerning special applied methods and quantitative results for the critical conditions are still ongoing. Here we present results using the typical medium theory for the one-particle and two-particle Green's function (conductivities) for the special case of Cauchy-distribution.

DY 35.9 Thu 17:15 H31

Dynamical current as tool to distinghuish degenerate spin states in open-shell graphene nanoribbons — •Nico Leumer, Thomas Frederiksen, and Geza Giedke — Donostia International Physics Center

The recent advances of surface synthesis unlocked the potential of open-shell physics in graphene nanoribbons (GNRs) which ever since have gained significant attention. Normally chemically unstable, these structures feature unpaired, localized p_z-electrons pinned at zero energy, giving rise to the unique phenomenon of π-magnetism. Intrinsically low spin-orbit/hyperfine interactions suppress spin relaxation, making GNRs ideal for tunable spin physics and spintronics applications. Although scanning probe techniques provide the necessary access to electron's spins and their interactions, state preparation, manipulation and detection remains an open challenge. Our ambition addresses the latter.

At half-filling certain GNRs host quasi degenerate spin singlets/triplets states with a vanishing energy gap for long ribbons. Without significantly increasing the gap, e.g., via magnetic fields, conventional current-based measurements hardly distinguish these spin textures. However, and even for absent gap, we demonstrate that in our setup $I(t)$ discriminates between the responsible states by exploiting the states's distinct spatial profiles. To probe the spatial information, we apply a constant bias between two STM tips. The scheme is suitable for single shot measurements and a quantum master equation (Hubbard model) accounts for the time evolution (GNR).

DY 35.10 Thu 17:30 H31

Josephson force in a vibrating carbon nanotube Josephson junction — •Andreas K. Hüttel[1,2], Jukka-Pekka Kaikkonen[2], Keijo Korhonen[2], and Pertti Hakonen[2] — [1]Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany — [2]Low Temperature Laboratory, Dept. of Applied Physics, Aalto University, Espoo, Finland

A single carbon nanotube suspended between superconducting electrodes acts simultaneously as nanomechanical resonator and as Josephson junction. Its energy-dependent density of states and thus displacement-dependent Josephson energy couple electronics and mechanics. Measurements on such a system display complex behaviour of the vibrational resonance with respect to junction biasing; strikingly, the resonance frequency decreases in a distinct parameter region where the bias is similar in size to the junction switching current.

We numerically solve the coupled differential equation system of the driven (via an ac gate voltage and an ac bias) system for realistic device parameters, using highly parallelized Julia code, and characterize the evolving steady state. Specific attention is given to the effect of the Josephson junction behaviour on the mechanical resonance frequency and the vibration amplitude. In the numerical results, we observe a clear impact of superconductivity on the mechanical response, with a rather counterintuitive dependence on externally tunable parameters.

DY 35.11 Thu 17:45 H31

Tunable nonlinear Duffing response of a driven carbon nanotube nanomechanical resonator — •Akong Loh, Furkan Özyigit, Fabian Stadler, Katrin Burkert, Niklas Hüttner, and Andreas K. Hüttel — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

Extremely lightweight and with very high quality factors, Carbon nanotube nanomechanical resonators have been used as ultrasensitive force, mass, and charge sensors [1-5]. When suspended on source and drain leads and gated, a CNT nanomechanical resonator can also be operated as a quantum dot. The motion of the nanotube is strongly coupled to single electron tunneling, dominating the nonlinear response [1-5]. Control of the strong nonlinear dynamics of a CNT will be useful for engineering mechanical qubits with information stored in the vibrations and mechanical Schrödinger's cat states [3]. Here, we analyze the nonlinear vibrational response of a driven CNT quantum dot, at ∼10mK in a dilution refrigerator and with opaque tunnel barriers to minimize dissipation. We demonstrate how the nonlinearity parameters of the coupled system can be controlled via Coulomb blockade and the associated gate voltage, leading to a rich interplay of frequency, damping, and Duffing behavior.

[1] A. K. Hüttel *et al.*, Nano Lett. 9, 2547 (2009).
[2] G. A. Steele *et al.*, Science 325, 1103 (2009).
[3] C. Samanta *et al*, Nat. Phys. 19, 1340 (2023).
[4] S. Blien *et al.*, Nat. Commun. 11, 1636 (2020).
[5] N. Hüttner *et al.*, Phys. Rev. Appl. 20, 064019 (2023).

DY 35.12 Thu 18:00 H31

Vibrational instabilities in molecular nanojunctions: A mixed quantum-classical analysis — •Martin Mäck, Samuel Rudge, Riley Preston, and Michael Thoss — Institute of Physics, University of Freiburg

Understanding the current-induced vibrational dynamics in molecular nanojunctions is critical for gaining insight into the stability of such systems. While it is well known that Joule at higher bias voltages plays an important role for the stability of the nanojunction, a different mechanism caused by current-induced nonconservative forces has been reported to cause vibrational instabilities already at much lower voltages [1].

In this contribution, we apply a mixed quantum-classical approach based on electronic friction and Langevin dynamics [2,3] to a model system for which vibrational instabilities have previously been reported.

Such a mixed quantum-classical description has the benefit of giving valuable insight into the electronic forces acting on the molecular vibrations. We analyze the possible occurrence of vibrational instabilities and compare our results to previous approaches, which were limited to small amplitude motion of the vibrational degrees of freedom [1].
[1] J.-T.Lü, M.Brandbyge, P.Hedegård, Nano Lett. **10**, 1657 (2010).
[2] S.L.Rudge, C.Kaspar, R.L.Grether, S.Wolf, G.Stock, M.Thoss, J.Chem. Phys.**160**, 184106 (2024).
[3] R.J.Preston, D.S.Kosov, J.Chem.Phys.**158**, 224106 (2023).

DY 35.13 Thu 18:15 H31

Vortex shedding in superfluid He-4 and in a Bose-Einstein condensate — •Wilfried Schoepe — Fakultät für Physik, Universität Regensburg, D-93040 Regensburg, Germany

Our experiments on vortex shedding from a microsphere oscillating in superfluid He-4 at mK temperatures is compared with experiments on vortex shedding from a laser beam moving in a Bose-Einstein condensate as observed by other authors. In either case a linear dependence of the shedding frequency fv=a(v-vc) is observed a above some critical velocity vc for the onset of turbulence and the coefficient a is proportional to the oscillation frequency f above some characteristic value and assumes a finite value for steady state motion f=0. An analytical relation between the superfluid Reynolds number and the superfluid Strouhal number is presented.

DY 36: Microswimmers and Microfluidics (joint session DY/BP/CPP)

Time: Thursday 15:00–17:45 Location: H37

Invited Talk DY 36.1 Thu 15:00 H37

Light-Driven Manipulation of Passive and Active Microparticles — •Svetlana Santer — Institute of Physics and Astronomy, University of Potsdam, Germany

Chemical gradient near a solid/liquid can result in lateral long-range fluid transport termed diffusioosmotic (DO) flow. For instance, when photosensitive surfactant is irradiated with light converting the majority of the molecules in one of the possible isomers, emerging concentration gradient of isomers generates an osmotic pressure gradient tangent to the wall actuating the surrounding liquid to flow. [1-3] In my talk I will show how one can manipulate microparticles and even induce their self-propulsion by light urtilizing light driven diffusioosmotic (LDDO) phenomenon. Depending on the applied wave length one can either disperse/remove or gather particles. We will discuss how to establish light-driven hydrodynamics as a useful and versatile tool for investigating collective motion of self-propelled particles and aggregation

[1] Feldmann, D.; Maduar S.R.; Santer, M.; Lomadze, N.; Vinogradova O.I.; Santer, S. Scientific Reports, 6 (2016) 36443. [2] Santer, S. J. Phys. D: Applied Physics, 51 (2017) 013002. [3] Arya, P.; Umlandt, M.; Jelken, J.; Feldmann, D.; Lomadze, N.; Asmolov , E. S.; Vinogradova, O. I.; Santer, S. A. The European Physical Journal E, 44(50) (2021), 1-10.

DY 36.2 Thu 15:30 H37

Regulated polarization of active particles in local osmotic flow fields — •Lisa Rohde, Desmond Quinn, Diptabrata Paul, and Frank Cichos — Molecular Nanophotonics Group, Peter Debye Institute for Soft Matter Physics, University Leipzig, Leipzig, Germany

Regulation in living systems is a fundamental principle for achieving robust functionality and maintaining specific non-equilibrium states. The control of certain properties and functionalities of systems on the microscale presents particular challenge since thermal fluctuations and environmental perturbations dominate. While synthetic active matter has demonstrated remarkable self-organization capabilities, examples of autonomous regulation processes at the single-particle level remain scarce. Here, we show experimentally that the interplay of two non-equilibrium processes leads to a regulated polarization state of active particles in local osmotic flow fields. Based on thermophoretic repulsive and attractive forces that are generated by a single heat source at the boundary, the active particles encircle the heat source at a stable distance depending on the heat source temperature. The balance of these temperature-induced processes causes a polarization of the active particles that is independent of the heat source temperature. The individual control of heat source and active particles in the experiment allows detailed investigation of the self-regulated polarization effect in which we find hydrodynamic interactions to dominate. As the effects rely on osmotic flows and phoretic interactions, we expect that the observed phenomena can be generalized to other active systems and flow fields.

DY 36.3 Thu 15:45 H37

Active particle steering in three dimensions — •Gordei Anchutkin and Frank Cichos — Molecular Nanophotonics Group, Peter Debye Institute for Soft Matter Physics, Leipzig University, Leipzig, Germany

Synthetic active particles serve as a model system that mimic the self-propulsion of living matter to explore fundamental aspects of non-equilibrium physics. Various collective phenomena of active agents have been studied, but mostly in the presence of hydrodynamic and physicochemical boundary effects. While theoretical works predict different collective dynamics in 3D, experimental investigations remain limited due the lack of experimental control over active swimmers in three dimensions.

Here we introduce three-dimensional control to the study of synthetic active matter. We demonstrate simultaneous control of thermophoretic microswimmers in 3D using single-particle tracking through digital holography and darkfield pattern tracking, with real-time wavefront shaping for steering. With the help of these experiments, we explore the interplay of thermophoretic propulsion, gravity, and optical forces for the active particles. By creating a three-dimensional active ensemble, we reveal how bulk interactions and boundary effects shape the collective behavior of active particles.

DY 36.4 Thu 16:00 H37

***Trypanosoma brucei* in microchannels: the role of constrictions** — •Zihan Tan, Julian I. U. Peters, and Holger Stark — Institute of Theoretical Physics, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Trypanosoma brucei (*T. brucei*), a single-celled parasite and natural microswimmer, is responsible for the fatal sleeping sickness in infected mammals, including humans. Understanding how *T. brucei* interacts with fluid environments and navigates through confinements is crucial for elucidating its movement through blood vessels and tissues, and across the blood-brain barrier.

Using a hybrid multiparticle collision dynamics (MPCD)–molecular dynamics (MD) approach, we investigate the locomotion of an in-silico *T. brucei* in three types of fluid environments: bulk fluid, straight cylindrical microchannels, and microchannels with constrictions. We observe that the helical swimming trajectory of the in-silico *T. brucei* becomes rectified in straight cylindrical channels compared to bulk fluid. The swimming speed for different channel widths is governed by the diameter of the helical trajectory. The speed first slightly increases as the channel narrows and then decreases when the helix diameter is compressed. An optimal swimming speed is achieved when the channel width is approximately twice the bulk helix diameter. Furthermore, *T. brucei* notably slows down when entering the narrow constriction in a microchannel and strongly speeds up upon exiting due to a release of deformation energy of the straightened cell body.

DY 36.5 Thu 16:15 H37

Helical motion of microorganisms can be more persistent than straight motion — •Leon Lettermann[1], Falko Ziebert[1], Mirko Singer[2], Freddy Frischknecht[2], and Ulrich S. Schwarz[1] — [1]BioQuant & Institute for Theoretical Physics, Heidelberg University — [2]Center for Integrative Infectious Disease Research, Heidelberg University

The movement of microorganisms has been extensively modeled by stochastic active particle models. In three dimensions, both swimming microorganisms, like sperm cells and some bacteria, and gliding microorganisms, like malaria sporozoites in the skin, often exhibit helical trajectories. If the internal driving force is the primary source of noise in the system, it induces random, yet time-correlated variations in the torque. To investigate this effect, we introduce a three-dimensional

active rotational Ornstein-Uhlenbeck particle model. We find that the presence of a rotational component and the resulting helical path can mitigate the effect of intrinsic noise in the drive, allowing for larger long-time mean square displacements than straight movement at the same speed. The model not only provides qualitative insights into the constraints faced by microbes that may have led to the evolutionary selection of certain motility patterns, but also presents an analytical, quantitative tool for extracting information from these movements. We present and analyze corresponding data for malaria parasites gliding through hydrogels.

15 min. break

DY 36.6 Thu 16:45 H37

Corrugated channels can filter ciliated microorganisms based on the metachronal wavelength — •Gonçalo Antunes and Holger Stark — Technische Universität Berlin, Institute of Theoretical Physics, Hardenbergstr. 36, 10623 Berlin, Germany

Many microorganisms (e.g. Paramecium) move by a carpet of cyclically beating cilia that cover their surface. These cilia often beat in an organized fashion, such that the beating phases form a traveling wave, referred to as a metachronal wave. In this study, we investigate the swimming of such microorganisms in corrugated microchannels. We model the motion of the cilia via a time-varying effective slip velocity applied on the microorganism's surface, which we approximate as an infinite slab. By employing the lubrication approximation, we show analytically that the swimming speed of ciliated microorganisms placed inside a corrugated channel is sensitive to the corrugation height, provided that the wavelength of the corrugation matches that of the metachronal wave. Indeed, the direction of motion itself may invert with respect to swimming in bulk fluid, with the channel acting as a virtual barrier which blocks microorganisms under specific conditions for corrugation and slip-velocity modulations, but allow others to pass through. We also show that the interplay between the corrugation and the slip velocity profile allows for the swimming of microorganisms with zero time-averaged slip velocity, which thus cannot swim in bulk fluid. Finally, we complement our theory with preliminary results from hydrodynamic simulations for radially-symmetric microorganisms of finite length in radially-symmetric corrugated channels.

DY 36.7 Thu 17:00 H37

Motion of a single particle partially exposed in a simple shear flow — •Dominik Geyer[1,2], Aouane Othmane[1], and Jens Harting[1,2] — [1]Helmholtz-Institut Erlangen-Nürnberg for Renewable Energy (IET-2), FZ Jülich — [2]Department of Physcis, FAU Erlangen-Nürnberg

Sand immersed in the water can be imagined as a wet granular matter. Besides sedimentation, friction, and surface roughness are two relevant physical phonemes within this system. Many body systems in a turbulent regime have been studied using discrete elements methods for a long time, but a single particle in the Stokes flow regime is particularly interesting for biological systems and microfluidic devices.

A layer of quadratic-arranged spheres models the rough surface. The question arises of how to describe the motion of a single traveling particle over this substrate.

We choose a combined numerical and analytical approach. The Stokes equation is solved analytically for the sphere near a rough wall. Lattice Boltzmann simulations with momentum-exchange particle coupling are performed for different wall roughness and friction coefficients.

Although, the Stokes equation assumes that the particle Reynolds number is zero. Surprisingly, the numerical results match our theoretical description until a particle Reynolds number of two. In this regime, friction between the moving particle and the substrate significantly influences the angular velocity but has a minor influence on the traveling velocity in the flow direction.

DY 36.8 Thu 17:15 H37

Rational Design of Smart Microfluidics in Responsive Channels — •Arwin Marbini — Albert-Ludwigs Universität Freiburg

Responsive microfluidics offers exciting potential for self-regulating biomimetic systems. This study explores bifurcating microchannel networks with pressure-sensitive resistances, combining experiments with simulations based on the Hagen-Poiseuille equation and a linear model. These methods extract critical, experimentally inaccessible parameters under steady-state and dynamic conditions. Our findings enable the design of adaptable microfluidic networks, unlocking precise flow control for future applications in biology, soft robotics, and advanced material systems.

DY 36.9 Thu 17:30 H37

Blue Water: A passive, reusable microfiltration device for water purification — •Tim R. Baumann, Ioannis Gkekas, Martina Viefhues, and Dario Anselmetti — Experimental Biophysics, Bielefeld University

Water is the most vital resource for life on Earth. Due to pollution of freshwater and oceans, this valuable resource has become globally endangered. The effects of microplastic pollution are widely discussed in scientific, political, and socioeconomic contexts. Despite regulations on single-use plastics and microplastic output, efforts should also focus on reintegrating microplastics to achieve a sustainable circular economy. Furthermore, microplastic-sized particles can migrate through organic tissue and can therefore be classified as contaminants of emerging concern. However, filtering plastics of this size is a challenging task.

Thus, this work examines and extends the findings of Divi et al. regarding the suspension feeding mechanisms of various ray species. We studied the filtration performance and efficiency for different geometric ratios of channel widths in simulations and laboratory environments. First, we have the main inner channel connected to the pressure inlet. From this, two rows of tilted lamellae structures branch off laterally to the outer secondary channels.

By applying sufficiently high pressure ($> 6 \cdot 10^5\ Pa$) to the inlet and achieving flow and particle velocities of $> 35\ \frac{m}{s}$, we can purify 82 % of half of the initial fluid. To prevent rupturing of our microfluidic chip under this pressure, we further investigated using glass fiber reinforced PDMS and lowering the operating pressure.

DY 37: Brownian Motion and Anomalous Diffusion

Time: Thursday 15:00–17:15 Location: H43

DY 37.1 Thu 15:00 H43

A universal class of exactly solvable diffusions — •Costantino Di Bello[1], Edgar Roldan[2], and Ralf Metzler[1] — [1]Potsdam University, Institute of Physics and Astronomy, Potsdam-Golm, Germany — [2]ICTP, Quantitative Life Sciences section, Trieste, Italy

We consider a general one-dimensional overdamped diffusion model described by the Ito stochastic differential equation (SDE) $dX_t = \mu(X_t, t)dt + \sigma(X_t, t)dW_t$, where W_t is the standard Wiener process. We obtain a specific condition that μ and σ must fulfill in order to be possible to solve the SDE via mapping the generic process, using a suitable space-time transformation, into the simpler Wiener process. By taking advantage of this transformation, we obtain the propagator in the case of open, reflecting, and absorbing boundary conditions for a large class of diffusion processes. With the same technique, we were also able to derive the first passage time (FPT) statistics of a large class of models. Moreover, as many physical observables in stochastic thermodynamics are described by an SDE of the same form, our result can provide the analytical expression of the probability distribution of many observables like work, entropy et similia. We stress the fact that our results are valid for many non-autonomous, non-linear and non-homogeneous processes.

DY 37.2 Thu 15:15 H43

Thermodynamic bounds on generalized transport: From single-molecule to bulk observables — •Cai Dieball and Aljaž Godec — Mathematical bioPhysics Group, Max Planck Institute for Multidisciplinary Sciences, 37077 Göttingen, Germany

We prove that the transport of any scalar observable in d-dimensional non-equilibrium systems is bounded from above by the total entropy production scaled by the amount the observation "stretches" microscopic coordinates. The result, a time-integrated generalized speed limit, reflects the thermodynamic cost of transport of observables, and places underdamped and overdamped stochastic dynamics as well as deterministic motion on equal footing. Our work fills an important gap in thermodynamic inference, since microscopic dynamics is, at least for short times, underdamped. Requiring only averages but not sample-to-sample fluctuations, the proven transport bound is practical and applicable not only to single-molecule but also bulk experiments where only averages are observed, which we demonstrate by examples.

[1] Phys. Rev. Lett. 133, 067101 (2024)

DY 37.3 Thu 15:30 H43

Foundation of classical dynamical density functional theory: uniqueness of time-dependent density–potential mappings — Michael Andreas Klatt[2,3,1], •Christian Bair[1], Hartmut Löwen[1], and René Wittmann[1,4] — [1]Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität, Düsseldorf, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für KI Sicherheit, Ulm, Germany — [3]DLR, Institut für Materialphysik im Weltraum, Köln, Germany — [4]Institut für Sicherheit und Qualität bei Fleisch, Max Rubner-Institut, Kulmbach, Germany

When can we uniquely map a classical density profile to an external potential? In equilibrium, without time dependence, the one-body density is known to uniquely specify the external potential that is applied to the many-body system. This mapping from a density to the potential is the cornerstone of classical density functional theory (DFT). Here, we consider non-equilibrium, time-dependent many-body systems that evolve from a given initial condition. We derive explicit conditions, for example, no flux at the boundary, that ensure that the mapping from the density to a time-dependent external potential is unique. We thus prove the underlying assertion of dynamical density functional theory (DDFT) - without resorting to the so-called adiabatic approximation often used in applications. By ascertaining uniqueness for all n-body densities, we ensure that the proof - and the physical conclusions drawn from it - hold for general superadiabatic dynamics of interacting systems.

DY 37.4 Thu 15:45 H43

Phase locking and fractional Shapiro steps in collective dynamics of microparticles — •Seemant Mishra[1], Artem Ryabov[2], and Philipp Maass[1] — [1]Institut für Physik, Universität Osnabrück, Germany — [2]Charles University, Faculty of Mathematics and Physics, Czech Republic

Nonlinear systems under time-periodic driving often exhibit phase locking, where synchronization between the system's dynamics and driving leads to robust stationary states. In this work, we show that phase-locked dynamics in a driven system of hardcore-interacting microparticles arises from running solitary cluster waves. Such cluster waves were recently predicted to occur in overdamped Brownian motion [1,2] and shortly after confirmed in experiments [3]. Particle currents are related to soliton velocities due to a unit displacement law saying that the total average shift of all particle positions per soliton period equals one wavelength of the periodic potential. The collective particle dynamics synchronize with the driving for certain particle diameters only. Based on an effective potential for solitary wave propagation, we derive dynamical phase diagrams of integer and fractional synchronization modes.

[1] A. P. Antonov, A. Ryabov, P. Maass, Phys. Rev. Lett. 129, 080601 (2022).
[2] A. P. Antonov, A. Ryabov, P. Maass, Chaos, Solitons & Fractals 132, 115079 (2024).
[3] E. Cereceda-López, A. P. Antonov, A. Ryabov, P. Maass, and P. Tierno Nat. Commun. 14, 6448 (2023).

DY 37.5 Thu 16:00 H43

Modeling charge attachment induced ion transport in glasses — •Quinn Emilia Fischer and Philipp Maass — Department of Physics, Universität Osnabrück, Germany

In charge attachment induced ion transport (CAIT), material foreign mobile ions can replace native mobile ions near the surface of a glass below the glass transition temperature. Insight into the ion dynamics during CAIT experiments is provided by measurements of near-surface concentration profiles.

We discuss the modeling of concentration profiles by coupling the Poisson equation to kinetic equations of linear irreversible thermodynamics. Solving the kinetic equations requires knowledge on the dependance of both the Onsager coefficients and chemical potentials of the mobile ions on the ion concentrations.

We show how chemical potentials can be derived for a model, where mobile ions occupy sites in a disordered energy landscape, and how Fermi energies are generalized to a system of multiple ion types. We further explain the determination of Onsager coefficients by modeling thermally activated hopping motion in the energy landscape and the relation between the coefficients and ion mobilities.

The dependence of both the Onsager coefficients and the chemical potentials on mobile ion concentration is sensitive to the form of the energy landscape. It is argued that this sensitivity needs to be taken into account in a consistent theoretical modeling of CAIT experiments, which requires solutions of the coupled Poisson and kinetic equations to reproduce measured concentration profiles.

DY 37.6 Thu 16:15 H43

Local and Diffusive Dynamics of Interlayer Lithium ions in Synthetic Fluoro-Hectorites: ^{2}H and^{7}Li NMR-Study — •Jepsinraj Kakkuzhiyulla Parambath and Michael Vogel — TU Darmstadt, Institut for Condensed Matter Physics, Hochschulstr. 6, 64289, Darmstadt, Germany

Investigating ion transport is a crucial part of developing robust devices for energy storage and sensors. Fluoro-Hectorite, a clay mineral of the Smectite group serves as a model material for this investigation, specifically Lithium Hectorite with the structural formula of $Li_{0.5}[Mg_{2.5}Li_{0.5}]Si_4O_{10}F_2$ and a layered structure. Due to the swelling properties of the Hectorites, the interlayer spacing and thus the degree of confinement can be varied with water content. The charge transports results from interlayer lithium ions, which are dissolved in water. The Hectorite confinements provide mechanical stability and guide the charge carriers over long distances, leading to fast ion transport [Hiebl et al., Chem. Mater. 2020, 32, 7445]. We use ^{2}H and ^{7}Li NMR to study the dynamics of the interlayer water molecules and lithium ions. Spin lattice relaxometry studies of local dynamics, including field cycling and static field gradient(SFG) measurements of diffusive dynamics show a strong dependence on the interlayer spacing.

DY 37.7 Thu 16:30 H43

Random Walks of Intermittently Self-Propelled Particles — Agniva Datta[1], Carsten Beta[1,2], and •Robert Grossmann[1] — [1]University of Potsdam, Potsdam, Germany — [2]Kanazawa University, Kanazawa, Japan

We present a dynamical model of intermittently self-propelled particles: active particles that recurrently switch between two modes of motion, namely an active run-state and a turn state, in which self-propulsion is absent. The durations of these motility modes are drawn from arbitrary waiting-time distributions. We derive the expressions for exact forms of transport characteristics like mean-square displacements and diffusion coefficients to describe such processes. Furthermore, the conditions for the emergence of sub- and superdiffusion in the long-time limit are presented. We give examples of some important processes that occur as limiting cases of our system, including run-and-tumble motion of bacteria, Lévy walks, hop-and-trap dynamics, intermittent diffusion and continuous time random walks. We eventually apply this modeling framework to describe bacterial swimming in polysaccharide matrices.

DY 37.8 Thu 16:45 H43

First-passage time for generalized telegrapher's processes under stochastic resetting — •Trifce Sandev — Macedonian Academy of Sciences and Arts, Skopje, Macedonia — Ss. Cyril and Methodius University in Skopje, Macedonia — Korea University, Seoul, Korea

We consider different generalizations of the telegrapher's process. One possible generalization is the so-called subordinated telegrapher's process, which can be obtained from the standard telegrapher's process subordinated by Lévy noise. Another possible generalization is a heterogeneous telegrapher's process which is a stochastic process with a multiplicative dichotomic noise and a position-dependent velocity. For both cases we analyze the non-equilibrium stationary states approached in the long time limit, as well as the survival probability, the first-passage time density and the mean first-passage time in the presence of Poissonian stochastic resetting of the particle to the initial position.

1 T. Sandev, A Iomin, *Phys. Rev. E* **110**, 024101 (2024)

2 K. Górska, F. J. Sevilla, G. Chacón-Acosta, T. Sandev, *Entropy* **26**, 665 (2024)

3 P. Jolakoski, P. Trajanovski, A. Iomin, L. Kocarev, T. Sandev, sibmitted (2024)

DY 37.9 Thu 17:00 H43

Diffusion and Homogeneous Linewidth – Phthalocyanine on Solid Rare-Gas Clusters — •Philipp Elsässer, Arne Morlok, Ulrich Bangert, Li Yilin, Felix Riedel, Lukas Bruder, Frank Stienkemeier, and Tanja Schilling — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany

Doped clusters are an important tool in the spectroscopy of organic molecules and the study of basic properties of confined quantum systems. It is crucial in these structures to understand the characteristics of the configurations between dopant and cluster. The binding sites may vary over time due to diffusion. Because of this, the diffusion behavior is valuable to characterize doped clusters.

We have studied the diffusion of free-base phthalocyanine (H_2Pc) on solid, icosahedral, rare-gas clusters of argon and neon by molecular dynamics simulations. We observe on both systems that the spacial motion of H_2Pc is confined on a single face of the icosahedron. The rotational movement of the molecule shows a cluster-size dependent anomalous-diffusive behavior on a picosecond timescale. This overall anomalous diffusion is in agreement with the homogeneous line width broadening observed in action-based two-dimensional electronic spectroscopy experiments.

DY 38: Focus Session: Innovations in Research Software Engineering (joint session BP/DY)

Research software engineering (RSE) is an emerging field in science, with practitioners spanning a continuous spectrum from "researchers who code" to "software engineers developing for science". In Germany, a growing movement supported by deRSE e.V. is gaining recognition, and more institutions are acknowledging the increasing demand across various disciplines. This focus session will provide a platform to highlight recent advances in applications, tooling, and software in the fields of biophysics, dynamics, and statistical physics, as well as developments in the recognition and proliferation of RSE as a profession within our field and academia in general.

Organized by Simon Christ and Sophia Rudorf (Hannover).

Time: Thursday 15:00–18:00 Location: H44

Invited Talk DY 38.1 Thu 15:00 H44

Community-driven software and data training for computational biology — •Toby Hodges — The Carpentries, Oakland, CA, USA

The Carpentries is a global community teaching essential software and data skills for research. Certified Instructors teach hundreds of workshops to thousands of learners all over the world every year, introducing them to essential skills for computational research such as programming, version control, and data organisation. In recent years, the community has also begun to develop and deliver lessons that build on these foundations, teaching more intermediate and advanced Research Software Engineering skills such as HPC, parallel programming, and containerised computing. This talk will explore how open source, collaborative training efforts can build capacity for computational research, discuss what makes this model work and some lessons learned along the way, and finish with a look at what the community plans to do next.

DY 38.2 Thu 15:30 H44

Python-based interface to micromagnetic simulation software: Ubermag — •Hans Fangohr[1,2,3], Martin Lang[1,2], Samuel J.R. Holt[1,2], Swapneel Amit Pathak[1,2], Kauser Zulfiqar[1,2,4], and Marijan Beg[5] — [1]MPSD, Hamburg, Germany — [2]CFEL, Hamburg, Germany — [3]Univ. Southampton, UK — [4]Univ. Hamburg, Germany — [5]Imperial College London, UK

We describe the Python-based user environment "Ubermag" to help scientists use well-established (micromagnetic) simulation packages.

Within Ubermag [1], researchers can express the physics problem they want to simulate in a scientist-friendly but machine readable problem definition based on Python syntax [2]. Ubermag translates this problem into the configuration files needed for micromagnetic simulation packages such as OOMMF or mumax3. On completion of the simulation, the computed data is presented back to the user at the Python level. Ubermag is often used in Jupyter Notebooks, and supports rich media to provide figures and equations within the notebook.

We report on the motivation for Ubermag, the design and implementation process, and our experiences made both from the perspective of science users and from the research software engineers. We touch on a range of topics, including interface design, domain specific languages, testing, packaging, Jupyter, and reproducibility.

This work was supported by EPSRC UK Skyrmion Grant EP/N032128/1, and the European research projects OpenDreamKit (676541) and MaMMoS (101135546).

[1] DOI 10.1109/tmag.2021.3078896; [2] DOI 10.1063/1.4977225

DY 38.3 Thu 15:45 H44

OCTOPOS.jl: A Julia-based tool for synonymous codon optimization — Simon Christ[1], Jan-Hendrik Trösemeier[2], and •Sophia Rudorf[1] — [1]Institute of Cell Biology and Biophysics, Leibniz University Hannover, Germany — [2]independent researcher

OCTOPOS.jl is a research software designed to optimize synonymous mRNA sequences for improved heterologous gene expression in various host organisms. Combining a detailed mechanistic model of in-vivo protein synthesis with machine learning, OCTOPOS.jl predicts protein expression based on codon choice. Originally developed as a Java desktop application, the software has been reimplemented in the Julia programming language to enhance performance, modularity, and scalability. The new implementation serves as the foundation for a graphical user interface and a web application, accessible at https://octopos.cell.uni-hannover.de/. These updates improve accessibility and usability, broadening its appeal to both computational and experimental biologists. OCTOPOS.jl supports organism-specific genetic sequence engineering and detailed analysis of translation dynamics, thus providing a valuable resource for the synthetic biology and biotechnology communities.

DY 38.4 Thu 16:00 H44

Invert pattern forming systems with BayesFlow to bridge the gap from simulation to experimental observation — •Hans Olischläger — Interdisciplinary Center for Scientific Computing (IWR) — Heidelberg University

The description of experimental systems by complex spatial models, be it with (stochastic) partial differential equations, agent-based simulation or otherwise, is often the condensation of all the central scientific hypotheses regarding a particular object of study.

I argue, that making progress in this kind of modelling is currently hindered by the lack of a tool that enables solving the following inverse problem: Given an observation, determine all the model configurations that are able to produce it. In other words, what is the posterior probability of all model configurations given some (set of) experimental data.

Instead of just preaching that in theory a Bayesian treatment would be nice, I will then continue to present such a tool: amortized Bayesian inference (as implemented in the software package BayesFlow). I will give examples on the classical Gierer-Meinhardt pattern forming PDE and a biophysical model, the Min system, which is used by E. coli to control cell division.

I will also take a step back to give a broader picture of the newly available statistical methods that support complex spatial modelling and their limitations. The aim is to provide some guidance on what you can and cannot infer from your state-of-the-art scientific simulator given observations, and how to do it.

DY 38.5 Thu 16:15 H44

FAIR Data Management for Soft Matter Simulations using NOMAD — •Bernadette Mohr[1], Esma Boydas[1], Nathan Daelman[1], José M. Pizarro[1], Tristan Bereau[3], Claudia Draxl[1], Luca M. Ghiringhelli[4], Martin Girard[2], Denis Usvyat[6], Roser Valentí[7], Silvana Botti[5], and Joseph F. Rudzinski[1,2] — [1]CSMB, HU Berlin — [2]MPIP Mainz — [3]ITP, Heidelberg Uni. — [4]Dept. of Mater. Sci. and Eng., FAU Erlangen — [5]RC-FEMS and Faculty of Physics, RUB Bochum — [6]Inst. für Chem., HU Berlin — [7]ITP, GU FfM

NOMAD [nomad-lab.eu][1, 2] is an open-source, community-driven data infrastructure designed to facilitate FAIR data management in materials science. Currently, it supports over 60 computational codes and encompasses DFT, classical MD, and many-body methods. This contribution will focus on recent developments, following modern software practices, to enhance NOMAD's applicability to soft matter and biological systems, including support for coarse-grained representations and advanced workflows such as free energy calculations. Combined with a schema for representing force fields, molecular topologies, and hierarchical system structures, NOMAD tracks data provenance and streamlines data analysis and the creation of AI-ready datasets. The NOMAD framework meets the classical simulation community's needs for improved data management standards and provides a foundation for building a cohesive, interconnected scientific data ecosystem.

[1] Scheidgen, M. et al., JOSS 8, 5388 (2023).

[2] Scheffler, M. et al., Nature 604, 635-642 (2022).

DY 38.6 Thu 16:30 H44

Estimation of kinetic rates by constrained optimization — •Federico Marotta[1], Maria Zimmermann-Kogadeeva[1], Peer Bork[1], Julia Mahamid[1], and Sophia Rudorf[2] — [1]European Molecular Biology Laboratory — [2]Leibniz Universität Hannover

Biological systems often rely on molecular motors to perform useful work. The kinetics of the reactions in a motor's cycle can be easily investigated *in vitro* or in model organisms, but it is difficult to generalize them to a different system. We present a method to estimate the transition kinetics in an uncharacterized system, where minimal data are available, by leveraging a reference system where the kinetics have been elucidated. The motor's activity is represented as a continuous-time Markov chain, characterized by an infinitesimal generator matrix Q whose entries are functions of the transition rates of the cycle (the vector ω) and possibly of the concentrations of external molecules. In the uncharacterized system, the available data induce a constraint on the admissible rates. By employing an extremum principle, we estimate the rates ω_{unc} that minimize the kinetic distance with respect to the reference rates ω_{ref} while respecting such constraint. As an application of this strategy, we describe a model of the translation elongation cycle, where reference data are available for *E. coli in vitro*, and estimate the rates either *in vivo* or in a different organism, under constraints on the total elongation time or the steady-state occupancies, respectively.

DY 38.7 Thu 16:45 H44

Software provisioning for HPC and RSE — •Martin Lang[1,2], Henning Glawe[1,2], Jehferson Mello[1,2], and Hans Fangohr[1,2,3] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [2]Center for Free-Electron Laser Science, Hamburg, Germany — [3]University of Southampton, Southampton, UK

All research software relies on existing libraries for various functionalities such as low-level math operations, FFTs, IO, or other domain-specific operations. Installing these dependencies, potentially based on different compilers or in multiple versions, with all inter-dependencies fulfilled is notoriously difficult.

In the first part of this talk we introduce the open-source package manager Spack, which has a strong focus on HPC and research software. Spack can install software in multiple versions and variants, and supports optimised compilation for the underlying hardware, including compiling on exotic hardware. It comes with a large, community-provided collection of commonly used packages. Spack's packaging files make it easy to specify required dependencies, provide optional features of a software, and ensure compatibility with other libraries.

In the second part we present the concrete setup at our institute. We use Spack to provide the software stack on the local HPC, including pre-compiled packages and toolchains (sets of compilers and libraries) for users to compile their own software. We report on requirements and challenges, and how we address these with Spack. We also touch on scripting the Spack-based installation process including the option to recreate the HPC software environment on a scientist's laptop.

DY 38.8 Thu 17:00 H44

Small scale Research Software Engineering — •Simon Christ — Leibniz Universität Hannover, Institut für Zellbiologie und Biophysik, Computational Biology

While we are in dire need of research software organizations on a faculty level or larger, small scale software engineering, that is one research software engineer in a group or institute, is something that can be achieved in a short time frame and is probably the most common form today. A field report from Computational Biology where research software engineers are involved in modeling, developing solutions, teaching and maintenance.

DY 38.9 Thu 17:15 H44

Estimation of pKa values in membrane bound proteins — •Jesse Jones[1], Nereu Montserrat i Busquets[1,2], Ana Gamiz Hernandez[3], Ville Kaila[3], and Maria Andrea Mroginski[1] — [1]Technische Universität Berlin, Berlin — [2]Freie Universität Berlin, Berlin — [3]Stockholm Universität, Stockholm

Many key bioenergetic processes involving electron and proton reactions take place in membrane bound protein complexes, generating a proton motive force. Yet the ionizable groups which facilitate these reactions are often buried in hydrophobic pockets in the membrane. These processes are mainly described through pK_a values, which continue to be poorly understood and difficult to obtain despite structural, biochemical and computational advances. Hence, estimating pK_a values of these residues without the need for weeks of work in a laboratory, is important to describe the dynamics of the system, providing information on possible proton pathways. In this work we preview Karlsberg3, a software which uses a Poisson Boltzmann Equation solver (APBS) for proteins and calculates pKa values. Karlsberg3 is, in contrast to its predecessor Karlsberg2+, parallelized, running in modern software environments, and able to take membranes into

consideration.

DY 38.10 Thu 17:30 H44

The teachingRSE project - Towards a professionalization of RSE education. — •Florian Goth[1] and Simon Christ[2] — [1]Universität Würzburg, Institut für theoretische Physik und Astrophysik, Am Hubland, 97074 Würzburg — [2]Leibniz Universität Hannover, Institut für Zellbiologie und Biophysik, Herrenhäuser Str. 2 30419 Hannover

At the deRSE23, the second conference for research software engineering(RSE) in Germany, a group of people came together for a small workshop to discuss how to deal with questions revolving around RSE education. Overwhelmed by the immense resonance to that workshop we took home a tremendous amount of feedback that made obvious that a short blog post will not suffice to adequately represent it. Now it is two years later, and the project produced its first output, the second position paper https://arxiv.org/abs/2311.11457 of de-RSE e.V. and it has sprawled out into a multitude of follow-up projects. In this talk, I will give an overview over the original ideas that we tried to convey in the position paper, and go into more detail on how domain sciences like physics need to change in light of this new specialization.

DY 38.11 Thu 17:45 H44

Python-Based Analysis Pipeline for the Quantification of Mechanics in Neural Organoids — •Michael Frischmann[1,2], Elijah R. Shelton[1], Achim T. Brinkop[1,2], and Friedhelm Serwane[1,2,3] — [1]Faculty of Physics & Center for NanoScience, LMU Munich, Germany — [2]Institute of Biophysics, Ulm University, Ulm, Germany — [3]SyNergy & GSN, Munich, Germany

Neuronal tissues form under the influence of mechanical forces guiding cellular movements. In the mammalian retina, neuronal translocations occur over hours. However, mechanical probing at those timescales in situ have posed experimental challenges. We employed magnetic ferrofluid droplets in mouse stem cell-derived retinal organoids to probe tissue mechanics from seconds to hours. To quantify tissue strain we have developed a Python-based analysis pipeline featuring an accessible graphical user interface (GUI). This pipeline automates strain quantification, image segmentation, and fitting procedures, enabling high-fidelity creep compliance measurements over extended durations. Our measurements reveal power-law scaling of dynamic compliance as well as tensile loss and storage modulus, consistent with soft glassy rheology just above the glass transition. These results demonstrate that neuronal tissues remodel in a scale-free manner while maintaining solid-like properties. This discovery provides a framework for understanding how mechanical signals may govern connectivity in the central nervous system. Integrating neural organoid models, mechanical probing, and computational methods, prepares us to investigate the interplay between biomechanics and neurodevelopment.

DY 39: Machine Learning in Dynamics and Statistical Physics II

Time: Thursday 15:00–16:30 Location: H47

DY 39.1 Thu 15:00 H47

Fast and energy-efficient reservoir computing using a resonant-tunneling diode — •Osamah Sufyan[1], Antonio Hurtado[2], and Kathy Lüdge[1] — [1]Technische Universität Ilmenau, Institut für Physik, Weimarer Straße 25, 98693 Ilmenau, Germany — [2]University of Strathclyde, Institute of Photonics, Glasgow, United Kingdom

Resonant-tunneling diodes (RTDs) have garnered significant attention as platforms for neuromorphic computing, owing to their fast operation and intricate nonlinear dynamics. Among the most hardware-friendly and energy-efficient paradigms in this domain is reservoir computing (RC), where the nonlinear dynamics of a physical system are leveraged to perform complex computational tasks.

In this work, we explore the use of a single RTD as a reservoir, employing time-multiplexing techniques for chaotic time-series prediction achieving similar performance to previous RC approaches [1]. Our findings highlight the relationship between the RTD's distinct dynamical regimes and the reservoir's performance in predicting future values of the Mackey-Glass and Lorenz system time series. Additionally, we investigate the RTD as an excitable system, demonstrating its potential for spiking neural network applications. We examine various data encoding and decoding strategies for spike-based operations, further underscoring the versatility of RTDs in neuromorphic computing.

[1] L. Jaurigue and K. Lüdge, *Neuromorph. Comput. Eng.*, **4**, 014001 (2024).

DY 39.2 Thu 15:15 H47

Tailored minimal reservoir computing: Connecting nonlinearities in the input data with nonlinearities in the reservoir — Davide Prosperino[1], Haochun Ma[1], Vincent Gross[2], and •Christoph Räth[3,2] — [1]Allianz Global Investors (AGI) — [2]Ludwig-Maximilians-Universität (LMU) — [3]Deutsches Zentrum für Luft- und Raumfahrt (DLR)

The traditional setup of reservoir computing (RC) for predicting time series uses random matrices to define the underlying network and the input layer. Here, we show that a few modifications, which eliminate randomness and minimize computational resources and data requirements, lead to significant and robust improvements in short- and long-term predictive performance. We introduce block-diagonal reservoirs, which implies that a reservoir can be composed of multiple smaller reservoirs. Further, the non-linear activation function at the nodes can be dispensed with if the non-linear step in the analysis chain is shifted to the output layer. The input weights are determined according to well-defined rules. Any random initialization has thus been eliminated. By varying the remaining four hyperparameters, it is now possible to systematically investigate the transition from a linear, disjunct mapping of the input data to the output data to a combined nonlinear one. It is further demonstrated that there is a connection between the nonlinearities in the input data and the nonlinearities in the reservoir such that the best prediction results are obtained when both nonlinearities match. It becomes thus possible to define an optimally tailored setup for minimal RC for data sets with given nonlinearities.

DY 39.3 Thu 15:30 H47

Physical Reservoir Computing with Ferroelectric Oxides — •Atreya Majumdar[1], Yan Meng Chong[2], Dennis Meier[2], and Karin Everschor-Sitte[1] — [1]Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Duisburg, Germany — [2]Department of Materials Science and Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Physical reservoir computing has shown remarkable potential in magnetic systems by utilizing their complex, non-linear, and history-dependent intrinsic dynamics for machine learning tasks [1]. More recently, ferroelectric materials - the electrical analogs of magnetic systems - have garnered attention. These materials not only meet all the essential criteria for reservoir computing but also bring unique advantages [2]. Here, we introduce the ferroelectric semiconductor ErMnO3 as a novel physical reservoir. By utilizing the material's non-linear and history-dependent photocurrent response, we demonstrate its capability to recognize varying input light pulse intensities. This study highlights the potential of ferroelectric materials in physical reservoir computing, paving the way for energy-efficient and scalable computing architectures.

[1] O. Lee, et al., Perspective on unconventional computing using magnetic skyrmions. Appl. Phys. Lett. 122, 260501 (2023).

[2] K. Everschor-Sitte, A. Majumdar, et al., Topological magnetic and ferroelectric systems for reservoir computing. Nat. Rev. Phys. 6, 455 (2024).

DY 39.4 Thu 15:45 H47

Describing heat transport in crystalline polymers in real and reciprocal space — Lukas Reicht[1], Lukas Legenstein[1], Sandro Wieser[2], and •Egbert Zojer[1] — [1]Graz University of Technology, Austria — [2]TU Wien, Austria

Heat transport modelling either relies on describing the propagation of phonons employing the Boltzmann transport equation or on simulating the real-space dynamics of atoms using (non)-equilibrium molecular dynamics techniques. Due to the structural complexity of crys-

talline polymers both approaches call for a highly accurate but at the same time numerically extremely efficient strategy for describing interatomic interactions. This is achieved via machine-learned potentials, where we combine an efficient active-learning strategy with moment-tensor potentials.[1,2] Additionally, real-space and reciprocal space approaches make fundamentally different approximations regarding anharmonicities and phonon occupations. Here, we show that for polymers of intermediate complexity, like crystalline polythiophene, real- and reciprocal space approaches yield consistent values of the thermal conductivities at least when using an accurate machine-learned potential. Interestingly, for the seemingly much simpler crystalline polyethylene such an agreement is only obtained when higher-order phonon scattering is considered. This can be traced back to a selection rule arising from the comparably simple phonon band structure of polyethylene. [1] npj Comput Mater 10, 18 (2024); [2] Molecules 29, 3724 (2024)

DY 39.5 Thu 16:00 H47

Reinforcement learning for autonomous navigation of active particles in complex flow fields — •Diptabrata Paul and Frank Cichos — Peter Debye Institute for Soft Matter Physics, Universität Leipzig, 04103 Leipzig, Germany

Sensing and feedback on environmental stimuli are integral to regulating diverse functions in living systems, ranging from sub-cellular processes to evolution of navigation strategies such as chemotaxis and phototaxis. Unlike living systems, noisy artificial microswimmers have limited ability to adapt to various stationary and dynamic environmental perturbations to yield optimized behaviour for a given task. Consequently, reacting to such environmental cues becomes indispensable for achieving effective navigation and control in complex and noisy settings. In this context, we explore incorporation of machine learning algorithm for autonomous decision making for navigation of an active microswimmer within noisy environments. While naive navigation policies yield inefficient and ineffective solutions under changing conditions, employing actor-critic reinforcement learning (RL) framework trained in experiments leads us to quasi-optimal policies that are capable of navigating, even in presence of complex flow fields. Our study exhibits that a model trained under noisy conditions successfully learns effective navigation policies and are robust with respect to environmental perturbations such as hydrodynamic flow fields as well as varying initial conditions. This work paves the way for development of online RL for modelling adaptive behaviour and navigation of active microswimmers in complex fluidic scenarios.

DY 39.6 Thu 16:15 H47

Predictability Analysis of Discrete Time-Series Data with a Hamiltonian-Based Filter-Projection Approach — •Henrik Kiefer and Roland Netz — Freie Universität Berlin, Fachbereich Physik, Berlin, Deutschland

The generalized Langevin equation (GLE), derived by projection from a general many-body Hamiltonian, exactly describes the dynamics of an arbitrary coarse-grained variable in a complex environment. However, analysis and prediction of real-world data with the GLE is hampered by slow transient or seasonal data components and time-discretization effects. Machine-learning (ML) techniques work but are computer-resource demanding and difficult to interpret. We show that by convolution filtering, time-series data decompose into fast, transient and seasonal components that each obey Hamiltonian dynamics and, thus, can be separately analyzed by projection techniques. We introduce methods to extract all GLE parameters from highly discretized time-series data and to forecast future data including the environmental stochasticity. For daily-resolved weather data, our analysis reveals non-Markovian memory that decays over a few days. Our prediction accuracy is comparable to ML long short-term memory (LSTM) methods at a reduced computational cost compared to LSTM. For financial data, memory is very short-ranged and the dynamics effectively is Markovian, in agreement with the efficient-market hypothesis; consequently, models simpler than the GLE are sufficient. Our GLE framework is an efficient and interpretable method for the analysis and prediction of complex time-series data.

DY 40: Members' Assembly

Time: Thursday 18:00–19:00 Location: H43

All members of the Dynamics and Statistical Physics Division are invited to participate.

DY 41: Quantum Dynamics, Decoherence, and Quantum Information (joint session DY/TT)

Time: Friday 9:30–11:15 Location: H37

DY 41.1 Fri 9:30 H37

Entanglement phase transitions in unitary circuit games with free fermions — •Raúl Morral-Yepes[1,2], Marc Langer[1,2], Adam Smith[3,4], Barbara Kraus[1,2], and Frank Pollmann[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences — [2]Munich Center for Quantum Science and Technology (MCQST) — [3]School of Physics and Astronomy, University of Nottingham — [4]Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems

In the recently introduced framework of unitary circuit games, two competing parties an entangler and a disentangler can induce an entanglement phase transition, distinct from measurement-induced transitions. In this work, we study such games within the context of matchgate dynamics, which correspond to free fermion systems. First, we investigate the entanglement properties of fermionic Gaussian states (FGS) and explore different methods for their disentangling. We propose a representation of FGS using a minimal matchgate circuit in a standard form, and introduce algorithms for updating this representation as unitary operations are applied. Within this framework, we define a natural disentangling procedure that reduces the number of gates in the circuit, thereby decreasing the system's entanglement. We then analyze the unitary game using this gate disentangler, observing a phase transition between a volume-law and area-law entanglement phase. The nature of this transition differs depending on whether we examine Rényi-0 or other entanglement entropies.

DY 41.2 Fri 9:45 H37

Measurement Induced Entanglement Transitions in Random Qudit Clifford Circuits — •Aamod Vinayak Atre, Raúl Morral Yepes, and Frank Pollmann — Department of Physics, Technical University of Munich

Random quantum circuits with local projective measurements uncover the universal dynamical properties of generic chaotic quantum many-body systems, as their unitary evolution is independent of the microscopic features of Hamiltonians. Entanglement measures characterize these universal dynamics into volume-law and area-law regimes, which exhibit bipartite entropy scaling proportional to the system volume and system boundary respectively. This continuous entanglement scaling transition, driven by the rate of measurement, has been extensively studied in spin-1/2 (qubit) systems of various spatial geometries. In this talk, we discuss the characterization the entanglement transitions in 1D random quantum circuits of spins (qudits) with arbitrary local Hilbert-space dimension d. This work employs the generalized stabilizer formalism, taking advantage of the Clifford group which forms a unitary 2-design on the space of unitaries. We find the nature of the entanglement transition, from volume-law to area-law regimes, to be preserved for $d > 2$. The critical measurement density increases, converging to $1/2$ in the limit $d \to \infty$. Lastly, we describe the stabilizer dynamics in the limit $d \to \infty$, by a dynamical classical model.

DY 41.3 Fri 10:00 H37

Entanglement phases, localization and ergodicity of monitored free fermions in 2D — •Karim Chahine and Michael Buchhold — Institut für Theoretische Physik, Universität zu Köln, D-50937 Cologne, Germany

Monitored quantum systems, characterized by the interplay be-

tween unitary evolution and mid-circuit measurements, have recently emerged as a novel expression of quantum dynamics. Despite their inherently out-of-equilibrium nature, these systems can host robust quantum phases and display measurement-induced phase transitions (MIPT) in the entanglement entropy. Remarkably, they are also unique in providing a link between quantum dynamics in D dimensions and quantum statistical mechanics in $D+1$ dimensions. In this talk, I will present our recent work on a new arena with a rich phenomenology: continuously monitored, $U(1)$-symmetric free fermions in 2D. I will address the emerging MIPT and its similarities and differences with Anderson-type localization transitions. Some emphasis will be put on the low-measurement regime, where intriguing features in the entanglement structure and ergodic properties emerge, revealing a richer phenomenology than previously anticipated.

DY 41.4 Fri 10:15 H37

Spectral Properties and Magic generation of T-doped Random Clifford Circuits — •Dominik Szombathy — Budapest University of Technology and Economics

We investigate the spectral properties and magic generation of T-doped random Clifford circuits. There is a direct relation between the structure of Pauli string orbits and the eigenvalue spectrum of a Clifford circuit. Operatively, we sample the closed trajectories with brick-wall circuits and determine the distribution of the eigenvalues $\lambda = e^{i\Theta}$. The autocorrelation function of the phases of the eigenvalues displays peculiar properties: extreme degeneracies as well as some level-repulsion, and features reminiscent of a fractal pattern.

To investigate the stability of orbits and head towards universal quantum computation, we introduce $\pi/4$ phase shift gates (T-gates). We find that even a single T-gate completely changes the properties of the circuit. By increasing the number of T-gates (N_T), the correlation function rapidly approaches that of the random unitary circuits. Nevertheless, some statistically significant fraction of non-trivial orbits persists at low T-gate densities (N_T/N).

We observe a similar phenomenology in the magic generation as a function of T-gate density. In particular, we find universal scaling of the maximum and mean magic as a function of N_T/N . We also highlight the structure of magic generated by these circuits. Injecting a few T-gates the distribution is discrete but becomes continuous as N_T increases. At large densities N_T/N , most of the weight is found in a sharp peak well below the theoretical maximum.

DY 41.5 Fri 10:30 H37

Magic transition in measurement-only circuits — •Poetri Sonya Tarabunga[1,2] and Emanuele Tirrito[3,4] — [1]Technical University of Munich, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany — [3]The Abdus Salam International Centre for Theoretical Physics (ICTP), 34151 Trieste, Italy — [4]Dipartimento di Fisica "E. Pancini", Università di Napoli "Federico II", 80126 Napoli, Italy

Magic quantifies the distance of a quantum state to the set of stabilizer states, and it serves as a necessary resource for potential quantum advantage over classical computing. In this work, we study magic in a measurement-only quantum circuit with competing types of Clifford and non-Clifford measurements, where magic is injected through the non-Clifford measurements. This circuit can be mapped to a classical model that can be simulated efficiently, and the magic can be characterized using any magic measure that is additive for tensor product of single-qubit states. Leveraging this observation, we study the magic transition in this circuit in both one- and two-dimensional lattices using large-scale numerical simulations. Our results demonstrate the presence of a magic transition between two different phases with extensive magic scaling, separated by a critical point in which the mutual magic exhibits scaling behavior analogous to entanglement. We further show that these two distinct phases can be distinguished by the topological magic. In a different regime, with a vanishing rate of non-Clifford measurements, we find that the magic saturates in both phases.

DY 41.6 Fri 10:45 H37

Developing a Framework for Predicting Useful Quantum Advantage in the Calculation of Molecular NMR Spectra — •Keith Fratus, Andisheh Khedri, Juha Leppäkangas, Michael Marthaler, and Jan Reiner — HQS Quantum Simulations GmbH, Karlsruhe, Germany

Demonstrating useful quantum advantage remains a primary goal of quantum computing efforts in the NISQ era. Key to such efforts is the ability to estimate the accuracy and performance of competing classical approximation methods when exact comparisons are not available. In this talk we report on our efforts to develop and understand the behaviour of various classical approximation methods which aim to solve a specific class of chemical simulation problems. In particular, we develop classical simulation methods designed to predict molecular NMR spectra, with the aim of being able to quantify the accuracy and computational requirements of performing these simulations, even for parameter regimes which we do not directly simulate. Using such methods, we work towards a framework for predicting in which parameter regimes, system sizes, and target accuracies one can expect the failure of classical methods for this class of systems, thus allowing for the possibility of quantum advantage.

DY 41.7 Fri 11:00 H37

Linear differential equation approach to the Loschmidt amplitude — •Michael Vogl — King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

The Loschmidt amplitude is a popular quantity that allows making predictions about the stability of quantum states under time evolution. We present an approach that allows us to find a linear differential equation that can be used to compute the Loschmidt amplitude. This approach, while in essence perturbative, has the advantage that it converges at finite order. We demonstrate that the approach for generically chosen matrix Hamiltonians often offers advantages over Taylor and cumulant expansions even when we truncate at finite order. Even in low dimensional systems such as two band Hamiltonians (multi-Weyl semimetals and AB bilayer graphene) it can be used to obtain general formulas for the Loschmidt amplitude after a quench. Results readily generalize to find transmission amplitudes and specific contributions of the partition function, too. Our method can also be applied to many body spin and fermionic Hamiltonians. Here, while the approach still offers advantages, more care has to be taken than in a generic case. We also provide an estimate for a breakdown time of the approximation.

DY 42: Stochastic Thermodynamics

Time: Friday 9:30–11:15 Location: H43

DY 42.1 Fri 9:30 H43

Stochastic Thermodynamics of the Interacting Non-reciprocal Particles and Fields — •Atul Tanaji Mohite and Heiko Rieger — Saarland University, Saarbrücken, Germany

Non-reciprocal interactions that violate Newtons law 'actio=reactio' are ubiquitous in nature and are currently intensively investigated in active matter, chemical reaction networks, population dynamics and many other fields. An outstanding challenge is the thermodynamically consistent formulation of the underlying stochastic dynamics that obeys local detailed balance and allows for a rigorous analysis of the stochastic thermodynamics of non-reciprocally interacting particles. Here we present such a framework for a broad class of active systems and derive by systematic coarse-graining exact expressions for the macroscopic entropy production. Four independent contributions to the thermodynamic dissipation can be identified, among which the energy flux sustaining vorticity currents manifests the presence of non-reciprocal interactions. Then, Onsager's non-reciprocal relations, the fluctuation-response relation, the fluctuation relation and the thermodynamic uncertainty relations for non-reciprocal systems are derived. Finally, we demonstrate that our general framework is applicable to a plethora of active matter systems and chemical reaction networks and opens new paths to understand the stochastic thermodynamics of non-reciprocally interacting many-body systems.

DY 42.2 Fri 9:45 H43

Staying on Time: Precision and Cost of a Controlled Clock — •Till Welker and Patrick Pietzonka — School of Physics and Astronomy, University of Edinburgh, United Kingdom

The precision of an autonomous clock is associated with an entropic cost. In overdamped systems, the precision-cost tradeoff is bounded by the thermodynamic uncertainty relation (TUR). To avoid paying immense costs while staying accurate over an extended period, the clocks in our phones, radios, and computers adapt their dynamics according to a precise reference clock.

We study the minimal model of the two-state controlled clock with one state running slower and one state running faster than the reference clock. At a rate R, the controlled clock reads out the reference clock and adjusts its state accordingly. While the clock hand progresses, the offset reaches an analytically solvable steady state, and the clock's error remains bounded.

The combined cost of the controlled and reference clock obeys the TUR. However, the operator of the controlled clock only needs to pay a part of that cost, namely the driving of the controlled clock and the cost of state adjustment. We show that there is an R-dependent tradeoff between the controlled clock's cost and its total error, and we explore the Pareto front of optimal clocks.

DY 42.3 Fri 10:00 H43

Active Brownian information engine: Self-propulsion induced colossal performance — •Rafna Rafeek and Debasish Mondal — Department of Chemistry and Center for Molecular and Optical Sciences and Technologies, Indian Institute of Technology Tirupati, Yerpedu 517619, Andhra Pradesh, India

Many biological systems operating in athermal (active) environments, can be modeled as an information engine, with the key aspect of utilizing information on the fluctuation to extort work from the noisy environment. In this study, we propose a feedback-driven information engine operating in a Gaussian-correlated active reservoir with characteristic strength (D_a) and correlation time (τ_a), which outperforms its thermal counterpart. We obtain the optimal functioning criteria for the enhanced performance of the active Brownian information engine (ABIE), reliant on the dispersion of the steady state, which is analogous to its passive analog. We notice that a weakly correlated active bath extracts colossal work due to the reduced relative loss of information in the relaxation process. In the limit of fractionally smaller correlation time ($t_a/t_r \to 0, t_a$ is thermal relaxation time), the upper bound on colossal work extraction is $0.202(D + D_a)$. The excess amount of extracted work reduces and converges to its passive counterpart in the higher limit of correlation time ($t_a/t_r \to high$). Interestingly, when correlation time is equivalent to relaxation time ($t_a/t_r = 1$), half the upper bound of excess work is achieved irrespective of activity strength. This study provides a new insight into understanding and designing the information-energy exchange of biological submicrometer motors.

DY 42.4 Fri 10:15 H43

Entropy estimation for partially accessible Markov networks based on imperfect observations: Role of finite resolution and finite statistics — •Jonas H. Fritz, Benjamin Ertel, and Udo Seifert — II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

Estimating entropy production from real observation data can be difficult due to finite resolution in both space and time and finite measurement statistics. We characterize the statistical error introduced by finite sample size and compare the performance of three different entropy estimators under these limitations for two different paradigmatic systems, a four-state Markov network and an augmented Michaelis-Menten reaction scheme. We consider the thermodynamic uncertainty relation, a waiting-time based estimator for resolved transitions and a waiting-time based estimator for blurred transitions in imperfect observation scenarios. For perfect measurement statistics and finite temporal resolution, the estimator based on resolved transitions performs best in all considered scenarios. The thermodynamic uncertainty relation gives a better estimate than the estimator based on blurred transitions at low driving affinities, whereas the latter performs better at high driving affinities. Furthermore, we find that a higher temporal and spatial resolution leads to slower convergence of measurement statistics, implying that for short measurement times, a lower resolution may be beneficial. Additionally, we identify a self-averaging effect for the waiting-time based entropy estimators that can reduce their variance for observations with finite statistics.

DY 42.5 Fri 10:30 H43

Stochastic Calculus Approach to Thermodynamic Bounds for Jump Processes — •Lars Stutzer, Cai Dieball, and Aljaž Godec — Mathematical bioPhysics Group, Max Planck Institute for Multidisciplinary Sciences, 37077 Göttingen, Germany

Thermodynamic inequalities bound dissipation from below in terms of fluctuations of, and correlations between, observable currents and densities. They are at the heart of thermodynamic inference. By establishing a stochastic-calculus for functionals of Markov-jump dynamics, we allow for immediate extensions of results derived for overdamped diffusion to discrete state spaces, which expands the range of bounds available for jump processes. Moreover, we use the calculus to prove new bounds for jump-processes, including transient thermodynamic uncertainty relations, finite-time correlation bounds, and the recently established transport bounds. While it was expected for these results carry over to discrete spaces, the methodological advance establishes them as an inherent property of stochastic equations of motion. Our results put Langevin and Markov-jump dynamics on a common footing on the level of individual stochastic trajectories. We illustrate the results by means of biologically motivated examples.

DY 42.6 Fri 10:45 H43

Is learning in Neural Networks just very high dimensional parameter fitting? — •Ibrahim Talha Ersoy — Universität Potsdam, Institut für Astronomie und Physik, Potsdam, Deutschland

Neural Networks (NNs) are known for their highly non-convex loss landscapes, shaped by the data and the error function. Unlike in convex optimization, the model navigates regions of changing curvature to find the global minimum. We anticipate qualitative changes in the model occurring at points where new error basins are explored. In information bottleneck settings, Tishby et al. (2015) suggested that transitions between distinct loss regions are associated with phase transitions, a concept proven in L2 setups by Ziyin et al. (2023), where they examined the onset of learning when varying the L2 regularizer strength. We extend the findings of Ziyin et al. (2023), interpreting them from an information geometric perspective and demonstrate further phase transitions when model changes. By distinguishing between the loss and error landscapes, we provide a rigorous argument that extends the scope of our results beyond the L2 setup. This approach enables a better understanding of the limitations of the free energy interpretation of the L2 loss function and provides a more accurate depiction. Finally, our results suggest a clear distinction between learning, characterised by phase transitions at points of model change,

and fitting, where the model remains qualitatively fixed, lacking phase transitions.

DY 42.7 Fri 11:00 H43

Coherent effects in the semiclassical limit of quantum work — •Nicolás Torres-Domínguez[1], Carlos Viviescas[2], and JD Urbina[3] — [1]Chalmers tekniska högskola, Göteborg, Sweden — [2]Universidad Nacional de Colombia, Bogotá, Colombia — [3]Universität Regensburg, Institut für Theoretische Physik

Within the framework of quantum thermodynamics, the use of quasiprobabilities can provide a comprehensive approach to the work statistics of quantum systems. In this formulation the effects of coherences in the initial state of the system are accounted in a natural way for all protocols and are expected to be displayed in the quantum features of the chosen quasidistribution [1]; yet clear examples of this are scarce in the literature. In this work we consider the semiclassical limit of the quantum work distribution obtained using the Kirkwood-Dirac quasiprobability, highlighting the effects of initial coherences on the energetics of the system and on the quantum behavior of the quasidistribution. We illustrate our results in a study of the work distribution of a forced quantum harmonic oscillator [2] in the Weyl-Wigner representation in phase space.

[1] M. Lostaglio, A. Belenchia, A. Levy, S. Hernández-Gómez, N. Fabbri, and S. Gherardini, Quantum 7, 1128 (2023). [2] P. Talkner, P. S. Burada, and P. Hänggi, Phys. Rev. E 78, 011115 (2008).

DY 43: Active Matter IV (joint session BP/CPP/DY)

Time: Friday 9:30–13:00 Location: H44

Invited Talk DY 43.1 Fri 9:30 H44

Wave propagation in systems of active filaments — •Kirsty Y. Wan — Living Systems Institute, University of Exeter, UK

Active hair-like protrusions called cilia are found in many eukaryotes where they produce physiological flows for a variety of functions. Cilia assume a myriad of configurations both external to an organism for the purposes of feeding or swimming motility, but also internally where they mediate mucociliary clearance in vertebrate tissues. Single cilia can propagate large-amplitude non-decaying bending waves, even in the absence of a cell body. These waves assume a variety of stereotyped forms and frequencies, depending on the species. Multiple cilia also interact to produce different types of local and global coordination patterns, including robust metachronal waves. Do these dynamic states of coordination arise spontaneously, or do they require some form of internal control by the cell or animal? We propose new and emerging organisms to address these questions.

DY 43.2 Fri 10:00 H44

Metabolic activity controls the emergence of coherent flows in microbial suspensions — •Florian Böhme[1], Alexandros Fragkopoulos[1,2], Nicole Drewes[2], and Oliver Bäumchen[1,2] — [1]University of Bayreuth, Experimental Physics V, 95447 Bayreuth, Germany — [2]Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Göttingen, Germany

Photosynthetic microbes have evolved and successfully adapted to the spatio-temporal variations of environmental parameters within their habitat. In the abscence of light, they can still sustain their biological functionality and metabolic activity through aerobic respiration. However, for the soil-dwelling microalga *Chlamydomonas reinhardtii*, their environment may be deprived of both oxygen and light, resulting in a significant reduction of their swimming velocity [1]. Here, we study the effect of motility and cell density of *C. reinhardtii* in a confined system, on the emergence of bioconvection [2]. This collective phenomenon can be reversibly switched by light and arises due to the natural tendency of the bottom-heavy cells to move against gravity. We show that the rate at which the system evolves, as well as the dominant wavelength of the instability can both be directly controlled by the number density of cells. Further, we provide insights on the internal flow fields and density profiles of single bioconvection plumes for different parameters.

[1] A.A. Fragkopoulos et al., *J. R. Soc. Interface* **18**, 20210553 (2021). [2] A.A. Fragkopoulos et al., *arXiv*:2407.09884 (2024)

DY 43.3 Fri 10:15 H44

Tumbling *E.coli* in bulk and close to surfaces — •Pierre Martin[1], Tapan Chandra Adhyapak[2], and Holger Stark[1] — [1]Institute of Theoretical Physics, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Indian institute of science education and research (IISER), Tirupati, India

Escherichia coli (*E. coli*) swims by rotating multiple flagella which are connected to the cell body forming a thick bundle. To change direction, *E. coli* performs tumble events by reversing the rotation of one or more flagella. The involved filaments undergo a series of polymorphic transformations, altering both their helicity and handedness. This complex phenomenon involves the interplay of semiflexible filaments and hydrodynamic flow fields. Here, we have developed a detailed numerical framework to simulate *E. coli*, capturing the full dynamics of flexible flagella, including their polymorphism and their hydrodynamic interactions. The filaments and the cell body are embedded in a viscous fluid, which we model using multi-particle collision dynamics. We analyzed a large number of tumble events, with fixed tumble time or taken from a gamma distribution, exploring the roles of hook and flagellar flexibility as well as flagellar polymorphism. We find that they strongly influence the distribution of tumble angles. Finally, we also show that close to a flat surface the mean tumble angle is strongly shifted to smaller values. This indicates that tumble events may not be recognized, which could give the impression of suppressed tumbling near surfaces.

DY 43.4 Fri 10:30 H44

***Trypanosoma brucei* (un)chained - effects of confinement on a parasitic microswimmer** — •Hannes Wunderlich[1], Marinus Thein[2], Lucas Brehm[2], Klaus Ersfeld[2], and Matthias Weiss[1] — [1]Experimental Physics I, University of Bayreuth — [2]Laboratory of Molecular Parasitology, University of Bayreuth

Trypanosoma brucei is a parasitic unicellular microswimmer that causes the African sleeping sickness. An active spiral movement of the parasite, mediated by a microtubule-driven flagellum that wraps around the cell body, is mandatory to evade the host's immune system while exploring tissues and blood vessels. In addition, the nematic subpellicular micotubule array plays a pivotal role in the elasticity, propulsion, and navigation of the parasite. To study the features and mechanisms behind the cell's motion in such complex environments, we have mimicked spatial confinement in microfluidic devices with different geometries. Our data show that spatial constraints in narrow channels and channel networks can improve cell locomotion of wild-type trypanosomes, supposedly due to the interaction of the elastic cell body and nearby walls. The addition of microtubule-disrupting drugs or the use of mutant strains with altered post-translational modifications of microtubules resulted in significantly altered swimming velocities and marked changes in the intermittent switching between run and tumble phases. Shape analyses of individual cells suggest that microtubules in the sub-pellicular array, the corset that keeps trypanosomes in their native spindle-like shape, are most affected in these cases.

DY 43.5 Fri 10:45 H44

Micro-swimmer motility in presence of signaling factors — Agniva Datta, Robert Grossmann, and •Carsten Beta — Institute of Physics and Astronomy, University of Potsdam, Germany

The navigation of bacteria through aqueous environments, driven by the rotation of helical flagella, has been a significant region of interest in the biophysics community for the last few decades. In this study, we focus on the motility of our model organism, Pseudomonas putida, which exhibits persistent mobile episodes (Active Brownian motion) interrupted by stochastic reorientation events (turns), driven by flagellar self-propulsion, thereby leading to a run-and-turn motility.

Key motility parameters including tumbling rates, run lengths, trajectory persistence (rotational diffusion coefficient), and the characteristics of the self-propulsion force*are hypothesized to depend on the density of quorum-sensing autoinducer molecules, produced by the bacteria themselves as signaling factors. To test this hypothesis, we expose swimming bacteria to aqueous environments with controlled autoinducer concentrations and analyze the resulting changes in motility

patterns. Through a combination of experimental data and theoretical modeling, we aim to elucidate the principles of micro-swimmer motility in presence of signaling molecules.

DY 43.6 Fri 11:00 H44

Collective dynamics of active dumbbells near a circular obstacle — •Chandranshu Tiwari[1] and Sunil Singh[2] — [1]Department of Physics, Indian Institute of Science Education and Research, Bhopal 462066, India. — [2]Department of Physics, Indian Institute of Science Education and Research, Bhopal 462066, India.

We present the collective dynamics of active dumbbells in the presence of a static circular obstacle using Brownian dynamics simulation. The active dumbbells aggregate on the surface of a circular obstacle beyond a critical radius, and the aggregate size increases with the activity and the curvature radius. The dense aggregate of active dumbbells displays persistent rotational motion with a certain angular speed, which linearly increases with activity. Furthermore, we show a strong polar ordering of the active dumbbells within the aggregate. The polar ordering exhibits long-range correlation, with the correlation length corresponding to the aggregate size. Additionally, we show that the residence time of an active dumbbell on the obstacle surface increases rapidly with area fraction due to many-body interactions that lead to a slowdown of the rotational diffusion. This article further considers the dynamical behavior of a tracer particle in the solution of active dumbbells. Interestingly, the speed of the passive tracer particle displays a crossover from monotonically decreasing to increasing with the size of the tracer particle upon increasing the dumbbells' speed. Furthermore, the effective diffusion of the tracer particle displays non-monotonic behavior with the area fraction; the initial increase in diffusivity is followed by a decrease for a larger area fraction.

DY 43.7 Fri 11:15 H44

Free growth under tension — •Chenyun Yao and Jens Elgeti — Forschungszentrum Jülich GmbH, Jülich, Germany

Ever since the ground breaking work of Trepat et al. in 2009, we know that cell colonies growing on a substrate can be under tensile mechanical stress. The origin of tension has so far been attributed to cellular motility forces being oriented outward of the colony. Works in the field mainly revolve around how this orientation of the forces can be explained, ranging from velocity alignment, self-sorting due to self-propulsion, to kenotaxis.

In this work, we demonstrate that tension in growing colonies can also be explained without cellular motility forces! Using a combination of well established tissue growth simulation technique and analytical modelling, we show how tension can arise as a consequence of simple mechanics of growing tissues. Combining these models with a minimalistic motility model shows how colonies can expand while under even larger tension. Furthermore, our results and analytical models provide novel analysis procedures to identify the underlying mechanics.

15 min. break

DY 43.8 Fri 11:45 H44

A route to active turbulence in circular activity spots — •Arghavan Partovifard and Holger Stark — Institute of Theoretical Physics, Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623Berlin, Germany.

Active nematics exhibit distinctive behavior such as active turbulence and regular flow patterns under spatially varying activity [1]. Utilizing the Doi-Edwards theory supplemented by an active stress tensor [1], we investigate active nematics confined to a circular spot by switching off activity outside the spot. The open boundary allows topological defects to enter and leave the spot.

We calculate the total topological defect charge inside the spot using three approaches: counting all defects, measuring the rotation of the director field along the rim of the spot, and integrating the diffusive charge density. All methods agree that for spot radii just larger than the nematic coherence length, the system has a total topological charge of $+1$, where two $+1/2$ defects perform a regular swirling motion. As the radius increases, more defects enter and their motion becomes more and more chaotic. Ultimately, the charge per unit area saturates at the value characteristic of bulk active turbulence. For the range of radii where the total charge in the spot is $+1$, the nematic director exhibits shear-induced anchoring at an angle of $45°$ with respect to the tangent at the spot rim. With increasing radius, when more defects enter, the anchoring angle deviates from $45°$ but its distribution still peaks around this value.

[1] A. Partovifard *et. al.*, Soft Matter **20**, 1800 (2024)

DY 43.9 Fri 12:00 H44

Cognitive flocks: order-disorder transitions and threat evasion — •Priyanka Iyer[1], Cecilia Soroco[2], and Gerhard Gompper[1] — [1]Forschungszentrum Jülich — [2]University of British Columbia, Canada

Directed self-propulsion is ubiquitous in living organisms. From E.Coli dispersing in biofilms to migrating bird flocks, living organisms are constantly out-of equilibrium. By sensing their environment and adjusting their movement, organisms can exhibit emergent patterns and collective behaviors, such as self-organization in human crowds [1], bird flocks, and fish schools. The Inertial Spin Model (ISM) was introduced to explain the fast and robust propagation of information in bird flocks [2], when only alignment interactions are considered. However, more generally, agents exhibit a variety of interactions like local avoidance, cohesion and threat evasion. We show how such behaviors can be incorporated within the framework of the ISM. It is found that local avoidance introduces emergent noise in the system, triggering an order-disorder transition. Exploring the flock dynamics near this transition reveals a complex interplay between cohesion, alignment, and local avoidance, resulting in diverse behaviors such as pronounced shape and density fluctuations, and diffusive motion of the flock. Lastly, by applying the model to a stationary threat scenario, we analyze flock properties that govern threat information propagation in the flock.

[1] Iyer, P. et al. , Comm. Phys. 7.1 (2024): 379.
[2] Attanasi, A. et al. , Nat. Phys. 10, 691-696, (2014)

DY 43.10 Fri 12:15 H44

Myosin-independent amoeboid cell motility — •Winfried Schmidt, Alexander Farutin, and Chaouqi Misbah — Univ. Grenoble Alpes, CNRS, LIPhy, F-38000 Grenoble, France

Mammalian cell motility is essential for many physiological and pathological processes, such as the immune system, embryonic development, wound healing, and cancer metastasis. Cells have developed the amoeboid migration mode which allows them to move rapidly in a variety of different environments, including two-dimensional confinement, three-dimensional matrix, and bulk fluids. We introduce a model for an amoeboid cell where the cortex is described as a thin shell along the cell surface. The cell shape evolves due to polymerization of actin filaments and the forces acting on the cortex. We find analytically and numerically that the state of a resting, non-polarized cell can become unstable for sufficiently large actin polymerization velocities, resulting in the spontaneous onset of cell polarity, migration, and dynamical shape changes. Notably, this transition only relies on actin polymerization and does not necessitate molecular motors, such as myosin. These findings yield a deeper understanding of the fundamental mechanisms of cell movement and simultaneously provide a simple mechanism for cell motility in diverse configurations.

DY 43.11 Fri 12:30 H44

Active membrane deformations of a synthetic cell-mimicking system — Alfredo Sciortino[1], •Dmitry Fedosov[2], Gerhard Gompper[2], and Andreas Bausch[1] — [1]Physik Department, Technische Universität München, Garching bei München, Germany — [2]Institute for Advanced Simulation, Forschungszentrum Jülich, Jülich, Germany

Biological cells are fascinating micromachines capable of adapting their shape due to the complex interaction between a deformable membrane and the dynamic activity of the cytoskeleton. We investigate the behavior of an active synthetic cell-mimicking system using simulations and experiments. In simulations, the model consists of a fluid vesicle with a few encapsulated growing filaments. In experiments, giant vesicles contain an active cytoskeletal network composed of microtubules, crosslinkers, and molecular motors. These active vesicles show strong shape fluctuations reminiscent of shape changes of biological cells. We analyze membrane fluctuations and show how the intricate coupling between soft confinement and internal active forces results in fluctuation spectra with distinct spatial and temporal scales, differing significantly from those of passive vesicles. Simulations demonstrate the universality of this behavior, quantifying the impact of correlated activity on the dynamics of membrane deformations. This model makes a step toward quantitative description of shape-morphing artificial and living systems.

DY 43.12 Fri 12:45 H44

Force Generation by Enhanced Diffusion in Enzyme-Loaded Vesicles — Eike Eberhard, •Ludwig Burger, Cesar Pastrana, Giovanni Giunta, and Ulrich Gerland — Physik komplexer Biosysteme, Technische Universität München, Deutschland

Recent experiments show that the diffusion coefficient of some metabolic enzymes increases with the concentration of their cognate substrate, a phenomenon known as enhanced diffusion. In the presence of substrate gradients, enhanced diffusion induces enzymatic drift, resulting in a non-homogeneous enzyme distribution. In this work, we study the behavior of enzyme-loaded vesicles exposed to external substrate gradients using a combination of computer simulations and analytical modeling. We observe that the spatially inhomogeneous enzyme profiles generated by enhanced diffusion result in a pressure gradient across the vesicle, which leads to macroscopically observable effects, such as deformation and self-propulsion of the vesicle. Our analytical model allows us to characterize dependence of the velocity of propulsion on experimentally tunable parameters. The effects predicted by our work provide an avenue for further validation of enhanced diffusion, and might be leveraged for the design of novel synthetic cargo transporters, such as targeted drug delivery systems.

DY 44: Droplets, Wetting, Complex Fluids, and Soft Matter (joint session DY/CPP)

Time: Friday 9:30–12:45 Location: H47

Invited Talk DY 44.1 Fri 9:30 H47

From Cavitation in Soft Matter to Erosion on Hard Matter — •Claus-Dieter Ohl — Institute of Physics, Otto-von-Guericke University, Magdeburg, Germany

Cavitation is the technical term for the formation of empty spaces in a liquid. These unstable voids eventually implode and focus energy on small volumes. Shock wave emission, light emission, erosion, and even nuclear reactions are the consequence of this near singular energy focusing. Here, I will present recent research related to cavitation not only in liquids but also in elastic solids and particularly at the interface of both materials. Singularities developing on the axis of symmetry in non-spherical collapses near boundaries are able to amplify shock waves through self focusing. We think that this mechanism is the primary cause for erosion. In contrast, the non-spherical collapse and shock wave focusing near a tissue allows for the penetration of the tissue with liquid jets at 1000m/s and above. The mechanism at play may be relevant in sports and battle zones, as they could lead to traumatic brain injuries.

DY 44.2 Fri 10:00 H47

Shape switching and tunable oscillations in adaptive droplets — •Tim Dullweber[1,2], Roman Belousov[1], Camilla Autorino[1,4], Nicoletta Petridou[1], and Anna Erzberger[1,3] — [1]European Molecular Biology Laboratory, Heidelberg, Germany — [2]University Heidelberg, Heidelberg, Germany — [3]Institute for Theoretical Physics, Heidelberg University, Heidelberg, Germany — [4]Faculty of Biosciences, Heidelberg University, Heidelberg, Germany

Soft materials can undergo irreversible shape changes when driven out of equilibrium. When shape changes are triggered by processes at the surface, geometry-dependent feedback can arise. Motivated by the mechanochemical feedback observed in multicellular systems, we study incompressible droplets that adjust their interfacial tensions in response to shape-dependent signals. We derive a minimal set of equations governing the mesoscopic droplet states, controlled by just two dimensionless feedback parameters. We find that interacting droplets exhibit bistability, symmetry-breaking, excitability and tunable shape oscillations ranging from near-sinusoidal to relaxation-type. We apply our framework to model shape measurements in zebrafish embryos and identify a shape-switching mechanism promoting boundary formation. The underlying critical points reveal novel mechanisms for physical signal processing through shape adaptation in soft active materials, and suggest new modes of self-organization at the collective scale.

DY 44.3 Fri 10:15 H47

Impact of the history force on the motion of droplets in shaken liquids — •Frederik Gareis and Walter Zimmermann — Theoretical Physics, University of Bayreuth

The Basset-Boussinesq history (BBH) force acts on droplets and solid particles in flows, alongside stationary viscous friction, inertia, and gravitational forces. This force arises from vortex shedding around objects undergoing unsteady acceleration. In this study, we analytically calculate the BBH force for spherical, sedimenting heavy particles in horizontally shaken (periodically accelerated) fluids at low Reynolds numbers and identify the parameter ranges where BBH effects are significant. Our results reveal that BBH can increase particle displacement amplitude by over 60 percent, particularly in the transition region between the low-frequency viscous Stokes regime and the high-frequency inertia-dominated regime. Additionally, we derive a power law for the oscillatory displacement amplitude of a particle around its mean position in a horizontally shaken fluid, facilitating clear experimental identification of BBH effects.

DY 44.4 Fri 10:30 H47

Bubble Dynamics and Transport in Porous Structures: Insights from Mesoscale Simulations — •Qingguang Xie[1], Othmane Aouane[1], and Jens Harting[1,2] — [1]Forschungszentrum Jülich GmbH, Helmholtz-Institut Erlangen-Nürnberg (IET-2), Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

Bubble formation, detachment, and transport within porous structures are critical phenomena in various applications, including electrolyzers and chemical reactors. We numerically investigate the dynamics of bubble growth and detachment at a catalytic surface using the lattice Boltzmann method. The departure radius of a bubble, growing with either a pinned or moving contact line, shows good agreement with theoretical predictions. Beyond detachment, we examine the subsequent transport of bubbles through a porous transport layer, systematically evaluating transport efficiency by considering factors such as pressure gradients, reaction rates, and pore wettability. Our findings provide valuable insights for optimizing the design of porous structures, potentially resulting in enhanced performance in electrolyzers and other gas-evolving devices.

DY 44.5 Fri 10:45 H47

Displacements in thin fluid and elastic films — •Andreas M. Menzel — Otto von Guericke University Magdeburg, Germany

We address the displacements of comparatively small objects in flat thin fluid films under low-Reynolds-number conditions or in flat thin elastic sheets under linear elasticity.
It is well-known that the fundamental solution of the corresponding continuum equations for forced in-plane displacements diverges logarithmically in strictly two-dimensional systems, the so-called Stokes paradox. We provide an illustrative way of interpretation and demonstrate how the divergence cancels under pairwise interactions and confinement [1,2]. Interestingly, logarithmic spatial dependencies prevail under rectangular clamping of elastic membranes [3]. Moreover, the divergence is still present in free-standing sheets of finite thickness, unless they are stabilized, for instance, by substrates [4,5].
We are confident that our analytical results will prove useful in corresponding quantitative experimental evaluations.

[1] S. K. Richter, A. M. Menzel, Phys. Rev. E **105**, 014609 (2022).
[2] T. Lutz, S. K. Richter, A. M. Menzel, Phys. Rev. E **106**, 054609 (2022).
[3] A. R. Sprenger, H. Reinken, T. Richter, A. M. Menzel, EPL (Europhys. Lett.) **147**, 17002 (2024).
[4] T. Lutz, A. M. Menzel, A. Daddi-Moussa-Ider, Phys. Rev. E **109**, 054802 (2024).
[5] A. Daddi-Moussa-Ider, E. Tjhung, T. Richter, A. M. Menzel, J. Phys.: Condens. Matter **36**, 445101 (2024).

DY 44.6 Fri 11:00 H47

Magnetic dynamics in ferromagnetic liquid crystal emulsions — •Christoph Klopp[1], Hajnalka Nádasi[1], Darja Lisjak[2], and Alexey Eremin[1] — [1]Otto von Guericke University, Institute of Physics, 39106 Magdeburg, Germany — [2]Jozef Stefan Institute, Department for Materials Synthesis, 1000 Ljubljana, Slovenia

We explore magnetic liquid crystal (LC) emulsions for applications as manipulatable chemical sensors in giant cells of Characean algae. Such

emulsions can be controlled by magnetic fields and provide targeted drug delivery or sensing [1]. The investigated emulsions consist of a ferromagnetic liquid crystal [2] dispersed in an aqueous solution. We investigate the dynamic magnetic response using AC-susceptometry [3] as a function of the carrier medium viscosity and the particle or droplet size distribution. The emulsions' magnetic spectra differ drastically from those in the bulk of the hybrid liquid crystal mixture. We demonstrate the influence of the liquid crystal director configuration at the water-droplet interface by analyzing the effect of different surfactants (mainly SDS and PVA) in the aqueous phase.

[1] F. von Rüling et al., Liquid Crystals, 2024, 51, 1546
[2] A. Mertelj, et al., Nature, 2013, 504, 237-241
[3] M. Küster et al., J. Magn. Magn. Mater., 2023, 588, 171368

This study was supported by DFG with projects ER 467/14-1 and NA1668/1-3.

15 min. break

DY 44.7 Fri 11:30 H47

Drying effects in soft colloidal monolayers — •Kai Luca Spanheimer[1], Matthias Karg[2], Nicolas Vogel[3], Liesbeth Janssen[4], and Hartmut Löwen[1] — [1]Institut für Theoretische Physik II: Weiche Materie Heinrich-Heine-Universität, 40225 Düsseldorf, Germany — [2]Physikalische Chemie I: Kolloide und Nanooptik Heinrich-Heine-Universität, 40225 Düsseldorf, Germany — [3]Lehrstuhl für Partikelsynthese Friedrich-Alexander-Universität,91058 Erlangen, Germany — [4]Soft Matter and Biological Physics Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands

Langmuir-Blodgett deposition is a staple of colloidal monolayer research. It is used in sample preparation for imaging techniques, that spatially resolve colloid patterns. Recent experimental observations have shown that drying can strongly rearrange micron sized microgel patterns after their deposition. The usual dictum that these drying effects do not play a role for colloidal deposition can thus not be held up as a general rule. While capillary effects are well known to be strong at microscopic length scales and play a significant role in drying processes they have been mostly neglected concerning Langmuir-Blodgett deposition. In order to better understand the mechanism of drying we propose a model based on capillary attraction as well as hard core and soft shell repulsion. This model reproduces colloid patterns observed at interfaces as well as ones that occur after drying in the corresponding parameter regimes. From here we are able to derive parameter ranges where drying can play a role in rearranging patterns of colloids and where it can't.

DY 44.8 Fri 11:45 H47

Interplay of Elasticity and Capillarity in Droplets on Flexible Sheets — •Salik Sultan and Holger Stark — Technische Universität Berlin, Institute of Theoretical Physics, Hardenbergstr. 36, 10623 Berlin, Germany

Droplets resting on flexible sheets deform into lens-like shapes, offering promising applications in areas like tunable liquid lenses. We have extended and employ our fully three-dimensional Boundary Element Method (BEM) simulation framework [1] to investigate dynamic wetting on thin flexible sheets. Our study focuses on the intricate interplay between the mechanical properties of the sheet and droplet behavior, particularly emphasizing contact angle and droplet shape. By varying the tension and mechanical properties of the sheet, our model demonstrates how we can control and tune the shape of the droplet. Additionally, by introducing stiffness gradients, we aim to explore the potential to steer droplets along the sheet via durotaxis. The versatility of our model suggests potential extensions to other soft material and droplet interactions, such as capillary origami. This work sheds light on the complex interactions between soft substrates and liquid interfaces, leading the way for advancements in material science and interfacial biology.

[1] J. Grawitter and H. Stark, Steering droplets on substrates with plane-wave wettability patterns and deformations, Soft Matter 20, 3161 (2024).

DY 44.9 Fri 12:00 H47

Cluster quasicrystals composed of ultrasoft particles vs. soft quasicrystals built of colloids with hard cores — Robert F.B. Weigel and •Michael Schmiedeberg — Theoretical Physics: Lab for Emergent Phenomena, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

We study and compare two different approaches for the stabilization of quasicrystals:

First, we consider a Phase Field Crystal model of complex patterns that self-assemble in systems consisting of ultrasoft colloids. Quasicrystals can be either stabilized by interactions with multiple length scales [1,2] or by preferred binding angles as in patchy colloids [3].

Second, we study a system with patchy colloids with a hard core with a Density Functional Theory. The hard-core is implemented by using a variant of the Fundamental Meassure Theory [4] that probably is the best mean field approach to hard particles.

While the ultrasoft particles assemble in cluster quasicrystals where the particles can completely overlap, in case of hard cores we observe structures that are rather dominated by the tiles that occur on a local level. Our results explain the differences between quasicrystlas that occur in different systems.

[1] Lifshitz, Petrich, PRL 79, 1261 (1997).
[2] Achim et al., PRL 112, 255501 (2014).
[3] Weigel, Schmiedeberg, Modelling Simul. Mater. Sci. Eng. 30, 074003 (2022).
[4] Rosenfeld, PRL 63, 980 (1989).

DY 44.10 Fri 12:15 H47

Beyond rings and chains: exploring porous crystals and flexible networks with magnetic colloids — •Carina Karner — Technische Universität Wien

We report on the self-assembly of magnetic colloids engineered with two distinct magnetic patches positioned at their poles, an advancement from traditional Janus particles with a single magnetic dipole. While Janus particles are known to form a variety of superstructures including chains, rings, and close-packed arrangements [1], the two-patch design significantly expands the range of achievable structures. Our simulation study reveals the formation of porous networks with adjustable flexibility, variable pore sizes, and controllable crystalline order. Notably, we observe the formation of a porous Kagome lattice, reminiscent of the experimental Kagome lattice observed colloids with two hydrophobic patches, the well known Janus-triblock system [2]. This enhanced self-assembly behavior in two-patch magnetic particles opens up further possibilities for creating fully tunable, field-responsive ferrofluids. Such systems could useful for applications requiring externally modulated viscosity, such as adaptive damping systems in automotive and aerospace engineering. [1] Vega-Bellido, G. I., DeLaCruz-Araujo, R. A., Kretzschmar, I., & Córdova-Figueroa, U. M. (2019). Self-assembly of magnetic colloids with shifted dipoles. Soft Matter, 15(20), 4078-4086. [2] Chen, Q., Bae, S. C., & Granick, S. (2011). Directed self-assembly of a colloidal kagome lattice.Nature,469(7330), 381-384.

DY 44.11 Fri 12:30 H47

Effect of geometrical confinement on friction in soft solids — •Aashna Chawla and Deepak Kumar — Department of Physics, Indian Institute of Technology Delhi, New Delhi 110016, India

Soft and biological materials come in a variety of shapes and geometries. When two soft surfaces with mismatched Gaussian curvatures are forced to fit together, beautiful patterns emerge at the interface due to geometry-induced stress. In this study, we explore the effect of geometrically incompatible confinement of a thin sheet on a soft hydrogel substrate on friction. We use a novel experimental setup to measure the friction between a thin flat elastic sheet placed on a low-friction hydrogel substrate. We show that the frictional force at the interface strongly depends on the geometry and is significantly larger for the geometrically incompatible configuration of a flat sheet on a spherical substrate compared to the other two geometrically compatible configurations: flat sheet on a flat substrate and flat sheet on a cylindrical substrate. Furthermore, for the incompatible configuration of the flat sheet on a spherical substrate, we observe that the frictional force increases monotonically with the sheet radius, with a transition in the behavior at an intermediate radius. We show that these effects arise from the coupling of the stress developed in the sheet due to its geometrically incompatible confinement with the curvature of the interface, resulting in an increased normal force, thereby increasing friction. The insights gained from this study could have significant implications for our understanding of friction in various biological, nanoscale, and other soft systems.

DY 45: Quantum Chaos (joint session DY/TT)

Time: Friday 11:30–13:00 Location: H37

DY 45.1 Fri 11:30 H37

Semiclassical foundation of universality in many-body quantum circuits — •Maximilian Kieler[1], Felix Fritzsch[2], and Arnd Bäcker[1] — [1]TU Dresden, Institut für Theoretische Physik, Dresden, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany

For single particle systems the fundamental equivalence of quantum chaotic systems and random matrix theory is well-understood by means of semiclassical periodic orbit theory. We propose an extension to spatially local many-body systems by incorporating the concept of symmetry-breaking. Using this we show that random matrix behavior arises generically in quantum chaotic many-body systems in the form of a symmetry breaking of local time-translation symmetries. This general framework is applied to quantum circuits where an explicit correspondence to the random matrix result for the spectral form factor can be shown.

DY 45.2 Fri 11:45 H37

Distribution of resonance poles of chaotic scattering systems — •Jan Robert Schmidt, Florian Lorenz, and Roland Ketzmerick — TU Dresden, Institute of Theoretical Physics, Dresden, Germany

The distribution of resonance poles of chaotic scattering systems is investigated in the semiclassical limit at unprecedented small wavelengths. For the paradigmatic three-disk scattering system, we study the spectral gap towards the real axis, the fractal Weyl law, which counts the number of resonance poles, and the distribution of decay rates. These properties are compared to previous analytical results, e.g. from random matrix theory. In contrast to this system with full escape, systems with partial escape have significantly different properties. For the example of a dielectric cavity, we show that results from random matrix theory cannot explain the distribution of decay rates.

DY 45.3 Fri 12:00 H37

Solved after 60 years: Exact Derivation of the Ericson Transition in Quantum Chaotic Scattering — •Simon Köhnes and Thomas Guhr — University of Duisburg-Essen, Lotharstr. 1, 47048 Duisburg, Germany

Scattering experiments are the prime source of information on the quantum world. Scattering theory nowadays has numerous applications in various branches of physics and beyond, even including classical wave phenomena. We analyze chaotic scattering systems in the framework of Random Matrix Theory. The distribution of the scattering matrix elements is the key quantity. A strong sign of chaos in complex quantum systems is the Ericson regime of strongly overlapping resonances in which the cross sections exhibit random behavior. We apply the Supersymmetry Method. For the three Wigner-Dyson symmetry classes, we analytically calculate the transition to the Ericson regime, facilitating direct comparison with experimental results. In the course of doing so, we also gather new information on features of the underlying supersymmetric non-linear sigma model.

DY 45.4 Fri 12:15 H37

Chaotic Quantum Scattering: Exact Solutions for Systems with Spin — •Nils Gluth and Thomas Guhr — Universität Duisburg-Essen, Duisburg, Germany

Scattering experiments facilitate access to quantum systems. Scattering theory is needed to fully describe the involved experimental situations. Over the years, it became a powerful tool with applications to a large variety of different systems, such as for example compound nuclei, atoms, molecules, quantum graphs or even microwave networks and cavities. These systems are typically complex or in a broad sense chaotic, calling for statistical approaches, in particular Random Matrix Theory. Considerably extending our previous work, we calculate the distribution of scattering matrix elements and cross sections using Supersymmetry. We focus on the symplectic symmetry class which had not yet been solved, because a theoretical understanding is needed in view of recent experiments. We provide a comparison of our results with experimental data.

DY 45.5 Fri 12:30 H37

Phase-space representations and exceptional points of coupled polarized modes in cylindrical cavities — •Tom Rodemund[1], Shilong Li[2], Síle Nic Chormaic[3], and Martina Hentschel[1] — [1]Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany — [2]College of Information Science and Electronic Engineering, Zhejiang University, Hangzhou, China — [3]Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan

% Optical microcavities are often assumed to be two-dimensional (2D). This allows a convenient phase-space representation in 2D, where Poincaré surface of section for particle dynamics and the Husimi function for their wave counterpart are prominent methods. Here we extend the concept of Husimi functions for open systems [1] to three-dimensional (3D) optical microcavities of arbitrary shape. In particular we study deformed cylindrical cavities and illustrate their mode dynamics in terms of generalized Husimi functions.

The coupling between the two different polarizations (TE and TM) is a new feature in realistic 3D optical cavities that is not present in 2D. We find the interaction of polarized modes to be governed by a network of exceptional points that reflects the openness, or non-Hermiticity, of the system. The mode coupling is analyzed using the extended Husimi formalism that we find to be a comprehensive and useful way to represent the mode structure of 3D microcavities [2].

[1] Hentschel et al., Europhys. Lett. 62 636 (2003)
[2] Rodemund et al., to be submitted.

DY 45.6 Fri 12:45 H37

The classical Maldacena-Shenker-Standford bound — •Gerrit Caspari, Fabian Haneder, Juan-Diego Urbina, and Klaus Richter — University of Regensburg, Regensburg, Deutschland

The Maldacena-Shenker-Stanford (MSS) bound [1] is a condition on a system's quantum Lyapunov exponent, defined as half the growth rate of the regularised out-of-time-ordered correlator (OTOC), which states that said exponent is bounded by the system's temperature, with, e.g., black holes as characteristic systems saturating the bound.

From the perspective of classical chaos, this is surprising, since the classical Lyapunov exponent seems not to be bounded. We study chaotic quantum systems in a hyperbolic geometry with and without cusps and magnetic fields [2][3] via Selberg's Trace Formula (STF). Through this we derive bounds on the classical Lyapunov exponent from analyticity conditions in the trace formula and relate them to the MSS bound.

We report our progress in studying these bounds using the STF, which entails an investigation of the analyticity condition needed to prove the STF for the partition function of our systems and its relation to possible phase transitions.

[1] Maldacena, J., Shenker, S.H. & Stanford, J. High Energ. Phys. 2016, 106 (2016).
[2] Aurich, R., & Steiner, F. (1992)., Proceedings: Mathematical and Physical Sciences, 437(1901), 693-714
[3] Avron, J.E., Klein, M. & Pnueli, A., Phys. Rev. Lett. 69 (1992)

DY 46: Statistical Physics of Biological Systems II (joint session DY/BP)

Time: Friday 11:30–13:00 Location: H43

Invited Talk DY 46.1 Fri 11:30 H43

Equilibrium and non-equilibrium dynamics of biological systems with memory — •Roland Netz — Freie Universität Berlin, Fachbereich Physik, Berlin

Biological systems are many-body systems. Thus, their dynamics, when described in terms of a low-dimensional reaction coordinate, is governed by the generalized Langevin equation (GLE), an integro-differential equation of motion which contains friction memory [1]. Two examples will be discussed:

Protein-folding kinetics is standardly described as Markovian (i.e., memoryless) diffusion in a one-dimensional free-energy landscape. By analysis of molecular-dynamics simulation trajectories of fast-folding proteins the friction is demonstrated to exhibit significant memory with a decay time of the same order as the folding and unfolding times [2,3,4]. Memory friction leads to anomalous and drastically modified protein kinetics: the folding and unfolding times are not dominated by free-energy barriers but rather by non-Markovian friction.

Active motion of organisms obviously is far from equilibrium. The parameters of an appropriate non-equilibrium GLE are extracted from trajectories. It is demonstrated that the motion of single-cellular algae is characterized by pronounced memory friction, which allows to classify and sort individual cells.

[1] Memory and Friction: From the Nanoscale to the Macroscale, BA Dalton, A Klimek, H Kiefer, F N Brünig, H Colinet, L Tepper, A Abbasi, RR Netz, https://arxiv.org/pdf/2410.22588

DY 46.2 Fri 12:00 H43

Mean transient drift of synaptic weights in feed-forward spiking neural networks with spike-timing-dependent plasticity — •Jakob Stubenrauch and Benjamin Lindner — BCCN Berlin and Physics Department HU Berlin, Germany

Spike-timing dependent plasticity (STDP) [1] is a phenomenological model for the dynamics of single synaptic weights. This concise microscopic (single-synapse) description allows for the derivation of macroscopic network theories, capturing for instance learning, forgetting, and representational drift.

For the development of such theories it is important to characterize the stochastic process of synaptic weights. Early attempts capture this process for Poissonian presynaptic spikes and conditionally Poissonian postsynaptic spikes [2]. However, since STDP depends on fine spike-timing differences below 20 ms [1], it is important to characterize the synaptic dynamics for neuron models that describe the fast response mechanistically.

Leveraging a recent theory [3] as well as established results for the leaky integrate-and-fire neuron [4,5], we analytically compute the drift and diffusion of feed-forward synapses in a setup where a layer of presynaptic Poisson processes feeds into a recurrent network of leaky integrate-and-fire neurons.

[1] Bi and Poo, J. Neurisci. (1998) [2] Kempter et al., Phys. Rev. E (1999) [3] Stubenrauch and Lindner, Phys. Rev. X (2024) [4] Brunel et al., Phys. Rev. Lett. (2001) [5] Lindner and Schimansky-Geier, Phys. Rev. Lett. (2001)

DY 46.3 Fri 12:15 H43

A Biophysical Model for Temperature-Sensitivity of Neurons — •Julian Voits[1], Wojciech Ambroziak[2,3], Jan Siemens[2,4], and Ulrich S. Schwarz[1,5] — [1]Institute for Theoretical Physics, University of Heidelberg, Germany — [2]Department of Pharmacology, University of Heidelberg, Germany — [3]Department of Translational Disease Understanding, Grünenthal GmbH, Aachen, Germany — [4]Molecular Medicine Partnership Unit (MMPU), European Molecular Biology Laboratory (EMBL), Heidelberg, Germany — [5]BioQuant-Center for Quantitative Biology, University of Heidelberg, Germany

Control of body temperature is essential for our well-being and especially important during periods of fever or heat acclimation, e.g. due to traveling or climate change. An essential element of body temperature control are temperature-sensitive neurons, particularly warm-sensitive ones in the preoptic area of the hypothalamus. Since the discovery of temperature-sensitive ion channels, it has become clear that the underlying molecular mechanisms are rather diverse. In this work, we introduce a mathematical model based on a reduced version of the Hodgkin-Huxley model that can predict the frequently observed linear dependence of spiking rates on temperature in warm-sensitive neurons. Additionally, we present data showing how neurons adapt to varying temperatures over time, along with evidence of hysteresis in many temperature-sensitive neurons.

DY 46.4 Fri 12:30 H43

Position-Dependent Non-Markovian Effects Improve Protein Folding Simulations — •Lucas Tepper, Cihan Ayaz, Benjamin Dalton, and Roland Nezt — Freie Universität Berlin

It's common to project a protein's full atomic resolution onto a one-dimensional reaction coordinate to capture key aspects of its folding process. As a direct consequence of this dimensionality reduction, non-Markovian memory effects emerge. Accounting for memory effects in the framework of the generalized Langevin equation (GLE) with linear friction has proven efficient, accurate and insightful. However, recent advances in deriving GLEs with non-linear, position-dependent friction kernels raise questions about their applicability to protein folding simulations. We derive a novel method to extract position-dependent friction kernels from time series data via conditional Volterra equations. When applied to two protein test systems, the position- and time-dependent friction is strongest for long memory times in the folded states, where atoms are tightly packed. Additionally, we propose a novel and numerically efficient GLE simulation setup, confirming the accuracy of the extracted kernels. Compared to linear friction GLE simulations, our results show that position-dependent non-Markovian effects are critical for accurately reproducing protein folding kinetics when using low-dimensional reaction coordinates.

DY 46.5 Fri 12:45 H43

Multicomponent mixtures exhibit a vast nucleation-and-growth regime — •Yicheng Qiang, Chengjie Luo, and David Zwicker — Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany

Phase coexistence is crucial for understanding how cells regulate biomolecular condensates. Despite of the multicomponent and multiphase nature of such condensates, the direct study of coexisting phases is limited to only few components since the parameter space is high-dimensional. So far, no theory provides a direct and concrete estimation of the phase coexistence behavior of multicomponent mixtures. As a first-level description of multicomponent phase behavior, we derive scaling relations for the number of coexisting phases in typical multicomponent mixtures in equilibrium. The scaling relations reveal that the interactions required to have many coexisting phases only scales very weakly with the number of components, whereas the stability analysis of the homogeneous state suggests a much stronger scaling. This discrepancy implies that large parts of the phase diagram of multicomponent mixture are in the nucleation-and-growth regime, where the homogeneous state is locally stable while multiple coexisting phases are preferred energetically. This suggests that multicomponent mixtures can achieve versatility and controllability in phase behavior with moderate interactions, which might be utilized by cells to create or destroy biomolecular condensates.

DY 47: Closing Talk (joint session BP/CPP/DY)

Time: Friday 13:15–14:00 Location: H2

Invited Talk DY 47.1 Fri 13:15 H2

Active control of forces, movement and shape: from biological to non-living systems — •Ulrich S. Schwarz — Heidelberg University, Heidelberg, Germany

Animal cells are highly dynamic and continuously generate force, for example for division, migration and mechanosensing. Their main force generators are myosin II molecular motors, whose activity is precisely controlled by biochemical circuitry. We first discuss how this system can be hijacked by optogenetics, thus that cellular force generation can be controlled in time and space using light. Next, we use active gel theory combined with van der Waals theory for myosin II molecules to demonstrate that cell contractility is sufficient to explain cell migration and that optogenetics can be used to initiate and revert migration. For two myosin II species, we predict the possibility of oscillations. We then move up in scale and analyze force generation in intestinal organoids, which are epithelia with the topology of a sphere. Combining experimental data, image processing and the bubbly vertex model, we show how apico-basal asymmetries can lead to cell extrusion and budding. We finally discuss how force generation and shape changes can be achieved in non-living systems, in particular for nematic elastomers, in which the direction of contraction is imprinted during polymerization and actuation is achieved by temperature control.