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Fachverband Dynamik und Statistische Physik (DY)

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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 Division has strong links and joint sessions with the Divisions 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 HÜL/0186, ZEU/0160, ZEU/0118, and ZEU/0114; Poster P5-ZEU/0250)

Invited Talks

DY 7.1	Mon	9:30–10:00	ZEU/0114	**Fast Rare Events in Exit Times Distributions of Jump Processes** — •Raffaella Burioni
DY 7.6	Mon	11:15–11:45	ZEU/0114	**Large deviations in resetting Brownian motions** — •Satya Majumdar
DY 8.5	Mon	10:30–11:00	ZEU/0118	**Mean-field approach to finite-size fluctuations in coupled oscillator systems** — •Oleh Omelchenko, Georg Gottwald
DY 15.1	Mon	15:00–15:30	ZEU/0114	**Monte Carlo Simulation Methods for Rare-Event Sampling** — •Wolfhard Janke
DY 17.8	Mon	17:00–17:30	ZEU/0160	**Topological transition in filamentous cyanobacteria: from motion to structure** — •Marco Mazza
DY 19.1	Tue	9:30–10:00	HÜL/S186	**Mechanics of entangled fibers** — •Olivier Pouliquen, Aubin Archambault, Ignacio Andrade, Jerome Crassous, Henri Lhuissier, Joël Marthelot
DY 21.7	Tue	11:15–11:45	ZEU/0114	**Why Life Is Hot** — •Tanja Schilling, Patrick Warren, Wilson Poon
DY 28.1	Tue	14:00–14:30	ZEU/0118	**Geometry of turbulent mixing in thermal convection** — •Jörg Schumacher
DY 29.5	Tue	15:00–15:30	ZEU/0160	**Designing topological edge states in bacterial active matter** — Yoshihito Uchida, Daiki Nishiguchi, •Kazumasa A. Takeuchi
DY 34.1	Wed	9:30–10:00	ZEU/0160	**Active turbulence and odd viscosity in a colloidal chiral active system in bulk and in patterned environments** — Joscha Mecke, Yongxiang Gao, •Marisol Ripoll
DY 37.1	Wed	11:15–11:45	ZEU/0118	**Topological defects in 2D amorphous ensembles** — •Peter Keim
DY 40.1	Wed	15:00–15:30	ZEU/0114	**Learning the statistical folding of bacterial chromosomes** — •Chase Broedersz
DY 49.1	Thu	9:30–10:00	ZEU/0160	**Active memory and non-reciprocity as pathways to pattern formation in conserved scalar fields** — •Supropriya Saha, Vaishnavi Gajendragad
DY 55.1	Thu	15:00–15:30	ZEU/0160	**Out-of-equlibrium synthetic cells: the future of active matter** — •Laura Alvarez
DY 55.3	Thu	15:45–16:15	ZEU/0160	**Chemotactic like behavior in by active Brownian particles: from single particles to to polymers** — •Hidde Vuijk

DY 55.5	Thu	16:45–17:15	ZEU/0160	**From non-reciprocal torques towards shape-flexible and responsive prototypic worms** — •Holger Stark, Jeanine Shea
DY 59.7	Fri	11:15–11:45	HÜL/S186	**Anyon dynamics in driven topologically ordered quantum systems** — •Francesco Petiziol
DY 62.1	Fri	9:30–10:00	ZEU/0160	**Morphogenesis, transport, and computation in micro-scale swarms** — •Akira Kakugo

Invited Talks of the joint Symposium SKM Dissertation Prize 2026 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	9:30–10:00	HSZ/0002	**Stochastic-Calculus Approach to Non-equilibrium Statistical Physics** — •Cai Dieball
SYSD 1.2	Mon	10:00–10:30	HSZ/0002	**Nonuniform magnetic spin textures for sensing, storage and computing applications** — •Sabri Koraltan
SYSD 1.3	Mon	10:30–11:00	HSZ/0002	**Anomalous Quantum Oscillations beyond Onsager's Fermi Surface Paradigm** — •Valentin Leeb
SYSD 1.4	Mon	11:00–11:30	HSZ/0002	**Coherent Control Schemes for Semiconductor Quantum Systems** — •Eva Schöll
SYSD 1.5	Mon	11:30–12:00	HSZ/0002	**On stochastic thermodynamics under incomplete information: Thermodynamic inference from Markovian events** — •Jann van der Meer

Invited Talks of the joint Symposium The Sustainability Challenge: A Decade of Transformation (SYSC)

See SYSC for the full program of the symposium.

SYSC 1.1	Mon	15:00–15:30	HSZ/AUDI	**Open-Endedness and Community-Based Approaches to Sustainability Challenges** — •Hiroki Sayama
SYSC 1.2	Mon	15:30–16:00	HSZ/AUDI	**Education as a Social Tipping Element: Evidence from Climate and Physics Education Research** — •Thomas Schubatzky
SYSC 1.3	Mon	16:00–16:30	HSZ/AUDI	**Mechanistic and Material Perspectives on Enzymatic Hydrolysis of Semicrystalline Polyesters** — •Birte Höcker
SYSC 1.4	Mon	16:45–17:15	HSZ/AUDI	**Decarbonization Options for Industry** — •Uwe Riedel
SYSC 1.5	Mon	17:15–17:45	HSZ/AUDI	**Impacts of Cosmic Dust and Space Debris in the Terrestrial Atmosphere** — •John Plane

Invited Talks of the joint Symposium Fluids with Broken Time-Reversal Symmetry: Odd/Hall Viscosity between Active Matter and Electron Flows (SYBS)

See SYBS for the full program of the symposium.

SYBS 1.1	Tue	9:30–10:00	HSZ/AUDI	**Odd viscosity in three-dimensional fluids: flows, wakes, and eddies** — •Tali Khain
SYBS 1.2	Tue	10:00–10:30	HSZ/AUDI	**Odd viscosity in two-dimensional hydrodynamic electron transport** — •Igor Gornyi, Dmitry Polyakov
SYBS 1.3	Tue	10:30–11:00	HSZ/AUDI	**Odd slip on chiral active surfaces** — •Andrej Vilfan, Yuto Hosaka
SYBS 1.4	Tue	11:15–11:30	HSZ/AUDI	**Parity-odd transport in electron fluids** — •Johanna Erdmenger
SYBS 1.5	Tue	11:30–11:45	HSZ/AUDI	**Curved Odd Elasticity** — Lazaros Tsaloukidis, Yuan Zhou, Jack Binysh, Nikta Fakhri, Corentin Coulais, •Piotr Surówka

Invited Talks of the joint Symposium France: Soft, Active and Alive: Emergent Properties in Living Matter (SYGF)

See SYGF for the full program of the symposium.

SYGF 1.1	Wed	15:00–15:30	HSZ/AUDI	**Liquid crystal geometries in type I collagen-based tissues** — •Nadine Nassif

SYGF 1.2	Wed	15:30–16:00	HSZ/AUDI	**Self-organization of the cytoplasm by physical instabilities** — •Jan Brugues
SYGF 1.3	Wed	16:00–16:30	HSZ/AUDI	**From morphogenesis to space partitioning by microtubules and molecular motors.** — •Manuel Thery
SYGF 1.4	Wed	16:45–17:15	HSZ/AUDI	**More than the sum: how composite interfaces govern function** — •Alba Diz-Muñoz
SYGF 1.5	Wed	17:15–17:45	HSZ/AUDI	**Swimming and Swarming of Intelligent Active Particles** — Segun Goh, Priyanka Iyer, Rajendra Singh Negi, •Gerhard Gompper
SYGF 1.6	Wed	17:45–18:15	HSZ/AUDI	**Perturbing the collective motion of fish with challenging environments** — •Aurélie Dupont

Invited Talks of the joint Symposium Tipping Points in Social and Climate Systems (SYTP)

See SYTP for the full program of the symposium.

SYTP 1.1	Thu	15:00–15:30	HSZ/AUDI	**Social Tipping in Heterogeneous and Polarized Populations** — •Sara Constantino, Sonke Ehret, Elke Weber, Sonja Vogt, Charles Efferson
SYTP 1.2	Thu	15:30–16:00	HSZ/AUDI	**Tipping points and regime shifts in coupled social-climate systems** — •Chris Bauch
SYTP 1.3	Thu	16:00–16:30	HSZ/AUDI	**How to tune Earth system models toward tipping?** — •Sebastian Bathiany, Niklas Boers
SYTP 1.4	Thu	16:45–17:15	HSZ/AUDI	**Algorithmic amplification and contextual sensitivity in political information exposure** — Iris Damião, Ana Vranic, Paulo Almeida, Lília Perfeito, •Joana Gonçalves de Sá
SYTP 1.5	Thu	17:15–17:45	HSZ/AUDI	**The complex interplay between democracy and platform power** — •Philipp Lorenz-Spreen

Sessions

DY 1.1–1.2	Sun	16:00–18:15	HSZ/0004	**Tutorium: Physics of Behavior (joint session SOE/TUT/DY)**
DY 2.1–2.5	Mon	9:30–12:15	HSZ/0003	**Focus Session: New Routes to Localization and Quantum Non-Ergodicity I (joint session TT/DY)**
DY 3.1–3.11	Mon	9:30–12:30	HSZ/0101	**Quantum-Critical Phenomena (joint session TT/DY)**
DY 4.1–4.11	Mon	9:30–12:45	BAR/SCHÖ	**Active Matter I (joint session BP/CPP/DY)**
DY 5.1–5.10	Mon	9:30–12:45	GÖR/0226	**Focus Session: Physics of Behavior (joint session SOE/DY)**
DY 6.1–6.13	Mon	9:30–13:00	HÜL/S186	**Machine Learning in Dynamics and Statistical Physics I**
DY 7.1–7.10	Mon	9:30–12:45	ZEU/0114	**Focus Session: Large Deviations and Rare Events I**
DY 8.1–8.10	Mon	9:30–12:30	ZEU/0118	**Nonlinear Dynamics, Synchronization, and Chaos**
DY 9.1–9.10	Mon	9:30–12:15	ZEU/0160	**Statistical Physics far from Thermal Equilibrium I**
DY 10.1–10.5	Mon	9:30–11:00	ZEU/0260	**Wetting, Fluidics and Liquids at Interfaces and Surfaces I (joint session CPP/DY)**
DY 11.1–11.5	Mon	11:30–12:45	ZEU/0260	**Wetting, Fluidics and Liquids at Interfaces and Surfaces II (joint session CPP/DY)**
DY 12.1–12.6	Mon	15:00–18:00	CHE/0089	**Focus Session: Relaxation Timescales in Open Quantum Systems (joint session TT/DY)**
DY 13.1–13.9	Mon	15:00–17:30	CHE/0091	**Focus Session: New Routes to Localization and Quantum Non-Ergodicity II (joint session TT/DY)**
DY 14.1–14.13	Mon	15:00–18:30	HÜL/S186	**Machine Learning in Dynamics and Statistical Physics II**
DY 15.1–15.12	Mon	15:00–18:30	ZEU/0114	**Focus Session: Large Deviations and Rare Events II**
DY 16.1–16.13	Mon	15:00–18:30	ZEU/0118	**Droplets, Wetting, and Microfluidics (joint session DY/CPP)**
DY 17.1–17.12	Mon	15:00–18:30	ZEU/0160	**Active Matter II (joint session DY/BP/CPP)**
DY 18.1–18.12	Tue	9:30–12:45	BAR/SCHÖ	**Active Matter III (joint session BP/CPP/DY)**
DY 19.1–19.10	Tue	9:30–12:45	HÜL/S186	**Franco-German Session on Granular Matter I**
DY 20.1–20.5	Tue	9:30–11:00	ZEU/LICH	**Focus Session: Water – from Atmosphere to Space I (joint session CPP/DY)**
DY 21.1–21.11	Tue	9:30–12:45	ZEU/0114	**Stochastic Thermodynamics**
DY 22.1–22.10	Tue	9:30–12:15	ZEU/0118	**Pattern Formation**

DY 23.1–23.12	Tue	9:30–12:45	ZEU/0160	**Complex Fluids and Soft Matter (joint session DY/CPP)**
DY 24.1–24.6	Tue	11:15–12:45	ZEU/LICH	**Focus Session: Water – from Atmosphere to Space II (joint session CPP/DY)**
DY 25.1–25.5	Tue	14:00–15:30	HÜL/S186	**Franco-German Session on Granular Matter II**
DY 26.1–26.5	Tue	14:00–15:30	ZEU/LICH	**Focus Session: Water – from Atmosphere to Space III (joint session CPP/DY)**
DY 27.1–27.6	Tue	14:00–15:30	ZEU/0114	**Statistical Physics far from Thermal Equilibrium II**
DY 28.1–28.4	Tue	14:00–15:15	ZEU/0118	**Fluid Physics and Turbulence**
DY 29.1–29.5	Tue	14:00–15:30	ZEU/0160	**Active Matter IV (joint session DY/BP/CPP)**
DY 30.1–30.12	Wed	9:30–12:45	CHE/0091	**Nonequilibrium Quantum Systems I (joint session TT/DY)**
DY 31.1–31.4	Wed	9:30–11:00	GÖR/0226	**Networks, From Topology to Dynamics – Part I (joint session SOE/DY)**
DY 32.1–32.12	Wed	9:30–12:45	HÜL/S186	**Many-body Systems: Equilibration, Chaos, and Localization (joint session DY/TT)**
DY 33.1–33.12	Wed	9:30–12:45	ZEU/0114	**Statistical Physics of Biological Systems I (joint session DY/BP)**
DY 34.1–34.10	Wed	9:30–12:30	ZEU/0160	**Focus Session: Fluids with Broken Time-Reversal Symmetry – Odd/Hall Viscosity Between Active Matter and Electron Flows**
DY 35.1–35.4	Wed	9:30–10:45	ZEU/0260	**Focus Session: Water – from Atmosphere to Space IV (joint session CPP/DY)**
DY 36.1–36.4	Wed	11:00–12:00	ZEU/0260	**Focus Session: Water – from Atmosphere to Space V (joint session CPP/DY)**
DY 37.1–37.5	Wed	11:15–12:45	ZEU/0118	**Glasses and Glass Transition (joint session DY/CPP)**
DY 38.1–38.9	Wed	15:00–17:30	HSZ/0105	**Nonequilibrium Quantum Systems II (joint session TT/DY)**
DY 39.1–39.3	Wed	15:00–15:45	GÖR/0226	**Networks, From Topology to Dynamics – Part II (joint session SOE/DY)**
DY 40.1–40.5	Wed	15:00–16:30	ZEU/0114	**Statistical Physics of Biological Systems II (joint session DY/BP)**
DY 41.1–41.16	Wed	15:00–18:00	P5	**Poster: Nonlinear Dynamics, Granular Matter, and Machine Learning**
DY 42.1–42.15	Wed	15:00–18:00	P5	**Poster: Quantum Dynamics and Many-body Systems (joint session DY/TT)**
DY 43.1–43.24	Wed	15:00–18:00	P5	**Poster: Statistical Physics**
DY 44.1–44.22	Wed	15:00–18:00	P5	**Poster: Active Matter, Soft Matter, and Fluids**
DY 45.1–45.6	Thu	9:30–11:15	GÖR/0226	**Focus Session: Physics of AI – Part I (joint session SOE/DY)**
DY 46.1–46.12	Thu	9:30–12:45	HÜL/S186	**Many-body Quantum Dynamics I (joint session DY/TT)**
DY 47.1–47.11	Thu	9:30–12:30	ZEU/0114	**Statistical Physics: General I**
DY 48.1–48.6	Thu	9:30–11:00	ZEU/0118	**Nonlinear Dynamics and Time-Delay Systems**
DY 49.1–49.11	Thu	9:30–12:45	ZEU/0160	**Active Matter V (joint session DY/BP)**
DY 50.1–50.7	Thu	10:15–12:45	BAR/0106	**Focus Session: Controlling Microparticles and Biological Cells by Ultrasound (joint session BP/CPP/DY)**
DY 51.1–51.6	Thu	11:15–12:45	ZEU/0118	**Networks: From Topology to Dynamics – Part III (joint session DY/SOE)**
DY 52.1–52.12	Thu	15:00–18:15	BAR/SCHÖ	**Statistical Physics of Biological Systems III (joint session BP/DY)**
DY 53.1–53.6	Thu	15:00–16:30	HÜL/S186	**Many-body Quantum Dynamics II (joint session DY/TT)**
DY 54.1–54.10	Thu	15:00–17:45	ZEU/0114	**Statistical Physics: General II**
DY 55.1–55.8	Thu	15:00–18:00	ZEU/0160	**Focus Session: Emergent Transport in Active Systems (joint session DY/BP)**
DY 56	Thu	18:00–19:00	ZEU/0160	**Members' Assembly**
DY 57.1–57.11	Fri	9:30–12:45	BAR/SCHÖ	**Statistical Physics of Biological Systems IV (joint session BP/DY)**
DY 58.1–58.10	Fri	9:30–12:45	GÖR/0226	**Focus Session: Physics of AI – Part II (joint session SOE/DY)**
DY 59.1–59.11	Fri	9:30–12:45	HÜL/S186	**Quantum Chaos and Coherent Dynamics (joint session DY/TT)**
DY 60.1–60.9	Fri	9:30–12:00	ZEU/0114	**Critical Phenomena and Phase Transitions**
DY 61.1–61.7	Fri	9:30–11:15	ZEU/0118	**Brownian Motion and Anomalous Transport**

DY 62.1–62.9	Fri	9:30–12:15	ZEU/0160	**Active Matter VI (joint session DY/BP)**
DY 63.1–63.5	Fri	11:30–12:45	ZEU/0118	**Nonlinear Stochastic Systems**
DY 64.1–64.1	Fri	13:15–14:00	HSZ/0002	**Closing Talk (joint session CPP/BP/DY)**

Members' Assembly of the Dynamics and Statistical Physics Division

Thursday 18:00–19:00 ZEU/0160

DY 1: Tutorium: Physics of Behavior (joint session SOE/TUT/DY)

The emerging field of the physics of behavior seeks to quantitatively characterize complex behavior in biological agents under naturalistic conditions, using tools from dynamical systems theory and statistical physics. Even in simple organisms, behavioral richness demands new methods of measurement and analysis, as well as new theoretical frameworks. In the absence of a first-principles theory, data-driven approaches are essential, and the many interacting degrees of freedom call for descriptions capable of handling high-dimensional systems.

This tutorial introduces how concepts from dynamical systems theory and statistical physics can be applied to quantify behavior across biological scales and to develop simple yet predictive models. It is intended for physicists at all levels, beginning with graduate students, who are interested in computational approaches to modeling animal behavior. The tutorial is accompanied by an openly accessible code repository to support hands-on exploration of selected topics.

Time: Sunday 16:00–18:15 Location: HSZ/0004

Tutorial DY 1.1 Sun 16:00 HSZ/0004

Physics of Behavior — •Greg Stephens — Vrije Universiteit Amsterdam, Amsterdam NL — OIST Graduate University, Tancha, JP

In these tutorials we view behavior as a complex dynamical system and we incorporate insights from dynamical systems theory and statistical physics to quantitatively capture what animals do. Of course, such theory was not historically developed to understand animal behavior, and there are particular challenges associated with the modeling of living systems. Of these, the most important is a lack of first-principles theory necessitating a data-driven approach.

In the first half of our session we will introduce two primary concepts. (1) Posture Space Analysis via Dimensionality Reduction. We explore posture space analysis by demonstrating how to decompose high-dimensional postural data into a few meaningful eigenpostures using Principal Component Analysis (PCA). The dataset used comes from C. elegans posture tracking. (2) Posture Space Dynamics via State Space Reconstruction. We review the concepts of state space and chaotic systems through a toy model. We then introduce a modern data-driven technique for state space reconstruction.

15 min. break

Tutorial DY 1.2 Sun 17:15 HSZ/0004

Physics of Behavior — •Antonio Carlos Costa — Paris Brain Institute, Paris, France

Animal behavior is inherently nonlinear and multiscale, spanning millisecond movements to hour-long strategies. In the second half of our session, we will complement first-principles approaches with data-driven methods to identify multiscale dynamics in behavioral data.

We will present three key techniques: (1) state space reconstruction combined with transfer operators to extract long-timescale modes from partial observations, (2) coarse-grained modeling to infer slowly-varying behavioral dynamics and explain heavy-tailed statistics, and (3) a multiscale distance metric for reconstructing behavioral phenotypes from dynamic observations.

We will review the theoretical foundations of slow mode identification using transfer operators (illustrated with stochastic and chaotic toy models), and then demonstrate their applicability to real-world data, including posture dynamics in C. elegans and zebrafish.

DY 2: Focus Session: New Routes to Localization and Quantum Non-Ergodicity I (joint session TT/DY)

This session explores how quantum many-body systems can fail to thermalize through mechanisms that extend beyond conventional many-body localization. Recent work has discovered new mechanisms that lead to non-ergodic behavior, including Hilbert-space fragmentation, disorder-free localization, and confinement effects that arise from destructive interference in Fock space. At the same time, experiments with ultracold atoms, trapped ions, Rydberg platforms, and superconducting qubits directly reveal many-body scars, slow relaxation, and unusual transport. This session highlights these developments and identifies the central open questions that are now driving the field forward.

Coordinators: Roderich Moessner (MPI PKS Dresden), Frank Pollmann (TU München)

Time: Monday 9:30–12:15 Location: HSZ/0003

Topical Talk DY 2.1 Mon 9:30 HSZ/0003

Eigenstate thermalization in thermal first-order phase transitions — •Maksym Serbyn — IST Austria, Am Campus 1, 3400 Klosterneuburg

In my talk I will discuss the fate of eigenstates in quantum systems in vicinity of thermal first order phase transition. The eigenstate thermalization hypothesis (ETH) posits how isolated quantum many-body systems thermalize, assuming that individual eigenstates at the same energy density have identical expectation values of local observables in the limit of large systems. In my talk I will show that ETH requires generalization in the presence of thermal first-order phase transitions. I will argue that for energies in the vicinity of the thermal phase transition, eigenstate expectation values do not need to converge to the same thermal value. The system has a regime with coexistence of two classes of eigenstates corresponding to the two branches with distinct expectation values at the same energy density, and another regime with Schrodinger-cat-like eigenstates that are inter-branch superpositions; these two regimes are separated by an eigenstate phase transition. I will also discuss potential extensions of these results to more physical models, and outline how the special structure of eigenstates near first order phase transition can be probed via quench dynamics.

Topical Talk DY 2.2 Mon 10:00 HSZ/0003

Stabilizing Floquet orders to infinite time — •Anushya Chandran[1], Shreyas Raman[2], Robin Schäfer[3], and Alicia Kollàr[4] — [1]Boston University, Boston, USA — [2]Boston University, Boston, USA — [3]Helmholtz-Zentrum Berlin, Berlin, Germany — [4]University of Maryland, College Park, USA

Floquet engineering, in which the properties of a quantum system are modified through the application of strong periodic drives, is an indispensable tool in atomic and condensed matter systems. It enables quantum simulation, the dynamic stabilization of unstable states, and the realization of exotic topological order and time crystals. However, it is inevitably limited by intrinsic heating processes, so that the engineered states are, at best, pre-thermal. I will describe a general-purpose dissipative scheme that autonomously cools a strongly driven system to close to a desired Floquet engineered state. I will demonstrate this stabilization in a driven many-body spin chain, that either

spontaneously breaks a symmetry or exhibits discrete time-crystalline order in the steady state.

Topical Talk DY 2.3 Mon 10:30 HSZ/0003

Dynamical landscape of out of equilibrium emergent lattice gauge theories in two dimensions — •Nilotpal Chakraborty — University of Cambridge

Many-body models with local constraints, such as dimer, ice or generally quantum link type models often are described as emergent gauge theories. I will describe a range of recent results, comprising classical and quantum dynamics of different kind, highlighting the rich dynamical phenomenology present in these models. In line with the session's topic, I will focus more on the two-dimensional U(1) quantum link model, and highlight its potential as a new route toward localisation and non-ergodicity in the absence of quenched disorder. In doing so, I will also present spectral signatures of such localization. Finally, I will end by discussing possibilities of realising the different constrained models and their dynamics in quantum simulators, for which there appears to be palpable current interest.

15 min. break

Topical Talk DY 2.4 Mon 11:15 HSZ/0003

Interference, topology, and new Hilbert-space routes to quantum non-ergodicity — •Yi-Ping Huang[1,2,3] and Tao-Lin Tan[1] — [1]Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan — [2]Physics Division, National Center for Theoretical Sciences, Taipei 10617, Taiwan — [3]Institute of Physics, Academia Sinica, Taipei 115, Taiwan

A central challenge in nonequilibrium quantum physics is to understand why certain many-body systems fail to thermalize even in the absence of disorder or integrability. In this talk, I will outline a different perspective in which non-ergodicity is governed by hidden geometric structures in Hilbert space rather than by conventional real-space mechanisms. This viewpoint leads to the concept of interference-caged quantum many-body scars (ICQMBS), where exact many-body destructive interference confines eigenstates to small regions of the Fock-space graph. Remarkably, interference zeros and graph automorphisms emerge as universal organizing principles, revealing a class of topological ICQMBS whose robustness originates from local Fock-space topology rather than symmetries or constraints. This framework not only explains diverse non-ergodic phenomena from one-dimensional systems to two-dimensional gauge models but also provides new tools for systematically identifying them. I will end with a brief look at stabilizing QMBS through the lens of Kramers-Wannier duality, illustrating the challenges and possibilities that arise when studying QMBS under duality.

Topical Talk DY 2.5 Mon 11:45 HSZ/0003

Fock-space cages and their spectral signatures — •Cheryne Jonay — University of Ljubljana

Generic quantum many-body systems thermalize. Yet several mechanisms can prevent this, notable examples include integrability, many-body localization, Hilbert-space fragmentation, and scars. We will discuss a new mechanism of ergodicity breaking that arises from destructive interference in Fock space. This leads to exact eigenstates localized on polynomially many configurations within an exponentially large, fully connected Hilbert space sector. We call these states Fock-space cages. They emerge naturally in kinetically constrained models with chiral symmetry. We will present graph-theoretic methods to explicitly construct cages with support ranging from O(1) to O(L) sites, and examine how their dynamical signatures, such as return probabilities and magnetization, resist thermalization. Finally, we will explore the spectral statistics through the lens of chiral random matrix theory. The exponentially degenerate zero-energy manifold produces distinctive signatures, yet the agreement with random matrix predictions varies across energy scales - a direct consequence of localized and thermal eigenstates coexisting within the same Hilbert space sector. We will also probe the stability of these phenomena: the gap between the zero-energy manifold and the spectral bulk may give rise to protected slow dynamics.

DY 3: Quantum-Critical Phenomena (joint session TT/DY)

Time: Monday 9:30–12:30 Location: HSZ/0101

DY 3.1 Mon 9:30 HSZ/0101

Possible Quantum Criticality Tuned by Pressure in $CeVGe_3$ — Rong-Zhu Lin[1], Po-Yuan Cheng[1], Yusei Shimizu[2], Timothée Vasina[3], Daniel Braithwaite[3], Hanshang Jin[4], Peter Klavins[4], Valentin Taufour[4], and •Chien-Lung Huang[1] — [1]Department of Physics, National Cheng Kung University and Center for Quantum Frontiers of Research & Technology, Tainan 701, Taiwan — [2]International Research Center for Nuclear Materials Science, Institute for Materials Research (IMR-Oarai), Tohoku University, Ibaraki 311-1313, Japan — [3]Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG, PHELIQS, 38000, Grenoble, France — [4]Department of Physics and Astronomy, University of California, Davis, California 95616, USA

In this work, we focus on the helical antiferromagnetic (AFM) $CeVGe_3$ to explore whether an AFM quantum critical point (QCP) can be approached. By performing resistivity measurements under pressure, we construct the pressure-temperature-field phase diagram and track the evolution of multiple field-induced phases. The AFM ordering temperature is suppressed at the critical pressure $p_c = 0.7$ GPa. The coefficient A in the temperature-dependent resistivity $\rho = \rho_0 + AT^2$ exhibits a maximum at p_c and gradually decreases at higher pressures, indicating enhanced electron-electron correlations near the critical point. These results reveal how the competition between Ruderman-Kittel-Kasuya-Yosida (RKKY) and Kondo interactions evolves under pressure, leading to a plausible pressure-induced QCP in $CeVGe_3$.

DY 3.2 Mon 9:45 HSZ/0101

Spin and charge criticality in the pseudogap two-impurity Anderson model — •Charlotte Beneke and Matthias Vojta — Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany

The Kondo effect originates from spin screening of localized impurities by conduction electrons. This Kondo screening can be suppressed by a fermionic bath following a pseudogap (i.e. power-law) density of states, by inter-impurity interactions, or by coupling to multiple conduction channels. We investigate the two-impurity Anderson model in various limits, and establish mappings to known Kondo and Anderson models. This leads to rich phase diagrams with Kondo-breakdown transitions of distinct universality classes giving rise to non-Fermi-liquid behavior. We analyze the phase diagram, and critical exponents of the pseudogap two-impurity Anderson model in the particle-hole symmetric, SU(2)-invariant case using perturbative renormalization-group techniques. We recover the transitions of the pseudogap single-impurity Anderson model, and find additional Kondo-breakdown quantum transitions to inter-impurity singlet-, triplet- and charge-ordered phases. At the quantum critical points, superconducting-pairing susceptibilities can be enhanced depending on the type of spin- and charge criticality. We discuss connections to heavy-fermion systems and two-quantum-dot realizations where quantum dots act as tunable magnetic impurities.

DY 3.3 Mon 10:00 HSZ/0101

Stability of Deconfined Quantum Critical Points Coupled to Quantum Phonons — •Anton Romen[1,2], Josef Willsher[1,2,3], David Hofmeier[4], Johannes Knolle[1,2,5], and Michael Knap[1,2] — [1]Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [4]University of Southern Denmark, Odense M, Denmark — [5]Imperial College London, London, United Kingdom

Deconfined quantum criticality (DQC) describes continuous transitions beyond the Landau-Ginzburg paradigm. A typical example is the VBS-Néel transition in frustrated antiferromagnets. Since the VBS order parameter breaks lattice symmetries, it can couple to lattice distortions (phonons). Field-theory (PRB 110, 125130 (2024)) predicts that static lattice vibrations induce strong first-order character. A full quantum treatment, however, indicates that DQC survives above a critical phonon frequency. In this work, we provide a detailed study on the stability of 1D DQC under spin-phonon coupling resorting to

a frustrated anisotropic J1-J2 model as a paradigmatic example. Using large-scale tensor network simulations, we determine the flow of the continuously varying critical exponents with phonon frequency and the critical phonon frequency, at which the transition becomes strongly first-order. By relating the critical theory to an Ashkin-Teller type model, we argue that the critical endpoint is in the four-state Potts universality class. We further compute dynamical phonon spectral functions that provide a powerful experimental signature of DQC.

DY 3.4 Mon 10:15 HSZ/0101

Inducing extraordinary-log criticality in the Heisenberg spin chain — •Grigorios Makris, Francesco Parisen Toldin, and Stefan Wessel — Institute for Theoretical Solid State Physics, RWTH Aachen University, Germany

We examine the ground state correlations emerging in a spin-1/2 Heisenberg chain upon coupling it to a quantum critical two-dimensional bilayer Heisenberg model. Based on the quantum-to-classical mapping and recent findings of unconventional surface criticality of three-dimensional classical Heisenberg models, extraordinary-log criticality is expected to become accessible within this setup along the coupled chain, which serves as a line defect. In particular, such a defect corresponds, through the quantum-to-classical mapping, to a planar defect in the classical case which exhibits extraordinary-log criticality. We use large-scale quantum Monte Carlo simulations to systematically explore this scenario, based on measurements of correlations and the spin stiffness, using the stochastic series expansion methods.

DY 3.5 Mon 10:30 HSZ/0101

Kibble-Zurek Dynamics in the Anisotropic Ising Model of the Si(001) Surface — •Gernot Schaller[1], Friedemann Queisser[1], Parya Katoorani[1], Christian Brand[2], Christian Kohlfürst[1], Mark Freeman[3], Alfred Hucht[2], Peter Kratzer[2], Björn Sothmann[2], Michael Horn-von Hoegen[2], and Ralf Schützhold[1,4] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany — [2]Fakultät für Physik, Universität Duisburg-Essen and CENIDE, Lotharstraße 1, 47057 Duisburg, Germany — [3]Department of Physics, University of Alberta, 4-181 Centennial Center for Interdisciplinary Science Edmonton, Alberta T6G 2E1, Canada — [4]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany

As a simplified description of the nonequilibrium dynamics of buckled dimers on the Si(001) surface, we consider the anisotropic two-dimensional (2D) Ising model [1,2] and study the freezing of spatial correlations during a cooling quench across the critical point. Depending on the cooling rate, we observe a crossover from one-dimensional (1D) to 2D behavior [3]. For rapid cooling, we find effectively 1D behavior in the strongly coupled direction, for which we provide an exact analytic solution of the nonequilibrium dynamics. For slower cooling rates, we start to see 2D behavior where our numerical simulations show an approach to the usual Kibble-Zurek scaling in 2D.

[1] C. Brandt *et al.*, Phys. Rev. Lett. **130**, 126203 (2023).
[2] C. Brandt *et al.*, Phys. Rev. B **109**, 134104 (2024).
[3] G. Schaller *et al.*, Phys. Rev. Lett. **134**, 246202 (2025).

DY 3.6 Mon 10:45 HSZ/0101

Frustration effects and self-consistent matter description in the Dicke-Ising model on the sawtooth chain — •Jonas Leibig, Max Hörmann, Anja Langheld, Andreas Schellenberger, and Kai Phillip Schmidt — Department of Physics, Staudtstraße 7, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

We investigate how the exact thermodynamic-limit mapping of the Dicke-Ising model to a self-consistent effective matter Hamiltonian applies to the geometrically frustrated sawtooth chain. The mapping, established in Ref. [2], was recently solved with NLCE+DMRG for the unfrustrated chain in our work [1]. Using the same method, we obtain the zero-temperature phase diagram of the sawtooth geometry and identify frustration-induced features absent in the unfrustrated case. In the frustrated Ising limit, an infinitesimal effective transverse field lifts the classical degeneracy and produces a disorder-by-disorder transition, analogous to the transverse-field Ising model [3].

[1] J. Leibig, M. Hörmann, A. Langheld, A. Schellenberger, and K. P. Schmidt, *to be published* (2025).
[2] J. Román-Roche, Á. Gómez-León, F. Luis, and D. Zueco, *Physical Review B* **111**, 035156 (2025).
[3] D. J. Priour, M. P. Gelfand, and S. L. Sondhi, *Phys. Rev. B* **64**, 134424 (2001).

15 min. break

DY 3.7 Mon 11:15 HSZ/0101

Potts nematic quantum phase transition in Dirac fermion systems — •Max Fornoville[1,2], Kilian Fraboulet[1], Michael M. Scherer[3], and Laura Classen[1,2] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]School of Natural Sciences, Technische Universität München, 85748 Garching, Germany — [3]Theoretische Physik III, Ruhr-Universität Bochum, 44801 Bochum, Germany

With the advent of 2D moiré materials, Dirac fermion models have yet again emerged as promising candidates to describe putative quantum critical points in these systems. The presence of gapless fermions provides an avenue towards criticality beyond the conventional universality classes because it profoundly alters the quantum critical behavior, also giving rise to non-Fermi liquid behavior. We investigate the onset of nematic order in Dirac systems with hexagonal symmetry. Owing to the sixfold rotational symmetry, the nematic director selects among three equivalent orientations and the associated order parameter is described by a 3-state Potts model coupled to the Dirac fermions via a Yukawa interaction. In the ordered phase, the fermions remain gapless but the Dirac points split, dynamically breaking rotational symmetry. At the mean-field level, the transition is of first order, which we demonstrate using a minimal lattice model. We further employ a functional renormalization group approach to investigate the influence of the Dirac fermions on the Potts model and the nature of the transition due to a possible fermion-induced continuous quantum critical point.

DY 3.8 Mon 11:30 HSZ/0101

Chiral Quantum Phase Transition in Moiré Dirac Materials at finite density — •Ana Garcia-Page[1] and Laura Classen[1,2] — [1]Max-Planck-Institute for Solid State Research, Stuttgart, Germany — [2]Technical University of Munich, Munich, Germany

Chiral quantum phase transitions in Dirac materials at finite density: Strong enough interactions induce a semimetal-to-insulator transition in Dirac materials, which can be viewed as the solid-state analogue of the chiral phase transition in quantum chromodynamics. Moiré Dirac materials such as twisted bilayer graphene offer a new opportunity to study this transition because they facilitate tuning the effective interaction via a twist angle. Motivated by this, we explore the quantum phase transition of a (2+1) dimensional Dirac material at T = 0K which spontaneously develops a gap that breaks an Ising symmetry. It is still an open question what is the structure of the phase diagram at finite chemical potential. To explore it, we study a Gross-Neveu-Yukawa model for the phase transition using both a mean-field theory and a functional renormalization group approach. Interestingly, we find an intermediate state between semi-metal and insulator where a homogeneous solution appears to be unstable.

DY 3.9 Mon 11:45 HSZ/0101

Pseudo-first-order transition from competing Dirac masses in one dimension — •Manuel Weber — Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

Emergent symmetries and slow crossover phenomena are central themes in quantum criticality and manifest themselves in the pseudocritical scaling experienced in the context of deconfined criticality. Here we discover its conceptual counterpart, i.e., a symmetry-enhanced *pseudo-first-order transition*. It emerges from a one-dimensional realization of deconfined criticality between charge- and bond-ordered states driven by competing Holstein and Su-Schrieffer-Heeger electron-phonon couplings, for which quantum fluctuations and thereby the nature of the transition can be tuned systematically via the phonon frequency ω_0. In the classical limit $\omega_0 \to 0$, a low-energy Dirac theory predicts a direct first-order transition with emergent U(1) symmetry. Using exact quantum Monte Carlo simulations, we provide strong evidence for symmetry enhancement and even finite-size scaling on intermediate length scales but in the thermodynamic limit it turns into a narrow intermediate phase where both order parameters are finite, as chiral U(1) symmetry is weakly broken on the lattice. Including quantum lattice fluctuations diminishes the width of the intermediate phase, gradually restores the U(1) symmetry, and eventually tunes the system to a deconfined quantum critical point.

DY 3.10 Mon 12:00 HSZ/0101

Spectral Optimization of the 2-Sphere and Applications to Classical and Quantum Interacting Spin Systems — •Jonas

Völler[1], Grigorios Makris[1], Fabian Hassler[2], and Stefan Wessel[1] — [1]Institute for Theoretical Physics, RWTH Aachen University, Germany — [2]Institute for Quantum Information, RWTH Aachen University, Germany

We investigate discretizations of the 2-sphere using non-uniform simplicial lattices. Starting from an icosahedral seed, we optimize the lattice by solving the free-particle tight-binding model and applying gradient descent to reduce spectral degeneracy breaking, with the goal of restoring the $2\ell + 1$-fold degeneracy of an $SO(3)$-symmetric system. We then perform Monte Carlo simulations of the critical Ising and Potts models and quantify the rotational symmetry breaking by projecting the two-point correlation function onto spherical harmonics. For sufficiently fine discretizations, we successfully recover the expected $SO(3)$-symmetric behavior. Finally, we carry out quantum Monte Carlo simulations of the transverse-field Ising model and locate its critical point by studying Binder-cumulant crossings.

DY 3.11 Mon 12:15 HSZ/0101

Hybrid Monte Carlo on the fuzzy sphere for conformal critical phenomena — •Lidia Stocker[1], Zheng Zhou[2], Yin-Chen He[3], Emilie Huffmann[4], and Johannes Stephan Hofmann[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada — [3]C. N. Yang Institute for Theoretical Physics, Stony Brook University, Stony Brook, NY, USA — [4]Department of Physics, Wake Forest University, Winston-Salem, NC, USA

The fuzzy sphere regularization was recently introduced to study conformal symmetry in the 3D Ising transition [1]. Preliminary analysis with this approach showed excellent agreement with the state*operator correspondence, even though the size of the system considered was particularly restricted. Building on a sign-problem-free formulation of quantum many-body models on the fuzzy sphere [2], we extend the study to significantly larger system sizes using a hybrid Monte Carlo (HMC) scheme. In contrast to microscopic lattice models, we study the deconfined quantum critical point from a low-energy perspective and address whether the transition is of first- or second-order nature, assuming SO(5) symmetry. Our results demonstrate that HMC on the fuzzy sphere is a powerful and scalable framework for exploring conformal critical phenomena in models with many degrees of freedom.

[1] Phys. Rev. X 13, 021009 (2023)
[2] SciPost Phys. Core 7, 028 (2024)

DY 4: Active Matter I (joint session BP/CPP/DY)

Time: Monday 9:30–12:45 Location: BAR/SCHÖ

DY 4.1 Mon 9:30 BAR/SCHÖ

Bayesian inference of magnetosensing in a magnetotactic bacterium — •Sascha Lambert[1], Emilie Gachon[2], Damien Faivre[2], and Stefan Klumpp[1] — [1]University of Göttingen, Institute for the Dynamics of Complex Systems, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany. — [2]Aix Marseille Université, CEA, CNRS, BIAM, 13115 Saint-Paul-Lez-Durance, France.

Magnetotactic bacteria are often assumed to align only passively with external magnetic fields, yet recent observations of the magnetotactic bacterium SS-5 reveal a pronounced increase in swimming speed under geomagnetic conditions. Because flagellated microorganisms typically follow helical paths, magnetic torques could, in principle, straighten their trajectories and create an apparent increase in speed, offering a purely mechanical explanation. We test this hypothesis using a physical swimming model based on Active Brownian Particles that incorporates magnetic torques, rotational propulsion, and helical motion, and we explore the relevant parameter space using Bayesian inference constrained by three-dimensional trajectory data. Posterior predictive simulations demonstrate that the mechanically induced increase in apparent speed is far too small to account for the experimental observations, even under extreme parameter choices. The results quantitatively rule out swaying as a sufficient explanation for the behaviour of SS-5 and instead support the presence of an active magnetic sensing mechanism.

DY 4.2 Mon 9:45 BAR/SCHÖ

Vorticity-induced surfing and trapping in porous media — •Pallabi Das[1], Mirko Residori[1], Axel Voigt[2,3,4], Suvendu Mandal[5], and Christina Kurzthaler[1,3,4] — [1]Max Planck Institute for the Physics of Complex Systems, Germany — [2]Institute of Scientific Computing, TU Dresden, Germany — [3]Center for Systems Biology Dresden, Germany — [4]Cluster of Excellence, Physics of Life, TU Dresden, Germany — [5]TU Darmstadt, Germany

Microorganisms often encounter strong confinement and complex hydrodynamic flows while navigating their habitats. Combining finite-element methods and stochastic simulations, we study the interplay of active transport and heterogeneous flows in dense porous channels. We find that swimming always slows down the traversal of agents across the channel, giving rise to robust power-law tails of their exit-time distributions. These exit-time distributions collapse onto a universal master curve with a scaling exponent of $\approx 3/2$ across a wide range of packing fractions and motility parameters, which can be rationalized by a scaling relation. We further identify a new motility pattern where agents alternate between *trapping* along fast streams and extended *surfing* phases, the latter determining the power-law exponent. Unexpectedly, trapping occurs in the flow backbone itself – not only at obstacle boundaries – due to vorticity-induced reorientation in the highly-heterogeneous flow environment. These findings provide a fundamentally new active transport mechanism with direct implications for biofilm clogging and the design of novel microrobots capable of operating in heterogeneous media.

DY 4.3 Mon 10:00 BAR/SCHÖ

Adhesion Patterns in Gliding Filamentous Cyanobacteria — •Elias Fischer[1], Paul Nieschwitz[2], Stefan Karpitschka[2], and Holger Stark[1] — [1]Institute of Physics and Astronomy, TU Berlin, Germany — [2]Department of Physics, Universität Konstanz, Germany

Filamentous cyanobacteria play an important role in many ecosystems and the carbon cycle of our planet. They 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.

Our recent measurements of filamentous cyanobacteria gliding across flat surfaces and visualized in kymographs show spatio-temporal adhesion regions along the filament, indicating an intrinsic helical shape. Based on our a novel approach for modeling the mechanical aspects of individual cyanobacteria filaments, we are able to interpret the complex kymograph patterns. Each filament is modeled as a helical chain of thin cylindrical segments in 3D with bending and twisting elasticity. The filaments interact with nearby surfaces and filaments via a hard-core repulsion and an exponentially decaying adhesion force. Importantly, the propulsion forces that push the filament forward are only applied locally at surface-contacting segments.

Our simulated kymographs reveal how both the helical shape and the adhesion strength strongly influence the filament's gliding speed and the dynamics of the surface-attachment regions. Thereby, we crucially contribute to the understanding of how real filamentous cyanobacteria generate their propulsion forces.

DY 4.4 Mon 10:15 BAR/SCHÖ

The 3D chirality of malaria parasites determines their motion patterns in 2D and originates at the apical pole — •Leon Lettermann[1], Mirko Singer[2], Smilla Steinbrück[2,3], Falko Ziebert[1], Sachie Kanatani[3], Photini Sinnis[3], Friedrich Frischknecht[2], and Ulrich Schwarz[1] — [1]Institute for Theoretical Physics & BioQuant, Heidelberg University — [2]Parasitology, Center for Infectious Diseases, Heidelberg University — [3]School of Public Health and Malaria Research Institute, Johns Hopkins University

Plasmodium sporozoites, the slender forms of the malaria parasite injected by mosquitoes into the skins of their vertebrate hosts, provide a medically highly relevant model system for active chiral particles. Using 3D tracking in synthetic hydrogels, we show that sporozoites consistently move on right-handed helical trajectories. When they encounter a two-dimensional substrate, they switch to clockwise circular motion, whereas circling on glass in medium occurs with the opposite sense of rotation, suggesting on glass they try to invade the medium above.

Using a sandwich assay, we demonstrate that chirality also determines the reverse transition from two-dimensional to three-dimensional motion. Combining these measurements with a theory for gliding motility allows us to identify the likely origin of chirality, namely an asymmetric distribution of adhesins. After confirming this via two-sided traction force microscopy, we finally use STED super-resolution microscopy to reveal a corresponding tilt in the apical ring complex. In summary, our analysis thus uncovers both the biological relevance and the molecular basis of chirality in the movement of malaria parasites.

DY 4.5 Mon 10:30 BAR/SCHÖ

Squirmer dynamics in porous environments — •Mirko Residori[1], Christina Kurzthaler[1], and Sebastian Aland[2] — [1]Max Planck Institute for the Physics of Complex Systems — [2]TU Freiberg

We introduce a computational framework for simulating the dynamics of micro-swimmers in complex porous environments. Specifically, we adopt a diffusive domain approach to represent the surface of a microswimmer, modeled as a squirmer. This method ensures accurate and stable finite-element simulations, even in highly confined geometries. Validation against analytical and numerical benchmarks confirms the model*s accuracy and robustness. We then apply it to explore squirmer motion in heterogeneous porous media, revealing how hydrodynamic interactions lead to behaviors such as dynamic trapping due to hydrodynamically induced re-orientations. Moreover, we demonstrate that the squirmer parameter and the repulsive potential critically influence a squirmer's ability to navigate and escape confinement. The proposed framework offers a versatile and efficient tool for studying active motion in complex fluids and provides new insights into micro-swimmer transport and control in natural and engineered systems.

DY 4.6 Mon 10:45 BAR/SCHÖ

Dynamics of passive tracers in active dumbbell suspension — •Chandranshu Tiwari and Sunil P. Singh — Department of Physics, Indian Institute of Science Education and Research, Bhopal 462066, India.

The transport of passive tracers in active fluids exhibits rich dynamics arising from persistent interactions between active agents and the tracer. In our work, we employ Brownian dynamics simulations to investigate the dynamical behaviour of both isotropic(circular) and anisotropic(elliptical) tracers in active dumbbell suspension, considering only steric interactions. For circular tracers, we find that the speed shows a crossover from monotonically decreasing to increasing with tracer size as the dumbbells' speed is increased. The tracer's effective diffusion also displays a non-monotonic dependence on area fraction: the diffusivity first increases and then decreases at higher area fractions.

For anisotropic tracers, the characteristic non-monotonic trend persists. Moreover, their motion along the major and minor axes differs significantly. Anisotropic accumulation of active particles around the tracer generates direction-dependent forces and fluctuations, favouring motion along the major axis. Consequently, both the speed and diffusivity along the major axis exceed those along the minor axis.

15 min. break

Invited Talk DY 4.7 Mon 11:15 BAR/SCHÖ

Modeling and inference of magnetotactic motility in complex environments — •Stefan Klumpp — Institute for the Dynamics of Complex Systems, University of Göttingen, Göttingen, Germany

Magnetotactic bacteria orient themselves and swim along field lines of the geomagnetic field. Their magnetically directed self-propelled motion makes them an instance of dipolar active matter. Here we focus on the interaction of these bacteria with walls or obstacles. Experiments in microfluidic systems show that interactions with walls result in (possibly transient) alignment parallel to the wall, which may compete with the alignment with the magnetic field. The dynamic behavior arising from the competition of the two alignments includes U-turn trajectories in circular chambers and trapping and escape dynamics in channels with overlapping cylindrical obstacles. In a phenomenological picture, the resulting motion can be described in an Active Brownian Particle model by introducing a wall torque that competes with the magnetic torque, which results in good agreement with experimental observations. Systematic Bayesian inference of the wall torque from observations shows that only a part of the torque function (dependence on incident angle) can be learned reliably from the data.

DY 4.8 Mon 11:45 BAR/SCHÖ

Quantifying aggregation behaviour of filamentous cyanobacteria — •Elias Illing and Stefan Karpitschka — Fachbereich Physik, Universität Konstanz

Cyanobacteria are ubiquitous in nature, frequently causing ecological and economic harm by explosive growth, so called blooms.

We investigate the collective dynamics of entangled filamentous cyanobacteria in open liquid media, reminiscent of their aggregates found during later stages of blooms. We investigate the impact of illumination on the clustering and spreading of the bacteria and quantify the morphology of the bacterial aggregates by image analysis. We determine the critical density necessary for initial clustering and track the evolution of the subsequent stages, ranging from stable clusters to spreading mats. These states can be modulated by light intensity variations, potentially allowing for control of the morphological evolution of cyanobacterial aggregates.

DY 4.9 Mon 12:00 BAR/SCHÖ

Dynamically Induced Spatial Segregation in Multi-Species Bacterial Bioconvection — •Mingqi Yan[1,2], Chenxi Wang[3], Oscar Gallardo-Navarro[4], Rinat Arbel-Goren[4], Joel Stavans[4], and Erwin Frey[1,2] — [1]Department of Physics, Ludwig-Maximilians-Universität München, Theresienstraße 37, 80333 München, Germany — [2]Max Planck School Matter to Life, Hofgartenstraße 8, 80539, München, Germany — [3]School of Science, Harbin Institute of Technology, 518055, Shenzhen, China — [4]Department of Physics of Complex Systems, Weizmann Institute of Science, 7610001, Rehovot, Israel

Bacterial bioconvection is a classic example of collective behavior in active matter, where upward-swimming bacteria create density instabilities leading to large-scale fluid flows. While this phenomenon is well-studied in single-species suspensions, natural environments are typically inhabited by diverse microbial communities. Here, we investigate the collective dynamics of multi-species bacterial suspensions. Combining experiments with a continum model, we show that different bacterial species can spontaneously segregate into stable, spatially interlocked domains. Our theoretical analysis reveals that this segregation is not driven by biochemical antagonism but rather by the interplay between species-specific motility characteristics and the self-generated hydrodynamic flows. This work provides new insights into how physical interactions alone can drive the spatial organization of complex microbial communities.

DY 4.10 Mon 12:15 BAR/SCHÖ

Light-switchable microbial rafts at air-liquid interfaces — •Gustav F. Nolte, Alexandros A. Fragkopoulos, Timo Völkl, Mechthild Rappold, and Oliver Bäumchen — University of Bayreuth, Experimental Physics V, 95447 Bayreuth, Germany

In biological active matter, clustering occurs across a wide range of time and length scales, from molecular assemblies such as actomyosin networks to macroscopic systems like fire ant rafts. Here, we report on a fast, light-switchable, and fully reversible clustering phenotype on the microscale, observed at air-liquid interfaces: the raft formation of the biciliated microalga *Chlamydomonas noctigama*.

C. noctigama is a relative of the model organism *Chlamydomonas reinhardtii*, which exhibits light-switchable adhesion and subsequent clustering at solid-liquid interfaces [1,2]. We show how the cluster morphology depends on cell density and discuss potential growth mechanisms by analyzing dynamics of individual clusters. Furthermore, we characterize the dependence of raft formation on the light spectrum and interfacial free energy. Using micropipette force spectroscopy [3], we show that single cells exploit capillary forces for light-switchable ciliary adhesion to the air-liquid interface, enabling raft formation. In their natural habitats, reversible clustering may provide an advantage by allowing cells to accumulate in locations optimal for photosynthesis while increasing resilience to environmental stress.

[1] C. T. Kreis, et al., *Nat. Phys.* **14**, 45 (2018).
[2] S. Till, et al., *Phy. Rev. Res.* **4**, L042046 (2022).
[3] M. Backholm and O. Bäumchen, *Nat. Protoc.* **14**, 594-615 (2019).

DY 4.11 Mon 12:30 BAR/SCHÖ

Circadian gravitaxis: Photosynthetic microswimmers remodel local pH to actively tune vertical migration — Arkajyoti Ghoshal[1], Soumitree Mishra[1], Jayabrata Dhar[2], Hans-Peter Grossart[3,4], and •Anupam Sengupta[1,5] — [1]Physics of Living Matter, Department of Physics and Materials Science, University of Luxembourg, Luxembourg — [2]Department of Mechanical Engineering, National Institute of Technology Durgapur, India — [3]Department

of Plankton and Microbial Ecology, Leibniz Institute of Freshwater Ecology and Inland Fisheries, Stechlin, Germany — [4]Institute of Biochemistry and Biology, Potsdam University, Germany — [5]Institute for Advanced Studies, University of Luxembourg, Luxembourg

Motile phytoplankton shuttle between bright surface waters and deeper nutrient rich layers, usually controlled by internal circadian clocks. Yet many species show irregular movements, defying the expected circadian rhythm. Studying a bloom forming photosynthetic species, we found that cells adjust their vertical migration by altering local pH, mediated by a shift in their gravitactic behavior. This self-modulation of pH generates sub-populations which are physiologically similar but swim differently, remaining vertically separated even under uniform conditions. Supported by a cell-level analysis and mathematical model, we confirm that the pH-mediated circadian shift is underpinned by morphological adjustments. Our results support a circadian gravitactic model in which diurnal pH control drives diversified migration, enhancing fitness particularly in acidifying oceans.

DY 5: Focus Session: Physics of Behavior (joint session SOE/DY)

Organizers: Greg Stephens (Vrije Univ. Amsterdam), Pawel Romanczuk (HU Berlin)

Physics has made important contributions to the remarkable progress in characterizing the molecules, cells, and circuits that generate natural behavior. Yet our understanding of behavior at the scale of the whole organism and in ecological and social contexts remains significantly less advanced. Even in simpler organisms, natural behavior is complex, requiring new tools for measurement (often through novel imaging), analysis, and theoretical insight. The emerging field of the physics of behavior addresses this gap by seeking to quantitatively characterize complex behavior in naturalistic settings. This focus session will highlight recent advances at the intersection of physics, neuroscience, biology, and social sciences with contributions from both theorists and experimentalists.

Time: Monday 9:30–12:45 Location: GÖR/0226

Invited Talk DY 5.1 Mon 9:30 GÖR/0226

Memory and equilibrium in collective animal behaviour — •Thierry Mora — Ecole normale supérieure and CNRS, Paris, France

Some animal groups behave in a highly coordinated way, reminiscent of ordered phases in physics. However, animals are also heterogeneous, have memory, and operate out of equilibrium. I will present recent attempts at modeling the complex dynamics of social groups of mice interacting freely in a controlled environment. I will then assess how far from equilibrium collective behaviour might be, both in recordings of real bird flocks and in flocking models.

DY 5.2 Mon 10:00 GÖR/0226

Spin-Waves without Spin-Waves: A Case for Soliton Propagation in Starling Flocks — •Andrea Cavagna — Institute for Complex Systems, Rome, Italy

Collective turns in starling flocks propagate linearly with negligible attenuation, indicating the existence of an underdamped sector in the dispersion relation. Beside granting linear propagation of the phase perturbations, the real part of the frequency should also yield a spin-wave form of the unperturbed correlation function. However, new high-resolution experiments on real flocks show that underdamped traveling waves coexist with an overdamped Lorentzian correlation. Theory and experiments are reconciled once we add to the dynamics a Fermi-Pasta-Ulam-Tsingou term.

DY 5.3 Mon 10:15 GÖR/0226

Modelling filamentous fungal growth — •Pascal Klamser[1], Carlos Aguilar-Trigueros[2] und Dirk Brockmann[1] — [1]Technische Universität Dresden, Dresden, Germany — [2]University of Jyväskylä, Jyväskylä, Finland

The growth of a filament forming fungi is mesmerizing and a great example of an organism that forms a transport network and explores its environment for nutrients. While recent research shows how nutrients and other compounds are transported through the network, we will focus on a transport-agnostic model to explore the possible ways of how the tip of a filament can choose its growth direction. We assume a purely external communication via the diffusion of enzymes released by the filaments and can recreate a wide range of phenotypes. We compare it with experiments by estimating the hierarchical structure of the network from microscopic images.

15 min. break

DY 5.4 Mon 10:45 GÖR/0226

Understanding how movement behaviors shape animal encounters and their ecological consequences — •Anudeep Surendran — Helmholtz-Zentrum Dresden-Rossendorf, Görlitz, Germany

Encounters between individuals underlie key ecological processes such as predation, mating, and disease transmission, making encounter rates a direct link between individual movement behavior and population-level outcomes. We investigate how two common features of animal movement-directional persistence and range residency-jointly shape encounter rates. Using the Ornstein Uhlenbeck with foraging (OUF) model, which integrates these two properties of animal movement, we derive exact analytical expressions for encounter rates and show that, for range-resident animals, the effect of persistence depends strongly on the degree of home-range overlap. Based on this theoretical result, we then introduce a new encounter-based metric that quantifies the spatial organization of home ranges at scales relevant to animal encounters. We finally apply this metric to movement data from lowland tapirs (Tapirus terrestris) in Brazils Pantanal region, and find a significant level of home-range spatial segregation that is consistent with the solitary behavior of this species.

DY 5.5 Mon 11:00 GÖR/0226

Composite and combined games in evolutionary dynamics in finite populations — Henry Brooks, Suzannah Gebbett, and •Jens Christian Claussen — University of Birmingham, UK

Evolutionary game theory connects dynamics to strategy by assuming few behavioral strategies, modeling costs and benefits from interactions via a payoff matrices, then casting these into replicator equations (in infinite populations) resp. stochastic processes (in finite populations) which comprise a "physics of behaviour" model of the collective decision dynamics (which may include cyclic oscillations). We build on previous results (PRL 95, 238701 and PRL 100, 058104 and subsequent) and discuss combinations of 2- and 3 strategy games in the context of different replicator dynamics, and stochastic processes derived from agent interaction models. We demonstrate how the previous concepts of drift reversal - how an attracting fixed point resulting from a Hopf bifurcation loses stabilty below a critical population size, applies to the combined games.

DY 5.6 Mon 11:15 GÖR/0226

A reversal in agent preference reveals partial segregation in the Schelling model — •Maksim Prusakov and Dirk Brockmann — Center Synergy of Systems, TUD Dresden University of Technology, Dresden, Germany

The Schelling model is one of the most famous and seminal models used to describe spatial segregation in social systems. We introduce a small modification to the basic rules of the model: instead of avoiding locations with too many neighbors of a different type, agents now seek places with a high proportion of same-type neighbors. Although this change may seem minor, it leads to qualitatively different behavior. For certain parameter values the system enters an unexpected

and new partial-segregation phase, where macroscopically stable segregated clusters coexist with mixed, dynamically active regions.

We construct the phase diagram across tolerance and density values and characterize all macroscopic regimes of the model. The partial-segregation phase emerges robustly across different neighborhood sizes, lattice geometries, and numbers of agent types, which suggests that this behavior follows from the modified preference rule itself rather than from microscopic implementation details. To complement these results, we develop a theoretical framework that describes the stability conditions of the observed phases, with particular attention to the mechanisms that sustain partial segregation. Ultimately, our findings show that even a minor change in the type of local preference can generate fundamentally new collective behavior within Schelling-type models.

DY 5.7 Mon 11:30 GÖR/0226

Emergence of power-laws and the uncertainty principle in human contact duration — •Jun Sun — GESIS - Leibniz Institute for the Social Sciences, Cologne, Germany

Consider the mechanism underlying human contact duration distributions as an aggregate effect of time-homogeneous processes, where the persistent probability of a contact (pairwise or higher-order) is drawn from a distribution but remains constant during its lifetime (Starnini et al., 2013). I propose a thermodynamic interpretation of the model, in which the persistent probability of a contact is mapped to a negative log-energy, identifying time as the inverse temperature, and the duration distribution as the partition function. I prove that under mild conditions, the contact duration distribution exhibits a power-law with potential cutoffs, a phenomenon commonly observed in empirical data. Such distributions are special in the thermodynamic framework as they have constant specific heat capacity, which corresponds to both the power-law exponent and the effective degrees of freedom. When contact agents act independently, the degrees of freedom equal the contact order. Behavioral correlation between agents reduces the effective degrees of freedom (therefore also the power-law exponent). Finally, I establish an uncertainty relation between time and persistent probability, revealing a fundamental limit within which contact durations can be characterized. Unlike the once-controversial notion of temperature fluctuation, the uncertainty of time in contact data is well-defined.

15 min. break

DY 5.8 Mon 12:00 GÖR/0226

Wired differently: Individual-level Adaptive Belief Networks — •Peter Steiglechner, Victor Møller Poulsen, Mirta Galesic, and Henrik Olsson — Complexity Science Hub, Vienna, Austria

Our beliefs about political issues are not independent; they are embedded within interconnected belief systems. Models such as the Networks of Beliefs (NB) theory (Dalege et al, 2025) formalise how individuals adjust their beliefs to reduce dissonance, and study how this leads to polarisation or consensus. In these models, the relations between beliefs are static, and the same belief network structure is assumed across individuals. This overlooks that perceived dissonance and belief relations can differ across individuals. And such heterogeneity in belief system structures can affect how individuals respond to external pressures or interventions, such as economic shocks or political scandals. We extend NB theory by allowing belief networks to evolve over time, shifting the focus from dynamics of belief content to the co-evolution of content and structure. In simulations of the model, individuals start with identical belief networks, but their structures diverge, producing stable disagreement between individuals. External events, inducing temporary pressure on a single belief, triggers lasting belief changes in some individuals (compliant), but only temporary or no changes in others (resilient and resistant), regardless of the strength of the pressure. Our model offers an illustrative and endogenous explanation of such asymmetries in responses to external events without requiring traits such as stubbornness, motivated cognition or identity biases.

DY 5.9 Mon 12:15 GÖR/0226

Critical Transitions of Reinforcement Learning Dynamics in Social Dilemmas — •Balakrishna Prabhu B N and Wolfram Barfuss — Center for Development Research(ZEF), University of Bonn, Germany

Understanding how cooperation emerges and persists among self-interested agents remains a crucial question in the human, animal, and machine behavioral sciences. Specifically, the aspect of the timescales required to reach a cooperative outcome has received little attention.

While the field of equilibrium game theory has addressed the possibility of cooperative outcomes, it offers little insight into how agents select and reach these equilibria, or the timescales required to do so. Evolutionary game theory and reinforcement learning have addressed some of these questions, but are yet to examine the temporal aspects of strategy adaptation and the critical transitions that occur with changes to basic payoff structures.

In this work, we develop a framework based on deterministic dynamics of reinforcement learning to study critical transitions between different social dilemma games. We find that boundaries involving the Chicken game exhibit strong criticality, whereas transitions involving the StagHunt game do not. We also explore convergence times and equilibrium selection and their variations across these boundaries for static and dynamic systems.

By uncovering the dynamic behavior between game transitions, our work lays the foundation for an integrated theory of coupled social-ecological tipping elements.

DY 5.10 Mon 12:30 GÖR/0226

Statistical mechanics of connected graphs in Scrabble — •Olivier Witteveen and Marianne Bauer — Department of Bionanoscience, Kavli Institute of Nanoscience Delft, TU Delft, Van der Maasweg 9, 2629 HZ Delft, The Netherlands

The crossword-like patterns of tiles in Scrabble form connected graphs of occupied sites on a square lattice. We are interested in describing the ensemble of these Scrabble graphs and comparing them across different languages. To find the most structureless description of Scrabble graphs, we build a maximum-entropy probability distribution; using real tournament data, we adapt a pseudo-likelihood method to the case of connected graphs on a lattice. We find that a maximum-entropy distribution that includes means and pairwise correlations captures the data: it correctly predicts simultaneous square occupation, word-length statistics, and geometric features of the Scrabble graphs, as well as the hierarchy among square types. Finally, we explore how language affects the structure of the Scrabble graphs. We adapt a Scrabble bot to self-play and generate graphs using different lexica. We find that the graphs produced by the bot have lower entropy compared to human players, and that lexica with shorter words yield higher entropy graphs. Remarkably, the pairwise maximum-entropy distribution is almost sufficient to correctly assign Scrabble graphs to their corresponding lexica.

DY 6: Machine Learning in Dynamics and Statistical Physics I

Time: Monday 9:30–13:00 Location: HÜL/S186

DY 6.1 Mon 9:30 HÜL/S186

Reservoir Computing with Hydrodynamically Coupled Active Colloidal Oscillators — •Veit-Lorenz Heuthe[1], Lukas Seemann[1], Samuel Tovey[2], and Clemens Bechinger[1,3] — [1]Universität Konstanz, Konstanz, Germany — [2]Universität Stuttgart, Stuttgart, Germany — [3]Centre for the Advanced Study of Collective Behavior, Konstanz, Germany

Reservoir computing is a newly emerging framework that exploites the dynamical response of complex physical systems to external perturbations. The high-dimensional, non-linear dynamics of active matter systems with hydrodynamic interactions offsers great potential for highly tunable physical reservoirs. Here, we present a physical reservoir that exploits the hydrodynamic interactions between several hundred colloidal oscillators for chaotic timeseries forecasting. We demonstrate that the inherent memory in this system facilitates detection of hidden anomalies in non-Markovian time-signals. Our results highlight the potential of active matter for locating subtle, non-disruptive signatures in e.g. financial stock markets, physiological measurements or seismic and climate data. Achieving such computing functinalities in physical systems could enable the development of intelligent hardware for edge-computing.

DY 6.2 Mon 9:45 HÜL/S186

From Phase-Space Fluctuations to Predictive Power: Entropy Production as a Metric for Swarm Reservoir Computing — •Patrick Egenlauf[1,2] and Miriam Klopotek[1,3] — [1]University of Stuttgart, Stuttgart Center for Simulation Science, SimTech Cluster of Excellence EXC 2075, Stuttgart, Germany — [2]University of Stuttgart, Interchange Forum for Reflecting on Intelligent Systems, IRIS3D, Stuttgart, Germany — [3]Heidelberger Akademie der Wissenschaften, WIN-Kolleg, Heidelberg, Germany

In reservoir computing, a time-varying input is projected onto a high-dimensional state space, allowing a simple linear readout to retrieve task-relevant features. Physical substrates such as active-matter swarms promise efficient, low-energy computation, but a quantitative selection criterion, that reliably indicates a good reservoir, is missing. We simulated an interacting swarm subjected to an external driver and evaluated two entropy measures: system entropy, quantifying phase-space density fluctuations, and environment entropy, representing heat dissipation. For each parameter set of the swarm interactions, we computed the relative differences for the system and environment entropy between undriven and driven cases and measured the driver work performed on the system. Both relative differences display robust linear correlations with forecast accuracy, while the driver work matches the performance curve almost perfectly, indicating that driver-induced entropy production dominates the reservoir's information-processing capacity. Consequently, entropy production offers a quantitative metric for tuning swarm-based reservoirs toward optimal performance.

DY 6.3 Mon 10:00 HÜL/S186

Performing inference with physical response: Reservoir computing with active matter substrates — Mario U. Gaimann[1] and •Miriam Klopotek[1,2] — [1]University of Stuttgart, Stuttgart Center for Simulation Science, SimTech Cluster of Excellence EXC 2075, Stuttgart, Germany — [2]WIN-Kolleg of the Young Academy, Heidelberg Academy of Sciences and Humanities, Heidelberg, Germany

We explore questions of real-time inference and forecasting of chaotic signals, re-interpreting them in terms of nonequilibrium physical response, by studying a model of information processing with an active matter substrate used in the reservoir computing (RC) paradigm. The system becomes robustly optimal for computing in a particular dynamical regime due to its intrinsic ability to relax efficiently, which, under driving, unlocks maximal dynamical diversity and susceptibility to chaotic input signals; the mechanisms include self-healing, multi-step dynamical response, and adaptive morphological reorganization [1,2]. Shifting the system's response away from direct-agent toward collective variables is key, as evidenced by cross-correlative functions in dynamics [2]. These ideas shed light on self-optimizing inference in bio-inspired or material computing that flexibly exploits dynamics across diverse collective scales.

[1] M. U. Gaimann and M. Klopotek, `arXiv:2505.05420` (2025).
[2] M. U. Gaimann and M. Klopotek, `arXiv:2509.01799` (2025).

DY 6.4 Mon 10:15 HÜL/S186

Learning single and multiple chaotic systems with minimal reservoir computers — •Francesco Martinuzzi and Holger Kantz — Max Planck Institute for the Physics of Complex Systems

Chaotic dynamics are present in a multitude of natural and engineered systems. Recently, chaos has been modeled using machine learning (ML) methods thanks to their ability to infer underlying governing equations without directly accessing them. Among ML models, echo state networks (ESNs) have been widely investigated because of their simple construction and efficient training. However, ESNs typically rely on randomly initialized reservoirs whose stochastic connectivity makes them difficult to interpret and tune. To what extent are random and complex reservoir topologies actually necessary for learning chaotic dynamics with ESNs? We show that deterministic constructions of the reservoir matrix outperform random initializations for the reconstruction of chaotic attractors. By testing ten distinct deterministic topologies against random reservoirs on over 90 different attractors, our results demonstrate consistently better performance for deterministic reservoirs. Furthermore, we show how the same deterministic reservoir topologies can be leveraged to learn multiple chaotic systems with a single reservoir computer, thereby showcasing multifunctionality.

DY 6.5 Mon 10:30 HÜL/S186

Understanding task performance of time-multiplexed optical reservoir computing via polynomial expansion — •Elias Koch[1], Julien Javaloyes[2], Svetlana V. Gurevich[1,3], and Lina Jaurigue[4] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str.9 48149 Münster, Germany — [2]Departament de Física and IAC3, Universitat de les Illes Balears, Campus UIB 07122 Mallorca, Spain — [3]Center for Data Science and Complexity (CDSC), University of Münster, Corrensstrasse 2, Münster, 48149, Germany — [4]Institute of Physics, Technische Universität Ilmenau , 98693 Ilmenau, Germany

We study the dynamics of a reservoir computer, realized as a linear optical microcavity with a time-multiplexed injection stream. In the first step, the output is processed with different nonlinearities, allowing to analyze the resulting polynomials and to what extend they can approximate different tasks. To that end, we compare two different discrete tasks, both derived from the Lorenz system through integration with a Runge-Kutta (4) scheme, but sampled to different stepsizes. There, we identify the respective underlying polynomial map and discuss the occuring terms. We compare these results with the impact of employing nonlinear nodes by introducing a Kerr nonlinearity in the optical microcavity.

DY 6.6 Mon 10:45 HÜL/S186

Physical Reservoir Computing with Ferroelectric Oxides for Time-series Classification Tasks — •Atreya Majumdar[1], Yan Meng Chong[2], Dennis Meier[1,2,3], 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 — [3]Research Center Future Energy Materials and Systems, Research Alliance Ruhr, Bochum, Germany.

Physical reservoir computing leverages the intrinsic complexity, nonlinearity, and fading memory of material systems to process temporal data for solving time-series pattern recognition tasks. Magnetic and ferroelectric materials have recently emerged as promising reservoir computers, offering dynamics well suited for processing time-dependent signals [1]. Here, we demonstrate that the photocurrent dynamics of the ferroelectric semiconductor ErMnO3 can be harnessed as an effective physical reservoir for real-time time-series classification. Moreover, the relaxation time of the photocurrent can be controllably tuned, providing flexibility to capture different temporal features and thereby enhancing performance. Altogether, the results highlight the potential of ferroelectric oxides as scalable, energy-efficient platforms for real-time physical reservoir computing.

[1] K. Everschor-Sitte, et al., Topological magnetic and ferroelectric

systems for reservoir computing. Nat. Rev. Phys. 6, 455 (2024).

15 min. break

DY 6.7 Mon 11:15 HÜL/S186

Checking the superiority of multi-model mean forecasts by reservoir computing — Daniel Estevez Moya[1,3], Erick A. Madrigal Solis[1,2], Ernesto Estevez Rams[3], and •Holger Kantz[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]University of Techology, Dresden, Germany — [3]Faculdad de Física, Universidad de La Habana, Cuba

In weather prediction and climate forecasts it has been observed that taking the arithmetic mean forecast of an ensemble of different models is often superior to most of the individual models. We use Reservoir Computing to generate easily a large ensemble of models and study their performance on deterministic toy models. While each individually trained reservoir comes with its own model error which is a systematic error, we verify that the arithmetic mean of these forecasts is closer to the truth than most of the individual forecasts. We present a detailed dynamical explanation for this observation.

DY 6.8 Mon 11:30 HÜL/S186

Controlling dynamical systems into unseen target states using machine learning — Daniel Köglmayr[1,2], Alexander Haluszczynski[3], and •Christoph Räth[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt (DLR) — [2]Ludwig-Maximilians-Universität (LMU) — [3]Allianz Global Investors (AGI)

Controlling nonlinear dynamical systems is a central task in many different areas of science and engineering. Combining previous work on controlling chaotic systems to arbitrary states [1] and extrapolating the system behavior into unseen parameter regions [2] using machine learning, we present here a novel, model-free, and data-driven methodology for controlling complex dynamical systems into previously unseen target states, including those with significantly different and complex dynamics. Leveraging a parameter-aware realization of next-generation reservoir computing (NGRC), our approach accurately predicts system behavior in unobserved parameter regimes, enabling control over transitions to arbitrary target states utilizing a new prediction evaluation and selection scheme [3]. By extending the applicability of machine learning-based control mechanisms to previously inaccessible target dynamics, this methodology opens the door to transformative new applications while maintaining exceptional efficiency. Our results highlight reservoir computing as a powerful alternative to traditional methods for dynamic system control.

[1] A. Haluszczynski & C. Räth, Sci Rep 11, 12991 (2021), [2] D. Köglmayr & C. Räth, Sci Rep 14, 507 (2024), [3] D. Köglmayr, A. Haluszczynski & C. Räth, submitted (https://arxiv.org/abs/2412.10251)

DY 6.9 Mon 11:45 HÜL/S186

Noise-Balanced Sparse Grid Surrogates for Multiscale Coupling of Monte Carlo and Continuum Models — •Tobias Hülser and Sebastian Matera — Fritz-Haber-Institut der MPG, Berlin

Incorporating a high-fidelity microscopic Monte Carlo model into multiscale simulations can easily become intractable, implying the necessity of surrogate models in many practical applications. Unfortunately, if the microscopic model depends on many macro-variables this can become quite challenging due to the 'curse of dimensionality'. Furthermore, the sampling noise in the underlying Monte Carlo data can lead to uncontrolled errors corrupting the surrogate even though it would be highly accurate in the case of noise-free data. To address these points, we have developed a novel sparse grids interpolation approach which balances interpolation and noise induced errors complemented by a multilevel on-the-fly construction during the multi-scale simulation. Besides its efficiency, an appealing feature is the ease of use of the approach with a single hyperparameter controlling the whole surrogate construction - from which data needs to be created (and how accurately) to the surrogate's accuracy with guaranteed convergence. We demonstrate the approach on examples from heterogenous catalysis, incorporating microscopic kinetic Monte Carlo models into convection-diffusion type reactor scale simulations.

DY 6.10 Mon 12:00 HÜL/S186

Learning Time Trajectories of a Stochastic Dynamical System with a Slowly Varying Parameter — •Changho Kim[1], Zihan Xu[1], Andrew Nonaka[2], and Yuanran Zhu[2] — [1]University of California, Merced, California, USA — [2]Lawrence Berkeley National Laboratory, Berkeley, California, USA

The statistics-informed neural network (SINN) is a reliable machine learning approach for learning and reproducing stochastic trajectories based on the statistical properties of sample trajectory data, particularly for stationary, Gaussian-like, multidimensional stochastic processes. However, to enable practical applications–such as surrogate modeling for the development of hybrid simulation methods–SINN must be extended to learn quasi-stationary dynamics driven by a slowly varying parameter. We enhance the SINN framework by incorporating this parameter as an additional input and by introducing loss functions to capture its influence, as well as proposing a new neural network structure that takes both white noise sequences and time trajectories of the slowly varying parameter as inputs. Additionally, we propose an alternative method for estimating a conditional probability density function to address computational constraints. We validate our approach through two benchmark problems: the dissociative adsorption problem and Langevin dynamics in an oscillating double-well potential.

DY 6.11 Mon 12:15 HÜL/S186

Learning spatiotemporal patterns from mean-field data — •Edmilson Roque dos Santos[1] and Tiago Pereira[2] — [1]MPI-PKS,Germany — [2]University of São Paulo, Brazil

Networks of coupled dynamical systems are fundamental models across the sciences, from physics to neuroscience. Despite their success, the governing equations of such systems are often unknown, limiting our ability to predict and control their dynamics. A major current effort is to learn these governing equations directly from data. However, existing approaches typically require access to the time series of all node states, which is rarely available outside controlled experiments. In most realistic scenarios, only aggregate or mean-field data, such as linear combinations of node states, can be measured. In this case, learning the governing equations from mean-field data inevitably becomes a secondary goal, since one must first learn the network trajectory that generated the observed measurements. This task is inherently challenging because distinct network states can yield identical macroscopic observations. Here, we address the problem of learning the network trajectory from random mean-field measurements. We show that accurate reconstruction becomes possible when the network exhibits structured spatiotemporal patterns, such as traveling waves. By representing these patterns sparsely in the Fourier domain, we leverage compressive sensing theory to formulate a convex optimization problem that robustly reconstructs the network trajectory. We illustrate our findings using a unidirectional ring of coupled Stuart-Landau oscillators.

DY 6.12 Mon 12:30 HÜL/S186

Discovering Mechanisms and Governing Laws with Sparse Regression — •Gianmarco Ducci, Maryke Kouyate, Juan Manuel Lombardi, Artem Samtsevych, Karsten Reuter, and Christoph Scheurer — FHI Berlin

Interpretable data-driven methods have proven viable for deriving complex vector fields directly from experimental data. Their inherent differential formulation, however, make them vulnerable to noise, which can compromise the sparsity of the inferred models. In order to promote sparsity, a weak formulation can be employed. Then, finding the optimal set of basis functions is a necessary prerequisite, yet a challenging task to determine in advance.

We present the release version of the Data-Driven Model Optimizer `ddmo`, a symbolic regression tool which provides fine-grained control over the admissible space of candidate terms. Its core contribution lies in the systematic optimization of the library of functions, implemented through two complementary engines: a standard SINDy-based differential formulation and a weak-form variant. Its modular structure further enables the optimization of test functions within the weak formulation. An overview of the software capabilities is provided, alongside with a case study illustrating the reconstruction of effective kinetics from experimental reactor data.

DY 6.13 Mon 12:45 HÜL/S186

POD-Subspace Reconstruction of Convective Reversal Dynamics from Limited Sensor Data — •Tim Kroll and Oliver Kamps — CDSC ,University of Münster

We introduce a data-driven modelling framework that leverages a hybrid LSTM-neural-network architecture to capture convection rever-

sals from limited time-series measurements.. The method operates entirely in POD space, enabling efficient and accurate reconstruction of complex dynamical systems from limited observations by modelling non-orthogonal modes as a superposition of POD modes. The corresponding dynamics are modelled by an LSTM, incorporating knowledge about the history of the timeseries. We demonstrate its effectiveness on convection processes, showing that measurements from a single sensor - of either temperature T or velocity V - are sufficient to recover the full spatiotemporal dynamics, consisting of temperature, velocity or a combination of both, within the reduced representation. Furthermore this approach has potential to be applied in different scientific fields detached from convection or fluid dynamics.

DY 7: Focus Session: Large Deviations and Rare Events I

The modeling and understanding of large deviations and rare events is of crucial importance in a wide range of real-world applications, including climate science, actuarial statistics (insurance statistics), natural disaster management, or the description of financial markets. At the same time, such effects are fundamental for the understanding of many systems in condensed-matter physics. In first-order phase transitions, for instance, the coexisting phases are connected by transition states involving droplet excitations whose probability is suppressed by dozens or hundreds of orders of magnitude as compared to the pure-phase peaks. Likewise, for many disordered systems the behavior of typical cases is incompatible with that of the average sample as the problem is described by very broad, heavy-tailed distributions, where averages are dominated by rare events. For many models, like the Kadar-Parisi-Zhang equation or random-graph properties, there has been considerable analytical progress in the last decade. Likewise, new or improved numerical techniques have been proposed that now allow for the treatment of previously inaccessible problems or regimes. This focus session is devoted to an update on the state of the art in this rapidly evolving area.

Organized by Alexander K. Hartmann (Oldenburg) and Martin Weigel (Chemnitz)

Time: Monday 9:30–12:45 Location: ZEU/0114

Invited Talk DY 7.1 Mon 9:30 ZEU/0114

Fast Rare Events in Exit Times Distributions of Jump Processes — •Raffaella Burioni — Department of Mathematics, Physics and Computer Sciences, University of Parma, Italy — INFN - Sezione di Milano Bicocca - Parma, Italy

Rare events in first-passage and exit-time statistics of jump processes can play a decisive role in triggering anomalous reactions and extreme responses in a wide range of systems. This is particularly relevant when jump lengths or waiting times follow broad, heavy-tailed distributions, for which rare events are not exponentially suppressed and can significantly affect macroscopic observables. Interestingly, in the presence of heavy-tailed distributions, large fluctuations follow the Big Jump Principle, a counterintuitive mechanism according to which rare events arise not from the accumulation of many small deviations, but from a single, dominant fluctuation.

We present a general framework for estimating the contribution of fast rare events to exit probabilities in jump processes with fat-tailed distributions. We apply this approach to discrete-time random walks, Lévy walks, and the Lévy-Lorentz gas, which are widely used to describe transport in biological systems and disordered media. We derive the scaling form of the probability distribution for fast exit events, in which the process leaves a finite interval over distances much larger than the typical scale and on timescales orders of magnitude shorter than the characteristic timescale of the dynamics. We discuss extensions to N independent walkers, where collective effects can further enhance the contribution of fast rare events to exit statistics.

DY 7.2 Mon 10:00 ZEU/0114

Rare Events, Many Searchers, and Fast Target Reaching in a Finite Domain — Elisabetta Ellettari[1], Giacomo Nasuti[1], •Alberto Bassanoni[1,2], Alessandro Vezzani[1,3], and Raffaella Burioni[1,2] — [1]University of Parma, Italy — [2]INFN, Parma associated group, Italy — [3]IMEM-CNR, Parma, Italy

Finding a target in a complex environment is a fundamental challenge in nature. An effective strategy to reduce the time needed to reach a target is to deploy many searchers, increasing the likelihood that at least one will succeed by using the statistics of rare events. When the underlying stochastic process involves broadly distributed step sizes, rare long jumps dominate the dynamics, making the use of multiple searchers particularly powerful. We investigate the statistics of extreme events for the mean first passage time in a system of N independent walkers moving with jumps distributed according to a power law, where target-reaching is governed by single, large fluctuations. We show that the mean first passage time of the fastest walker scales as $\langle \tau_N \rangle \sim 1/N$, representing a dramatic speed-up compared to classical Brownian search strategies. We derive a scaling law relating the number of walkers required to reach a target within a given time to the size X of the search region. As an application, we model biological fertilization, predicting how the optimal number of spermatozoa scales with uterus size across species. Our predictions match empirical data, and this theory applies broadly to any population of searchers operating within a region of size X, providing a universal framework for efficient search in disordered environments.

DY 7.3 Mon 10:15 ZEU/0114

Large deviations and uncertainty relations for self-interacting jump processes — •Francesco Coghi[1,2], Amarjit Budhiraja[3], and Juan P. Garrahan[1,2] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, University of Nottingham, Nottingham, NG7 2RD, UK — [3]Department of Statistics and Operations Research, University of North Carolina, Chapel Hill, NC 27599, USA

Self-interacting jump processes are stochastic systems where transition rates depend on the process' own empirical occupation measure – that is, the time-averaged distribution of the states visited by the process – introducing a feedback that breaks Markovianity. In this talk, I will present a large deviation framework for such systems. Specifically, I will derive the level-2.5 rate functional describing the joint fluctuations of occupation and flux, obtained via an exponential tilting construction extended to the non-Markovian setting. From this, I will show how memory modifies fluctuation bounds, leading to kinetic and thermodynamic uncertainty relations that generalise those of standard Markov processes. I will conclude with two examples that illustrate how feedback reshapes fluctuation-dissipation trade-offs: a minimal two-state model and a collective exploration process inspired by ant dynamics.

DY 7.4 Mon 10:30 ZEU/0114

A pedestrian's approach to large deviations in semi-Markov processes with an application to entropy production — •Jonas H. Fritz, Alexander M. Maier, and Udo Seifert — II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

Semi-Markov processes play an important role in the effective description of partially accessible systems. They occur, for instance, in coarse-graining procedures such as state lumping and when analyzing waiting times between few visible Markovian events. The finite-time measurement of any coarse-grained observable in a stochastic system depends on the specific realization of the underlying trajectory. Moreover, the fluctuations of such observables are encoded in their rate function that

follows from the rate function of the empirical measure and the empirical flow in the respective process. Derivations of the rate function of empirical measure and empirical flow in semi-Markov processes with direction-time independence (DTI) exist in the mathematical literature, but have not received much attention in the stochastic thermodynamics community. We present an accessible derivation of the rate function of the tuple frequency in discrete-time Markov chains and extend this to the rate function of the empirical semi-Markov kernel in semi-Markov processes without DTI [1]. From this, we derive an upper bound on the rate function of the empirical entropy production rate, which leads to a lower bound on the variance of the mean entropy production rate measured along a finite-time trajectory. We illustrate these analytical bounds with simulated data. [1] Alexander M. Maier, Jonas H. Fritz and Udo Seifert, arXiv:2509.15077, 2025

DY 7.5 Mon 10:45 ZEU/0114

Concentration of observables in slow-fast dynamical systems with noise — •Xizhu Zhao[1,2] and Aljaž Godec[1,2] — [1]Mathematical Physics and Stochastic Dynamics, Institute of Physics, University of Freiburg, Freiburg, Germany — [2]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany

Stochastic differential equations involving separated timescales play an important role in modeling the dynamics of complex systems in physics, biology, and climate science. We explore the concentration of observables, i.e. functions or functionals of dynamical variables, in slow-fast dynamical systems with noise. Using stochastic analysis and singular perturbation theory, we determine the domains of concentration for observables in systems with a stable manifold or undergoing a bifurcation. We also derive bounds for the distribution of the first-exit time from these domains. The results show that the concentration of observables exhibits behavior distinct from that of microscopic sample paths.

15 min. break

Invited Talk DY 7.6 Mon 11:15 ZEU/0114

Large deviations in resetting Brownian motions — •Satya Majumdar — CNRS, LPTMS, Universite Paris-Saclay, Orsay 91405, France

After a brief introduction to large deviations, I will focus on one dimensional resetting Brownian motions, first on a single particle and then on a gas of multiparticles. I will show that for a single partcle, while the position distribution of a resetting Brownian motion approaches a stationary form at long times, the relaxation to this stationary state is unusual: it is described by a large deviation function that undergoes a second order dynamical phase transition. The same rate function also shows up in the distribution of the maximum up to time t of a set of independent resetting Brownian motions with a distributed initial positions. I will discuss the difference between the 'quenched' and 'annealed' initial positions and how they affect the statistics of the maximum.

DY 7.7 Mon 11:45 ZEU/0114

Large deviations and condensation in the cost of stochastic resetting — •John C. Sunil[1], Martin R. Evans[1], Richard A. Blythe[1], and Satya N. Majumdar[2] — [1]SUPA, School of Physics and Astronomy, University of Edinburgh, Peter Guthrie Tait Road, Edinburgh EH9 3FD, United Kingdom — [2]Université Paris-Saclay, CNRS, LPTMS, 91405 Orsay, France

Searching for misplaced objects is a task that we are all familiar with. In particular, the way we search for a misplaced object, such as keys, is by repeatedly resetting to the object*s last known location. It has been shown that such resetting expedites the mean time to complete the search process. However, in practice, resets must also incur costs, whether in time, energy, or money. This motivates examining the probabilities of rare cost fluctuations that deviate significantly from typical behaviour. In this talk, I will demonstrate the effect of costly resets and the large deviations exhibited by the tails of the total cost distribution using an exactly solvable model of diffusion with stochastic resetting. Further, I will discuss the eventual breakdown of the large deviation principle for certain classes of cost, resulting in a phase transition known as condensation.

References

(i) J. C. Sunil, R. A. Blythe, M. R. Evans and S. N. Majumdar, The cost of stochastic resetting, J. Phys. A: Math. Theor. 56 (2023) 395001.

(ii) M. R. Evans and J. C. Sunil, Stochastic Resetting and Large Deviations, SciPost Phys. Lect. Notes, vol. 103, 2025.

DY 7.8 Mon 12:00 ZEU/0114

Perturbative framework for finding the transition rates for active particles — •Vito Seinen[1], Peter Bolhuis[1], Daan Crommelin[2], Michel Mandjes[3], and Sara Jabbari-Farouji[1] — [1]University of Amsterdam — [2]Centrum Wiskunde & Informatica — [3]University Leiden

Activated escape or transition rates between metastable states have been a growing topic of research due to their relevance in many physical processes and their roles in certain non-equilibrium phase transitions. In the context of motility-induced phase separation (MIPS), such active transition rates are known to govern the nucleation processes that initiate phase separation. To gain insight into these phenomena, we develop a projection-operator formalism for a generic model of an active particle in a multi-well potential. We compute the transition rates perturbatively in two asymptotic regimes: one in which the dynamics of the activity (the driving process) is much faster than that of the particle (the driven process), and one in which the activity dynamics is much slower. From these asymptotic expansions, we construct an approximation that interpolates across the intermediate regime, thereby capturing all parameter ranges relevant in the rare-event limit. Our results provide deeper understanding of the complex dependence of active transition rates on the magnitude of the activity, the thermal noise strength, and the dynamical timescale of the active (driving) process*its persistence time

DY 7.9 Mon 12:15 ZEU/0114

Large deviation properties of Brownian particles in switching harmonic traps — •Chinmay Pradeep Chandratre and Alexander K. Hartmann — Institut of Physics, University of Oldenburg, Oldenburg (Germany)

For N independent particles in a harmonic trap with stiffness switching between μ_1 and μ_2, a complete characterization of the non-equilibrium steady state including the computation of joint distribution of particle positions has been performed under the stochastic-resetting protocol [1]. In the large-N limits, this allows for the computation of observables such as the distribution of the position M_k of the k-th rightmost particle (Extreme value statistics), spacing distributions $D_k = M_k - M_{k+1}$ and the particle count $N_L = |\{ i : |x_i| \leq L \}|$ for an interval $[-L, L]$. However, the finite-N regime with significant large-deviation corrections is analytically unknown. The numerical limitations in resolving the support of the distribution, especially in the tails, are circumvented through specialized large-deviation algorithms [2] by deploying modified Markov Chain Monte Carlo methods. The distributions $P(M_k)$, $P(D_k)$ and $P(N_L)$ and corresponding rate functions were obtained numerically from simulations performed for several system sizes. Conditional distribution rendered further insight into the correlations between M_k, D_k, and N_L.

[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 7.10 Mon 12:30 ZEU/0114

Optimal escape processes of run-and-tumble particles — Karthik Cheruvary[2], •Rafael Diaz Hernandez Rojas[1], and Peter Sollich[1] — [1]University of Göttingen — [2]IISER Pune

Run-and-tumble (RT) motion is a fundamental mode of self-propulsion observed across diverse biological systems from bacterial chemotaxis to immune cell migration. Modelling this non-equilibrium system is challenging due to the non-Gaussian noise governing the self-propulsion direction, θ. To address this, we investigate the trajectories of a particle confined by a potential in $d = 2$ and subject to both thermal fluctuations and RT motion. We incorporate tumbling by modelling changes in θ as Poisson shot noise process with rate λ and generic distribution of angle changes, Δ. Employing a path-integral formalism in the weak noise limit, we derive exact equations of motion for all degrees of freedom, valid for arbitrary λ and distributions of Δ. This allows us to map the problem of finding the most likely escape trajectory to the minimisation of an appropriate action. Our analysis reveals that the effects of the non-Gaussian noise are more prominent in the limit of small λ, which corresponds to highly persistent RT motion. There, we show analytically that, regardless of the distribution of Δ, RT escape paths are exponentially more probable –exhibiting a lower action– than their active Brownian particle equivalent. The optimal RT trajectories are non-trivial and can exhibit discontinuities or very

rapid changes in θ, implying that RT particles will exploit their tumbling ability to optimize escape from potential wells. We verify our theoretical predictions through extensive numerical simulations.

DY 8: Nonlinear Dynamics, Synchronization, and Chaos

Time: Monday 9:30–12:30 Location: ZEU/0118

DY 8.1 Mon 9:30 ZEU/0118

Coherence properties of collective modes in oscillator networks — •Arkady Pikovsky — University of Potsdam, Potsdam, Germany

Synchronization transition in populations of coupled oscillators is manifested by an appearance of a global oscillating mode. While oscillations are perfect in the thermodynamic limit, for finite ensembles the collective mode is subject to fluctuations. Here we focus on the properties of diffusion of the global phase, which determine coherence time of the collective oscillations. We discuss scaling of the diffusion constant with the system size, and describe cases where the coherence is perfect.

DY 8.2 Mon 9:45 ZEU/0118

Phase locking and multistability in the topological Kuramoto model on cell complexes — •Iva Bačić[1,2], Michael T. Schaub[3], Jürgen Kurths[4], and Dirk Witthaut[1,5] — [1]Institute of Climate and Energy Systems: Energy Systems Engineering (ICE-1), Forschungszentrum Jülich, 52428 Jülich, Germany — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]RWTH Aachen University, Aachen, Germany — [4]Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany — [5]Institute for Theoretical Physics, University of Cologne, 50937 Köln, Germany

Higher-order group interactions fundamentally shape the dynamics and stability of oscillator networks. The topological Kuramoto model captures these effects by extending classical synchronization models to include interactions between cells of arbitrary dimension within simplicial and cell complexes. We present the topological nonlinear Kirchhoff conditions algorithm, a nonlinear generalization of Kirchhoff's circuit laws, that systematically identifies all phase-locked states in the topological Kuramoto model and reveals how higher-order topology governs multistability. Applying this framework to rings, Platonic solids, and simplexes, we uncover structural cascades of multistability inherited across dimensions, and demonstrate that cell complexes can exhibit richer multistability patterns than simplicial complexes of equal dimension. We find evidence hinting at universal multistability classes. Our results reveal how higher-order interactions affect synchronization and open new directions for understanding collective dynamics in systems with non-pairwise interactions.

DY 8.3 Mon 10:00 ZEU/0118

From quaternion order parameter to extreme synchronization transitions — •Moritz Thümler[1], Seungjae Lee[1], Lennart J. Kuklinski[1], and Marc Timme[1,2] — [1]Chair of Network Dynamics, Center for Advancing Electronics Dresden (cfaed) and Institute of Theoretical Physics, TUD Dresden University of Technology, 01062 Dresden, Germany — [2]Lakeside Labs, Lakeside B04b , 9020 Klagenfurt, Austria

Synchrony plays a fundamental role in the operation of many systems across physics, biology, and engineering. Fifty years after the introduction of the paradigmatic Kuramoto model*which provides a mathematically tractable framework for studying transitions to synchrony*several open questions remain, particularly concerning finite-size systems. An analytic continuation of the Kuramoto model from real to complex variables has been proposed to address this challenge [1]. Here, we introduce a generalized quaternion order parameter that captures complex-valued state vectors and demonstrate its effectiveness by uncovering a link between real-valued Kuramoto dynamics and complex locked states calculated via self-consistency and newly uncovered explosive transitions to synchrony [2].

[1]*Moritz Thümler et al., Synchrony for Weak Coupling in the Complexified Kuramoto Model, Physical Review Letters 130:187201 (2023).

[2] Lee, Seungjae, Kuklinski, Lennart J., Thümler, Moritz and Timme, Marc. "Hopf-induced desynchronization" Zeitschrift für Naturforschung A, vol. 80, no. 11, 2025,

DY 8.4 Mon 10:15 ZEU/0118

Transition to turbulence in wind turbine wakes: synchronisation and non-linear dynamics — •Thomas Messmer, Michael Hölling, and Joachim Peinke — Carl von Ossietzky Universität Oldenburg, School of Mathematics and Science, Institute of Physics, Oldenburg, Germany

The wake of a wind turbine is a typical shear flow that transitions from near- to far-wake, ultimately reaching fully developed turbulence. In this study, we investigate experimentally in a wind tunnel the wake dynamics of a periodically excited model wind turbine*a scenario motivated by applications such as floating wind turbines and periodic control strategies. Our findings reveal distinct excitation regimes with unique wake behaviours.

In one regime, the wake synchronises with the excitation period, forming an organised flow structure that accelerates the transition to turbulence. In another regime, nonlinear quasi-periodic dynamics emerge, characterised by the formation of multiple coherent structures that interact nonlinearly and also accelerate the transition to the far wake.

At the conference, we will discuss the mechanisms underlying synchronisation and quasi-periodic dynamics, as well as their implications for the fundamental problem of the transition to turbulence.

Invited Talk DY 8.5 Mon 10:30 ZEU/0118

Mean-field approach to finite-size fluctuations in coupled oscillator systems — •Oleh Omelchenko[1] and Georg Gottwald[2] — [1]University of Potsdam, Germany — [2]University of Sydney, Australia

Networks of coupled phase oscillators are one of the most studied dynamical systems with numerous applications in physics, chemistry, biology, and engineering. A variety of methods exists to explain their properties and dynamics in the thermodynamic limit, when the network size tends to infinity. However, the behavior of such systems in the more realistic case of a finite number of oscillators still remains poorly understood. In this talk, we revisit the paradigmatic Kuramoto-Sakaguchi model describing synchronization transitions in networks of all-to-all coupled heterogeneous phase oscillators, and propose an ab initio approach for characterizing analytically the statistical properties of finite-size fluctuations in this system. Our framework is applicable to any stationary partially synchronized state and does not require any prior knowledge about its structure. Moreover, it is sufficiently general such that it can be applied to a broader class of interacting particle systems.

15 min. break

DY 8.6 Mon 11:15 ZEU/0118

Energy Transfer in a Coupled Duffing System — •Martyna Sedlmayr and Andrzej Rysak — Faculty of Mechanical Engineering, Lublin University of Technology, 36 Nadbystrzycka St., 20-618 Lublin, Poland

The Duffing system is a non-linear prototypical chaotic system, of interest in studies of damping and energy harvesting. In this work we analyse modifications to the energy transfer in the system when it is magnetically coupled to a harmonic oscillator. The form of the magnetic interaction is obtained from a fit to experimental data. Numerical analyses then determine the power either dissipated by, or supplied to, the Duffing system by its individual components. In all simulations, the Duffing potential itself is not changed. Our analysis focuses on assessing the impact of the coupled oscillator on the energy efficiency of the system. We demonstrate the effects of changing the value of the mass, the damping and the elasticity of the perturbing system. We focus on searching for configurations of the perturbation for which an increase in efficiency occurs, which can be caused by either modifying the dynamics or by providing additional energy.

DY 8.7 Mon 11:30 ZEU/0118

Transient Signatures of Flow-Topological Transitions in Non-

linear Quantum Oscillators — •Alejandro S. Gómez and Javier del Pino — Department of Theoretical Condensed Matter Physics, (IFIMAC), Universidad Autónoma de Madrid

Non-equilibrium phases in driven-dissipative systems are ubiquitous. Often, they appear as classical fixed point attractors and limit cycles, with standard phase transitions triggered by local instabilities. Yet the flow-topology framework [1] shows that transitions can also arise from nonlocal reorganizations, leaving attractors unchanged and emerging only in transients. Stationary quantum states still reflect these structures as probability hotspots, and local changes can induce Liouvillian spectral degeneracies. However, how the nonlocal, transient reorganizations manifest in the Liouvillian remains open.

In this talk, I will introduce a topological framework that extends the classification of fixed points [1] to capture the full phase-space connectivity considering also limit cycles. By linking open quantum dynamics to the classification of Morse-Smale flows [2], Crucially, we demonstrate that our graph invariant exposes transitions the Liouvillian spectrum misses altogether, related to global flow-topology transitions. I illustrate this framework by mapping the dissipative phases of a two-photon-driven Kerr resonator with added gain.

[1] G. Villa et al., Topological classification of driven-dissipative nonlinear systems, Sci. Adv. (2025).

[2] A. A. Oshemkov, Classification of Morse-Smale flows on two-dimensional manifolds, Sbornik Math. (1998).

DY 8.8 Mon 11:45 ZEU/0118

The disordered logistic map — Joseph W. Baron[1] and •Tobias Galla[2] — [1]Department of Mathematical Sciences, University of Bath, Bath, BA2 7AY, UK — [2]Instituto de Fisica Interdisciplinar y Sistemas Complejos IFISC (CSIC-UIB), 07122 Palma de Mallorca, Spain

The logistic map is a central model of low dimensional chaos. In disordered systems with many degrees of freedom on the other hand, one finds high-dimensional chaos, induced by heterogeneous interactions.

Here, we study a system of many logistic maps with quenched random interactions. Using dynamic mean-field theory, random matrix theory and simulations we show that minimal disorder removes the period-doubling cascade in the conventional logistic map. The cascade is replaced by a sudden onset of chaos. We find a separate and qualitatively different transition to chaos with more smoothly evolving trajectories. The power spectra of fluctuations exhibit different power-law behaviour near the two transitions. In a disordered Henon map we find very similar behaviour.

Our results show that even minimal disorder can severely disrupt the behaviour of well-known dynamical systems. The work also shows that discrete-time disordered systems can exhibit rather different behaviour from their continuous-time cousins [1]. Disordered maps highlight that different chaotic behaviours can be observed in one single system, and that each of these behaviours leaves a fingerprint before chaos sets in.

[1] J. W. Baron, T. J. Jewell, C. Ryder, and T. Galla, Breakdown of random-matrix universality in persistent Lotka-Volterra communities, Physical Review Letters 130, 137401 (2023).

DY 8.9 Mon 12:00 ZEU/0118

Transient nature of recurrence based local dimension estimates from finite time series — •Reik V. Donner — Magdeburg-Stendal University of Applied Sciences, Magdeburg, Germany — Potsdam Institute for Climate Impact Research, Potsdam, Germany

Local fractal dimensions are a widely used concept in dynamical system theory. However, comparing their empirical spatial patterns across published works reveals surprising inconsistency with theoretical expectations. This points to the fact that corresponding estimates obtained from finite time series are notoriously spurious. As an example, a very long trajectory of the Lorenz-63 system in its chaotic regime is subsampled in two different ways: generating ensembles of individual state vectors drawn independently at random from the complete record versus ensembles of contiguous time series segments. In the latter situation, which is commonly present in time series analysis, one obtains a broad distribution and non-random spatial pattern of local dimension estimates, while consideration of independent samples provides much more narrowly distributed and spatially unstructured estimates. While finite-time estimates may still be useful for identifying transient structures caused by the proximity to unstable periodic orbits or similar dynamically invariant objects, their practical interpretation for real-world time series should be carefully reconciled.

DY 8.10 Mon 12:15 ZEU/0118

Two-dimensional turbulent condensates without bottom drag — •Adrian van Kan[1], Alexandros Alexakis[2], and Edgar Knobloch[3] — [1]Department of Mathematics, Texas A&M University, College Station, USA — [2]Laboratoire de Physique de l'Ecole Normale Supérieure, ENS, Université PSL, CNRS, Paris, France — [3]Department of Physics, UC Berkeley, Berkeley, California, USA

The extent to which statistical equilibrium theory applies to driven dissipative dynamics remains an important open question in many systems. We use extensive direct numerical simulations of the incompressible two-dimensional (2D) Navier-Stokes equation to examine the steady state of large-scale condensates in 2D turbulence at finite Reynolds number Re in the absence of bottom drag. Large-scale condensates appear above a critical Reynolds number $Re_c \approx 4.19$. For $Re \gtrsim Re_c$, we find a power-law scaling of the energy with $Re - Re_c$, with the energy spectrum at large scales following the absolute equilibrium form proposed by Kraichnan. At larger Re, the energy spectrum deviates from this form, displaying a steep power-law range at low wave numbers with exponent -5, with most of the energy dissipation occurring within the condensate at large scales. We show that this spectral exponent is consistent with the logarithmic radial vorticity profile of the viscously saturated condensate predicted by quasilinear theory. Our findings shed new light on the classical problem of large-scale turbulent condensation in forced dissipative 2D flows in finite domains, showing that the large scales are close to equilibrium dynamics in weakly turbulent flows but not for strong condensates ($Re \gg 1$).

DY 9: Statistical Physics far from Thermal Equilibrium I

Time: Monday 9:30–12:15 Location: ZEU/0160

DY 9.1 Mon 9:30 ZEU/0160

Dissipation enables robust extensive scaling of multipartite correlations — •Krzysztof Ptaszyński[1,2], Maciej Chudak[1], and Massimiliano Esposito[2] — [1]Institute of Molecular Physics, Polish Academy of Sciences, Mariana Smoluchowskiego 17, 60-179 Poznań, Poland — [2]Complex Systems and Statistical Mechanics, Department of Physics and Materials Science, University of Luxembourg, 30 Avenue des Hauts-Fourneaux, L-4362 Esch-sur-Alzette, Luxembourg

We investigate the multipartite mutual information between N discrete-state stochastic units interacting in a network that is invariant under unit permutations [1]. We show that when the system relaxes to fixed point attractors, multipartite correlations in the stationary state either do not scale extensively with N, or the extensive scaling is not robust to arbitrarily small perturbations of the system dynamics. In particular, robust extensive scaling cannot occur in thermodynamic equilibrium. In contrast, mutual information scales extensively when the system relaxes to time-dependent attractors (e.g., limit cycles), which can occur only far from equilibrium. This demonstrates the essential role of dissipation in the generation and maintenance of multipartite correlations. We illustrate our theory with the nonequilibrium Potts model. Finally, we present a generalization of our approach to permutation-invariant open quantum systems [2].

[1] Phys. Rev. Lett. 135, 057401 (2025)
[2] Phys. Rev. E 112, 054137 (2025)

DY 9.2 Mon 9:45 ZEU/0160

Nested Stochastic Resetting: Nonequilibrium Steady States and Exact Correlations — •Callum Britton[1], Henry Alston[2], and Thibault Bertrand[1] — [1]Imperial College London, London, United Kingdom — [2]Laboratoire de Physique de l'Ecole Normale Supérieure, Paris, France

Stochastic resetting has gained a lot of traction over the past few years. It has been shown to drive the formation of nonequilibrium steady states and the optimization of first-passage properties in an analytically tractable setting. Yet, most works have thus far focused on single-particle stochastic resetting. In this talk, we introduce nested

stochastic resetting, an exactly solvable, many-body stochastic resetting model achieved by harnessing resets as unilateral interactions between particles. We look at a system of n particles, where the position of particle i is independently reset to the instantaneous position of particle $i-1$ according to a Poisson process. We derive analytically the steady-state statistics of these nested stochastic resetting processes including the stationary distribution for each process as well as its moments. In this system, we go one step further and calculate exactly the steady-state two-point correlations $\langle x_i x_j \rangle$ between processes by mapping the problem to one of the ordering statistics of random counting processes. We expect this framework will both help build a model-independent framework for random processes with unilateral interactions and find immediate applications, e.g., in the modelling of lossy information propagation.

DY 9.3 Mon 10:00 ZEU/0160

Mutual linearity: A generic property of steady-state Markov networks — •Robin Bebon and Thomas Speck — Institute for Theoretical Physics 4, University of Stuttgart, Heisenbergstraße 3, 70569 Stuttgart, Germany

Nonequilibrium response theory has long sought universal principles to characterize the behavior of observables under external perturbations. While powerful tools exist near thermal equilibrium, general results far from equilibrium remain sparse and often rely on specific assumptions that severely limit their applicability, e.g., a specific parametrization of transition rates. In this work, we prove a remarkably simple, yet broadly applicable result: In a Markov network, any two steady-state probabilities remain linearly related when perturbing transition rates along a single edge of the network. This mutual linearity holds for every irreducible Markov network, arbitrarily far from equilibrium, and is independent of the chosen rate parametrization. As key implications, we demonstrate that the relative response of all states in the network is identical and show that analogous linear relations follow for a broad class of observables, including generic state-dependent and counting observables. Crucially, the coefficients that enter these linear relationships are empirically accessible, which makes our results not only conceptually significant but also provide a novel practical tool for inference and model validation in biological and chemical systems.

DY 9.4 Mon 10:15 ZEU/0160

Stochastic Path Integrals for Non-Markovian Dynamics: Fractional Operators, and Entropy Production — •Felipe Abril-Bermudez — Independent Researcher (formerly University of Aberdeen, UK)

Stochastic dynamics with long-range correlations, multiplicative noise, and memory effects give rise to rich non-equilibrium behaviors, including anomalous diffusion, metastability, and nontrivial entropy production. In this work, we develop a unified stochastic path integral (SPI) framework that extends the Parisi-Sourlas supersymmetric formalism to treat multidimensional Langevin systems with multiplicative noise, thresholds, and fractional operators driven by fractional Gaussian noise. The resulting generalized Fokker-Planck equation is solved for representative processes, enabling analytical estimation of Shannon entropy and entropy production rates, which exhibit the emergence of quasi-steady states with non-monotonic dissipation. In parallel, the formalism recovers the standard underdamped Langevin and Klein-Kramers results while providing a systematic treatment of non-Markovian dynamics responsible for anomalous transport, weak ergodicity breaking, and dynamical phases such as time glasses and time crystals. Thus, it is shown how the SPI can serve as a unified approach to study anomalous stochastic phenomena in complex systems.

DY 9.5 Mon 10:30 ZEU/0160

Thermophoresis of a tracer particle via coarse graining of an explicit nonequilibrium medium — •Wade Hodson and Aljaz Godec — Mathematical Physics and Stochastic Dynamics, Institute of Physics, University of Freiburg

We investigate the transport of a tracer particle embedded in an explicitly represented medium with a position-dependent temperature. The medium consists of a chain of harmonic oscillators, in which a temperature gradient is established by connecting each particle to its own heat reservoir. We then couple a tracer to this medium via a generic potential. Under these conditions, we find that the tracer preferentially diffuses in one direction due to the temperature gradient, a phenomenon known as thermophoresis. We study the model analytically in various regimes, including the weak coupling, low temperature, overdamped, Markovian, and hydrodynamic limits, and supplement these results with numerical computations. In the Markovian limit, we are able to coarse-grain over the medium's degrees of freedom to obtain a Langevin equation for the tracer, with a potential of mean force, a damping coefficient, and a diffusion coefficient which can be evaluated in the low-temperature regime. We focus on the analysis of this low-temperature Langevin equation, with a particular interest in the parameter regimes where the tracer can potentially exhibit negative thermophoresis, in which the tracer diffuses preferentially towards higher temperatures. Finally, we generalize our results to higher dimensions, by coupling the tracer to a two- or three-dimensional medium.

DY 9.6 Mon 10:45 ZEU/0160

Volterra Series leads to exact Dynamical Density Functional Theory — •Ion Santra — KU LEUVEN

We derive an exact Volterra series expansion for a mean mesoscopic field of an interacting particle system subject to a potential perturbation, expressing the Volterra expansion kernels in terms of the field's response functions, to any order. Applying this formalism to the mean particle density of a simple interacting fluid, we identify a form reminiscent of dynamical density functional theory, with, however, fundamental differences: A generally nonlocal mobility kernel appears, and the internal force derives from a functional of the *history* of mean density. In the limit of a slowly varying external force, the expansion kernels of this functional turn into the equilibrium direct correlation functions of the corresponding order, thereby, in this limit, recovering the equilibrium density functional. We identify a freedom in deriving this expansion, which, e.g., allows different forms of mobility kernels, and we explore two choices: A nonlocal mobility kernel results in a concise ans simple form to linear order. For interacting Brownian particles, a local mobility kernel results in a form reminiscent of previous forms for the density current.

15 min. break

DY 9.7 Mon 11:15 ZEU/0160

Thermal Relaxation on Random Graphs via Metropolis and Glauber Dynamics — •Marija Vucelja — University of Virginia, Charlottesville, US — MPI-PKS, Dresden, Germany

Efficient sampling algorithms rely on dynamics that drive a physical system rapidly toward its target state. I will introduce the Mpemba effect – an anomalous thermal relaxation phenomenon in which a system initially at a higher temperature cools down more quickly than one starting at a lower temperature – and its heating analog, in which a cooler initial state can lead to faster heating than a hotter initial state. We investigate thermal relaxation in quenched disordered systems under Metropolis and Glauber dynamics, examining how varying transition rates affect relaxation behavior. We show that Metropolis dynamics on a complete graph cannot exhibit the Mpemba effect, whereas on an incomplete graph it can. Even rank-one perturbations of the transition rates are sufficient to generate anomalous relaxation. Finally, we discuss the probability of observing the Mpemba effect in the large-temperature limit.

DY 9.8 Mon 11:30 ZEU/0160

Fermionic quantum criticality far from equilibrium — •Rohan Mittal, Tom Zander, Johannes Lang, and Sebastian Diehl — Universität Zu Köln

Driving a quantum system out of equilibrium while preserving its subtle quantum mechanical correlations on large scales presents a major challenge, both fundamentally and for technological applications. At its core, this challenge is pinpointed by the question of how quantum effects can persist at asymptotic scales, analogous to quantum critical points in equilibrium. In this work, we construct such a scenario using fermions as building blocks. These fermions undergo an absorbing-to-absorbing state transition between two topologically distinct and quantum-correlated dark states. Starting from a microscopic, interacting Lindbladian, we derive an effective Lindblad-Keldysh field theory in which critical fermions couple to a bosonic bath with hydrodynamic fluctuations associated with particle number conservation. A key feature of this field theory is an emergent symmetry that protects the purity of the fermions' state even in the presence of the thermal bath. We quantitatively characterize the critical point using a leading-order expansion around the upper critical dimension, thereby establishing the first non-equilibrium universality class of fermions. The symmetry protection mechanism, which exhibits parallels to the problem of directed percolation, suggests a pathway toward a broader class of ro-

bust, universal quantum phenomena in fermionic systems.

DY 9.9 Mon 11:45 ZEU/0160

ultrafast thermodynamics of the ferroelectric soft mode in laser-excited SrTiO3 — •Yulong Qiao and R. Matthias Geilhufe — Department of Physics, Chalmers University of Technology, Gothenburg, Sweden

Intense THz laser pulses allow to selectively pump and control optical phonon modes. This has led to the realization of metastable phases of matter, phonon-induced magnetism, and ultrafast magnetic switching. Following such a nonthermal path-way in the sub-picosecond timescale, has recently sparked questions on the temporal evolution of thermodynamic quantities, such as heat and entropy production, in the context of ultrafast thermodynamics [1].

In this work, we simulate the dynamics of the ferroelectric soft mode in SrTiO3 driven by a THz laser pulse using molecular dynamics [2]. We show that both the soft-mode dynamics and the associated energy transfer from the soft mode to other ionic degrees of freedom are accurately described by our stochastic thermodynamic theory. Moreover, the molecular dynamics simulations clearly reveal that the power spectral density of the noise is frequency-dependent. This indicates that the commonly adopted Markovian approximation breaks down. In this talk, I will also discuss the non-Markovian effects induced by the ultrafast laser pulse.

[1] L. Caprini, H. Löwen, and R. M. Geilhufe, Nature. Communication. 15, 94 (2024).

[2] F. Eriksson, Y. Qiao, E. Fransson, R. M. Geilhufe, and P. Erhart, in preparation.

DY 9.10 Mon 12:00 ZEU/0160

Ultrafast Thermodynamics - entropy, heat and criticality on picosecond timescales — •R. Matthias Geilhufe — Chalmers University of Technology, Gothenburg, Sweden

Materials are composed of a vast number of ions and electrons, arranging themselves in regular patterns. Due to immense progress in ultrafast spectroscopy, ranging from the low-frequency infrared to high-frequency X-ray regimes, collective excitations of charge, spin, lattice, and orbital degrees of freedom can now be triggered and probed on their characteristic time and length scales. Probing such excitations far from equilibrium motivates the field of ultrafast thermodynamics, which translates well-understood concepts, such as entropy and heat, to picosecond dynamics. I will introduce the concept of ultrafast thermodynamics using the example of entropy production due to laser-driven phonons [1] and magnons [2] using stochastic thermodynamics. Furthermore, I will show extensions of the formalism to non-Markovian behavior and quantum mechanics.

[1] L. Caprini, H. Löwen, R. M. Geilhufe, Nature Communications, 15, 94 (2024) [2] F. Tietjen, R. M. Geilhufe, PNAS Nexus, 4, 3 (2025)

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

Time: Monday 9:30–11:00 Location: ZEU/0260

Invited Talk DY 10.1 Mon 9:30 ZEU/0260

Cleaning of dusty surfaces — •Doris Vollmer[1], Franziska Sabath[1], Abhinav Naga[2], Stefanie Kirschner[1], Tarik Karakaya[1], Rüdiger Berger[1], Hans-Jürgen Butt[1], and Halim Kusumaatmaja[2] — [1]Max Planck Institute for Polymer Research, 55128 Mainz, Germany — [2]Ackermannweg 10

The accumulation of dust, sand or other contaminants on solar modules leads to significant efficiency losses. Billions of litres of water are used annually to clean solar modules, and other natural or man-made surfaces. However, the complex interplay between capillary and frictional forces, which determines successful removal or unwanted redeposition, is still poorly understood. By combining confocal microscopy and Boltzmann lattice simulations, we observe and quantify the removal of particles from smooth and rough surfaces by a water droplet, varying the hydrophobicity of the surface and the particles. Hydrophilic particles aquaplane, resulting in negligible friction and easy particle removal. For hydrophobic particles, the tangential component of the capillary force promotes or counteracts particle removal. Undesirable redeposition depends on the number and wettability of the particles. On superhydrophobic surfaces, the small contact area facilitates easy removal. For individual particles, we propose a phase diagram for particle removal.

DY 10.2 Mon 10:00 ZEU/0260

Marangoni contracted droplets on Textured Surfaces: Insights from Lubrication Theory — •Raphael Saiseau, Ze Xu, and Stefan Karpitschka — Fachbereich Physik, Universität Konstanz, 78464 Konstanz, Germany

Wetting and evaporation of droplets on micropatterned surfaces are central to both natural processes and technological applications, from anti-icing and spray cooling to inkjet printing and semiconductor processing. Droplet behavior on such surfaces is set by surface chemistry and topography, and most control strategies traditionally rely on specific materials or designs, limiting their versatility.

By depositing droplets on top of a pillars-decorated substrate in a vapor-controlled chamber, we show that the spreading and wicking can be controlled, and even temporarily suppressed, by using the vapor of a second, low-surface tension liquid, generating Marangoni stresses through its condensation near the droplet edge. We present numerical and semi-analytical solutions of the thin film equation coupled to a composition evolution equation, and diffusion-limited evaporation. The wicking effect of the texture is implemented through an effective height-dependent pressure, analogous to classical hemiwicking models. The emerging Marangoni flows oppose the prevailing capillary flows, leading to a quasi-stationary rather than a spreading or wicking drop. We derive a predictive relation between material parameters and drop shape, opening the way for designing controlled coating, cleaning and drying strategies on textured surfaces.

DY 10.3 Mon 10:15 ZEU/0260

Photoswitchable Arylazopyrazole Monolayers on Aluminum Oxide for Tunable Wettability — •Tim Blinzer, Christian Honnigfort, and Björn Braunschweig — Institute of Physical Chemistry and Center of Soft Nanoscience, University of Münster, Corrensstraße 28-30, Münster 48149, Germany

Smart surfaces that can change their wettability on demand are interesting for applications such as self-cleaning or microreactors. To tune the surface wettability, we functionalized aluminum oxide surfaces with arylazopyrazole (AAP) phosphonic acids using a Langmuir-Blodgett transfer. AAP molecules in the deposited monolayers undergo reversible E/Z photoisomerization driving changes in surface wettability. This was investigated as a function of surface coverage, where the responsiveness—i.e. the changes in molecular structure and in the apparent contact angle—was studied in detail. Here time-dependent sum-frequency generation (SFG) was used to obtain in situ information on the dynamic changes in monolayer upon E/Z switching with 520 nm green and 365 nm UV light. Furthermore, we show that increasing surface roughness by depositing nanoaggregates of the AAP phosphonic acid leads to a drastic increase in the change of the contact angle when switching from the E to the Z isomer. Indeed, the change in contact angle increased from only 7° for homogeneous monolayers to about 20° for nanostructured surfaces using AAP aggregates.

DY 10.4 Mon 10:30 ZEU/0260

Motion and interaction of Marangoni contracted droplets on micropatterned surfaces — •Ze Xu, Raphael Saiseau, and Stefan Karpitschka — Fachbereich Physik, Universität Konstanz, Konstanz, Germany

Wetting of micropatterned surfaces is ubiquitous in nature and key to many technological applications like inkjet printing and semiconductor processing. Overcoming the intrinsic, chemistry- and topography-governed wetting behaviors often requires specific materials, leading to contradicting requirements between the processing strategy and the final product. Here, we demonstrate that droplet spreading and wicking on hydrophilic patterns can be controlled by the vapor of a lower-surface-tension liquid. Condensation of the vapor induces Marangoni forces that delay capillary wicking and contract liquid into a droplet on top of the imbibed film. Consequently, a Marangoni-contracted droplet coexists with a finite imbibition film for prolonged times. We demonstrate how these droplets interact with each other, both by their vapor cloud, and by the imbibed liquid film that surrounds them. Modu-

lating the ambient vapor, also these interactions can be modulated, devising new strategies for coating, cleaning, and drying functional surfaces.

DY 10.5 Mon 10:45 ZEU/0260

Wetting of Swelling Polyelectrolyte Surfaces on a Macroscopic and Nanoscopic Scale — •Mona Meltschoch and Regine von Klitzing — Soft Matter at Interfaces, Institute for Condensed Matter Physics, TU Darmstadt, Hochschulstraße 8, D-64289 Darmstadt, Germany

Wetting on adaptive polymer interfaces plays an important role in soft matter physics, particularly when spreading is affected by substrate hydration. Polyelectrolyte multilayers (PEMs) are suitable model systems because they absorb water and evolve across multiple time scales, creating a link between nanoscale polymer mobility and macroscopic contact line motion. PEM films were prepared by the layer-by-layer method, and their wetting behaviour was examined at different scales. Nanoscale morphology and hydration were characterised by atomic force microscopy (AFM), while macroscopic wetting was followed via optical contact angle (CA) measurements. Previous studies report a decrease in water CA on PSS-terminated PEMs under humid atmosphere. To assess how film architecture affects wetting, PEMs with varying bilayer numbers and terminal charge (PSS vs. PAH) were fabricated, showing smooth surfaces and a linear thickness increase. Current work explores AFM beyond static surface imaging by applying it directly to droplets on PEM films. This approach aims to track local swelling, interface deformation and contact line behaviour under liquid exposure. Measurements with different droplet liquids are being established, with the long-term goal to link nanoscale hydration dynamics to macroscopic changes in contact angle and wetting evolution.

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

Time: Monday 11:30–12:45 Location: ZEU/0260

DY 11.1 Mon 11:30 ZEU/0260

Do the particle number and wettability affect their removability by a single water drop? — •Franziska Sabath[1], Abhinav Naga[2], Halim Kusumaatmaja[2], and Doris Vollmer[1] — [1]Max Planck Institute for Polymer Research, 55128 Mainz, Germany — [2]Institute for Multiscale Thermofluids, School of Engineering, University of Edinburgh, United Kingdom

The accumulation of dust on surfaces, *e.g.* windows and solar panels, is a well-known phenomenon in everyday life. The ratio of the capillary force between particles and drop and the resistive forces between particles and surface, *i.e.* friction and adhesion, determine whether the particles can be removed by a water drop. The likeliness of particle removal depends on both particle and surface wettability. It is still questionable how the particle arrangement, the total resistive force acting and the unwanted redeposition of particles depend on the number and wettability of the particles. Here, we investigate the removal of hydrophobic and hydrophilic spherical particles from a flat surface. As the number of hydrophobic particles increases, the total resistive force increases, but not linearly, and overcomes the capillary force, causing particle redeposition. In contrast, the hydrophilic particles slide on a thin water film, reducing the particle-surface friction and no resistive force is measured within our experimental resolution.

DY 11.2 Mon 11:45 ZEU/0260

Modelling and simulation of capillary adhesion between rough surfaces — •Yizhen Wang, Martin Ladecký, and Lars Pastewka — University of Freiburg, Freiburg, Germany

At a small enough length scale, surfaces are always rough, regardless whether they are generated by nature or via artificial process. When two such surfaces are placed close enough, the water molecules in the humid air are adsorbed and hence form capillary bridges. Theories for adhesive interactions typically use simple cohesive laws, which are good models for Van-der-Waals interactions but may not be appropriate for capillary adhesion. We here construct a phase-field model that explicitly represents water present between two contacting rough interfaces. We show results obtained with this model on synthetic, computer-generated, self-affine rough interfaces. In quasi-static simulation, we observe the merging and splitting of droplets under the normal and shear movement of the interfaces. The overall force is dominated by the perimeter of the droplet, indicating the importance of a detailed understanding of droplet morphology.

DY 11.3 Mon 12:00 ZEU/0260

Impact of surface wettability on the removal of montmorillonite aggregates by water drops How natural dirt is removed from various surfaces — •Stefanie Kirschner, Franziska. Sabath, Azadeh Sharifi-Aghili, Tarik Karakaya, and Doris Vollmer — Max Planck Institute for Polymer Research, 55128 Mainz, Germany

Natural dust on photovoltaic modules or windows, is a critical factor that reduces their performance. Previous experiments focused on the removal on single or many spherical particles. The removal of aggregates of natural particles, is not yet understood. Here, we focus on minerals, commonly present in desert dust. Using confocal laser scanning microscopy the detachment behavior upon contact with a water drop is measured on surfaces with different wettability. In addition, the force required to remove the aggregate by a sliding water drop was investigated. During drying on a hydrophilic surface, the dispersed particles cover a larger area. This increases the total contact area, resulting in higher adhesion and reduced detachment. In contrast, hydrophobic surfaces promoted more compact aggregates with improved removability. Finally, I will compare the detachment forces and the removal behavior of different natural aggregates, e.g. soot, salt and humic acid.

DY 11.4 Mon 12:15 ZEU/0260

Equilibrium droplets on deformable substrates exhibit cloaking and demixing at the three-phase contact line — •Khalil Remini[1], Ralf Seemann[1], Dirk Peschka[2], and Barbara Wagner[2] — [1]Universität des Saarlandes — [2]Weierstrass Institute for Applied Analysis and Stochastics

This work examines the equilibrium shape of liquid droplets on viscoelastic PDMS substrates with varying elasticities. By combining atomic force microscopy (AFM) with an initial lift-off step, we reveal not only the top contour of the droplets but also the buried droplet*substrate interface. A second lift-off step provides additional structural details near the three-phase contact line (TPCL), where the interfacial tensions adopt a Neumann balance. Quantitative analysis of the reconstructed 3D droplet shapes shows that non-crosslinked, liquid PDMS molecules are extracted from the elastic network under stress and accumulate as a liquid rim around the droplet base, thereby altering both the droplet shape and the substrate profile close to the TPCL. These liquid molecules also cloak the droplets with a thin film, modifying the effective surface tensions. Furthermore, dewetting experiments demonstrate that this demixed liquid already appears at an early stage of dewetting and remains at an approximately constant amount throughout the process.

DY 11.5 Mon 12:30 ZEU/0260

Tuning Sliding Drop Shape — •Fiona Berner, Chaurasia Rishi, Sajjad Shumaly, Chirag Hinduja, Hans-Jürgen Butt, and Rüdiger Berger — Max-Planck-Institut für Polymerforschung

The understanding of wetting phenomena plays a crucial role in many daily processes. For example, dirt repelling glasses can be achieved by a hydrophobic coating. Recently, Hinduja et al, reported on a scanning drop friction force instrument (sDoFFI) to analyse friction forces of drops on surfaces. A drop is fixated to an elastic force sensor with spring constant κ. The sample underneath the drop is moved with a constant speed u leading to sliding of the drop at a defined trajectory along surfaces. The deflection of the capillary,d, provides information about the friction force between the drop and the surface, $F_{meas} = \kappa \cdot d$ Forces arising from CAH are given by the Furmidge equation, where the drop*s sliding force F_{CAH} corresponds to

$$F_{CAH} = k \cdot \gamma \cdot w \cdot \big(cos(\theta_{rec}) - cos(\theta_{adv})\big) \quad (1)$$

where k is a geometrical factor, γ is the liquid surface tension, w the width of the drop and θ_{rec} and θ_{adv} are the receding and advancing contact angles, respectively. For small u we assume $F_{meas} = F_{CAH}$. The parameters γ, w, θ_{rec} and θ_{adv} are known or can be measured optically. Thus, the geometrical factor k can be calculated. We realize

different geometries of the drop by glueing metal rings to the elastic glass capillary. Shaping the metal rings forces the drop to shape. We discuss experiments where we shape the drop into different width and length and discuss dependence of the geometrical factor k.

DY 12: Focus Session: Relaxation Timescales in Open Quantum Systems (joint session TT/DY)

In the quantum year 2025 many applications of quantum systems are revisited for their actual physical implementability. Realizing that no quantum system is truly isolated from its environment highlights the need for a thorough understanding of the coupling between an open system and its environment. While many standard treatments lead to Lindblad equations, the underlying approximations are not always applicable and require detailed case-by-case studies. This theoretical focus session provides a platform discussing modern developments in the field in the regime of strongly interacting or driven open systems and their impact on relaxation timescales. We aim to enhance attention and trigger also experimental activity in the field of system-environment interactions and the induced relaxation timescales.

Coordinators: Gernot Schaller (Helmholtz-Zentrum Dresden-Rossendorf), Nikodem Szpak (Universität Duisburg-Essen)

Time: Monday 15:00–18:00 Location: CHE/0089

Topical Talk DY 12.1 Mon 15:00 CHE/0089
Markovian and non-Markovian approaches to quantum relaxation — •Heinz-Peter Breuer — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Relaxation and decoherence processes in open quantum systems are often approximated by means of a Markovian evolution in which the open system irretrievably loses information to its surroundings, expressing the memoryless nature of the dynamics. However, strongly coupled open systems often exhibit a pronounced non-Markovian behavior distinguished by a flow of information from the environment back to the open system. This information backflow implies the presence of memory effects and represents the key feature of non-Markovian quantum dynamics. In the talk we will discuss fundamental physical concepts used to characterize and quantify non-Markovian relaxation dynamics in open systems, and present some applications to irreversibility and entropy production in nonequilibrium quantum thermodynamics.

Topical Talk DY 12.2 Mon 15:30 CHE/0089
Asymptotic relaxation in quantum Markovian dynamics — •Susana Huelga — Institute of Theoretical Physics, Ulm University, Germany

We investigate the long-time dynamics of generic time-dependent GKLS master equations and provide sufficient conditions such that the dynamics is asymptotically independent of the initial state. These conditions represent a natural extension of the Spohn-Frigerio theorem to the case of a time-dependent generator. To illustrate our results, we analyze a specific master equation for driven systems and connect our conditions to the microscopic Hamiltonian of system and environment. The case of a 3-level system is also treated in detail. A brief mention of the non-Markovian case is included, with specific focus on time-local master equations which are asymptotically in Lindblad form. These findings pave the way for the development of a more general theory of relaxation beyond the Markovian case.

Topical Talk DY 12.3 Mon 16:00 CHE/0089
Floquet engineering of open quantum Systems — •André Eckardt — Institut für Physik und Astronomie, TU Berlin, Berlin

In recent years, we have seen tremendous progress in the control of quantum systems by means of time-periodic driving. This includes the realization of effective time-independent Hamiltonians with interesting properties, such as artificial magnetic fields coupling to the motion of charge neutral particles in quantum simulators (e.g. of ultracold atoms in optical lattice or photons in superconducting circuits). Also phenomena without equilibrium counterpart, like chiral edge modes connecting Bloch bands with zero Chern number, have been investigated. Another paradigm for the control of quantum systems is reservoir engineering. Here a system is coupled to a controlled environment that is designed to either cool the system or to stabilize a non-equilibrium steady state of interest. I will report on recent theoretical work, where we combine both approaches in open Floquet systems. One motivation is to use dissipation in order to counteract unwanted heating, as it necessarily occurs in Floquet engineered systems, e,.g. for the preparation of Floquet engineered topological states of matter. The other motivation is the stabilization of interesting non-equilibrium steady states beyond the strict constraints of thermal equilibrium. Here I will discuss driving-induced non-equilibrium Bose condensation in high-temperature environments. Finally, I will also briefly address challenges arising when simulating open many-body quantum systems out of equilibrium and ideas how to tackle them.

15 min. break

Topical Talk DY 12.4 Mon 16:45 CHE/0089
Nonequilibrium thermodynamics of time-dependent quantum transport — •Janine Splettstoesser — Chalmers University of Technology, Gothenburg, Sweden

Quantum transport induced by time-dependent driving fields is not only of interest when considering the conductor's charge response. On the contrary, in recent years there has been strong interest in the thermodynamics and energetic properties of quantum conductors. By applying time-dependent driving fields to a conductor cyclic quantum heat engines can be implemented and quantum properties can be used to rapidly load and discharge so-called quantum batteries.

In this presentation, I will first show how different time-scales in the response of a quantum dot impact the (energy) decay of a quantum dot brought out of equilibrium. This is visible both in the relative entropy, where Coulomb interaction results in an anomalous decay referred to as Mpemba effect [1], as well as in the geometric properties of a slowly driven cyclic engine [2]. I will then show how the precision of time-dependently driven engines is bounded by the produced or dissipated power [3].

[1] J. Graf, J. Splettstoesser, J. Monsel, J. Phys.: Condens. Matter 37, 195302 (2025)
[2] J. Monsel, J. Schulenborg, Th. Baquet, J. Splettstoesser, Phys. Rev. B 106, 035405 (2022)
[3] L. Tesser, J. Balduque, J. Splettstoesser, arXiv:2509.07583 (2025)

Topical Talk DY 12.5 Mon 17:15 CHE/0089
Connecting time-nonlocal and time-local quantum master equations — •Maarten Wegewijs — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany — Institute for Theory of Statistical Physics, RWTH Aachen, 52056 Aachen, Germany

A perhaps puzzling feature of open-system dynamics is that it admits both a retarded description via a *time-nonlocal* memory-kernel $\mathcal{K}$ and an *equivalent* time-convolutionless description by a *time-local* generator $\mathcal{G}$. This leads to a split in approaches to the problem of time scales in open quantum systems.

In this talk I discuss an elegant fixed-point relation $\mathcal{G} = \hat{\mathcal{K}}(\mathcal{G})$ that connects these two approaches directly, without first solving the respective quantum master equations for the dynamics ultimately of interest. As applications, I connect the distinct results (!) obtained when expanding in the same perturbation parameter and relate distinct timescales (!) obtained by approximations approaching the same, exact stationary state. The fixed-point relation is also explicitly related to

quantum Markovianity as defined by completely-positive divisibility of the dynamics (Huelga, Rivas, Plenio): What generates the retardation of the memory kernel turns out to be precisely what defines the Markovian divisibility of the dynamics. Exact solutions of simple models of electron transport (resonant level) and atomic-decay (dissipative Jaynes-Cummings) illustate these findings.
[1] SciPost Phys. 7, 012 (2019)
[2] Phys. Rev. X 11, 021041 (2021)
[3] Phys. Rev. B 104, 155407 (2021)
[4] SciPost Phys. 12, 121 (2022)
[5] J. Chem. Phys. 161 (2024)

DY 12.6 Mon 17:45 CHE/0089

Coupling–energy driven pumping through quantum dots: The role of coherences — •Lukas Litzba[1], Gernot Schaller[2], Jürgen König[1], and Nikodem Szpak[1] — [1]Universität Duisburg-Essen, Duisburg, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

We study the impact of off–resonant tunneling and coherences on the electron transport through quantum dots. We focus on two electron pump setups where first–order tunneling processes are suppressed and the pumping mechanism is exclusively driven by modulations of the coupling energy. For calculations we use an exact solution for a non–Coulomb interacting situation. The first setup is driven by a coupling and decoupling procedure of the quantum dot and the environment and the second setup by measurement–induced effects resembling the anti–Zeno effect. We show that both electron pumps are based on decoherence operations and modulations of the coupling energy and there is quantitative and qualitative agreement between them. Furthermore, we show that non–Markovian effects can increase the performance of the devices and are signatures for the importance of coherences in electron transport.

DY 13: Focus Session: New Routes to Localization and Quantum Non-Ergodicity II (joint session TT/DY)

Time: Monday 15:00–17:30 Location: CHE/0091

DY 13.1 Mon 15:00 CHE/0091

Localized obstructed pairs with zero superfluid stiffness from doping an antiferromagnetic insulator — •Tamaghna Hazra[1], Nishchhal Verma[2], and Jörg Schmalian[1] — [1]Institüt für Theorie der Kondensierten Materie, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Department of Physics, Columbia University

Doping a Mott antiferromagnet is widely expected to yield mobile Cooper pairs whose kinetic energy sets the superfluid stiffness. We show instead that, when doped charges propagate on the line graph of a lattice with strong antiferromagnetic exchange, they bind into *obstructed* Cooper pairs, which are compact localized bosons that possess *zero* superfluid stiffness at leading order in the strong-coupling expansion. The pair-hopping Hamiltonian generates an exactly flat bosonic band whose compact localized states dominate the low-energy Hilbert space, yielding a ground-state manifold with extensive degeneracy and a phase stiffness that vanishes anomalously as the *third* inverse power of the pairing strength in the strong-coupling limit. At quarter filling, the frustrated dynamics maps onto a quantum dimer model at the Rokhsar-Kivelson point, realizing a d-wave resonating-valence-bond spin liquid with topological ground-state degeneracy and deconfined holon excitations. Our results establish a mechanism for interaction-driven localization without disorder, in which strong magnetically-mediated pairing produces Cooper pairs whose kinetic energy collapses to zero, revealing a distinct failure mode of unconventional superconductivity in strongly-correlated materials.

DY 13.2 Mon 15:15 CHE/0091

Disorder-free localization from mass-imbalanced fractionalization — •Shi Feng, Johannes Knolle, and Michael Knap — Technical University of Munich, Garching, Germany

We report disorder-free localization of Majorana fermions over intermediate timescales in an emergent gapless non-integrable Z_2 quantum liquid. A large density of heavy visons induced by an external magnetic field provides coherent disorder that localizes the light fermions while preserving translation symmetry. Compelling evidence of the localization within intermediate time scale is provided by the time evolution of the local energy density, which shows negligible spreading after a local quench on its ground state; and a vanishing energy current response despite the gapless energy spectrum. These results demonstrate that the disorder-free localization can also occur near equilibrium at low energy, and offer an explanation to the thermal paradox in recent experiments where a linear specific heat coexists with vanishing thermal transport in frustrated Mott insulators with disorder-free gapless quantum magnets.

DY 13.3 Mon 15:30 CHE/0091

Fock space fragmentation in quenches of disordered interacting fermions — •Ishita Modak[1], Rajesh Narayanan[2], Ferdinand Evers[3], and Soumya Bera[1] — [1]Department of Physics, Indian Institute of Technology Bombay, Mumbai, India. — [2]Department of Physics, Indian Institute of Technology Madras, Chennai, India — [3]Institute of Theoretical Physics and Halle-Berlin-Regensburg Cluster of Excellence CCE, University of Regensburg, Regensburg, Germany

Hilbert space fragmentation primarily originates from specific kinematic constraints or emergent conservation laws in many-body systems with translation invariance. It leads to non-ergodic dynamics and breakdown of the eigenstate thermalization hypothesis. We demonstrate that also in disordered systems (e.g. random-field XXZ model), fragmentation appears as a natural concept offering fresh perspectives on many-body delocalization (MBdL). We split the Fock-space into potential-energy shells, which contain the accessible phase space for the relaxation of a quenched initial state. In this construction, dynamical observables reflect properties of the shell geometry, e.g., the drastic sample-to-sample fluctuations observed in the weak disorder regime, $W < W_c$, represent fluctuations of the shell-mass. Upon crossing over to strong disorder, $W > W_c$, the potential-energy shell decays into fragments; we argue that, unlike percolation, fragmentation is a strong-coupling scenario with turn-around flow: $W_c(L)$ diverges with increasing system size. We conjecture that the slowing down of the relaxation dynamics reported in traditional MBdL studies is a manifestation of Fock-space fragmentation introduced here.

DY 13.4 Mon 15:45 CHE/0091

Non-ergodic one-magnon magnetization dynamics of the Kagome lattice antiferromagnet — Henrik Schlüter, •Jannis Eckseler, and Jürgen Schnack — Bielefeld University

The present view of modern physics on non-equilibrium dynamics is that generic systems equilibrate or thermalize under rather general conditions, even closed systems under unitary time evolution. The investigation of exceptions thus not only appears attractive, in view of quantum computing where thermalization is a threat it also seems to be necessary. Here, we present aspects of the one-magnon dynamics on the Kagome lattice antiferromagnet as an example of a non-equilibrating dynamics due to flat bands. Similar to the one-dimensional delta chain localized eigenstates also called localized magnons lead to disorder-free localization and prevent the system from thermalization [1].
[1] H. Schlüter, J. Schnack and J. Eckseler, Zeitschrift für Naturforschung A (2025) doi:10.1515/zna-2025-0249

DY 13.5 Mon 16:00 CHE/0091

Cooling dynamics of a disorder-free localized Kitaev model — •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 Kitaev spin-1/2 model on a 2D honeycomb lattice has a Z_2 gauge symmetry that translates to an effective picture of free Majorana fermions on a background static charge field. This yields a ground state that realizes a quantum spin liquid (QSL) with fractional excitations. 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 with a symmetry

breaking interaction. We envisage that signatures obtained from this dynamics could act as probes for QSL.

15 min. break

DY 13.6 Mon 16:30 CHE/0091

Scrambling signature of scars — •Thomas Michel[1], Mathias Steinhuber[2], Juan Diego Urbina[2], and Peter Schlagheck[1] — [1]Université de Liège, Liège, Belgique — [2]Universität Regensburg, Regensburg, Germany

We study signatures of scrambling, such as out-of-time-ordered correlators, that are associated with weakly unstable periodic orbits in a mixed or chaotic classical phase space, fulfilling Heller's criterion [1] for the existence of scars. As verified within generic dynamical systems like the kicked rotor and the driven pendulum, evaluating scrambling observables for coherent states centred in phase space about such periodic orbits gives rise to characteristic scar features both in the short and long time regimes, the latter amounting to a significant amendment of the characteristic growth exponent with respect to the generic semiclassical prediction [2,3]. Extensions to many-body scars in Bose-Hubbard rings [4] are discussed.

[1] E. J. Heller, Phys. Rev. Lett. 53, 1515 (1984).
[2] J. Rammensee, J.-D. Urbina, and K. Richter, Phys. Rev. Lett. 121, 124101 (2018).
[3] T. R. Michel, J. Diego Urbina, and P. Schlagheck, J. Phys. A: Math. Theor. 58, 275303 (2025).
[4] Q. Hummel, K. Richter, and P. Schlagheck, Phys. Rev. Lett. 130, 250402 (2023).

DY 13.7 Mon 16:45 CHE/0091

Many-Body Cages - Flat bands on the state graph — •Tom Ben-Ami[1,2], Markus Heyl[1], and Roderich Moessner[2] — [1]University of Augsburg, D-86135 Augsburg, Germany — [2]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, Dresden 01187, Germany

We identify the many-body counterpart of flat bands, which we term many-body caging, as a general mechanism for non-equilibrium phenomena such as a novel type of glassy eigenspectrum order and many-body Rabi oscillations in the time domain. We focus on constrained systems of great current interest in the context of Rydberg atoms and synthetic or emergent gauge theories. We find that their state graphs host motifs which produce flat bands in the many-body spectrum at a particular set of universal energies. Basis states in Fock space exhibit Edwards-Anderson type order in the absence of quenched disorder, with an intricate, possibly fractal, distribution over Fock space. This is reflected in a distinctive structure of a non-vanishing post-quench long-time Loschmidt echo, an experimentally accessible quantity. In general, phenomena familiar from single-particle flat bands manifest themselves in characteristic many-body incarnations, such as a reentrant 'Anderson' delocalisation, offering a rich ensemble of experimental signatures in the abovementioned quantum simulators. The variety of single-particle flat band types suggests an analogous typology–and concomitant phenomenological richness to be explored–of their many-body counterparts.

DY 13.8 Mon 17:00 CHE/0091

Dynamics in the presence of local symmetry-breaking impurities — •Yahui Li[1,2], Pablo Sala[3,4], Frank Pollmann[1,2], Sanjay Moudgalya[1,2], and Olexei Motrunich[3,4] — [1]Technical University of Munich, Germany — [2]Munich Center for Quantum Science and Technology, Germany — [3]California Institute of Technology, USA — [4]Walter Burke Institute for Theoretical Physics, USA

Continuous symmetries lead to universal slow relaxation of correlation functions in quantum many-body systems. In this talk, I will show how local symmetry-breaking impurities affect the dynamics of these correlation functions using Brownian quantum circuits. While explicitly breaking the symmetry is generally expected to lead to eventual restoration of full ergodicity, we find that approximately conserved quantities that survive under such circumstances can still induce slow relaxation. This can be understood using a super-Hamiltonian formulation, where low-lying excitations determine the late-time dynamics. We show that in one dimension, symmetry-breaking impurities modify diffusive and subdiffusive behaviors associated with U(1) and dipole conservation at late times, e.g., by increasing power-law decay exponents of the decay of autocorrelation functions. On the other hand, for an impurity that disrupts strong Hilbert space fragmentation, it leads to prethermal plateaus in autocorrelation functions. Overall, our approach systematically characterizes how symmetry-breaking impurities affect relaxation dynamics in symmetric systems.

DY 13.9 Mon 17:15 CHE/0091

Late time dynamics of quantum entanglement — •Felix Dusel[1,2], Frank Pollmann[1,2,3], Tobias Micklitz[4], and Alexander Altland[5] — [1]Department of Physics, Technical University of Munich, 85748 Garching, Germany — [2]Munich Quantum Valley, 80807 Munich, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstraße 4, 80799 Munich, Germany — [4]Centro Brasileiro de Pesquisas Físicas, Rua Xavier Sigaud 150, 22290-180 Rio de Janeiro, Rio de Janeiro, Brazil — [5]Institut für Theoretische Physik, Universität zu Köln, Zülpicher Straße 77, 50937 Cologne, Germany

We study entanglement spreading in quantum circuits composed of local qudits with large Hilbert space dimension, and single-particle dynamics relaxing slower than the characteristic timescale for entangling of neighboring qudits.

DY 14: Machine Learning in Dynamics and Statistical Physics II

Time: Monday 15:00–18:30 Location: HÜL/S186

DY 14.1 Mon 15:00 HÜL/S186

Machine-learned classical density functional theory in higher dimensions with convolutional layers — Felix Glitsch, Jens Weimar, and •Martin Oettel — Institut für Angewandte Physik, Universität Tübingen

Through minimization of a grand free energy functional in classical density functional theory (cDFT), inhomogeneous systems in equilibrium can be efficiently computed. For that, the functional of the excess (over ideal gas) free energy is required which is known explicitly only in a few cases. Recent advancements use machine learning for constructing this functional from simulation data, mostly for systems with one-dimensional, planar inhomogeneities. We propose a machine learning model for application in two dimensions [1] akin to density functionals in weighted density forms, as, e.g., in fundamental measure theory. We implement the model with fast convolutional layers only and apply it to a system of hard disks in fully 2D inhomogeneous situations. The model is trained on a combination of smooth and steplike external potentials in the fluid phase. Pair correlation functions from test particle geometry show very satisfactory agreement with simulations although these types of external potentials have not been included in the training. The method should be fully applicable to 3D problems.

[1] F. Glitsch, J. Weimar and M. Oettel, Phys. Rev. E 111, 055305 (2025)

DY 14.2 Mon 15:15 HÜL/S186

Scalable Boltzmann Generators for equilibrium sampling of large-scale materials — •Maximilian Schebek[1], 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]Microsoft Research AI for Science, 10178 Berlin — [4]Department of Chemistry, Rice University, Houston, Texas 77005, USA — [5]Initiative for Computational Catalysis, Flatiron Institute, New York, New York 10010, USA

Generating equilibrium ensembles is essential for modeling molecules and materials, yet traditional simulators like molecular dynamics suffer from limited sampling efficiency. Boltzmann Generators introduced the concept of one-shot deep learning for equilibrium sampling, but scalability to large systems has remained a major challenge. Here, we overcome this scaling limitation with a new Boltzmann Generator architecture that can model large materials systems. Our approach combines augmented coupling flows with graph neural networks to exploit local environments, enabling energy-based training and rapid

inference. Compared to previous designs, it trains faster, uses fewer resources, and achieves superior sampling efficiency. Crucially, it transfers to much larger system sizes, allowing efficient sampling of materials with simulation cells exceeding a thousand atoms. We demonstrate its capabilities on Lennard-Jones crystals, mW water ice phases, and the silicon phase diagram, producing accurate equilibrium ensembles and free energies across scales where finite-size effects vanish.

DY 14.3 Mon 15:30 HÜL/S186

Autoencoder Learning Dynamics on MCMC Ising Dataset — •Max Weinmann[1,2,3] and Miriam Klopotek[1,3] — [1]University of Stuttgart, Stuttgart Center for Simulation Science, SimTech Cluster of Excellence EXC 2075, Stuttgart, Germany — [2]University of Stuttgart, Interchange Forum for Reflecting on Intelligent Systems, IRIS3D, Stuttgart, Germany — [3]Heidelberger Akademie der Wissenschaften, WIN-Kolleg, Heidelberg, Germany.

While consistent and abstract descriptions of learning dynamics in neural networks remain rare, they have become omnipresent and are used in many branches of science. As a result, predicting dynamics under diverse choices of ML model parameters can fail catastrophically and it remains difficult to mitigate these failures. Reliable control requires a deep understanding of the relevant mechanisms and conditions for learning particular kinds of datasets. Our study focuses on autoencoder architectures that perform well if they encode the dataset into a compressed representation that reflects core physical concepts of the data it is trained on, succeeding at a self-learned inverse model to decode this representation to reconstruct the original input (of physical origin). Some physical concepts are learned in a particular order, which depend on theoretical complexity of the representation and that of the ML architecture. We measure generalization ability against hard theoretical baselines and investigate the information geometry, stability, and physical interpretability of latent space over training time.

DY 14.4 Mon 15:45 HÜL/S186

Learning order: can neural networks discover phase transitions without symmetry functions? — •Carina Karner — Institute for Theoretical Physics, TU Wien, Vienna, Austria

Phase transitions in soft matter systems from crystallization to gelation arise from collective particle rearrangements that are challenging to capture in full microscopic detail. Conventional approaches rely on order parameters or symmetry functions to characterize emerging structures, but such descriptors may overlook crucial features in the often complex organisation of biolgical materials or synthetic superstructures. Here we investigate whether machine learning can uncover these hidden features directly from raw particle configurations. Using autoencoders trained on simulated trajectories of serveral soft matter systems, we show that the latent space encodes clear signatures of structural transitions without the need for handcrafted inputs. Our results suggest that neural networks can serve as unbiased tools to detect and interpret phase behavior in complex soft matter systems, revealing patterns that elude traditional symmetry-based analysis.

DY 14.5 Mon 16:00 HÜL/S186

Microscopy on Autopilot: Self-Supervised Transformers for Feature Detection and Control — •Damián Baláž, Gianmarco Ducci, Christoph Scheurer, Karsten Reuter, and Hendrik H. Heenen — Fritz-Haber-Institut der MPG, Berlin

The evaluation of microscopy experiments often relies on manual inspection or supervised machine learning. The former is inefficient, whereas the latter requires extensive labeling and may introduce human bias. Self-supervised learning, by contrast, learns from raw image data, capturing intrinsic visual patterns without the need for manual annotation. This improves generalization and objectivity, making it ideal for complex and dynamic microscopy data. Motivated by these advantages, we use a pre-trained self-supervised machine learning model (DINO), based on vision transformer architecture. This constitutes our central tool for feature detection and temporal analysis in microscopy experiments.

We demonstrate the versatility of our approach for two microscopy experiments: i) observing graphene flake growth on liquid copper ii) tracking crack formation in a cobalt oxide catalyst. In both cases, the model enables label-free, qualitative monitoring by identifying related structures based on similarity in the learned feature space. Beyond using it for analysis, we show how the same feature space representations can be used to predict experimental dynamics to autonomously steer processes toward desired targets via planning in feature space. Our findings highlight the potential of self-supervised vision models for real-time analysis and control in microscopy-based experiments.

DY 14.6 Mon 16:15 HÜL/S186

Learning microstructure in active matter — •Writu Dasgupta, Suvendu Mandal, Aritra Mukhopadhyay, and Benno Liebchen — Technische Universität Darmstadt, Darmstadt, Germany

Understanding the full parameter dependence of microscopic structure in active matter remains a central challenge, particularly for strong activity and high density, where simulations become increasingly expensive. Here, we present a data-driven approach that learns radial and angular correlations in terms of the pair-correlation function $g(r,\theta)$ of passive and active Brownian particles. Our predictions are in close quantitative agreement with Brownian dynamics simulations, even for parameter values that the neural networks had not previously encountered during training. Our predictions are subsequently distilled into compact, closed-form expressions using symbolic regression, providing an interpretable description of the underlying structure. Our approach offers a unified and computationally efficient route to understanding non-equilibrium correlations.

DY 14.7 Mon 16:30 HÜL/S186

Physical embodiment enabled learning for autonomous navigation of active particles in complex flow fields — •Diptabrata Paul[1], Nikola Milosevic[2], Nico Scherf[2], and Frank Cichos[1] — [1]Molecular Nanophotonics Group, Peter Debye Institute for Soft Matter Physics, Leipzig University, 04103 Leipzig, Germany — [2]Max Planck Institute for Human Cognitive and Brain Sciences, 04103 Leipzig, Germany

Autonomous navigation at the microscale is a major challenge in active matter due to strong environmental noise and hydrodynamic disturbances. While living systems rely on sophisticated sensing and feedback to regulate functions from sub-cellular processes to chemotactic navigation strategies, artificial microswimmers lack such adaptive mechanisms and therefore struggle to respond effectively to stationary or dynamic perturbations. In this work, we introduce an actor-critic reinforcement learning (RL) framework and demonstrate that physical embodiment alone enables adaptive navigation without explicit environment sensing. Training of the active particle agent in strong and spatially varying flow fields leads to emergence of robust strategies that counteract hidden hydrodynamic perturbations excluded from the agent's observation space. This reveals that embodied dynamics encode sufficient information for effective decision-making, enabling RL to exploit morphology-environment coupling as an implicit sensing channel. Our approach bridges the gap between simple stimulus response schemes and higher-level adaptive behavior and establishes a foundation for online learning, and microscale robotics.

15 min. break

DY 14.8 Mon 17:00 HÜL/S186

Machine Learning for Electric-Field Driven Nuclear Dynamics in Solids and Liquids — •Elia Stocco[1], Christian Carbogno[2], and Mariana Rossi[1] — [1]MPI for the Structure and Dynamics of Matter, Hamburg, Germany — [2]Fritz Haber Institute of the MPS, Berlin, Germany

Simulating the interaction of electric fields with matter is fundamental to study dielectric properties and their interplay with structural and vibrational degrees of freedom. Therefore, it is desirable to obtain a general method that is able to deal with static and time-dependent fields, that is scalable to large complex systems, and that retains ab initio accuracy. We describe a machine-learning molecular dynamics method within the electric dipole approximation that describes the coupling of insulating materials to diverse electric fields, spanning liquids, solids, and confined systems [1]. In particular, we also take into account the influence of the electric field on the lattice degrees of freedom. We train equivariant MACE models [2], using density-functional theory data to learn the potential energy and dipole surfaces, including the multivalued nature of the polarization in periodic systems. The external forces on various degrees of freedom are obtained through automatic differentiation. We present calculations of the dielectric permittivity of water, the temperature and light-driven ferroelectric-paraelectric phase transition of $LiNbO_3$, and simulations of piezoelectric systems. [1] Stocco, E., Carbogno, C. Rossi, M., Npj Comput. Mater. 11, 304 (2025). [2] Batatia, I., et al., Adv. Neural Inf. Proc. Sys. 35, 11423 (2022).

DY 14.9 Mon 17:15 HÜL/S186

Machine-learned Potentials for Vibrational Properties of Acene-based Molecular Crystals — •Shubham Sharma, Burak Gurlek, Paolo Lazzaroni, and Mariana Rossi — MPI for the Structure and Dynamics of Matter, Hamburg, Germany

Machine-learning potentials (MLPs) have enabled efficient modelling of complex atomistic systems with ab-initio accuracy. A major challenge, however, is the construction of sufficiently large and diverse reference datasets using first-principles calculations. To mitigate this, several active-learning strategies have been proposed to improve training efficiency, especially when combined with molecular-dynamics sampling. In this work, we develop protocols for building training sets of MACE potentials [1], targeting an accurate description of the vibrational properties of weakly-bound condensed-phase systems [2]. We assess the performance of MACE against the VASP-ML framework [3], highlighting differences in predictive accuracy for energies, forces, and vibrational properties. We also propagate committee-based uncertainties to estimate errors in dynamical quantities coming from imperfect force predictions. Finally, we demonstrate the generalisation capability of the acene-based potential by applying it to host-guest systems, enabling the identification of distinct vibrational modes within the complex dynamical spectra. [1] I. Batatia et. al., Nat Mach Intell 7, 56-67 (2025); [2] B. Gurlek, S. Sharma et. al., npj Comput Mater 11, 318 (2025); [3] R. Jinnouchi et. al., PRB 100, 014105 (2019).

DY 14.10 Mon 17:30 HÜL/S186

Spin-phonon systems in the age of modern atomistic simulations — •Ilija Srpak[1,2], Michael J. Willatt[2], Stuart C. Althorpe[1], and Ali Alavi[1,2] — [1]Yusuf Hamied Department of Chemistry, University of Cambrige, Cambridge, United Kingdom — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany

Spin-phonon systems are molecules or crystals containing open-shell atoms whose spin-spin interaction is significantly affected by lattice displacements, sometimes leading to spin-Peierls phase transition. They typically inherit some of the most challenging aspects of statistical physics where many configurations across the phase space may contribute to its properties, and of "strongly-correlated" physics where mean-field methods such as density functional theory and self-consistent field approaches break down.

Over the years a plethora of Monte Carlo based techniques was developed to tackle this problem with some success, but not without (sometimes significant) limitations. Approaching this problem from atomistic simulations background, we developed a path integral molecular dynamics framework which doesn't require any Monte Carlo during the simulation runtime to sample the phase space, it can take arbitrary system parametrizations or even ab-initio description and simulate the system at an arbitrary temperature as well as include nuclear quantum effect. Using neural networks we have developed this framework further. We achieved a speed up of 2-3 orders of magnitude and are able to treat higher dimensional systems.

DY 14.11 Mon 17:45 HÜL/S186

Self-Consistent Benchmarking of Machine Learning Force Fields via Energy-Landscape Exploration — •Anand Sharma[1,2], Igor Poltavskyi[1], and Alexandre Tkatchenko[1] — [1]Department of Physics and Materials Science, University of Luxembourg, Luxembourg — [2]Indian Institute of Science Education and Research Pune, India

The rapid growth of Machine Learning Force Field (MLFF) models has prompted the development of diverse benchmarks to assess their accuracy and transferability. Most existing approaches rely on predefined test datasets, introducing biases and limiting fair comparison between models.

We introduce a general, system- and model-agnostic benchmarking framework that evaluates MLFFs through self-generated datasets. For each model, molecular structures are obtained by sampling random initial configurations of atoms and relaxing them using the model's predicted forces. The resulting datasets are analyzed through (i) comparison with the model's original training data, (ii) validation against ab-initio reference calculations, and (iii) cross-model dataset comparison. Applied to the SO3LR [1] and MACE-MP-0 [2] models, our framework identifies gaps in their training set coverage and enables unbiased evaluation of models' predictive capabilities. Overall, our approach provides a consistent, extensible foundation for comparing and improving next-generation broadly applicable MLFFs.

[1] A. Kabylda, et. al, J. Am. Chem. Soc. 147, 33723 (2025).
[2] I. Batatia, et. al, J. Chem. Phys. 163, 184110 (2025).

DY 14.12 Mon 18:00 HÜL/S186

Solving Classical and Quantum spin glasses with Deep Boltzman Quantum States — Luca Leone[1], •Arka Dutta[1], Markus Heyl[1], Enrico Prati[2], and Pietro Torta[2] — [1]Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, Augsburg, Germany. — [2]Department of Physics, University of Milan, Milan, Italy.

Variational neural network models achieved remarkable success in preparing the ground state of quantum many-body systems. However, addressing classical and quantum spin glasses remains challenging, as exponential growth of deep local energy minima due to disorder and energy frustration hinder conventional Monte Carlo methods. To bridge this gap, we introduce Deep Boltzmann Quantum States, a class of neural quantum states inspired by deep Boltzmann machines, trained by devising Neural Quantum Annealing, an algorithm incorporating the principles of quantum annealing. It solves large-scale classical and quantum spin glasses, matching the exact solution or the best available estimate for several instances of Ising spin-glass models with infinite-range interactions and hundreds of spins.

DY 14.13 Mon 18:15 HÜL/S186

Optimization and Representability of time-dependent Neural Quantum States: a study of the 1D critical quantum Ising model — •Wladislaw Krinitsin[1,2], Mohammad Abedi[1,2], Jonas Rigo[2], and Markus Schmitt[1,2] — [1]PGI-8, Forschungszentrum Jülich, Jülich, Germany — [2]Faculty for Informatics and Data Science, Regensburg University, Germany

In recent years, neural quantum states have emerged as a competitive and powerful numerical approach for many body systems. While they provide a flexible and scalable ansatz, able to represent any state as suggested by the function-approximation theorem, their practical limitations are still opaque, in particular regarding representability and optimization. In this work we investigate these questions within the framework of variational Monte Carlo on the example of the time evolution of the critical transverse-field Ising model in one dimension. Even for moderate system sizes, the departure from the exact solution occurs very early in the dynamics, allowing us to systematically analyze the representability of the state at each time step as well as the impact of different sampling strategies.

DY 15: Focus Session: Large Deviations and Rare Events II

The modeling and understanding of large deviations and rare events is of crucial importance in a wide range of real-world applications, including climate science, actuarial statistics (insurance statistics), natural disaster management, or the description of financial markets. At the same time, such effects are fundamental for the understanding of many systems in condensed-matter physics. In first-order phase transitions, for instance, the coexisting phases are connected by transition states involving droplet excitations whose probability is suppressed by dozens or hundreds of orders of magnitude as compared to the pure-phase peaks. Likewise, for many disordered systems the behavior of typical cases is incompatible with that of the average sample as the problem is described by very broad, heavy-tailed distributions, where averages are dominated by rare events. For many models, like the Kadar-Parisi-Zhang equation or random-graph properties, there has been considerable analytical progress in the last decade. Likewise, new or improved numerical techniques have been proposed that now allow for the treatment of previously inaccessible problems or regimes. This focus session is devoted to an update on the state of the art in this rapidly evolving area.

Organized by Alexander K. Hartmann (Oldenburg) and Martin Weigel (Chemnitz)

Time: Monday 15:00–18:30 Location: ZEU/0114

Invited Talk DY 15.1 Mon 15:00 ZEU/0114

Monte Carlo Simulation Methods for Rare-Event Sampling — •Wolfhard Janke — Institut für Theoretische Physik, Universität Leipzig, IPF 231101, 04081 Leipzig, Germany

Large fluctuations and rare events play an important role in many physical systems, with nucleation phenomena, first-order phase transitions and frustrated (disordered) systems being only the most prominent examples. To cope with such processes in Monte Carlo computer simulations, several generalized-ensemble approaches such as parallel and simulated tempering and "flat-histogram" methods have been devised and further improved over the years. After a brief overview of the basic ideas of multicanonical (MuCa), Wang-Landau (WL), and Stochastic Appxoximation Monte Carlo (SAMC) schemes, the talk will focus on more recently proposed "non-flat" variants that put even more emphasis on strongly suppressed rare events, and alternative formulations based on the (real) microcanonical ensemble. As illustrations, performance tests and results will be shown for spin glasses, first-order phase transitions in the q-state Potts and Blume-Capel model, Lennard-Jones particle and polymer clusters, and the density of states of O(n) spin models on triangular and hypercubic lattices spanning many hundreds orders of magnitude.

DY 15.2 Mon 15:30 ZEU/0114

Sampling rare events with neural networks — Moritz Riedel[1], Johannes Zierenberg[2], and •Martin Weigel[1] — [1]Institut für Physik, 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, and we also propose hybrid algorithms combining the neural network approach with traditional Monte Carlo techniques.

DY 15.3 Mon 15:45 ZEU/0114

Large deviation simulation of the coupling time of an Ising ferromagnet — •Mathis Groenhagen[1], Peter Werner[2], and Alexander K. Hartmann[1] — [1]Institut für Physik, Carl von Ossietzky Universität Oldenburg — [2]Laboratoire de Météorologie Dynamique - ENS, Paris

Coupling from the past, introduced by Propp and Wilson [1], is a Markov-chain Monte Carlo (MCMC) method capable of generating perfectly independent samples from a finite set of states, following exactly a given distribution. The performance of this algorithm for a given model can be characterized by it's *coupling time* τ_c, which measures the time to perfect statistical independence and depends on the used random numbers.

The algorithm is tested for one and two-dimensional Ising models without external field with the single-spin-update heat-bath algorithm. In order to access the distribution $p(\tau_c)$ over a wide range of the support down to densities as small as 10^{-200}, a large-deviation MCMC algorithm is used. With this, we have obtained $p(\tau_c)$ for different lattice dimensions D, edge lengths L and heat-bath temperatures T.

In particular, we observe a change of the shape of $p(\tau_c)$ at T_c for $D = 2$. For the paramagnetic case of $D = 2$ and $D = 1$, $p(\tau_c)$ follows a Gumbel distribution as predicted for the thermodynamic limit [2]. We have studied the dependency of the distribution parameters on T and L.

[1] J. Propp, D. Willson, Random Struct. Algoritms **9**, 223-252 (1996).
[2] A. Collevechio et al., J. Stat. Phys. **170**, 22-61 (2018).

DY 15.4 Mon 16:00 ZEU/0114

Large deviations in response functions of the two-dimensional bond-diluted Ising model — •Lambert Münster[1], Alexander K. Hartmann[2], and Martin Weigel[1] — [1]Institut für Physik, TU Chemnitz, 09107 Chemnitz, Germany — [2]Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26129 Oldenburg, Germany

Studies in statistical physics are most commonly focused on the typical, average behavior of a system. However, there exist cases in which rare events can have a significant impact on physical properties. The Griffiths phase in systems with quenched disorder is one such example. In this case rare regions in the disorder degrees of freedom cause large tails in response functions of physical observables such as the magnetic susceptibility and the specific heat. In this study rare-region effects are investigated by analyzing the distributions of physical observables in the bond-diluted Ising model. In order to obtain these distributions over a wide range of their support, a special type of Markov chain Monte Carlo algorithm is utilized for sampling rare events [1].

[1] L. Münster, A. K. Hartmann and M. Weigel, Phys. Rev. E **110**, 054112 (2024).

DY 15.5 Mon 16:15 ZEU/0114

Universality of the order-parameter large-deviation function for the critical 2D Ising and Blume-Capel models — Nikolaos G. Fytas[1], Víctor Martín-Mayor[2], Attilio L. Stella[3], Gianluca Teza[4], Alexandros Vasilopoulos[1], and •David Yllanes[5] — [1]University of Essex — [2]Universidad Complutense de Madrid — [3]Università di Padova — [4]MPIPKS, Dresden — [5]Universidad de Zaragoza

We revisit the longstanding question of universality in the probability density function (pdf) of the order parameter at criticality, traditionally assumed to hold only for the central region of the distribution. Focusing on the dimensionless magnetization $u = m/\sqrt{\langle m^2 \rangle}$, whose moments are universally defined in the thermodynamic limit, we hypothesize that universality extends to the full pdf $p_L(u)$, including its exponentially suppressed large-deviation tails scaling as $u^{1+\delta}$. We test this conjecture with large-scale Tethered Monte Carlo simulations

of the 2D Blume-Capel model at criticality for several values of the crystal field Δ, including the Ising limit ($\Delta = -\infty$) and approaching the tricritical point $\Delta_c \approx 1.97$. We simulate lattices up to $L = 4096$ with a tethered cluster algorithm, reaching the asymptotic regime for probability densities as small as 10^{-200}. Our results are strong numerical evidence for universality in the full $p_L(u)$ and settle the debated non-universality of the large-deviation function for m, where system-dependent amplitudes obscure scaling behavior. We consider the universality of the unusual combination of a finite-size amplitude with an amplitude for a scaling law related to the large-deviation function.

DY 15.6 Mon 16:30 ZEU/0114

Ising Model under Stochastic Resetting — •Shashank Kallappara[1], Parbati Saha[2], Varsha Banerjee[2], and Martin Weigel[1] — [1]Institut für Physik, TU Chemnitz, Germany — [2]Department of Physics, Indian Institute of Technology Delhi, India

Stochastic resetting refers to the interruption of a system's natural evolution by randomly returning it to a prescribed initial configuration. In this work, we investigate the effect of stochastic resetting on the Ising model and extend the results of Ref. [1] by examining how the resetting protocol modifies energetic properties of the system. In particular, we analyse the behaviour of the energy under different resetting rates and initial magnetisations. Furthermore, we study the impact of resetting in the case of conserved-order-parameter Ising model using Kawasaki dynamics, revealing qualitatively distinct behaviour compared to the nonconserved Glauber dynamics.

[1] Magoni, M., Majumdar, S. N. & Schehr, G. Ising model with stochastic resetting. Phys. Rev. Research 2, 033182 (2020).

15 min. break

DY 15.7 Mon 17:00 ZEU/0114

Classical nucleation theory for active non-conserved scalar field theories — •Michalis Chatzittofi[1], Noah Ziethen[1], Cesare Nardini[2], and Michael Cates[1] — [1]DAMTP, Centre for Mathematical Sciences, University of Cambridge, Cambridge CB3 0WA, United Kingdom — [2]Service de Physique de l' Etat Condense, CNRS UMR 3680, CEA-Saclay, 91191 Gif-sur-Yvette, France

Classical nucleation theory (CNT) has been successfully used in equilibrium conserved theories to explain the behaviour of growing droplets. However, in non-equilibrium field theories such description is more challenging since the dynamics cannot be derived from a free-energy. In this work, we show that it is possible to generalize CNT for the case of out-of-equilibrium non-conserved field theories. By projecting onto the slow manifold of the dynamics, we propose a systematic recipe for deriving an exact analytical expression for the dynamics of the growing nucleus and the corresponding quasipotential. Our findings allow for analytical progress in the context of large deviations and can compliment numerical/machine learning approaches for finding instanton trajectories.

DY 15.8 Mon 17:15 ZEU/0114

Precise large deviations in statistical field theories with weak noise — •Timo Schorlepp[1], Tobias Grafke[2], Rainer Grauer[3], Georg Stadler[1], and Shanyin Tong[4] — [1]NYU Courant, USA — [2]Warwick, UK — [3]Bochum, Germany — [4]UPenn, USA

Large deviation theory (LDT) provides a common theoretical framework to compute probabilities of rare events in stochastic systems out of equilibrium. The theory consists of a saddlepoint evaluation of the path integral describing the stochastic process under study, and has successfully been used in various systems such as growing interfaces, active matter, lattice gases and macroscopic fluctuation theory, fluid dynamics and turbulence, etc. I will describe recent progress in going beyond leading-order LDT asymptotics, developing tractable methods to evaluate 1-loop (Gaussian) corrections around nontrivial LDT minimizers for weak noise Langevin equations and field theories. This allows for quantitative rare event probability estimates, beyond the usual log-asymptotics. To compute the corresponding LDT prefactors, I will present two complementary approaches based on either matrix Riccati differential equations, or (possibly renormalized) Fredholm determinants. I will illustrate these methods in multiple analytical/numerical examples: extreme growth events in the 1d KPZ equation at short times [1], extreme concentrations of a randomly advected passive scalar [2], and extreme strain events in the stochastically forced incompressible 3d Navier-Stokes equations [3]. References: [1] Schorlepp, Grafke, Grauer, J Stat Phys, 2023; [2] Schorlepp, Grafke, arXiv:2502.20114, 2025; [3] Schorlepp, Tong, Grafke, Stadler, Stat. Comput., 2023.

DY 15.9 Mon 17:30 ZEU/0114

Probability graphons and large deviations for random weighted graphs — •Giulio Zucal — Max Planck Institute of Molecular Cell Biology and Genetics, Dresden, Germany — Max Planck Institute for Physics of Complex Systems, Dresden, Germany — Center for Systems Biology Dresden, Dresden, Germany

Graph limit theory studies the convergence of sequences of graphs as the number of vertices grows, providing an effective framework for representing large networks. In this talk, I will give a brief introduction to graph limits and report on recent extensions to weighted graphs and multiplex networks (probability graphons and P-variables). As an application of this theory I will present a large deviation principle (LDP) for random weighted graphs that generalizes the LDP for Erdős–Rényi random graphs by Chatterjee and Varadhan (2011), based on joint work with Pierfrancesco Dionigi.

DY 15.10 Mon 17:45 ZEU/0114

Extreme Value Analysis for Finite, Multivariate and Correlated Systems with Finance as an Example — •Benjamin Köhler, Anton J Heckens, and Thomas Guhr — Universität Duisburg-Essen, Germany

Extreme values and the tail behaviour of probability distributions are essential for quantifying and mitigating risk in complex environmental and socio-economic systems. In multivariate settings, accounting for correlations is crucial. Although extreme value analysis for truly infinite correlated systems remains an open challenge, we propose a practical framework for handling a large but finite number of time series.

We study the extremal behavior of high-frequency stock returns after rotating them into the eigenbasis of the correlation matrix. This separates information on the market as a whole and on sectoral behavior while allowing us to use univariate tools of extreme value analysis, even for high-frequency data where discretization effects normally complicate analysis.

Using a Peaks–over–threshold approach, we estimate the tail shape of the rotated returns while explicitly accounting for non-stationarity, a key feature in finance and many other complex systems. Our framework allows for tail risk estimation relative to larger trends and intraday seasonalities at both market and sectoral levels.

DY 15.11 Mon 18:00 ZEU/0114

On the Reconstruction and Predictability of Ocean Rogue Waves — Christian Behnken, Finn Köhne, Metthias Wächter, and •Joachim Peinke — Institute of Physics, University Oldenburg, Oldenburg

We present a data-driven algorithm which allows to reconstruct rogue wave events from surface elevation measurements of ocean gravity waves. In particular we extract from the data stochastic equations for joint multipoint statistics [1]. Our procedure is applied to measurements from the Sea of Japan and the German North Sea over several days. The estimated stochastic equations allow to generate large ensembles of realistic wave time series to investigate the predictability of rogue waves. Furthermore we use the large deviation algorithm "Trajectory-Adaptive Multilevel Sampling" [2] to predict up to now unkown extreme wave events. While the North Sea equations do not lead to Rogue Waves, we do find those for the Sea of Japan. Averaging over several similar rogue waves, we obtain well-known rogue wave patterns like the "three sisters", proposed by from nonlinear-wave equations. i.e. nonlinear Schrödinger equation [3].

[1] Hadjihoseini, A.; et al: EPL (Europhysics Letters) 120 (2017), Nr. 3, 30008

[2] Lestang, T.; et.al Journal of Statistical Mechanics: Theory and Experiment 2018 (2018), Nr. 4, S. 043213

[3] Akhmediev, N.; et al: Physics Letters A 373 (2009), Nr. 6, S. 675–678

DY 15.12 Mon 18:15 ZEU/0114

Forecasting Extreme Events in Atmospheric Turbulence — •Finn Köhne and Joachim Peinke — Institute of Physics and ForWind, University of Oldenburg, Küpkersweg 70, D-26129 Oldenburg, Germany

Extreme wind speed fluctuations on time scales of seconds to minutes generate potentially significant mechanical loads for example on wind turbines and may lead to strong fluctuations in the power output [1,2].

Reliable short-term forecasts of such turbulent events are therefore of high relevance for many applications.

In this contribution, we use a stochastic framework based on the Fokker-Planck-equation (FPE) to forecast wind speed fluctuations in the atmospheric turbulence. We estimate drift and diffusion from measurement data to derive FPEs that describe the probabilistic evolution of wind speed increments without requiring data normalization [3].

The resulting model is used to perform probabilistic forecasts for extreme wind speed fluctuations. The quality of the forecast is quantified using receiver operating characteristic curves. The results demonstrate that the Fokker-Planck-based approach provides reliable short-term predictions of extreme events in the atmospheric turbulence.

[1] Davenport, A. G.; Proc. Inst. Civ. Eng. 19 (1961), Nr. 4, S. 449-472.

[2] DeMarco, A.; Basu, S.; Wind Energy 21 (2018), Nr. 10, S. 892-905.

[3] Peinke, J.; Tabar, M. R. R.; Wächter, M.; Annu. Rev. Condens. Matter Phys. 10 (2019), S. 107-132.

DY 16: Droplets, Wetting, and Microfluidics (joint session DY/CPP)

Time: Monday 15:00–18:30 Location: ZEU/0118

DY 16.1 Mon 15:00 ZEU/0118

Rayleigh instability in the presence of elastocapillarity — •Niphredil Klint and Andreas Isacsson — Chalmers University of Technology, Gothenburg, Sweden

A liquid jet, such as a stream of water, will disintegrate and form droplets if the length-to-radius ratio exceeds a critical value. This occurs due to propagating surface instabilities, a phenomenon known classically as the Rayleigh instability. At the nanoscale, thermal fluctuations affect the breakup dynamics, which may enter a stochastic regime [1]. Placing an elongated nanoscale liquid drop with a high aspect ratio on top of a highly compliant surface, the breakup process is affected by additional noise from thermally excited flexural phonons [2] as well as effects whereby the wetting causes the underlying surface to deform. We use large scale molecular dynamics (MD) simulations to examine the dynamics of the Rayleigh instability in the presence of elastocapillary effects at ambient temperatures. Specifically, we study the interactions between water and suspended graphene, where wetting induced deformations may occur for nanoscale droplets [3]. We focus on characterising the breakup and instability wavelength and isolate the effects of introducing graphene through a comparison of these results to simulations of only water. We also identify the correlation between out-of-plane fluctuations of the graphene and the concentration of water.

[1] J. Eggers, Phys. Rev. Lett. 89, 084502 (2002).
[2] M. Ma et al., Nature Mater. 15, 66 (2016).
[3] M. Kateb et al, Langmuir 39, 12610 (2023).

DY 16.2 Mon 15:15 ZEU/0118

Air layers and wetting under drops impacting on pre-wetted surfaces — •Kirsten Harth and Shiva Moradimehr — Fachbereich Technik, Technische Hochschule Brandenburg, Germany

Drop impact at low Weber numbers causes the formation of a (temporary) air cushion between the drop liquid and the substrate. On hard, dry substrates, its qualitative thickness profile and the location of the thinnest point are strongly governed by the Weber number. For impact on bulk, soft surfaces, like PDMS gels, it was found that impacts on softer substrates entrap more air [1]. Are there similar effects of thin liquid films?

We address the air layer shapes, entrapped air volume and wetting underneath droplets impacting on a hard substrate pre-wetted by microscopic oil layers. We control the Weber number, the oil layer thickness (in the range of micrometers), the oil viscosity, and in that way the *softness* of the substrate. Despite the thinness of the film, we observe clear effects of the oil layer on the volume and drainage of the air entrapment, its profile shapes, and the wetting behavior.

[1] K.R. Langley et al., Soft Matter 16, 5702 (2020)

We acknowledge funding by DFG within SPP2171 (HA8467/2-1, 2-2).

DY 16.3 Mon 15:30 ZEU/0118

Memory Effects in Contact Line Friction — •Niklas Wolf and Nico van der Vegt — TU Darmstadt, Darmstadt, Germany

When a drop of liquid comes into contact with a solid surface, it relaxes towards an equilibrium configuration, either wetting the surface or remaining in a droplet-like shape with a finite contact angle. The speed of this relaxation strongly depends on a friction force opposing the movement of the three-phase contact line. In analogy to the treatment of hydrodynamic friction we present an exact method, based on the Mori-Zwanzig formalism, to extract this friction from equilibrium data. Within the linear response regime, we obtain the frequency-dependent dissipative and elastic response of the contact line to an external perturbation, including a frequency-dependent friction coefficient. We find that the contact line exhibits long-lasting memory with a power-law decay due to coupling to the systems hydrodynamic modes. As a result the microscopic contact line dynamics are neither Markovian nor determined by the movement of a few molecules in the vicinity of the contact line.

DY 16.4 Mon 15:45 ZEU/0118

Reaction-Mediated Arrest and Gradient-Driven Droplet Transport — •Stefan Köstler[1,2], Yicheng Qiang[1], Malcolm Steen[1,2], Guido Kusters[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

Controlling droplet size and position is central to many biological and engineering processes. Chemical reactions can arrest coarsening and sustain spatial concentration gradients, while hydrodynamic flows generally accelerate coarsening and drive droplets along chemical gradients. Using continuum theory, we show that the competition between reactions, diffusion, and hydrodynamic advection yields rich behavior even in binary systems: Advection dominates the coalescence of small droplets, diffusion leads to Ostwald ripening for intermediate sizes, and reactions finally suppress coarsening. Interestingly, a range of droplet sizes is stable, depending on initial conditions and the strength of advection. Crucially, chemical gradients can actively steer droplets and couple to size-control. Our results demonstrate practical routes to control both the size distribution and spatial organization of droplets by tuning chemical activity and gradient-driven flows.

DY 16.5 Mon 16:00 ZEU/0118

From bipedal to chaotic motion of chemically fueled partially wetting liquid drops — •Florian Voss[1] and Uwe Thiele[1,2] — [1]Institute of Theoretical Physics, University of Münster — [2]Center for Data Science and Complexity (CDSC), University of Münster

Chemomechanical coupling is essential to various phenomena in soft matter systems that are kept permanently out of thermodynamic equilibrium, e.g., in reactive complex liquids. Based on a thermodynamically consistent continuum model, we demonstrate that partially wetting liquid drops covered by chemically reacting surfactants display a variety of biomimetic motility modes like shuttling, bipedal, rotational and quasi-random motion when supplied with chemical fuel from an ambient bath. The dynamics originates from chemomechanical feedback between the reaction network on the drop and the Marangoni effect [1] and becomes increasingly complex as a result of competing length scales. Due to the generic underlying thermodynamic structure, we expect that our results are also relevant for other chemically active mixtures and soft matter systems.

[1] F. Voss and U. Thiele, Phys. Rev. Fluids 10, 94005 (2025).

DY 16.6 Mon 16:15 ZEU/0118

Odd Droplets — •Thomas Appleford — University of Amsterdam, Amsterdam, Netherlands

In chiral systems such as active spinning colloidal matter, time-reversal symmetry-breaking interactions often give rise to a macroscopic continuum description in which the stress tensor contains off-diagonal terms. In fluids, these off-diagonal components lead to so-called "odd-viscous" deformations, in which energy is not dissipated. Odd viscous fluids have been shown to exhibit a rich variety of phenomena, including symmetry-broken flow around translating droplets and asymmetric

droplet spreading on superhydrophobic surfaces. Our work investigates the behaviour of droplets in suspension. In particular, we present an analytical solution to the droplet-in-shear problem within the framework of two-dimensional odd Stokes flow, followed by the derivation of a formula for the apparent viscosity of a dilute emulsion. We then explore how chirality can be parametrically varied to tune the bulk rheological properties and control the system's overall energy dissipation.

DY 16.7 Mon 16:30 ZEU/0118

Stretching and Sliding Capillary Bridges — •Lennard Holschuh and Lars Pastewka — University of Freiburg, Department of Microsystems Engineering

Capillary forces play a critical role in the adhesion between two contacting bodies. However, existing theories of macroscopic adhesion on rough surfaces often assume dry conditions, attributing adhesive interactions solely to dispersion forces and overlooking the effects of capillary bridge formation. This study employs molecular dynamics simulations to directly examine the interactions of nanoscale probes with nominally flat surfaces in the presence of liquid bridges, which form due to condensation in humid environments. The objective is to link the thermodynamic understanding of capillary bridges with molecular simulations and atomic-force microscopy experiments. These calculations focus on investigating energy dissipation during adhesion (normal separation of the probe from the surface) and friction (lateral motion of the probe). By quantifying the interplay between relative humidity, adhesion, and friction, this work aims to improve the understanding of macroscopic adhesion in humid conditions and guide the development of materials with tailored properties for high-precision applications, such as microelectronic manufacturing.

15 min. break

DY 16.8 Mon 17:00 ZEU/0118

Hyperuniformity in Ternary Fluid Mixtures: The Role of Wetting and Hydrodynamics — •Nadia Bihari Padhan and Axel Voigt — Institute of Scientific Computing, TU Dresden, 01069 Dresden, Germany

Phase separation in multicomponent fluids underlies the organization of complex materials and biological structures, including biomolecular condensates. The Cahn-Hilliard-Navier-Stokes (CHNS) framework provides a natural description of such systems by coupling diffusive and hydrodynamic processes. In this talk, I will present our study of hyperuniformity–suppressed large-scale density fluctuations–in ternary CHNS mixtures. We show that hydrodynamics systematically drives the system toward less hyperuniform states and generates a rich set of morphologies, such as interconnected droplets and double emulsions reminiscent of biological phase separation. In partial-wetting regimes, all three components display comparable hyperuniformity, whereas in complete-wetting regimes the preferred wetting component exhibits a marked loss of hyperuniformity. These results identify wetting asymmetry as a key control parameter for spatial order in multiphase fluids and offer a pathway for tuning large-scale organization in soft-matter and biological systems.

References [1] Boyer, F. and Lapuerta, C., Study of a three component Cahn-Hilliard flow model, ESAIM: Mathematical Modelling and Numerical Analysis, 40, 653-687 (2006). [2] Padhan, Nadia Bihari and Voigt, Axel, Hyperuniformity in ternary fluid mixtures: the role of wetting and hydrodynamics, arXiv:2506.22647, (2025).

DY 16.9 Mon 17:15 ZEU/0118

Effect of Flow Coupling on Defect Binding and Unbinding in Nematic Fluids — •Jayeeta Chattopadhyay, Simon Guldager Andersen, Kristian Thijssen, and Amin Doostmohammadi — Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, Copenhagen, Denmark.

Topological defects play a central role in the ordering and dynamics of nematic fluids. We investigate how coupling to fluid flow modifies defect-mediated phase transitions in two-dimensional nematics using fluctuating nematohydrodynamic simulations. The system is driven by tuning the fluctuation strength, with increasing and decreasing fluctuations defining forward and backward protocols. Without flow coupling, the system undergoes a Berezinskii–Kosterlitz–Thouless (BKT)–like transition via the reversible binding and unbinding of $\pm 1/2$ defect pairs. When hydrodynamics is included, the transition depends on the flow–alignment parameter: non-aligning nematics ($\lambda = 0$) retain BKT-like behavior, whereas strain-rate–aligning nematics ($\lambda \neq 0$) form bend–splay walls, lowering the defect-creation threshold and preventing recombination, leaving defects unbound across all fluctuation strengths. In active nematics, defects remain unbound for all λ, showing that self-generated flows also inhibit bound-pair formation. These results demonstrate that coupling to fluid flow fundamentally alters topological phase behavior, suppressing the equilibrium BKT binding mechanism.

DY 16.10 Mon 17:30 ZEU/0118

Electrophoresis in charged chiral active fluids with odd viscosity — •Reinier van Buel, Bogdan Cichocki, and Jeffrey Everts — Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland

Understanding the motion of colloidal particles dissolved in fluids that exhibit odd viscosity – a specific component of the viscous stress tensor found in e.g. chiral active fluids – is of particular interest for realising nontrivial particle transport and characterising out-of-equilibrium thermodynamic properties. Although three-dimensional odd viscosity has not yet been experimentally observed, charge stabilisation is expected to be vital in enabling such measurements. Therefore, we introduce the notion of a charged chiral active fluid and we investigate some of its non-trivial electrokinetic properties. In particular, we focus on electrophoresis of a charged sphere suspended in such an odd viscous fluid. Here, the peculiar nature of odd viscosity breaks the spherical symmetry of the system, and through coupling with the electric double layer and its screening properties, alters the electrophoretic mobility. Using the Lorentz reciprocal theorem, we derive expressions for the electrophoretic mobility of a spherical particle based on the analytical solution for the uncharged flow. Furthermore, we highlight how the Hückel and Smoluchowski limits of the electrophoretic mobility are affected by odd viscosity. Our results demonstrate that odd viscosity leads to directional asymmetries in the electrophoretic mobility tensor, suggesting mechanisms for active control of charged colloidal motion in systems where odd viscosity is prevalent.

DY 16.11 Mon 17:45 ZEU/0118

Experimentally probing microscale torsional memory in a viscoelastic fluid — •Niloyendu Roy[1], Rupayan Saha[2], Debankur Das[2], Matthias Krüger[2], and Clemens Bechinger[1] — [1]Fachbereich Physik, Universität Konstanz, Konstanz, Germany — [2]Institut für Theoretische Physik, Universität Göttingen, Göttingen, Germany

Motion of a colloid inside viscoelastic fluids follows non-Markovian dynamics, meaning its trajectory is influenced by past motion. Such memory effects are typically attributed to intrinsic material timescales arising from relaxation of the fluid microstructure and are usually probed using translationally driven colloids. Here we show experimentally that rotational driving of a colloid by a controlled torque elicits a far richer form of memory: the relaxation of the resulting torsional stresses spans a broad distribution of timescales, even though the fluid itself possesses a single dominant relaxation time. This behaviour allows time-dependent torsional driving histories to be encoded and subsequently read out through characteristic non-monotonic recoil responses. By mapping the flow field and the spatial distribution of torsional stresses, we demonstrate that the geometry of rotation generates an orthogonality between the propagation of angular momentum and the storage of torsional stresses, producing a spatio-temporal memory field not accessible through translational forcing. These results establish torsional driving as a powerful route to generate, store, and retrieve memory in viscoelastic fluids, opening new possibilities for soft-matter information storage and torque-responsive microdevices.

DY 16.12 Mon 18:00 ZEU/0118

3D Optofluidic Control Using Reconfigurable Thermal Barriers — •Falko Schmidt[1,2], Carlos David Gonzalez[3], Marc Sulliger[1], Emilio Ruiz-Rena[4], Raul A. Rica[3,5], Jaime Ortega-Arroyo[1], and Romain Quidant[1] — [1]Department of Mechanical and Process Engineering, ETH Zurich, Zurich 8092, Switzerland — [2]Peter Debye Insitute for Soft Matter Physics, Leipzig University, 04103 Leipzig, Germany — [3]Universidad de Granada, Department of Applied Physics, Granada 18071, Spain — [4]Department of Applied Physics II, University of Malaga, Malaga 29071, Spain — [5]Universidad de Granada, Research Unit Modeling Nature (MNAT), Granada 18071, Spain

Optothermal manipulation enables precise control of small particles via optical and thermal forces, leveraging thermo-osmotic and con-

vective flows for short- and long-range motion. We present a reconfigurable optofluidic method enabling diverse manipulations such as guiding, sorting, trapping, and separating particles. Using light absorption on plasmonic surfaces of gold nanorods, localized hot spots are generated, creating temperature-driven flows. A near-infrared laser spatially modulates temperature landscapes, monitored by 3D holographic microscopy and optical diffraction tomography. Single and double heat sources produce three-dimensional flow control. This creates an optofluidic barrier that redirects particles within a microfluidic chamber. This approach offers a versatile foundation for advancing microfluidic technologies, enabling applications in sorting, trapping, and adaptive system design.

DY 16.13 Mon 18:15 ZEU/0118

Dynamics and Ordering of Microdroplets in Marangoni Flow Field — •Akshay Kallikkunnath and Frank Cichos — Molecular Nanophotonics, Peter Debye Institute for Soft Matter Physics, Faculty of Physics and Earth System Sciences, Leipzig University, Linnéstraße 5, 04103 Leipzig, Germany

Collective organization and internal dynamics are intimately linked and emerge across biological scales, with ordered structures providing a framework within which individual constituents remain dynamically active. Here, we study a system of water-in-oil microdroplets containing heat-releasing particles that organize under thermally induced flows. A sub-kelvin temperature increase from the heated particle at the air-oil interface generates Marangoni circulation that advects the droplets. Interactions through the flow field lead to robust ordering, while internal particle dynamics reflect coupling between local thermal gradients and microscale hydrodynamics. This provides a controllable platform to probe self-organization and emergent order by generating flows driven by weak, localized thermal fields in a fully fluid-in-fluid environment.

DY 17: Active Matter II (joint session DY/BP/CPP)

Time: Monday 15:00–18:30 Location: ZEU/0160

DY 17.1 Mon 15:00 ZEU/0160

Field-controlled self-organization in an active spin system — Mintu Karmakar[1,2,3], •Matthieu Mangeat[4], Swarnajit Chatterjee[5,4], Heiko Rieger[4], and Raja Paul[3] — [1]WIUCAS, Beijing, China — [2]Universitat de Barcelona, Barcelona, Spain — [3]IACS, Kolkata, India — [4]Saarland University, Saarbrücken, Germany — [5]CY Cergy Paris Université, Cergy-Pontoise, France

We investigate the collective response of active Potts particles to an external magnetic field and uncover three striking nonequilibrium phenomena. We first examine how the flocking transition is reshaped for a homogeneous and unidirectional field: the coexistence regime between an apolar gas and a polar liquid is replaced by a phase separation between two polar-ordered phases, a low-density, weakly polarized background and a high-density, strongly polarized band, both moving along the field. Second, when the particles self-organize into a high-density longitudinal lane whose long axis is perpendicular to the field, the lane slowly treadmills against the field direction, driven by the weakly polarized background. Finally, we identify a field-induced interface pinning regime that arises when the domain is divided into two regions with opposite field directions, causing particles to accumulate and perform a back-and-forth motion at the interface. This pinning phenomenon also leads to the emergence of a disordered state in the presence of a random field orientation. A coarse-grained hydrodynamic theory supports and confirms the phenomena observed in our microscopic simulations.

DY 17.2 Mon 15:15 ZEU/0160

Nucleation kinetics in two-dimensional polar active fluids — •Yuta Kuroda and Thomas Speck — Institute for Theoretical Physics IV, University of Stuttgart, Germany

Polar active fluids constitute one of the most important classes of active matter. These systems possess alignment interactions that cause the local polarization to align with that of neighboring particles, leading to a flocking transition in which global polar order emerges. Extensive numerical and analytical studies have established that the flocking transition is discontinuous, and consequently, the phase diagram possesses a coexistence region in which propagating polar bands appear. Despite intensive studies on flocking transitions, the nucleation mechanism responsible for the formation of these bands remains poorly understood. In this work, we numerically investigate the nucleation kinetics of polar bands using a particle model, namely active Brownian particles with a Kuramoto-type alignment interaction, and we report the behavior of the nucleation rate over a wide range of parameters.

DY 17.3 Mon 15:30 ZEU/0160

Collision dynamics of active Brownian hard disks — •Jonas Buba — Soft Matter Theory Group, Theoretical Physics: Lab for Emergent Phenomena, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

Active matter systems, composed of self-driven agents, display emergent behaviors such as collective motion, clustering, and motility-induced phase separation (MIPS). To better understand the microscopic origin of MIPS, we study collisions of active Brownian hard disks within the framework of dynamical density functional theory (DDFT). The particle interactions are modeled using fundamental measure theory (FMT). Each particle is represented by a Gaussian density peak, which allows us to quantify the mean delay from collisions for different configurations. The post-collision density resulting from the simulation can be described by a convolution of the pre-collision density, enabeling the analysis of different contributions to the delay.

DY 17.4 Mon 15:45 ZEU/0160

Active Ornstein-Uhlenbeck Particles: A Stochastic Path Integral Approach — •Carsten Littek, Mike Brandt, and Falko Ziebert — Institut für Theoretische Physik, Universität Heidelberg, Germany

In a recent publication (arXiv:2509.26296) we have developed a path integral formulation of the stochastic dynamics of a single active Brownian particle (ABP), with or without a constant torque, confined by a harmonic trap. This approach is based on the particle's microscopic degrees of freedom and we have derived exact analytic time-dependent expressions for key observable quantities such as the mean position and mean square displacement without the necessity of solving the Fokker-Planck equation. Here we present the application of this approach to the dynamics of active Ornstein-Uhlenbeck particles (AOUP). In particular, we generalize our formulation to systems of many AOUPs interacting via a suitable two-particle potential and derive the statistical quantities relevant in the context of collective phenomena, such as motility-induced phase separation (MIPS).

DY 17.5 Mon 16:00 ZEU/0160

Self-alignment and chirality in dense active matter: from flocking to circling crystals — •Marco Musacchio[1], Alexander Antonov[1], Hartmut Löwen[1], and Lorenzo Caprini[2] — [1]Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany — [2]Physics Department, University of Rome La Sapienza, P.le Aldo Moro 5, IT-00185 Rome, Italy

Several experimental systems in active matter are characterized, at the single-particle level, by an effective torque that aligns particle orientation with their instantaneous velocity. This mechanism, known as self-alignment, appears in both biological and granular active systems. In dense active systems, a sufficiently strong self-alignment can suppress mips and drive the system from a clusterized flocking state to an homogeneous one, where all particles move collectively, with aligned velocities. This flocking transition is approached for a broad range of densities, even close to maximal packing, where the system is in a crystalline configuration. Specifically, in the crystal case, the flocking transition can be predicted analytically since the dynamics can be mapped onto a velocity-dependent Landau*Ginzburg free energy, revealing that this disorder*order transition is second order. The onset of chirality drives the system from collective flocking to a circling crystal phase, characterized by coherent circular motion of all the system. Further increasing chirality suppresses the global rotation, leading to a vortex-like structure in the velocity field. These findings are experimentally testable in systems governed by self-alignment and chirality.

DY 17.6 Mon 16:15 ZEU/0160

Number fluctuations distinguish different self-propelling dynamics — •Tristan Cerdin[1,2], Sophie Marbach[2], and Carine Douarche[1] — [1]Université Paris-Saclay, CNRS, FAST, 91405, Orsay, France — [2]CNRS, Sorbonne Université, Physicochimie des Electrolytes et Nanosystèmes Interfaciaux, F-75005 Paris, France

In nonequilibrium suspensions, static number fluctuations N in virtual observation boxes reveal remarkable structural properties, but the dynamic potential of $N(t)$ signals remains unexplored. Here, we develop a theory to learn the dynamical parameters of self-propelled particle models from $N(t)$ statistics.

Theoretical plots of the mean-squared number difference $\langle \Delta N^2(t) \rangle$ exhibit 3 scaling regimes in time corresponding to the 3 regimes of self-propelled particles: diffusive, advective and effectively diffusive again at long times. By expanding the theory in each of these regimes, we recover limiting laws for the number fluctuations, which can be used in practice to quantify self-propulsion properties.

Additionally, unlike traditional trajectory analysis, $N(t)$ statistics distinguish between models, by sensing subtle differences in reorientation dynamics that govern re-entrance events in boxes. This paves the way for quantifying advanced dynamic features in dense, out-of-equilibrium suspensions.

DY 17.7 Mon 16:30 ZEU/0160

Flocking transitions in dense mixtures of active self-aligning and passive particles — •Weizhen Tang[1], Amir Shee[2], Zhangang Han[1], Pawel Romanczuk[3,4], Yating Zheng[3,4], and Cristián Huepe[1,5,6] — [1]School of Systems Science, Beijing Normal University, Beijing, China — [2]Department of Physics, University of Vermont, USA — [3]Department of Biology, Humboldt Universität zu Berlin, Unter den Linden 6, Berlin, Germany — [4]Research Cluster of Excellence 'Science of Intelligence', Berlin, Germany — [5]Northwestern Institute on Complex Systems and ESAM, Northwestern University, Evanston, USA — [6]CHuepe Labs, 2713 West Augusta Blvd #1, Chicago, USA

We investigate the passivity-driven flocking transition in a dense mixture of self-aligning active particles and passive particles, using a minimal model of active polar disks. We show that anisotropic damping leads to a discontinuous flocking transition as a function of the fraction of passive components, whereas isotropic damping produces a smooth transition where the final ordered state can display sustained oscillations and remain trapped in a metastable state, depending on the exact spatial arrangement of the passive particles. We also explore in detail the emergence of metastable oscillatory ordered states and their relation to the spatial distribution of passive particles and interstitial voids. Our findings demonstrate that heterogeneous activity and mobility anisotropy can result in a rich variety of self-organized states in various biological systems, synthetic active materials, and robotic swarms.

15 min. break

Invited Talk DY 17.8 Mon 17:00 ZEU/0160

Topological transition in filamentous cyanobacteria: from motion to structure — •Marco Mazza — Loughborough University, Loughborough, UK

Many active systems are capable of forming intriguing patterns at scales significantly larger than the size of their individual constituents. Cyanobacteria are one of the most ancient and important phyla of organisms that has allowed the evolution of more complex life forms. Despite its importance, the role of motility on the pattern formation of their colonies is not understood. Here, we investigate the large- scale collective effects and rich dynamics of gliding filamentous cyanobacteria colonies, while still retaining information about the individual constituents' dynamics and their interactions. We investigate both the colony's transient and steady-state dynamics and find good agreement with experiments. We furthermore show that the Péclet number and aligning interaction strength govern the system's topological transition from an isotropic distribution to a state of large-scale reticulate patterns. Although the system is topologically non-trivial, the parallel and perpendicular pair correlation functions provide structural information about the colony, and thus can be used to extract information about the early stages of biofilm formation. Finally, we find that the effects of the filaments' length cannot be reduced to a system of interacting points. Our model proves to reproduce both cyanobacteria colonies and systems of biofilaments where curvature is transported by motility.

DY 17.9 Mon 17:30 ZEU/0160

Novel Phase Coexistence in a Multi-Species Vicsek Model — •Eloise Lardet[1], Letien Chen[1,2], and Thibault Bertrand[1] — [1]Imperial College London, UK — [2]University of Edinburgh, UK

A hallmark in natural systems, self-organization often stems from very simple interaction rules between individual agents. While single-species self-propelled particle (SPP) systems are well understood, the behavior of mixtures of self-propelled particles with general alignment interactions remains largely unexplored with a few scattered results hinting at the existence of a rich emergent phase behavior. Here, we first present a generalization of the two-species Vicsek model with reciprocal intra- and interspecies (anti-)alignment couplings, uncovering a rich phenomenology of emergent states. Notably, we show that rather than destroying polar order, anti-aligning interactions can promote phase separation and the emergence of global polar order. Secondly, we derive a kinetic theory for the system, finding good agreement between theoretical predictions and particle simulations. This includes a novel mechanism for microphase separation, as predicted by a Turing instability. We finally show that these coexistence patterns can be generalized to multi-species systems with cyclic alignment interactions.

DY 17.10 Mon 17:45 ZEU/0160

Flocking in weakly nonreciprocal mixtures — •Charlotte Myin — Max Planck Institute for Dynamics and Self-Organization (MPI-DS), 37077 Goettingen, Germany

We show that weakly nonreciprocal alignment leads to large-scale structure formation in flocking mixtures. By combining numerical simulations of a binary Vicsek model and the analysis of coarse-grained continuum equations, we demonstrate that nonreciprocity destabilizes the ordered phase formed by mutually aligning or anti-aligning species in a large part of the phase diagram. For aligning populations, this instability results in one species condensing in a single band that travels within a homogeneous liquid of the other species. When interactions are anti-aligning, both species self-assemble into polar clusters with large-scale chaotic dynamics. In both cases, the emergence of structures is accompanied by the demixing of the two species, despite the absence of repulsive interactions. Our theoretical analysis allows us to elucidate the origin of the instability, and show that it is generic to nonreciprocal flocks.

DY 17.11 Mon 18:00 ZEU/0160

Collective behavior in nonreciprocal multi-species Vicsek model with permutation symmetry — •Jae Dong Noh[1], Chul-Ung Woo[2], and Heiko Rieger[2] — [1]Department of Physics, University of Seoul, Seoul 02504, Korea — [2]Department of Theoretical Physics and Center for Biophysics, Saarland University, Saarbrücken, Germany

Nonreciprocal systems are typically built upon asymmetric roles among interacting agents, such as a pursuer-evader relationship. We propose a multi-species nonreciprocal active matter model that is invariant under permutations of the particle species. The nonreciprocal, yet symmetric, interactions emerge from a constant phase shift in the velocity alignment interactions, rather from an asymmetric coupling matrix. This system displays rich collective behaviors, including a species-mixed chiral phase with quasi-long-range polar order and a species-separated vortex cell phase. We present numerical evidence for these phases using particle-based Monte Carlo simulations and analytic evidence using continuum Boltzmann and hydrodynamic equations. Our work demonstrates that multi-species chiral fluids can be realized by a nonreciprocal but symmetric alignment interaction, where the rich collective behavior is a consequence of the interplay between nonreciprocity and permutation symmetry.

DY 17.12 Mon 18:15 ZEU/0160

Flocking with random non-reciprocal interactions — •Jiwon Choi[1], Jae Dong Noh[2], and Heiko Rieger[1] — [1]Department of Physics & Center for Biophysics, Saarland University, Campus E2 6, 66123 Saarbrücken, Germany — [2]Department of Physics, University of Seoul, Seoul, 02504, Korea

Flocking is ubiquitous in nature and emerges from alignment interactions among self-propelled agents. Two species that anti-align or interact non-reciprocally exhibit complex collective phenomena, ranging from parallel and anti-parallel flocking and run-and-chase behavior to chiral phases. Whether such behavior survives in the presence of

many species with random non-reciprocal interactions has remained unclear. As a first step, we study a continuous-time Vicsek-like model with fully random non-reciprocal interactions between particles. For infinite-range interactions, flocking emerges once the alignment bias becomes comparable to the non-reciprocal interactions, and deep inside this phase random non-reciprocity can still support slow global chiral and oscillating states. For short-range interactions, even without alignment bias, self-organized cliques form, where medium-sized clusters with predominantly aligning interactions remain stable over long times. We further investigate the robustness of clique formation and the coexistence phase under angular noise using a discrete-time Vicsek model with random non-reciprocal interactions. These results provide a basis for studying multi-species flocking with complex non-reciprocal interactions.

DY 18: Active Matter III (joint session BP/CPP/DY)

Time: Tuesday 9:30–12:45 Location: BAR/SCHÖ

DY 18.1 Tue 9:30 BAR/SCHÖ

inertia-driven re-entrant coil-Globule transition of active ring polymers — •Sunil P Singh[1], Roland G Winkler[2], Rakesh Palariya[1], and Arindam Panda[1] — [1]Indian Institute of Science Education and Research Bhopal, India — [2]Theoretical Physics of Living Matter, Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Germany

The role of inertia in the collective dynamics of active systems has been a subject of increasing interest in recent studies. The present study investigates the inertial effects on active agents. We present the conformational and dynamical characteristics of an active Brownian ring polymer using Langevin dynamics simulations. We show that a long active ring polymer shrinks into globular-like structures even in the absence of attractive interactions. This transition becomes sharper and the structures more compressed as the reduced moment of inertia of the monomers increases, particularly in the intermediate range of activity. We demonstrate that the ring polymer undergoes a coil-globule-coil transition, which is modulated by both activity and rotational inertia. The coil-to-globule transition is mapped in the inertial parameter space (J-M) using the radius of gyration. Additional physical quantities, including bond-bond correlations, scaling behavior in the compressed state, monomer contact probability, geometric distances, coordination number, and effective temperature, further elucidate the physical mechanism driving the collapse. Finally, we show that the effective diffusivity of the ring polymer increases with the reduced moment of inertia as $D_p \sim \sqrt{J}$.

DY 18.2 Tue 9:45 BAR/SCHÖ

Shape selectivity by complex buckling dynamics in poroelastic active gels — •Kinjal Dasbiswas[1], Subhaya Bose[1], Arnab Roy[1], Michael Vennettilli[1], and Anne Bernheim[2] — [1]University of California, Merced, USA — [2]Ben Gurion University, Israel

Shape change in animal cells is prototypically driven by active forces, generated by myosin molecular motors bound to the actin cytoskeleton. Inspired by experiments on disc-shaped extracts of crosslinked actomyosin gels, we aim to show how a family of 3D shapes can arise from buckling caused by non-uniform active stresses. Although synthesized with identical composition of actin, myosin and the crossliker fascin, these gels contract and buckle into different shapes depending on the initial aspect ratio of the disc: thinner gels tend to wrinkle, while thicker gels tend to form domes. By incorporating active stresses, actin alignment, and stress-dependent myosin binding kinetics into a 2D poroelastic gel model, we qualitatively capture trends in gel contraction dynamics observed from quantitative particle image velocimetry (PIV). Next, we carry out numeric simulations of a geometric elastic model for thin sheets to obtain 3D buckled shapes from the strain rates predicted by the poroelastic model. Our results show that the coupling of elasticity to solvent flow, motor binding and fiber alignment play an important role in shape changes in living matter. Our studies have implications for shape changes during tissue morphogenesis and cell migration.

DY 18.3 Tue 10:00 BAR/SCHÖ

The energy cost to build a spindle — •Dongliang Zhang[1], Xingbo Yang[4], Jan Brugués[2,1,3,4], and Frank Jülicher[1,3,4] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck Institute of Molecular Cell Biology and Genetics, Dresden, Germany — [3]Center for Systems Biology Dresden, Dresden, Germany — [4]Physics of Life, Cluster of Excellence, TU Dresden, Dresden, Germany

Spindle is a structure actively build from microtubules (MTs), and plays an important role for chromosome segregation during cell cycle. It's observed in experiments that the spindle size and shape depends on the cell level metabolic rate. In this work, we developed a minimal model that captures the active, energy-consuming processes such as MT turnover and active stress generation, which shows the energy cost for spindle mass maintenance and spindle-shape formation. We show that a spindle can be self-organized through these active processes. We aim to predict how the size and shape of the spindle depends on the energy input, and explain relative experimental phenomena, e.g. spindle shrinkage when the metabolism level is reduced.

DY 18.4 Tue 10:15 BAR/SCHÖ

Cytoskeletal oscillations drive large-scale flows and nuclear organization in early embryonic systems. — •Lara Koehler, Elissavet Sandaltzopoulou, and Jan Brugués — Physics Of Life, TU Dresden

Synchronization drives early embryonic development, enabling simultaneous cell divisions and the spatial organization of nuclei within the embryo. In organisms such as Xenopus, Drosophila, and zebrafish, mitotic waves coordinate cell cycles across distances that exceed diffusion limits, guided by a chemical oscillator. At the same time, global cytoplasmic flows in these syncytial tissues contribute to the large-scale self-organization of nuclei, yet the coupling between biochemical signaling and cytoskeletal mechanics that underlies these directed flows remains poorly understood. Here, we relax the geometric constraints of the embryo and investigate nuclear dynamics in Xenopus egg extracts and complementary simulations. We show that the periodic polymerization and depolymerization of microtubule asters are sufficient to generate robust large-scale directed flows, even though the asters are intrinsically isotropic. Furthermore, we demonstrate that cell division stabilizes short-range order in a global synchronized system. Together, these findings reveal a minimal physical mechanism by which cytoskeletal dynamics and biochemical oscillations jointly organize flows and patterns, with implications for understanding the emergent principles that shape early development across species.

DY 18.5 Tue 10:30 BAR/SCHÖ

Geometric control of cell migration in disordered porous media — •Laeschkir Würthner[1] and Frederik Graw[2] — [1]European Molecular Biology Laboratory, Heidelberg, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg and Universitätsklinikum Erlangen, Erlangen, Germany

Cell migration is a dynamic process that plays a central role in development, wound healing, and immune responses. Active cell movement is controlled by several biochemical and mechanical cues, including chemokine gradients and the mechanical properties of the extracellular matrix (ECM). Although the biochemical pathways underlying directed cell motion are increasingly well understood, the influence of the porous structure of the ECM on active cell motion remains largely unexplored. Using a combination of computational modeling and theory, we investigate how active cells move through 3D disordered porous environments. We show that cell migration in disordered porous media can be understood as a generalized random walk among "traps", with the effective diffusivity determined by the geometry of the microenvironment. A key implication of our work is that spatial heterogeneities in porosity effectively direct cell motion, revealing a guidance mechanism that we refer to as porotaxis. Overall, our work connects geometry with cell motility and underscores the microenvironment as a key regulator of cell migration.

DY 18.6 Tue 10:45 BAR/SCHÖ

Motility-induced mixing transition in exponentially growing multicellular spheroids — •Torben Sunkel[1,2], Lukas Hupe[1,2], and Philip Bittihn[1,2] — [1]MPI for Dynamics and Self-Organization,

Göttingen, Germany — [2]Institute for the Dynamics of Complex Systems, University of Göttingen, Germany

Growth drives cellular dynamics in various dense aggregates, but its effects on other relevant activities have only received limited attention. Here, we investigate the interplay of unconstrained growth, steric repulsion and motility in a minimal agent-based model of exponentially growing, three-dimensional spheroids. Our results reveal a diverging mixing time scale at a critical motility threshold, below which mixing of cells is completely suppressed. Above the threshold, large-scale mixing is enabled. Using an effective phenomenological model parameterized from full simulations, we identify two fundamental mechanisms governing this transition: On the cell scale, weak motility-induced active motion is locally suppressed by growth-induced steric repulsion, consistent with an Active Brownian Particle type description of single-cell dynamics. Beyond this, the expanding nature of the system inhibits global mixing purely geometrically by limiting the exploration range of diffusive cell motion. Both mechanisms naturally scale with the growth rate, highlighting the nature of the transition as an interplay between proliferation and motility. The results provide a baseline for identifying additional biological mechanisms in experiments and could be relevant for competition, heterogeneous tumor evolution and other manifestations of motile proliferating active matter.

15 min. break

DY 18.7 Tue 11:15 BAR/SCHÖ

Fluctuation-Response Theory of Non-Equilibrium Complex Fluids — •Ryota Takaki[1] and Frank Jülicher[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, TU Dresden, Dresden, Germany

Active soft materials such as cytoplasm and tissues are constantly driven by chemical reactions and often retain long-lived mechanical memory. In this work, we develop a generalized hydrodynamic framework applicable to non-equilibrium fluids with memory at finite wavevectors and frequencies. Our approach is based on exact correlation-function identities, leading to a fluctuation-response relation for steady states, including non-equilibrium. Applying the theory to chemically driven active fluids, we uncover Active Viscoelastic Memory, in which reaction cycles dynamically renormalize the viscous response and can generate negative storage moduli at finite frequency, absent in conventional viscoelastic materials. Our results provide a first-principles basis for modeling memory-dependent dynamics in a broad class of biological and synthetic active systems, and suggest concrete rheological signatures of chemical driving that can be tested experimentally.

DY 18.8 Tue 11:30 BAR/SCHÖ

Chemically Active Liquid Bridges Generate Repulsive Forces — •Noah Ziethen — DAMTP, University of Cambridge, UK

Intracellular droplets help organize cells by compartmentalizing biomolecules and mediating mechanical interactions. When such droplets bridge two structures, they generate capillary forces that depend on the surface properties and the separation between the structures. While the forces exerted by passive liquid bridges are well understood, the impact of active chemical reactions, ubiquitous in biological condensates, remains unclear.

Here, we investigate a single liquid bridge with continuous chemical turnover, in which the production and degradation of droplet material maintain a non-equilibrium steady state. In this active bridge, the reactions dynamically set the bridge radius, thereby controlling the force-distance relation. In striking contrast to passive systems, we find that activity can generate purely repulsive forces over a broad range of separations. These results show that chemical activity can qualitatively alter capillary forces generated by liquid bridges, suggesting a potential route for cells to actively regulate mechanical coupling via droplets.

DY 18.9 Tue 11:45 BAR/SCHÖ

Shared Laws of Pattern Formation in Reaction-Diffusion and Phase Separation — •Daniel Zhou[1] and Erwin Frey[1,2] — [1]Arnold Sommerfeld Center for Theoretical Physics — [2]Max Planck School Matter to Life

Many nonlinear field theories generate a strikingly similar repertoire of patterns: arrested coarsening, traveling waves, and spatiotemporal chaos appear both in phase-separating systems and in classical reaction-diffusion models. These descriptions have different physical origins, yet recent studies on Turing mixtures and foams in protein systems [1] and on chemotaxis-driven phase separation in cell populations [2] have already highlighted unexpected connections between these ostensibly different mechanisms, linking foam-like, phase-separating, and reaction-diffusion-type patterns. The present work revisits the relation between kinetic and phase-separating descriptions from a more general viewpoint. A unifying perspective is developed that places different modeling frameworks on comparable footing, identifies the conditions under which they yield effectively equivalent patterns, and suggests how stability criteria and design principles can be translated between them. This points toward a more systematic classification of pattern-forming dynamics that cuts across traditional divides between reaction-diffusion, chemotactic, and phase-separating systems.

[1] H. Weyer et. al, Deciphering the Interface Laws of Turing Mixtures and Foams, arXiv:2409.20070 (2024).

[2] H. Weyer et. al, Chemotaxis-Induced Phase Separation, Physical Review Letters 135, 208402 (2025).

DY 18.10 Tue 12:00 BAR/SCHÖ

Spatial self-organization of enzymes in complex reaction networks — •Vincent Ouazan-Reboul[1,2], Ramin Golestanian[2,3], and Jaime Agudo-Canalejo[2,4] — [1]LPTMS, CNRS, Université Paris-Sud, 91400, Orsay, France — [2]Max Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, D-37077, Göttingen, Germany — [3]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, OX1 3PU, Oxford, UK — [4]Department of Physics and Astronomy, University College London, WC1E 6BT, London, UK

Living systems contain intricate biochemical networks whose structure is closely related to their function and allows them to exhibit robust behavior in the presence of external stimuli. Such networks typically involve catalytic enzymes, which can have non-trivial transport properties, in particular chemotaxis-like directed motion along gradients of substrates and products. Here, we find that taking into account enzyme chemotaxis in models of catalyzed reaction networks can lead to their spatial self-organization in a process similar to biomolecular condensate formation. We develop a general theory for arbitrary reaction networks, and systematically study all closed unimolecular reaction networks involving up to six chemicals. Importantly, we find that network-wide propagation of concentration perturbations can be key to enabling self-organization, in a manner which is highly sensitive on the global network structure.

DY 18.11 Tue 12:15 BAR/SCHÖ

Spatial organisation of the cell's metabolic power plant via phase separation — •Kathrin S. Laxhuber[1,2] and Frank Jülicher[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck School Matter to Life

Cell metabolism is the power plant that fuels the active processes essential to life. Recent experimental results show that glycolytic enzymes, central to sugar metabolism, phase-separate to form foci under energetic stress and can localise to sites of demand. To understand this phenomenon, we build and study a minimal theoretical model. We show that droplet formation can act as a metabolic switch that enables the system to maintain energetic homeostasis at higher output power. Notably, the metabolic droplets that emerge from this switch can self-organise to colocalise with demand. We discuss the non-equilibrium features and spatial energetic profiles in this system.

DY 18.12 Tue 12:30 BAR/SCHÖ

Emergent interactions lead to collective frustration in robotic matter — •Onurcan Bektas[1,3], Adolfo Alsina[2,3], and Steffen Rulands[1,3] — [1]Arnold-Sommerfeld-Center for Theoretical Physics and Center for NanoSciences, Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 München, Germany — [2]GISC, Universidad Rey Juan Carlos, Tulipán, 28933, Móstoles, Spain — [3]Max-Planck-Institute for the Physics of Complex Systems, Noethnitzer Str. 38, 01187 Dresden, Germany

Current artificial intelligence systems show near-human-level capabilities when deployed in isolation. Systems with intelligent agents are deployed to perform tasks collectively. This raises the question of whether robotic matter, where many learning and intelligent agents interact, shows emergence of collective behaviour. And if so, what kind of phenomena would such systems exhibit? Here, we study a paradigmatic model for robotic matter: a system composed of a large collection of stochastic interacting particles where each particle is endowed with a deep neural network that optimizes its transitions based on the parti-

cles' environments. For a 1D model, robotic matter exhibits complex phenomena arising from emergent interactions, including transitions between long-lived learning regimes, the emergence of particle species, and frustration. We also find an abrupt, density-dependent change in the behaviour of particles. Using active matter theory, we show that this phenomenon is a reflection of a phase transition with signatures of criticality. Our model captures key phenomena observed in more complex forms of robotic systems.

DY 19: Franco-German Session on Granular Matter I

Granular media exhibit rich collective behavior arising from simple interactions such as friction, collisions, elasticity, and confinement. This session brings together experimental, numerical, and theoretical studies addressing key transitions in granular systems, including jamming, viscous-to-inertial regimes, clustering, gas cooling, and impact dynamics, highlighting the links between microscopic mechanisms and macroscopic responses.

Organized by Baptiste Darbois Texier (Paris) and Franco Antonio Tapia Uribe (Dresden)

Time: Tuesday 9:30–12:45 Location: HÜL/S186

Invited Talk DY 19.1 Tue 9:30 HÜL/S186

Mechanics of entangled fibers — •Olivier Pouliquen[1], Aubin Archambault[1], Ignacio Andrade[2], Jerome Crassous[3], Henri Lhuissier[1], and Joël Marthelot[1] — [1]IUSTI, CNRS-Aix Marseille University, Marseille, France — [2]Departamento de Física, Universidad de Chile, Santiago, Chile — [3]CNRS - ESPCI Université PSL/Sorbonne Université/Université de Paris, paris, France

When long, flexible fibers are densely packed, they form cohesive structures, such as those found in bird*s nests, cotton balls, or fibrous insulation materials. These peculiar granular assemblies exhibit complex mechanical behaviors: they can be compacted and sustain tensile stress, despite the absence of adhesive bonds. Through experiments on model materials and discrete-element simulations, we investigate the interplay between elasticity and friction that governs the mechanics of entangled, non-bonded fiber networks.

DY 19.2 Tue 10:00 HÜL/S186

Rheology of suspensions of non-Brownian spheres across the jamming and viscous-to-inertial transition — •Franco Tapia[1,2], Olivier Pouliquen[2], Chong-Wei Hong[2], Pascale Aussillous[2], and Elisabeth Guazzelli[3] — [1]Institute of Urban and Industrial Water Management, TU Dresden, Dresden, Germany — [2]Aix-Marseille Université, CNRS, IUSTI, Marseille, France — [3]Université Paris Cité, CNRS, Matiére et Systèmes Complexes (MSC) UMR 7057, Paris, France

We study the rheology of suspensions of non-Brownian hard and soft particles across the jamming transition and within both viscous and inertial flow regimes, using a custom-built pressure- and volume-imposed rheometer. Our results, expressed in terms of the effective friction coefficient and packing fraction, demonstrate that suspensions of hard spheres exhibit continuous shear thickening when inertia becomes significant at a transitional Stokes number of 10, independent of the packing fraction. These findings can be extended to a Soft Granular Rheology model by renormalizing the volume fraction and friction coefficient to pressure-dependent values, incorporating both viscous and inertial stress scales. SGranR successfully captures the rheological behavior, showing an approximate collapse into two branches through power-law scaling relative to the distance from the jamming point: (i) above the jamming transition, where the behavior is described by a generalized Herschel-Bulkley law with yield stress and shear thinning, and (ii) below the jamming point, where the behavior follows a critical power law, with shear thinning near the jamming point.

DY 19.3 Tue 10:15 HÜL/S186

granular drag towards zero gravity — •tianhui liao[1], tivadar pongo[1], jinchen zhao[1], simeon völkel[2], valentin dichtl[2], raúl c. hidalgo[3], and kai huang[1,2] — [1]Collective Dynamics Lab, Division of Natural and Applied Sciences, Duke Kunshan University, 215306 Kunshan, Jiangsu, China — [2]Experimentalphysik V, Universität Bayreuth, 95440 Bayreuth, Germany — [3]Department of Physics and Applied Mathematics, University of Navarra, 31009 Pamplona, Spain

The role of gravity on the drag force F_{d} acting on a projectile impacting granular media is investigated experimentally using embedded inertial measurement unit (IMU) sensor and numerically with discrete element method (DEM) simulations. As gravity approaches zero, the inertial drag plays a dominating role, leading to qualitatively different scaling laws and cavity dynamics. Similarly to fluid dynamics, we define a dimensionless granular drag coefficient C_{gd}, which yields a constant of $\approx 1.2 \pm 0.2$ under microgravity, and a term inversely proportional to the impact velocity v_0 is added in the presence of gravity. This connection to fluid drag sheds light not only on a wide range of applications of granular media in space exploration, but also on drag force in non-Newtonian fluids from a first principle perspective.

DY 19.4 Tue 10:30 HÜL/S186

Impact of Roughness on Packing Fraction — •Adrien Luyckx and Eric Opsomer — GRASP Institute, Liege University, Belgium

This study investigates the impact of particle rugosity on the mechanical properties of piles using computational methods. We focus on smooth, non-convex particles (rod, cross, and star shapes) approximated via multisphere approach. Our research introduces the concepts of macro-rugosity, which increases as we progress from rod to cross to star shapes, and meso-rugosity, which is adjusted by varying the number of spheres composing the particles. Key findings include: (1) A limited meso-rugosity is sufficient to capture the mechanical properties of a pile, such as its height. (2) As macro-rugosity increases, the required meso-rugosity decreases. These results demonstrate that particle representation can be optimized by balancing meso-rugosity with the imposed macro-rugosity, significantly reducing computational demands. Our findings contribute to the ongoing efforts in enhancing the efficiency and accuracy of discrete element methods (DEM) in modeling complex particle systems.

DY 19.5 Tue 10:45 HÜL/S186

Tangential forces govern viscous-inertial transition in dense frictional granular suspensions — •Sudarshan Konidena[1], Franco Tapia[1], Alireza Khodabakhshi[1], Élisabeth Guazzelli[2], Pascale Aussillous[3], and Bernhard Vowinckel[1] — [1]Institute of Urban and Industrial Water Management, Technische Universität Dresden, 01062 Dresden, Germany — [2]Université Paris Cité, CNRS, Matière et Systèmes Complexes (MSC) UMR 7057, Paris, France — [3]Aix Marseille Université, CNRS, IUSTI, Marseille, France

Using pressure-imposed rheology, we carry out particle-resolved simulations to study dense suspensions of frictional suspensions as they move from a viscous regime into an inertial one. By independently tuning the liquid viscosity, the shear rate, and the confining granular pressure, we determine that the onset of this transition always appears at a Stokes number near 8 and does not depend on the volume fraction. A key outcome is that the shear stress evolves toward its inertial behavior more slowly than the particle pressure. This delayed response arises from the combined influence of tangential contact forces and lubrication interactions, which govern how frictional particles gradually switch from predominantly rolling motions to predominantly sliding ones. Although the Stokes number dictates the overall shift, the degree of proximity to jamming also plays a role. We further explore how stronger inter-particle friction alters the characteristics of the viscous*inertial transition.

15 min. break

DY 19.6 Tue 11:15 HÜL/S186

Rheology of Granular Sediment Beds from Dense to Creeping Regimes — •Bernhard Vowinckel[1], Pascale Aussillous[2], and

Élisabeth Guazzelli[3] — [1]Institute of Urban and Industrial Water Management, Technische Universität Dresden, 01062 Dresden, Germany — [2]Aix Marseille Université, CNRS, IUSTI, Marseille, France — [3]Université de Paris, CNRS, Matière et Systèmes Complexes (MSC) UMR 7057, Paris, France

We investigate the rheology of sheared sediment beds using grain-resolved direct numerical simulations supported by experimental data. Poiseuille and Couette configurations are examined, extending monodisperse systems to polydisperse beds with diameter ratios up to 10. The simulations provide depth-resolved stress profiles, fluid-particle momentum exchange, particle volume fraction, and granular pressure. For monodisperse beds, shear and normal viscosities and the effective friction coefficient follow established correlations, with a critical particle volume fraction of about 0.3 marking the transition from dense to dilute regimes. In the dilute transport layer, hydrodynamic interactions are screened and the effective viscosity approaches the Einstein relation. For polydisperse mixtures, we generalize $\mu(J)$-rheology by linking its parameters to the maximum packing fraction, achieving good agreement with reference data. Access to very low viscous numbers shows that the friction coefficient in the creeping regime tends to a finite quasi-static value, reducing the critical friction coefficient by a factor of three. These findings refine closure relations for two-phase sediment transport models.

DY 19.7 Tue 11:30 HÜL/S186

Elastic Soft-Shell Packings — •Eric Opsomer and Nicolas Vandewalle — University of Liege, Liege, Belgium

The evolution of pressure at the bottom of a two-dimensional pile of thin elastic rings is investigated for increasing filling height of the system. Due to the soft nature of the particles, contact forces are only weakly deviated which causes a delay of the pressure saturation that is commonly observed in hard grain system. More importantly, for large fillings, an abrupt transition within the structure of the granular pile is encountered once the surrounding pressure leads to the buckling of the rings composing the bottom layers of the pile. The latter transition can be predicted based on the mechanical properties of the thin rings and the global evolution of pressure can be modeled by extending Janssen's model to an effective two-phase granular media.

DY 19.8 Tue 11:45 HÜL/S186

Rheology of dense suspension: the effects of wall-boundaries on viscous-inertial transition — •Alireza Khodabakhshi, Sudarshan Konidena, Franco Tapia, and Bernhard Vowinckel — Institute of Urban and Industrial Water Management, TU Dresden, Dresden, Germany

The transition from the viscous to the inertial regime in dense suspensions is still not fully clarified. Volume-imposed rheometers with fixed-gap walls offer valuable information by reporting shear and normal stress as functions of shear rate, yet the influence of confining boundaries, especially in narrow-gap configurations relevant to industrial and natural flows, remains insufficiently explored. In this study, we perform particle-resolved Direct Numerical Simulations (pr-DNS) of dense non-Brownian suspensions sheared between rough walls in a confined volume-imposed rheometer. The simulations capture the overall viscous-inertial trend reported in recent experiments and reproduce the observed weakening of the effective friction coefficient during the transition. We analyze multiple cases by varying wall roughness and rheometer height, showing that both parameters strongly affect stress levels by altering particle layering. All configurations develop pronounced layering, but the case with the roughest wall and weaker confinement enhances inter-layer mixing, producing higher stress levels. After sufficient strain, this configuration evolves toward a more ordered, low-mixing state, reducing stress to values similar to the other cases. Despite variations in stress magnitude, all cases follow a consistent viscous-inertial transition.

DY 19.9 Tue 12:00 HÜL/S186

Two time scales drive the formation of transient networks in a ferrogranular experiment - and how to control them — •Ali Lakkis[1], Matthias Biersack[1], Oksana Bilous[2], Sofia Kantorovich[2], and Richter Reinhard[1] — [1]Experimentalphysik 5, Universität Bayreuth — [2]Fakultät für Physik, Universität Wien

We are reporting experiments on the aggregation dynamics in a horizontally confined granular mixture composed of glass and magnetized steel spheres under vertical vibration. Upon a sudden decrease of the shaking amplitude, magnetized particles undergo a transition from a dispersed to an aggregated state. For deep quenches, a transient, percolating network of magnetized spheres rapidly emerges and gradually coarsens into compact clusters. In contrast, moderate amplitude reductions lead directly to dense cluster formation without intermediate networking. Using structural and network metrics such as coordination number and its mean value, we identify two characteristic timescales: a fast one governing the head-to-tail chaining typical of dipolar hard spheres (DHS), and a slower one corresponding to the restructuring into compact aggregates [1]. This progression is driven by the intrinsic susceptibility of the beads but is challenged by inter-sphere-friction. Thus, the employed susceptible dipolar hard spheres (SDHS) are a minimal model for phase separation with two intrinsic time scales in only one constituent.

[1] A. Lakkis, M. Biersack, O. Bilous, S. S. Kantorovich, R. Richter, *Soft Matter* (2025) doi:10.1039/d5sm00726g

DY 19.10 Tue 12:15 HÜL/S186

CT-resolved flow-induced particle migration in pipe bends during concrete pumping — •Daniil Mikhalev[1], Moritz Kluwe[2], Rüdiger Schwarze[2], and Viktor Mechtcherine[1] — [1]TU Dresden, Institute of Construction Materials, 01187 Dresden — [2]TU Bergakademie Freiberg, Institute for Mechanics and Fluid Dynamics, 09599 Freiberg

In this study, we investigate how the granular microstructure of pumped fresh concrete evolves as the suspension passes through a 90° pipe bend. The material is pumped under realistic operating conditions and allowed to harden in situ. To identify shear-dominated regions, a dyed low-viscosity premix is introduced as a passive tracer. Hardened bend sections are then analysed using high-resolution X-ray computed tomography. Segmentation of individual grains, voids, and tracer regions enables spatial statistics of solid volume fraction, grain-size distributions, air-void patterns, and shear-zone geometry along the inflow-bend-outflow transition.

Preliminary results reveal measurable deviations from the symmetric plug - lubrication-layer structure known from straight pipe flow, including radial and azimuthal segregation and restructuring of both solid and air phases. The combined tracer-based and tomographic approach provides a foundation for linking experimentally resolved microstructure with continuum suspension models and particle-migration theories in complex geometries.

General Discussions

DY 20: Focus Session: Water – from Atmosphere to Space I (joint session CPP/DY)

Water plays a vital role in diverse Earth processes across multiple scales, from atmospheric cycles and aerosol chemistry to geological porous media and nanoscale biological functions of hydrated proteins. Despite its fundamental importance and numerous anomalous properties, such as the diverging heat capacity of supercooled water, pure bulk water remains poorly understood. Key phenomena like evaporation and crystallization are relevant not only on Earth but also in extraterrestrial environments. In Germany, molecular water research is flourishing across prestigious centers, exemplified by the new BlueMat cluster at Hamburg University of Technology, the renewed RESOLV cluster at Ruhr-University Bochum, and the Max Planck Society's expanding Liquid Initiative in Mainz. The 2025 inauguration of the Centre for Molecular Water Science (CMWS) at Hamburg's DESY campus further strengthens a Europe-wide interdisciplinary network, uniting 47 founding members from 12 countries to advance water science across disciplines and methods. Within this focus session the state of molecular water research shall be discussed and interactions between the physical sub-fields shall be fostered.

Organized by Alexander Schlaich, Katrin Amann-Winkel, Mischa Bonn.

Time: Tuesday 9:30–11:00 Location: ZEU/LICH

Topical Talk DY 20.1 Tue 9:30 ZEU/LICH

Surface adsorption and protonation equilibrium of atmospheric organics at the aqueous surface — •Nønne Prisle — Center for Molecular Water Science, Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, D-22607 Hamburg, Germany — Institute of Inorganic and Applied Chemistry, University of Hamburg, Martin-Luther-King-Platz 6, D-20146 Hamburg, Germany — Center for Atmospheric Research, University of Oulu, P.O. Box 4500, FI-90014, Oulu, Finland

Atmospheric aerosols comprise a significant fraction of organic species which frequently exhibit both surface activity and Brönsted acidity or basicity in aqueous solutions. The high surface area to bulk volume ratios of nano- and microscopic aerosols and droplets further favor surface-specific states, affecting both bulk-phase and heterogeneous chemistry.

We used X-ray Photoelectron Spectroscopy (XPS) in combination with high-brilliance synchrotron radiation to directly observe the protonation state of atmospheric acids and bases at the surfaces of aqueous aerosol and droplet models. We found that for each acid-base pair, the neutral species is enhanced in the surface, consistent with its higher surface activity, compared to the charged conjugate. This introduces a shift in the protonation equilibrium at the aqueous surface corresponding to an apparent change in pKa of 1-2 pH units, depending on the concentration, acidity, and surface activity of the conjugate acidic and basic species.

DY 20.2 Tue 10:00 ZEU/LICH

The Effect of pH on the Structure of Model Sea Spray Aerosol Surfaces — •Clara M. Saak, Lars Höhner, and Ellen H.G. Backus — Institute of Physical Chemistry, Faculty of Chemistry, University of Vienna, Währinger Straße 42, 1090 Vienna, Austria

Aerosols play a key role in the global climate due to their ability to scatter and reflect solar radiation and to act as cloud condensation nuclei (CCN), exerting a pronounced cooling influence on the global climate. In particular, the surface availability of ions and organic compounds is known to affect the hygroscopicity of the particle and thereby its ability to act as a CCN [1]. While the surface propensity of individual compounds has been studied widely, much less is known about more complex systems. Here we focus on the impact of bulk pH on the architecture of mixed aqueous interfaces. In atmospheric systems the pH has been shown to range from roughly pH 8 to 2 [2]. Using sum-frequency-generation (SFG) spectroscopy in conjunction with surface tension data we study the surface composition and structure of short and long chain organic acids at different protonation stages, obtained by varying the pH. Using this approach, we find pronounced changes in the structuring of the aqueous sub-surface layers depending on the specific composition and pH, and in the Gibbs free energy of adsorption of the studied organics. Our results show that it is feasible for subtle environmental changes to considerably affect structure and composition of the aqueous interface, which is known to play a key role in aerosol hygroscopicity. [1] Zieger, Nat. Commun. 2017, 8, 15883. [2] Angle, PNAS, 2021, 118, 2, e2018397118

DY 20.3 Tue 10:15 ZEU/LICH

Crystallization behaviour of nanoparticle suspensions — •Isabell Zick[1,2], Eduard Edel[2], and Katrin Amann-Winkel[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität, Staudinger Weg 7, 55128 Mainz, Germany — [2]Max-Planck-Institut für Polymerforschung, Ackermannweg 10, 55128 Mainz, Germany

Water is one of the most abundant substances in the world and due to this in close contact with many materials including micro- and nanoplastic particles. Those have been detected not only in sea but also in the atmosphere, where the particles can interact with water and act as cloud condensation nuclei or ice-nucleating particles. Emerging evidence suggests that nanoparticles with increased surface roughness or chemical functionalities may promote heterogeneous ice nucleation through different processes like, e.g., contact- and immersion-freezing. Such a behaviour affects cloud properties with significant implications for Earth*s radiative balance and the hydrological cycle.

We investigate atmospherically relevant nanoparticles dispersed in water to investigate their influence on the ice crystallization. Our experiments include calorimetry (DSC) as well as X-ray diffraction measurements (XRD). Our measurements show that the crystallization temperature depends on the particle size, concentration, and the chemical surface of the particles. Using XRD, we investigate the restructuring of the water molecules during supercooling, observed by a shift in the characteristic main diffraction peak of water and the subsequent crystallization process.

DY 20.4 Tue 10:30 ZEU/LICH

Laser-Excited X-ray Reflectivity of Aqueous SrCl2 at the Air-Water Interface — •Ali Ashtiani Abdi[1,2], Julia Kobus[1,2], Svenja C. Hövelmann[1,2], Philipp Jordt[1,2], Nicolas Hayen[1,2], Prashant Hitaishi[1,2], Ajay Ajay[1,2], Rabia Qamar[1,2], Otto Lippmann[1,2], Chen Shen[3], Florian Bertram[3], and Bridget M. Murphy[1,2] — [1]IEAP, CAU Kiel University, Kiel, Germany — [2]Ruprecht Haensel Laboratory, DESY, Hamburg, Germany — [3]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Understanding aqueous interfaces is essential for describing chemical processes in atmospheric, marine, and geochemical environments. While monovalent salts have been widely studied, the interfacial behavior of divalent ions is less understood, despite their relevance in seawater aerosols and reactive brines. SrCl2 is a representative divalent electrolyte whose interfacial structure may show alteration by laser illumination.

We investigate aqueous SrCl2 solutions at different concentrations using X-ray reflectivity (XRR) at the liquid-air interface. Measurements were performed at the LISA setup at beamline P08, PETRA III (DESY), where controlled laser illumination can be applied directly to the X-ray footprint, following the instrumentation concept of Warias and Hovelmann et al. (J. Synchrotron Rad. 2024). Reflectivity curves were recorded with and without laser exposure. The data demonstrate the suitability of SrCl2 surfaces for laser-assisted XRR and the sensitivity of the method to potential changes in interfacial structure, including indications of near-surface layering.

DY 20.5 Tue 10:45 ZEU/LICH

Monitoring Uptake, Release and Reaction of Gases at the Liquid-Vapor Interface — •Tillmann Buttersack[1], Shirin Gholami[1], Clemens Richter[1], Daniela Torres-Diaz[1], Bernd

Winter[1], Pavel Jungwirth[2], Stephen Bradforth[3], Markus Ammann[4], Ruth Signorell[5], Ivan Gladich[6], Remi Dupuy[7], Philip Mason[2], and Hendrik Bluhm[1] — [1]Fritz Haber Institute, Max Planck Society, Berlin, GER — [2]IOCB, Czech Academy of Sciences, Prague, CZ — [3]University of Southern California, Los Angeles, USA — [4]Paul Scherrer Institut, Villigen, CH — [5]EZH Zürich, CH — [6]University of Urbino, Urbino, I — [7]Sorbonne Université, Paris, F

Multiphase reactions are omnipresent in nature, industrial applications. The direct observation of reactions at the liquid-vapor interface requires spectroscopic techniques that are surface specific and chemically sensitive to detect low concentrations, e.g., photoelectron spectroscopy (XPS). Furthermore, the sample delivery method must allow sufficient time for an interface reaction to proceed. These complex challenges require individual approaches for each system of interest. One example for a multiphase process is the reaction between liquid alkali metal and water vapor, which is extremely fast. We used a slow droplet train of NaK in a wet atmosphere and observed the formation of golden aqueous solutions with metallic properties with XPS. An example with relevance for atmospheric chemistry is the formation and the release of sulfur dioxide (SO2) from aqueous sulfite solutions due to acidification. We demonstrated that dissolved gases can be detected with XPS even though their concentration is only about 1 mM.

DY 21: Stochastic Thermodynamics

Time: Tuesday 9:30–12:45 Location: ZEU/0114

DY 21.1 Tue 9:30 ZEU/0114

Thermodynamic bounds and error correction for faulty coarse graining — •Jann van der Meer and Keiji Saito — Department of Physics No. 1, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan

At the nanoscale, random effects govern not only the dynamics of a physical system but may also affect its observation. This work introduces a novel paradigm for coarse graining that eschews the assignment of a unique coarse-grained trajectory to a microscopic one. Instead, observations are not only coarse-grained but are also accompanied by a small chance of error. Formulating the problem in terms of path weights, we identify a condition on the structure of errors that ensures that the observed entropy production does not increase. As a result, the framework of stochastic thermodynamics for estimating entropy production can be extended to this broader class of systems. As an application, we consider Markov networks in which individual transitions can be observed but may be mistaken for each other. We motivate, derive, and illustrate thermodynamic bounds that relate the error sensitivity of the observed entropy production to the strength of the driving and are valid for arbitrary network topologies. If sufficiently many transitions in the network can be observed, redundancies in the coarse-grained trajectories can be used to detect and correct errors, which potentially improves naive estimates of entropy production. We conclude with an outlook on subsequent research on thermodynamic bounds for erroneous coarse graining.

DY 21.2 Tue 9:45 ZEU/0114

Between heat engine and information engine, characteristics of the entropy production rate in a Brownian ratchet. — Adrien Meynard, Marc Lagoin, Caroline Crauste-Thibierge, and •Antoine Naert — Univ Lyon, Ens de Lyon, Univ Claude Bernard, CNRS, Laboratoire de Physique, F-69342 Lyon, France

A two-state device such as a Brownian ratchet can be regarded as a *heat engine* or an *information engine*. Our experiment, at the centimeter scale, gives access to long time series of all observables of interest, resolved in time. These are the heat flux $\dot{q}_1(t)$ supplied by the hot (athermal) bath, at an (effective) temperature kT_1, and the work produced per unit time $\dot{w}(t)$.

Taking advantage of the discreet operation of such 1-bit elementary information device, an example of a Maxwell's demon, we can measure the rate of entropy production. We infer a comprehensive characterization of the rate of entropy produced by this device, in the Boltzmann sense. Our findings are compatible with a Poisson point process.

In steady state operation, this entropy is to be released as heat into the surrounding, at ambient temperature $k_{\mathrm{B}}T_2$. (Note that $\dot{q}_2(t)$ is distinct from the various losses.) The heat over temperature ratios of the exchanges with the hot and cold baths are of the same order of magnitude:

$$\frac{\langle \dot{q}_1 \rangle}{kT_1} \simeq \frac{\langle \dot{q}_2 \rangle}{k_{\mathrm{B}}T_2}. \tag{2}$$

We confirm that, within the limit of experimental uncertainties, entropy is conserved in a lossless heat engine, just like energy is.

DY 21.3 Tue 10:00 ZEU/0114

Minimum Action Principle for Entropy Production Rate of Far-From-Equilibrium Systems — •Atul Tanaji Mohite and Heiko Rieger — Department of Theoretical Physics and Center for Biophysics, Saarland University, Saarbrücken, Germany

The Boltzmann distribution connects the energetics of an equilibrium system with its statistical properties, and it is desirable to have a similar principle for non-equilibrium systems. Here, we derive a variational principle for the entropy production rate (EPR) of far-from-equilibrium discrete state systems, relating it to the action for the transition probability measure of discrete state processes [1,2]. This principle leads to a tighter, non-quadratic formulation of the dissipation function, speed limits, the thermodynamic-kinetic uncertainty relation, the large deviation rate functional, and the fluctuation relation, all within a unified framework of the thermodynamic length [2]. Additionally, the optimal control of non-conservative transition affinities using the underlying geodesic structure is explored, and the corresponding slow-driving and finite-time optimal driving exact protocols are analytically computed [1,3]. We demonstrate that discontinuous endpoint jumps in optimal protocols are a generic, model-independent physical mechanism that reduces entropy production during finite-time driving of far-from-equilibrium systems [3].

[1]A.T. Mohite and H. Riger, arXiv:2511.00967. [2]A.T. Mohite and H. Riger, arXiv:2511.00970. [3]A.T. Mohite and H. Riger, arXiv:2511.00974.

DY 21.4 Tue 10:15 ZEU/0114

Asymptotic limit laws of projected empirical currents — •Felix Tippner and Aljaz Godec — Mathematical Physics and Stochastic Dynamics, Institute of Physics, University of Freiburg (GER)

Most experimental measurements capture only a restricted subset of a system's degrees of freedom at any given time. As a result, the higher-dimensional stochastic process that describes the full physical system, such as the high-dimensional conformational dynamics of proteins, can typically be observed only in terms of low-dimensional projections, which are also subject to experimental and sampling constraints. These projections inevitably give rise to non-Markovian behaviour and typically obscure key features of the underlying dynamics, including irreversible probability currents that distinguish driven from reversible systems. The main result of the present work is an asymptotic limit law, i.e., a sharpening of the central limit theorem, for empirical currents of projected observables.

DY 21.5 Tue 10:30 ZEU/0114

Nonlinear Response Theory for Nonequilibrium Biochemical Networks — Ruicheng Bao[1] and •Shiling Liang[2,3,4] — [1]University of Tokyo, Tokyo, Japan — [2]MPI-PKS, Dresden, Germany — [3]MPI-CBG, Dresden, Germnay — [4]CSBD, Dresden, Germany

Living cells process information through biochemical networks operating far from equilibrium. Understanding how these systems respond to finite perturbations, such as changes in enzyme concentrations or metabolic fluxes, is essential, yet the fluctuation-dissipation theorem applies only near equilibrium.

This talk introduces a framework that fills this gap. We derive an exact identity that links nonlinear responses to linear ones through a physically meaningful scaling factor, based on a connection between steady-state responses and mean first-passage times. This provides bidirectional inference: predicting global responses from local biochemical changes, and inferring metabolic costs from measurable observables. We also establish a universal response-resolution limit, a strong-perturbation analogue of the fluctuation-dissipation theorem, which sets fundamental bounds on signal detectability.

Using transcriptional regulation as an example, we show how these parameter-independent bounds constrain the computational expressibility of gene networks. Reliable detection of transcription factor changes requires fold-changes above a universal threshold. Overall, this framework defines general physical limits on cellular information processing, with implications for metabolic control and signal transduction.

DY 21.6 Tue 10:45 ZEU/0114

Compensating random transition-detection blackouts in Markov networks — •Alexander Maier, Benjamin Häsler, and Udo Seifert — II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

In Markov networks, measurement blackouts with unknown frequency compromise observations such that thermodynamic quantities can no longer be inferred reliably. In particular, the observed currents neither discern equilibrium from non-equilibrium nor can they be used in extant estimators of entropy production. Our strategy to eliminate these effects is based on formally attributing the blackouts to a second channel connecting states. The unknown frequency of blackouts and the true underlying transition rates can be determined from the short-time limit of observed waiting-time distributions. A post-modification of observed trajectory data yields a virtual effective dynamics from which the lower bound on entropy production based on thermodynamic uncertainty relations can be recovered fully. Moreover, the post-processed data can be used in waiting-time based estimators. Crucially, our strategy does neither require the blackouts to occur homogeneously nor symmetrically under time-reversal. Reference: Alexander M. Maier, Benjamin Häsler and Udo Seifert, arXiv:2511.14679 (2025)

15 min. break

Invited Talk DY 21.7 Tue 11:15 ZEU/0114

Why Life Is Hot — •Tanja Schilling[1], Patrick Warren[2], and Wilson Poon[3] — [1]Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]The Hartree Centre, STFC Daresbury Laboratory, Warrington, WA4 4AD, United Kingdom — [3]School of Physics and Astronomy, The University of Edinburgh, Peter Guthrie Tait Road, Edinburgh EH9 3FD, United Kingdom

Biological organisms use strongly driven cycles to optimize the output of chemical reactions. This mechanism is versatile, it is employed to meet a large variety of cost functions such as robustness, precision, or sensitivity to external stimuli. However, the improvements over the equilibrium behaviour come at the cost of increased production of heat. We show that the heat generated by this mechanism constitutes a large part of the total heat produced by living organisms. Further we demonstrate that the effect saturates and that nature operates near saturation. Hence we conclude that the heat production of living organisms is consequence of their need to function accurately and to adapt flexibly to varying demands.

DY 21.8 Tue 11:45 ZEU/0114

Optimal Localisation against a Flow — •Till Welker and Patrick Pietzonka — School of Physics and Astronomy, University of Edinburgh, United Kingdom

How much work does it cost for a propelled particle to stay localised near a stationary target, defying thermal noise and a constant flow that would carry it away? We study the control of such a particle in finite time and find optimal protocols for time-dependent propulsion speed and diffusivity, without feedback. Accuracy, quantified via the mean squared deviation from the target, and energetic cost turn out to be connected by a trade-off relation, which complements the one between precision and cost known in stochastic thermodynamics. We show that accuracy better than a certain threshold requires active driving , which comes at a cost that increases with accuracy. The optimal protocols have discontinuous propulsion speed and diffusivity, switching between a passive drift state with vanishing diffusivity and an active propulsion state. If the initial position is fixed, an initial jump of the particle, enabled by a sudden burst of propulsion, can be optimal. This study highlights how a time-dependent diffusivity enhances optimal control and sets benchmarks for artificial self-propelled particles navigating noisy environments.

DY 21.9 Tue 12:00 ZEU/0114

Thermodynamic optimal control out of equilibrium: insights from active and driven systems — •Kristian Olsen[1], Rémi Goerlich[2,1], Yael Roichman[2,3], and Hartmut Löwen[1] — [1]Institut für Theoretische Physik II - Weiche Materie, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany — [2]Raymond & Beverly Sackler School of Chemistry, Tel Aviv University, Tel Aviv 6997801, Israel — [3]Raymond & Beverly Sackler School of Physics & Astronomy, Tel Aviv University, Tel Aviv 6997801, Israel

Optimal control far from equilibrium raises intriguing questions in stochastic thermodynamics and offers a route to design microscopic engines that operate out of equilibrium. We study thermodynamically optimal protocols for a harmonically trapped particle driven by arbitrary time-dependent forces, including those from active matter or external fields [1]. The resulting protocols are able to harness non-equilibrium forces to extract a net work. We provide exact solutions for the optimal protocol and associated work for arbitrary forces and protocol duration. We also derive a quasistatic work bound that splits into three parts: an information-geometric term capturing energy stored in an initial non-equilibrium state, the work extracted from time-averaged forces, and extra work from fast dynamical modes. Finally, we analyze the energetic cost of adding boundary constraints, giving insights into the cost of precision in these protocols.

1. Harnessing non-equilibrium forces to optimize work extraction, Kristian Stølevik Olsen, Rémi Goerlich, Yael Roichman and Hartmut Löwen, In press Nature Communications, arXiv: 2504.07049, 2025.

DY 21.10 Tue 12:15 ZEU/0114

Searching with Memory: Experiments on Stochastic Resetting in Complex Fluids — •Felix Ginot and Clemens Bechinger — University of Konstanz, 78457 Konstanz, Germany

Many natural and technological search processes, from molecular reactions to robotic exploration, benefit from occasionally resetting and trying again. This mechanism, known as stochastic resetting (SR), is well understood in simple memoryless environments, but real systems often exhibit complex relaxation dynamics that retain information about recent motion.

We experimentally investigate SR in a viscoelastic fluid by tracking a colloidal particle undergoing controlled resets. The fluid's delayed elastic response creates restoring forces that oppose each reset and reduce search efficiency. We show that these memory effects can be tuned: holding the particle at the trap center allows the fluid to relax and erase residual memory. With a target present, this control significantly lowers the mean passage time, with optimal performance at intermediate resetting rates. In this regime, memory induces temporal correlations that bunch target encounters and speed up repeated hits.

These results demonstrate that environmental memory can both hinder and enhance search, and they point to new strategies for optimizing transport in non-Markovian media.

DY 21.11 Tue 12:30 ZEU/0114

Information as a Thermodynamic Resource in Non-Markovian Stochastic Systems — •Lokesh Chinnakanna Muruga, Felix Ginot, and Clemens Bechinger — Fachbereich Physik, Universität Konstanz, Konstanz, Germany

The interplay between information and thermodynamics lies at the core of modern stochastic physics. Classical thermodynamics links quantities such as entropy, temperature, and free energy solely to the physical state of a system. Contemporary developments from Maxwell demon and Szilard engine led to fluctuation theorems which revealed that information itself acts as a thermodynamic resource. The acquisition, storage, and use of information can reshape energy landscapes, enable work extraction, and modulate entropy production without violating the second law. In this work, we explore how information stored in unobserved degrees of freedom affects work extraction and equilibrium dynamics in stochastic systems. Using time-resolved position measurements of an optically trapped Brownian particle in a non-Markovian fluid, we show that correlations in the measurement encode memory effects that reveal multiple hidden configurational states. We introduce a new protocol to distinguish these information-bearing states experimentally and quantify their influence on relaxation and work extraction efficiency. Our results highlight how information, whether explicit or hidden can be leveraged as a functional resource for energy extraction and control at the microscale.

DY 22: Pattern Formation

Time: Tuesday 9:30–12:15 Location: ZEU/0118

DY 22.1 Tue 9:30 ZEU/0118

Unexpected wave patterns observed within an extended parameter range of the Barkley model — Vladimir Zykov and •Eberhard Bodenschatz — Max Planck Institute for Dynamics and Self-Organization, D-37077 Goettingen, Germany,

The Barkley model is a widely accepted example of reaction diffusion systems demonstrating different self-organization processes including a creation of self-sustained spiral waves. Recently the study of the spiral wave dynamics performed within the extending parameter region of the Barkley model allowed us to reveal some unexplored features of these processes [1]. The latest computational results performed under a further expansion of the parameter range demonstrate the existence of spiral wave under completely unexpected conditions in monostable and bistable regions. These spirals exhibit absolutely unusual instability, which should be investigated. In parallel to spiral waves self-supported wave segments remaining critical fingers have been observed, which also demonstrated a similar unusual instability.

[1] V. S. Zykov and E. Bodenschatz, Unexplored aspects of the spiral wave dynamics in the Barkley model within an extended parameter range, Phys. Rev. E. 110, 064209 (2024).

DY 22.2 Tue 9:45 ZEU/0118

Dynamics of localized states in a weakly dissipative Korteweg-de Vries-Kuramoto-Sivashinsky Equation — •Justus Keussen[1], Daniel Greve[1], Julien Javaloyes[2], and Svetlana V. Gurevich[1,2,3] — [1]Institute for Theoretical Physics, University of Münster, Münster, Germany — [2]Universitat de les Illes Balears, Palma, Spain — [3]Center for Data Science, University of Münster, Münster, Germany

We are interested in the dynamics of localized solutions in a weakly dissipative Korteweg de Vries Kuramoto Sivashinsky equation, using a combination of analytical, numerical, and path-continuation methods. We show that a traveling solitary soliton exists and is stable over a certain parameter range, even though the homogeneous state is linearly unstable. Furthermore, we employ a variational ansatz to analytically determine the selected velocity of the localized state. Finally, path continuation in the domain size reveals that the corresponding bifurcation points on both the homogeneous and solitary branches follow a power-law scaling with the system length, implying that each domain size admits a finite interval of parameter values in which a stable solitary wave exists.

DY 22.3 Tue 10:00 ZEU/0118

Pattern formation and route to chaos in a two-species reaction-diffusion model with one conservation law — •Simon Navia Rafide[1] and Uwe Thiele[2] — [1]University of Münster, Münster Germany — [2]University of Münster, Münster Germany

In many intracellular reactions, the total amount of a substance remains constant. For example, in reactions involving proteins that can adopt different conformations, it is possible to observe spatio-temporal concentration patterns that differ in their behaviour from those in systems without such constraints. We explore a relatively simple two-species reaction-diffusion model with a single mass conservation law governing cell polarisation [1, 2]. Here, we investigate the bifurcation behaviour of the model in detail and, using numerical continuation and time simulations, show that time-periodic patterns follow a period-doubling route to chaos, which appear in two different flavours. Moreover, we propose an approximate model based on the first two instability modes that allows us to understand the underlying mechanisms behind the first steps of pattern formation.

[1] Kuwamura, M., Izuhara, H., & Ei, S. I., Oscillations and bifurcation structure of reaction-diffusion model for cell polarity formation. J. Math. Biol., 84, 2022. [2] S. Ishihara, M. Otsuji, A. Mochizuki, Transient and steady state of massconserved reaction-diffusion systems, Phys. Rev. E 75, 015203, 2007.

DY 22.4 Tue 10:15 ZEU/0118

The 3-Components Problem — •Davide Toffenetti[1], Beatrice Nettuno[1], Henrik Weyer[2], and Erwin Frey[1] — [1]Ludwig Maximilian University of Munich (LMU), Munich, Germany — [2]KITP, UC Santa Barbara, USA

Our work develops a general framework that connects reaction-diffusion systems with active-matter theories. Earlier studies showed that two-component mass-conserving reaction-diffusion (2cMcRD) systems can be mapped onto Model-B-type dynamics [1], which leads to the coarsening of patterns. We extend this idea by introducing a minimal three-component mass-conserving reaction-diffusion (3cMcRD) model. Using adiabatic elimination, we derive an effective active description for the total-mass dynamics, reminiscent of the well-known AMB+ theory. We validate the mapping through extensive numerical simulations.

Only 3cMcRD systems and their associated effective active theory produce finite-wavelength patterns such as dots, stripes, and foam-like structures, in contrast to the coarsening dynamics of 2cMcRD models. Employing a local quasi-steady-state approximation, we further determine the thresholds separating distinct pattern-forming regimes. In particular, we analyze how fingering instability emerges from an initially flat interface, marking the transition to foam-like patterns.

Our approach naturally generalizes to systems with more than three components and and to more general active-matter theories.

[1] Weyer, Brauns & Frey (2023). Phys. Rev. E 108, 064202.

DY 22.5 Tue 10:30 ZEU/0118

Coarsening dynamics and interface instabilities in coupled conserved pattern-forming systems — Benjamin Winkler[1], Sergio Alonso[2], and •Markus Bär[3] — [1]RKI and FU Berlin, Germany — [2]UPC Barcelona, Spain — [3]PTB and TU Berlin, Germany

We investigate the coarsening dynamics of non-variationally coupled, mass-conserved pattern-forming systems. Our main example is a model describing multiscale pattern formation via the interaction of membrane binding proteins with a multicomponent lipid membrane. We find that the coupling of a reaction-diffusion system for a protein species to an equation describing the phase composition of a lipid membrane exhibiting active phase separation leads to arrested coarsening for strong enough coupling. In addition, inverse coarsening is found if simulations start from large domains. We show that these phenomena are closely connected with interface instabilities and an exceptional point in the linear properties of the spatially homogeneous state both of which emerge for strong-enough non-variational coupling. Similar phenomena are also found in a version of the non-reciprocally coupled Cahn-Hilliard equations, which have similar linear behavior and instabilities, and in a qualitative model for a compressible active polar fluid. The nonlinear evolution of the interface instability and the emerging complex patterns depend, however, on the specific form of the chosen model. This is demonstrated with a survey of possible dynamical evolutions in different models.

DY 22.6 Tue 10:45 ZEU/0118

Leading mechanisms of defibrillation: A computational approach to study the differences between monophasic and biphasic waveforms — •Daniel Frühwald[1] and Thomas Lilienkamp[1,2] — [1]Nuremberg Institute of Technology Georg Simon Ohm, Computational Physics for Life Science, Nuernberg, Germany — [2]Max Planck Institute for Dynamics and Self-Organization, Biomedical Physics Group, Goettingen, Germany

Sudden cardiac death caused by, for example, malignant ventricular arrhythmia, results in an estimated 600,000 deaths per year in the European Community alone. In addition, atrial fibrillation is the most common cardiac arrhythmia worldwide, affecting worldwide more and more people with around 33.5 million in 2010 and 59 million people in 2019. In both diseases, the heart can be reset to sinus rhythm by cardioversion: The application of a high-energy defibrillation shock delivered either from an external device, or from implantable cardioverter defibrillators (ICDs). In both cases, patients suffer from significant side effects due to this treatment, including additional tissue damage and post-traumatic stress. The introduction of biphasic waveforms, instead of monophasic ones enabled a significant reduction in energy leading to mitigated side-effects. While many hypotheses for the increased efficiency of biphasic waveforms exist, the underlying mechanisms are not entirely understood. In a statistically driven multi-scale study, we use numericalsimulations to investigate the influence of different cardiovascular structures on the success rate of defibrillation.

15 min. break

DY 22.7 Tue 11:15 ZEU/0118

Travelling waves of invasion in ecological communities with phenotypic variation — •Pierre A. Haas — Max Planck Institute for the Physics of Complex Systems — Max Planck Institute of Molecular Cell Biology and Genetics — Center for Systems Biology Dresden

Bacterial populations can switch to slowly growing "persister" subpopulations that are resilient to competition. Here, I will present a minimal model for the effect of this phenotypic variation on the spatial competition of two species. One of these species switches, both randomly and in response to the other, competitor species, to such a persister phenotype. One would expect this phenotypic switching to slow down the travelling wave by which the competitors invade the first species.
Combining exact results and numerical calculations, I will show that, surprisingly, this expectation does not hold true: phenotypic switching does not affect the speed of this wave. Somewhat conversely, I will demonstrate that phenotypic switching can speed up the reverse wave by which this species invades the competitors. This suggests that, counterintuitively, persisters can be an offensive, rather than defensive ecological strategy.

DY 22.8 Tue 11:30 ZEU/0118

How spatial patterns can lead to less resilient ecosystems — •David Pinto-Ramos and Ricardo Martinez-Garcia — Center for Advanced Systems Understanding (CASUS), Helmholtz-Zentrum Dresden-Rossendorf, Görlitz D-02826, Germany

Several theoretical models predict that spatial patterning increases ecosystem resilience. However, these predictions rely on simplifying assumptions, such as assuming isotropic and infinitely large ecosystems, and empirical evidence directly linking spatial patterning to enhanced resilience remains scarce. We introduce a unifying framework, encompassing existing models for vegetation pattern formation in water-stressed ecosystems, that relaxes these assumptions. This framework incorporates finite vegetated areas surrounded by desert and anisotropic environmental conditions that lead to non-reciprocal plant interactions. Under these more realistic conditions, we identify a novel desertification mechanism, known as nonlinear convective instability in physics but largely overlooked in ecology. These instabilities form when non-reciprocal interactions destabilize the vegetation-desert interface and can trigger desertification fronts even under stress levels where isotropic models predict stability. Importantly, ecosystems exhibiting periodic vegetation patterns are more susceptible to nonlinear convective instabilities than those with homogeneous vegetation, suggesting that spatial patterning may reduce, rather than enhance, resilience. These findings challenge the prevailing view that self-organized patterning enhances ecosystem resilience.

DY 22.9 Tue 11:45 ZEU/0118

Time-crystals in actively mode-locked lasers — Elias Koch[1], Ruiling Weng[2], Jesús Yelo-Sarrión[2], Josep Batle[2], Julien Javaloyes[2], and •Svetlana V. Gurevich[1,3] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str.9 48149 Münster, Germany — [2]Departament de Física and IAC3, Universitat de les Illes Balears, Campus UIB 07122 Mallorca, Spain — [3]Center for Data Science and Complexity (CDSC), University of Münster, Corrensstrasse 2, Münster, 48149, Germany

We propose a time-delayed model for the study of active mode-locking that is devoid of restriction regarding the values of the round-trip gain and losses. There, we report the occurence of discrete time-crystal phases and crystallites. By tuning either the bias current or the modulation frequency, the system undergoes a spontaneous symmetry-breaking transition from the harmonically mode-locked state towards robust, highly coherent time-crystal states that persist indefinitely. Two equivalent time-crystal configurations, shifted by one driving period, can coexist as domains separated by sharp, long-lived boundaries analogous to domain walls. Additionally, we present recent experimental results that are in good quantitative agreement with the theoretical predictions. Our findings demonstrate that mode-locked semiconductor lasers offer a readily accessible platform to explore and control non-equilibrium phases of light, enabling practical implementations of time-crystal physics in photonic systems.

DY 22.10 Tue 12:00 ZEU/0118

Unified Simulation Framework for Multi-Soliton Dynamics in Femtosecond Lasers — •Julia A. Lang[1], Julien Javaloyes[2], Svetlana V. Gurevich[3], and Georg Herink[1] — [1]University of Bayreuth, Germany — [2]University of the Balearic Islands, Spain — [3]University of Münster, Germany

Ultrafast lasers exhibit a rich variety of multi-pulse dynamics, strongly influenced by the underlying laser architecture and system-specific nonlinear effects.

In this contribution, we present a novel simulation approach that flexibly integrates diverse effects into a single, unified framework. A key feature of our model is the inclusion of full gain dynamics. This enables us to reproduce a wide range of experimentally observed soliton interactions, including harmonic mode-locking in erbium fiber lasers [1], the formation of soliton molecules via delayed feedback [2] or Raman-induced soliton molecules in Ti:sapphire lasers [2].

We introduce a classification of characteristic inter-soliton trajectories by attributing hierarchies of critical weights to nonlinear effects. The resultant classification provides deeper insights into the origins of multi-pulse interactions and enables novel approaches for harnessing multi-soliton applications.

[1] Lang JA et al. Sci Adv. 2024;10(2):eadk2290.
[2] Nimmesgern L et al. Optica. 2021;8(10):1334.
[3] Völkel A et al. Nat Commun. 2022;13(1):2066.

DY 23: Complex Fluids and Soft Matter (joint session DY/CPP)

Time: Tuesday 9:30–12:45 Location: ZEU/0160

DY 23.1 Tue 9:30 ZEU/0160

Process-Directed Self-Assembly of Copolymer Blends: Micro- and Macrophase Separation — •Jiayu Xie and Marcus Müller — Institute for Theoretical Physics, Georg August University Göttingen, 37077 Göttingen, Germany

The equilibrium phase behavior of binary diblock copolymer blends involves a complex interplay between microphase and macrophase separation. We investigate blends of linear diblock copolymers, A_1B_1 (cylinder-forming) and A_2B_2 (cylinder- or lamella-forming), using a combination of self-consistent field theory (SCFT) and single-chain-in-mean-field (SCMF) simulations. When the chain-length asymmetry between the A_1B_1 and A_2B_2 copolymers becomes large, the equilibrium phase diagram exhibits a wide macrophase-separation channel. Strikingly, our simulations reveal a strong pathway dependence within this region: rapid quenching yields a spatially homogeneous structure with narrow cylinder-size distributions and strong hexagonal order, whereas gradual annealing promotes local demixing, resulting in bimodal domain sizes and weaker order. We demonstrate that this process-dependent nonequilibrium behavior can be explained by the distinct evolutions of the system state and free-energy landscape of the blends under quenching or annealing. These findings highlight how different processing conditions can direct nanostructure formation in block copolymer blends, and establish a mechanistic link between processing pathway and the final morphology, thus offering insights into rational design of targeted nanostructured materials.

DY 23.2 Tue 9:45 ZEU/0160

Topological defect engineering enables size and shape control in self- assembly — Lara Koehler[1,3], Markus Eder[2], Vincent Ouzan-Reboul[3], Christoph Karfusehr[2], Andrey Zelenskiy[3], Pierre Ronceray[4], Friedrich Simmel[2], and •Martin Lenz[3] — [1]MIPPKS, Dresden, Germany — [2]TU Munich, Germany — [3]U. Paris-Saclay, Orsay, France — [4]Aix-Marseille-Université, Marseille, France

Equilibrium self-assembly is a powerful way to build nano- and microscale structures out of interacting subunits. The size and shape of such structures must be controlled in many biological and technological functions, posing significant practical challenges as current strategies require multiple subunit types or the precise control of their shape and mechanics. Here we introduce an alternative approach that circumvents these obstacles. Our method uses subunits whose interactions promote crystals, but also favor crystalline defects. We show

theoretically that the magnitude of these interactions, which is well controlled in experiments, governs the self-assembly through topological restrictions on the scope of the defects. Using DNA origami, we demonstrate both size and shape control in two-dimensional disk- and fiber-like assemblies. Our basic concept of defect engineering operates well beyond these examples, and provides a broadly applicable framework to control self-assembly.

DY 23.3 Tue 10:00 ZEU/0160

Soft colloidal monolayers under drying conditions — •Kai Luca Spanheimer[1], Maret Ickler[2], Julian Ringling[3], Nicolas Vogel[2], Matthias Karg[4], and Hartmut Löwen[1] — [1]Insitut für Theoretische Physik II, Heinrich-Heine-Universität, 40225 Düsseldorf, Germany — [2]Institute of Interfaces and Particle Technology, Friedrich-Alexander University, Erlangen, Germany — [3]Physikalische Chemie I: Kolloide und Nanooptik Heinrich-Heine-Universität, 40225 Düsseldorf, Germany — [4]Institut für Chemie, Martin-Luther-Universität Halle-Wittenberg, 06099 Halle, Germany

Langmuir-Blodgett deposition is a well established technique in research and industry. Even though, there still are effects in this process that are not yet explored from a theoretical standpoint. It is usually assumed that the deposited pattern is identical with the one appearing at the water-air interface. In recent experimental studies, strong reorganization during the drying of soft colloidal monolayers has been observed [1]. Capillary forces during drying are known to change nanoscopic structures, sometimes even leading to their destruction. To model these processes we propose a combination of overdamped particle dynamics coupled to dewetting dynamics of an evaporating liquid film. The patterns produced by this model fit those observed in experiment. This theoretical approach allows exploration of the drying dynamics. Thereby we gain new insights into the drying process and makes experimental results produced with Langmuir-Blodgett deposition more reliable.

[1] K. Kuk, et al: Adv. Sci., 11, 2406977 (2024).

DY 23.4 Tue 10:15 ZEU/0160

Mechanical assessment of microfluidically-generated poroelastic microgel particles — Aude Sagnimorte[1,2], Anke Lindner[2], and •Joshua McGraw[1] — [1]Gulliver-CNRS, ESPCI-PSL, 10 rue Vaquelin, 75005 Paris — [2]PMMH-CNRS, ESPCI-PSL, 10 rue Vaquelin, 75005 Paris

Soft microgels have numerous applications in diverse fields,such as tissue engineering, drug delivery systems, soft robotics, or as model systems for suspensions or colloids. Among these, photopolymerized hydrogels such as poly(ethylene glycol) diacrylate (PEGDA) are commonly used due to their highly tunable mechanical properties. However, proper characterisation of these properties is challenging, in part due to their small scale, on the order of tens of microns, and in particular the lack of assessment of their time-dependent properties. Here we provide a comprehensive mechanical characterisation of individual photopolymerised microgels particles using atomic force microscopy (AFM) for precise local measurements. In particular, we performed indentation-relaxation tests on PEGDA microdisks immersed in water. By varying indentation depth and probe diameter, we changed the contact area and observed relaxation responses which are indicative of poroelastic behaviour. In particular, larger contact areas resulted in longer relaxation times. Our results also show that increasing the amount of solvent increased the relaxation time. Our collected results are consistent with a simple, Herzian poroelastic model giving good agreement with both the approach and relaxation phases of the experiments.

DY 23.5 Tue 10:30 ZEU/0160

Nonlinear Viscoelastic Response and Stress Shielding in Driven Bistable Spring Chains — •Sven Pattloch[1,2] and Joachim Dzubiella[1,2] — [1]Applied Theoretical Physics-Computational Physics, Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, D-79104 Freiburg, Germany. — [2]Cluster of Excellence livMatS@FIT-Freiburg Center for Interactive Materials and Bioinspired Technologies, Albert-Ludwigs-Universität Freiburg, D-79110 Freiburg, Germany

Bistable micromodules are a promising route to design adaptive mechanical metamaterials with tunable viscoelastic response. Here, a driven one-dimensional chain of bistable springs is studied in which both the mechanical deformation and the internal excitation states evolve dynamically under time-dependent forcing. Their coupling produces rich nonlinear viscoelastic behaviour, including frequency-dependent susceptibilities, delayed deformation, and pronounced hysteresis in cyclic loading.

Using analytical linear response theory complemented by numerical simulations, the model quantifies how microscopic parameters and driving protocols control effective stiffness, loss, and phase lags. A key result is a strong attenuation ('shielding') of stress propagation along the chain that is already present for monostable springs but is markedly amplified by excitation switching in bistable modules. These findings provide simple design principles for tailoring nonlinear viscoelasticity, hysteresis, and stress shielding in driven soft matter and mechanical metamaterial systems.

DY 23.6 Tue 10:45 ZEU/0160

Euler buckling on curved surfaces — •Shiheng Zhao[1,2,3] and Pierre A. Haas[1,2,3] — [1]Max Planck Institute for the Physics of Complex Systems — [2]Max Planck Institute of Molecular Cell Biology and Genetics — [3]Center for Systems Biology Dresden

Nearly three hundred years ago, Euler showed that an inextensible straight elastic line in the plane buckles under compression when the compressive force F reaches a critical value $F_* > 0$. But how does such an elastic line buckle within a general curved surface? Here [1], we reveal that the classical instability changes fundamentally: By weakly nonlinear analysis of the buckling of an asymptotically short elastic line, we show that the critical force for the lowest buckling mode is $F_* = 0$ and discover a new bifurcation structure in which the modes of classical Euler buckling split into pairs. For long elastic lines, we numerically find an additional bifurcation by which the second of these new modes becomes the lowest mode and show that, at sufficiently large F, they undergo discontinuous snap-through to higher end-to-end compression. We explain these bifurcations in terms of the general unfolding of a pitchfork. This constitutes the foundations for a class of mechanical instabilities within curved surfaces from which, for example, biological shape emerges in development.

[1] S. Zhao and P. A. Haas, Phys. Rev. Lett. (in press)

15 min. break

DY 23.7 Tue 11:15 ZEU/0160

Linking molecular dynamics and experimental FORCs in multicore magnetic nanoparticles — Ekaterina Novak[1], •Malika Khelfallah[2], Andrey Kuznetsov[3], Deniz Mostarac[4], Claire Carvallo[2], Amélie Juhin[2], and Sofia Kantorovich[3] — [1]Ekaterinburg, Russia — [2]Sorbonne Université, Paris, France — [3]University of Vienna, Vienna, Austria — [4]University of Edinburgh, Edinburgh, United Kingdom

Multicore magnetic nanoparticles - clusters of several magnetic grains embedded in a nonmagnetic matrix - exhibit collective behaviour distinct from single-core particles and are promising candidates fro drug targeting and magnetic hyperthermia. Their magnetic cores possess finite anisotropy, and the multicore assemblies range from near-spherical to elongated ellipsoids, features that strongly affect their response to external fields. To study these effects, we use molecular dynamics simulations [1] to model internal structure, anisotropy distribution, and collective switching. As a key diagnostic, we employ First Order Reversal Curves [2], which experimentalists routinely measure for immobilised multicore particles, enabling direct comparison between simulations and experiments. FORC diagrams reveal coercivity distributions and magnetic interactions between grains, offering detailed insight into interaction mechanisms and domain processes.

The work was financially supported by the RSF grant No. 25-22-00762.

[1] R. Weeber et al. (2024), Comprehensive Computational Chemistry, 3, 578-601. [2] C. R. Pike et al., J. Appl. Phys., 1999, 85, 6660

DY 23.8 Tue 11:30 ZEU/0160

Hydrodynamics substantially affects induced structure formation in magnetic fluids — •Henning Reinken and Andreas M. Menzel — Otto-von-Guericke-Universität Magdeburg, Germany

Magnetorheological fluids consist of micrometer-sized magnetic particles suspended in a carrier liquid [1]. Sufficiently strong external magnetic fields lead to the formation of string-like particle aggregates, which results in complex magnetorheological behavior. This mechanism can further be used in the production of magnetic elastomers during the polymerization process when the carrier medium is still fluid and particulate structure formation still possible [2]. Using numerical

simulations that spatially resolve both fluid flows and magnetization, we demonstrate that hydrodynamic interactions play a substantial role during structure formation. Hydrodynamics supports the emergence of string-like aggregates, while magnetic interactions align them. Considering besides this fundamental insight the enormous technical importance and potential of magnetic fluids, our results are substantial also from an application perspective.

We acknowledge support by the German Research Foundation DFG through Research Unit FOR 5599 on structured magnetic elastomers.

[1] S. Odenbach, Arch. Appl. Mech. **86**, 269 (2016).
[2] D. Günther, D. Yu Borin, S. Günther, S. Odenbach, Smart Mater. Struct. **21**, 015005 (2012).

DY 23.9 Tue 11:45 ZEU/0160

Near-surface colloidal dynamics in jammed and slipping microgel suspensions — •Masoodah Gunny[1], Frédérick Caetano[2], Matilde Bureau[2], Alexandre Vilquin[1], Marie Le Merrer[2], Catherine Barentin[2], and Joshua McGraw[1] — [1]Gulliver - CNRS, ESPCI-PSL 10 Rue Vauquelin 75005 Paris, France — [2]ILM - CNRS, Claude Bernard University, 16 Enrico Fermi 69100 Villeurbanne, France

Jammed suspensions of soft microgel particles exhibit wall slip along smooth boundaries. The direct observation of dynamics within a supposed depletion layer near the wall were difficult to achieve as a result of the layers' supposed sub-micrometric dimensions. We use total internal reflection fluorescence microscopy (TIRFM) to observe colloidal-particle dynamics near the interface between glass and microgel suspensions. Remarkably, microgel suspensions display nanoscale velocity profiles with a slope rupture; particle velocity increases with distance near the wall, and tends to a constant beyond a distance which is characteristic of the ones predicted previously. Beyond velocimetry, we also study the statistical particle altitude distributions near the wall in TIRFM measurements. These distributions are strongly pressure dependent, with nanoparticles more likely found near the solid/liquid interface when the fluid is transported faster near the wall. This high-velocity particle enrichment, not seen for the Newtonian case, is consistent with the development of a depletion layer under such conditions. Taken together, our observations give strong support for the existence of a depletion layer being responsible for wall slip.

DY 23.10 Tue 12:00 ZEU/0160

Random close packing as a conserved directed percolation transition — •Thomas Axmann and Michael Schmiedeberg — Theoretical Physics: Lab for Emergent Phenomena, Soft Matter Theory Group, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

In studying quenches in soft sphere systems O'Hern et al. related the onset of overlaps to isostaticity [1], and consequently to the random close packing scenario. The conditions that lead to the avoidance of overlaps between spheres can be studied with the random organization model [2], which was initially introduced to investigate self organization in sheared colloids. Modifications of this model, which dynamically reduce interparticle overlaps, were used to characterize the random close packing problem as the critical point of a dynamic absorbing state transition in the $d+1$ dimensional conserved directed percolation universality [3,4].

We aim to deepen the understanding of this connection by demonstrating that the configuration change at each time step can be chosen with a fully deterministic strategy while retaining the features of the transition. We clarify difficulties in the treatment of percolating clusters and find that the median overlap depth proves to be a more useful order parameter.

[1] O'Hern et al. PRE 68 (2003)
[2] Corté et al. Nat. Phys. 4 (2008)
[3] Milz et al. PRE 88 (2013)
[4] Wilken et al. PRE 128 (2021)

DY 23.11 Tue 12:15 ZEU/0160

Rescaled mode-coupling scheme for dynamics in binary mixtures of highly charged colloids — •Daniel Weidig and Joachim Wagner — University of Rostock, Rostock, Germany

We investigate dynamic processes in binary mixtures of highly charged colloidal particles by means of Brownian dynamics and multi-component mode-coupling theory (MCT). As input for MCT, thermodynamically consistent, static structure factors from integral equations with Rogers-Young closure are used which are in quantitative agreement to Fourier transforms of static pair correlation functions resulting from simulations.

MCT based on partial structure factors in many-particle systems predicts dynamic properties such as long-time self-diffusion coefficients in qualitative agreement to simulation trajectories. Using instead structure factors from systems with slightly reduced number of effective charges as input, a quantitative agreement of MCT with simulations is achieved. In mixtures of identically charged particles with different short-time mobilities, this rescaled MCT scheme accurately predicts coupling effects in long-time dynamics observed in Brownian dynamics simulations.

DY 23.12 Tue 12:30 ZEU/0160

Electric double layers - the software package capDFT — Fabienne Dressler and •Andreas Härtel — Institute of Physics, University of Freiburg

Electric Double Layers are used to store electric energy, they can be utilized to harvest energy from waste heat or steps in concentrations, and they stabilize colloidal systems. In all cases, mobile ions arrange themselves to screen surface charges, resulting in sometimes densely packed regions of microscopic particles far from bulk states that dominate the macroscopic physical properties of the system. Modeling these complex systems has theoretical and numerical limitations, but good although expensive solutions exist. We present an open-source software package to treat the described modeling utilizing classical density functional theory [1]. The package has been used successfully in studies of underscreening [2] and allows to go beyond the standard mean-field approximation of primitive models [3]. We will demonstrate the package by discussing an example, where we study capacities of structured electrodes.

[1] https://github.com/andreashaertel/capdft
[2] Anomalous Underscreening in the Restricted Primitive Model. A. Härtel, M. Bültmann, and F. Coupette. Phys. Rev. Lett. 130, 108202 (2023)
[3] The primitive model in classical density functional theory: beyond the standard mean-field approximation. M. Bültmann and A. Härtel. J. Phys. Condens. Matter 34, 235101 (2022)

DY 24: Focus Session: Water – from Atmosphere to Space II (joint session CPP/DY)

Time: Tuesday 11:15–12:45 Location: ZEU/LICH

DY 24.1 Tue 11:15 ZEU/LICH

Microscopic diffusion and reactivity in aqueous solutions: photogenerated nascent halogen atoms, solvated electrons and subsequent dihalide formation — •Zhangatay Nurekeyev[1,2], Hyein Hwang[1,2], Fernando Rodriguez Diaz[1], Mei Bai[3], Michael Thorwart[3], Michaela Schäfer[4], Carmen Herrmann[4], and Christian Bressler[1,2,5] — [1]Inst. of Exp. Physics, Universität Hamburg — [2]The Hamburg Centre of Ultrafast Imaging (CUI) — [3]I. Inst. of Theor. Physics, Universität Hamburg — [4]Dept of Chemistry, Universität Hamburg — [5]European XFEL, Schenefeld

The solvent plays an important role in the assembly, stability and reactivity of (bio)chemical molecules. Small changes of the caging solvent can alter the reaction outcome, but little is known about the atomic-scale solvation shell dynamics. Our approach utilizes aqueous mono-atomic halide solutes, which are transformed into nascent neutral halogen atoms upon femtosecond optical excitation together with a separated solvated electron. Combining X-ray absorption with transient optical absorption spectroscopies we monitor the subsequent diffusion-driven atom-electron recombination, each focusing on the halogen atom and on the solvated electron, respectively. We also monitor the appearance of dihalides on the tens of picosecond time scale. Using all x-ray and laser observables we deliver a new picture of the ensuing dynamics, for which the existence of the long-lived (X:e) contact pair is not required. Next steps aim to trace more complex guest-host scenarios towards functional proteins in solution.

DY 24.2 Tue 11:30 ZEU/LICH

Surface Propensity of Halide Ions in Water: New Evidence from LJ-XPS — •Daniela Torres-Díaz[1], Shirin Golami[1], Tillmann Buttersack[1], Qi Zhou[1], Rémi Dupuy[2], Bernd Winter[1], Chistophe Nicolas[3], and Hendrik Bluhm[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]Laboratoire de Chimie Physique - Matière et Rayonnement (Sorbonne Université, CNRS), Paris, France — [3]Synchrotron SOLEIL, Saint-Aubin, France

The surface propensity of halide ions in water is still a matter of debate. While the famous Onsager&Samaras model indicates that charged species should avoid the interface, more recent Molecular Dynamics simulations that take into account the polarizability of the ions indicate notably that iodide and bromide prefer the interface while chloride and fluoride avoid it. Different models, however, differ in how strong this effect is, while experimental studies have reported contradictory results. Here I will discuss recent results obtained using Liquid-Jet X-Ray Photoemission Spectroscopy on water interfaces for potassium halide solutions. In particular, the measurement of the photoelectron angular distributions allow for a higher spatial resolution than classic XPS measurements.

DY 24.3 Tue 11:45 ZEU/LICH

Ion Correlations Drive Collective Adsorption of Hydronium Ions at the Air-Electrolyte Interface — •Elena Köhler Ruiz, Maximilian Becker, Louis Lehmann, and Roland Netz — Fachbereich Physik, Freie Universität Berlin, Germany

Acids exhibit distinct interfacial behavior at the air-water interface compared to simple monoatomic salts. While monoatomic ions are largely repelled from the interface, hydronium ions preferentially reside at the interface due to formation of an interfacial hydrogen-bond network. To investigate these contrasting behaviors, we perform molecular-dynamics simulations with thermodynamically optimized force fields, analyzing ionic distributions at the interface as well as resulting surface tensions and potentials. The simulated surface potentials reproduce the concentration-dependent trends observed in SFG experiments: At high concentrations, interfacial hydronium promotes co-adsorption of counterions, which results in a decrease of the surface potential with rising concentration, consistent with experimental observations. These findings highlight the critical role of ion-ion correlations at interfaces, which are not accounted for by modified Poisson-Boltzmann models.

DY 24.4 Tue 12:00 ZEU/LICH

Calcium-amino acid complexation in water probed by Intermolecular Coulombic Decay — •Michele Pugini, Nicolas Velasquez, Harmanjot Kaur, Florian Trinter, Qi Zhou, Lukas Tomaník, Uwe Hergenhahn, and Bernd Winter — Fritz-Haber-Institut, Berlin

The Ca2+ ion is the most abundant metal ion in the human body, playing essential roles in numerous biological processes, many of which involve interactions with proteins. Gaining molecular-level insight into the nature of the interaction between Ca2+ ions and solvated amino acids is therefore crucial for understanding calcium's biological function. Intermolecular Coulombic decay (ICD), a non-local autoionization process, offers unique sensitivity to the local chemical environment and can selectively probe interactions within the first solvation shell of solvated Ca2+ ions.

Here, we demonstrate the sensitivity of resonant ICD3 to the chemical composition of the solvation shell, enabling the identification of Ca2+ associations with specific amino acids. Our model system is the amino acid proline. The interaction, if present, is revealed via the ICD electrons resulting from the ionization of the biomolecule upon the 2p to 3d excitation of Ca2+.

Our results unequivocally identify Ca2+-proline interactions, indicating substitution of water molecules in the ion's coordination shell by proline. These findings establish ICD as a sensitive probe of metal-biomolecule interactions and highlight its potential as a powerful spectroscopic tool for investigating biomolecular structure in solution.

DY 24.5 Tue 12:15 ZEU/LICH

Distinguishing cavity and non-cavity solvation structures of the hydrated electron — •Sy Dat Ho and Benjamin Philipp Fingerhut — Department of Chemistry and Centre for NanoScience, Ludwig-Maximilians-Universität München, 81377 München, Germany

Solvated electrons in water are prototypical low-dimensional quantum systems that are coupled to a fluctuating, many-body environment. However, their hydration structure is still a matter of debate, with both cavity and non-cavity models having been suggested. First-principles molecular dynamics simulations are performed of excess-electron localization in liquid water, using hybrid-meta-GGA and hybrid-GGA density functionals that accurately reproduce bulk water structure. Perturbations to the local hydrogen bond structure of water due to interaction with the excess charge are identified, giving rise to specific signatures in transient radial distribution functions. These patterns are then compared with preliminary liquid-phase MeV-UED data obtained during an early science campaign at SLAC. In order to distinguish the structural changes induced by excess electrons in the diffraction patterns, long-time simulations at an unprecedented level of theory are required in order to minimise statistical noise. Our results clarify the coupling of hydrated electrons to solvent fluctuations and provide microscopic insight into polaron formation in disordered condensed phases.

DY 24.6 Tue 12:30 ZEU/LICH

Mesoscopic Structures in Water/HFIP based Electrolytes — •Sophie Zeilinger[1,2] and Markus Mezger[1] — [1]Center for Nano Structure Research, Faculty of Physics, University of Vienna, AT-1090 Vienna — [2]Institute of Physical Chemistry, Faculty of Chemistry, University of Vienna, AT-1090 Vienna

Previous studies have shown that binary water/hexafluoroisopropanol (HFIP) mixtures exhibit nanoscale heterogeneties that strongly affect properties such as reaction rates. The complex hydrogen bonding network of the binary mixture together with the amphiphilic character of the HFIP molecule provides a sensitive environment in which subtle changes in interactions can generate nanoscale heterogeneties. Here, we study the structure formation in water/HFIP under the influence of hydrophilic and hydrophobic ions by Small Angle X-Ray Scattering (SAXS). Depending on water content, pH, salt concentration and temperature we observe monotonous and oscillatory density correlations with structural parameter on the nanometer length scale. These structures are explained by the coupling of coulombic interactions between charged hydrophilic and hydrophobic ions vs. local fluctuations in water/HFIP concentrations.

DY 25: Franco-German Session on Granular Matter II

Granular media exhibit rich collective behavior arising from simple interactions such as friction, collisions, elasticity, and confinement. This session brings together experimental, numerical, and theoretical studies addressing key transitions in granular systems, including jamming, viscous-to-inertial regimes, clustering, gas cooling, and impact dynamics, highlighting the links between microscopic mechanisms and macroscopic responses.

Organized by Baptiste Darbois Texier (Paris) and Franco Antonio Tapia Uribe (Dresden)

Time: Tuesday 14:00–15:30 Location: HÜL/S186

DY 25.1 Tue 14:00 HÜL/S186

Avalanches of a granular medium reinforced with flexible fibres — •Baptiste Darbois Texier, Georges Gauthier, and Ladislas Wierzchalek — FAST, CNRS UMR 7608, University Paris-Saclay

Debris flows and landslides are catastrophic geophysical events that typically occur on sloped terrains and involve a large amount of granular materials in motion. At the laboratory scale, such events can be studied by observing avalanches of granular materials flowing down a slope and analyzing the factors that influence their initiation and cessation. In this study, we explore the effect of incorporating flexible fibres into granular media as a strategy to attenuate avalanches and stabilize granular piles. While fibre reinforcement has been shown to enhance the mechanical strength of soils, its influence on avalanche dynamics remains largely unexplored. We perform rotating-drum experiments at low rotation speeds using mixtures of grains and flexible fibres with varying volume fractions and aspect ratios. We measure the angles at which avalanches start and stop, as well as the relaxation dynamics following individual events. Increasing the fibre content or aspect ratio systematically raises both start and stop angles and broadens their distributions, accompanied by a marked rise in the number of small-amplitude avalanches. Analysis of relaxation curves further shows that fibres enhance dissipation, leading to slower, more gradual avalanche decay compared with pure grains. These findings provide quantitative evidence of the stabilizing effects of fibres on granular slopes and their role in dissipating energy during avalanches.

DY 25.2 Tue 14:15 HÜL/S186

Magnetic-Field Controlled Self-Diffusion and Clustering in Ferrogranular Mixtures — •Oksana Bilous[1], Kirill Okrugin[1], Ali Lakkis[2], Richter Reinhard[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

We investigate self-diffusion in ferrogranular mixtures of magnetic and glass beads via Langevin/molecular dynamics of quasi-2D Stockmayer spheres mixed with repulsive non-magnetic ones, complemented by mm-scale experiments. We vary out-of-plane magnetic induction and total area fraction. The field aligns dipoles and reduces in-plane aggregation by inducing repulsion, while dipole-dipole interactions and central attractions (or susceptibility in experiments) drive chain-like and compact clustering. Increasing area fraction counteracts field-induced suppression and stabilizes larger clusters. Single magnetic particles and glass beads remain mostly diffusive, with diffusion only weakly concentration dependent, whereas particles embedded in clusters show persistent subdiffusion. The field also alters diffusion type: cluster-bound particles exhibit robustly non-Gaussian dynamics that amplify with area fraction and field. At sufficiently high induction and crowding, the glass component becomes non-Gaussian, revealing field-driven dynamical freezing of the non-magnetic species. Simulations and experiments consistently show how external fields, dipolar self-assembly, and crowding govern transport in ferrogranular layers.

DY 25.3 Tue 14:30 HÜL/S186

Angular Velocity of Spherical Particles in a Granular Gas under Microgravity during Granular Cooling — •Mahdieh Mohammadi[1], Raúl Cruz Hidalgo[2], Dmitry Puzyrev[3], Ralf Stannarius[1,3], and Kirsten Harth[1,3] — [1]Department of Engineering, Brandenburg 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]MARS and MTRM, Otto von Guericke University Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

We investigate the rotational dynamics of spherical particles in a granular gas in microgravity, which allows a clean realization and observation of collisional kinetics. The system starts in a highly excited state and undergoes dissipative collisional cooling (loss of mean kinetic energy). Patterned spheres were tracked from video data using two cameras, their 3D trajectories and velocities were extracted. Surface markers enable 3D orientation reconstruction via feature-based and projection-consistent analysis. Continuous angular trajectories are obtained by interpolating missing orientation data. From these, we extract angular velocities and analyze their evolution across different cooling intervals.

Our studies are funded within by the German Aerospace Center (DLR) projects PARADYSE, KORDYGA and EVA-II (50WM2542, 50WM2242, 50WK2348).

DY 25.4 Tue 14:45 HÜL/S186

Granular gas mixtures: Experiments and numerical simulations — •Dmitry Puzyrev[1], Kirsten Harth[2,1], Torsten Trittel[2,1], Raúl 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]University of Navarra, Pamplona, Spain

Granular gases are ensembles of free-moving macroscopic particles which collide inelastically, which leads to effects like unusual heating (gain of mechanical energy from external sources) and cooling (dissipative loss of mechanical energy), clustering, and spontaneous collective movement. Such systems can exist in different dynamical regimes depending on filling fraction, particle shapes and material properties, as well as external energy input. Our investigation is focused on 3D microgravity experiments with ensembles of non-spherical, rod-shaped particles [1] and their mixtures [2]. Machine learning-aided software used for particle detection, 3D matching and tracking is available as an open-source package [3] and can be applied to other multiparticle tracking problems. In addition to previously published results for a mixture of thinner and thicker rods [2], we present the initial results for a short/long rods mixture. Our studies are funded within by the German Aerospace Center (DLR) projects EVA-II, VICKI, KORDYGA and PARADYSE (50WK2348, 50WM2252, 50WM2242, 50WM2542). [1] K. Harth et al., Rev. Lett., 120, 214301 (2018) [2] Puzyrev et al., npj Microgravity, 10, 36 (2024) [3] A. Niemann et al., github.com/ANP-Granular/ParticleTracking, JOSS 10(109), 5986 (2025)

DY 25.5 Tue 15:00 HÜL/S186

Granular gases of non-convex particles: Experiments and numerical simulations — Torsten Trittel[1,2], Mohammad Enezz[1], Dmitry Puzyrev[2], Kirsten Harth[1], Raúl Cruz Hidalgo[3], and •Ralf Stannarius[1,2] — [1]Brandenburg University of Applied Sciences, Brandenburg an der Havel, Germany — [2]Otto von Guericke University Magdeburg, Magdeburg, Germany — [3]University of Navarra, Pamplona, Spain

Granular gases are dilute ensembles of macroscopic particles that are not in permanent contact. Owing to the low packing fraction, they interact only by random inelastic collisions. Consequences are permanent dissipative loss of mechanical energy (granular cooling) and spontaneous clustering. Most experiments and numerical simulations so far considered spheres. The present study investigates spatial crosses (hexapods). They add more complexity in the particle interactions, and alter the role of the collisions in the exchange of translational and rotational kinetic energies. We present experiments performed in microgravity on a suborbital rocket flight [1], demonstrate particle tracking from the optical video data [2], and show results of DEM simulations of these systems. The study is funded within by DLR within projects EVA-II and JACKS (50WK2348, 50WM2340).

[1] https://sscspace.com/six-science-projects-to-space-from-sweden/

[2] A. Niemann et al., JOSS 10(109), 5986 (2025)

General Discussion

DY 26: Focus Session: Water – from Atmosphere to Space III (joint session CPP/DY)

Time: Tuesday 14:00–15:30 Location: ZEU/LICH

Topical Talk DY 26.1 Tue 14:00 ZEU/LICH

Why water in plants survives negative pressure — Marin Šako[1,2], Emanuel Schneck[3], Roland Netz[4], and •Matej Kanduč[1] — [1]Jožef Stefan Institute, Ljubljana, Slovenia — [2]University of Ljubljana, Faculty of Mathematics and Physics, Ljubljana, Slovenia — [3]Physics Department, Technische Universität Darmstadt, Darmstadt, Germany — [4]Fachbereich Physik, Freie Universität Berlin, Berlin, Germany

It may seem surprising that we can lower the pressure in a liquid to negative values, far below the saturated vapor pressure at which a vapor phase should form. In water, such deeply metastable states are possible only when it is exceptionally pure and free of nucleation sites. It is therefore even more striking that plants transport water at negative pressures down to −100 atm without cavitation, even though xylem sap is anything but pure: it contains dissolved ions, sugars, lipids, and other organic molecules. How is this possible?

In this talk, I will show how molecular simulations and theory can explain this surprising behavior. We find that amphiphilic molecules such as lipids can adsorb onto hydrophobic surface crevices — places that would normally trap nanobubbles. Once coated, these surface defects can no longer stabilize bubbles, which allows water to stay intact even under strong tension. This mechanism offers a molecular-level explanation for how trees transport water to heights of over 100 meters without cavitation. More broadly, it illustrates how soft-matter physics and interfacial molecular organization can control the mechanical stability of liquids under extreme conditions.

DY 26.2 Tue 14:30 ZEU/LICH

Cholesterol Controlled Photo-Switching Activity of Azobenzene Glycoconjugates in Lipid Membranes — •Prashant Hitaishi[1,2], Svenja C. Hövelmann[1,2], Michael Röhrl[3], Nicolas Hayen[1], Ella Diebell[1], Ali Ashtiani[1], Carlotta Mager[1], Thisbe Lindhorst[3], and Bridget M. Murphy[1,2] — [1]Institute of Experimental and Applied Physics, Kiel University, Leibnizstraße 19, Kiel, 24118, Germany — [2]Ruprecht Haensel Laboratory, Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, Hamburg, 22607, Germany — [3]Otto Diels-Institut für Organische Chemie, University of Kiel, Germany

Reversible photo-switchable molecules enable precise optical control of soft interfaces and are attractive for smart surfaces and light-triggered drug delivery. Azobenzene glycoconjugates (Azo) undergo reversible trans-cis isomerization under alternating UV and visible illumination, thereby modulating their conformation and interactions with lipid membranes. Here, Azo is incorporated into DPPC monolayers containing 0, 15, or 30 mol% cholesterol to mimic biologically relevant membrane compositions. Langmuir monolayer isotherm studies combined with time-resolved illumination cycles and X-ray measurements are used to quantify Azo-induced changes in membrane structure and relaxation kinetics. Increasing cholesterol slows Azo photo-switching, indicating a more constrained, rigid nanoenvironment, and shows that membrane composition can be used to tune light responsiveness in lipid interfaces for designing azobenzene-based responsive biomaterials.

DY 26.3 Tue 14:45 ZEU/LICH

Photoelectron Angular Distributions of Ions Influenced by Surfactants at the Solution-Vapor Interface — •Shirin Gholami[1], Tillmann Buttersack[1], Clemens Richter[2], Rémi Dupuy[3], Daniela Torres-Díaz[1], Christophe Nicolas[4], Uwe Hergenhahn[1], and Hendrik Bluhm[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]SPECS Surface Nano Analysis GmbH, Berlin, Germany — [3]Sorbonne Université, CNRS, Paris, France — [4]Synchrotron SOLEIL, Paris, France

Aqueous liquid-vapor interfaces play key roles in atmospheric and oceanic processes. The ocean-air boundary forms the largest aqueous-vapor interface, covering over 70 % of Earth's surface. In addition to Na^+ and Cl^-, Mg^{2+} and SO_4^{2-} are the most abundant ions in ocean water.

Here, we investigate how Mg^{2+} and SO_4^{2-} ions behave at the aqueous solution-vapor interface in the presence of charged surfactants. Using sub-monolayer coverages of octylamine $-CNH_3^+$ and octanoate $-COO^-$, we examine how these surfactants modify the distance of the ions from the interface. Liquid-jet X-ray photoelectron spectroscopy in combination with photoelectron angular distributions provides Å-scale depth sensitivity, enabling us to quantify ion-surfactant interactions.

Our results show that differently charged surfactants shift the interfacial positioning of Mg^{2+} and SO_4^{2-}, and that specific ion-ion interactions influence their interfacial propensity.These findings reveal how surfactants govern the depth distribution of ions, providing insight into oceanic and atmospheric processes.

DY 26.4 Tue 15:00 ZEU/LICH

Contact line dynamics on moving fibers measured by X-ray holography — •Louisa E. Kraft[1,2], Jens Lucht[3], Fiona Berner[1,2], Hannes P. Hoeppe[3], Tobias Eklund[1,2], Yizhi Liu[1], Markus Osterhoff[3], Tim Salditt[3], Hans-Jürgen Butt[1], and Katrin Amann-Winkel[1,2] — [1]Max Planck Institute for Polymer Research, Mainz, Germany — [2]Johannes Gutenberg University, Institute for Physics, Mainz, Germany — [3]Georg-August-University, Institute of X-ray Physics, Göttingen, Germany

The wetting properties of solid surfaces are important for many natural and industrial processes, especially with respect to dynamic wetting. The wetting dynamic of solid surfaces, in particular the quantitative description of the dynamic contact angles, is still under debate. Dynamic contact angle variations connect macroscopically measured quantities with microscopic processes. Most studies rely on optical or confocal microscopy which limits the experimental access to the submicroscopic region where these processes take place. We present data from X-ray holography experiments, imaging the three-phase contact line on moving glass fibers with an improved spatial resolution of about 450 nm combined with a temporal resolution of 10 Hz. We used the GINIX nanofocusing setup at the P10 beamline at PETRA III (DESY, Hamburg). The used glass fibers were pulled out of a liquid bath filled with varying aqueous solutions while changing the lateral velocity. We could clearly observe a decrease of the receding dynamic contact angle with increasing fiber velocity confirming the predictions of dynamic wetting theory.

DY 26.5 Tue 15:15 ZEU/LICH

Properties of micrometre-sized supercooled water droplets — Claudia Goy[1], •Frédéric Caupin[2], Felix Lehmkühler[1], and Robert E. Grisenti[3,4] — [1]Deutsches Elektronen Synchrotron DESY, Hamburg, Germany — [2]Université Claude Bernard Lyon 1, Villeurbanne, France — [3]GSI, Darmstadt, Germany — [4]J. W. Goethe-Universität, Frankfurt am Main, Germany

Water displays a wide range of anomalous behaviors, many of which become particularly pronounced in the supercooled state, where its properties deviate strongly from those of other liquids. A prevailing hypothesis suggests that, at low temperatures, water may locally adopt two distinct structural motifs. This presentation will discuss results from temperature-dependent experiments that probe the physical and chemical properties of liquid water. The studies employ evaporatively cooled liquid jets in vacuum, investigated with techniques such as Raman spectroscopy and X-ray spectroscopy. These approaches enable a detailed examination of inter- and intramolecular vibrational modes, providing insight into the molecular dynamics of cooling water and optical properties, including the refractive index. Together, these experimental methods offer a comprehensive view of the temperature-dependent behavior of water, shedding light on the complex interactions that drive its anomalies. Through these studies, we aim to elucidate the mechanisms governing water's unique behavior in the supercooled regime and contribute to a deeper understanding of its structural transformations and physical properties.

DY 27: Statistical Physics far from Thermal Equilibrium II

Time: Tuesday 14:00–15:30 Location: ZEU/0114

DY 27.1 Tue 14:00 ZEU/0114

Efficiency of Carnot-like engine for intracellular diffusivity fluctuations and diffusing diffusivity — •Yuichi Itto — Aichi Institute of Technology, Japan — ICP, Universität Stuttgart, Germany

In contemporary physics of intracellular diffusion, much attention is paid to understanding how environmental conditions affect the diffusivity [1], the change of which is crucial, e.g., for tuning the rates of biochemical reactions. Recently, the heat-like engine for local diffusivity fluctuations, which slowly vary and obey a universal exponential law, has been constructed to extract the diffusivity change in a cycle realized by compression/expansion of cells and temperature change [2]: it has the Carnot-like efficiency determined by the average diffusivity.

Here, the effect of slowly varying fluctuation on the efficiency [3] is discussed based on "diffusing diffusivity" [4] that describes the dynamics of the fluctuation distribution by an advection-diffusion equation, the stationary solution of which is of the exponential type. The entropy of the fluctuations, which gives the exponential law at its maximum, takes positive production rate under the dynamics. The tendency to approach the (stationary) average diffusivity is dominantly governed by the factor characterizing the diffusion term in its square root, showing its peculiar role in view of the fact that the exponential law is due to the advection term.

References [1] N. Bellotto, J. Agudo-Canalejo, R. Colin, R. Golestanian, G. Malengo, V. Sourjik, eLife 11, e82654 (2022). [2] Y. Itto, Eur. Phys. J. B 98, 183 (2025). [3] Y. Itto, arXiv:2511.06851 (2025). [4] M. V. Chubynsky, G. W. Slater, Phys. Rev. Lett. 113, 098302 (2014).

DY 27.2 Tue 14:15 ZEU/0114

Relaxation speed in quenched-random force fields — •Jan Meibohm and Sabine H.L. Klapp — Technische Universität Berlin, Institut für Physik und Astronomie, Fachgruppe Theoretische Physik, Hardenbergstraße 36, 10623 Berlin, Germany

We determine the asymptotic relaxation speed of a Brownian particle in quenched-random force fields with a harmonic background in dimensions $d \geq 2$. For random forces derived from a potential, we show that relaxation is generally slower than in the unperturbed case when the background is isotropic. By contrast, for strongly anisotropic backgrounds, where the background is stiffer in all directions except one, we find a crossover between slow and fast relaxation, similar to the one-dimensional case discussed in [1]. Allowing for non-potential forces changes this picture and leads to generally faster relaxation. In the limits of small and large correlation length of the random force, we identify universal regimes in which the relaxation speed becomes independent of of the details of the random forces. Finally, we analyse a scaling limit for quasi-isotropic backgrounds at weak disorder, where the change in relaxation speed becomes anomalously large.

[1] Meibohm & Klapp, Phys. Rev. Lett., 134.8, 087101 (2025)

DY 27.3 Tue 14:30 ZEU/0114

Mpemba effect for a particle in a bistable potential: classical versus quantum — •Jannis Michael Melles[1], Hartmut Löwen[1], Benno Liebchen[2], and Alexander Antonov[1] — [1]Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany — [2]Institut für Physik der kondensierten Materie, Technische Universität Darmstadt, Darmstadt, Germany

An anomalous cooling behavior where initially hot systems cool faster than initially warm ones is referred to as the Mpemba effect and clearly goes beyond quasi-static thermodynamics. For classical particles, such a cooling behavior has been thoroughly studied for a simple paradigmatic set up involving a single classical colloidal particle in a bistable optical potential [1]. We quantize this model and consider a quantum particle coupled to an external bath with the Lindblad damping [2]. The Mpemba effect does occur during the cooling of this quantum system; however, the origin of the anomalous cooling is qualitatively massively different from that of its classical counterpart for temperatures close to or at zero. Additionally, we identify a doubled inverse quantum Mpemba effect when the system is heated instead. Our results are amenable for an experimental verification with an ultracold atom in a suitable laser-optical trap potential.

[1] A. Kumar and J. Bechhoefer, Nature **584**, 64 (2020)

[2] J. Melles, H. Löwen, B. Liebchen and A. Antonov, to be published

DY 27.4 Tue 14:45 ZEU/0114

Brownian gyrators: from mono- to quadrupolar gyration — •Iman Abdoli and Hartmut Löwen — Institut für Theoretische Physik II - Soft Matter, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany

Thermally anisotropic Brownian systems-where different spatial directions are coupled to different effective temperatures-break detailed balance and generate circulating probability currents, exemplified by the Brownian gyrator. Such systems provide a minimal framework for studying nonequilibrium energy conversion and the emergence of directed motion and torques driven purely by fluctuations. We demonstrate how these anisotropic fluctuations can be harnessed as a microscopic heat engine, whose efficiency can approach Carnot performance at maximum power when appropriately loaded with external mechanical forces [1]. Furthermore, we show that confining a thermally anisotropic particle to a narrow ring produces quadrupolar steady-state gyration, a symmetry-protected circulation pattern arising solely from anisotropic noise [2]. These results highlight the rich flux structures and energetic functionalities enabled by thermal anisotropy.

[1] I Abdoli, A Sharma, H Löwen, Phys. Fluids. 37 (4)

[2] I Abdoli, H Löwen, arXiv preprint arXiv:2508.08792

DY 27.5 Tue 15:00 ZEU/0114

Role of kinetics in mesoscopic dynamics of a driven Potts model — •Maciej Chudak[1], Massimiliano Esposito[2], and Krzysztof Ptaszyński[1] — [1]Institute of Molecular Physics, Polish Academy of Sciences, Mariana Smoluchowskiego 17, 60-179 Poznań, Poland — [2]Department of Physics and Materials Science, University of Luxembourg, 30 Avenue des Hauts-Fourneaux, L-4362 Esch-sur-Alzette, Luxembourg

The Potts model is a generalization of the Ising model, where spins can take more than two states. We study a driven three-state nonequilibrium Potts model with homogeneous all-to-all coupling. At a macroscopic level, this model exhibits complex behavior such as synchronization and persistent oscillations (limit cycles). In the mean-field limit the model dynamics is described via deterministic equations of motion. Choice of the transition rate function can reshape the phase diagram of the model. We identified seven distinct dynamical phases separated by seven bifurcation types. Beyond the mean-field analysis, we characterize the effect of rare fluctuations on the model behavior. We determine the coherence lifetime of the oscillations and compare it to a thermodynamic bound given by the entropy production per cycle. The trade-off between coherence lifetime and entropy production can be fine-tuned. We characterize the rare stochastic transitions among the coexisting mean-field attractors using the instanton approach. Such transitions tend to relax the system to a single attractor that determines the macroscopic behavior of the model. In case of multistability, the ordered state is usually the most likely.

DY 27.6 Tue 15:15 ZEU/0114

Continuous-time multifarious systems — •Jakob Metson[1], Saeed Osat[1,2], and Ramin Golestanian[1,3] — [1]Max Planck Institute for Dynamics and Self-Organization (MPI-DS), 37077 Göttingen, Germany — [2]Institute for Theoretical Physics IV, University of Stuttgart, 70569 Stuttgart, Germany — [3]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

Multifarious assembly models consider multiple structures assembled from a shared set of components. We explore Gillespie simulations of lattice-based assembly models, comparing these to Monte Carlo simulations. We start with an equilibrium model, in which detailed balance is obeyed. However, due to the rough energy landscape, the systems often end up in long-lived metastable states. Despite this, the Gillespie and Monte Carlo simulations are largely consistent. We present physical arguments to predict the state boundaries, which also reconciles a small discrepancy between the two simulation methods. We furthermore study an explicitly non-equilibrium model, the non-reciprocal multifarious self-organisation model. Here, non-reciprocal interactions between the building blocks break detailed balance. Also in this case, the Gillespie and Monte Carlo simulations demonstrate the

same range of behaviours. Additionally, we explore the timescales of shape-shifting present in this model, developing analytical calculations to compare with simulations. Overall, these results demonstrate that both Gillespie and Monte Carlo simulations can be relied on to explore such systems, even when the dynamics are far from equilibrium.

DY 28: Fluid Physics and Turbulence

Time: Tuesday 14:00–15:15 Location: ZEU/0118

Invited Talk DY 28.1 Tue 14:00 ZEU/0118

Geometry of turbulent mixing in thermal convection — •Jörg Schumacher — Institut für Thermo- und Fluiddynamik, TU Ilmenau, Germany

Thermal convection flows, which are driven by buoyancy forces, are ubiquitous in nature and technology ranging from atmospheric dynamics to heat transfer in blankets of nuclear fusion devices. They are mostly connected to further physical processes, such as phase changes, radiation or magnetic fields, but the paradigm to all these turbulent flows is the plane Rayleigh-Bénard convection layer that is uniformly heated from below and cooled from above. In my talk, I will review some recent numerical investigations, both in the Eulerian and Lagrangian frames of reference, which shed new light on geometric aspects of these flows. This comprises the organization of thermal plumes in hierarchical and self-affine near-wall networks, the large-scale organization of the flow structures, and the organization of tracer particle tracks to extreme swirling events. Consequences for the turbulent transport of heat and momentum across the convection layer and their necessary modeling will be discussed.

DY 28.2 Tue 14:30 ZEU/0118

Compression, simulation, and synthesis of turbulent flows — •Stefano Pisoni[1,2], Raghavendra Peddinti[2], Siddhartha Morales[2], Egor Tiunov[2], and Leandro Aolita[2] — [1]TUHH, Hamburg, Germany — [2]TII Abu, Dhabi, UAE

Numerical simulations of turbulent fluids are paramount to real-life applications. However, they are also computationally challenging due to the intrinsically non-linear dynamics, which requires a very high spatial resolution to accurately describe them. A promising idea is to represent flows on a discrete mesh using tensor trains (TTs), where the values of the velocity field are encoded as a product of matrices (also known as Matrix Product States). This representation features an exponential compression of the number of parameters, under the assumption of low inter-scale correlations. However, it is yet not clear how the achieved compression of TTs is affected by the complexity of the flows. In fact, no TT fluid solver has been extensively validated in a fully developed turbulent regime yet. We fill this gap by analyzing TTs as an Ansatz to compress, simulate, and generate 3D snapshots with turbulent-like features. We first investigate the effect of TT compression on key turbulence statistical signatures. Second, we present a TT solver to time evolve a 3D fluid fields according to the incompressible Navier-Stokes equations. Third, we develop a memory-efficient TT algorithm to generate artificial snapshots displaying turbulent-like features. In all three cases we observe that the memory-efficient TT representation captures the relevant features of turbulent flows, offering a powerful quantum-inspired toolkit for their computational treatment.

DY 28.3 Tue 14:45 ZEU/0118

Physics-based reduced order modeling of complex chemical reactors — •Lisanne Gossel[1], Leon L. Berkel[2], Maira Gauges[2], Paul Brand[1], Mathis Fricke[1], Christian Hasse[2], Alessandro Stagni[3], Hendrik Nicolai[2], Dieter Bothe[1], and Tiziano Faravelli[3] — [1]Mathematical Modeling and Analysis, Technical University of Darmstadt, Darmstadt, Germany — [2]Simulation of Reactive Thermo-Fluid Systems, Technical University of Darmstadt, Darmstadt, Germany — [3]CRECK Modeling Group, Politecnico di Milano, Milan, Italy

Understanding and predicting observables in complex reacting flows is crucial for many applications related to the clean energy transition. We are interested in describing chemical reactors with detailed, often multiphase chemistry including thousands of reactions. While detailed understanding of the fluid physics can be gained by highly-resolved numerical models of the reactors, i.e., different types of Computational Fluid Dynamics (CFD) simulations, these usually rely on strongly simplified chemistry models to retain computational tractability. On the other hand, we use a physics-based reduced order method that allows to complement CFD by detailed chemistry computations. This is achieved by describing the reactor by a network of modeling components representing certain states of the reactor. The talk will focus on recent achievements in the development of algorithms for creating these network models based on prior CFD results. We discuss the roles of model consistency and defining proper trade-offs between model accuracy and complexity.

DY 28.4 Tue 15:00 ZEU/0118

Numerical investigation of surface wind veer in a transitional Atmospheric Boundary Layer — •Maharun Nesa Shampa, Heiko Schmidt, and Marten Klein — Brandenburgische Technische Universität Cottbus-Senftenberg, Cottbus, Germany

The Atmospheric Boundary Layer (ABL) is defined as the lower part of the atmosphere that dynamically couples the free atmosphere and Earth's surface. Transitional features and strong variability in boundary layer thickness due to surface heating and cooling pose a challenge for modeling atmospheric dynamics, placing a burden on flow profile and surface-flux parameterizations. This study addresses the mentioned challenge by investigating an idealized ABL, the so-called Ekman Boundary Layer (EBL) using a stochastic One-dimensional Turbulence (ODT) model as standalone tool. The EBL is characterized by absence of stratification such that a statistically stationary force balance between the pressure-gradient, Coriolis and drag forces is reached asymptotically for a prescribed synoptic pressure gradient. A single non-dimensional parameter, the Reynolds number, characterizes the flow regime and reflects the range of the turbulent scales participating in the flow. It is demonstrated that ODT is capable of capturing surface properties (like friction velocity, wind-turning angle) compatible with reference data and appropriate parameterization for transitional Reynolds numbers. In addition, the model offers additional insight into the boundary layer structure and statistical flow properties, which are likewise discussed. By constraining the stochastic sampling of turbulent length scales, an outlook to cut-off mechanisms is given.

DY 29: Active Matter IV (joint session DY/BP/CPP)

Time: Tuesday 14:00–15:30 Location: ZEU/0160

DY 29.1 Tue 14:00 ZEU/0160

Automated decision-making by chemical echolocation in active droplets — •Aritra K. Mukhopadhyay[1], Ran Niu[2], Linhui Fu[2], Kai Feng[2], Christopher Fujta[1], Qiang Zhao[2], Jinping Qu[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 that enables synthetic microswimmers, including autophoretic colloids, droplet swimmers, and ion-exchange-driven modular swimmers, to make autonomous navigational decisions. These swimmers generate chemo-hydrodynamic signals that interact with boundaries, producing echoes that encode structural information about the environment. These echoes trigger automatic responses, such as synthetic chemotaxis, allowing swimmers to avoid dead ends and autonomously find paths through complex mazes. We show the mechanism remains robust across different maze geometries, ensuring reliable navigation without external cues. Our findings illustrate how simple physical principles can endow synthetic systems with advanced navigation functionalities.

DY 29.2 Tue 14:15 ZEU/0160

Dead or alive?—Probing scale-dependent liveliness in multiscale active matter — •Joscha Mecke[1] and Klaus Kroy[2] — [1]Institute for Advanced Study, Shenzhen University, Shenzhen, China — [2]Institut für Theoretische Physik, Universität Leipzig, Leipzig, Germany

If you have ever watched live and dead trouts swimming upstream, side by side, you may have wondered how closer inspection of their mesoscale activity might help to tell them apart. But probing spatially heterogeneous activity in living matter is a major challenge. We demonstrate the emergence of multiple effective ("active") temperatures in nonequilibrium molecular- and Brownian-dynamics simulations of an active polymer. Energy injection at different length scales leads to mode coupling, inter-modal energy transfer, and entropy production. We put forward a generalised Langevin equation for a labelled monomer, which, by application of a harmonic potential, can serve as a spectroscopic device. Upon varying the trap stiffness, we can selectively scan through the emergent effective temperatures and thereby resolve the scale-dependent activity. Our approach thus provides a minimally invasive spectroscopic tool to generate quantitative maps of liveliness, across multiple scales.

DY 29.3 Tue 14:30 ZEU/0160

Tuning the velocity of thermophoretic microswimmers with thermo-sensitive polymers — Franziska M. Braun, Aritra K. Mukhopadhyay, Samad Mahmoudi, Benno Liebchen, and •Regine von Klitzing — Institute for Condensed Matter Physics, TU Darmstadt, Hochschulstrasse 8, 64289 Darmstadt

Understanding and controlling the motion of self-propelled particles in complex fluids is crucial for applications in targeted drug delivery, microfluidic transport, and the broader field of active matter. Here, we investigate the thermophoretic self-propulsion of partially gold-coated polystyrene Janus particles (Au-PS) in temperature-responsive linear Poly(N-isopropyl acrylamide) (PNIPAM) solutions across various PNIPAM concentrations and temperatures. Particle velocities are examined at three representative temperatures: far below, near but below and above the LCST. In pure water, Au-PS Janus particles propel with the PS hemisphere leading, driven by their intrinsic thermophoretic response. Conversely, the positive Soret coefficient of PNIPAM results in depletion forces that induce motion of the Janus particle towards the hot Au side. The experiments reveal a non-monotonic dependence of particle velocity on temperature, with a maximum near the LCST. Interfacial processes like ion movement in the electric double layer and PNIPAM adsorption at the Au-PS particles are separated from processes that are coupled to the bulk solution. Theoretical calculations are in good agreement with the experimental findings and are essential for the understanding of the complex interplay of microswimmers with thermoresponsive polymers.

DY 29.4 Tue 14:45 ZEU/0160

Non-reciprocal multifarious self-organization — •Saeed Osat[1] and Ramin Golestanian[2] — [1]Institute for Theoretical Physics IV, University of Stuttgart, Heisenbergstraße 3, 70569 Stuttgart, Germany — [2]Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Goettingen, Germany

Biological systems exhibit a unique ability to design diverse structures from a shared set of building blocks, with a plethora of proteins made from a limited set of amino acids as a prime example. Furthermore, these systems often use building blocks efficiently by introducing transformations between different structures. A structure might undergo structural transformations to form a new structure with different functional purposes, without the need to discard the current structure and start anew. To unravel this mystery, one must examine the underlying non-equilibrium processes that make this shape-shifting behavior feasible.

Here, we leverage non-reciprocal interactions between building blocks to provide a foundation for designing dynamic structures. We used a multifarious self-assembly (MSA) model, which is the molecular counterpart of the Hopfield associative memory. By upgrading the MSA model to its non-equilibrium counterpart with non-reciprocal interactions, we introduce the ability to not only self-assemble different structures on demand but also facilitate shifts and transformations that lead to shape-shifting behavior.

Invited Talk DY 29.5 Tue 15:00 ZEU/0160

Designing topological edge states in bacterial active matter — Yoshihito Uchida[1], Daiki Nishiguchi[2,1], and •Kazumasa A. Takeuchi[1] — [1]The University of Tokyo, Tokyo, Japan — [2]Institute of Science Tokyo, Tokyo, Japan

Besides its potential relevance to the life sciences, active matter also manifests as a novel, intrinsically non-equilibrium kind of matter, endowed with characteristic transport properties distinguished from conventional matter. A challenge is how to control and design transport in active matter. A potentially useful, emerging concept here is topological transport developed in condensed matter physics, which was extended to active matter successfully, but experimental realizations have thus far relied on the chirality of the active particles, which limits design capabilities.

Here we report a controlled realization of topological edge states in dense bacterial suspension, induced by microfabricated geometry instead of the bacteria's chirality. First we demonstrate that we can rectify bacterial collective motion by a channel with asymmetric shape. Then we construct networks made of asymmetric channels and show that we can control the emergence of topological edge states through the network design. Through modelling and experiments, we discuss what properties of the network and the bacterial flow are crucial to the observed topological phenomenon. We expect our results may pave the way for establishing a control and design principle of topological transport in such active matter systems.

Ref) Y. Uchida, D. Nishiguchi, and K. A. Takeuchi, to appear.

DY 30: Nonequilibrium Quantum Systems I (joint session TT/DY)

Time: Wednesday 9:30–12:45 Location: CHE/0091

DY 30.1 Wed 9:30 CHE/0091

Quantum geometric force in nonlinear phononics — •Sota Kitamura and Takahiro Morimoto — University of Tokyo, Tokyo, Japan

When phonons are resonantly excited by intense laser fields, nonlinear effects can dynamically alter the crystal structure. The field of controlling material properties through such processes is referred to as nonlinear phononics. In conventional theoretical frameworks of nonlinear phononics, the electron dynamics are typically assumed to be adiabatic. However, this assumption generally breaks down under strong driving, and nonadiabatic corrections become essential.

Using nonequilibrium Green function methods, we investigate the electron dynamics under resonant phonon excitation beyond the adiabatic approximation, thereby exploring nonadiabatic effects appearing in the phonon equations of motion. Our analysis reveals that quantum geometric contributions originating from the electronic Berry curvature give rise to unconventional forces on phonons. These quantum geometric corrections are then applied to the dynamical control of crystal chirality, i.e., right- or left-handedness of chiral crystals, using a minimal tight-binding model coupled to the Peierls phonon.

DY 30.2 Wed 9:45 CHE/0091

Macroscopic mechanical torque for lattice and electronic chirality measurement — •Nikolai Peshcherenko[1], Ning Mao[1], Claudia Felser[1], and Yang Zhang[2,3] — [1]Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany — [2]Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA — [3]Min H. Kao Department of Electrical Engineering and Computer Science, University of Tennessee, Knoxville, Tennessee 37996, USA

The concept of chirality is known to be critical for a number of phenomena related either to a structural asymmetry or topological electronic band crossings. In the present work we develop a robust chirality probe of TR-symmetric systems with mechanical torque measurement. Namely, we show that driving a system out of equilibrium with temperature gradient (or electric field to excite electrons) would result in uncompensated angular momentum and mechanical torque. Calculations are made for both phonons (insulating case) and electrons (metallic case) carrying angular momentum. For phonons, our theoretical findings stand in reasonable agreement with a recent experiment [1]. For electronic subsystem, we discuss both cases of structural and topological electronic chirality probe.

[1] H. Zhang, N. Peshcherenko, F. Yang, T. Ward, P.Raghuvanshi, L.Lindsay, C.Felser, Y.Zhang, J.-Q. Yan, H.Miao, Nat.Phys.1 (2025)

DY 30.3 Wed 10:00 CHE/0091

Hybrid quantum–classical matrix-product state and Lanczos methods for electron–phonon systems with strong electronic correlations: Application to disordered systems coupled to Einstein phonons — •Heiko Georg Menzler[1], Suman Mondal[2], and Fabian Heidrich-Meisner[1] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, D-37077 Göttingen, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden

We present two quantum-classical hybrid methods for simulating the time-dependence of electron-phonon systems that treat electronic correlations numerically exactly and optical-phonon degrees of freedom classically. These are a time-dependent Lanczos and a matrix-product state method, each combined with the multi-trajectory Ehrenfest approach. Due to the approximations, reliable results are expected for the adiabatic regime of small phonon frequencies. We discuss the convergence properties of both methods for a system of interacting spinless fermions in one dimension and provide a benchmark for the Holstein chain. As a first application, we study the decay of charge density wave order in a system of interacting spinless fermions coupled to Einstein oscillators and in the presence of quenched disorder. We investigate the dependence of the relaxation dynamics on the electron-phonon coupling strength and provide numerical evidence that the coupling of strongly disordered systems to classical oscillators leads to delocalization, thus destabilizing the (finite-size) many-body localization in this system.

This research is supported by the DFG (Deutsche Forschungsgemeinschaft) via SFB 1073 and FOR 5522.

DY 30.4 Wed 10:15 CHE/0091

Frozen non-equilibrium dynamics of exciton Mott insulators in moiré superlattices — Shibin Deng[1], •Jonas Reimann[2], Heonjoon Park[3], Jonas M. Peterson[1], Ammon Fischer[2], Xiaodong Xu[3], Dante M. Kennes[2,4], and Libai Huang[1] — [1]Department of Chemistry, Purdue University, West Lafayette, IN 47907, USA — [2]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, 22761 Hamburg, Germany — [3]Department of Physics, University of Washington, Seattle, WA 98195, USA — [4]Institut für Theorie der Statistischen Physik, RWTH Aachen University, 52056 Aachen, Germany

Moiré superlattices, such as those formed from transition metal dichalcogenide heterostructures, have emerged as an exciting platform for exploring quantum many-body physics. A key open question is the coherence and dynamics of the quantum phases arising from photoexcited moiré excitons, particularly amid dissipation. Here we use transient photoluminescence and ultrafast reflectance microscopy to image non-equilibrium exciton phase transitions. Counterintuitively, experimental results and theoretical simulations indicate that strong long-range dipolar repulsion freezes the motion of the Mott insulator phase for over 70 ns. In mixed electron-exciton lattices, reduced dipolar interactions lead to diminished freezing dynamics. These findings challenge the prevailing notion that repulsion disperses particles, whereas attraction binds them. This talk focuses on the theoretical efforts that support the experimental data.

DY 30.5 Wed 10:30 CHE/0091

Cavity-induced Eliashberg effect: superconductivity vs charge density wave — •Md Mursalin Islam[1,2], Michele Pini[1,2], Rafael Flores- Calderón[2], and Francesco Piazza[1,2] — [1]Theoretical Physics III, Institute of Physics, University of Augsburg, 86135 Augsburg, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Nothnitzer Straße 38, 01187 Dresden, Germany

Recent experiments have shown that non-equilibrium effects can play a key role in cavity-based control of material phases, notably in systems with charge-density-wave order. Motivated by this, we extend the theory of the Eliashberg effect, originally developed for superconducting phases, to charge-density-wave phases. Starting from a minimal electronic model where superconductivity and charge-density-wave order are equivalent at equilibrium, we introduce coupling to cavity photons, which are in turn coupled to an environment at a temperature different from the one of the electronic environment. This drives the system into a non-thermal steady state, which breaks the equivalence between superconductivity and charge-density-wave order. In the superconducting case, we recover the known behavior: a shift from continuous to discontinuous phase transitions with bistability. In contrast, the charge-density-wave case displays richer behavior: tuning the cavity frequency induces both continuous and discontinuous transitions, two distinct ordered phases, and a bistable regime ending at a critical point. These findings demonstrate that the scope of cavity-based non-thermal control of quantum materials is broader than at thermal equilibrium, and strongly depends on the targeted phases.

DY 30.6 Wed 10:45 CHE/0091

Quantum Monte Carlo Nonequilibrium work estimator of Rényi negativites — •Jannis Kastell and David Luitz — Universität Bonn, Bonn, Germany

We develop a Quantum Monte Carlo method for the calculation of Rényi generalizations of the logarithmic negativity, an entanglement measure for mixed states. Extending previous works using the replica trick and nonequilibrium-work-based estimators of Rényi entanglement entropy, we adapt this framework to the moments of the partially transposed reduced density matrix at finite temperature. Using the stochastic series expansion (SSE) method, we compute these moments in bi- and tri-partitioned systems. We apply this approach to the spin-1/2 isotropic Heisenberg antiferromagnet on a 3D simple cubic lattice, analysing the scaling of the higher order moments with subsystem size for both contiguous and disjoint partitions. Our results demonstrate that this approach provides an efficient and scalable method for estimating mixed-state entanglement measures in large quantum many-body systems.

15 min. break

DY 30.7 Wed 11:15 CHE/0091

Enhancing quantum metric using periodic driving — •Dhruv Tiwari, Roderich Moessner, and Johannes S. Hofmann — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The advent of periodically driven systems has revolutionized modern condensed matter physics by offering two transformative opportunities. First, they enable 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 models. The quantum metric, a fundamental geometric property of the band structure, plays a crucial role in stabilizing various correlated phases. Here, we present results demonstrating that an appropriately chosen periodic drive can amplify the quantum metric and modify density-density interactions. Using both numerical and analytical techniques, we map out the phase diagram of the resulting model.

DY 30.8 Wed 11:30 CHE/0091

Scattering in periodic fields: Floquet resonances — •Sebastian Eggert, Christoph Dauer, and Axel Pelster — University of Kaiserslautern-Landau (RPTU)

An alternative mechanism of tuning many-body interactions in atomic systems is proposed, which is based on dynamically creating Floquet bound states using time-periodic fields. By developing a Floquet-scattering theory we show that sharp Floquet resonances occur at which the effective interaction can be tuned to very large attractive or repulsive values. The resulting predictions explain recent experimental data and provide additional tuning possibilities. Analytic predictions are given for adjusting amplitude, frequency and mean of the applied oscillating field in order to to accurately choose location and width of scattering resonances over a wide range. This paves the road to a versatile toolbox of tailored interactions in setups with multiple atomic species.

DY 30.9 Wed 11:45 CHE/0091

A comparative study of perturbative and nonequilibrium Green's function approaches for Floquet sidebands in periodically driven quantum systems — •Karun Gadge[1], Marco Merboldt[2], Wiebke Bennecke[2], Jan Philipp Bange[2], Marcel Reutzel[3], Stefan Mathias[2], Michael A Sentef[4], Michael Schüler[5], and Salvatore R Manmana[1] — [1]Institute for Theoretical Physics, Georg-August-University Göttingen, Friedrich-Hund-Platz 1, D-37077 Göttingen, Germany — [2]I. Physikalisches Institut, Georg-August-University Göttingen, Friedrich-Hund-Platz 1, D-37077 Göttingen, Germany — [3]Fachbereich Physik, Philipps-University Marburg, Marburg, Germany — [4]Institute for Theoretical Physics and Bremen Center for Computational Materials Science, University of Bremen, 28359 Bremen, Germany — [5]Laboratory for Materials Simulations, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

We compare two complementary theoretical approaches to compute and interpret Floquet sidebands in periodically driven quantum materials: a first-order perturbative approach (PB1) and time-dependent nonequilibrium Green's functions (tdNEGF). Using graphene as a model Dirac system, we disentangle in pump-probe setups Floquet-dressed initial states, Volkov-dressed final states (also known as laser-assisted photoelectric effect, LAPE), and their interference. We quantify how photoemission matrix elements, polarization, incidence angle, and near-surface screening shape the momentum-resolved sideband intensity observed in tr-ARPES.

DY 30.10 Wed 12:00 CHE/0091

Towards Floquet-GW: interacting electrons in time-periodic potentials — •Ayan Pal[1,2], Erik G C P Van Loon[1,2], and Ferdi Aryasetiawan[1,3] — [1]Division of Mathematical Physics, Lund University, Professorsgatan 1, 223 63, Lund, Sweden — [2]NanoLund, Lund University, Professorsgatan 1, 223 63, Lund, Sweden — [3]LINXS Institute of advanced Neutron and X-ray Science, Lund, Sweden

The Floquet theory of time-periodic systems provides a middle ground between equilibrium and far-from-equilibrium physics, making it ideal for studying non-equilibrium steady states. We employ this framework to interacting electrons exposed to spatially and time-periodic potentials by combining Floquet theory with RPA and GW. This is applied to both the homogeneous electron gas and lattice Hamiltonians, allowing us to resolve the interplay between periodic driving, electronic correlations, and collective charge excitations. We compute Floquet-induced Greens function, dielectric function, and screened interaction; and demonstrate the formation of Bloch-Floquet sidebands in the electronic spectral function and in direct and inverse photoemission spectra. The periodic modulation further induces plasmonic sidebands and generates additional Floquet-umklapp regions for the electron-hole continuum. Our analysis highlights how the structure of the travelling drive - frequency, amplitude, and momentum controls the redistribution of spectral weight and the renormalisation of collective modes. This framework provides a route for predicting the plasmonic, dielectric, and optical response properties of weakly to moderately correlated materials under periodic laser driving.

DY 30.11 Wed 12:15 CHE/0091

Emergent Floquet Fermi Surfaces from Disorder — Inti Sodemann Villadiego, Akihiro Ozawa, and •Felix Frederking — Institut für Theoretische Physik, Universität Leipzig, Brüderstraße 16, 04103 Leipzig, Germany

We investigate the non-equilibrium steady states of periodically driven fermions coupled to a fermionic heat bath and in the presence of disorder (i.e. random impurities). In the absence of disorder, the steady state occupation would be a "stair-case" version of the Fermi-Dirac distribution, which is smooth at finite temperatures. Remarkably, however, we have found that disorder induces non-analyticities in the occupation of states that behave as emergent Fermi surfaces. We will discuss the physical phenomena arising from these non-equilibrium emergent Fermi surfaces and make the case for the feasibility of their detection in ulta-clean 2D materials subjected to low frequency radiation.

DY 30.12 Wed 12:30 CHE/0091

Emergent Fermi surfaces from non-equilibrium heat baths: exact results from Keldysh formalism — •Akihiro Ozawa and Inti Sodemann Villadiego — Institut für Theoretische Physik, Universität Leipzig, 04103, Leipzig, Germany

Recent studies have shown that periodically driven fermions coupled to a boson bath display non-analyticities in their occupation functions of momentum that behave like emergent Fermi surfaces. Remarkably, we have found that analogous non-equilibrium emergent Fermi surfaces can arise when the system is coupled to two baths at different temperatures, even without external periodic driving. The mechanism driving the formation of these non-equilibrium Fermi surfaces, is a kind of transfer from non-analyticities from the density of states into the occupation of states which is only allowed away from equilibrium, in the absence of detailed balance in the scattering rates. We demonstrate that this result is exact at weak coupling using the Keldysh formalism and propose a numerical scheme to investigate the fate of these non-analyticities at finite coupling.

DY 31: Networks, From Topology to Dynamics – Part I (joint session SOE/DY)

Time: Wednesday 9:30–11:00 Location: GÖR/0226

Invited Talk DY 31.1 Wed 9:30 GÖR/0226

Dynamics and Structure in Temporal Networks — •Natasa Djurdjevac Conrad — Zuse Institute Berlin, Germany

Temporal networks are a powerful tool for describing real-world systems in which interactions change over time, such as social contacts or transportation systems. Understanding how these networks evolve is crucial for uncovering the mechanisms that drive system behavior. From a dynamical systems perspective, clustering temporal networks and tracking the dynamics of clusters enables the identification of long-lived structures, metastable states and tipping points. In this talk, I will present recent work on temporal network analysis using random walk-based approaches, with a focus on network clustering and detecting structurally coherent time-periods. These methods provide a natural connection between network science and dynamical systems, relating to transfer operator frameworks and spectral theory. Through examples from synthetic models and real-world datasets, I will illustrate how these tools uncover key patterns and dynamic changes in complex networks.

DY 31.2 Wed 10:00 GÖR/0226

From Quiescence to Synchrony: Noise-Shaped Dynamics in Coupled Neuronal Systems — •Max Contreras[1,2] and Philipp Hövel[2] — [1]Technische Universität Berlin, Germany — [2]Saarland University, Saarbrücken, Germany

Stochastic fluctuations are usually regarded as promoters of activity in excitable and oscillatory systems, giving rise to phenomena such as coherence resonance. Here, we show that the opposite can occur in the small-noise regime, where noise can inhibit spiking activity in weakly coupled neuronal units. Using a ring of diffusively coupled, oscillatory FitzHugh-Nagumo neurons, we demonstrate how the interplay of noise and coupling strength generates different collective behaviors. We systematically classify the dynamical scenarios by an in-depth time-series analysis that combines multiple, complementary measures. As a result, we are able to automatically identify distinct dynamical clusters in parameter space: quiescent state, noisy synchronization, complete synchronization, and intermittent switching. The presented workflow can be universally applied in coupled oscillator networks and provides a unified framework to study collective dynamics.

15 min. break

DY 31.3 Wed 10:30 GÖR/0226

Learning collective variables for time-evolving networks — •Sören Nagel, Nataša Djurdjevac Conrad, Stefanie Winkelmann, and Marvin Lücke — Zuse Institute Berlin

We address the challenge of model reduction for time-evolving networks by identifying collective variables for stochastic rewiring processes driven by opinion homophily. [Lücke et al., Phys. Rev. E 109, L022301 (2024); Djurdjevac Conrad et al., Chaos 34, 093116 (2024)].

Utilizing the *transition manifold framework*, we identify a simple consensus measure as a collective variable for an ergodic and a non-ergodic model, and learn the dynamics of the projected system. We show that the learned model reduction can be obtained from the corresponding graphon process in the case of large and not too sparse graphs with uniformly distributed opinions. Our data-driven approach successfully identifies the collective variables in more general cases, highlighting the possibility to study low-dimensional model reductions in systems that have not been understood theoretically.

DY 31.4 Wed 10:45 GÖR/0226

Time-delayed dynamics in regular networks of Kuramoto oscillators with inertia — •Philipp Hövel[1], Esmaeil Mahdavi[2], Mina Zarei[2], and Farhad Shahbazi[3] — [1]Saarland University, Saarbrücken, Germany — [2]Institute for Advanced Studies in Basic Sciences, Zanjan, Iran — [3]Isfahan University of Technology, Isfahan, Iran

We investigate the complex interplay between inertia and time delay in regular rotor networks within the framework of the second-order Kuramoto model. By combining analytical and numerical methods, we demonstrate that intrinsic time delays – arising from finite information transmission speeds – induce multistability among fully synchronized phase-locked states. Unlike systems without inertia, the presence of inertia destabilizes these phase-locked states, reduces their basin of attraction, and gives rise to nonlinear phase-locked dynamics over specific inertia ranges. In addition, we show that time delays promote the emergence of turbulent chimera states, while inertia enhances their spatial extent. Notably, the combined influence of inertia and time delay produces dynamic patterns reminiscent of partial epileptic seizures. These findings provide new insights into synchronization phenomena by revealing how inertia and time delay fundamentally reshape the stability and dynamics of regular rotor networks, with broader implications for neuronal modeling and other complex systems.

DY 32: Many-body Systems: Equilibration, Chaos, and Localization (joint session DY/TT)

Time: Wednesday 9:30–12:45 Location: HÜL/S186

DY 32.1 Wed 9:30 HÜL/S186

Compression of Floquet random circuits — •Francesca De Franco[1,2], David Luitz[3], Dante Kennes[4], Matteo Rizzi[1,5], and Markus Schmitt[1,2] — [1]FZ Juelich, Institute of Quantum Control (PGI-8) — [2]University of Regensburg — [3]University of Bonn — [4]RWTH Aachen University — [5]University of Cologne

Current quantum computing hardware suffers from significant dissipation due to the coupling to the environment. This limits the depth of unitary quantum circuits which can be applied with high fidelity and hence the physical timescales reachable by digital quantum simulation. Here, we show that the reachable timescale in practice depends strongly on the physics of the many-body system under investigation: For systems deep in a many-body localized phase, we can find shallow circuit representations of the evolution operator U to late times, while in a chaotic regime this is not possible. The associated compressibility of the late time evolution operator is hence associated with the accessibility of long times on noisy quantum hardware. Moreover, we compare the performance of these compressed, variationally obtained circuits to tensor-network simulations, which allow us to compute quantum-information-spreading diagnostics such as entanglement entropy and out-of-time-ordered correlators.

DY 32.2 Wed 9:45 HÜL/S186

Spectral pairing statistics in Floquet time crystals — Alexander-Georg Penner[1], •Harald Schmid[1,2,3], Leonid I. Glazman[4], and Felix von Oppen[1] — [1]Dahlem Center for Complex Quantum and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [2]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [4]Department of Physics, Yale University, New Haven, Connecticut 06520, USA

Floquet time crystals are characterized by the subharmonic behavior of temporal correlation functions. Studying the paradigmatic time crystal based on the disordered Floquet quantum Ising model, we show that its temporal spin correlations are directly related to spectral characteristics and that this relation provides analytical expressions for the correlation function of finite chains, which compare favorably with numerical simulations. Specifically, we show that the disorder-averaged temporal spin correlations are proportional to the Fourier transform of the splitting distribution of the pairs of eigenvalues of the Floquet operator, which differ by pi to exponential accuracy in the chain length. We find that the splittings are well described by a log-normal distribution, implying that the temporal spin correlations are characterized by two parameters. We discuss possible implications for the phase diagram of Floquet time crystals.

DY 32.3 Wed 10:00 HÜL/S186

Spin-Spin Correlations and Multifractality in 1D disordered $SU(2)$-Invariant Heisenberg Spin Chains — •Debasmita Giri,

Julian Siegl, and John Schliemann — Institute for Theoretical Physics, University of Regensburg, Regensburg, Germany

Disorder and interactions in one-dimensional quantum spin chains give rise to rich non-ergodic phenomena that lie beyond the conventional eigenstate thermalization hypothesis (ETH). In the presence of sufficiently strong quenched disorder, many-body localization (MBL) can emerge: transport is frozen, entanglement growth is logarithmically slow, and local operators retain memory of their initial conditions even at infinite temperature. On the contrary, studies on models with non-Abelian symmetries have demonstrated that continuous symmetries, such as $SU(2)$, can obstruct the construction of local integrals of motion and thus hinder full localization. We investigate spin correlations in one-dimensional $SU(2)$-invariant Heisenberg chains with exchange disorder for spin lengths $S = 1/2$ and $S = 1$. In the weak-disorder regime, the eigenmodes of the spin-spin correlation matrix are delocalized, consistent with ergodic behavior. Under strong disorder, the system enters a quasi-localized multifractal phase characterized by exponentially decaying, dimer-like spin correlations. Finite-size scaling of the inverse participation ratios of the correlation-matrix eigenmodes yields a correlation dimension, $D_2 \approx 0.37 - 0.39$, confirming the presence of a multifractal regime that is distinct from both the ergodic limit ($D_2 = 1$) and the fully localized limit ($D_2 = 0$).

DY 32.4 Wed 10:15 HÜL/S186

Timescales for Deep and Full Thermalization — •Tabea Herrmann[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, Dresden, Germany

Isolated quantum systems typically approach thermal equilibrium as described by the Eigenstate Thermalization Hypothesis (ETH). Going beyond this involves either higher order correlators (full ETH) or the approach of moments of the reduced density matrix towards thermal equilibrium (deep thermalization). In this talk we compare these two types of thermalization using extensive numerical studies within a paradigmatic model for chaotic many-body quantum dynamics. For this we find exponential relaxation for both types: For deep thermalization all moments relax with the same rate, which approximately equals the relaxation rate of two-point correlation functions within full ETH. In contrast, all higher order correlation functions approach equilibrium twice as fast.

DY 32.5 Wed 10:30 HÜL/S186

Free Cumulants and Full Eigenstate Thermalization from Boundary Scrambling — •Felix Fritzsch, Gabriel O. Alves, Michael A. Rampp, and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Out-of-time-order correlation functions (OTOCs) represent important probes of quantum information dynamics and scrambling. We introduce a solvable many-body quantum circuit model, which we term boundary scrambling, for which the full dynamics of OTOCs is analytically tractable. These dynamics support a decomposition into free cumulants and unify recent extensions of the eigenstate thermalization hypothesis (full ETH) with predictions from random quantum circuit models. We moreover obtain exact expressions for higher-order correlations between matrix elements as predicted by the full ETH. The solvability is enabled by the identification of a higher-order Markovian influence matrix, capturing the effect of the full system on a local subsystem.

DY 32.6 Wed 10:45 HÜL/S186

Mechanism of Eigenstate Thermalization Breakdown — •Rafał Świetek[1,2,3] and Lev Vidmar[2,3] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, D-37077 Göttingen, Germany — [2]Department of Theoretical Physics, J. Stefan Institute, SI-1000 Ljubljana, Slovenia — [3]Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana, SI-1000 Ljubljana, Slovenia

Establishing a common framework for ergodicity-breaking transitions has many potential applications and provides insight into the nature of non-ergodic phases. In this work, we show that the softening of fluctuations within the recently established fading ergodicity framework can be derived directly from the emergence of the Fermi Golden Rule (FGR), ultimately classifying fading ergodicity as manifestation of FGR physics in quantum many-body systems. We show that this framework identifies the width of the local density of states and the fractal nature of eigenstates in the unperturbed basis as building blocks for fading ergodicity. Furthermore, we argue that our theory can be also applied to integrability-breaking transitions, where the critical point drifts exponentially with system size to a singular point, providing a common framework for ergodicity breaking in RMT models and integrability-breaking in local Hamiltonians.

15 min. break

DY 32.7 Wed 11:15 HÜL/S186

Entanglement in bipartite systems with symmetry: coupled chaotic kicked Bose-Hubbard systems — •Jan Himmelsbach[1], Maximilian F.I. Kieler[1,2], and Arnd Bäcker[1] — [1]TU Dresden, Institut für Theoretische Physik, Dresden, Germany — [2]CESAM research unit, University of Liège, B-4000 Liège, Belgium

We study the eigenstate entanglement of a time-periodically driven Bose-Hubbard system in a bipartite setting with a tunable coupling between two subsystems. By incorporating the symmetry of the particle conservation and employing perturbation theory we find that the entanglement transition for varying coupling strength is described by a universal transition parameter. It turns out that the entanglement transition is governed by localization for the particle conservation symmetry and a thermalizing process between the subsystems.

DY 32.8 Wed 11:30 HÜL/S186

Dynamical Pictures for Growth of Entanglement and Decay of Correlators in U(1) Conserving Random Circuits — •Marco Lastres[1,2], Olexei I. Motrunich[3], and Sanjay Moudgalya[1,2] — [1]Technical University of Munich, School of Natural Sciences, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [3]Department of Physics, Caltech, Pasadena, CA, USA

We study the dynamics of random circuit models with a global $U(1)$ charge conservation law. Prior work showed that systems without conservation laws exhibit linear growth of entanglement, linked to domain wall dynamics in an effective ferromagnetic model. In contrast, rigorous upper bounds for $U(1)$-conserving systems indicate that diffusive charge transport constrains Rényi entropies to grow only diffusively as $\sqrt{t}$. We study the second Rényi entropy in $U(1)$-conserving random circuits by mapping its dynamics onto the low-energy physics of an effective interacting Hamiltonian. This approach explicitly demonstrates the microscopic mechanism which produces diffusive growth of entanglement in the effective replica model. We also show that the same effective model naturally captures the recently discovered subexponential decay of non-hydrodynamic correlations through a closely related mechanism. Further, we demonstrate that in a different regime this model can also describe the dynamics of entanglement in noisy free-fermion systems, which also exhibit diffusive entanglement growth, but through a different mechanism. Finally, we discuss extensions to other continuous symmetries and to higher Rényi entropies.

DY 32.9 Wed 11:45 HÜL/S186

Correspondence principle, dissipation, and Ginibre ensemble — •David Villaseñor, Hua Yan, Matic Orel, and Marko Robnik — CAMTP - Center for Applied Mathematics and Theoretical Physics, University of Maribor, Mladinska 3, SI-2000 Maribor, Slovenia, European Union

The correspondence between quantum and classical behavior has been essential since the advent of quantum mechanics. This principle serves as a cornerstone for understanding quantum chaos, which has garnered increased attention due to its strong impact in various theoretical and experimental fields. When dissipation is considered, quantum chaos takes concepts from isolated quantum chaos to link classical chaotic motion with spectral correlations of Ginibre ensembles. This correspondence was first identified in periodically kicked systems with damping, but it has been shown to break down in dissipative atom-photon systems [Phys. Rev. Lett. 133, 240404 (2024)]. In this contribution, we revisit the original kicked model and perform a systematic exploration across a broad parameter space, reaching a genuine semiclassical limit. Our results demonstrate that the correspondence principle, as defined through this spectral connection, fails even in this prototypical system. These findings provide conclusive evidence that Ginibre spectral correlations are neither a robust nor a universal diagnostic of dissipative quantum chaos.

DY 32.10 Wed 12:00 HÜL/S186

Quantum Mpemba effect from Stark localization — •Nico

Albert[1], Masudul Haque[1], and Shovan Dutta[2] — [1]TU Dresden, Dresden, Germany — [2]Raman Research Institute, Bangalore, India

In the Mpemba effect a system prepared at a higher temperature cools down faster to a target equilibrium state than the same system prepared at a lower temperature. We investigate how quantum effects can influence the occurence of such an effect. As an example we consider a bosonic chain subject to a suitable onsite potential that is dissipatively cooled to its ground state, and find that Stark localization significantly enhances the Mpemba effect compared to analogous classical systems.

DY 32.11 Wed 12:15 HÜL/S186

Robustness of interference-caged QMBS under real-space local perturbations: analysis through the Fock-space local interference pattern — •Tao-Lin Tan[1] and Yi-Ping Huang[1,2,3] — [1]Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan — [2]Physics Division, National Center for Theoretical Sciences, Taipei 10617, Taiwan — [3]Institute of Physics, Academia Sinica, Taipei 115, Taiwan

Quantum many-body scars (QMBS) represent a notable violation of the eigenstate thermalization hypothesis (ETH), hosting non-thermal eigenstates embedded in an otherwise thermal spectrum. Despite recent progress, a systematic understanding of their stability under real-space local (r-local) perturbations remains lacking. Building on recent insights of interference-caged quantum many-body scars (ICQMBS), protected by exact many-body destructive interference on Fock-space graphs, we develop an interference-based diagnostic to assess the robustness of ICQMBS in various lattice Hamiltonians. Applying this framework to quantum link models (QLM) and quantum dimer models (QDM), we analyze how r-local perturbations deform the underlying Fock-space local (f-local) interference structure, thereby identifying heuristic mechanisms that stabilize or destabilize ICQMBS. Our results broaden the applicability of the interference-based perspective beyond previously studied models and provide practical criteria for evaluating the persistence of ICQMBS in experimentally relevant Hamiltonians.

DY 32.12 Wed 12:30 HÜL/S186

Scrambling and Scarring in Topological Materials — •Nicholas Sedlmayr, Dominik Szpara, and Szczepan Głodzik — Institute of Physics, M. Curie-Skłodowska University, 20-031 Lublin, Poland

Topological insulators and superconductors have recently attracted considerable attention, and many different theoretical tools have been used to gain insight into their properties. Here we investigate how perturbations can spread through exemplary one-dimensional topological insulators and superconductors using out-of-time ordered correlators. Out-of-time ordered correlators are often used to consider how information becomes scrambled during quantum dynamics. The wavefront of the out-of-time ordered correlator can be ballistic regardless of the underlying system dynamics, and here we confirm that for topological free fermion systems the wavefront spreads linearly at a characteristic butterfly velocity. We pay special attention to the topologically protected edge states, finding that information can become trapped in the edge states and essentially decoupled from the bulk, surviving for relatively long times - a form of scarring. We further investigate what happens due to the chiral and helical edge modes of two dimensional topological models. The information travels around the edge, carried by the edge mode, but again is not scrambled over very long time scales.

DY 33: Statistical Physics of Biological Systems I (joint session DY/BP)

Time: Wednesday 9:30–12:45 Location: ZEU/0114

DY 33.1 Wed 9:30 ZEU/0114

Metastability in the mixing/demixing of two species with reciprocally concentration-dependent diffusivity — •Benjamin Lindner[1,2], Alexander B. Neiman[3,4], and Xiaochen Dong[2] — [1]Department of Physics, Humboldt University Berlin, Berlin, Germany — [2]Bernstein Center for Computational Neuroscience Berlin — [3]Department of Physics and Astronomy, Ohio University, Athens, OH, United States — [4]Neuroscience Program, Ohio University, Athens, OH, United States

It is known that two species of diffusing particles can separate from each other by a reciprocally concentration-dependent diffusivity: the presence of one species at a certain location amplifies the diffusion coefficient of the respective other one in this location, causing the two densities of particles to separate spontaneously. In a minimal model, Schimansky-Geier et al. (2021) observed this with a quadratic dependence of the diffusion coefficient on the density of the other species. Here, we consider a sigmoidal dependence in the form of a logistic function on the other particle's density averaged over a finite sensing radius. The sigmoidal dependence leads to a new regime in which a homogeneous disordered (well-mixed) state and a spontaneously separated ordered (demixed) state coexist, forming two long-lived metastable configurations. In systems with a finite number of particles, random fluctuations induce repeated transitions between these two states. By tracking an order parameter that distinguishes mixed from demixed phases, we measure the corresponding mean residence in each state.

DY 33.2 Wed 9:45 ZEU/0114

Phase separation in a mixture of proliferating and motile active matter — Lukas Hupe[1], Joanna M. Materska[2], David Zwicker[1], Ramin Golestanian[1,3], Bartlomiej Waclaw[2,4], and •Philip Bittihn[1] — [1]MPI for Dynamics and Self-Organization, Göttingen, Germany — [2]Dioscuri Centre for Physics and Chemistry of Bacteria, Institute of Physical Chemistry, Warsaw, Poland — [3]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, United Kingdom — [4]School of Physics and Astronomy, The University of Edinburgh, United Kingdom

Proliferation and motility are ubiquitous drivers of activity in biological systems. Here, we study a dense binary mixture of motile and proliferating particles with exclusively repulsive interactions, where homeostasis in the proliferating subpopulation is maintained by pressure-induced removal. Using large-scale simulations, we show that this heterogeneous active matter undergoes spontaneous phase separation at high density and weak enough self-propulsion. We recapitulate this behavior using an effective Active Brownian Particle model that incorporates the emergent effects of the proliferating matrix on motile particles: enhanced diffusion, renormalized self-propulsion, reduced persistence, and an effective attraction between motile particles. Our results establish a new type of phase transition and reveal how mechanical activity from growth can mediate non-equilibrium interactions and fluctuations. This mechanism provides a conceptual framework to reinterpret the physics of dense pattern-forming cellular populations, such as bacterial colonies or tumors, as systems of mixed active matter.

DY 33.3 Wed 10:00 ZEU/0114

Reentrant phase separation and critical behaviour in cellular aggregates — •Subhadip Chakraborti[1,2] and Vasily Zaburdaev[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Max-Planck-Zentrum für Physik und Medizin, Erlangen, Germany

We study pili-mediated bacterial colonies as a paradigm for attractive cellular aggregates. The interplay between inherent motility and intercellular attraction leads to a reentrant phase separation between attraction-induced and motility-induced phase separation separated by a homogenous state. Using finite-size scaling of the largest cluster we characterise these two transitions and thereby determine the associated critical lines in terms of the control parameters - density, pili lifetime and attraction strength. We further evaluate critical exponents corresponding to two transitions in the parameter space and from their relations determine the respective universality classes.

DY 33.4 Wed 10:15 ZEU/0114

Phase separation with non-local interactions — Filipe C. Thewes, Yicheng Qiang, Oliver W. Paulin, and •David Zwicker — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Phase separation takes place in many complex systems, notably biological cells. While simple theories predict coarsening until only macroscopically large phases remain, concrete models often exhibit patterns with finite length scales, e.g., caused by chemical reactions, elasticity, membrane interactions, or charge. To unify such models, we here

propose a field theory that combines phase separation with non-local interactions. If these interactions are long-ranged, they generally suppress coarsening, whereas systems with non-local short-range interactions additionally exhibit a continuous phase transition to patterned phases. Only the latter system allows for the coexistence of homogeneous and patterned phases, which we explain by mapping to the conserved Swift–Hohenberg model. Taken together, our generic model provides a framework that unifies similar phenomena observed in many complex phase-separating systems.

DY 33.5 Wed 10:30 ZEU/0114

Motile response of bacterial swimmers towards competing chemical signals — •Agniva Datta[1], Robert Grossmann[1], and Carsten Beta[1,2] — [1]Institute of Physics and Astronomy, University of Potsdam, Germany — [2]Nano Life Science Institute (WPI-NanoLSI), Kanazawa University, Kakuma-machi, Kanazawa 920-1192, Japan

Understanding how bacteria navigate in bulk fluid has gained significant interest in the field of active matter and random transport processes in the last few decades. We use the soil bacterium *Pseudomonas putida* as our model organism, the motility pattern of which is characterized by persistent runs, interrupted by random reorientation events (turns). In addition to this, bacteria sense chemical signals and adapt their motility pattern accordingly. Recent experiments show that bacteria can change the frequency of turns (duration of runs) depending on the concentration of nutrients as well as auto-inducer molecules that they themselves produce in the medium. This complex interplay of the dynamics of nutrients, auto-inducers and bacterial density may lead to dynamic instabilities. Combining experiments and theory, we are elucidating the dynamics of bacteria in the presence of these two competing signaling factors.

DY 33.6 Wed 10:45 ZEU/0114

Anisotropic hierarchy decides the fate of an amorphous droplet — •Andrey Zelenskiy, Pietro Caracciolo di Torella, and Martin Lenz — LPTMS, CNRS, Orsay, France

The classical description of ordering, from theories of phase transitions to classical nucleation, typically emphasizes a direct transition from disorder to order. Yet, the majority of systems in nature deviate from this simple description, and often choose indirect pathways to ordering. In particular, complex structures often form via disordered or partially ordered intermediates – the amorphous precursors.

We present a model of self-assembling patchy particles, where the interactions are characterized by a hierarchy of geometric competitions. By tuning the anisotropy, we can stabilize a variety of aggregate morphologies, including crystals, gels, lamellar sheets, and fibers. However, due to geometric frustration, self-assembly proceeds via a dense amorphous intermediate, where the anisotropic interactions are largely averaged out. Our simple framework based on an anisotropic hierarchy sheds light on this non-classical mechanism of particle assembly, and provides a platform for new experimental principles of complex structure design.

15 min. break

DY 33.7 Wed 11:15 ZEU/0114

Improving neuronal information transmission with pathway splitting — •Kolja Klett[1,2] and Benjamin Lindner[1,2] — [1]Humboldt University, Berlin — [2]Bernstein Center for Computational Neuroscience, Berlin

In many organisms sensory information can take different neuronal paths from sensory cells to destinations in the brain. These paths can be made up of neurons serving distinct functions. Often, pathways consisting of neurons coding the increase (ON) or decrease (OFF) of a signal are observed which have be found to improve the transmission static signals. Here, we consider a simple network of spiking ON and OFF neurons to study the effects of pathway splitting on the transmission of dynamic signals. To that end, we use the coherence function as a frequency-resolved measure of informations transmission. We relate the information transmission of the whole network to that of the constituting neurons by employing response theory leading to approximate relations for the coherence function. For a simple white noise driven integrate-and-fire model of spiking neurons, we find an optimal mixture of ON and OFF neurons which maximizes the coherence function over a broad frequency range. The effect can be attributed to the nonlinear response of the neurons that only becomes relevant for sufficiently strong stimuli.

DY 33.8 Wed 11:30 ZEU/0114

Population sparseness in recurrent spiking neural networks — •Jakob Stubenrauch[1,2], Naomi Auer[3], Richard Kempter[2,3,4], and Benjamin Lindner[1,2] — [1]Physics Department HU Berlin — [2]Bernstein Center for Computational Neuroscience Berlin — [3]Institute for Theoretical Biology HU Berlin — [4]Einstein Center for Neurosciences Berlin

It is long known that in association tasks for neural networks, the fraction of active neurons in patterns to be associated plays an important role. Specifically, the number of patterns that can be simultaneously remembered grows when the information content per pattern is decreased. In binary networks, this content can be constrained by the population sparseness (one minus fraction of active neurons). For neurons with graded activity, population sparseness can be quantified by the Treves-Rolls measure or by the Gini coefficient. Here, we present results on the spontaneous and evoked population sparseness in different variants of recurrent neural networks of integrate-and-fire neurons. We find that the type of competition between neurons plays an important role and discuss that neurons in fully disordered networks can, in a mean field limit, only compete across a low-dimensional effective inhibition hub. We showcase the relevance of our findings for association tasks in spiking neural networks.

DY 33.9 Wed 11:45 ZEU/0114

Minority-triggered reorientation yields macrocscopic cascades and maximal responsiveness in a Vicsek swarm — •Simon Syga[1], Chandraniva Guha Ray[2,3,4], Josué Manik Nava Sedeño[5], Fernando Peruani[6], and Andreas Deutsch[1] — [1]Technische Universität Dresden, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Max Planck Institute of Molecular Cell Biology and Genetics, Dresden, Germany — [4]Center for Systems Biology Dresden, Germany — [5]Universidad Nacional Autónoma de México, Mexico City, Mexico — [6]CY Cergy Paris Université, Paris, France

Collective motion in animals and cells often exhibits bursty reorientations and scale-free velocity correlations associated with criticality. This ensures that information, like the presence of predators, quickly spreads through a group, ensuring an adequate response. To explain this phenomenon, we introduce a simple, biologically plausible mechanism, a minority-triggered reorientation rule: when local order is high, agents sometimes follow a strongly deviating neighbor instead of the majority. This generates heavy-tailed cascades of reorientations and macroscopic spatial correlations over broad parameter ranges, without fine-tuning. Our mechanism preserves cohesion while markedly enhancing collective responsiveness: localized directional cues elicit amplified, group-level reorientation. Our results provide a parsimonious, biologically interpretable route to critical-like fluctuations and high susceptibility in collective motion.

DY 33.10 Wed 12:00 ZEU/0114

Noise structure shapes transitions in cell differentiation processes — •Sara Oliver-Bonafoux[1], Javier Aguilar[1,2], Tobias Galla[1], and Raúl Toral[1] — [1]Institute for Cross-Disciplinary Physics and Complex Systems IFISC (CSIC-UIB), Campus UIB, Palma de Mallorca, Spain — [2]Laboratory of Interdisciplinary Physics, Department of Physics and Astronomy "G. Galilei", University of Padova, Padova, Italy

Stochastic differential equations provide a natural framework to describe dynamical systems influenced by random fluctuations, but they require specifying the structure of the noise term (e.g., additive, demographic, or environmental). In biological systems, the choice of an appropriate noise description remains a matter of debate. Understanding how stochastic fluctuations shape biological dynamics is a central challenge in biophysics and systems biology.

We address this question in the context of a model of cell differentiation, the process by which an unspecialised cell commits to a specialised cell type with a specific structure and function. Both the undifferentiated state and differentiated states are stable, and transitions between them are induced by noise. A recent study has provided theoretical evidence that different noise structures can give rise to substantially distinct differentiation paths. Here, we use stochastic bridges to sample differentiation paths under different types of noise and for varying noise intensity.

DY 33.11 Wed 12:15 ZEU/0114

Darwin's paradox of the peacock tail: a stochastic perspective on sexual selection — •Ian Magalhaes Braga — CASUS,

Gorlitz, Germany

Many species show male traits that are extravagant, costly, and seemingly disadvantageous, yet they evolve and persist. Classical explanations especially deterministic versions of Fisher's runaway struggle to fully account for this pattern, mostly because they ignore the inherent randomness of evolutionary processes. In this work, I propose that stochasticity is not a secondary detail but the key element that reshapes the dynamics of trait preference coevolution. Treating sexual selection at the microscopic, probabilistic level reveals a simple but unexpected idea: in finite populations, a costly trait can actually support the evolution of female preference. I refer to this effect as the cost advantage. The basic picture is that stochastic fluctuations change the timing of fixation events, creating conditions under which preference benefits from the very cost that penalizes the trait. Using large-scale simulations across multiple evolutionary architectures, I show that this behavior is general and does not depend on specific modelling choices. The results suggest that costly ornaments are not paradoxical after all they may simply reflect the true stochastic nature of evolutionary change.

DY 33.12 Wed 12:30 ZEU/0114

Local equations for the generalized Lotka-Volterra model on sparse asymmetric graphs — •David Machado Pérez[1,2,3], Pietro Valigi[1], Tommaso Tonolo[4,5], and Maria Chiara Angelini[6] — [1]Physics Department, Sapienza University of Rome, Rome I-00185, Italy — [2]Department of Theoretical Physics, Physics Faculty, University of Havana. CP10400, Havana, Cuba — [3]CNR-NANOTEC, Rome Unit, Rome I-00185, Italy — [4]Gran Sasso Science Institute, 67100 L'Aquila, Italy — [5]INFN-Laboratori Nazionali del Gran Sasso, 67100 Assergi (AQ), Italy — [6]INFN, Sezione di Roma I, 00185 Rome, Italy

Real ecosystems are characterized by sparse and asymmetric interactions, posing a major challenge to theoretical analysis. We introduce a new method to study the generalized Lotka-Volterra model with stochastic dynamics on sparse graphs. By deriving local Fokker-Planck equations and employing a mean-field closure, we can efficiently compute stationary states for both symmetric and asymmetric interactions. We validate our approach by comparing the results with the direct integration of the dynamical equations and by reproducing known results and, for the first time, we map the phase diagram for sparse asymmetric networks. Our framework provides a versatile tool for exploring stability in realistic ecological communities and can be generalized to applications in different contexts, such as economics and evolutionary game theory.

DY 34: Focus Session: Fluids with Broken Time-Reversal Symmetry – Odd/Hall Viscosity Between Active Matter and Electron Flows

Viscosity is a fundamental property of fluids and an important physical quantity characterizing resistance to flow and energy dissipation. While time-reversal symmetry holds in conventional fluids, its violation can lead to striking phenomena, one of which is the emergence of a dissipationless transport coefficient called odd viscosity. Odd viscosity, also known as Hall viscosity, was originally proposed by Avron et al., as a quantized observable in electron fluids with a magnetic field. Since this seminal work, odd viscosity has been studied in various systems, such as 2D electron fluids, fractional Hall fluids, and ionic crystals. Although odd viscosity was also known in plasma physics, it was largely overlooked in fluid dynamics, mainly due to the technical challenges involved in its experimental realization. In recent years, however experiments in driven colloidal systems led to a surge of interest in odd viscosity in the active matter community. In parallel, our understanding of odd phenomena was advanced by continuum theories with many novel exact solutions. Major open questions in the field include the microscopic mechanisms that lead to odd viscosity, its experimental manifestations, the transition from two- to three-dimensional systems, and the effect of odd viscosity on hydrodynamic phenomena at different length scales, ranging from microrheology to turbulent flows. This Focus Session will connect the wider condensed matter and active matter physics communities with recent theoretical advances in odd viscosity. It is organized along with a Symposium on the same topic.

Organized by Yuto Hosaka (Göttingen) and Ewelina M. Hankiewicz (Würzburg)

Time: Wednesday 9:30–12:30 Location: ZEU/0160

Invited Talk DY 34.1 Wed 9:30 ZEU/0160

Active turbulence and odd viscosity in a colloidal chiral active system in bulk and in patterned environments — Joscha Mecke[1,2], Yongxiang Gao[1], and •Marisol Ripoll[2] — [1]Institute for Advanced Study, Shenzhen University, Shenzhen, China — [2]Institute for Advanced Simulation, Forschungszentrum Jülich, Jülich, Germany

Experiments for a chiral active fluid composed of a carpet of standing and spinning colloidal rods are compared with simulations for synchronously rotating hard discs in a hydrodynamic explicit solvent [1]. The emergence of multi-scale eddies, with features of self-similar dynamics, indicates the existence of active turbulence, while the particles accumulation in the centre of the vortices allows the quantification of the system odd viscosity. The existence of a non-negligible substrate friction can be shown to be responsible of the truncation of the energy spectra and the related reduction of the vortex size [2], and the interaction with fixed obstacles shows to originate a flow opposite to the rotation direction which induces a pinning vortex effect [3].

[1] J. Mecke, Y. Gao, C. Ramirez-Medina, D. Aarts, G. Gompper and M. Ripoll, Comm. Phys. 6 (2023), 324 [2] J. Mecke, Y. Gao, G. Gompper and M. Ripoll, Comm. Phys. 7 (2024), 332 [3] J. Mecke, Y. Gao and M. Ripoll, Phys. Fluids 37 (2025), 112016

DY 34.2 Wed 10:00 ZEU/0160

From Gels to Rotors: Tunable Chiral Phases in Odd Colloidal Fluids — •Dennis Schorn[1], Stijn van der Ham[2], Suvendu Mandal[1], Benno Liebchen[1], and Hanumantha Rao Vutukuri[2] — [1]Institute for Condensed Matter Physics, 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 reveal a phase in which the passive particles form a gel-like network, with significant holes filled with self-organized, rotating chiral clusters composed of spinners. This phase can be reversed by changing the system's composition and magnetic field strength, resulting in a spanning spinner phase with embedded counter-rotating chiral clusters made of passive colloids. Both phases exhibit odd viscosity and diffusivity, whose magnitudes depend sensitively on spinner fraction and magnetic field strength. Our system may open the route towards a new type of viscoelastic active chiral matter involving nonreciprocal interactions between both species.

DY 34.3 Wed 10:15 ZEU/0160

Odd Droplets: Fluids with Odd Viscosity and Highly Deformable Interfaces — •Hugo França and Maziyar Jalaal — Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam, Science Park 904, Amsterdam, 1098XH, The Netherlands

Flows with deformable interfaces are commonly controlled by applying an external field or modifying the boundaries that interact with the fluid, but realizing such solutions can be demanding or impractical in various scenarios. Here, we demonstrate that fluids with broken symmetries can self-control their mechanics. We present a continuum model of a viscous fluid with highly deformable interfaces subject to capillary stresses. Our model features odd viscosity, a parity-violating property that emerges in chiral fluids. Using direct numerical simulations, we focus on the impact of an odd droplet on a superhydrophobic surface. By numerically solving the full conservation equations, we are able to study this highly non-linear problem hardly accesible through analytical methods. We demonstrate that odd viscosity dramatically disrupts conventional symmetric spreading by inducing asymmetric deformations and chiral flow patterns. Our analysis reveals a variety of dynamic regimes, including leftward and rightward bouncing, as well as rolling, depending on the relative strength of the odd viscosity. Our work illustrates that regulating odd viscosity provides a promising framework for controlling multiphase flows and designing functional metamaterials with tailored fluidic properties.

DY 34.4 Wed 10:30 ZEU/0160

The notion of dissipation in three-dimensional fluids with odd viscosity — •Jeffrey Everts[1,2], Laura Meissner-Oszer[1], and Bogdan Cichocki[1] — [1]Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland — [2]Institute of Physical Chemistry, Polish Academy of Sciences, 01-224 Warsaw, Poland

Odd viscosity is a transport coefficient that occurs in fluids where the constituent particles carry a non-trivial spin angular momentum. Exemplary realisations in this context are chiral active fluids and electronic systems in an external magnetic field. Due to the symmetry properties of the resulting viscosity tensor it is often stated in the literature that odd viscosity does not contribute to viscous dissipation. In this talk, I will explicitly demonstrate that this statement is incorrect for incompressible odd viscous fluids in three spatial dimensions. In this case, the fluid flow velocity can be affected by odd viscosity, which gives a non-trivial contribution to the dissipated power. As an example, we will show by explicit calculation how odd viscosity contributes to viscous dissipation for a spherical (colloidal) particle immersed in an odd viscous fluid. Furthermore, we will make general statements for viscous dissipation by generalising the Helmholtz minimum dissipation theorem -which is well known for ordinary Stokesian fluids - to fluids with odd viscosity.

DY 34.5 Wed 10:45 ZEU/0160

Exact flow patterns in systems with odd viscosity — •Laura Meissner-Oszer[1], Bogdan Cichocki[1], and Jeffrey Everts[1,2] — [1]nstitute of Theoretical Physics, Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland — [2]Institute of Physical Chemistry, Polish Academy of Sciences, 01-224 Warsaw, Poland

Chiral active fluids are composed of self-spinning particles with a non-trivial spin-angular momentum that is maintained through a continuous injection of energy at the microscopic scale. Due to this property, there are antisymmetric contributions in the viscosity tensor, which are called odd viscosity. In the low Reynolds-number regime we show that there is a uniqueness theorem for such flows akin to ordinary Stokesian fluids. In order to analyse the effect of odd viscosity on flow patterns of a three-dimensional incompressible fluid in the creeping flow regime, we focus on a simple model of a chiral active fluid described by one shear viscosity and one odd viscosity. By considering the Green's function of the linear momentum-balance equation in the presence of a point force, we derive exact closed-form analytical expressions for the velocity and pressure field of the fluid around a translating and rotating spherical particle. Furthermore, we highlight specific features of such flows due to the presence of odd viscosity and we demonstrate how the direction of spin momentum affects the qualitative features of the streamlines.

15 min. break

DY 34.6 Wed 11:15 ZEU/0160

Resonances in Odd Viscoelastic Materials — •Julius Kiln and Alexander Mietke — Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford, United Kingdom

Active matter describes materials that are powered by microscopic sources of energy. This injection of energy can lead to a wide variety of phenomena and unconventional material properties, including odd elasticity and odd viscosity. Despite recent analytical examination of these systems, a widely applicable method for solving force balance equations for odd materials on finite domains was so far not available.

The Papkovich-Neuber (PN) ansatz, introduced almost a hundred years ago, has proved an invaluable method for solving the force balance equation of a Stokes fluid and of a passive linearly elastic solid. We generalise this idea and find an ansatz for odd solids and fluids that reduces to the known PN solutions in the limit of vanishing odd material parameters. Altogether, this provides a new and versatile method for finding analytical solutions to this class of problems. Using this result, we construct the displacement field for an odd elastic material in circular domain under both displacement and stress boundary conditions. Further extending this method to write displacement and flow solutions of an odd viscoelastic material explicitly, we study the response to oscillatory forcing at the boundary, finding resonances at certain forcing frequencies even in an overdamped system. Finally, based on these new PN solutions, we propose rheological protocols for measuring odd material properties.

DY 34.7 Wed 11:30 ZEU/0160

Edge currents shape condensates in chiral active matter — •Boyi Wang[1,2], Patrick Pietzonka[4], and Frank Jülicher[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, TU Dresden, Germany — [4]SUPA, School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom

Chiral active matter, which breaks both parity symmetry and detailed balance, is widespread in living systems. Here, we introduce a minimal two-dimensional chiral active Ising model by incorporating stochastic, biased local rotations. At low temperatures, the system coarsens into condensates with chiral orientations and faceted, crystal-like shapes rather than circular ones observed under Kawasaki dynamics. The interfaces align at characteristic angles to the lattice axes and support persistent, unidirectional, angle-dependent edge currents.

To generalise these results, we develop a continuum theory by adding an active edge-current term to Model B. An edge current with n-fold symmetry produces condensates with corresponding n-fold polygonal shapes. In the sharp-interface limit, we construct an effective active surface potential that predicts the steady-state condensate geometry, consistent across both the lattice model and the continuum description.

Our results reveal how local chiral activity generates global edge currents and demonstrate their fundamental role in governing phase separation and interfacial dynamics in chiral active systems.

DY 34.8 Wed 11:45 ZEU/0160

A mobility based approach to self diffusion in odd-mobile systems — •Filippo Faedi and Abhinav Sharma — University of Augsburg

Odd-diffusive systems, defined by antisymmetric diffusion tensors, display unusual dynamics including enhanced self-diffusion due to interactions, oscillatory force autocorrelation functions in over-damped systems, and reversal of particle mobility. This work introduces a mobility-based approach by externally driving particles with constant forces, uncovering profound transport anomalies. We demonstrate an inverted density wake around a driven tracer, where increasing oddness reverses collision effects, reducing effective friction and enhancing mobility. Using fluctuation-dissipation, mobility-derived self-diffusion confirms prior findings, providing a unified view of interaction-induced anomalous dynamics in chiral media.

DY 34.9 Wed 12:00 ZEU/0160

Exceptional points, chirality and entropy production in non-reciprocal polar active matter — Kim L. Kreienkamp and •Sabine H. L. Klapp — Institut für Physik, Technische Universität Berlin, Germany

Non-reciprocal couplings significantly impact the collective dynamics of mixtures. A particularly striking consequence of such couplings is the spontaneous emergence of time-dependent phases that break parity-time symmetry. Here, we study a paradigmatic model of a non-reciprocal polar active mixture by combining field-theoretical analyses

and particle-based simulations. When different species have opposing alignment tendencies, flocking states with spontaneously broken rotational symmetry transform into chiral states characterized by a rotating polarization direction. At the field-theoretical level, the transition to these parity-time-symmetry-breaking chiral states is indicated by so-called exceptional points. We demonstrate that these theoretical concepts have clear counterparts in particle-based systems [1]: we observe chimera-like states with coexisting locally synchronized and disordered regions, and find that both the spontaneous chirality and the entropy production rate [2] peak at coupling strengths corresponding to the exceptional points. Our results highlight the diverse effects of non-reciprocity across different scales.

[1] K. L. Kreienkamp and S. H. L. Klapp, Communications Physics **8**, 307 (2025)

[2] K. L. Kreienkamp and S. H. L. Klapp, arXiv:2508.05209 (2025)

DY 34.10 Wed 12:15 ZEU/0160

The chiral random walk: A model for odd transport on the lattice — Jan Wójcik[1] and •Erik Kalz[2] — [1]Institute of Theoretical Physics and Astrophysics, University of Gdánsk, 80-308 Gdánsk, Poland — [2]Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany

We present a model for an isotropic chiral random walk on a lattice. Inspired by the quantum random walk framework, we equip the walker with an internal degree of freedom representing chirality and show, both numerically and analytically, that this model resembles odd transport properties on the continuum level. Chirality further acts as a control parameter, and the model resembles unitary transport in the strong-chirality regime. Building on established results from Quantum Random Walk theory, we analyse features such as topologically protected transport in this limit. We find that this qualitative persists also into the dissipative regime, allowing us to theoretically ground edge-transport phenomena, characteristics of dissipative odd systems. We illustrate our approach in spatially confined geometries and in systems with random chirality.

DY 35: Focus Session: Water – from Atmosphere to Space IV (joint session CPP/DY)

Time: Wednesday 9:30–10:45 Location: ZEU/0260

Topical Talk DY 35.1 Wed 9:30 ZEU/0260

Synchrotron X-Ray Studies on Structural Transitions in Water and Alcohol containing Ice Analogues — •Christina M. Tonauer — Institute of Physical Chemistry, University of Innsbruck, Austria — Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg, Germany

To this date, 21 different crystalline and at least 3 distinct amorphous forms of water ice have been discovered. In addition to the structural versatility of pure water ice phases, water forms solid guest-host systems, so-called 'clathrate hydrates' where water builds cage-like structures around guest molecules of various sizes (e.g., Ar, CO2, methane, ethanol).

Ices in space are exposed to various forms of (external) stress, e.g., impacts, cosmic rays, UV/Vis radiation as well as endogenous thermal fluctuations, thereby undergoing structural changes. By studying such structural transitions in ice analogues upon heating (and/or radiation), conclusions can be drawn about the conditions at various extraterrestrial environments.

Therefore, we here present temperature-resolved wide- and small-angle synchrotron X-ray scattering data of vapor-deposited water-ethanol mixtures of various concentrations, collected at PETRA 3/DESY. While the SAXS data allows for monitoring of changes of the morphology of the microporous sample, the WAXS data reveals the formation sequence of two different hydrates, offering new insights into the crystallisation of astrophysical ices.

DY 35.2 Wed 10:00 ZEU/0260

Water in exoplanetary atmospheres: from molecular spectra to Water Worlds — •Sergey Yurchenko — Department of Physics and Astronomy, University College London, Gower Street, WC1E 6BT London, United Kingdom

Water vapour is one of the key tracers of atmospheric physics and chemistry on exoplanets, from hot Jupiters to temperate sub-Neptunes and so-called Water Worlds. In this contribution I will give an overview of the role of H_2O across this diversity of atmospheres, focusing on how we infer its presence from transmission and emission spectra. I will review both low-resolution transit spectroscopy and high-resolution cross-correlation techniques, and show how they are applied to data from space- and ground-based facilities, including JWST, Hubble and VLT, as well as future observations with the ELT and ESA's Ariel mission. Special emphasis will be placed on the way clouds and hazes imprint themselves on the observed spectra.

I will summarise the current observational status of water detections and non-detections – including recent and sometimes controversial claims for habitable-zone planets. A central theme of the talk will be the importance of accurate laboratory and theoretical data for water and related species. I will highlight how comprehensive molecular line lists and cross sections from the ExoMol and HITRAN databases, together with other laboratory measurements, underpin the modelling and retrieval of exoplanet spectra over a wide range of temperatures, pressures and compositions, thereby linking detailed molecular physics to the emerging picture of water in exoplanetary atmospheres.

DY 35.3 Wed 10:15 ZEU/0260

Structures of Ices by Quantum Crystallography and PDF — Krzysztof Wozniak[1], •W. Sławiński[1], G. Łach[2], R. Gajda[1], M. Chodkiewicz[1], P. Rejnhardt[1], M. Arhangelskis[1], Ch. Ridley[3,4], and C. L. Bull[3,5] — [1]Deptm. of Chem., Univ. of Warsaw,Poland — [2]Deptm. of Phys., Univ. of Warsaw, Poland — [3]ISIS Neutron and Muon Source, STFC, RAL, Harwell Campus, UK. — [4]Spallation Neutron Source, Oak Ridge Nat. Lab., Oak Ridge, Tennessee 37830, USA — [5]Univ. of Edinburgh, UK.

Ice is the solid form of water (H*O). The most familiar form of ice is the hexagonally structured ice Ih. However, water can crystallize into at least 21 distinct phases, unique in structure, depending on T and P and route of formation. In this contribution, will present details of structures of ices (VI[3], VII[1,2], Ih [4]) obtained with quantum-crystallographic Hirshfeld Atom Refinement against single crystal X-ray and electron diffraction data. We will also present the first quantitative characterisation of disorder in D2O ice VII and VI obtained through a combination of Pair Distribution Function (PDF) analysis, Reverse Monte Carlo (RMC) modelling, and high-pressure neutron scattering. Our results provide a detailed decomposition of both the average and local atomic structures of Ice VII, revealing a previously unquantified level of structural disorder. References [1] R. Gajda et al., IUCRJ, 12(3) (2025) 288-294; [2] W. A. Sławiński et al., Hidden complexity in D2O Ice VII, Acta Mat., (2025) submitted; [3] M. L. Chodkiewicz et al., IUCRJ, 9 (2022) 573-579; [4] M. L. Chodkiewicz et al., IUCRJ, 11(5) (2024) 730-736.

DY 35.4 Wed 10:30 ZEU/0260

Water dynamics in conductive PEDOT:PSS/cellulose nanocomposite films in dependence of relative humidity and temperature — •Lucas Kreuzer[1], Marie Betker[2], Marcell Wolf[1], Jacques Ollivier[3], Daniel Söderberg[4], and Stephan V. Roth[2,4] — [1]Heinz Maier-Leibnitz Zentrum (MLZ), TUM, Garching, Germany — [2]Deutsches Elektronen Synchrotron, Hamburg, Germany — [3]Institut Laue-Langevin, Grenoble, France — [4]Department of Engineering Mechanics, Royal Institute of Technology KTH, Stockholm, Sweden

PEDOT:PSS is a conductive and water-soluble polymer blend widely used in organic electronics. However, pure PEDOT:PSS films absorb significant amounts of water, causing swelling, degradation, and eventually a decrease in conductivity. Integrating PEDOT:PSS with cellulose nanofibrils (CNFs) overcomes these issues by limiting water absorption and enhancing mechanical stability. However, a minor amount of water is still absorbed, leading to a change in film morphology: high humidity induces de-wetting of PEDOT:PSS from the CNFs, reducing conductivity, whereas drying generally leads to a re-wetting of PEDOT:PSS, thereby restoring conductivity. To investigate further the role of water, quasi-elastic neutron scattering is applied, which reveals two water species in the films: mobile bulk water and slower hydration water. Upon drying, bulk water is released completely, while hydration water remains in the films, supporting the re-wetting of PEDOT:PSS. Moreover, at higher temperatures, different diffusive behav-

ior was found for bulk and hydration water.

DY 36: Focus Session: Water – from Atmosphere to Space V (joint session CPP/DY)

Time: Wednesday 11:00–12:00 Location: ZEU/0260

DY 36.1 Wed 11:00 ZEU/0260

Scalable Machine Learning Model for Energy Decomposition Analysis in Aqueous Systems — •Thomas Kühne — CASUS/HZDR, Görlitz, Germany

Energy decomposition analysis (EDA) based on absolutely localized molecular orbitals provides detailed insights into intermolecular bonding by decomposing the total molecular binding energy into physically meaningful components. Here, we develop a neural network EDA model capable of predicting the electron delocalization energy component of water molecules, which captures the stabilization arising from charge transfer between occupied absolutely localized molecular orbitals of one molecule and the virtual orbitals of another. Exploiting the locality assumption of the electronic structure, our model enables accurate prediction of electron delocalization energies for molecular systems far beyond the size accessible to conventional density functional theory calculations, while maintaining its accuracy. We demonstrate the applicability of our approach by modeling hydration effects in large molecular complexes, specifically in metal-organic frameworks.

DY 36.2 Wed 11:15 ZEU/0260

Advances in absolute-scale electronic structure measurements of liquid water and aqueous solutions — •Florian Trinter — Fritz-Haber-Institut, Berlin, Germany

Recent advances in liquid-jet photoelectron spectroscopy (LJ-PES) have enabled the precise determination of absolute electronic energetics of liquid water and aqueous solutions, both in the bulk and at interfaces. By implementing refined vacuum and Fermi-level referencing procedures, rooted in condensed-matter concepts, vertical ionization energies (VIEs) and solution work functions can now be measured with high accuracy. We show that binding energy determinations near the ionization threshold are strongly influenced by quasi elastic electron scattering and indirect ionization processes. Vibrational excitation and autoionization via super-excited states lead to spectral distortions at electron kinetic energies below ∼14 eV, necessitating careful data interpretation to extract intrinsic properties. Applying these methods to neat water and aqueous solutions of sodium iodide (NaI) and tetrabutylammonium iodide (TBAI), we reveal solute-specific effects: NaI primarily alters water's bulk structure, increasing the $1b_1$ binding energy with concentration, while TBAI affects surface potentials through interfacial dipole formation, leading to an apparent binding energy decrease. Additionally, we determine the work function of neat water as 4.73 ± 0.09 eV and quantify its reduction in TBAI solutions. These findings establish a framework for quantitative studies of molecular interactions and electronic-structure modifications in aqueous systems, with implications for electrochemical and interfacial science.

DY 36.3 Wed 11:30 ZEU/0260

Liquid-vapor critical behavior of the TIP4P/2005 water model: Effects of NaCl solutes and hydrophobic confinement — •Mayank Sharma and Peter Virnau — Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany

The liquid-vapor critical behavior of water is strongly influenced by both ionic solutes and confinement. Molecular dynamics simulations of aqueous NaCl solutions using the TIP4P/2005 water model and the Madrid-2019 ion parameters reveal a systematic increase in the liquid-vapor critical temperature and pressure with salt concentration, consistent with experimental trends. In contrast, confinement between parallel hydrophobic plates leads to a depression of the critical point. The critical temperature was determined using the Binder cumulant crossing in the NVT ensemble, based on a recently developed method originally applied to an active Brownian particle system [1]. The reliability of this approach was verified through complementary NPT simulations using histogram reweighting. We further demonstrate the pronounced sensitivity of the estimated critical point to the van der Waals cutoff distance, underscoring the importance of properly accounting for long-range interactions. The present results capture qualitative shifts in the critical point of water arising from ionic interactions and confinement, and the Binder-cumulant framework used here is readily extendable to other critical phenomena, including the putative liquid-liquid critical point of water.

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

DY 36.4 Wed 11:45 ZEU/0260

Cooperative molecular dynamics and nuclear quantum effects in bulk water — •Margarita Russina — Helmholtz-Zentrum Berlin for Materials and Energy, Berlin, Germany

The cooperative dynamics in water remain difficult to access due to the lack of long-range order and the short lifetimes of molecular correlations. Neutron scattering is well suited to probe such phenomena on the nanoscale but has been hindered by the weak coherent signal of H2O. Using a novel neutron polarization-analysis approach, we directly measure the coherent scattering in H2O and D2O with high accuracy [1]. Beyond self-diffusion and molecular rotation, we identify a picosecond cooperative process in liquid water, likely associated with rearrangements of several neighboring molecules and the reorganization of hydrogen bonds. This process may act as a precursor to large-scale molecular transport. In the intermediate wave-vector range $Q < 1$ 1/Å, the coherent signal in H2O is enhanced compared to the expectation for rigid, noninteracting, randomly oriented molecules. Since this Q-range corresponds to distances of several molecular spacings, our results provide evidence that intermolecular correlations in water extend beyond short-range correlations and involve more distant neighbors, giving rise to cooperative dynamical fluctuations. Such an enhancement can be rationalized by correlated preferential molecular orientations, hydrogen-bond rearrangements, and nuclear quantum effects. In contrast, D2O follows a more hydrodynamic behavior consistent with reported differences in the molecular bonding and symmetry of H2O and D2O. [1] M. Russina et al., J. Phys. Chem. Lett. (2025).

DY 37: Glasses and Glass Transition (joint session DY/CPP)

Time: Wednesday 11:15–12:45 Location: ZEU/0118

Invited Talk DY 37.1 Wed 11:15 ZEU/0118

Topological defects in 2D amorphous ensembles — •Peter Keim — Heinrich-Heine-Universität Düsseldorf

Topological defects are key to understand melting of crystals in two dimensions. A dilute gas of bound thus virtual pairs of dislocations cause the softening of a crystal in the vicinity of melting. If thermal energy is high enough to unbind dislocation pairs, translational order is destroyed and the crystal to melts due to the lack of shear resistance. In an amorphous solid, the concept of topology seems useless for the first glance due to the absence of order. Here, we discuss, how the definition of virtual dislocations can be generalized for a two-dimensional glass. Based on positional data of a binary colloidal monolayer we determine the fugazity of generalized virtual dislocations and measure elasticity close to the glass transition: Youngs modulus gets 16π at melting in surprisingly close analogy to Kosterlitz-Thouless-Halperin-Nelson-Young (KTHNY) - theory for melting of 2D crystals.

DY 37.2 Wed 11:45 ZEU/0118

Glass transition and universal scaling in ultra-low crosslinked microgels — Alessandro Martinelli[1], Rajam Elancheliyan[1], Andrea Scotti[2], Alexander V. Petrunin[3], •Domenico Truzzolillo[1], and Luca Cipelletti[1,4] — [1]Laboratoire Charles Coulomb (L2C), UMR 5221 CNRS-Universitè de Montpellier, F-34095 Montpellier,France — [2]Division of Physical Chemistry, Lund University, SE-22100 Lund, Sweden — [3]Institute of Physical Chemistry, RWTH Aachen University, Landoltweg 2, 52074 Aachen,Germany — [4]Institut Universitaire de France, F-75231 Paris, France

We investigate the glassy dynamics of Ultra-Low Crosslinked (ULC) poly(N-isopropylacrylamide) (PNIPAM) microgels. The glass transition is reached by varying either the temperature (modulating microgel swelling) or the colloidal number density. Our Dynamic Light Scattering (DLS) measurements confirm that the dynamic slowdown is solely governed by the effective volume fraction (φ), with ULC microgels behaving as fragile glass formers. Small-Angle X-ray Scattering data further indicates that the center-to-center inter-microgel distance is insensitive to temperature, scaling geometrically with mass fraction, while the height of the first peak of the static structure factor decreases with increasing concentration, suggesting structural melting above glass transition. We finally we report on the striking emergence of a universal dynamic behavior for the relaxation time (τ_α) dependence on the scattering vector (q) across the entire supercooled and glass regimes, allowing the data to collapse onto a master curve, whose features will be discussed.

DY 37.3 Wed 12:00 ZEU/0118

Strain-rate dependent rheological memory in a model glass former — •Monoj Adhikari and Jürgen Horbach — Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany

We investigate the shear response of deeply supercooled liquids far below the mode coupling critical temperature of a model glass former. Our system is based on the Kob-Andersen binary Lennard-Jones mixture (KABLJM) model but incorporates polydispersity, allowing us to combine SWAP Monte Carlo (MC) with Molecular Dynamics (MD) simulations. This hybrid approach enables equilibration at temperatures far below the Mode-Coupling critical temperature, T_{MCT}, while maintaining an equation of state similar to the original binary KABLJM model. We examine the response of these equilibrated samples to shear deformation at finite temperature and strain rate. By combining MD with SWAP MC during shear, we demonstrate that states with stress far below the yield stress can be accessed, making Newtonian fluid behavior observable even at temperatures well below T_{MCT}. To characterize the Newtonian fluid states obtained from this hybrid approach, as well as the solid-like states from standard MD, we employ a strain-rate switching protocol on the steady states. When applying this protocol to the stationary states, we observe intriguing memory effects. In the transient regime, stress overshoots appear when increasing the strain rate, whereas a striking stress undershoot emerges when decreasing it, mirroring recent experimental observations in polymer glasses.

DY 37.4 Wed 12:15 ZEU/0118

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

Recent studies on 2D non-network glass formers, enabled by the million-fold acceleration of Swap Monte Carlo, have revealed clear deviations from Gaussian behavior in the inherent-structure (IS) density of states and linked these features to the fragile-to-strong crossover (FSC) and the emergence of a low-energy depletion regime.

Here, we establish such a connection by introducing a direct analytical relation between thermodynamic PEL statistics and dynamical properties within a trap-like description of supercooled liquids. We illustrate this relation using a binomial distribution of IS states and show that it naturally yields a characteristic trap size for polydisperse systems. This trap size reflects the effective number of degrees of freedom that collectively determine the depth and barrier of a metabasin participating in an activated relaxation event, thereby offering a physically transparent measure of cooperativity.

By combining this analytical framework with simulation data for a polydisperse 2D glass former, we obtain a coherent and quantitatively consistent landscape-based interpretation of the FSC.

[1] Andreas Heuer, J. Condens. Matter Phys. 2008, 20, 373101

[2] Anshul D. S. Parmar, Andreas Heuer, 2023 arXiv preprint arXiv:2307.10143

DY 37.5 Wed 12:30 ZEU/0118

Single particle vs. collective diffusion dynamics in a glass-forming ternary Lennard-Jones mixture — •Anna Pini and Jürgen Horbach — Institut für Theoretische Physik II: Soft Matter, Heinrich Heine-Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf

Ternary fluid mixtures exhibit a rather complicated diffusion dynamics compared to their binary counterparts. Apart from three self-diffusion coefficient, there are three interdiffusion coefficients. In this work, we study a ternary ABC Lennard-Jones mixture using molecular dynamics computer simulation. It is based on the Kob Andersen binary Lennard-Jones mixture (KABLJM) [1] to which we have added a third C component. While C-C and A-C interactions are respectively identical to A-A and A-B interactions, B-C interactions are different from those between A and B particles. We study the glassy dynamics of this system at a high density of $\rho = 1.2$ and compare it to that of the original KABLM. While the self-diffusion coefficient show a similar temperature dependence for the binary and the ternary system, the behavior of the interdiffusion coefficients in the ternary system is significantly different from that in the binary one; in particular, unlike the binary system, the Darken equation does not hold in the ternary one. [1] W. Kob and H. C. Andersen, Phys. Rev. Lett. **73**, 1376 (1994).

DY 38: Nonequilibrium Quantum Systems II (joint session TT/DY)

Time: Wednesday 15:00–17:30 Location: HSZ/0105

DY 38.1 Wed 15:00 HSZ/0105

Nonlocal Correlation Effects in the Relaxation Dynamics of the Photo-Excited Hubbard Model — •Gusein Bedirkhanov[1], Nagamalleswararao Dasari[2], Alexander I. Lichtenstein[2], and Evgeny A. Stepanov[1] — [1]CPHT, CNRS, École polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France — [2]Institut für Theoretische Physik, Universität Hamburg, 22607 Hamburg, Germany

Experiments on ultrafast irradiation of correlated materials have revealed a variety of exotic nonequilibrium phenomena. A theoretical investigation of these phenomena requires methods capable of accurately describing a complex interplay between the non-perturbative local correlations and nonlocal collective electronic fluctuations throughout their relaxation pathway. A recently developed real-time nonequilibrium *D-GW* method allows for such a description by incorporating nonlocal charge and spin fluctuations diagrammatically, going beyond the dynamical mean-field theory solution. In this work, we apply *D-GW* to track the relaxation dynamics of a photo-excited Hubbard model across different interaction strengths, including the particularly challenging region near the Mott transition. To simulate the transfer of electronic energy to other degrees of freedom, we introduce controlled cooling by coupling the electronic system to various relaxation baths and compare their efficiency and physical implications. We analyze the emergent steady and metastable states, and investigate how interaction strength and nonlocal correlations shape the relaxation pathway.

DY 38.2 Wed 15:15 HSZ/0105

Optimizing energy conversion with nonthermal resources in steady-state quantum devices — •Elsa Danielsson, Henning Kirchberg, and Janine Splettstoesser — Chalmers University of Technology, Sweden

In quantum transport, particle currents are investigated through quantum devices coupled to multiple contacts, which are defined by their electrochemical potentials and temperatures. However, when reaching the nanoscale, particles might no longer equilibrate with their thermal surroundings. Consequently, in the investigation of energy conversion processes, nonthermal distributions become highly relevant descriptors of the particles' environment. I will present how a nonthermal resource can be exploited to generate power or cool a contact and how to maximize the efficiency or precision for these processes. Utilizing coherent electron scattering, the optimization is made by adjusting the transmission probabilities of electrons at different energies. Importantly, we also address the issue of how to define an efficiency as the energy current cannot be neatly divided into heat and work, due to the presence of a nonthermal resource. Based on this, we show that for a fixed output current the optimal transmission function is a series of band-passes in the energy spectrum, depending on the shape of the nonthermal distribution. When applying this result on example systems with nonthermal resources we find that all performance quantifiers improve compared to thermal counterparts. These findings highlight the importance of designing nanoelectronic devices according to the electron distributions their contacts.

DY 38.3 Wed 15:30 HSZ/0105

Excited State Phases of Matter in the SymTFT Paradigm — •Ludwig Zweng[1,2], Apoorv Tiwari[3], and Sanjay Moudgalya[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences — [2]Munich Center for Quantum Science and Technology (MCQST) — [3]Southern Denmark University, Center for Quantum Mathematics at IMADA

Recent works have developed a unifying framework for classifying ground state phases of matter with a wide range of discrete symmetries—both group-like and non-invertible symmetries—via a holographic correspondence between symmetric operators in d dimensions and topological operators in a d+1 dimensional system often known as the SymTO or SymTFT. Its lattice formulation naturally yields fixed-point commuting Hamiltonians that realize these phases in their ground state. In this work, we extend this framework to non-equilibrium settings by analyzing excited states of these fixed-point models. Characterizing symmetry breaking patterns in the excited states requires new tools and diagnostic methods, which we develop to find that they can differ dramatically from their ground state counterparts, leading to a rich and sometimes surprising phenomenology. We illustrate these phenomena by constructing lattice models for a variety of invertible and non-invertible symmetries, classifying the distinct excited state phases that arise in each case. Finally, we propose a concrete definition of excited state phases of matter and argue that the SymTFTs that capture ground state phases do not fully capture the intricacies of the excited states.

DY 38.4 Wed 15:45 HSZ/0105

Improving the stability of the hierarchical equations of motion approach for generic bosonic spectral densities — •Salvatore Gatto, Samuel Rudge, and Michael Thoss — University of Freiburg

The hierarchical equations of motion (HEOM) constitute a numerically exact method for investigating the dynamics of open quantum systems across a wide range of environmental conditions [1]. In this contribution, we investigate the stability of HEOM for generic bosonic spectral densities and identify temperature- and coupling-dependent instabilities in the time evolution. We show that, upon increasing the system-bath coupling strength, the conventional HEOM formulation may become unstable, and that simply extending the hierarchy depth does not cure these long-time divergences [2]. Starting from the HEOM structure, we derive a multidimensional phase-space differential equation that generalizes the Quantum Fokker-Planck equation to arbitrary temperature [3]. We further demonstrate that expanding this new equation in an alternative basis removes the numerical instabilities inherent to the standard HEOM representation.

[1] J. Bätge, Y. Ke, C. Kaspar, M. Thoss, PRB 103, 235413 (2021)
[2] I. S. Dunn, R. Tempelaar, D. R. Reichman, J. Chem. Phys. 150, 184109 (2019)
[3] T. Li, Y. Yan, and Q. Shi, J. Chem. Phys. 156, 064107 (2022)

DY 38.5 Wed 16:00 HSZ/0105

Non-Local Correlation effects in DC and optical conductivity of the Hubbard model — Nagamalleswararao Dasari[1], Hugo Strand[2], Martin Eckstein[1], Alexander Lichtenstein[1], and •Evgeny Stepanov[3] — [1]Universität Hamburg, Germany — [2]Örebro University, Sweden — [3]CPHT, CNRS, École polytechnique, France

Many-body effects in correlated materials can be explored through various response functions, with transport measurements being among the simplest and most direct probes. Accurately addressing the unconventional transport properties of materials requires accounting for spatial electronic correlations. These correlations can significantly influence transport characteristics by modifying the electronic spectral function and giving rise to complex multi-electron scattering processes, known as vertex corrections, which can both strongly impact the conductivity. In this talk, I will discuss the impact of non-local correlations on the conductivity of the single-band Hubbard model within the recently developed D-GW method [arXiv:2507.16673]. I will demonstrate that the impact of non-local correlations on the conductivity differs between the correlated metallic and Mott insulating phases. Incorporating non-local correlations in both the electronic spectral function and vertex corrections is crucial for accurately describing the optical conductivity at finite frequencies in both these regimes. The crossover between the metallic and Mott insulating phases can be identified by a vanishing contribution of vertex corrections to the DC conductivity.

15 min. break

DY 38.6 Wed 16:30 HSZ/0105

Conditioning Subsystem Magnetization into the Large-Deviation Regime in Quantum Spin Chains — •Kriti Baweja[1], Samuel Garratt[2], David Luitz[1], Ali Zahra[3,4], and Jérôme Dubail[3,5] — [1]Institute of Physics, University of Bonn, Germany — [2]Department of Physics, Princeton University, USA — [3]Laboratoire de Physique et Chimie Théoriques, University of Lorraine, France — [4]Centro de Análise Matemática, Departamento de Matemática, Universidade de Lisboa, Portugal — [5]Centre Européen de Sciences Quantiques and ISIS, University of Strasbourg, France

We investigate the ground-state and finite-temperature properties of free-fermion and XXZ spin systems when a contiguous spatial region of the chain is conditioned to have a fixed value of its total S^z. We analyze

how this conditioning operation reshapes the local magnetization profile and longitudinal spin-spin correlations both within the constrained region and in its surrounding environment. To access regimes beyond analytically tractable limits, we extend an existing post-measurement Quantum Monte Carlo (QMC) framework by introducing new update rules that enable efficient sampling of states with arbitrary subsystem magnetization. Using this post-measurement QMC approach, we probe the finite-temperature properties of these conditioned states and characterize how magnetization constraints modify local structure in both interacting and non-interacting spin models. Our results provide a computational tool for exploring measurement-induced constraints and conditioned ensembles in quantum many-body systems.

DY 38.7 Wed 16:45 HSZ/0105

Consistent quantum treatments of nonconvex kinetic energies — Christina Koliofoti, Mohammad Atif Javed, and •Roman-Pascal Riwar — Peter Grünberg Institut (PGI-2), Forschungszentrum Jülich, 52428 Jülich, Germany

The task of finding a consistent relationship between a quantum Hamiltonian and a classical Lagrangian is of utmost importance for basic, but ubiquitous techniques like canonical quantization and path integrals. Nonconvex kinetic energies (which appear, e.g., in nonlinear capacitors or classical time crystals) pose a fundamental problem: the Legendre transformation is ill-defined, and the more general Legendre-Fenchel transformation removes nonconvexity essentially by definition. Arguing that such anomalous theories follow from suitable low-energy approximations of well-defined, harmonic theories, we show that seemingly inconsistent Hamiltonian and Lagrangian descriptions can both be valid, depending on the coupling strength to a dissipative environment. There occurs a dissipative phase transition from a nonconvex Hamiltonian to a convex Lagrangian regime, involving exceptional points in imaginary time. Our approach thus resolves apparent inconsistencies and provides computationally effcient methods to treat anomalous, nonconvex kinetic energies.

DY 38.8 Wed 17:00 HSZ/0105

Lanczos-Pascal approach to correlation functions in chaotic quantum systems — •Merlin Füllgraf, Jiaozi Wang, Robin Steinigeweg, and Jochen Gemmer — University of Osnabrück, Departement of Mathematics/Computer Science/Physics, D-49076 Osnabrück, Germany

We suggest a method to compute approximations to temporal correlation functions of few-body observables in chaotic many-body systems in the thermodynamic limit based on the respective Lanczos coefficients. Given the knowledge of these Lanczos coefficients, the method is very cheap. Usually accuracy increases with more Lanczos coefficients taken into account, however, we numerically find and analytically argue that the convergence is rather quick, if the Lanczos coefficients exhibit a smoothly increasing structure. For pertinent examples we compare with data from dynamical typicality computations for large but finite systems and find good agreement if few Lanczos coefficients are taken into account. From the method it is evident that in these cases the correlation functions are well described by a low number of damped oscillations.
[1] Accepted in Phys. Rev. Lett.

DY 38.9 Wed 17:15 HSZ/0105

Many-body neural network wavefunction for a non-Hermitian Ising chain — •Lavoisier Wah — Max Planck Institute for the Science of Light, 91058 Erlangen, Germany

Non-Hermitian (NH) quantum systems have emerged as a powerful framework for describing open quantum systems, non-equilibrium dynamics, and engineered quantum optical materials. However, solving the ground-state properties of NH systems is challenging due to the exponential scaling of the Hilbert space, and exotic phenomena such as the emergence of exceptional points. Another challenge arises from the limitations of traditional methods like exact diagonalization (ED). For the past decade, neural networks (NN) have shown promise in approximating many-body wavefunctions, yet their application to NH systems remains largely unexplored. In this paper, we explore different NN architectures to investigate the ground-state properties of a parity-time-symmetric, one-dimensional NH, transverse field Ising model with a complex spectrum by employing a recurrent neural network (RNN), a restricted Boltzmann machine (RBM), and a multilayer perceptron (MLP). We construct the NN-based many-body wavefunctions and validate our approach by recovering the ground-state properties of the model for small system sizes, finding excellent agreement with ED. Then, for larger system sizes, we demonstrate that the RNN outperforms both the RBM and MLP. These results highlight the potential of neural network-based approaches - particularly for accurately capturing the low-energy physics of NH quantum systems both in case of weak and strong non-Hermiticity.

DY 39: Networks, From Topology to Dynamics – Part II (joint session SOE/DY)

Time: Wednesday 15:00–15:45 Location: GÖR/0226

DY 39.1 Wed 15:00 GÖR/0226

Combining machine-learning and dynamic network models for sepsis prediction — •Juri Backes[1,3], Artyom Tsanda[1,2], Tobias Knopp[1,2], Wolfgang Renz[3], and Eckehard Schöll[4] — [1]TU Hamburg — [2]UKE Hamburg — [3]HAW Hamburg — [4]TU Berlin

We enhance short-term sepsis predictions by integrating machine learning techniques like Auto-Encoders and Gated-Recurrent-Units with a dynamical 2-layer network model of adaptive phase oscillators [1] representing the interaction between parenchymal cells (functional organ cells) and the immune system via cytokines. The model trajectories determined by machine learning are used for detection and prediction of critical infection states and mortality. The model-based predictions are compared with those of purely data-based approaches in terms of predictive power and interpretability. To this end we project real high-dimensional medical patient data into the low-dimensional parameter space of the model.

[1] R. Berner, J. Sawicki, M. Thiele, T. Löser, and E. Schöll: Critical parameters in dynamic network modeling of sepsis. Front. Netw. Physiol. 2, 904480 (2022).

DY 39.2 Wed 15:15 GÖR/0226

Forecasting emergency department visits in the reference hospital of the Balearic Islands: the role of tourist and weather data — •Paride Crisafulli, Tobias Galla, Raul Toral, and Claudio Mirasso — IFISC (UIB-CSIC), Palma de Mallorca, Spain

Accurate forecasting of patient arrivals at emergency departments (EDs) is vital for efficient resource allocation and high-quality patient care. Despite its significance and extensive prior research, certain conditions can significantly impact the accuracy of these estimates. This study investigates the relevance of tourism and weather data alongside traditional calendar and demographic variables in forecasting ED visits in the reference hospital in Palma de Mallorca, a city with significant seasonal population fluctuations due to tourism. Utilizing a machine learning approach, we develop a model that predicts ED visits based solely on exogenous variables. We test three different machine learning algorithms (random forests, support vector machines, and feed-forward neural networks) with four different input combinations, comparing their mean average percentage errors (MAPEs) and prediction horizons.

DY 39.3 Wed 15:30 GÖR/0226

Beyond Averages: How Disease Severity and Social Structure Interact to Shape Pandemic Dynamics — •Fabio Sartori, Sophia Horn, Sven Banisch, and Michael Maes — Chair of Sociology and Computational Social Science, Karlsruhe Institute of Technology, Karlsruhe

Epidemiological models typically rely on population averages, overlooking behavioral polarization and social structure. We developed a compartmental framework examining how polarization and homophily shape outcomes across mask-wearing, testing, and vaccination interventions. Results reveal intervention-specific effects: polarization benefits masks but harms testing and vaccination. Homophily worsens outcomes for low-infectivity diseases by removing protective barriers, but improves outcomes for highly infectious diseases through protective bubbles. Calibrating with German survey data (n=1,612), homogeneous models showed large errors. Intervention effectiveness depends critically on social structure and pathogen characteristics, not just average compliance.

DY 40: Statistical Physics of Biological Systems II (joint session DY/BP)

Time: Wednesday 15:00–16:30 Location: ZEU/0114

Invited Talk DY 40.1 Wed 15:00 ZEU/0114

Learning the statistical folding of bacterial chromosomes — •Chase Broedersz — Vrije Universiteit, Amsterdam, Nertherlands

The physical organization of bacterial chromosomes is inherently variable, with large conformational fluctuations both from cell to cell and over time. Yet, chromosomes must also be structured to facilitate processes such as transcription, replication, and segregation. A physical description of this dynamic statistical folding of bacterial chromosomes remains largely elusive. Hi-C experiments probe chromosome organization by measuring average contact frequencies of chromosomal loci pairs. I will present a principled approach to infer and analyze the dynamic and statistical organization of chromosomes. In particular, we developed a rigorous and fully data-driven 4D Maximum Entropy approach to extract a generative model for the dynamic organization of a replicating bacterial chromosome directly from time-course Hi-C and microscopy data. This data-driven approach aims to unravel the dynamic statistical folding of chromosomes - and its impact on functional processes - in growing and replicating bacteria. Finally, I will discuss how these data-driven inferences can be used to develop mechanistic insights into the contributions of various chromosome segregation mechanisms, including ParABS and loop-extruding SMC complexes. Together, our results illustrate how changes in the geometry and topology of the polymer, induced by DNA-replication and loop-extrusion, impact the organization and segregation of bacterial chromosomes.

DY 40.2 Wed 15:30 ZEU/0114

A freely jointed chain with two-state hinges — •Minsu Yi and Panayotis Benetatos — Department of Physics, Kyungpook National University, Daegu, South Korea

We discuss aspects of the stretching and bending elasticity of a freely jointed chain, where the hinges can be open or closed in a random fashion. This two-state-hinge model captures a specific degree of freedom associated with the local bending stiffness of the polymer, and its variation can be due to internal changes or to the attachment of ligands from the environment. In this presentation, we focus on comparing the effects of two different types of disorder on the hinges: annealed (reversible Freely Jointed Chain, rFJC) or quenched (quenched Freely Jointed Chain, qFJC). It turns out that, as expected, those different types of disorder yield qualitatively different behaviors. For finite-size systems, we obtain a recurrence relation, which allows us to calculate the exact force-extension relation numerically for an arbitrary size of the system for both systems. In the thermodynamic limit, when the contour length is much larger than the persistence length, we obtain an exact expression for the force-extension relation. The difference between the two systems still exists in the thermodynamic limit.

[1] M. Yi, D. Lee and P. Benetatos, J. Chem. Phys. 161 (23): 234908 (2024)

[2] M. Yi and P. Benetatos, J. Stat. Mech. 073501 (2025)

DY 40.3 Wed 15:45 ZEU/0114

Impact of cytosine methylation on the diffusion of charges along DNA: a quantum perspective — •Mirko Rossini, Dennis Herb, Paul Raschke, and Joachim Ankerhold — Institute for Complex Quantum Systems, University of Ulm, Ulm, Germany

We develop a coarse-grained tight-binding (TB) framework that treats electrons and holes on equal footing. TB parameters, required to characterize the model, are derived from an ab-initio molecular scheme (linear-combination-of-atomicorbitals (LCAO)) that includes all valence orbitals. Simulations address unmethylated vs. methylated CpG-rich and regulatory sequences sensible to DNA methylation, enabling us to investigate the impact methylation has on the charge diffusion along models of critical relevance in epigenetics and shedding new light on possible undiscovered mechanisms for epigenetic regulation in cells.

Methylation substantially lowers cytosine charge energies (˜150 meV) while leaving the opposite guanine nearly unchanged (<20 meV), thereby introducing site-selective energetic shifts that redesign diffusion pathways. Statistical investigations, such as time-averaged populations and Inverse Partecipation Ratio (IPR) analyses, show enhanced electron localization at methylated cytosines, contrasted by increased hole delocalization: these dual trends suppress electron-hole co-localization (localization at same sites) and reduce recombination probability, leading to higher trapping times of excess charges along the DNA. Consistently, modelled excitations lifetimes increase upon cytosine methylation.

DY 40.4 Wed 16:00 ZEU/0114

Efficient control of F_1 molecular motor — •Deepak Gupta — Institut für Physik und Astronomie, Technische Universität Berlin, Germany

Designing low-dissipation control driving protocols for small-scale systems is an active field of research. In this talk, I will specifically discuss designing efficient driving procedures for a biomolecular motor-the F_1ATPase. In general, designing such protocols is challenging due to the spatial nonlinearity of the systems and the presence of environmental thermal fluctuations. Nonetheless, a near-equilibrium (linear response) framework is found to apply to a broad class of small-scale systems. We follow this framework to design non-trivial protocols to drive the F_1's γ-shaft to synthesize ATP at low-dissipation cost. Our analysis reveals that the designed protocols, based on the linear response approach, dissipate lower energy as compared to the constant velocity driving protocol for a wide range of protocol durations[1]. In the second part of my talk, I will show our recent experimental results on the F_1 ATPase motor, where we compared the dissipation of driving this motor using two experimentally viable protocols: angle clamp and torque clamp. Our experimental results (supported by analytical findings) suggest that angle clamp driving requires less work than that of the torque clamp[2].

[1] J. Phys. Chem. Lett. 13 (51), 11844-11849 (2022). [2] Phys. Rev. Lett. 135 (14), 148402 (2025).

DY 40.5 Wed 16:15 ZEU/0114

Elementary spectrum for the dissonance curve: from biophysics to number theory of musical harmony — •Alexandre Guillet — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Musical harmony, as the ancient problem of finding tunings and scales based on the commensurability of sound waves, has been approached by Helmholtz in terms of a dissonance curve in the frequency domain. This model is here recast in an elementary form related to number theory and a thermodynamical formalism for musical intervals and frequency ratios. The idea of the pioneer of biophysics connects with Riemann's zeta function along the critical line, and Minkowski's question mark measure. The former models rational relationships resulting from the acoustics of a harmonic timbre, while the latter models the probability distribution of the neurocognitive effort to assess the commensurability of frequency pairs. The spectrum of the resulting fractal curve predicts the quasi-periods of widely used musical scales, from the pentatonic division of the octave to microtonal ones, thus constituting a biophysical and mathemusical common ground to harmony across musical genres and cultures.

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

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

DY 41.1 Wed 15:00 P5

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

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

DY 41.2 Wed 15:00 P5

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

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

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

DY 41.3 Wed 15:00 P5

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

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

DY 41.4 Wed 15:00 P5

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

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

DY 41.5 Wed 15:00 P5

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

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

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

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

DY 41.6 Wed 15:00 P5

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

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

DY 41.7 Wed 15:00 P5

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

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

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

DY 41.8 Wed 15:00 P5

Mesoscopic interface laws in patterns formed by non-

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

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

DY 41.9 Wed 15:00 P5

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

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

DY 41.10 Wed 15:00 P5

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

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

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

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

DY 41.11 Wed 15:00 P5

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

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

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

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

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

DY 41.12 Wed 15:00 P5

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

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

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

DY 41.13 Wed 15:00 P5

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

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

DY 41.14 Wed 15:00 P5

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

Obtaining phase diagrams and density distributions via Grand canonical Monte Carlo simulations (GCMC) for classical fluids still requires substantial computational resources. Here, classical density functional theory (cDFT) is more efficient if the excess functional for the free energy is known. Recently, machine learning (ML) methods have become popular to learn such functionals (which are broadly applicable) from a limited amount of training data obtained in random, inhomogeneous external potentials [1]. We discuss an extension of an ML scheme to lattice fluids and apply it to the case of hard rods in two dimensions (2D). This model shows demixing between majority phases of vertically resp. horizontally oriented rods. This is typical of demixing in a binary, continumm fluid whose phase diagram has been learned recently in [2] employing only training data inhomogeneous in 1D. The use of explicit 2D training data allows applications to more general inhomogeneous situations [3].
[1] A. Simon and M. Oettel, Machine learning approaches to classical density functional theory (review), arXiv:2406.07345
[2] S. Robitschko et al, J. Chem. Phys. 163, 161101 (2025)
[3] F. Glitsch, J. Weimar and M. Oettel, Phys. Rev. E 111, 055305 (2025)

DY 41.15 Wed 15:00 P5

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

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

DY 41.16 Wed 15:00 P5

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

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

DY 42: Poster: Quantum Dynamics and Many-body Systems (joint session DY/TT)

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

DY 42.1 Wed 15:00 P5

Operator spreading through the lens of the information lattice — •Luca Gawalleck[1,2], Maxime Debertolis[1], Jens H. Bardarson[3], and David J. Luitz[1] — [1]Institut of Physics, University of Bonn, Nußallee 12, 53115 Bonn, Germany — [2]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany — [3]Department of Physics, KTH Royal Insititute of Technology, Stockholm, 106 91 Sweden

We study the entanglement growth during Heisenberg time evolution by extending the framework of the information lattice to operators using the operator entanglement entropy. We focus on one-dimensional quantum spin chains and work in the tensor network formalism. The generalization of the information lattice to matrix product operators allows us to observe the spreading of initially local operators in a way that is not biased by the choice of a probing operator. We demonstrate that the operator information lattice we introduce contains all information typically provided by the out-of-time-order correlator with the additional ability to resolve the correlations on different scales. This method provides a good way to analyze systematically the time dependence of entanglement and can seamlessly be integrated into existing information-lattice-based algorithms.

DY 42.2 Wed 15:00 P5

Non-Perturbative Out-Of-Equilibrium Dynamics with Initial Four-Point-Correlations — Jürgen Berges, Louis Jussios, and •Cosima Schmitt — ITP Heidelberg

We investigate how initial correlations affect the equilibration dynamics of closed systems in quantum field theory. For interacting scalar fields with N components, we derive nonequilibrium evolution equations from a self-consistent large-N expansion to next-to-leading-order. By going beyond conventional Gaussian initial conditions, we point out the role of initial four-point correlations for the propagator evolution at early times and in the late-time approach to thermal equilibrium.

DY 42.3 Wed 15:00 P5

Nonequilibrium Green Function Simulations for Large Systems — •Erik Schroedter, Jan-Philip Joost, and Michael Bonitz — Christian-Albrechts-Universität zu Kiel, Kiel, Germany

Nonequilibrium Green Functions (NEGF) provide a powerful framework for accurately simulating the dynamics of correlated many-body systems. A major limitation of standard NEGF approaches is the cubic scaling of computational cost with the number of time steps. Recently, the G1-G2 scheme [1] overcame this limitation, achieving linear scaling. However, it introduces its own challenges, such as numerical instabilities at strong coupling and large memory requirements, which have so far restricted simulations to small systems with fewer than 150 basis states. Here, we introduce a NEGF-based quantum fluctuations approach (NEGF-QF)[2] that builds on earlier works [3] to efficiently factorize the two-particle Green function. This method drastically reduces computational costs for advanced self-energy approximations, including GW and T-matrix, while enabling straightforward parallelization. As a result, NEGF-QF allows simulations of systems with up to ten thousand basis states. We demonstrate the approach for large Hubbard clusters and graphene nanoribbons, illustrating its effectiveness for large, strongly correlated systems.

This work was funded by the Deutsche Forschungsgemeinschaft (DFG), Project No. 464370560.

[1] Schlünzen et al., Phys. Rev. Lett. 124, 076601 (2020)
[2] Schroedter et al., to be published (2026)
[3] Schroedter et al., Cond. Matt. Phys. 25, 23401 (2022)

DY 42.4 Wed 15:00 P5

Quantum Chaos in a Classical Counterpart to the Fermi-Hubbard model through an exact Path-Integral Formalism — •Louis Renck[1], Wolfgang Hogger[2], Juan Diego Urbina[2], and Peter Schlagheck[1] — [1]IPNAS, CESAM research unit, Univer-

sité de Liège, Belgium — [2]Institut für Theoretische Physik, Universität Regensburg, Germany

Understanding quantum chaos in interacting many-fermion systems remains challenging : unlike many-bosons systems - where quantum-classical correspondence can be established using semiclassical tools such as the van Vleck-Gutzwiller propagator [1] -, most interacting fermions models still lack a sensible classical limit where Hamiltonian chaos can be defined.

We propose a candidate to the first classical Hamiltonian for the Fermi-Hubbard model with integrability broken by a random onsite potential. Starting from the fermionic Hamiltonian, we apply a Jordan-Wigner transformation and switch to the Schwinger-boson representation to obtain a bosonic form. A recently developed exact bosonic path-integral formalism [2] then provides a classical Hamiltonian symbol defined over a symplectic phase space. We investigate the resulting quantum-classical correspondence by comparing the effective dynamics with the quantum evolution, and we present quantitative checks of chaos based on spectral properties and out-of-time ordered correlators.

[1]. T. Engl, J. Dujardin, A. Argüelles, P. Schlagheck, K. Richter, and J. D. Urbina, Phys. Rev. Lett. 112, 140403 (2014).

[2]. F. Bruckmann and J. D. Urbina (2018)

DY 42.5 Wed 15:00 P5

Adaptive Fermion Circuits with chiral transport — •Markus Siegl and Michael Buchhold — Department of Theoretical Physics, Universität Innsbruck, Austria

Nonequilibrium quantum transport, where coherent many-body dynamics coexist with directional motion remains a central challenge in modern quantum physics. This project investigates transport phenomena in two coupled fermionic chains designed to break chiral symmetry. Using fermionic adaptive circuits and measure-ment-feedback protocols, we aim to control nonequilibrium dynamics and induce directional motion in an other-wise symmetric quantum system. By linking classical universality, quantum many-body effects, and information transport, the research seeks to uncover new mechanisms for controlled, symmetry-broken quantum transport, establishing a model system for genuinely nonequilibrium quantum matter.

DY 42.6 Wed 15:00 P5

Absorbing-State Dynamics and Feedback Control in Quantum Many-Body Scar Systems — •Lara Schorr — University of Innsbruck

We look at quantum many-body scar states, which are special excited states in non-integrable systems that do not thermalize. To better understand their non-equilibrium dynamics, we translate the problem to a measurement-based quantum circuit equipped with feedback control. Focusing on a spin-1/2 chain with SU(2) symmetry, we show that local unitary feedback enables controlled manipulation of non-local charges, allowing the system to relax into highly entangled dark states. By analyzing the convergence towards the target state, we find that the dynamics resembles an emergent absorbing-state process, in which non-local charges diffuse and annihilate over time. Studying the scaling of convergence times allows us to identify conditions under which the dynamics may exhibit an absorbing-state phase transition.

DY 42.7 Wed 15:00 P5

Floquet-Magnus expansion for driven quantum systems and spin dynamic mean-field theory in NMR — •Antonia Joëlle Bock — TU Dortmund University, Germany

An accurate and reliable theoretical description of periodically driven quantum systems is highly relevant to many applications, such as for magic-angle spinning (MAS) in nuclear magnetic resonance (NMR) and ultracold atoms in driven optical lattices. Typically, the first step in capturing the dynamics is to determine an effective time-independent Hamiltonian, for which one can choose from a broad range of slightly different, hence often confusing, theories. Thus, I specifically investigated two widely used theories: Average Hamiltonian theory (AHT) and the Floquet-van Vleck approach (secular averaging). I was able to quantify the importance of the kick operator for the equivalence between perturbative and numerically exact approaches. This was achieved through analytical calculations and numerical evaluations of exemplary spin systems. These crucial insights then build the foundation for the second step of my project: a dynamic mean-field theory for dense spin ensembles applicable to complex couplings between three or more spins (MAS-DMFT). The recently developed spinDMFT (cp., e.g., Gräßer et al., 2024) has proven to be efficient, accurate and applicable to large spin systems yielding 2-particle interactions.

DY 42.8 Wed 15:00 P5

Phonon mediated indirect spin interaction — •Pablo Reiser and Habib Rostami — University of Bath, Bath, United Kingdom

Due to the lack of inversion symmetry in the hBN monolayer, circular polarized vibration in solids, or chiral phonons, with nonzero angular momentum are allow. These chiral phonons can couple to spins of different nature through their angular momentum. Within this context, we explored the coupling of chiral phonons with non-zero angular momentum to two impurities spins in hBN. Using field theory methods, we obtained the spin susceptibility and studied it*s properties like the mass dependence of the coupling, frequency of oscillation and rate of decay. The momentum transfer due to this coupling may opens the door for non-trivial thermal or spin transport effects.

DY 42.9 Wed 15:00 P5

Dynamical Phases and Instabilities in Periodically Driven Bogoliubov-de Gennes Superconductors — •Subhadip Chakraborty, Animesh Panda, and Ferdinand Evers — Institute of Theoretical Physics, University of Regensburg, D-93040 Regensburg, Germany

We investigate the nonequilibrium dynamics of a superconductor subjected to a periodic modulation of the interaction strength starting with Bogoliubov-de Gennes (BdG) mean field Hamiltonian. Using numerical solutions of the time-dependent Bogoliubov-de Gennes equations, we first explore several dynamical superconducting regimes. Our analysis reveals a rich variety of phases, including Rabi-Higgs oscillations, synchronized Higgs dynamics, and time-crystalline responses, and shows how their stability varies across driving parameters. In some regions of parameter space, infinitesimal initial seeds of finite momentum pairing grow exponentially during our driving protocol. By computing the momentum-resolved pairing response, we identify the instability bands associated with these finite-momentum modes, quantify their growth rates, and determine their dependence on driving frequency and drive amplitude. These results provide a comprehensive numerical characterization of the dynamical phases and instabilities that arise in periodically driven superconductors before the final steady state is reached.

DY 42.10 Wed 15:00 P5

Higher order Magnus expansion for two-level quantum dynamics — •Chen Wei and Frank Grossmann — Institut für Theoretische Physik, 01062 Dresden, Germany

This study investigates the Magnus expansion[1] for a generic time-dependent two-level system. By using its convergence condition[2], we find that elementary unitary transformations significantly extend the validity of the Magnus expansion. Furthermore, higher order terms admit particular physical interpretations. By virtue of su(2) Lie algebra, the expansion is decomposed into a commutator-free form. To illustrate its usefulness, we study the Landau-Zener[3] model, which displays a special case of non-adiabatic transitions. Using agian the Magnus expansion, Hermitian and non-Hermitian versions of the semiclassical Rabi model are systematically treated by determining the Floquet quasienergy[4] and Bloch-Siegert shift[5]. As a noteworthy by-product, the Magnus expansion provides a quantitative characterization of the adiabatic theorem[6].

[1] W. Magnus, Commun. Pure Appl. Math. 7, 649-673 (1954). [2] M. M. Maricq, J. Chem. Phys. 86, 5647-5651 (1987). [3] C. Zener and R. H. Fowler, Proc. R. Soc. Lond. A 137, 696-702 (1932). [4] J. H. Shirley, Phys. Rev. 138, B979 B987 (1965). [5] F. Bloch and A. Siegert, Phys. Rev. 57, 522-527 (1940). [6] M. Born and V. Fock, Z. Phys. 51, 165-180 (1928).

DY 42.11 Wed 15:00 P5

Distribution of complex amplitudes of chaotic resonance states — •Jan Möseritz-Schmidt and Roland Ketzmerick — TU Dresden, Institut für Theoretische Physik, Dresden, Germany

Resonance states of chaotic scattering systems have complex amplitudes in the position representation. Naively, one would expect that the phase of the complex amplitude is uniformly distributed, however, we observe significant deviations. We find that part of this is a finite-size effect which is already present in the random wave model. It is enhanced by the multifractal structure of chaotic resonance states, which follows from the factorization conjecture. We quantify these

deviations using the phase rigidity and analyze its scaling behavior in the semiclassical limit. Numerically, this is demonstrated for the paradigmatic three-disk scattering system.

DY 42.12 Wed 15:00 P5

Complex dynamics and particle-wave correspondence in anisotropic mesoscopic cavities — •Silvan Stopp, Samuel Schlötzer, Lukas Seemann, and Martina Hentschel — Technische Universität Chemnitz, 09107 Chemnitz, Germany

Mesoscopic billiard systems with different geometries are well-known model systems for investigating complex dynamics and quantum chaos. While the breaking of spatial cavity symmetries is typically considered to be the origin of chaotic dynamics, we show that anisotropies, i.e., broken symmetries in momentum space, can also cause chaotic particle dynamics. To this end, we investigate bilayer graphene systems (BLG) [1] and birefringent optical microcavities [2], both of which have preferred propagation directions. Anisotropy prevent angular momentum to be a conserved quantity, and consequently, the angles of incidence and of reflection of a particle trajectory deviate. Therefore, we implementing an advanced ray tracing algorithm that we apply to BLG and birefringent cavities. We show that the presence of anisotropies induces chaotic dynamics even in circular cavities. We investigate the interplay of the cavity shape and the Fermi line geometry and illustrate how it affects the cavity dynamics. In particular, we find that certain trajectories can be stabilized by matching the symmetry in real and momentum space. In addition, we use Kwant and transformation optics to demonstrate ray/particle-wave correspondence in real space as well as in phase space using the Husimi function.

[1] L. Seemann, A. Knothe, M. Hentschel, PRB 107, 205404 (2023)
[2] M. Hentschel, S. Schlötzer, L. Seemann, Entropy 27(2):132 (2025)

DY 42.13 Wed 15:00 P5

Periodic orbit theory approach for a non-Hermitian Riemann operator — •Sebastian Hörhold, Andreas Hötzinger, Juan Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

The Riemann Hypothesis (RH) is one of the most important open problems in mathematics. Among the various approaches toward its proof is the Hilbert-Pólya (HP) conjecture, stating that there should exist a Hermitian operator whose eigenvalues t_n are given by the zeros of the Riemann zeta function $\zeta(1/2 + it_n)$. The RH would then follow from the reality of these eigenvalues.

In a recent contribution toward a proof of the RH, a non-Hermitian Hamiltonian has been introduced, referred to as a Riemann operator, whose spectrum contains the t_n, and from which one can construct an HP operator [1]. Our work focuses on a similar Hamiltonian, and we intend to make use of semiclassical tools to support earlier work by Berry and Keating, who obtained a formal asymptotic expression for the counting function of the nontrivial Riemann zeros [2]. Their results suggest a strong connection between the spectral statistics of these zeros and classically chaotic systems.

In this poster contribution, we show the emergence of the Riemann zeros within the spectrum of our non-Hermitian Hamiltonian and discuss how periodic orbit theory can be applied.

[1] E. Yakaboylu, arXiv:2408.15135
[2] M. V. Berry and J. P. Keating, SIAM Review 41.2 pp. 236-266

DY 42.14 Wed 15:00 P5

Echo state network prediction of billiard dynamics — •Anna Skopnik, Lukas Seemann, and Martina Hentschel — Institut für Physik, TU Chemnitz, Germany

Machine Learning has attracted a lot of interest recently. Here, we apply an Echo State Network (ESN) algorithm to two mesoscopic billiard systems in order to explore its usability in the prediction of the internal dynamics of ballistic cavities. First, we study the well-known Limaçon system with chaotic dynamics. Second, we study the more complex dynamics in an anisotropis system inspired by bilayer graphene (BLG) representing a mixed space dynamics with regular and chaotic trajectories. Here, we present preliminary results on the training and hyperparameter optimization for both systems, Limaçon and BLG.

DY 42.15 Wed 15:00 P5

Anomalous Dynamics in Complex Quantum Systems — •Irina Petreska[1], Pece Trajanovski[1,2], Ervin Kaminski Lenzi[3], and Trifce Sandev[1,2,4] — [1]Ss. Cyril and Methodius University in Skopje, Macedonia — [2]Macedonian Academy of Sciences and Arts, Skopje, Macedonia — [3]Universidade Estadual de Maringá, Maringá, Brazil — [4]Korea University, Seoul, Korea

We will give an overview of our recent works related to some generalizations of the Schrödinger equation. Special attention will be paid to the fractional Schrödinger equation, pointing out physical examples where the time-fractional Schrödinger equation naturally emerges under certain geometric constraints. Additionally, we include a long-range interaction term, modeled by an integral operator, which captures spatial nonlocalities. Using the Green's function approach, we derive analytical solutions and explore their implications in the time-space domain. Our findings reveal anomalous behavior arising from the interplay of fractional dynamics, nonlocal potentials and memory effects.

DY 43: Poster: Statistical Physics

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

DY 43.1 Wed 15:00 P5

Extended classical nucleation theory for active phase separation in the reversed Ostwald regime — •Wanja Becker[1], Cesare Nardini[2,3], and Michael te Vrugt[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany — [2]Service de Physique de l'Etat Condensé, CEA, CNRS Université Paris-Saclay, CEA-Saclay, 91191 Gif-sur-Yvette, France — [3]Sorbonne Université, CNRS, Laboratoire de Physique Théorique de la Matière Condensée, 75005 Paris, France

Classical nucleation theory (CNT) is a model to describe how rare fluctuations lead to nucleation and thus describes the kinetics of phase transitions. In Ref. [1], CNT was extended to describe phase separation in Active Model B+ - a scalar field theory for active matter - for the case of positive active surface tension. Here, we further extend the theory to be applicable for negative active surface tensions. In this regime a stable fixed-point radius is expected to be found. Droplets smaller than this radius grow and droplets larger than this radius shrink, i.e. reverse Ostwald ripening. In Ref. [1], the theory was formulated by expanding the order parameter in powers of 1/R, up to order 1/R. Here, terms of order 1/R^2 are included to describe nucleation for negative surface tension. In doing this the effective potential acquires an additional linear contribution. We calculate the prefactor of the linear contribution numerically to determine whether it suffices to capture the nucleation of droplets at negative surface tension that afterwards grow by reversed Ostwald processes.

[1] M. E. Cates and C. Nardini, Phys. Rev. Lett. 130, 098203 (2023)

DY 43.2 Wed 15:00 P5

Classical fractionally charged quasiparticles in kagome lattices and at interfaces — •Jannis Waldmann, Malte Grunert, 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 have also been predicted in the absence of magnetic fields 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 results on the transport properties of classical particles with nearest-neighbor repulsion on a kagome lattice including Andreev-like reflection at interfaces between frustrated and 'normal', i.e., non-frustrated matter. This involves a coupling between kagome lattice and an infinite particle reservoir via transport channels. Through kinetic Monte Carlo simulations, we study the transition from classical hopping at high temperatures and electric fields to transport dominated by half-charged quasiparticles at low temperatures and special filling factors.

[1] P. Fulde et al., Ann. Phys. 514, 892-900 (2002)
[2] F. Pollmann et al., J. Magn. Magn. Mat. 310, 966-968 (2007)

DY 43.3 Wed 15:00 P5

Non-markovian master equation for Thioacetylacetone Coupled to bosonic bath — •Zahra Sartipi[2], Richard Gundermann[1], Janet Anders[2,3], and Peter Saalfrank[1] — [1]University of Potsdam, Institute of Chemistry, Theoretical Chemistry, Karl-Liebknecht-Str. 24-25, D-14476 Potsdam, Germany — [2]University of Potsdam, Institute of Physics and Astronomy, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany — [3]Physics and Astronomy, University of Exeter, Exeter EX4 4QL, United Kingdom

The Canonically Consistent Quantum Master Equation (CCQME) is used to address intramolec-ular proton transfer in thioacetylacetone , with an N -level quantum system coupled to an organic solvent. In this setup, the solvent is modeled as a harmonic bath (a continuum of oscillators) characterized by a Drude-cutoff Ohmic spectral density.

The results highlight that while the Redfield and CCQME (canonical consistent quantum master equation) approaches agree in the weak-coupling regime, they diverge at stronger couplings. Redfield incorrectly drives the system toward the canonical Gibbs state of the bare system Hamiltonian, neglecting the influence of correlations, and may thus yield thermodynamically inconsistent predictions. By contrast, CCQME incorporates the bath's effect on the system's energy landscape, ensuring relaxation toward the correct mean-force Gibbs state. This guarantees both positivity and consistency with statistical mechanics, even at stronger coupling.

DY 43.4 Wed 15:00 P5

An O(logN) Kinetic Monte Carlo Algorithm for Transport Simulation with Long-Range Interactions — •Bat-Amgalan Bat-Erdene, Roya Ebrahimi Viand, Karsten Reuter, and Sebastian Matera — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin

When transport is controlled by activated events, kinetic Monte Carlo (kMC) simulation is the method of choice. However, a characteristic of charge transport is the presence of long-range Coulomb interactions, leading to a complexity of $O(N)$ in the system size N for the updates of the transition rates. In contrast, kMC with only short-range interactions can be made to scale as $O(\log N)$ per step, and thus Coulomb interactions cause a significant computational overhead. We address this issue by a novel time discretization approach. Starting with exact values for the rates, the approach conducts fast incremental updates ($O(\log N)$) in every step based on a truncated short-range potential. Inevitably, this leads to a deviation of the rates from their true values as simulation proceeds. Therefore, a full $O(N \log N)$ recalculation is conducted once every $O(N)$ steps, resulting in an average cost of $O(\log N)$ per step. We demonstrate the scheme for charge transport on a cubic lattice using our in-house kMC framework. Special emphasis is placed on the balance between discretization error and efficiency, as well as the influence of the truncation radius on both.

DY 43.5 Wed 15:00 P5

Quantifying stochastic resonance in bistable systems: a new measure based on passive observation — •Christian Muñoz[1], Bart Vos[1], Till Münker[1], Dorian Marx[1], Matthias Krüger[2], and Timo Betz[1] — [1]Third Institute of Physics - Biophysics, Georg August University Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [2]Institut für Theoretische Physik, Georg August University Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Stochastic resonance (SR) is a noise-assisted phenomenon of broad relevance whose complexity motivates its study in simple and controllable systems. In this work, SR is investigated using a single Brownian particle confined in a bistable potential created with optical tweezers. In such a system, SR emerges from the interplay between thermal fluctuations and the periodic modulation of the potential landscape. First, several well-established approaches from literature are revised to determine under which conditions SR is enhanced. In particular, the strength of the first peak of the residence time distribution displays a clear maximum. Additionally, we propose a new protocol to quantify SR based on the novel quantity of the mean back relaxation (MBR). The new quantifier, which measures the amplitude of the oscillations that MBR displays, shows quantitative agreement with the average work done by the system. Our findings may provide a new approach for analyzing the stochastic energetics of a system by mere passive observation.

DY 43.6 Wed 15:00 P5

Random Organization in a Many-Body Reaction System — •Mishael Derla and Michael Schmiedeberg — Soft Matter Theory Group, Theoretical Physics: Lab for Emergent Phenomena, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen

Random organization refers to certain simplified simulation protocols of the reversibility-irreversibility transition in sheared colloid suspensions. It displays an absorbing state transition believed to be in the conserved directed percolation universality class. We present a related analytical time-continuous many-body reaction-diffusion model. It features two species of spherical grains (of diameter σ): diffusing active grains A (with diffusion constant D), and motionless inactive grains I. A spontaneously decay $A \to I$ with rate μ and overlapping grains react with $A + I \to 2A$ and $I + I \to 2A$, respectively at rate λ. When $\lambda \gg \mu \gg D\sigma^{-2}$ overlapping grains are almost certainly active and non-overlapping ones almost certainly inactive and hence a time-continuous (or small step-size) version of random-organization is recovered.

DY 43.7 Wed 15:00 P5

Stochastic Simulation Algorithm for Spatiotemporal Chemical Master Equations — •Fatemeh Tavakkoli, Roya Ebrahimi Viand, Bat-Amalgam Bat-Erdene, Karsten Reuter, and Sebastian Matera — Fritz-Haber-Institut der MPG, Berlin

Spatiotemporal chemical master equations (SCME) have a number of applications ranging from biochemistry to sociodynamics, and have gained interest in mathematical physics. Describing high-dimensional Markov jump processes, SCMEs are typically not solvable, neither analytically nor numerically, but need to be addressed by stochastic simulation using kinetic Monte Carlo methods. We present a software framework for this purpose based on the Berlin Extended Stochastic Simulation Software (BeESSS). A simple to use Python frontend allows to define an SCME model and the software generates efficient backend C++ code (controllable by the Python frontend). The sparse nature of BeESSS allows to exploit the local nature of SCMEs where space is decomposed into compartments and only neighboring compartments interact. We demonstrate the tool on Lottka-Volterra-type predator-prey models and use it to evaluate the time complexity and memory limitations of our simulation approach.

DY 43.8 Wed 15:00 P5

Bottom-Up DPD Thermostat Parameterization for Coarse-Grained Molecular Liquids — •Karan Venkatesh and Nico F. A. van der Vegt — Technische Universität Darmstadt

Coarse-grained (CG) models substantially accelerate molecular dynamics simulations but often yield dynamical properties that diverge from those of fine-grained (FG) systems. We introduce a dynamic coarse-graining framework that bottom-up parameterizes a Markovian Dissipative Particle Dynamics (DPD) thermostat in conjunction with a CG model of liquid cyclohexane, enabling more consistent reproduction of FG dynamical behavior. We determine the Markovian friction for the DPD thermostat by extracting its distance dependence from the fluctuations of pair forces measured in the FG simulations. The resulting distance-dependent friction is subsequently scaled by an amplitude optimized through an iterative procedure to match the long-time diffusion coefficient[1]. Compared to standard DPD[2], our bottom-up parameterized model significantly improves the reproduction of velocity autocorrelation functions (VACFs) on all time scales. It also yields a closer match to the frequency-dependent viscosity. Overall, this method offers a physically grounded, systematic route to parameterizing DPD thermostats for molecular liquids, preserving the efficiency of single-site coarse-graining while delivering improved dynamics across all time scales.

[1] V. Klippenstein; N F A van der Vegt; J. Chem. Theory Comput. 2023, 19(4), 1099-1110. [2] C. Junghans; M. Praprotnik; K. Kremer; Soft Matter 2008, 4(1), 156-161.

DY 43.9 Wed 15:00 P5

Reduction of interaction order in hard combinatorial optimization through conditionally independent degrees of freedom — •Alexandru Ciobanu[1], David Dahmen[1], John Paul Strachan[2], and Moritz Helias[1] — [1]Forschungszentrum Jülich, Jülich, Germany — [2]Peter Grünberg Institut (PGI-14), Aachen, Germany

Combinatorial optimization problems have a broad range of applications and map to physical systems with complex dynamics. Among them, the 3-SAT problem is prominent due to its NP-complete nature. In physics terms, its solution corresponds to finding the ground state of a disordered Ising spin Hamiltonian with third-order, or tensor, in-

teractions. The large growth of the number of third-order interactions with number of variables poses technical difficulties for the physical implementation of minimizers. In this work, we employ the renormalization group to create a pairwise interacting system from the original third-order system while preserving the free energy. Our procedure utilizes additional degrees of freedom that now exhibit conditional independence. A step-wise trace of the extra variables while running the minimization is therefore computable, yielding a state-dependent effective interaction. We use the effective interaction to reconstruct the original third-order energy spectrum.

DY 43.10 Wed 15:00 P5

From Gradients to Flux: Towards A General Strategy for Non-Equilibrium Molecular Dynamics Simulations — •Daniel Padilla-González, Diego Veloza-Diaz, Mauricio Sevilla, Kurt Kremer, and Robinson Cortes-Huerto — Max Planck Institute for Polymer Research, Mainz, Germany

The numerical simulation of molecular systems under external gradients is crucial for understanding processes in which local solvation and diffusion play a central role, common to applications in nanofluidics and biological transport. Few computational methods can handle the stationary non-equilibrium, open-boundary conditions present in reality while consistently sampling the grand canonical (GC) ensemble in equilibrium. The Hamiltonian Adaptive resolution simulation (AdResS) provides a framework for this purpose by coupling a fully atomistic region to a coarse-grained reservoir that acts as a thermodynamic bath. AdResS can be combined with particle insertion (PI) steps [1] to reproduce GC conditions and to impose controlled gradients by connecting the atomistic region to multiple reservoirs at different state points [2]. This strategy enables the study of non-equilibrium situations in which particle fluxes appear across the system. In this project, by considering simple liquids and mixtures, we aim to evaluate the applicability of the AdResS+PI methodology to the study of stationary flows generated by temperature, density, and concentration gradients.

[1] J. Chem. Phys. 162, 080901 (2025)
[2] J. Chem. Phys. 152, 194104 (2020)

DY 43.11 Wed 15:00 P5

Coexistence in chemically driven mixtures — •Ellen Meyberg[1], Joshua Robinson[2,3], and Thomas Speck[1] — [1]Institute for Theoretical Physics IV, University of Stuttgart, Stuttgart, Germany — [2]STFC Hartree Centre, Sci-Tech Daresbury, Warrington, United Kingdom — [3]H. H. Wills Physics Laboratory, University of Bristol, United Kingdom

Underlying virtually any biological function is the organization of proteins and other molecules in time and space. A current challenge in statistical physics is to uncover universal principles governing the self-organization of macromolecules in crowded environments and driven away from equilibrium. Usually, Ostwald ripening leads to the macroscopic phase separation. In contrast, aggregates of proteins in living cells typically show "size control" and are stable over an extended time without coarsening, which can be rationalized in terms of reverse Ostwald ripening. We study a thermodynamically consistent, chemically driven two component reaction-diffusion system in which particles of one species attract each other. Combining insights from stochastic thermodynamics and active field theories, we aim to understand how phase coexistence is modified by the chemical activity.

DY 43.12 Wed 15:00 P5

Coarsening in the $1D$ XY model with long-range interactions — •Dustin Warkotsch, Fabio Müller, and Wolfhard Janke — Institut für Theoretische Physik, Universität Leipzig, 04103 Leipzig, Germany

We investigate the phase-ordering kinetics of the $1D$ XY model with long-range interactions using a simplified version of the recently established fast, hierarchical Metropolis algorithm. Owing to the sparse predictions concerning the nonequilibrium dynamics of this model in one dimension, we seek to close this gap via Monte Carlo simulations with our highly efficient method. Regarding the scaling behavior of correlation function $C(r,t)$, the structure factor $S(k,t)$ and the characteristic length scale $\ell(t)$, we find consistent behavior for all studied growth exponents $\sigma \leq 1$.

DY 43.13 Wed 15:00 P5

Strong coupling phases of conserved growth models are crumpled — •Debayan Jana and Abhik Basu — Saha Institute of Nuclear Physics (SINP), Kolkata, India

We show that stochastically driven nonequilibrium conserved growth models admit generic strong coupling phases for sufficiently strong nonlocal chemical potentials underlying the dynamics. The models exhibit generic roughening transitions between perturbatively accessible weak coupling phases satisfying an exact relation between the scaling exponents in all dimensions d, and strong coupling phases. In dimensions below the critical dimension d_c, the latter phases are unstable and argued to be crumpled, and thus distinct from the well-known strong coupling rough phase of the Kardar-Parisi-Zhang equation in dimensions $d \geq 2$. At d_c, conventional spatio-temporal scaling in the weak coupling phase is logarithmically modulated and are exactly obtained.

DY 43.14 Wed 15:00 P5

Universality of shocks in conserved driven single-file motion with bottlenecks — •Sourav Pal and Abhik Basu — Theory Division, Saha Institute of Nuclear Physics, a CI of Homi Bhabha National Institute, Kolkata, India

Driven single-file motion, in which particles move unidirectionally along one-dimensional channels, sets the paradigm for wide variety of one-dimensional directed movements, ranging from intracellular transport and urban traffic to ant trails and controlled robot swarms. Motivated by the phenomenology of these systems in closed geometries, regulated by number conservation and bottlenecks, we explore the domain walls (DWs) or shocks in a conceptual one-dimensional cellular automaton with a fixed particle number and a bottleneck. For high entry and exit rates of the cellular automaton, and with sufficiently large particle numbers, the DWs formed are independent of the associated rate parameters, revealing *universality* in their *shapes*, which are however enclosed by nonuniversal boundary layers. In contrast, the DWs do depend upon these parameters, if they are small, and hence have nonuniversal shapes, but without boundary layers. Nonuniversal delocalized DWs can be formed by additional tuning of the control parameters. Experimental verification of our theoretical predictions can be performed via high-resolution ribosome profiling on mRNA loops with slow codons, or video imaging of vehicular flow, ant trails, and robotic swarms on confined tracks.

DY 43.15 Wed 15:00 P5

Dynamics of dense phase separation — •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

Phase separation in mixtures is a ubiquitous phenomenon in nature. In dense systems, it involves an intriguing interplay of phase separation dynamics with slowing down due to crowding effects. We investigate such systems by encoding the approach to dynamic arrest in the kinetic coefficient at the level of a continuum description. We predict the phase behaviour of such kinetically constrained multicomponent mixtures, including density and composition of both mobile and arrested phases, using a suitable constrained free energy minimization. We probe the coarsening dynamics numerically and find, for the baseline one-component case, a crossover between two distinct domain growth power laws. For binary mixtures with three equilibrium phases (one gas and two demixed liquids), we see a Warren-like scenario where collective diffusion first leads to gas-liquid phase separation without fractionation, before the mixture components eventually start to demix. Surprisingly, this demixing dynamics is interface-induced, i.e. it begins at the interfaces of the initial gas-liquid domains. We rationalize this by controlled numerical experiments starting from constrained (without demixing) gas-liquid equilibria and by theoretical analysis of the local spinodal growth rates.

DY 43.16 Wed 15:00 P5

Linear coupling reduces entropy production in nonequilibrium multicomponent systems — •Vansh Kharbanda[1,2], Anton Burnet[1,2], and Benedikt Sabass[1,2] — [1]Faculty of Physics and Center for NanoScience, Ludwig-Maximilians-Universität München, 80752 Munich, Germany — [2]Fakultät Physik, Technische Universität Dortmund, 44227 Dortmund, Germany

Many biological and synthetic systems operate far from equilibrium and pay an energetic cost quantified by the steady-state entropy production rate (EPR). We investigate how linear coupling between subsystems modifies this dissipation in a class of Hurwitz-stable Langevin dynamics. For networks of diffusively coupled Ornstein-Uhlenbeck processes, we derive closed-form expressions for the EPR of n-coupled

two-dimensional units and show that any attractive symmetric coupling reduces the EPR, which monotonically approaches the single-unit value in the strong-coupling limit. This behaviour is traced to a suppression of probability currents, driving the collective closer to detailed balance. We then generalize to higher dimensions and arbitrary symmetric coupling topologies and conjecture a structural criterion: commuting coupling and diffusion matrices together with negative semidefinite coupling are sufficient for a monotonic EPR decrease. Violating this criterion generates mismatch-induced irreversible currents, which can increase EPR. Finally, we illustrate this mechanism in nonlinear biological models of bacterial chemotaxis and inner-ear hair bundles, where coupling substantially lowers dissipation without hindering performance metrics.

DY 43.17 Wed 15:00 P5

Energetics of coupled stochastic circular limit-cycle oscillators — •Anton Francis Burnet[1,2], Vansh Kharbanda[1,2], David Tobias[1], and Benedikt Sabass[3,1,2] — [1]Faculty of Physics and Center for NanoScience, Ludwig-Maximilians-Universität München, 80752 Munich, Germany — [2]Department of Veterinary Sciences, Ludwig-Maximilians-Universität München, 80752 Munich, Germany — [3]Fakultät Physik, Technische Universität Dortmund, 44227 Dortmund, Germany

Stochastic oscillations serve important functions in many biological systems, including hair-cell bundles of the inner ear and neuronal activity. Sustaining coherent cycles in noisy environments requires continuous energy dissipation, quantified by the steady-state entropy production rate (EPR). We study an idealized, analytically tractable model of a stochastic circular limit cycle and examine how mutual diffusive coupling in pairs and populations alters dissipation. Three factors contribute to the EPR: intrinsic frequency asynchrony, tangential velocity fluctuations, and mean tangential velocity. The dynamics are characterized by an effective temperature, which depends on diffusion and intrinsic relaxation timescales. For radial (amplitude), phase (Kuramoto-like), and Cartesian couplings, we derive analytical expressions for the EPR and confirm them numerically. Varying the effective temperature and system size strongly influences how the EPR depends on coupling strength and, in some cases, results in qualitatively distinct behaviors. Moreover, the coupling types affect the tangential velocity distributions differently.

DY 43.18 Wed 15:00 P5

Localized Driving of the Jamming Transition in a Quasi-2D Colloidal Platform — •Jordan D. Groh, Timo Betz, and Bart Vos — Drittes Physikalisches Institut, Göttingen, Deutschland

The jamming transition marks the abrupt emergence of rigidity when a dense assembly of particles is compressed beyond a critical packing fraction. Decades of experiments and simulations have identified its static signatures, a sharp rise of the shear modulus and contact-network percolation, for globally driven systems. What remains largely unexplored is how a jammed material reacts to localized perturbations and whether they can steer the system into new metastable states.

We therefore construct a reproducible quasi-2D colloidal chamber that confines a binary mixture of polyacrylamide hydrogel beads (elastic stress sensors) and polystyrene beads (optically addressable active centres). A small fraction of temperature-responsive pNIPAm beads allows us to tune the effective packing fraction; cooling below the LCST swells them, thereby raising the global packing fraction with high precision. High-speed confocal microscopy provides particle trajectories, from which we locate the jamming point and perform contact-network analysis.

The platform enables calibrated optical forces on single beads and local heating-induced volume changes, yielding full spatiotemporal maps of displacement and stress fields. This testbed will allow us to map a local-driving jamming phase diagram, study force-propagation lengths, and ultimately design amorphous metamaterials with programmable mechanical heterogeneity.

DY 43.19 Wed 15:00 P5

Critical behaviour of ferroelectrics with divergence-free polarization — •Svitlana Kondovych[1], Asle Sudbø[2], and Flavio S. Nogueira[1] — [1]Institute for Theoretical Solid State Physics, Leibniz Institute for Solid State and Materials Research Dresden, Helmholzstr. 20, D-01069 Dresden, Germany — [2]Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

Unconventional phase transitions often display unusually large anomalous dimensions, often attributed to fractionalization and emergent gauge fields [1]. Here we show that similar behaviour can arise without fractionalization when the order parameter is constrained to be divergence-free, as occurs in ferroelectrics where the polarization $\vec{P}$ remains locally charge-neutral, div$\vec{P}$=0 [2]. This constraint forces polarization into loop-like textures and reshapes the critical behaviour.

Our analysis reveals a new universality class in which internal symmetry becomes intrinsically linked to spatial dimensionality [3]. The resulting critical point exhibits strongly enhanced fluctuations and a remarkably large anomalous dimension. These findings show that conventional ferroic materials can exhibit non-Landau criticality driven by local conservation laws. This reveals a new conceptual pathway for unconventional critical phenomena and suggests nanoscale ferroelectrics as experimentally accessible platform for exploring these ideas.

[1] T. Senthil, et al., Science 303:1490 (2004). [2] I. A. Lukyanchuk, et al., Phys. Rep. 1110:1 (2025). [3] S. Kondovych, A. Sudbø, F. S. Nogueira, arXiv:2510.13960 (2025).

DY 43.20 Wed 15:00 P5

Nonequilibrium phase transition in single-file transport at high crowding — •Annika Vonhusen[1], Sören Schweers[1], Artem Ryabov[2], and Philipp Maass[1] — [1]Universität Osnabrück, Institut für Physik, Germany — [2]Charles University, Faculty of Mathematics and Physics, Czech Republic

In driven single-file Brownian motion across periodic energy landscapes, fast particle transport can occur for potential barriers orders of magnitude larger than the thermal energy. The fast transport is mediated by solitary cluster waves forming at high crowding of interacting particles [1]. Cluster waves were first predicted theoretically for hard spheres [2] and shortly after confirmed in experiments [3]. Here we show that persistent cluster wave propagation sets in at a critical density and gives rise to a nonequilibrium phase transition that manifests itself in a singular point of the current-density relation [4]. The critical density varies in a complex manner with the particle size and temperature, which can be understood from a simple geometric principle.

[1] A. P. Antonov, A. Vonhusen, A. Ryabov, P. Maass, Nonlinear Dyn. 113, 31529 (2025).
[2] A. P. Antonov, A. Ryabov, P. Maass, Phys. Rev. Lett. 129, 080601 (2022).
[3] E. Cereceda-López, A. P. Antonov, A. Ryabov, P. Maass, and P. Tierno, Nat. Commun. 14, 6448 (2023).
[4] A. Vonhusen, S. Schweers, A. Ryabov, P. Maass, arXiv:2511.16234 (2025), to appear in Chaos.

DY 43.21 Wed 15:00 P5

Sampling of ground states for the bimodal random-field Ising model — •Jana Lukin, Tony Albers, and Martin Weigel — Institut für Physik, TU Chemnitz, 09107 Chemnitz, Germany

The Gaussian random-field Ising model (RFIM) is well understood, largely because its ground state is non-degenerate and can therefore be computed efficiently using polynomial-time optimization methods. In contrast, the bimodal RFIM exhibits degenerate ground states, which has hindered precise numerical investigations of its critical behavior. Here, we introduce a perturbation to lift this degeneracy. This approach enables the application of a max-flow algorithm to obtain exact ground states and thereby allows a more accurate characterization of the phase transition in the bimodal RFIM.

DY 43.22 Wed 15:00 P5

Critical behaviour of non-reciprocal Ising models — •Max Haessler and Martin Weigel — TU Chemnitz Institut für Physik, Chemnitz, Germany

Equilibrium statistical physics is based on symmetric, Hamiltonian interactions fulfilling Newton*s Third Law. On the other hand, active matter like bacteria or bird flocks, predator-prey relations in nature and social systems violate time-reversal symmetry due to non-reciprocal interactions, hence they are non-equilibrium systems.

We try to investigate the fundamental mechanisms that govern such systems by investigating non-reciprocal modifications of the Ising model.

We especially focus on investigating the impact of the non-reciprocal interactions on the critical behaviour of those models.

DY 43.23 Wed 15:00 P5

Analysis of phase transitions in the random-field Blume-Capel model via exact ground state calculations — •Tony

Albers, David Müller-Bender, and Martin Weigel — Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany

The random-field Blume-Capel model is a generalization of the well-known Ising model, where spin variables can take three values (-1,0,1) corresponding to three orientations of the spins with respect to an external field. We perform exact ground-state calculations of this 3-label problem using a suitable transformation to a 2-label problem [1] and an advanced graph-cut method called generic cuts [2]. The obtained ground states can be used to study phase transitions in dependence on the zero-field splitting parameter and the strength of the random field resulting in a phase diagram which is compared to the one obtained by a mean-field approximation [3]. Preliminary results suggest the presence of first- and second-order phase transitions. With the help of a finite-size scaling analysis, we obtain a set of critical exponents for the latter and compare them with the exponents of related universality classes.

[1] C. Arora and S. N. Maheshwari, 2014 IEEE Conf. Comput. Vis. Pattern Recognit., 1346 (2014)

[2] C. Arora, S. Banerjee, P. K. Kalra, and S. N. Maheshwari, IEEE Trans. Pattern Anal. Mach. Intell. 37, 1323 (2015)

[3] S. Mukherjee and Sumedha, J. Stat. Phys. 188, 22 (2022)

DY 43.24 Wed 15:00 P5

Shear-driven diffusion process and its generalizations — •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 shear-driven diffusion process, which represents a two-dimensional Brownian motion in presence of a linear shear flow. One possible generalization is the shear-driven anomalous diffusion motion which occurs due to the long-tailed waiting time of the particle, effect described by a two-dimensional Fokker-Planck equation with memory kernel. Another possible generalization is the shear-driven finite-velocity diffusion, that is a shear-driven motion, but now, at random times, the walker changes its direction to the opposite one. The corresponding process can be described by a two-dimensional telegrapher's-like equation. We also explore the corresponding processes under stochastic resetting and find that the systems reach non-equilibrium stationary states in the long time limit that also result in saturation of the evolution of the corresponding mean squared displacement, variance, skewness and kurtosis.

DY 44: Poster: Active Matter, Soft Matter, and Fluids

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

DY 44.1 Wed 15:00 P5

Directed autonomous motion of active Janus particles induced by wall-particle alignment interactions — •Poulami Bag — Presidency University Kolkata

We propose a highly efficient mechanism to rectify the motion of active particles by exploiting particle-wall alignment interactions. Through numerical simulations of active particles' dynamics in a narrow channel, we demonstrate that a slight difference in alignment strength between the top and bottom walls or a small gravitational drag suffices to break upside-down symmetry, leading to rectifying the motion of chiral active particles with over 60% efficiency. In contrast, for achiral swimmers to achieve rectified motion using this protocol, an unbiased fluid flow is necessary that can induce orbiting motion in the particle's dynamics. Thus, an achiral particle subject to Couette flow exhibits spontaneous directed motion due to an upside-down asymmetry in particle-wall alignment interaction. The rectification effects caused by alignment we report are robust against variations in self-propulsion properties, particle's chirality, and the most stable orientation of self-propulsion velocities relative to the walls. Our findings offer insights into controlled active matter transport and could be useful to sort artificial as well as natural microswimmers (such as bacteria and sperm cells) based on their chirality and self-propulsion velocities.

DY 44.2 Wed 15:00 P5

Emergent Interaction in Attractively Coupled Active Particles — •Ritwick Sarkar and Urna Basu — S. N. Bose National Centre for Basic Sciences, India.

We investigate the dynamics of N pair-wise harmonically coupled active Brownian particles (ABPs) in the presence of thermal fluctuations. The harmonic coupling and the bounded nature of the active noise ensure that the relative distance between each pair of particles eventually reaches a stationary state. Depending on the interplay between the active time-scale and the relaxation time-scale associated with the harmonic coupling, three regimes emerge: strong, moderate, and weak coupling. We analytically show that in the strong coupling regime, an effective short-range repulsion emerges between ABP pairs with speed heterogeneity, both in the presence and absence of thermal fluctuations. The short-range repulsion also persists when the ABP pairs are coupled by a generic long-range attractive potential.

Reference

[1] Ritwick Sarkar, Urna Basu, Soft Matter 21, 3595-3603 (2025).

[2] Ritwick Sarkar, Sreya Chatterjee, and Urna Basu, J. Phys. A: Math. Theor. 58 415001 (2025).

DY 44.3 Wed 15:00 P5

AMEP: Analyzing Active and Soft Matter Simulations — •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

AMEP [1] is a Python library that focuses on the fast and user-friendly analysis of active and soft matter simulations. It can natively analyze data from molecular dynamics, Brownian dynamics, and continuum simulations from software such as LAMMPS, HOOMD-blue, and GROMACS. With a plethora of methods for calculating observables and visualizing results, AMEP is suitable for calculating complex observables equally for advanced studies of active and soft matter, as well as for beginners in the field. Computationally expensive methods are parallelized to run on any system from laptops and workstations to high-performance computing clusters.

The methods range from correlation functions and order parameters to cluster detection and coarse-graining methods. Due to the Python-based implementation, the methods can be easily extended and individualized. Information and examples are available at https://amepproject.de. AMEP can be installed via pip and conda.

[1] L. Hecht et al., Comput. Phys. Commun. 309, 109483 (2025).

DY 44.4 Wed 15:00 P5

Environmental Control of Self-Aligning Chiral Bristlebots — •Timo Wagner, Thomas Ihle, and Horst-Holger Boltz — University Greifswald, Institute for Physics, Greifswald

The subject of our work is the interplay of two very topical aspects of active matter systems, self-alignment and chirality, with complex environments. Chirality refers to a handedness of the dynamics manifesting itself in circular trajectories and self-alignment is a specific realization of physical memory in which the direction of the actual velocity and that of the self-propulsion are not identical, but are coupled. We present experimental results of an implementation of self-aligning chiral dynamics by custom augmentation of commercial toy bristlebots (Hexbugs) and extend the accessible parameter range by inferring a numerical model capable of reproducing the observable data. In particular, we study the control of edge currents (cf. Caprini et al, arXiv:2509.05053) by chiral environments. Additionally, we show that this simple system is sufficient to observe mode-switching between collectively moving and arrested states in active solids (cf. Hernandez-Lopez et al, PRL 132, 238303 (2024)).

DY 44.5 Wed 15:00 P5

Stochastic Path Integral for the Active Brownian Particle in a Harmonic Potential — •Mike Brandt[1], Carsten Littek[2], and Falko Ziebert[1] — [1]Institut für Theoretische Physik Philosophenweg 19, D-69120 Heidelberg, Germany — [2]Institut für Theoretische Physik Philosophenweg 12, D-69120 Heidelberg, Germany

We present a path-integral approach for the motion of active particles

in harmonic traps, developed in our recent preprint [arXiv:2509.26296]. We apply the Martin-Siggia-Rose formalism to the overdamped Langevin equations of an active Brownian particle (ABP). The associated action can be separated into an exactly solvable passive reference motion and an "activity operator" to be treated perturbatively. This method allows for the calculation of the exact, time-dependent correlation functions for the ABP in a harmonic potential. Furthermore, the probability density can be perturbatively expanded in a series, which already captures important qualitative features of the system at low orders. This is exemplified by discussing the transition between a ring-shaped distribution for a weak potential and a peaked distribution for a strong potential in the long-time limit. Finally, we present full time-dependent expressions for the mean-square displacement of the Brownian circle swimmer (BCS), along with comparisons to simulations.

DY 44.6 Wed 15:00 P5

Continuum models for active matter: Derivation and overview — •Juliette Wegner and Sebastian Heidenreich — Physikalisch-Technische Bundesanstalt Braunschweig und Berlin, Abbestr. 2-12, 10587 Berlin, Germany

Turbulence and collective motion in active matter provide an interesting insight into non-equilibrium systems. Many different models have been suggested to describe the prevalent dynamics, mainly including polar and nematic systems. Each of these systems is developed under different assumptions considering different systems, but their similarities and differences are often not obvious.

In our poster we start from a simple micro-swimmer model to derive a general continuum model incorporating both nematic and polar order parameter equations, following the procedure from [1]. To this general continuum model, we then systematically introduced further restrictions and assumptions to derive more specific models which are in line with popular continuum models from literature. Specifically, we obtain models with nematic and polar symmetries similar to those studied by Saintillan and Shelley, as well as active Nematics, and active Polar suspension. Finally, we also consider theories that only incorporate the overall bacterial motion, such as the Toner Tu equation or the hydrodynamic approach of Slomka and Dunkel.

[1] Henning Reinken, Sabine HL Klapp, Markus Bär, and Sebastian Heidenreich. Derivation of a hydrodynamic theory for mesoscale dynamics in microswimmer suspensions. Physical Review E, 97(2):022613, 2018.

DY 44.7 Wed 15:00 P5

Active Brownian ellipsoids in three spatial dimensions — •Sebenzile Tsabedze and Michael te Vrugt — Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany

We investigate ellipsoidal active Brownian particles with alignment interactions in three spatial dimensions that are propelled orthogonal to their symmetry axis. Their propulsion direction makes the particles biaxial, implying that their dynamics is considerably more complex than in the usually considered case of particles being propelled along their symmetry axis. We use Brownian dynamics simulations and assume the particles to interact via a Gay-Berne potential (for the ellipsoidal repulsion) and a Heisenberg potential (for the interaction).

DY 44.8 Wed 15:00 P5

Dynamics of Aligning Active Matter: Mapping to a Schrödinger Equation and Exact Diagonalization — •Tara Steinhöfel, Horst-Holger Boltz, and Thomas Ihle — University Greifswald, Institute for Physics, Greifswald

We investigate models of Viscek-like particles with long-ranged interactions subject to noise and alignment interactions of polar and nematic symmetries. It is shown how the relevant N-particle Fokker–Planck equation can be mapped onto a Schrödinger equation in imaginary time for arbitrary particle numbers. Focusing on the minimal case of $N = 2$, we construct a complete eigenbasis by exact diagonalization of the corresponding self-adjoint Hamiltonian. In a treatment formally equivalent to standard quantum mechanics, this yields the fully time-resolved relaxation of the N-particle-probability density from arbitrarily correlated initial conditions into the stationary state. By marginalization, the one-particle angular modes which include the usual hydrodynamic modes are obtained; we discuss their relaxation backed by agent-based simulations and give comparisons for the resulting exact relaxation rates to mean-field and to predictions from approximate field theories (G. Spera, C. Duclut, M. Durand, J. Tailleur, PRL 132, 078301 (2024)). Furthermore, we discuss possible extensions of the method to $N \geq 3$ particles, as well as modifications due to non-reciprocal interactions.

DY 44.9 Wed 15:00 P5

Absence of chiral long-range order in the 2d non-reciprocal Vicsek model — •Chul-Ung Woo[1], Heiko Rieger[1], and Jae Dong Noh[2] — [1]Department of Theoretical Physics and Center for Biophysics, Saarland University, Saarbrücken, Germany — [2]Department of Physics, University of Seoul, Seoul, Korea

Nonreciprocal interactions in active matter have been predicted to generate homogeneous chiral phases, in which the polarization order parameter rotates at a constant frequency as a result of a nonreciprocal phase transition. Here we revisit the non-reciprocal Vicsek model in two space dimensions with short-range interactons and ask whether the putative chiral phase survives in the thermodynamic limit. Using large-scale simulations, we show that a spatially homogeneous chiral state, while long-lived in small systems, is generically unstable to the spontaneous nucleation of spiral defects that invade the system and drive it into spatio-temporal chaos. The global chiral order parameter, τ exhibits a robust finite-size scaling $\tau(J_-; L) = J_-\tau_r(LJ_-)$, where $J_= J_{AB} - J_{BA}$ is the anti-symmetric part of the interaction matrix, with the asymptotic behavior $\tau_r(x) \sim x^{-1}$ at large x, implying that global chirality vanishes in the thermodynamic limit. Controlled droplet-seeding experiments and a Boltzmann kinetic description support the droplet nucleation and growth scenario for the breakdown of chiral order. Our results demonstrate that paradigmatic non-reciprocal flocking models display chiral long-range order only in mean-field, whereas it is only metastable in two space dimensions and replaced there by spatio-temporal chaos.

DY 44.10 Wed 15:00 P5

Phase properties of constant density interacting flocks — •Astik Haldar and Heiko Rieger — Center for Biophysics & Department of Theoretical Physics, Universität des Saarlandes, Saarbruecken 66123, Germany

We present a field-theoretic study of a mixture of two polar Malthusian species in two dimensions with distinct aligning and propulsion strengths. The system exhibits rich phase behavior, including oriented flocking states (both parallel and anti-parallel) and a coherently rotating chiral phase. We map the parameter regions for these phases and characterize their universal properties.

DY 44.11 Wed 15:00 P5

Influence of shape on dynamic properties of magnetic active particles — •Ekaterina Novak[1], Elena Pyanzina[1], Tatyana Belyaeva[1], and Sofia Kantorovich[2] — [1]Ekaterinburg, Russia — [2]University of Vienna, Vienna, Austria

This study investigates the influence of shape on the dynamic properties of active magnetic particles. The focus is on ellipsoidal particles of two variations and spherical particles, aiming to understand the relationship between particle shape and motion characteristics. The research is motivated by the need to improve the control and efficiency of active particles, which have significant potential in medical and technological applications, such as precise drug delivery.

Active particles, inspired by natural systems like bacteria, can convert chemical energy into directed motion. However, challenges arise in maintaining precise control over their orientation and direction over time. By introducing a rigidly fixed permanent dipole moment and utilizing a strong external magnetic field, it is possible to minimize thermal fluctuations and achieve precise control.

The study also explores the anisotropic properties of ellipsoidal particles, which can have two possible orientations of the magnetic moment depending on the material. This behavior is analogous to magnetic cubes with integrated nanomotors. The findings from this research contribute to the development of optimal particle shapes for effective transportations, opening new possibilities in various fields.

The work was financially supported by the RSF grant No. 25-22-00327.

DY 44.12 Wed 15:00 P5

Order and shape dependence of mechanical relaxation in proliferating active matter — Jonas Isensee[1,2], •Finn Albrecht[1,2], Lukas Hupe[1,2], and Philip Bittihn[1,2] — [1]MPI for Dynamics and Self-Organization, Göttingen, Germany — [2]Institute for the Dynamics of Complex Systems, University of Göttingen, Germany

The collective behavior of dense, proliferating anisotropic active matter, such as elongated cells or bacteria, arises from an interplay between growth, division, and mechanical interactions, often mediated by particle shape. In classical models of prolate, rod-like growth, flow-induced alignment and division geometry reinforce one another, leading to robust nematic order under confinement. Here we introduce a complementary regime by considering smooth convex particles whose geometry can be oblate for part or all of their growth cycle, creating a tunable competition between these two alignment mechanisms. Using agent-based simulations of particles with tunable curvature profiles in both channel and open-domain geometries, we systematically vary particle shapes to span regimes of cooperation and competition between ordering cues. We find that oblate growth can reverse classical flow-alignment, destabilize microdomain formation in intermediate regimes, and, in combination with variations in curvature, lead to entirely new global order patterns. These findings are then reconciled using an order- and shape-dependent mechanical relaxation interpretation that is supported by explicit measurements.

DY 44.13 Wed 15:00 P5

The impact of particle shape for self-diffusiophoresis — •Leif Peters[1], Benjamin J. Walker[2], and Christina Kurzthaler[1,3,4] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany — [2]Department of Mathematics, University College London, WC1H 0AY London, UK — [3]Center for Systems Biology Dresden, Pfotenhauerstraße 108, 01307 Dresden, Germany — [4]Cluster of Excellence, Physics of Life, TU Dresden, Arnoldstraße 18, 01062 Dresden, Germany

Self-diffusiophoretic micron-sized particles are paradigmatic examples of synthetic microswimmers where the swimming behavior depends not only on the patterning of the chemically active surface, i.e., the activity and phoretic mobility, but also on the particle shape itself. Accounting for the governing chemical and hydrodynamic equations we investigate how the particle shape influences the self-propulsion velocity and the agent's chemotactic behavior. To derive analytical expressions for anisotropic and curved particles we employ slender body theory and the Lorentz reciprocal theorem. Furthermore, we corroborate our results with a boundary element method. Our numerical framework allows going beyond the slender-particle limit and lays the foundation for addressing the physics of hydro-chemically interacting active agents and the emergent collective phenomena.

DY 44.14 Wed 15:00 P5

Dynamics of thermophoretic Janus particles in homogeneous light fields — •Samad Mahmoudi, Franziska Michaela Braun, and Regine von Klitzing — Institute of Condensed Matter Physics,TU Darmstadt, Hochschulstraße 8 64289 Darmstadt

We study the thermophoretic motion and orientational dynamics of individual Au-polystyrene Janus particles under uniform laser illumination. Light-driven Janus colloids serve as a model system for active Brownian motion and non-equilibrium transport in soft matter. The particles are illuminated by a defocused, approximately homogeneous laser spot and observed with dark-field microscopy. Image-processing routines in Python yield long-time trajectories, center-of-mass positions and in-plane orientations of the gold cap. From the mean-squared displacement we extract effective self-propulsion velocities and compare them with active Brownian particle models and simple expectations for thermophoretic motion. Our first measurements show that the tracking procedure resolves both translational and rotational motion of single Janus particles and yields thermophoretic velocities in the expected range for micrometer-sized swimmers. In future work, we will use this analysis to study how light gradients and cap design can create transient barriers for Janus particles and control their thermophoretic motion.

DY 44.15 Wed 15:00 P5

Static and dynamic states of compound drops on heated substrates — •Dominik Thy, Jan Diekmann, and Uwe Thiele — Institute of Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9, 48149 Münster, Germany

We present a mesoscopic thin-film model for interface dominated compound drops including a vertical temperature gradient [1]. Starting with established findings for the passive case, i.e., (isothermal) gradient dynamics that show relaxation to equilibrated compound drops of different configurations [2], we then drive the system out of equilibrium. To this end, we introduce a vertical temperature gradient that renders the system active by introducing thermal Marangoni flows. We discuss different static and dynamic states.

[1] Pototsky, Bestehorn, Merkt, Thiele. The Journal of Chemical Physics, 2005. doi: 10.1063/1.1927512.

[2] Diekmann, Thiele. Physical Review Fluids, 2025. doi: 10.1103/physrevfluids.10.024002.

DY 44.16 Wed 15:00 P5

Evaporation Induced Salt Precipitation in Porous Media: A Lattice Boltzmann Approach — •Alexander Reinauer[1], Louis Oberer[1], Alexander Schlaich[2], and Christian Holm[1] — [1]Institute for Computational Physics, Stuttgart, Germany — [2]Institute for Physics of Functional Materials, Hamburg University of Technology, Hamburg, Germany

We present a lattice Boltzmann model for simulating coupled evaporation and salt precipitation in porous media. The approach integrates Shan-Chen multiphase flow with a volume-based discretization of salt transport and incorporates a precipitation rule, which converts fluid cells into solid crystals once the local concentration exceeds a crystallization threshold.

The model is validated by reproducing analytical predictions for crystal growth. Besides, it features a tunable evaporation rate, enabling pore-scale studies of evaporation-induced salt precipitation. Investigations of the wettabilities of both the salt and the porous matrix reveal a pronounced impact on precipitation patterns. The simulations show distinct shifts in pore-clogging behavior depending on the relative wetting properties, with highly wetting crystals causing the strongest clogging and the slowest evaporation, arising from how wetting influences the spatial distribution of precipitation.

DY 44.17 Wed 15:00 P5

Power-Law to Maxwell Transition in Soft Glassy Materials under Large Amplitude Oscillations — •Raffaele Mendozza[1], Shanay Zafari[1], Sarah Köster[1], and Peter Sollich[1,2] — [1]Institute for Theoretical Physics, University of Göttingen, Göttingen, Germany — [2]Department of Mathematics, King's College London, London, United Kingdom

Soft glassy materials, such as colloidal suspensions and biological networks, exhibit complex rheological behaviour. We present a modified version of the Soft Glassy Rheology (SGR) model, introducing an upper cutoff on the yield rate that prevents unphysical yield rate increases at large strains. In the nonlinear response to step strains, the modified model exhibits a crossover from short-time exponential (Maxwell-like) relaxation to the power law relaxation obtained in the original model. This qualitatively reproduces results from strain-ramp experiments on actin networks. Under large amplitude oscillatory strain (LAOS) we similarly find Maxwell-like viscoelastic spectra at higher frequencies, crossing over to the original SGR power-law spectrum at low frequencies. We demonstrate that this can be rationalized qualitatively by Fourier transforming the nonlinear step strain results. The nonlinear spectra break the usual phase angle relations for power law (linear) response, however, which we explain using a quasistatic approximation. The stress response to LAOS at fixed frequency becomes more anharmonic for increasing strain amplitudes up to a critical value; beyond this point, harmonicity is eventually restored due to the crossover to Maxwell behavior.

DY 44.18 Wed 15:00 P5

Gelation versus bundling in parallel-aligned directed polymers — •Panayotis Benetatos and Minsu Yi — Department of Physics, Kyungpook National University, Daegu, South Korea

In many soft-matter and biological systems, bundles of similarly charged parallel-aligned filaments form when a short-range attraction overcomes the longer-range electrostatic repulsion. It is also known that permanent cross-links in parallel-aligned directed polymers can yield a directed gel with a finite in-plane shear modulus. Because permanent cross-links effectively act as a short-range attraction, we are motivated to investigate the interplay of gelation versus bundling in such a system. Using the theoretical tools of replica field theory, where the cross-links are treated as quenched disorder following the Deam-Edwards distribution, we show that the effective attraction due to spring-like permanent cross-links is too weak to induce bundling before the gelation transition.

DY 44.19 Wed 15:00 P5

Thermoresponsive liquid-liquid phase behaviour of biomolecular condensates in programmable thermal landscapes — •Ilona Kundi[1], Falko Schmidt[1], Rasmus Krogh Norrild[2],

Alexander Kai Büll[2], and Frank Cichos[1] — [1]Peter Debye Institute for Soft Matter Physics, Leipzig University, 04103 Leipzig, Germany — [2]Department of Biotechnology and Biomedicine, DTU, 2800 Kgs. Lyngby, Denmark

Liquid-liquid phase separation (LLPS) of biomolecules drives the formation of membraneless organelles in cells. The LLPS behavior of the intrinsically disordered N-terminal region of the DEAD-box helicase DDX4 (DDX4N) is examined under precisely controlled and reconfigurable local temperature fields.

Locally tunable thermal landscapes are generated by scanning a focused laser beam over an absorbing metal thin film, creating microscale temperature profiles around DDX4N condensates. Here, the spatiotemporal evolution of condensate nucleation, growth, coarsening, and dissolution is tracked, linking local thermal forces to mesoscale LLPS dynamics.

By repeatedly cycling the temperature across the LLPS boundary, kinetic and thermodynamic parameters of the DDX4N phase transition are measured, revealing switching thresholds, hysteresis, and condensate material properties. Controlled microthermal perturbations thus provide a powerful means to probe and program protein LLPS, establishing a versatile platform for testing models of thermoresponsive intrinsically disordered proteins.

DY 44.20 Wed 15:00 P5

Rheology of Semi-Flexible Polymer Networks — •Sanjay Bhandarkar[1] and Peter Sollich[1,2] — [1]Institute for Theoretical Physics, University of Göttingen, Germany — [2]Department of Mathematics, King's College London, London

Semiflexible polymers, both in solution and organized into networks, continue to be a major focus in biological physics owing to their critical relevance to the structural and mechanical functions of living systems. The mechanics of the cytoskeleton emerges from the collective properties of semiflexible biopolymers such as actin filaments, microtubules, and intermediate filaments [1,2]. We investigate the rheology of semiflexible polymer networks using molecular dynamics simulations, performing Small-Amplitude Oscillatory Shear (SAOS) tests on permanently cross-linked systems to demonstrate how filament stiffness and monomer density control the frequency dependence of the complex shear modulus G*. In addition, we examine the connection between power-law rheology and the self-similar structural features observed in biopolymer networks and gels [3,4]. We further analyze how crosslinking dynamics and activity-induced stresses modify the network mechanics. Together, this rheological framework lays the groundwork for future models that incorporate more detailed structural and biochemical complexity.

[1] P. Kollmannsberger and B. Fabry, 2011
[2] Broedersz, C. P. and MacKintosh, F. C., 2014
[3] J. Martin, D. Adolf, and J. P. Wilcoxon, 1989
[4] M. Bantawa et al., 2023

DY 44.21 Wed 15:00 P5

Dynamic magnetic susceptibility of magnetic elastomers taking into account the internal magnetic anisotropy of particles — •Alla Dobroserdova[1] and Sofia Kantorovich[2] — [1]Ekaterinburg, Russia — [2]University of Vienna, Vienna, Austria

Magnetic elastomers are non-magnetic elastic matrices with embedded magnetic particles. These systems can be controlled using an external magnetic field, which provides the basis for their practical applications in both industry and medicine.

The aim of this study is to investigate the dynamic magnetic response of magnetic elastomers. Two previously developed elastomer models suitable for molecular dynamics simulations are used. This study reveals the dependence of the response on the intensity of interparticle interactions, the rigidity of the elastic non-magnetic matrix, and the internal magnetic anisotropy of the particles.

Support by RSF (project 25-22-00270) is acknowledged.

DY 44.22 Wed 15:00 P5

Computer simulation of the dynamic susceptibility of ellipsoidal multicore particles: the effect of inter-core interaction — •Vladimir Zverev[1], Ekaterina Novak[1], Andrey Kuznetzov[2], and Sofia Kantorovich[2] — [1]Ekaterinburg, Russia — [2]University of Vienna, Vienna, Austria

This report presents a study of the magnetic dynamic susceptibility of MNPs under the influence of a low-amplitude alternating plane-polarized magnetic field. We consider ellipsoidal MNPs modeled as a collection of spherical subparticles with fixed spatial positions relative to each other. This corresponds to a scenario where nanoparticles are embedded in a polymer or other rigid non-magnetic matrix. The modeling employs the molecular dynamics simulations using the ESPResSo software package, which accounts for magnetic anisotropy. The model is based on the concept proposed in [1]. The core idea is that the orientation of the magnetic moment in a subparticle is determined by solving the stochastic Landau-Lifshitz-Gilbert equation in a reference frame fixed to the particle body, neglecting precession and the Barnett effect. To form a single-domain-like particle assembly, their common convex hull approximates an elongated ellipsoid of revolution with a preset aspect ratio, enabling comparison with spherical particles.

The work was financially supported by the Russian Science Foundation grant No. 25-22-00338.

[1] Pyanzina E. S. et al. Dynamic Magnetic Response of Multicore Particles: The Role of Grain Magnetic Anisotropy and Intergrain Interactions //Journal of Molecular Liquids. - 2025. - P.126842.

DY 45: Focus Session: Physics of AI – Part I (joint session SOE/DY)

The focus session is organized by Claudius Gros (Goethe-Universität Franfurt), Moritz Helias (Forschungszentrum Jülich), Peter Sollich (Georg-August-Universität Göttingen)

This focus session brings together experts in the field of physics-inspired theory of machine learning and artificial intelligence, who aim to supplement the engineering-driven success of AI by a principled theory of neural information processing. Contributions will address how statistical and dynamical perspectives explain learning in modern AI systems and how these insights support interpretability as well as prediction of performance, generalization, and the required resources.

Time: Thursday 9:30–11:15 Location: GÖR/0226

Invited Talk DY 45.1 Thu 9:30 GÖR/0226

Generative AI and diffusion models: a statistical physics approach — •Giulio Biroli — Ecole Normale Superieure, Paris, France

Generative AI represents a groundbreaking development within the broader *Machine Learning Revolution,* significantly influencing technology, science, and society. In this colloquium, I will focus on the state-of-the-art *diffusion models*, which are currently used to generate images, videos, and sounds. They are very fascinating algorithms for physicists, as they are very much connected to concepts from stochastic thermodynamics, particularly time-reversed Langevin dynamics. These diffusion models start from a simple white noise input and make it evolve through a Langevin process to generate complex outputs such as images, videos, and sounds. I will show that statistical physics provides principles and methods to characterise this generation process. Specifically, I will discuss how phenomena such as the transition from memorization to generalization and the emergence of features can be understood through the lens of symmetry breaking, phase transitions, slow dynamics, and methods used to study disordered systems.

DY 45.2 Thu 10:00 GÖR/0226

Statistical Physics of Classifier-free Diffusion Guidance — •Enrico Ventura[1], Beatrice Achilli[1], Carlo Lucibello[1], and Luca Ambrogioni[2] — [1]Bocconi University, Milan, Italy — [2]Radboud University, Nijmegen, The Netherlands

Classifier-free Guidance (CFG) is a simple yet effective technique that helps diffusion models better follow a user's prompt. By combining standard unconditional diffusion with diffusion conditioned on a specific class of the data, it steers generation toward samples (e.g. images, videos or text) that more clearly reflect the intended content. We propose a description of the sampling dynamics of a diffusion model under CFG based on the statistical mechanics of disordered systems. Specifically, we study the time-dependent transformation of the diffusion potential providing a quantitative prediction of the way a complex target distribution is deformed to improve data generation. Moreover, we leverage our results to propose alternative theory-based guidance schedules that enhance such beneficial effects.

DY 45.3 Thu 10:15 GÖR/0226

Fundamental operating regimes, hyper-parameter fine-tuning and glassiness: towards an interpretable replica-theory for trained restricted Boltzmann machines — •Alberto Fachechi[1], Elena Agliari[1], Miriam Aquaro[1], Anthony Coolen[2], and Menno Mulder[2] — [1]Department of Mathematics, Sapienza University of Roma, P. le A. Moro 5, 00185 Roma, Italy — [2]Theoretical Biophysics, DCN Donders Institute, Faculty of Science, Radboud University, 6525 AJ Nijmegen, The Netherlands

Since the seminal work by Amit, Gutfreund and Sompolinsky, statistical mechanics of spin-glasses with structural disorder has acquired a crucial role in theoretical investigations of artificial neural networks, as it enables the representation of their generalization and information processing capabilities as phases within the space of parameters. We study the relaxation towards equilibrium of the training procedure of restricted Boltzmann machines with a binary visible layer and a Gaussian hidden layer with an unlabelled dataset consisting of noisy realizations of a single ground pattern. We develop a statistical mechanics framework to describe the network generative capabilities by exploiting replica theory. We outline the effective control parameters (e.g., the relative number of weights to be trained, the regularization parameter), whose tuning can yield qualitatively different operative regimes. We also provide analytical and numerical evidence for the existence of a sub-region in the space of the hyperparameters where replica-symmetry breaking occurs.

DY 45.4 Thu 10:30 GÖR/0226

Mirror, Mirror of the Flow: How Does Regularization Shape Implicit Bias? — •Tom Jacobs, Chao Zhou, and Rebekka Burkholz — CISPA Helmholtz Center, Saarbrucken, Germany

Implicit bias plays an important role in explaining how overparameterized models generalize well. Explicit regularization like weight decay is often employed in addition to prevent overfitting. While both concepts have been studied separately, in practice, they often act in tandem. Understanding their interplay is key to controlling the shape and strength of implicit bias, as it can be modified by explicit regularization. To this end, we incorporate explicit regularization into the mirror flow framework and analyze its lasting effects on the geometry of the training dynamics, covering three distinct effects: positional bias, type of bias, and range shrinking. The mirror flow framework relies on Noether style parameter symmetry preservation, the regularization controls them. Our analytical approach encompasses a broad class of problems, including sparse coding, matrix sensing, single-layer attention, and LoRA, for which we demonstrate the utility of our insights. To exploit the lasting effect of regularization and highlight the potential benefit of dynamic weight decay schedules, we propose to switch off weight decay during training, which can improve generalization, as we demonstrate in experiments.

DY 45.5 Thu 10:45 GÖR/0226

Generalization performance of narrow one-hidden layer networks in the teacher-student setting — Rodrigo Pérez Ortiz[1], •Gibbs Nwemadji[2], Jean Barbier[3], Federica Gerace[1], Alessandro Ingrosso[4], Clarissa Lauditi[5], and Enrico Malatesta[6] — [1]Alma Mater Studiorum * Università di Bologna (Unibo), Bologna, Italy — [2]International School of Advanced Studies (SISSA), Trieste, Italy — [3]The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy — [4]Radboud University, Nijmegen, The Netherlands — [5]Harvard University, Cambridge, US — [6]Bocconi University, Milano, Italy

Generalization on simple input-output distributions is best studied in the teacher-student setting, but fully connected one-hidden-layer networks with generic activations still lack a complete theory. We develop such a framework for networks with a large but finite number of hidden neurons, using statistical-physics tools to obtain closed-form predictions for both Bayesian and ERM estimators through a few summary statistics. We also identify a specialization transition when the sample size matches the number of parameters. The resulting theory accurately predicts generalization errors for networks trained with Langevin dynamics or standard full-batch gradient descent.

DY 45.6 Thu 11:00 GÖR/0226

Testing generalization through tiny task switching frameworks — •Daniel Henrik Nevermann and Claudius Gros — Institut für Theoretische Physik, Goethe-Universität Frankfurt, Deutschland

With an ever-growing interest in advancing the performance and efficiency of large language models (LLMs), and therein particularly the transformer architecture, the need for tiny testing frameworks is pressing, as many researchers cannot afford to train models on large GPU clusters. We here propose a tiny testing framework, extending the recently published IARC task switching framework, that despite being trivial to implement offers suitable complexity to be non-trivial to learn for small scale transformer models with a few million parameters or less. Beyond model benchmarking, the framework is also suitable for probing phenomena relevant to problems arising in physics of AI, where controlled, interpretable testbeds are essential. The proposed training and evaluation scheme relies on integer sequences to be predicted by the model. These integer sequences are generated by simple deterministic tasks designed to abstract typical challenges arising in natural language processing, such as short and long range correlations, or context awareness. Within the sequences, tasks are randomly switched, where a switch is indicated by a control token. An important quality of LLMs is the ability to generalize at inference time. We here extend the existing task switching framework with new tasks able to probe models generalization capacities in a tiny, yet meaningful manner.

DY 46: Many-body Quantum Dynamics I (joint session DY/TT)

Time: Thursday 9:30–12:45 Location: HÜL/S186

DY 46.1 Thu 9:30 HÜL/S186

Nonequilibrium transport in adaptive fermionic circuits — •Paul Weiss[1], Karim Chahine[2], and Michael Buchhold[1] — [1]Department of Theoretical Physics, Universität Innsbruck, Austria — [2]Institute for Theoretical Physics, University of Cologne, Germany

We investigate nonequilibrium dynamics in one-dimensional adaptive fermionic circuits, where monitored fermions undergo local unitary evolution conditioned on measurement outcomes. By tuning the measurement strength and the duration of the unitary gates, the dynamics can be continuously interpolated between incoherent, classical transport and coherence-dominated quantum transport. In the classical limit, we recover the asymmetric simple exclusion process (ASEP), while in the quantum regime we uncover a coherent analogue of the Burgers equation along with coherence-enhanced Kardar-Parisi-Zhang (KPZ) transport. Our analytical approach, based on transport equations and Keldysh field theory, is supported by numerical simulations.

DY 46.2 Thu 9:45 HÜL/S186

Frustration-Free Control and Absorbing-State Transport in Entangled State Preparation — •Tobias Dörstel[1,2], Thomas Iadecola[3,4,5], Justin H. Wilson[6,7], and Michael Buchhold[1,2] — [1]Department of Theoretical Physics, University of Innsbruck, Austria — [2]Institute for Theoretical Physics, University of Cologne, Germany — [3]Department of Physics, The Pennsylvania State University, USA — [4]Institute for Computational and Data Sciences, The Pennsylvania State University, USA — [5]Materials Research Institute, The Pennsylvania State University, USA — [6]Department of Physics and Astronomy, Louisiana State University, USA — [7]Center for Computation and Technology, Louisiana State University, USA

We study frustration-free control, a measurement-feedback protocol for quantum state preparation that extends the concept of frustration-free Hamiltonians to stochastic dynamics. The protocol drives many-body systems into highly entangled target states, common dark states of all measurement projectors, through minimal local unitary corrections that realize an absorbing-state dynamics without post-selection. We show that relaxation to the target state is governed by emergent transport of nonlocal charges, such as singlet excitations in SU(2)-symmetric dynamics. While measurement-feedback annihilates compatible charge configurations, both measurement and scrambling unitaries induce charge transport and thus determine the convergence time. Mapping a baseline model of SU(N) SWAP measurements with local corrections to a solvable absorbing random walk yields a runtime scaling $t \sim L^z$ with transport exponent $z = 2$.

DY 46.3 Thu 10:00 HÜL/S186

Quantum typicality approach to energy flow between two spin-chain domains at different temperatures — Laurenz Beckemeyer[1], •Markus Kraft[1], Mariel Kempa[1], Dirk Schuricht[2], and Robin Steinigeweg[1] — [1]University of Osnabrück, Department of Mathematics/Computer Science/Physics,D-49076 Osnabrück, Germany — [2]Institute for Theoretical Physics, Utrecht University, 3584CC Utrecht, The Netherlands

We discuss a quantum typicality approach to examine systems composed of two subsystems at different temperatures. While dynamical quantum typicality is usually used to simulate high-temperature dynamics, we also investigate low-temperature dynamics using the method. To test our method, we investigate the energy current between subsystems at different temperatures in various paradigmatic spin-1/2 chains, specifically the XX chain, the critical transverse-field Ising chain, and the XXZ chain. We compare our numerics to existing analytical results and find a convincing agreement for the energy current in the steady state for all considered models and temperatures.

[1] Beckemeyer et al. arXiv:2507.23439

DY 46.4 Thu 10:15 HÜL/S186

Revisiting boundary-driven method for transport: Finite-size effects and the role of system-bath coupling — •Mariel Kempa[1], Markus Kraft[1], Sourav Nandy[2], Jacek Herbrych[3], Jiaozi Wang[1], Jochen Gemmer[1], and Robin Steinigeweg[1] — [1]University of Osnabrueck, Osnabrueck, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Wroclaw University of Science and Technology, Wroclaw, Poland

Understanding transport in interacting quantum many-body systems is a central challenge in condensed matter and statistical physics. Numerical studies typically rely on two main approaches: Dynamics of linear-response functions in closed systems and Markovian dynamics governed by master equations for boundary-driven open systems. While the equivalence of their dynamical behavior has been explored in recent studies, a systematic comparison of the transport coefficients obtained from these two classes of methods remains an open question. Here, we address this gap by comparing and contrasting the dc diffusion constant $\mathcal{D}_{\mathrm{dc}}$ computed from the aforementioned two approaches. We find a clear mismatch between the two, with $\mathcal{D}_{\mathrm{dc}}$ exhibiting a strong dependence on the system-bath coupling for the boundary-driven technique, highlighting fundamental limitations of such a method in calculating the transport coefficients related to asymptotic dynamical behavior of the system. We trace the origin of this mismatch to the incorrect order of limits of time $t \to \infty$ and system size $L \to \infty$, which we argue to be intrinsic to boundary-driven setups.

DY 46.5 Thu 10:30 HÜL/S186

Synchronized Aharonov-Bohm Motifs via Engineered Dissipation — •Christopher Wächtler and Gloria Platero — ICMM-CSIC, Madrdi, Spain

The interplay between external gauge fields and lattice geometry can induce extreme localization dynamics through complete destructive interference. We show that combining this flux-induced localization with engineered dissipation leads to robust spin synchronization in rotationally symmetric spin geometries, referred to as Aharonov-Bohm motifs, with cyclic symmetries of any order. The synchronized dynamics is independent of initial conditions and features entanglement among spins within each motif. We further demonstrate that multiple motifs can fully synchronize when coupled, which is achieved by applying additional collective dissipation acting on all intra-motif spins. These results reveal a direct connection between flux-induced localization, dissipative engineering, and collective quantum synchronization.

DY 46.6 Thu 10:45 HÜL/S186

Krylov space dynamics of ergodic and dynamically frozen Floquet systems — •Luke Staszewski[1], Asmi Haldar[2], Pieter Claeys[1], and Alexander Wietek[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden — [2]Laboratoire de Physique Theorique - IRSAMC, Toulouse

In isolated quantum many-body systems periodically driven in time, the asymptotic dynamics at late times can exhibit distinct behavior such as thermalization or dynamical freezing. Understanding the properties of and the convergence towards infinite-time (nonequilibrium) steady states however remains a challenging endeavor. We propose a physically motivated Krylov space perspective on Floquet thermalization which offers a natural framework to study rates of convergence towards steady states and, simultaneously, an efficient numerical algorithm to evaluate infinite-time averages of observables within the diagonal ensemble. The effectiveness of our algorithm is demonstrated by applying it to the periodically driven mixed-field Ising model, reaching system sizes of up to 30 spins. Our method successfully resolves the transition between the ergodic and dynamically frozen phases and provides insight into the nature of the Floquet eigenstates across the phase diagram. Furthermore, we show that the long-time behavior is encoded within the localization properties of the Ritz vectors under the Floquet evolution, providing an accurate diagnostic of ergodicity.

15 min. break

DY 46.7 Thu 11:15 HÜL/S186

Chaotic many-body quantum dynamics, spectral correlations, and energy diffusion — •Dominik Hahn and John Chalker — Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

We present results on the quantum dynamics of a minimal model with spatial structure and local interactions. The model features a time-independent Hamiltonian, in contrast to the widely studied quantum circuits, and is analytically tractable in the limit of large local Hilbert space dimension and weak intersite coupling. In this regime, we show that the energy dynamics are governed by a classical master equation

exhibiting diffusive behavior. Furthermore, we demonstrate that the spectral form factor can be expressed exactly in terms of the solution to this master equation, demonstrating how the linear ramp emerges at long times, while locality gives rise to an additional enhancement at short times.

DY 46.8 Thu 11:30 HÜL/S186

Dissipative diffusion in quantum state preparation — •Tim Pokart[1], Lukas König[1], Sebastian Diehl[2], and Jan Carl Budich[1,3,4] — [1]Institute of Theoretical Physics, Technische Universität Dresden — [2]Institut für Theoretische Physik, Universität zu Köln, 50937 Cologne, Germany — [3]Würzburg-Dresden Cluster of Excellence ct.qmat, 01062 Dresden, Germany — [4]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany

Dissipative quantum protocols that engineer a desired state as their dark state provide a powerful route to preparing quantum many-body states. We investigate a number conserving variant of such a dissipative protocol which is able to stabilize a topologically nontrivial phase. We show that the protocol admits a unique and stable dark state. Furthermore, we find that the cooling is diffusive in nature, supported by both analytical arguments and numerical simulations.

DY 46.9 Thu 11:45 HÜL/S186

First principles simulation of spin diffusion using dynamic mean-fields — •Timo Gräßer[1], Matthias Ernst[1], and Götz S. Uhrig[2] — [1]Institute of Molecular Physical Science, ETH Zurich, 8093 Zurich, Switzerland — [2]Condensed Matter Physics, TU Dortmund University, 44227 Dortmund, Germany

The transfer of a globally conserved polarization among a homogeneous spin ensemble is called spin diffusion and one of the most important phenomena in the broad field of magnetic resonance. Describing spin diffusion theoretically is a notoriously difficult task due to the large number of spins involved. We use a description through dynamic mean-fields (dubbed spinDMFT [1]) to derive an effective model for spectral spin diffusion. The approach is benchmarked for two crystalline test samples, malonic acid and dipotassium α-D-glucopyranose-1-phosphate dihydrate, yielding a remarkable agreement with experimental data and requiring only little computational effort. This strongly supports the use of spinDMFT, which may be extended in future works to understand spin diffusion in dynamic nuclear polarization (DNP) experiments [2].

[1] T. Gräßer et al., Phys. Rev. Research 3, 043168 (2021), DOI 10.1103/PhysRevResearch.3.043168

[2] J. Eills et al., Chem. Rev. 123, 1417 (2023), DOI 10.1021/acs.chemrev.2c00534

DY 46.10 Thu 12:00 HÜL/S186

Simulating universal long-time dynamics in integrable quantum spin chains — •Angelo Valli[1], Catalin Pascu Moca[2], Miklos Antal Werner[3], Marton Kormos[1], Doru Sticlet[6], Balazs Dora[1], Ziga Krajnik[4], Tomaz Prosen[5], and Gergely Zarand[1] — [1]Budapest University of Technology and Economics, Budapest (Hungary) — [2]University of Oradea, Oradea (Romania) — [3]Wigner Research Centre for Physics, Budapest (Hungary) — [4]New York University, New York (USA) — [5]University of Ljubljana, Ljubljana (Slovenia) — [6]National Institute for R&D of Isotopic and Molecular Technologies, Cluj-Napoca (Romania)

We introduce a novel tensor-network approach to calculate cumulants of the full counting statistics to unprecedentedly long times. We investigate spin-transfer in quantum spin chains, where the superdiffusive transport with dynamical exponent z=3/2 has been conjectured to fall within the Kardar-Parisi-Zhang (KPZ) universality class of classical interface growth. Recent experimental evidence on quantum simulators challenged this hypothesis. Our results extend far beyond the experimental timescales and provide unambiguous evidence that spin transfer in integrable quantum spin chains is indeed incompatible with KPZ universality. However, spatio-temporal fluctuations of the spin analogue of surface roughness exhibit a self-similar Family-Vicsek (FV) scaling, relating roughness, growth, and dynamical exponents in all transport regimes and across models with SU(N) symmetry. Our results shed light on how classical universal scaling laws extend to the quantum many-body realm.

DY 46.11 Thu 12:15 HÜL/S186

Few-body structures of Quantum impurity problems in the Heisenberg picture — •Maxime Debertolis — University of Bonn

Quantum impurity problems are known to exhibit a simplified representation of their ground state or for quench protocols when an optimized single-particle basis is chosen. This work extends the study of single-particle rotations taylored to operators in the Heisenberg picture. We present the concept of natural super-orbitals for many-body operators, defined as the eigenvectors of the one-body super-density matrix associated with a vectorized operator. These objects are related to measures of non- Gaussianity of operators associated to the occupations of the natural super-orbitals. We perform a numerical investigation of the natural super-orbitals corresponding to both the time-evolution operator and a time-evolved local operator in the t-V model and in a quantum impurity model using tensor network simulations. In the quantum impurity model, occupations of the natural orbitals for both operators decay exponentially at all times. More surprisingly, the non-Gaussianity of the local operator saturates in time. This indicates that only a small number of orbitals contribute significantly to quantum correlations, enabling a compact matrix-product-operator representation. This framework opens the door to future research that leverages the compressed structure of operators in their natural super-orbital basis, enabling for instance the computation of out-of-time-order correlators in large interacting systems over extended time scales.

DY 46.12 Thu 12:30 HÜL/S186

Propagating the Hierarchical Equations of Motion (HEOM) using the Multi-Configurational Time-Dependent Hartree method (MCTDH) — •Luisa R. Grether[1], Uwe Manthe[2], Samuel L. Rudge[1], and Michael Thoss[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg im Breisgau, Deutschland — [2]Theoretische Chemie, Fakultät für Chemie, Universität Bielefeld, Universitätsstr. 25, 33615 Bielefeld, Deutschland

The Hierarchical Equations of Motion (HEOM) are a powerful, numerically exact approach for simulating the time evolution of an open quantum system. Over the past decade, several tensor-train- and tensor-network-based approaches have been suggested and realized to make the HEOM applicable to ever larger model systems [1,2].

In this contribution, we build upon the existing twin-space formulation of the HEOM [2] and introduce a novel approach employing the Multi-Configurational Time-Dependent Hartree method (MCTDH) [3] for the time propagation of the HEOM. We demonstrate the applicability of the resulting HEOM+MCTDH method by presenting electron transport calculations for a nanojunction model, for which fully quantum results have not been available previously.

[1] Q. Shi *et al.*, J. Chem. Phys. **148**, 174102 (2018).
[2] Y. Ke *et al.*, J. Chem. Phys. **156**, 194102 (2022).
[3] H.-D. Meyer *et al.*, Chem. Phys. Lett. **165**, 73 (1990).

DY 47: Statistical Physics: General I

Time: Thursday 9:30–12:30 Location: ZEU/0114

DY 47.1 Thu 9:30 ZEU/0114

Microcanonical ensemble out of equilibrium — •Roman Belousov[1], Jenna Elliott[1,2], Florian Berger[3], Lamberto Rondoni[4,5], and Anna Erzberger[1,2] — [1]European Molecular Biology Laboratory (EMBL), Heidelberg, Germany — [2]Heidelberg University, Heidelberg, Germany — [3]Utrecht University, Utrecht, The Netherlands — [4]Politecnico di Torino, Turin, Italy — [5]Istituto Nazionale di Fisica Nucleare (INFN), Turin, Italy

The microcanonical ensemble serves as the fundamental representation of equilibrium thermodynamics in statistical mechanics by counting all possible realizations of a system's states. Ensemble theory connects this idea with probability and information theory, leading to the notion of Shannon-Gibbs entropy and, ultimately, to the principle of maximum caliber describing *trajectories* of systems—in and out of equilibrium. While the latter phenomenological generalization reproduces many results of nonequilibrium thermodynamics, its physical justification remains an open area of research. What is the microscopic origin and physical interpretation of this variational approach? What guides the choice of relevant observables? We address these questions by extending Boltzmann's method to a microcanonical caliber principle. Thereby we systematically develop generalized local detailed-balance relations, clarify the statistical origins of inhomogeneous transport, and provide an independent derivation of key equations from stochastic thermodynamics. This approach introduces a *dynamical* ensemble theory, which we verify in numerical simulations of spatially extended, driven, and active systems.

DY 47.2 Thu 9:45 ZEU/0114

Ensemble dependence of the critical behavior of a system with long range interaction and quenched randomness — •Nir Schreiber, Reuven Cohen, and Simi Haber — Department of Mathematics, Bar Ilan University, Ramat Gan, Israel 5290002

A system with long range interaction (LRI) is usually non-additive. In other words, such a system with volume V and energy E, cannot be divided into two subsystems with energies E_1, E_2 , where $E = E_1 + E_2 + o(V)$.

The canonical and the microcanonical ensembles are expected to be equivalent when describing additive systems. Conversely, non-additivity may result in peculiar microcanonical phenomena that are not observed in the canonical ensemble, such as negative specific heat or the presence of microstates that are inaccessible to the system, leading to breaking of ergodicity.

The Blume-Emery-Griffiths (BEG) model with mean-field-like interaction is a simple example of a model with LRI. We employ that model to demonstrate inequivalence of the two ensembles, without interfering with the interaction content. Specifically, we consider a hybrid system governed by the BEG Hamiltonian, where the spins are randomly quenched such that some of them are "pure" Ising and the others admit the BEG states. It is found, by varying the concentration of the Ising spins while keeping the parameters of the Hamiltonian fixed, that the model displays different canonical and microcanonical phase portraits in concentration-temperature plain. Indications that these portraits are rich and rather unusual are provided.

DY 47.3 Thu 10:00 ZEU/0114

Quasicrystals with large rotational symmetries: Amorphous-like on small but ordered at large lengths scale — Alan Rodrigo Mendoza Sosa[1,2], Atahualpa S. Kraemer[1], Erdal C. Oğuz[2], and •Michael Schmiedeberg[3] — [1]Departamento de Física, Facultad de Ciencias, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510, Mexico City, Mexico — [2]Key Laboratory of Soft Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing, 100190, China — [3]Soft Matter Theory group, Institut für Theoretische Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

We study hyperuniformity in quasicrystals with large rotational symmetry. Hyperuniform systems are characterized by anomalously suppressed long-wavelength (i.e., large-length-scale) density fluctuations compared to those found in ordinary gases and fluids as well as in amorphous solids. We show that the degree to which the large-scale fluctuations are suppressed reveals a new characteristic length-scale. Below this length the patterns behave like amorphous systems while only above this length the long-ranged order becomes important leading to hyperuniformity in all cases.

DY 47.4 Thu 10:15 ZEU/0114

Emergence of mixed orientational ordering in quasi-one-dimensional superdisk and superball fluids — •Sakineh Mizani[1], Martin Oettel[1], Péter Gurin[2], and Szabolcs Varga[2] — [1]Institute for Applied Physics, University of Tübingen, Auf der Morgenstelle 10, 72076 Tübingen, Germany — [2]Physics Department, Centre for Natural Sciences, University of Pannonia, PO Box 158, Veszprém, H-8201 Hungary

We investigate the collective behavior of hard anisotropic particles confined in quasi-one-dimensional channels where particle centers are constrained to a line but particles can rotate freely. For superdisks and superballs with tunable curvature, equilibrium properties are calculated using an exact transfer-operator method. We reveal the emergence of a novel state of mixed orientational order which is characterized by a close-packing state with particles having two distinct orientations, distributed randomly over the line [1]. This ordering is highly sensitive to particle shape: small deviations from ideal spherical symmetry can stabilize or destabilize the mixed phase, demonstrating the the subtle interplay between particle geometry and confinement. Our results provide new insights into entropically driven ordering in confined systems, offering potential guidelines for designing colloidal assemblies and understanding phase behavior in narrow channels. [1] S. Mizani et al, arXiv:2510.06918, J. Mol. Liq. (accepted).

DY 47.5 Thu 10:30 ZEU/0114

Scaling of the Mpemba effect in the Ising model — •Janett Prehl and Martin Weigel — Institute of Physics, Technisch Universität Chemnitz, Chemnitz, Germany

The Mpemba effect – originally observed by Mpemba and Osborne for water [1] – describes the counterintuitive situation in which a hotter system relaxes faster than an initially colder one when both are instantaneously brought into contact with the same (cold) reservoir. Lately this phenomenon has been identified in various systems undergoing phase transitions [2 – 4]. Here, we investigate the Mpemba effect in the 2D Ising model with a critical temperature T_c. Using Monte Carlo simulations with different update dynamics, we study how initial temperatures and different initial magnetization influence the coarsening dynamics of different structural properties while quenching below T_c. In detail we investigate observables such as the energy per spin $\langle e \rangle$ and the average domain length $\langle \ell \rangle$. While Mpemba-like curve crossings appear for several conditions, they occur in the finite-size limited regime and weaken with increasing system size L. In contrast, non-zero initial magnetization enhances the effect, producing robust inversions in relaxation behavior.

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

DY 47.6 Thu 10:45 ZEU/0114

Work extraction from a single negative-temperature bath considered as a temperature gradient-driven heat flow — •Wolfgang Bauer — Dept. of Internal Medicine I, Comprehensive Heart Failure Centre, UKW, Würzburg, Germany — EPV, Institute of Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany}

Work can dissipate as heat within a bath. The reverse, i.e. extracting work from a thermal bath without changing the state of the working system contradicts the 2nd law of thermodynamics. However, this does not hold for a bath at negative absolute temperature. Our approach reconciles the 2nd law with sole work extraction from a bath at negative temperature. We consider not only a single, but rather a large assembly of working systems. Within the assembly the working systems may exchange mutually energy by weak thermal coupling. This assembly is now assigned from Shannon entropy a canonical temperature. While this framework may seem unconventional for macroscopic working machines, it naturally becomes clear for very small, molecular-scale ma-

chines. We show for paradigmatic examples of working machines, that their initial canonical temperature is positive. Consequently, sole extraction of work from a bath at negative temperature represents simply heat flow from a hot system (bath at negative temperature) to a cool system (assembly of working machines), consistent with the 2nd law of thermodynamics.

15 min. break

DY 47.7 Thu 11:15 ZEU/0114

Advancing Stochastic 3-SAT Solvers by Dissipating Oversatisfied Constraints — •Joachim Schwardt[1,2] and Jan Budich[2,1] — [1]Max Planck Institute for the Physics of Complex Systems — [2]Institute of Theoretical Physics at TU Dresden

We introduce and benchmark a stochastic local search heuristic for the NP-complete satisfiability problem 3-SAT that drastically outperforms existing solvers in the notoriously difficult realm of critically hard instances. Our construction is based on the crucial observation that well established previous approaches such as WalkSAT are prone to get stuck in local minima that are distinguished from true solutions by a larger number of oversatisfied combinatorial constraints. To address this issue, the proposed algorithm, coined DOCSAT, dissipates oversatisfied constraints (DOC), i.e. reduces their unfavorable abundance so as to render them critical. We analyze and benchmark our algorithm on a randomly generated sample of hard but satisfiable 3-SAT instances with varying problem sizes up to N = 15000. Quite remarkably, we find that DOCSAT outperforms both WalkSAT and other well known algorithms including the complete solver Kissat. The essence of DOCSAT may be seen as a way of harnessing statistical structure beyond the primary cost function of a combinatorial problem to avoid or escape local minima traps in stochastic local search.

DY 47.8 Thu 11:30 ZEU/0114

Quest for optimal quantum resetting: Protocols for a particle on a chain — •Pallabi Chatterjee, S. Aravinda, and Ranjan Modak — Department of Physics, Indian Institute of Technology Tirupati, Tirupati 517619, India

In the classical context, it is well known that, sometimes, if a search does not find its target, it is better to start the process anew. This is known as resetting. The quantum counterpart of resetting also indicates speeding up the detection process by eliminating the dark states, i.e., situations in which the particle avoids detection. In this work, we introduce the most probable position resetting(MPR) protocol, in which, at a given resetting step, resets are done with certain probabilities to the set of possible peak positions that could occur because of the previous resets, followed by uninterrupted unitary evolution, irrespective of which path was taken by the particle in previous steps. In a tight-binding lattice model, there exists a twofold degeneracy (left and right) of the positions of maximum probability(peak). The survival probability with optimal restart rate approaches zero when the particle is reset with equal probability on both sides path independently. This protocol significantly reduces the optimal mean first-detected-passage time, and it performs better even if the detector is far apart compared to the usual resetting protocols in which the particle is brought back to the initial position. We propose a modified protocol, an adaptive two-stage MPR, by making the associated probabilities of going to the right and left a function of steps. We see a further reduction of the optimal mean FDT and improvement in the search process.

DY 47.9 Thu 11:45 ZEU/0114

Quantification of correlations by Fisher matrix — •Jakub Grabarczyk and Krzysztof Byczuk — Faculty of Physics, University of Warsaw, Poland

Quantum Fisher Information (QFI) is a concept based on relative entropy used to measure the distinctiveness of the given statistical ensemble. When applied to a lattice model, it quantifies the measurable difference between two instances of the model characterized by different parameter values. In my work, I demonstrate the significance of QFI in understanding microscopic properties of correlated quantum particles. The results are verified numerically. I compare the QFI across several important lattice models including the bosonic and fermionic Hubbard models as well as the Heisenberg model. Furthermore, I discuss how QFI relates to physically measurable quantities.

DY 47.10 Thu 12:00 ZEU/0114

Universal irreversibility—an information loss paradigm — •Jürgen Stockburger — Institut for Complex Quantum Systems, Ulm University

I develop a general prescription to incorporate irreversibility into any physical dynamics governed by a reversible microscopic dynamics with interactions. A description of irreversibility is introduced from the perspective that reversibility is *infeasible* due to insufficient means, not as a fundamental alteration of any microscopic theory.

With an arbitrary partitioning into subsystems, a coupled dynamics between a projected (decorrelated) and a residual (complementary) state is formulated, still fully equivalent to the reversible dynamics. All partitions are treated equally, without designation of "system" and "bath". With a (variable) truncation of the memory of the residual state, I recognize the fact that correlations in the distant past are undetectable in the present. The notion of irrecoverable correlation information is also implicit in current open-system approaches such as repeated interaction models [1]; the need to consider heat baths equally as a "system of interest" arises, e.g., in the context of quantum bolometry [2]. The framework of *entropy augmentation through subadditive excess* (EASE) introduces not only a universal view on irreversibility, it also provides a roadmap for actual computation [3].

[1] F. Ciccarello *et al.*, Phys. Rep. **954**, 1 (2022)
[2] B. Karimi *et al.*, Nat. Comm. **11**, 367 (2020)
[3] Stockburger, J.T., Eur. Phys. J. Spec. Top. (2025). https://doi.org/10.1140/epjs/s11734-025-01923-2

DY 47.11 Thu 12:15 ZEU/0114

Temperature as joules per bit — Charles Alexandre Bédard[1], •Sophie Berthelette[2], Xavier Coiteux-Roy[3], and Stefan Wolf[2,4] — [1]École de technologie supérieure, Montreal, Canada — [2]Università della Svizzera italiana, Lugano, Switzerland — [3]University of Calgary, Calgary, Canada — [4]Facoltà indipendente di Gandria, Gandria, Switzerland

In statistical mechanics, entropy is defined as a fundamental quantity. However, its unit, J/K, involves that of temperature, which is only subsequently defined — and defined in terms of entropy. This circularity arises with the introduction of Boltzmann's constant into the very expression of entropy. The J/K carried by the constant prevents entropy from finding a unit of its own while simultaneously obfuscating its informational nature. Following the precepts of information theory, we argue that entropy is well measured in bits and coincides with information capacity at thermodynamic equilibrium. Consequently, not only is the temperature of a system in equilibrium expressed in J/bit, but it acquires a clear meaning: It is the cost in energy to increase its information capacity by 1 bit. Viewing temperature as joules per bit uncovers the strong duality exhibited by Gibbs long ago between available capacity and free energy. It also simplifies Landauer's cost and clarifies that it is a cost of displacement, not of erasure. Replacing the kelvin with the bit as an SI unit would remove Boltzmann's constant from the seven defining constants.

DY 48: Nonlinear Dynamics and Time-Delay Systems

Time: Thursday 9:30–11:00 Location: ZEU/0118

DY 48.1 Thu 9:30 ZEU/0118

From Case Counts to Contact Networks: Inferring Epidemic Coupling in Space and Time — •Adrian Pelcaru and Dirk Brockmann — Center Synergy of Systems (SynoSys), TUD Dresden University of Technology, Dresden, Germany

Inferring spatio-temporal transmission structure from incidence data alone is a central problem in epidemic modelling, with implications for real-time surveillance and for how we interpret mobility and contact information. We analyse discrete-time renewal SIRS models on a network of metapopulations that incorporate infection-age structure, seasonality, mobility between regions, and time-varying local contact rates. In the analysis, these ingredients are combined into an effective spatio-temporal contact kernel that quantifies how cases in region m at a given infection age contribute to new infections in region n one day ahead. Stacking multi-region incidence histories across lags into a delay-embedded state, the renewal dynamics define a map on this reconstructed space whose local Jacobian is the convolution operator determined by the contact kernel and the susceptibles. Aggregating the kernel over infection age with suitable weights yields a time-dependent effective contact matrix and associated effective distances that summarise how infections propagate between regions. This construction provides a transparent link between mechanistic assumptions about mobility and varying infection rates and the resulting effective couplings in space and time, and identifies a natural operator that can, in principle, be compared to reconstructions from incidence data to detect systematic deviations from mobility-based expectations.

DY 48.2 Thu 9:45 ZEU/0118

Beyond the Balance: A Minimal Model Unifying Regime Shifts, Long Transients, and Critical Transitions — •Misha Chai and Holger Kantz — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, D 01187, Germany

By the late 20th century, ecologists recognized that classical equilibrium views — nature is deterministic and always converges to a single, stable state — often fail to capture real-world dynamics. A nonequilibrium perspective emerged: ecological systems are frequently dominated by long transients that can persist over a super-long periods of time, with recurrent cyclic and chaotic behavior, until a sudden regime shifts changes the dynamics and transitions the system to an unpredictable new state.

However, models that integrate these key features — alternative stable states, stochastic drivers, long transients, and critical transitions — while also quantifying stability via resilience, remain rare.

We propose a minimal model that encapsulates these key properties of nonequilibrium ecology, while remaining amenable to theoretical analysis.

DY 48.3 Thu 10:00 ZEU/0118

Anticipated synchronization in systems with distributed delay — •David Ortiz, Tobias Galla, and Raúl Toral — Instituto de Física Interdisciplinar y Sistemas Complejos IFISC (CSIC-UIB), Campus UIB, 07122 Palma de Mallorca, Spain

Anticipated Synchronization (AS) describes counterintuitive situations in which a system synchronizes with the future state of another, even though the coupling between the systems is perfectly causal. Thus, the driven system 'forecasts' the driver. Common setups include two identical copies of a system, coupled with a fixed delayed interaction. AS has been reported in chaotic, excitable and spatially extended systems.

We extend AS to linear and nonlinear systems coupled with distributed delay. This models situations with uncertainty on the delay, or systems in which there are multiple distinct delay channels. The damped harmonic oscillator can be studied analytically, and shows stable AS provided the coupling strength and mean delay are not too large. We compute the anticipation time, and show that the driven system amplifies the oscillations in the driver. Our theoretical predictions are confirmed by numerical simulations. Numerically, we also investigate nonlinear chaotic and excitable systems. We confirm that AS can occur in the presence of distributed delay. Similar to the case of linear systems, we again find instances of signal enhancement.

DY 48.4 Thu 10:15 ZEU/0118

Dynamics of Temporal Localized States in an Injected Resonant Saturable Absorber Mirror — •Martin P. Szymiczek[1], Elias R. Koch[1], Julien Javaloyes[2], and Svetlana V. Gurevich[1,2,3] — [1]Institut für Theoretische Physik, Universität Münster — [2]Universitat de les Illes Balears, Palma — [3]Center for Data Science and Complexity, Universität Münster

We are interested in the dynamical behaviour of temporal localized states (TLS) and corresponding frequency combs in an injected microcavities subjected to a strong time-delayed feedback. A nonlinear optical system consist of a short injected microcavity with a thin slice of a saturable absorber, coupled to a long external cavity introducing a time delay and closed by a feedback mirror. We disclose sets of multistable bright TLSs coexisting on their respective bistable homogeneous backgrounds and show that they are mainly generated through the locking of domain walls leading to a collapsed snaking structure. The results provide insights into the control and design of emission in delay-coupled micro-resonator systems.

DY 48.5 Thu 10:30 ZEU/0118

FPGA-integrated analog simulations of time-delayed differential equations — •Matthias Hering[1], Julien Javaloyes[2], and Svetlana V. Gurevich[1,2,3] — [1]Institute of Theoretical Physics, Münster, Germany — [2]Departament de Física and IAC[3], Universitat de les Illes Balears, Spain — [3]Center for Data Science and Complexity, Münster, Germany

Real-world complex systems can be strongly influenced by time-delays due to unavoidable finite signal propagation speeds and time-delayed dynamical systems (TDSs) have proven to be a fertile framework for the modeling of nonlinear phenomena. However, they are difficult to study experimentally due to the need for precise delay elements. We present a hybrid implementation by integrating a digital feedback loop powered by an FPGA into an analog circuit to realize a damped harmonic oscillator with a piecewise nonlinear, delayed restoring force. Operating at 125 MS/s enables the FPGA to enable a clean reconstruction of the system*s dynamics up into the MHz regime without digital artifacts. The experiment not only reproduces the expected Turing bifurcation in the long delay limit, but also reveals the formation of robust localized states and square-waves patterns.

DY 48.6 Thu 10:45 ZEU/0118

Experimental realisation of thermalisation in a nonlinear non-Hermitian optical lattice — •Julia Görsch[1], Joshua Feis[1], Andrea Steinfurth[1], Sebastian Weidemann[1], Georgios G. Pyrialakos[2], Matthias Heinrich[1], Mercedeh Khajavikhan[2], Alexander Szameit[1], and Demetrios N. Christodoulides[2] — [1]Institute of Physics, University of Rostock, Rostock, Germany — [2]Ming Hsieh Department of Electrical and Computer Engineering, University of Southern California, Los Angeles, California, USA

Optical thermodynamics has emerged as an efficient framework for describing and predicting the dynamics of strongly multimode, nonlinear systems. Yet, in non-Hermitian settings, many of the theoretically predicted effects have remained experimentally unexplored. Here, we report the first experimental observation of thermalisation in a nonlinear, non-Hermitian optical lattice using a platform based on coupled optical fiber loops. This arrangement emulates light propagation in a one-dimensional lattice by coupling two fiber loops of unequal length via a beam splitter, thereby mapping pulse evolution onto a doubly discrete (1+1)D lattice. Within this system, we engineer a pseudo-Hermitian lattice whose non-Hermiticity arises from anisotropic nearest-neighbor coupling, implemented via a tunable beam-splitting ratio combined with amplitude modulation. Following excitation with a superposition of eigenmodes, the system undergoes a clear thermalisation process - despite its intrinsic non-Hermiticity - revealing a previously inaccessible regime of non-Hermitian optical thermodynamics and opening the door to further experimental investigations.

DY 49: Active Matter V (joint session DY/BP)

Time: Thursday 9:30–12:45 Location: ZEU/0160

Invited Talk DY 49.1 Thu 9:30 ZEU/0160

Active memory and non-reciprocity as pathways to pattern formation in conserved scalar fields — •Suropriya Saha and Vaishnavi Gajendragad — Max Planck Institute for Dynamics and Self-organisation

Active phase separation has emerged as a field within active matter that investigates pattern formation in number-conserving scalar fields. The field has also gained momentum from developments in biological systems, where phase separation has been implicated in the formation of biological condensates. In this talk, I will explore two different paths to non-Hermiticity in number-conserving scalar fields. Non-Hermiticity, or the emergence of complex eigenvalues in the linear dynamics of scalar densities, is associated with traveling patterns that break time-reversal symmetry and parity.

The first pathway I will discuss is a feedback mechanism in which particles store and use information about their past trajectories to influence their time evolution. I will present a model in which the particle velocity acquires an active contribution that depends on its past trajectory, weighted by a memory kernel. This memory kernel is independent of the thermal noise acting on the particle, implying a microscopic violation of detailed balance. The number density of these particles is described by a modified Cahn*Hilliard equation that incorporates this non-equilibrium effect. The second pathway involves non-reciprocal interactions between two or more species. I will describe the phenomenology observed in both cases, focusing on the role of fluctuations, nonlinearities, and the stability of the resulting patterns.

DY 49.2 Thu 10:00 ZEU/0160

Self-propulsion via non-transitive phase coexistence in chemically active mixtures — •Yicheng Qiang, Chengjie Luo, and David Zwicker — Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany

Chemical activity is common in many active matter systems. For example, active reactions can lead to the self-propulsion of particles, which can finally give rise to rich collective dynamics, including phase separation, even in the absence of attractive interactions. With interactions that already favor phase separation, chemical activity and multiple coexisting phases will further intertwine. To unveil the basic effect of active reactions on coexistence, we study mixtures where solvent species interconvert while solutes segregate. We demonstrate that active reactions alter the chemical potential balance between the coexisting phases and defy the construction of pseudo-pressure balance. As a result, the transitivity of phase coexistence is broken, and the bulk compositions depend on the contact topology among all the coexisting phases. With cyclic topologies, the pressure imbalance leads to self-propelled phases and other complex dynamics such as budding and engulfment.

DY 49.3 Thu 10:15 ZEU/0160

Contraction waves in pulsating active liquids: from pacemaker to aster dynamics — Tirthankar Banerjee[1], Thibault Desaleux[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 Supérieure, CNRS, Inserm, Université PSL, 46 rue d*Ulm, 75005 Paris, France

We propose a hydrodynamic theory to examine the emergence of contraction waves in dense active liquids composed of pulsating deformable particles. Our theory couples the liquid density with a chemical phase that determines the periodic deformation of the particles. This mechanochemical coupling regulates the interplay between the flow induced by local deformation, and the resistance to pulsation stemming from steric interaction. We show that this interplay leads the emergent contraction waves to spontaneously organize into a packing of pacemakers. We reveal that the dynamics of these pacemakers is governed by a complex feedback between slow and fast topological defects that form asters in velocity flows. In fact, our defect analysis is a versatile platform for investigating the self-organization of waves in a wide range of contractile systems. Our results shed light on the key mechanisms that control the rich phenomenology of pulsating liquids, with relevance for biological systems such as tissues made of confluent pulsating cells. Refs: arXiv:2509.19024, arXiv:2407.19955

DY 49.4 Thu 10:30 ZEU/0160

Topology of pulsating active matter: Defect asymmetry controls emergent motility — •Luca Casagrande[1], Alessandro Manacorda[2], and Étienne Fodor[1] — [1]Department of Physics and Materials Science, University of Luxembourg, Luxembourg City, Luxembourg — [2]CNR Institute of Complex Systems, Uos Sapienza, Rome, Italy

When heartbeats become irregular, spiral waves and motile defects emerge at the surface of cardiac tissues [1]. Capturing the emergence of defect motility despite the absence of any cellular flows is a theoretical challenge which has recently been tackled by models of actively deforming particles [2-4]. The interplay between individual pulsation of particles sizes, synchronization, and repulsion yields deformation waves resembling those of cardiac tissues. Combining particle-based and hydrodynamic approaches, we examine the statistics of defects in the collective deformation of particles. We rationalize defect motility as stemming from the breakdown of time-reversal and spatial symmetries, and provide predictions for the deformation profile near the defect core to quantify motility. [1] A. Karma, Annu. Rev. Condens. Matter Phys., 4, 313-337 (2013) [2] Y. Zhang, É. Fodor, Phys. Rev. Lett., 131, 238302 (2023) [3] A. Manacorda, É. Fodor, Phys. Rev. E, 111, L053401 (2025) [4] W. Piñeros, É. Fodor, Phys. Rev. Lett., 134, 038301 (2025)

DY 49.5 Thu 10:45 ZEU/0160

Avalanche statistics in dense active matter — •Vinay Vaibhav[1] and Peter Sollich[1,2] — [1]Institut für Theoretische Physik, University of Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [2]Department of Mathematics, King's College London, The Strand, London, UK

Reorganization processes in dense active matter remain a central open question in non-equilibrium physics. In particular, how persistent self-propulsion drives local rearrangements and triggers collective failure events is not well understood. Here, we investigate such activity-induced rearrangements, that sometimes rapidly cascade to avalanches, in a dense assembly of self-propelled particles with extremely persistent activity. These systems evolve through abrupt transitions between mechanically stable configurations, giving rise to rich intermittent behavior. Using large-scale simulations, we systematically characterize avalanche statistics across a range of system sizes and activity protocols. We quantify the scaling properties of avalanche-size distributions for two widely studied active matter models: active Brownian particles and active Ornstein-Uhlenbeck particles. By comparing these classes of dynamics, we identify how the nature of the propulsion mechanism influences the exponents associated with the avalanche size distribution. In addition, we report the frequency and temporal organization of avalanches. Our results provide a unified picture of how persistent activity drives rearrangements in dense active systems and highlight the connections between active intermittency, mechanical stability, and avalanche dynamics.

15 min. break

DY 49.6 Thu 11:15 ZEU/0160

Coupling intracellular processes and extracellular environment in a Cellular Potts model — •Cornelis Mense[1,2], Falko Ziebert[1,2], and Ulrich Schwarz[1,2] — [1]ITP, Heidelberg — [2]BioQuant, Heidelberg

The Cellular Potts Model (CPM) is a computationally very efficient framework to study cell dynamics, wherein cells are simulated through Hamiltonian based update rules on a discretised lattice. The model has traditionally been used to predict cell migration and shape in scenarios such as immune response, morphogenesis, cancer, and wound healing. In contrast to e.g. active gel models, however, the CPM usually does not represent subcellular processes. Here, we propose an extension to the CPM by which cells can contract their bulk to both actively transport material and strain their substrate. This model allows us to represent feedback loops between intracellular processes, cell shape and the mechanical and geometrical properties of the extracellular environment. Migration can emerge both as internal symmetry break or as response to an external gradient. We apply it to some standard situations of experimental interest, in particular 3D-printed scaffolds

for cell adhesion and migration.

DY 49.7 Thu 11:30 ZEU/0160

Exact Stationary State of a d-dimensional Run-and-Tumble Particle in a Harmonic Potential — •Mathis Guéneau[1], Grégory Schehr[2], and Satya N. Majumdar[3] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden, Germany — [2]Sorbonne Université, Laboratoire de Physique Théorique et Hautes Energies, CNRS UMR 7589, 4 Place Jussieu, 75252 Paris Cedex 05, France — [3]LPTMS, CNRS, Univ. Paris-Sud, Université Paris-Saclay, 91405 Orsay, France

We study the stationary state of a run-and-tumble particle (RTP) confined in a harmonic potential in arbitrary dimension d. Owing to isotropy, all statistical properties of the steady state are fully encoded in the distribution of a single coordinate. This coordinate follows an effective one-dimensional dynamics with a piecewise-constant self-propulsion velocity drawn from a prescribed distribution. We obtain the exact stationary distribution by identifying a stick-breaking process and a Dirichlet process in the dynamics, and by using known results for these processes. This framework allows us to compute exactly the full radial distribution, the joint law of the coordinates, and their moments, and to extend these results to include thermal noise. We further characterize the shape transition of the stationary state, from active-like to passive-like behavior, and show that it can be analyzed for arbitrary external potentials.

DY 49.8 Thu 11:45 ZEU/0160

Jerky active particles — •Hartmut Löwen and Stephy Jose — Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf

We introduce jerky active particles, a generalization of inertial active Brownian particles subjected to jerk, the time derivative of acceleration. These particles can be realized by feedback in active macroscopic granules or in mesoscopic colloids moving in a viscoelastic background with memory. We analytically derive their mean squared displacement (MSD) and show that there is a gigantic dynamical spreading with extremely high scaling exponent of the MSD as a function of time [1]. We also generalize jerky dynamics to a chiral active particle and demonstrate that the mean displacement shows damped and exploding Lissajous-like patterns alongside the well-known classical spira mirabilis [2]. Our work on jerky chiral active particles opens a new route to explore rich dynamical effects in active matter.

[1] H. Löwen, Physical Review E 112, 045412 (2025)
[2] S. Jose, H. Löwen, Chiral jerky active particles, New Journal of Physics (in press), see also arXiv:2508.18180

DY 49.9 Thu 12:00 ZEU/0160

Diffusion of active particles on curved manifolds — •Maxim Root[1], Lorenzo Caprini[2], and Hartmut Löwen[1] — [1]Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany — [2]Physics Department, Sapienza University of Rome, 00185 Rome, Italy

Active Matter rarely exists in isolated idealized systems. In nature, it is rather typical that active particles are surrounded by complex environments and experience external forces. So far, passive Brownian motion constrained to curved surfaces [1,2] was studied extensively and similar work was done on clusters of active particles [3]. In this talk we explore the emergent effects of active particles constrained to two-dimensional curved surfaces and in presence of an external homogeneous force field, e.g., gravity. This is done for an overdamped active particle that exhibits persistent motion on a short time scale and diffusion in the long-time limit. The lateral long-time diffusion coefficient is computed for different scenarios and criteria for localization are derived.

[1] T. Ohta and S. Komura, *Lateral diffusion on a frozen random surface*, EPL **132**, 50007 (2020)
[2] A. Naji and F. L. H. Brown, *Diffusion on ruffled membrane surfaces*, J. Chem. Phys. **126**, 235103 (2007)
[3] E. D. Mackay et al., *Emergent Dynamics of Active Systems on Curved Environments*, arXiv:2505.24730 (2025)

DY 49.10 Thu 12:15 ZEU/0160

Modeling dissipation in quantum active matter — Alexander P. Antonov[1], Sangyun Lee[2], Benno Liebchen[3], Hartmut Löwen[1], Jannis Melles[1], Giovanna Morigi[4], Yehor Tuchkov[2], and •Michael te Vrugt[2] — [1]Institut für Theoretische Physik II, Weiche Materie, Heinrich-Heine-Universität Düsseldorf — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz — [3]Institut für Physik der kondensierten Materie, Technische Universität Darmstadt — [4]Theoretische Physik, Universität des Saarlandes

In classical active matter systems, dissipation plays a major role. Currently, there is an increased focus in exploring quantum mechanical active matter systems, for which the question of how to model dissipation is far from obvious. In fact, for open quantum systems, a variety of quantum heat bath models have been proposed that are valid in different physical situations. Here, we compare the effects of different quantum heat baths based on a recently proposed quantum active matter model [Phys. Rev. Res. **7**, 033008 (2025)]. We find that the choice of the quantum heat bath strongly influences the dynamics at short timescales, which is the regime in which quantum effects are most relevant.

DY 49.11 Thu 12:30 ZEU/0160

Active Magnetic Particles in Magnetic Gradient Fields — •Laris Berekovic, Margaret Rosenberg, and Hartmut Löwen — Heinrich-Heine University Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf

Active particles are common in nature, underlying many complex phenomena. Since the motion of active particles has no intrinsic directionality, steering the particles' motion requires an additional control parameter, such as a magnetic interaction. In this contribution, we present an analysis of the effect of magnetic vortex fields created by a current carrying wire on the ground states and motion of active Brownian particles (ABP) carrying a fixed magnetic dipole moment. We present an analytical solution for the single-particle case, compute the ground state for multiple particles via simulated annealing in the passive case and explore the activity-induced phase transition created by increasing the self-propulsion. We find new forms in the ground state, as well as a rich variety of activity-induced structures. These results can be applied to ferrofluid systems, biophysical systems of magnetotactic bacteria or form the basis of more complex industrial applications.

DY 50: Focus Session: Controlling Microparticles and Biological Cells by Ultrasound (joint session BP/CPP/DY)

Recently ultrasound has emerged as a very promising physical modality to control the behavior of microparticles and even of biological cells, which can be moved and stimulated by sound waves. For biological cells, one can further control the effect of sound through gene expression (sonogenetics), similar to the control by light (optogenetics). However, because the wavelength of sound is much larger than the one of light, one of the challenges is to localize the effect of sound waves, e.g. by using gas bubbles. Here, we bring together experimental and theoretical researchers who currently explore the potential of ultrasound to control active and passive microsystems and to develop new applications ranging from biomedicine to soft robotics.

Organized by Peer Fischer and Ulrich S. Schwarz (Heidelberg)

Time: Thursday 10:15–12:45 Location: BAR/0106

Invited Talk DY 50.1 Thu 10:15 BAR/0106

Mechanogenetics for Cell ImmunoTherapy — •Yingxiao Wang — 1002 childs way, Los Angeles, CA 90089

Cell-based cancer immunotherapy is a promising therapeutic intervention for cancer treatment. However, non-specific toxicity against healthy tissues (e.g. off-tumor toxicity) is a major hurdle for solid tumor treatment. We have developed controllable on-switch gene cassettes in which a specific antigen production on the target cancer cell can be remotely and mechanically induced by an external focused ultrasound (FUS). FUS was applied to stimulate the production of the synthetic and clinically validated antigen on tumor cell surface orthogonal to the endogenous proteins. SynNotch was further engineered into primary human T cells (SynNotch-CAR T) to recognize the synthetic antigen expressed on the ultrasound-induced tumor cells and activate the production of CAR, which can lead to the recognition of a native tumor specific antigen (TSA) universally expressed on the whole population of tumor cells for immunotherapy. We applied this system to treat prostate cancer cells whose locally metastasized tumors are confined in space but intermingled with vessels and nerves. Our results showed that FUS can mechanically induce the synthetic antigen production in prostate cancer cells, which results in the engagement and activation of SynNotch CAR T cells for the tumor eradication. This local activation of engineered tumor cells by FUS should allow a high precision and safety in eradicating tumors. Hence, this approach for immunotherapy should open new opportunities to integrate engineering mechanics with genetic medicine for successful translation.

DY 50.2 Thu 10:45 BAR/0106

Shaping sound to tickle cells — •Dimitris Missirlis[1,2], Athanasios Athanassiadis[1,2], Rom Lerner[1,2], and Peer Fischer[1,2] — [1]Institute for Molecular Systems Engineering and Advanced Materials, Im Neuenheimer Feld 225, 69120 Heidelberg, Germany — [2]Max Planck Institute for Medical Research, Jahnstr. 29, 69120, Heidelberg, Germany

The ability to shape ultrasonic waves precisely is finding growing relevance in biomedical applications, where ultrasound is increasingly used to noninvasively stimulate biological tissues for therapeutic purposes. However, it remains an unsolved question how high-frequency ultrasound can interact with cells to excite biological responses. Our recent work on shaping and controlling ultrasound waves has provided us with a new tool to address the fundamental question how ultrasound interacts with and influences cells. To this end we have developed adaptable setups where we can control relevant ultrasound parameters in vitro as well as in vivo. By systematically examining the critical parameters, we discuss the role of different ultrasonic effects, including thermal effects, radiation forces, and sound-induced shear flows. Further, we discuss both physical and sonogenetic methods that can be used to enhance the coupling of ultrasound to cells.

DY 50.3 Thu 11:00 BAR/0106

A Theoretical Model for Ultrasound-Induced Intracellular Streaming — •Niels Gieseler[1,2,3], Falko Ziebert[1,2], and Ulrich S. Schwarz[1,2] — [1]Institute for Theoretical Physics, Heidelberg University, Philosophenweg 19, Heidelberg 69120 Germany — [2]BioQuant, Heidelberg University, im Neuenheimer Feld 267, Heidelberg 69120 Germany — [3]Max Planck Institute for Medical Research, Jahnstrasse 29, Heidelberg 69120, Germany

Ultrasound is not only the basis of an essential imaging method for biomedicine, recently it has also become a promising avenue to control biological systems, for example, in sonogenetics or ultrasound neuromodulation. However, the underlying physical effects are not well understood, and a complete theoretical description is missing. In fact, many different physical effects compete, including radiation forces, streaming, cavitation, and local heating. Here, we focus on intracellular streaming, which might induce organelle movement or alter gene expression, as the steady second-order rotational flow generated by an acoustic source. As a model for the viscoelastic nature of cells and their surroundings, we use Oldroyd-B fluids. Building on existing work, we calculate the streaming flows inside and outside of a sphere sonicated with a plane wave. The streaming is treated as a second-order perturbation expansion of the Navier-Stokes equations, which is solved separately for both media and combined using suitable boundary conditions. Our work shows under which conditions intracellular streaming can be induced in biological cells.

15 min. break

Invited Talk DY 50.4 Thu 11:30 BAR/0106

Recent theoretical progress on sound-propelled microsystems — •Raphael Wittkowski — Department of Physics, RWTH Aachen University, 52074 Aachen, Germany — DWI – Leibniz Institute for Interactive Materials, 52074 Aachen, Germany

The research area of sound-propelled microsystems is growing fast and has a great potential for various future applications in engineering, medicine, and other fields. The progress in this area is accelerated by theoretical methods, as analytical modeling and computer simulations can provide new insights that cannot be obtained by experiments.

In this talk, I will address the theoretical investigation of sound-propelled microsystems and present examples from the recent research progress in this area. The talk will cover different types of sound-propelled microsystems including microrobots, micromachines, artificial muscles, and soft robots.

Funded by the Deutsche Forschungsgemeinschaft (DFG) – 535275785.

DY 50.5 Thu 12:00 BAR/0106

Rarefaction wave amplification from non-resonant deforming bubbles — Yuzhe Fan, Saber Izak Ghasemian, and •Claus-Dieter Ohl — Otto-von-Guericke University, Magdeburg, Germany

Gas bubbles in liquids or soft matter exposed to acoustic waves behave as oscillators, with maximum response at their resonance frequency. When driven below resonance at sufficient pressure amplitudes, bubbles can collapse with strong energy focusing and even emit light; when driven near resonance, surface instabilities and fast jet flow develop during oscillation. Like other oscillators, bubbles cease to respond when driven far above resonance. Although their oscillations are minimal, bubbles in this regime act as pressure-release interfaces, can reflect high peak pressure shock into rarefaction wave, and may therefore seed cavitation when interacting with high-power therapeutic ultrasound. Yet, here we show that even diagnostic ultrasound with peak positive pressures as low as ∼10 MPa can nucleate cavitation in microseconds. This is caused through the non-resonant deformation of the bubble into a concave shape that refocuses scattered waves, amplifying the tension leading to microcavitation. Our findings reveal that cavitation can be triggered by high-frequency positive pressure over a much wider amplitude range than previously recognized, offering a new perspective for current safety guidelines for ultrasound bioeffects and applications in medical ultrasound.

DY 50.6 Thu 12:15 BAR/0106

Optimizing acoustically propelled microrobots using genetic algorithms — •Lennart Gevers[1,2,3] and Raphael Wittkowski[1,2,3] — [1]Department of Physics, RWTH Aachen University, Aachen, Germany — [2]DWI – Leibniz Institute for Interactive Materials, Aachen, Germany — [3]Institute of Theoretical Physics, Center for Soft Nanoscience, University of Münster, Münster, Germany

The promising potential applications of acoustically propelled microparticles demand methods to create particle designs that allow for targeted autonomous motion. Current methods remain largely based on experiments due to the intricate nature of the underlying dynamics. Large-scale computational studies, specifically when combined with optimization algorithms, are impeded by the cost of traditional acoustofluidic simulations.

In this talk, we present the implementation of an analytical framework describing non-Brownian motion of colloidal molecules driven by acoustic streaming. The analytical framework is combined with vectorized, GPU-accelerated, and distributed computation. This enables fast, large-scale simulations, where 10^5 trajectories over 10 s real time can be simulated on a normal personal computer within one minute. Coupling this approach with genetic algorithms reveals particle geometries, control parameters, and underlying principles for acoustically propelled particles that exhibit controllable and stable behavior over long times.

Funded by the Deutsche Forschungsgemeinschaft (DFG) – 535275785.

DY 50.7 Thu 12:30 BAR/0106

Equations of motion for arbitrarily shaped acoustically propelled rigid microparticles — •Justus Schnermann[1,2,3] and Raphael Wittkowski[1,2,3] — [1]Department of Physics, RWTH Aachen University, Aachen, Germany — [2]DWI – Leibniz Institute for Interactive Materials, Aachen, Germany — [3]Institute of Theoretical Physics, Center for Soft Nanoscience, University of Münster, Münster, Germany

Much experimental research concerns the acoustic propulsion of microparticles, but theoretically, only axisymmetric particles with a stable orientation have been studied thus far. In this talk, we present an analytical derivation of the ordinary differential equation of motion for an arbitrarily shaped acoustically propelled rigid microparticle. This equation governs the time evolution of the orientation and position of the particle. Its parameters depend only on the particle's leading-order oscillation velocity field. Based on this equation, we classify qualitatively the possible long-term trajectories of arbitrary particles in unidirectional ultrasound.

Funded by the Deutsche Forschungsgemeinschaft (DFG) – 535275785.

DY 51: Networks: From Topology to Dynamics – Part III (joint session DY/SOE)

Time: Thursday 11:15–12:45 Location: ZEU/0118

DY 51.1 Thu 11:15 ZEU/0118

Remote Tipping in Networks — •Philip Marszal[1], Malte Schröder[1], and Marc Timme[1,2] — [1]Chair of Network Dynamics, Center for Advancing Electronics Dresden (cfaed) and Institute of Theoretical Physics, TUD Dresden University of Technology, 01062 Dresden, Germany — [2]Lakeside Labs, Lakeside B04b , 9020 Klagenfurt, Austria

Tipping of a single unit in a complex networked system can trigger large-scale cascades that shift the system's macroscopic state. Typically, such cascades propagate diffusively, with each tipping event destabilizing adjacent units.

Here we report a novel form of tipping cascade in systems of coupled bistable oscillators, that results in the tipping of non-adjacent nodes. One node can trigger transitions in distant nodes while intermediate neighbors remain unaffected. Which nodes tip and which ones remain unaffected depends intricately on the local oscillator dynamics and the underlying network structure. We study the transition between locally spreading and non-local cascades and characterize the conditions necessary for the emergence of non-local cascades.

DY 51.2 Thu 11:30 ZEU/0118

Ponderomotive Route to Tipping in Open Networks — Seungjae Lee[1], •Marisa Fischer[1], and Marc Timme[1,2,3] — [1]Chair for Network Dynamics, Institute of Theoretical Physics and Center for Advancing Electronics Dresden (cfaed), Technische Universität Dresden, 01062 Dresden, Germany — [2]Center Synergy of Systems, Technische Universität Dresden, 01062 Dresden, Germany — [3]Lakeside Labs, Lakeside B04b, 9020 Klagenfurt, Austria

External fluctuations impact the dynamics of complex networked systems, from cells and ecosystems to engineered infrastructures. Strong external forcing may cause tipping that compromises such systems' functionality. Here, we identify a generic ponderomotive route to tipping in open, periodically driven systems. Upon increasing the driving amplitude, the time-average of the oscillatory responses persistently shifts away from the original system's operating point – a system-level ponderomotive effect. We characterize the shift as the fixed-point solution of a slow dynamics resulting from a two-time-scale analysis. A bifurcation point of the shift defines the tipping point beyond which the system settles into another collective state, diverges gradually, or exhibits finite-time blow-up. The ponderomotive shift together with its bifurcation yields the novel type of *ponderomotive tipping*. It generically emerges across disparate systems from science and engineering and is independent of their diverse post-tipping dynamics.

DY 51.3 Thu 11:45 ZEU/0118

Linear dynamics on infinite networks — •Bernd Michael Fernengel — HIFMB, Oldenburg, Germany

Linear evolutionary equations are often used to describe the time evolution of a physical system. Their solution operator can be written in an exponential form of exp(t A), with some generator A. When the generator is a finite dimensional matrix, we can interpret its time evolution as a hopping dynamics on a finite network, where the dynamics of the network can be transferred to the dynamics of the solution operator.

In order to study special types of solution operators for non-interacting systems of countable dimensions, we construct countable, infinitely large networks using the iterated Cartesian product of finite graphs, where the dynamics is known. We discuss the possibilities to infer properties like the time evolution and the stationary solution of the infinite network from finite approximations via the thermodynamic limit. This is closely related to the question, under which conditions it is possible to approximate a countable, infinite system by finite subsystems.

DY 51.4 Thu 12:00 ZEU/0118

Localizing sparse perturbation sources in driven nonlinear networks — •Julian Luca Fleck, Jose Casadiego, and Marc Timme — Chair of Network Dynamics, Center for Advancing Electronics Dresden (cfaed) and Institute of Theoretical Physics, TUD Dresden University of Technology, 01062 Dresden, Germany

Network dynamical systems under the influence of external perturbations abound in nature and engineered systems, ranging from neural circuits to electrical power grids. The external driving can drastically change the system's operating mode and be fatal for system stability. Localizing sources of perturbations in a network is crucial to mitigate systems failure. We present a linear response approach to infer the location from a multivariate time series of a recorded subset of nodes. We employ a compressed-sensing algorithm to locate one or multiple perturbation sources utilizing the sparsity of such locations. The approach additionally yields the time series of the unmeasured nodes and the external driving. We test for random linear systems, and illustrate the applicability to electrical power grids.

DY 51.5 Thu 12:15 ZEU/0118

Elucidating structure-function relationships in physical networks via ensnarlment — •Yu Tian[1,2,3,4], Chinmayi Subramanya[1,3,4], and Carl Modes[1,3,4] — [1]Center for Systems Biology Dresden, Dresden, Germany — [2]Max Planck Institute for the Physics of Complex Systems — [3]Max Planck Institute of Molecular Cell Biology and Genetics — [4]Dresden University of Technology, Dresden, Germany

Understanding physical networks – whose structure is constrained by

the physical properties of their nodes and links – is a growing interdisciplinary challenge, especially in biological systems. Physical constraints such as volume exclusion and non-crossing conditions, along with biological functionality, can drive these networks into non-optimal spatial configurations. One prominent feature is that cycles may go through each other's interior space, which may not be unraveled without removing edges, leading to an ensnarled state. Characterizing the ensnarlment in the space, and its interplay with the functional behaviours of the network, is essential for revealing structure-function relationships in such systems. In this work, we introduce a graph-theoretic framework based on the linking operator, obtained by the Gauss linking integral applied to the cycles in the network. This approach enables a multiscale analysis of entanglement, spanning local, intermediate, and global structures. Our goal is to reveal how topological complexity shapes, and is shaped by, biological functions, providing new insights into the organizational principles of physical and biological networks.

DY 51.6 Thu 12:30 ZEU/0118

Transient stability properties for transitions between stationary power flows — •Leo Heidweiler[1,2] and Frank Hellmann[2] — [1]TU Dresden — [2]Potsdam Institute for Climate Impact Research

The increasing incorporation of renewable energy sources into electrical power grids fundamentally changes their dynamical behaviour and introduces new challenges for system stability. While network expansion and operation are traditionally based on stationary power flow analysis, dynamical effects following line faults, such as loss of synchronization of a single generator or whole part of the network, may occur even when a stable post-fault power flow exists and operational constraints are fulfilled. Direct assessment of transient stability, however, requires time-resolved simulations that are computationally expensive and unsuitable for large-scale planning and real-time applications. This motivates the question of whether transient stability properties can be inferred from static characteristics of the network, such as power flow solutions and topology.

In this work, we develop stability indicators for the IEEE39 Bus power system and investigate their predictability using PowerDynamics.jl, a Julia Library for numerical Power Grid simulations. In particular, we make use of the complex oscillator formulation of Power Systems and machine learning. This helps us assess whether stability margins can be predicted from stationary quantities alone or whether intrinsically dynamical information is indispensable. If so, we can deduce what minimal dynamical information is sufficient for reliable prediction.

DY 52: Statistical Physics of Biological Systems III (joint session BP/DY)

Time: Thursday 15:00–18:15 Location: BAR/SCHÖ

DY 52.1 Thu 15:00 BAR/SCHÖ

Efficiency of Droplet Formation and Dissolution by Chemical Reactions — •Gerrit Wellecke[1,2], Riccardo Rossetto[1,2], Jan Kirschbaum[1], and David Zwicker[1] — [1]Theory of Biological Fluids, 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 are vital for intracellular organization, and cells often control the formation and dissolution of these droplets through chemical reactions. To understand how cells can influence droplets in space and time, we consider a ternary system that exhibits a bistability between homogeneous and phase-separated states. We use a thermodynamically consistent approach to describe the diffusive and reactive dynamics, which allows us to quantify the energy dissipation and entropy production during transitions between these states. We find that reaction-controlled droplet formation and dissolution in the bistable regime are fundamentally different processes. While droplet formation is generally aided by relaxation to equilibrium, we find that a droplet's size determines whether it is best dissolved internally or externally. Further, our model identifies plausible mechanisms by which cells may regulate their intracellular droplets, providing insights that could guide the development of synthetic soft matter systems with tunable droplet behaviour.

DY 52.2 Thu 15:15 BAR/SCHÖ

Size control and fluctuations of chemically active droplets — •Guido Kusters and David Zwicker — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Biological cells use liquid-liquid phase separation to dynamically compartmentalize their environment for various applications, many of which require size control. This process is challenging because (i) large droplets tend to grow at the expense of smaller ones, and (ii) thermal fluctuations can disturb droplets since cells are typically small and soft. Chemical reactions can, in principle, control droplet sizes, but there are no clear guidelines on how to robustly achieve size control. To provide guidelines, we consider a binary fluid model driven out of equilibrium by chemical reactions. We reveal two different classes of size-controlled droplets, depending on the ratio of droplet radius to the reaction-diffusion length. Moreover, we determine parameter regimes in which droplets become small. To study fluctuations in this case, we use fluctuation-dissipation arguments to predict the size fluctuations of size-controlled droplets, consistent with our numerical simulations. Taken together, our theory allows us to predict the chemical reactions necessary for maintaining small droplets, e.g., in biological cells or synthetic applications.

DY 52.3 Thu 15:30 BAR/SCHÖ

Anomalous diffusion and directed coalescence of condensates out of equilibrium — •Andriy Goychuk — Helmholtz Centre for Infection Research, Braunschweig, Germany — Lower Saxony Center for Artificial Intelligence and Causal Methods in Medicine, Hannover, Germany

Phase separation is ubiquitous in engineered and in biological systems. For example, biomolecular condensates contribute to the organization of the cytoplasm and nucleoplasm in cells. Here, I will first extend our understanding of textbook phase separation models by showing how condensates consisting of nonpolar molecules can effectively polarize and undergo coarsening by directed coalescence when subjected to a global drift, for example due to electrostatic potential gradients, chemical concentration gradients, or gravitation. Next, to better model the intracellular solution, I will incorporate viscoelastic stress propagation and nonequilibrium fluctuations. In this context, the Brownian motion of condensates has been barely explored despite being a cornerstone of statistical and colloidal Physics. If the active stresses, for example generated by molecular motors, have a different correlation time than the viscoelastic relaxation time of the solution, then the fluctuation-dissipation theorem is broken and the mixture is driven out of equilibrium. In this case, the size-dependence of the center-of-mass diffusion coefficient of the condensates can be either suppressed or enhanced, and the droplet can show superdiffusive motion. Together, these findings improve our understanding of the dynamics of domains in viscoelastic media and conserved order parameters in general.

DY 52.4 Thu 15:45 BAR/SCHÖ

A Minimal Theoretical Framework Linking Translation Activity to Stress-Induced Condensates — •Pascal S. Rogalla[1], Alessandro Barducci[1], and Luca Ciandrini[1,2] — [1]Centre de Biologie Structurale, Université de Montpellier, CNRS, INSERM, Montpellier, France. — [2]Institut Universitaire de France

The formation of intracellular membraneless organelles, such as stress-granule-like condensates formed via liquid-liquid phase separation (LLPS), is a common response to cellular stress. RNA, including mRNA, promotes the assembly of many of these condensates, while the resulting aggregation of mRNAs reduces their availability for translation and thereby modulates ribosome loading. This establishes a feedback loop between condensate formation and translational activity. Here we develop a minimal physical model that makes this coupling explicit by combining Flory-Huggins theory for LLPS with the Totally Asymmetric Simple Exclusion Process (TASEP) for ribosomal traffic on mRNAs. This hybrid framework provides a proof-of-principle description of how LLPS and translation dynamically influence one another. Our analysis reveals that the phase behaviour of both subsystems becomes mutually dependent: a low-occupancy ribosomal phase promotes mRNA aggregation, whereas a high-occupancy phase sup-

presses condensate formation. These results suggest that cells may regulate condensate formation through translation modulation and, conversely, that LLPS can reshape the translatome. This provides a first proof-of-principle framework for quantifying stress-induced reorganisation of the translational landscape.

DY 52.5 Thu 16:00 BAR/SCHÖ

Optimal sensing through phase separation — •Henry Alston[1], Mason Rouches[2], Arvind Murugan[2], Aleksandra Walczak[1], and Thierry Mora[1] — [1]Laboratoire de Physique, Ecole Normale Superieure — [2]The James Franck Institute & Department of Physics, The University of Chicago

Cells are constantly tasked with making accurate measurements of their surroundings. A paradigmatic example is the sensing of signalling molecule concentrations: the work of Berg and Purcell derived limits for the precision and speed of this sensing through ligand-receptor binding. However, recent experimental work has identified the formation of condensates (liquid droplets coexisting with the cell cytoplasm through phase separation) as a potential mechanism for selectively initiating downstream processes by effectively amplifying small concentration differences between competing signalling molecules. Using a minimal model for droplet nucleation and growth in a fluid mixture, we observe that phase separation can distinguish concentration differences of 1% in minutes, a significant improvement upon well-established pathways for precise concentration sensing.

DY 52.6 Thu 16:15 BAR/SCHÖ

Thermodynamics of DNA sequence recognition by a transcription factor — •Jonas Neipel[1,2,3], Anne Schwager[1], Yahor Savich[1,2,3], Douglas Diehl[1], Anthony A. Hyman[1], Frank Jülicher[2,3], and Stephan W. Grill[1,3] — [1]Max Planck Institute for Molecular Cell Biology and Genetics, Dresden Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden Germany — [3]Center for Systems Biology Dresden, Dresden, Germany

Transcription factors (TFs) are proteins that regulate the transcription of genes by binding to specific genomic positions defined by the DNA sequence. The sequence of preference of a TF is typically characterized by a single sequence motif that maximizes binding affinity. However, eukaryotic TFs bind to a spectrum of low affinity binding sites that vastly outnumber canonical motif sequences in the genome. Here, we develop an Ising model of DNA sequence recognition that yields quantitative prediction of TF binding energies across sequence space for the human TF KLF-4. The model is parametrized by in vitro experiments, where we quantify relative binding energies for various sequences in a competitive assay using fluorescence anisotropy. Strikingly, we find that the thus fully parametrized thermodynamic model quantitatively predicts KLF-4 occupancy across the human genome. Finally, we discuss how this genomic energy landscape guides the formation of TF condensates.

15 min. break

DY 52.7 Thu 16:45 BAR/SCHÖ

Kinetic inference of entropy production — •Ivan Di Trelizzi — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Nonequilibrium steady states, from planetary dynamics to biological processes, constantly dissipate energy to their environment, producing entropy at a constant rate. Quantifying this dissipation is key to understanding how far systems operate from equilibrium but remains experimentally challenging. I will present a new approach to infer entropy production directly from trajectory data, using measurable kinetic quantities known as traffic and inflow rate, without requiring knowledge of microscopic forces or fluxes. The method remains effective even under partial observation, providing a practical framework to quantify nonequilibrium behaviour in complex physical and biological systems.

DY 52.8 Thu 17:00 BAR/SCHÖ

Frequency-space trajectory Fisher Information to quantify sensitivity in complex living systems — •Zhiheng Wu[1] and Isabella Graf[1,2] — [1]European Molecular Biology Laboratory, Heidelberg, Germany — [2]Department of Physics and Astronomy, Heidelberg University, Heidelberg, Germany

Living systems sense their environment by stochastically mapping external signals onto internal states. For example, several animals including fruit flies and pit vipers encode small changes in the ambient temperature in terms of changes in the interspike time of neurons. The sensitivity of these measurements can be evaluated by the so-called Fisher information (rate). While living systems constantly adapt to changing environments, calculations of Fisher information have so far mostly focused on static signals and internal states. To evaluate measurement sensitivity in the non-static case, we evaluate the trajectory Fisher information and show that, under common assumptions, it can be expressed as an integral over frequency space involving the power spectral density. This expression provides a tractable way to quantify information in adaptive and complex biological systems and we discuss some interesting applications.

DY 52.9 Thu 17:15 BAR/SCHÖ

Ergodicity shapes inference in biological reactions driven by a latent trajectory — •Ricardo Martinez-Garcia[1], Benjamin Garcia de Figueiredo[2], Justin Calabrese[1], and William Fagan[3] — [1]CASUS-HZDR, Görlitz, Germany. — [2]Princeton University, Princeton NJ, USA. — [3]University of Maryland, College Park MD, USA.

Many natural phenomena, from intracellular reactions to predator-prey encounters, can be described as counts of events triggered at random intervals when an underlying dynamical system enters reactive regions of its phase space. These reactions control biological functions across scales, from cellular processes to ecosystem services and stability. We compute the exact distribution of inter-count times under the only assumption that the latent dynamical system is Markovian and ergodic, recovering widely used Poisson statistics as a limiting case. These results limit what information about the latent process can be inferred from a local detector, which we explore in two biophysical scenarios. First, in estimating an animal's activity from detector crossings, we show that mean counts may fail to capture movement parameters, encoded in higher-order moments. Second, we show that the variance of inter-reaction times imposes a fundamental limit on how precisely detector measurements can infer the size of an ensemble of trajectories, generalizing the Berg-Purcell limit for chemosensation. Overall, we develop a flexible framework for quantifying inter-event time distributions in reaction-diffusion systems that shows which properties of latent processes are inferable from observed reactions.

DY 52.10 Thu 17:30 BAR/SCHÖ

Information Bottleneck in Gene Regulation — •Marianne Bauer — TU Delft

Biological systems need to process information in order to perform specific functions. In the context of gene regulation, regulatory regions process transcription factor signals in order for cells to differentiate towards correct fates. Previously, we have shown that the information bottleneck (IB) framework provides a useful framework for understanding regulatory binding site regions. Here, I will discuss two recent collaborative advances to provide an improved biological understanding from IB based predictions. First, using two complementary models for clustering transcription factors at binding site sensors, we can study information transfer during early fly embryo development with local transcription factor clustering. We find that weak cooperativity or clustering can allow for maximal information transfer, especially about the relevant variable, and that weak clustering also allows the binding site sensors to achieve optimality consistent with the IB bound. Second, we investigate how optimal activation changes when multiple binding site elements can process information, and find that activation profiles consistent with IB optimality resemble gene expression profiles in the early fly embryo.

DY 52.11 Thu 17:45 BAR/SCHÖ

Binary karyotypes are universally selected for across cancers — •Lucija Tomašić[1], Shane A. Fiorenza[1], Hajime Okada[2], Thomas W. van Ravesteyn[3], Uri Ben-David[2], Geert J.P.L. Kops[3], and Nenad Pavin[1] — [1]Univ. of Zagreb, Zagreb, Croatia — [2]Tel Aviv University, Tel Aviv, Israel — [3]Hubrecht Institute, Utrecht, the Netherlands

Aneuploidy, an abnormal chromosome number, is a defining feature of most cancers, yet its vast diversity has made it difficult to identify universal evolutionary rules. By analyzing over 90,000 patient-derived cancer karyotypes using a new visualization approach and mathematical modeling, we uncover a simple organizing principle. Across cancer types, and even in yeast, aneuploid genomes overwhelmingly assemble into "binary karyotypes" composed of only two chromosome copy numbers. Despite the enormous space of theoretically possible chro-

mosome configurations, these states dominate patient data, comprising more than three-quarters of observed karyotypes. Our model shows that this pattern arises from a modest but consistent fitness advantage of binary karyotypes over more complex configurations. This principle also provides insight into how aneuploid cells withstand stress responses, as binary karyotypes exhibit lower rates of tumor suppressor gene inactivation. Together, our results identify binary karyotypes as a conserved evolutionary class of aneuploidy, governed by global organizational rules that may reveal shared vulnerabilities across cancers.

DY 52.12 Thu 18:00 BAR/SCHÖ

Inertial instability of blood in cross microchannels — •Joséphine Van Hulle and Christian Wagner — Experimental Physics, Saarland University, Germany

A localized reduction of vessel diameter (stenosis) increases the local blood flow speed and can trigger downstream recirculation which promotes conditions for the vessel blockage (thrombosis). The role of fluid elasticity in these flows remains underexplored. We isolate the extensional effects using cross-slot microfluidics, which creates an elongation plane with a well-defined inertial instability. By varying the hematocrit and plasma composition, we show that red blood cell deformability and plasma viscoelasticity lower the critical Reynolds number for the onset of vortex formation. These results highlight that even weak elastic stresses of blood can favor recirculation, a characteristic rarely modeled but necessary for physiologically realistic arterial simulations.

DY 53: Many-body Quantum Dynamics II (joint session DY/TT)

Time: Thursday 15:00–16:30 Location: HÜL/S186

DY 53.1 Thu 15:00 HÜL/S186

general framework for understanding and modeling irreversibility: relaxator Liouville dynamics — •Martin Janssen and Janos Hajdu — Institut für Theoretische Physik, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany

Irreversibility is explained as an emergent phenomenon brought about by a separation between two characteristic time scales: the time t_s up to which relevant degrees of freedom of a system are tracked is extremely much shorter than the spectral resolution time t_e necessary to resolve the spectrum of all degrees of freedom involved. A relaxator that breaks reversibility condenses in the Liouville operator of the relevant degrees of freedom. The irrelevant degrees of freedom act as an environment. The relaxator Liouville equation is a most general equation of motion in a many body quantum system and contains memory effects and initial correlations of all degrees of freedom, generalizing the well known semi-group dynamics. Stationary states turn out to be generically unique and independent of the initial conditions and exceptions are due to degeneracies. Equilibrium states lie in the relaxator's kernel yielding a stationary Pauli master equation and a non negative entropy production rate is identified. Kinetic equations for one-particle densities are constructed as special cases and Kubo's linear response theory is generalized to relaxator Liouville dynamics. In weak coupling between system and environment the relaxator can be factorized in environmental correlations and bilinear system operators.

DY 53.2 Thu 15:15 HÜL/S186

Ground-State Exploration Driven by Thermal and Quantum Fluctuations — •Yoshiaki Horiike[1] and Yuki Kawaguchi[1,2] — [1]Department of Applied Physics, Nagoya University, Nagoya, Japan — [2]Research Center for Crystalline Materials Engineering, Nagoya University, Nagoya, Japan

Simulated annealing provides a heuristic solution to combinatorial optimization problems. The cost function of a problem is mapped onto the energy function of a physical many-body system, and, by using thermal or quantum fluctuations, the system explores the state space to find the ground state, which may correspond to the optimal solution of the problem. Studies have highlighted both the similarities and differences between thermal and quantum fluctuations. Nevertheless, fundamental understanding of thermal and quantum annealing remains incomplete, making it unclear how quantum annealing outperforms thermal annealing. Here, we investigate the many-body dynamics of thermal and quantum annealing by examining all possible interaction networks of $\pm J$ Ising spin systems up to seven spins. Our comprehensive investigation reveals that differences between thermal and quantum annealing become prominent for particular interaction networks, indicating that the structure of the energy landscape distinguishes the two dynamics. We identify the microscopic origin of these differences through probability fluxes in state space, finding that the two dynamics are broadly similar but that quantum tunnelling produces qualitative differences. (arXiv:2511.16457)

DY 53.3 Thu 15:30 HÜL/S186

Symmetry re-breaking in an effective theory of quantum coarsening — •Federico Balducci[1], Anushya Chandran[2], and Roderich Moessner[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden — [2]Boston University, Boston, MA

We present a simple theory accounting for two central observations in a recent experiment on quantum coarsening and collective dynamics on a programmable quantum simulator [T. Manovitz et al., Nature 638, 86 (2025)]: an apparent speeding up of the coarsening process as the phase transition is approached; and persistent oscillations of the order parameter after quenches within the ordered phase. Our theory, based on the Hamiltonian structure of the equations of motion in the classical limit of the quantum model, finds a speeding up already deep within the ordered phase, with subsequent slowing down as the domain wall tension vanishes upon approaching the critical line. Further, the oscillations are captured within a mean-field treatment of the order parameter field. For quenches within the ordered phase, small spatially-varying fluctuations in the initial mean-field lead to a remarkable long-time effect, wherein the system dynamically destroys its long-range order and has to coarsen to re-establish it. We term this phenomenon symmetry re-breaking, as the resulting late-time magnetization can have a sign opposite to the initial magnetization.

DY 53.4 Thu 15:45 HÜL/S186

Pairing-induced phase transition in the non-reciprocal Kitaev chain — •Pietro Brighi and Andreas Nunnenkamp — Faculty of physics, University of Vienna, Boltzmanngasse 5, 1090, Vienna, Austria

Investigating the robustness of non-reciprocity in the presence of competing interactions is central to understanding non-reciprocal quantum matter. In this work, we use reservoir engineering to induce non-reciprocal hopping and pairing in the fermionic Kitaev chain, and reveal the emergence of a pairing-induced phase transition. The two phases appear in the spectrum of the non-Hermitian Kitaev Hamiltonian describing the dynamics of correlations, separated by an exceptional point. In the non-reciprocal phase, dynamics are characterized by directionality and slow relaxation, and the steady state supports non-reciprocal density and spatial correlations. At strong pairing, we uncover an unexpected density wave phase, featuring short relaxation times, a modulation in particle occupation and strikingly different correlation spreading depending on pairing non-reciprocity. Our work highlights the non-trivial breakdown of non-reciprocity due to superconducting pairing and invites experimental investigation of non-reciprocal fermionic systems.

DY 53.5 Thu 16:00 HÜL/S186

Harnessing spin qubit decoherence to probe strongly interacting quantum systems — Marcin Płodzień[1], •Sambunath Das[2], Maciej Lewenstein[1,3], Christina Psaroudaki[4], and Katarzyna Roszak[2] — [1]Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]Institute of Physics of the Czech Academy of Sciences, Na Slovance 1999/2, 182 00 Prague, Czech Republic — [3]Passeig Lluis Companys 23, 08010 Barcelona, Spain — [4]Laboratoire de Physique de l' École Normale Supérieure, Université PSL, CNRS, Sorbonne Université, Université de Paris, 75005 Paris, France

Using a mobile qubit as a probe to study the properties of a larger quantum system is a novel technique that leverages the quantum nature of the probe, the system under study, and the interaction between them [1-3]. By analyzing qubit decoherence, one accesses to properties that are difficult to measure classically. We apply this method to the

anisotropic Heisenberg XXZ spin-1/2 chain, an archetypal example of strongly correlated system, and show that qubit dynamics encode key system parameters, including quantum phase transitions and perturbation propagation velocity [4]. This demonstrates the effectiveness of small quantum probes for exploring large quantum systems.

References: 1. F. Casola, T. van der Sar et al, Nat. Rev. Mat. 3, 17088 (2018). 2. J. F. Rodriguez-Nieva, K. Agarwal et al. Phys. Rev. B 98, 195433 (2018). 3. S. Chatterjee, J. F. Rodriguez-Nieva et al, Phy. Rev. B 99, 104425 (2019). 4. M Płodzień, S. Das et al, Phy. Rev. B 111, L161115 (2025).

DY 53.6 Thu 16:15 HÜL/S186

Enhancing efficiency of local-information time evolution — •Moksh Bhateja[1], Jonas Rigo[2], and Markus Schmitt[2,3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Universität Regensburg, Regensburg, Germany — [3]PGI-8: Forschungszentrum Jülich, Jülich, Germany

The time evolution of an initially unentangled system under the von Neumann equation generally leads to rapid entanglement growth. This poses challenges for numerical tractability. The Information Lattice framework addresses this by systematically discarding accumulated non-local information (i.e., entanglement) to maintain computational feasibility. Within the local-information time evolution (LITE) approach, we propose Rényi-2 entropy as a measure of information, eliminating the need for matrix decomposition. When combined with additional approximations, this approach significantly enhances the efficiency and scalability of simulations in terms of both system size and duration of time evolution. We demonstrate the accuracy of this method by computing high-quality diffusion coefficients and local observables for a large non-integrable system.

DY 54: Statistical Physics: General II

Time: Thursday 15:00–17:45 Location: ZEU/0114

DY 54.1 Thu 15:00 ZEU/0114

Fluctuating hydrodynamics of non-equilibrium interacting many-body systems — •Felipe Pereira-Alves and Aljaž Godec — Mathematical Physics and Stochastic Dynamics, Institute of Physics, University of Freiburg (GER)

Extending fluctuating hydrodynamics to non-equilibrium systems remains a significant theoretical challenge. In this work we investigate, on the level of distribution-valued fluctuating hydrodynamics, general short-range interacting systems as well as the long-range interacting Dyson process evolving from deterministic non-equilibrium initial conditions. We characterize the probability measure of the distribution-valued fluctuation field during the relaxation to equilibrium and illustrate the results on the example of discretely (in space) observed fluctuation field and compare the results to particle-resolved simulations.

DY 54.2 Thu 15:15 ZEU/0114

Non-ergodicity and breakdown of hydrodynamics in a one-dimensional cold gas — Taras Holovatch[1,2], Yuri Kozitsky[3], Krzysztof Pilorz[3], and •Yurij Holovatch[1,2,4,5] — [1]Yukhnovskii Institute for Condensed Matter Physics of the NAS of Ukraine, Lviv, Ukraine — [2]L4 Collaboration and Doctoral College for the Statistical Physics of Complex Systems, Lviv-Leipzig-Lorraine-Coventry, Europe — [3]Institute of Informatics and Mathematics, Maria Curie-Skłodowska University, Lublin, Poland — [4]Centre for Fluid and Complex Systems, Coventry University, Coventry, UK — [5]Complexity Science Hub, Vienna, Austria

We study dynamics of a 1D chain of elastically interacting particles with masses alternating between two different values, M,m,M,m,.. . Its dynamics is initiated by giving unit velocity in the positive direction to the particle located at the origin. For random particle positions, the resulting long-time behavior was found (S. Chakraborti et al., SciPost Phys. 2022, 13, 074) to posses rather remarkable features: (i) a shock front develops in the bulk of the gas and is governed by Euler hydrodynamics, (ii) the recoiled particles in the splatter move ballistically. In our study we have found (T. Holovatch et al., Phys. Rev. E 2025, 112, L052101) that for equidistant particle positions there exist mass ratios M/m for which (i) the splatter is absent; (ii) the number of simultaneously moving particles is at most three; (iii) the blast front moves in the ballistic way. We support our explicit calculations by MD simulations.

DY 54.3 Thu 15:30 ZEU/0114

Geometry-induced timescales in viscoelastic fluids — •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 provide a powerful window into the non-Markovian properties of complex fluids, revealing memory effects that are usually obscured in conventional rheological measurements. While translational recoil of colloidal probes in viscoelastic media has been successfully modelled with **few distinct timescales**, orientational recoil exhibits an **unbounded** relaxation spectrum, manifested in the divergence of the recoil amplitude with increasing shear-time (t_{sh}) or system size (L). To resolve its physical origin, we design a **first-principles theoretical framework** rooted in the *geometric constraints of torsional flow*. Our model, based on concentric spherical shells, demonstrates that the orthogonality between angular momentum propagation and torsional stress storage generates **a radial scaling law for relaxation modes**. The theory thus establishes **geometry**—not material-complexity—as the primary candidate for engineering complex memory in soft matter. We finally elucidate why such *long relaxation times* have not been previously discovered through conventional rheology.

DY 54.4 Thu 15:45 ZEU/0114

Ion and Water Density Profiles in Nano-Confinement — •Haoyuan Quan, Maximilian Becker, Hanne Antila, and Roland Netz — Freie Universität Berlin, Berlin, Germany

Confined salt solutions are important in biology and in technical applications, such as environmentally friendly energy conversion, yet even basic trends of how ion and water densities change in confinement remain unclear. Using molecular dynamics simulations of graphene slits in equilibrium with bulk aqueous salt solutions, we determine concentration profiles of a variety of alkali-halide ion pairs as a function of slit width and bulk concentration. Using ion and water depletion lengths, which clearly reflect ion-specific effects, we construct a robust and thermodynamically consistent theory to describe water and ion concentrations in confined systems for varying slit widths and bulk salt concentrations.

DY 54.5 Thu 16:00 ZEU/0114

The electron transfer process at the electrode/electrolyte solution interface: A stochastic model and its Monte Carlo implementation — •Diego Veloza-Diaz[1], Friederike Schmid[1], Robinson Cortes-Huerto[2], Pietro Ballone[2], and Nancy C. Forero-Martinez[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany — [2]Max Planck Institute for Polymer Research, Germany

A kinetic model of the electron transfer at the electrode/electrolyte interface is developed, implemented in a Monte Carlo framework, and applied to simulate this process in idealised systems consisting of the primitive model of electrolyte limited by an impenetrable conducting surface. A charged, spherical interface surrounding an equally spherical sample of electrolyte is introduced to model a single-electrode system, providing a computational analogue to the conceptual half-cell picture widely used in electrochemistry. The electron transfer itself is described as a simple surface-hopping process underlying a first-order reaction corresponding to one of the coupled M/M+ and X*/X half-reactions. Then, electron transfer at the interface is combined with the self-diffusion of ions in the electrolyte, which supply reagents and disperse products, allowing the system to settle into a stationary non-equilibrium state. Simulations of the primitive model of an electrolyte in contact with a charged, impenetrable surface show that, after a brief transient, the system sustains a steady current through the half-cell. Since the simulated interface is very idealised, strategies to overcome the limitations of the present model are outlined and briefly discussed.

DY 54.6 Thu 16:15 ZEU/0114

Fermion as a non-local particle-hole excitation — •Girish Setlur — Department of Physics, Indian Institute of Technology Guwahati

We show that the fermion, in the context of a system that comprises many such entities, which, by virtue of the Pauli exclusion principle, possesses a Fermi surface at zero temperature, may itself be thought of as a collection of non-local particle-hole excitations across this Fermi surface. This result is purely kinematical and completely general, not restricted to any specific dimension, and is applicable to both continuum and lattice systems. There is also no implication that it is applicable only to low-energy phenomena close to the Fermi surface. We are able to derive the full single-particle dynamical Green function of this fermion at finite temperature by viewing it as a collection of these non-local particle-hole excitations. The Green function of the fermion then manifests itself as a solution to a first-order differential equation in a parameter that controls the number of particle-hole pairs across the Fermi surface, and this equation itself reveals variable coefficients that may be identified with a Bose-Einstein distribution, implying that there is a sense in which the non-local particle-hole excitations have bosonic qualities while not being exact bosons at the level of operators. We also recall the definition of the non-local particle-hole operator that may be used to diagonalize the kinetic energy of free fermions of the sort mentioned above. Number-conserving products of creation and annihilation operators of fermions are expressible as a (rather complicated) combination of these non-local particle-hole operators.

15 min. break

DY 54.7 Thu 16:45 ZEU/0114

Emergence of generic first-passage time distributions for large Markovian networks — •Julian B. Voits[1] and Ulrich S. Schwarz[1,2] — [1]Institute for Theoretical Physics, University of Heidelberg, Germany — [2]BioQuant-Center for Quantitative Biology, University of Heidelberg, Germany

In many situations of practical interest, for example for decision-making in biological systems, it is sufficient to characterize a stochastic process by the time at which a final, absorbing state is reached (first-passage time). A prominent example is kinetic proofreading, where cells achieve remarkably accurate decisions through non-equilibrium reaction cycles. Earlier work studying corresponding models observed that as the system size grows, the first-passage time distributions converged to one of two universal forms on the time scale of its mean: either quasi-deterministic (delta-like) or quasi-memoryless (exponential). Building on the graph-theoretical interpretation of first-passage processes, here we provide a unifying explanation for these universal limits based on the distribution of the eigenvalues of the generator matrix. Then, we derive general conditions under which the distribution converges to either the deterministic or exponential limit. We demonstrate the theory by applying it to a generic birth-death process and conclude by discussing illustrative cases where the simple limiting behavior does not hold, which contradicts the naive expectation that a forward bias is sufficient to lead to a deterministic outcome.

DY 54.8 Thu 17:00 ZEU/0114

Derivation of a multi-dimensional non-equilibrium generalized Langevin equation — •Benjamin Hery — Department of Physics, Freie Universität Berlin, 14195 Berlin, Germany

The Mori-Zwanzig formalism is a powerful theoretical framework for deriving generalized Langevin equations (GLEs) for observables of interest using evolution and projection operators. Using a multi-dimensional Mori projection operator, we derive a non-equilibrium Mori GLE for a multi-dimensional observable of interest $\vec{A}$ that consists in a Markovian force, a running integral over time of a non-Markovian friction force, and a orthogonal force that is often interpreted as a random force. We study the structure of the derived GLE in three limiting cases: when the components of $\vec{A}$ are uncorrelated, when the system is at equilibrium, and when both conditions happen at the same time. In particular, we highlight the presence of a contribution to the Markovian force that takes the form of an instantaneous friction force which only vanishes when the components of $\vec{A}$ are uncorrelated.

DY 54.9 Thu 17:15 ZEU/0114

Predicting Friction Modifications under Harmonic Confinement via Perturbative Mori Projections — •Felix Riesterer and Roland Netz — Department of Physics, Freie Universität Berlin, Germany

Previous studies have shown that external potentials can alter friction, yet a comprehensive theoretical explanation for this effect is still lacking. This issue is particularly relevant for enhanced sampling techniques, such as umbrella sampling, where applied biases can distort dynamical observables.

We present a theoretical framework based on perturbative projections within the Mori Generalized Langevin Equation (GLE). The approach provides an explicit first-order prediction of the friction correction due to an external potential using only unbiased simulations. Furthermore, it clarifies the conditions under which such corrections arise.

To validate the theory, we perform molecular dynamics simulations of a Lennard-Jones fluid (argon) confined in a harmonic potential of varying strength. The theoretical predictions capture the friction enhancement to first order in the potential stiffness. These results demonstrate how harmonic umbrella sampling can modify friction, highlighting the potential impact on the interpretation of dynamical quantities obtained from biased simulations.

DY 54.10 Thu 17:30 ZEU/0114

Perturbative projection of many-body systems with applications in enhanced sampling of biomolecules — •Joan Salas-Llabrés — Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany

Using a modification of the well-known Mori-Zwanzig projection operator formalism, a Generalized Langevin Equation (GLE) is derived for a general observable of interest that only depends on the phase space positions, from a many-body Hamiltonian in the presence of a constant linear external potential. In particular, the friction memory kernel is analytically computed, and via an operator perturbative expansion, it is expanded in terms of the external potential up to first order in the potential strength. We name this approach "perturbative projection", and it allows to see the effects that this bias can have on the effective dynamics of a reaction coordinate, in particular on its friction. To test the obtained analytical expression and thus compare to some order of approximation the change in friction with direct results, we choose the conformational dynamics of alanine nonapeptide in water, obtained via molecular dynamics simulations. The results show agreement over a range of bias strengths. This provides new insight into the effects of an external bias on the dynamics of a system of interest, pointing to its fundamental nature in the level of its Hamiltonian, and which in particular has important consequences for the analysis of results coming from enhanced sampling techniques.

DY 55: Focus Session: Emergent Transport in Active Systems (joint session DY/BP)

Collective motion and directed transport are hallmark phenomena of active matter, arising from the interplay of self-propulsion, interactions, and nonequilibrium fluctuations. Even in the absence of global biases, assemblies of active particles can exhibit spontaneous currents, self-organized chemotaxis, and rectified transport due to broken symmetries or nonlinear feedbacks. Directed transport often emerges in inhomogeneous environments, where variations in particle activity or interaction strength can bias motion and organization. Activity gradients represent a particularly relevant example, providing a tunable mechanism to steer collective motion and pattern formation. These processes link microscopic activity to macroscopic material behavior and transport. This focus session aims to bring together theorists and experimentalists working on the fundamental mechanisms and control of emergent transport in active systems.

Organized by Abhinav Sharma (Augsburg) and Jens-Uwe Sommer (Dresden)

Time: Thursday 15:00–18:00 Location: ZEU/0160

Invited Talk DY 55.1 Thu 15:00 ZEU/0160

Out-of-equilibrium synthetic cells: the future of active matter — •Laura Alvarez — Univ. Bordeaux, CNRS, CRPP, UMR 5031

Colloidal active swimmers are broadly used as model systems to design microswimmers, yet their rigid and solid architecture limits their adaptability and functionality. A promising alternative is using bioinspired soft compartments for the design of cell-mimetic functional architectures while avoiding the complexity of living cells.

Here, I will showcase our latest results on driving giant unilamellar vesicles (GUVs) out of equilibrium via controlled external actuation to mimic and study life-like processes. We fabricate phase-separated Janus lipid vesicles, harnessing membrane fluidity to obtain reconfigurable motion. Under external electric fields, these asymmetric compartments self-propel and display transient run-and-tumble-like dynamics arising from the coupling between mobile membrane domains and the field. By tuning lipid composition and using temperature as an external trigger, we modulate membrane fluidity and phase separation, enabling in situ control over the frequency of tumble events. Beyond motility, we exploit electric fields to induce controlled shape transformations and vesicle division events, showing that the same actuating scheme can access higher-order cell-like functions. In parallel, we use light to drive strong, localized membrane fluctuations, providing a route to study active, non-thermal shape dynamics in soft compartments. These results highlight synthetic cell membranes as versatile platforms in which different functions can be triggered using simple external fields.

DY 55.2 Thu 15:30 ZEU/0160

Biohybrid active matter: active cargo transport by motile cells — Jan Albrecht[1], Lara S. Dautzenberg[1], Manfred Opper[2], Carsten Beta[1], and •Robert Grossmann[1] — [1]University of Potsdam, Potsdam, Germany — [2]Technical University Berlin, Berlin, Germany

We describe the transport of polystyrene beads whose motion is actively driven by cells via direct mechanical contact. We will first discuss the stochastic dynamics of a single cell-cargo pair, focusing on the existence of an optimal cargo size that enhances the diffusion of the load-carrying cells, and estimate the active forces exerted by cells to move colloids. Furthermore, we present the collective transport of these micron-sized particles on a monolayer of motile cells. The colloids' mean-square displacement shows a crossover from superdiffusive to normal-diffusive dynamics. The particle displacement distribution is, however, distinctly non-Gaussian even at macroscopic timescales exceeding the measurement time. We attribute the non-Gaussian statistics to heterogeneity and non-stationarity of the dynamics, and particularly apply a likelihood-based inference framework to estimate the heterogeneity of the bead dynamics from their discretely sampled trajectories. We showcase how this approach can deal with information-scarce situations and provides natural uncertainty bounds for heterogeneity estimates. Similar transport properties are expected for many composite active matter systems. These results thus provide the basis for the future design of cellular microcarriers and for more advanced transport tasks in complex, disordered environments, e.g. tissues.

Invited Talk DY 55.3 Thu 15:45 ZEU/0160

Chemotactic like behavior in by active Brownian particles: from single particles to to polymers — •Hidde Vuijk — University of Augsburg, Universitätsstraße 1, 86159, Augsburg, Germanz

Active Brownian particles can be used as simplified models for microscopic, motile organisms. This research investigates the behavior of such self-propelled objects in spatial gradients of activity, where their self-propulsion speed varies with position. A single active particle tends to accumulate in low-activity regions. When activity is assumed to be proportional to fuel, this corresponds to antichemotactic like behavior. We demonstrate how this behavior can be reversed by structuring particles into simple complexes. For example, by connecting active particles to passive cargo or linking them into chains, we predict a crossover from accumulation in low-activity regions to accumulation in high-activity regions, that is chemotaxic like behavior. These active dimers and polymers can autonomously move up an activity gradient, accumulating where the fuel concentration is highest. This emergent gradient-sensing arises from the physical interactions, offering a novel mechanism for the design of active matter and providing insight into how primitive life forms without complex information processing might have located nutrients.

DY 55.4 Thu 16:15 ZEU/0160

Fluctuation-induced transition in transport of active colloidal cells — •Shashank Ravichandir[1,2], Jens-Uwe Sommer[1,2], and Abhinav Sharma[1,3] — [1]Leibniz Institute of Polymer Research, Dresden, Germany — [2]Technical University Dresden, Dresden, Germany — [3]University of Augsburg, Augsburg, Germany

The transport of active-passive assemblies and their self-localization behavior have been studied in some detail in recent years [1,2]. The "chemotactic" property these exhibit has been attributed to the separation of time scales, i.e between the persistence time of the active particle and the characteristic time scale associated with the interaction between the particles (ex - harmonic springs). We consider a gas of active particles enclosed in a circular vesicle and observe that the transport behavior of the vesicle depends on the density of the enclosed gas or the number of active particles. This is a new mechanism for achieving desired transport of active colloidal cells as no new timescales are introduced by changing the number of active particles. This transition in transport behavior of these vesicles seems to be driven by fluctuations. The proposed model is also experimentally reproducible, contrary to the active-passive assemblies that have been studied so far.

References: [1] H. D. Vuijk et al., Phys. Rev. Lett., 126(20), 2021. [2] P. L. Muzzeddu et al., Phys. Rev. Lett., 133(11), 2024.

15 min. break

Invited Talk DY 55.5 Thu 16:45 ZEU/0160

From non-reciprocal torques towards shape-flexible and responsive prototypic worms — •Holger Stark and Jeanine Shea — Institute of Physics and Astronomy, Theoretical Physics, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Non-reciprocal interactions as seen in active matter allow the formation of novel collective states that are only observable in the non-equilibrium. They may serve as prototypes for mimicking what is observed in the real world or for guiding robotic applications.

We start from non-reciprocal orientational interactions, where an active Brownian particle turns away from its neighbors [1]. By varying range and strength of the torque, we discover novel states such as travelling bands or dynamic flocking. Reversing the sign, makes

the orientational interaction cohesive. We combine it with aligning torques and again for varying range and torque strength observe multiple, rotary, and persistent worms as well as an aster state [2]. In particular, the persistent worm represents a prototype for a flock of active constituents, either natural or robotic, which shows a remarkable flexibility and integrity when performing shape changes. This becomes obvious when hunting a prey, which leaders inside the worm sense via some chemotactic mechanism. In contrast to the macroscopic world, here without inertia, moving on a straight line seems the best strategy to escape. We also observe that the worm stays intact, even when squeezing through a narrow, long pore.

[1] M. Knezevic, T. Welker & H. Stark, Sci. Rep. 12, 19437 (2022).
[2] Jeanine Shea & Holger Stark, EPJE 48, 22 (2025).

DY 55.6 Thu 17:15 ZEU/0160

Directed motion of active collectives in activity gradients — •Hossein Vahid[1], Jens-Uwe Sommer[1,2], and Abhinav Sharma[1,3] — [1]Leibniz-Institut für Polymerforschung Dresden, 01069 Dresden, Germany — [2]Technische Universität Dresden, 01069 Dresden, Germany — [3]Institute of Physics, University of Augsburg, Universitätsstraße 1, 86159 Augsburg, Germany

Directed motion appears across all scales of active matter, from biomolecular condensates inside cells to large assemblies of migrating filaments. By simulating active particles and polymers, we identified the mechanisms that enable activity gradients to steer these collectives and control their assembly [1,2]. In cohesive mixtures, droplets climb activity gradients, fragment when the activity becomes too intense, and reassemble in low activity regions. This creates a robust cycle of positioning without needing any biochemical feedback. Similarly, in assemblies of active polar polymers, spatial gradients in activity, combined with temporally stochastic propulsion, generate net body forces on dimers, asters, and multiarm structures. This biases their motion toward high-activity regions and stabilizes long-lived entangled clusters even at low concentrations.

[1] H. Vahid, J.-U. Sommer, A. Sharma, Self-Organization and Cyclic Positioning of Active Condensates, arXiv preprint arXiv:2510.15771 (2025). [2] H. Vahid, J.-U. Sommer, A. Sharma, Collective dynamics in active polar polymer assemblies, Phys. Rev. Res. 7, L042031 (2025).

DY 55.7 Thu 17:30 ZEU/0160

Activity hallmarks in kinetic theory: Exceptional Points, Disorder Regularization, Non-Reciprocal Orientation-Displacement Coupling — •Horst-Holger Boltz and Thomas Ihle — University Greifswald, Institute for Physics, Greifswald

The dynamics of active systems are not subject to the same constraints as that of passive classical systems. This is particularly true for self-propelled particles with alignment interactions that have orientation-displacement coupling, i.e. the alignment is dependent on the relative position of the interacting particles to each other. We present recent work within first-principle kinetic theory that highlights key hallmarks of these more generalized dynamics. In particular, we discuss the effect of a cascade of exceptional points in the relevant dynamical operators under finite noise and also how to generally include noise in collision-based kinetic theory beyond mean-field. This allows us to provide analytical insights into the numerically established scaling relations (Kürsten, 2025) underlying the critical exponents in flocking transitions. Also, we are going to explain how to derive a systematic mesoscopic description for aligning self-propelled particles with orientation-displacement coupling and will present results showing a flocking transition in a system of a single species with purely anti-aligning torques and without any forces, simplifying an earlier reported flocking by turning-away mechanism (Das et al, 2024).

References: Boltz, Ihle, in preparation; Kürsten, arXiv:2402.18711 (2025); Das et al, Phys. Rev. X 14, 031008 (2024); Boltz et al, Entropy, 26(12), 1054 (2024); Ihle et al, arXiv:2303.03357 (2023)

DY 55.8 Thu 17:45 ZEU/0160

Rouse Polymers in Time-dependent Nonequilibrium Baths — •Bhavesh Valecha[1] and Abhinav Sharma[1,2] — [1]Mathematisch-Naturwissenschaftlich-Technische Fakultät, Institut für Physik, Universität Augsbur, Augsburg, Germany — [2]Leibniz-Institut für Polymerforschung Dresden, Institut Theory der Polymere, Dresden, Germany

Directed transport is a characteristic feature of numerous biological systems in response to nutrient and chemical gradients. These signals are often time-dependent owing to the high complexity of interactions in these systems. In this study, we focus on the steady-state behavior of polymeric systems responding to such time varying signals. We model them as ideal Rouse chains submerged in a time-dependent and inhomogeneous nonequilibrium bath, which is described by a spatially and temporally varying self-propulsion wave field experienced by the monomer units. Through a coarse-graining analysis, we show that these chains display rich emergent response to the temporal stimuli as a function of their length and topology. In particular, for slow moving waves, short chains composed of up to 3 monomers drift against self-propulsion wave, whereas, longer chains drift in the direction of the wave. In contrast, for fast moving waves, all chains drift along the wave regardless of their length. Moreover, we find that the star topology displays the highest drift for both slow and fast moving waves. We confirm these analytical predictions with robust numerical simulations, showing that response of polymeric systems to temporal stimuli can be controlled by the topology or the length of the polymer.

DY 56: Members' Assembly

Time: Thursday 18:00–19:00 Location: ZEU/0160

All members of the Dynamics and Statistical Physics Division are invited to participate.

DY 57: Statistical Physics of Biological Systems IV (joint session BP/DY)

Time: Friday 9:30–12:45 Location: BAR/SCHÖ

Invited Talk DY 57.1 Fri 9:30 BAR/SCHÖ

Swimming in complex environments — •Christina Kurzthaler — Max Planck Institute for the Physics of Complex Systems

Microorganisms are omnipresent in the ocean, the human body, and our soils and therefore play an important role for various geological, biological, and medical processes. To optimize their survival and perform biological functions many microorganisms convert chemical energy into directed motion. In this talk, I will illustrate the underlying physical concepts and show concrete examples of our research, focusing on the interactions of microorganisms with their complex habitats. I will first discuss the motion of sperm in complex fluids and address their emergent dynamics in the presence of a hyperactivation agonist, modifying the sperm beating pattern. Second, I will focus on the first-passage-time statistics of active agents moving towards a target boundary. Our results highlight how swim gait impacts spreading and search efficiency in active systems with potential consequences for sperm motion in the reproductive tract and the accumulation of microbial communities.

DY 57.2 Fri 10:00 BAR/SCHÖ

Motor shot noise explains active fluctuations in a single cilium — •Maximilian Kotz[1], Veikko F. Geyer[2], and Benjamin M. Friedrich[1] — [1]Cluster of Excellence Physics of Life, TU Dresden, Dresden, Germany — [2]B CUBE, TU Dresden, Dresden, Germany

Molecular motors drive seemingly regular motion, making living matter move - yet also cause non-equilibrium fluctuations that can serve as a probe of internal motor dynamics. Here, we use motile cilia as a model system to investigate how small-number fluctuations shape collective dynamics. Motile cilia exhibit regular bending waves; this motion is driven by the self-coordinated activity of thousands of molecular motors inside the cilia's cytoskeletal core. By developing, to the best of our knowledge, the first stochastic model of cilia beating, we

show that the finite number of motors leads to active fluctuations on the mesoscale, sufficient to explain frequency jitter in beating cilia observed in experimental data. We rigorously compare observables of this model, including the quality factor of the oscillation, to experimental data in which motors have been partially extracted from cilia. This is a strong test of this stochastic model. The model also reproduces other phenomena of experimental data, like correlation lengths of intra-cilium synchronization and noise-induced phase slips. We propose that active fluctuations are important new observables, which can guide theoretical models of motor dynamics in beating cilia and other motor systems.

DY 57.3 Fri 10:15 BAR/SCHÖ

Theory of Forces Between Crosslinked Filaments — •Cedrik Barutel and Sebastian Fürthauer — Institute of Applied Physics TU Wien Austria

The cytoskeleton drives essential cellular processes like cell division and chromosome segregation. It consists of filaments that are crosslinked by proteins, many of which are molecular scale motors that consume ATP to do work. The forces that crosslinking proteins generate between cytoskeletal filaments are the key drivers of active cellular mechanics. We derive a generic theory to describe such crosslinking forces.

We construct a theory to describe and predict the forces generated collectively by crosslinking proteins between biofilaments using symmetries, conservation laws, and out-of equilibrium thermodynamic principles. Our approach identifies the full set of phenomenological coefficients governing entropic, active, and frictional crosslinking forces, which allows a quantitative comparison between the effects of different crosslinker mixtures between two filaments. We demonstrate the power and validity of this framework by quantitatively explaining a set of different experimental setups, which combine the effects of passive and active crosslinks

DY 57.4 Fri 10:30 BAR/SCHÖ

Modeling Cooperative Remodeling and Energy Landscapes in the Bacterial Flagellar Motor — •Nils-Ole Walliser — Laboratoire Charles Coulomb, University of Montpellier, Montpellier, France

Bacteria use the flagellar motor to adapt their motility to changing mechanical conditions. This rotary motor tunes its torque by recruiting and releasing torque-generating stator units. I will present statistical-physics-based models that use single-motor measurements to infer interaction potentials and energy landscapes in the bacterial flagellar motor. First, using single-motor bead assays that resolve stepwise changes in rotation speed and thus stator occupancy, we model stator recruitment as a finite-size lattice gas and infer stator-stator cooperativity from occupancy fluctuations. This reveals moderate attractive interactions and shows that the motor operates in a regime that balances responsiveness to load changes with noise in stator number. Second, I will discuss experiments where the motor load is actively perturbed, uncovering a strong asymmetry in the relaxation to the steady state when starting from higher versus lower stator occupancy. A two-state catch-bond model quantitatively explains this stoichiometry-dependent asymmetry and captures the mechanosensitive nature of stator anchoring to the cell wall. Finally, I will show how high-temporal-resolution rotation traces can be used to reconstruct, in a model-independent way, the tilted periodic energy landscape of the rotor/LP ring within a Smoluchowski framework, yielding barrier heights, torque and internal friction.

DY 57.5 Fri 10:45 BAR/SCHÖ

Anisotropic (sub)diffusion of organelles in living cells — •Aranyak Sarkar, Pooja Yadav, and Matthias Weiss — Experimental Physics I, University of Bayreuth, Universitätsstraße 30, 95447 Bayreuth

Eukaryotic cells are neatly organized into distinct, membrane-enclosed compartments ('organelles') with specific duties. A prominent example are peroxisomes, which feature vesicle-like shapes with radii $0.1-1\ \mu$m that are dispersed across the cytoplasm. Using time-lapse fluorescence microscopy, we have tracked the motion of individual peroxisomes over extended periods. Analysis of the experimental data revealed two distinct modes of motion: a prevailing (sub)diffusive motion and a quite rare super-diffusive characteristics that is associated with motor-driven transport along microtubules. Focussing on the seemingly unremarkable subset of (sub)diffusive trajectories, we have found a significant anisotropy in the motion that persisted even when microtubules were disrupted. In particular, diffusive steps along the cells' long axis were seen to be favored over steps in the perpendicular direction, indicating an anisotropic materials characteristic of the cytoplasm. Using a simple model, we were able to capture and explain the observed features of the anisotropic diffusion of organelles.

15 min. break

DY 57.6 Fri 11:15 BAR/SCHÖ

Understanding Influenza A Virus particles detaching from reconstructed cell surfaces — •Thomas Kolbe[1,2], Pierre Gaspard[1], and Bortolo Matteo Mognetti[1,2] — [1]CENOLI, Université Libre de Bruxelles (ULB) — [2]IB2 - Interuniversity Institute of Bioinformatics in Brussels

Influenza infection is a multistage process that involves the trafficking of viral particles across the cell membrane. Before endocytosis, virions target the membrane by binding hemagglutinin ligands to sialic acid residues on cell receptors. After budding, neuraminidase cleaves these residues, enabling virions to detach from the infected cell surface.

We examine detachment dynamics through simulations and theoretical analysis. We explain experimental findings showing that the time required for virions to detach can decrease as the single-trajectory average number of bonds increases - a counterintuitive result specific to neuraminidase activity. Furthermore, we demonstrate that the detachment time is not governed by a Poisson distribution but depends on multiple factors, including ligand-receptor reaction rates, virion size, and receptor diffusion constant. These results clarify how biochemical parameters regulate the residence time of virions at the cell surface.

DY 57.7 Fri 11:30 BAR/SCHÖ

Band pattern formation of erythrocytes in density gradients is due to competing aggregation and net buoyancy — •Felix Maurer[1], Camila Romero[1], Nikolas Lerch[1], Thomas John[1], Lars Kaestner[1,2], Christian Wagner[1,3], and Alexis Darras[1,4] — [1]Experimental Physics, Saarland University, Saarbruecken, Germany — [2]Department of Theoretical Medicine and Biosciences, Saarland University, Homburg, Germany — [3]Physics and Materials Science Research Unit, University of Luxembourg, Luxembourg — [4]School of Physics, University of Bristol, Bristol, United Kingdom

Centrifugation of biological matter in density gradient solutions is a standard method for separating cell types or components. It is also used to separate RBCs by age, as they lose water and become denser over their lifespan. When the density gradient is prepared with Percoll, discrete bands of RBCs are systematically observed, despite the continuous density distribution of RBCs. We developed a continuity equation incorporating cell aggregation to describe the macroscopic evolution of RBC volume fraction in a density gradient, considering a continuous RBC density distribution. Numerical solutions demonstrate that the competition between net buoyancy and aggregation is sufficient to create band patterns. Our model reproduces the temporal evolution observed in experiments, but also predicts several types of bifurcation-like behaviors for the steady-state patterns in constant gradients, depending on RBC volume fraction and aggregation energy.

DY 57.8 Fri 11:45 BAR/SCHÖ

Adaptive self-organization in excitable biological collectives — •Bianca Ariani[1,3], Yunus Sevinchan[2,3], and Pawel Romanczuk[2,3] — [1]Bernstein Center for Computational Neuroscience, Berlin — [2]Science of Intelligence, TU Berlin — [3]Institute for Theoretical Biology, HU Berlin

Biological collectives often display complex, context-dependent behavior, such as coordinated responses to predators, despite individuals following simple local rules. This class of phenomena is broadly understood as self-organization.

We examine a system showing rich spatio-temporal dynamics: Sulphur Mollies, Mexican freshwater fish whose group behavior resembles a stochastic excitable medium. To probe the mechanisms behind their collective activity, we study a bio-inspired agent-based model in which individuals estimate the shoal's mesoscale activity from the cues they perceive as they move. Each agent adjusts its sensitivity to cues through a simple homeostatic plasticity rule, allowing the group to regulate its collective state. This formulation links individual adaptation to population-level patterns.

Our results show that local adaptive regulation reproduces key qualitative features of the biological system. More generally, they illustrate how distributed plasticity mechanisms can support robust self-organization in complex biological collectives.

DY 57.9 Fri 12:00 BAR/SCHÖ

Visual-based Collective Shepherding in Swarm Robotic System — •Yating Zheng[1,2] and Pawel Romanczuk[1,2] — [1]Department of Biology, Humboldt Universität zu Berlin, Berlin, Germany — [2]Research Cluster of Excellence 'Science of Intelligence', Berlin, Germany

Collective shepherding presents a rich example of two interacting multi-agent systems coupled through non-reciprocal interactions. While most existing models assume that shepherd agents have global knowledge of the flock-an unrealistic premise for physical or biological systems-we introduce a vision-based, locally interacting model that captures the essential physics of shepherd-flock coordination. The model produces robust, self-organized behavior among shepherds without explicit communication, and we analyze how key control parameters, such as flock size and the number of shepherds, shape the resulting dynamics.

The framework also performs effectively in more challenging regimes, including the manipulation of non-cohesive agents and passive (non-self-propelled) agents, demonstrating its broad dynamical applicability. We further validate the model on a mixed-reality swarm-robotic platform, where physical robots successfully shepherd a virtual flock.

Overall, these results provide a minimal yet powerful physics-based description of multi-agent herding using only local visual information, offering insight into non-reciprocal collective behavior and enabling scalable real-world implementations in swarm robotics.

DY 57.10 Fri 12:15 BAR/SCHÖ

Polymer theory shows DNA motors extrude loops in the monomeric mode — Kirill Polovnikov[1,2] and •Dmitry Starkov[2] — [1]Institute for Physics and Astronomy, University of Potsdam, Potsdam-Golm, Germany — [2]Moscow, Russia

Cohesin-dependent loop extrusion is a key active mechanism of DNA organization, yet it remains unclear whether chromatin loops in living cells are generated primarily by individual cohesin motors or by higher-order structures. To fill this major gap, we build an analytical polymer-physics model that extracts a missing parameter - *the linear density of loops* - directly from Hi-C data. We focus on short genomic distances, where contact statistics simplify, resulting in a perturbative expression for the contact probability of a looped chain under a finite contact-detection radius. Our theory recapitulates a characteristic dip in the *logarithmic derivative* of the contact-probability that is *broadly observed in experiments*. By fitting this minimal model to a diverse range of mammalian Hi-C datasets, we infer approximately six loops per megabase. Independent imaging and mass spectrometry measurements of cohesin density are consistent with our inferred loop density, supporting the monomeric mode of DNA motors extrusion.

DY 57.11 Fri 12:30 BAR/SCHÖ

Universal loop statistics from active extrusion — •Anastasia Chervinskaya[1] and Kirill Polovnikov[1,2] — [1]Moscow, Russia — [2]Institute for Physics and Astronomy, University of Potsdam, Potsdam-Golm, Germany

Cohesin-dependent loop extrusion is a key active mechanism of genome organization, yet quantitative links between extrusion kinetics and measurable loop statistics remain incomplete. We develop an analytical model that predicts the mean loop scale, full loop-length distributions, state composition, and arm-arm correlations for one-sided versus two-sided extrusion. The theory maps the master equations onto diffusion on a state graph yielding state-resolved loop-length PDFs.

We show that one-sided extrusion yields a universal exponential loop-length distribution, whereas two-sided extrusion generates a sum of exponentials that approaches a gamma-like form at high barrier density. The model also predicts a strictly positive lower bound of 1/4 on arm-arm correlations.

Parameterized with independent measurements for HeLa G1 (cohesin residence and spacing; barrier densities and lifetimes), our model quantitatively accounts for the observed loop size. Also, it reproduces the experimentally measured distribution of CTCF-CTCF loop lengths under the assumption of two-sided extrusion, providing additional evidence that cohesin extrusion in living cells is predominantly bidirectional. Our results provide a compact route to infer biophysical parameters of active extrusion from experimental data.

DY 58: Focus Session: Physics of AI – Part II (joint session SOE/DY)

Time: Friday 9:30–12:45 Location: GÖR/0226

Invited Talk DY 58.1 Fri 9:30 GÖR/0226

What can we learn from neural quantum states? — Brandon Barton[10], Juan Carrasquilla[10], Anna Dawid[9], Antoine Georges[3,6,7,8], Megan Schuyler Moss[1,2], Alev Orfi[3,4], Christopher Roth[3], Dries Sels[3,4], Anirvan Sengupta[3,5], and •Agnes Valenti[3] — [1]Perimeter Institute for Theoretical Physics, Waterloo — [2]University of Waterloo, Waterloo — [3]Flatiron Institute, New York — [4]New York University, New York — [5]Rutgers University, New Jersey — [6]Collège de France, Paris — [7]École Polytechnique, Paris — [8]Université de Genève, Genève — [9]Universiteit Leiden, The Netherlands — [10]ETH Zürich, Switzerland

Neural quantum states (NQS) provide flexible parameterizations of quantum many-body wave-functions that serve as powerful tools for the ground-state search. At the same time, NQS offer something that standard machine-learning tasks and datasets fundamentally lack: a known underlying Hamiltonian and quantum-physics tools that allow direct examination of the encoded wavefunction. This additional structure makes NQS an interesting platform for probing the behavior of classical neural networks themselves. I will first show how pruning and scaling-law phenomena change when the learning task is the quantum wavefunction itself, and link effects depend on the underlying Hamiltonian. I will then discuss generalization and double descent through the lens of quantum observables, by analyzing how NQS fail at the interpolation threshold. Finally, I will discuss how these results relate back to practical consequences for training and architecture search in the context of the ground state search for quantum many-body systems.

DY 58.2 Fri 10:00 GÖR/0226

The NN/QFT correspondence — •Ro Jefferson — Utrecht University

Exciting progress has recently been made in the study of neural networks by applying ideas and techniques from theoretical physics. In this talk, I will discuss a precise relation between quantum field theory and deep neural networks, the NN/QFT correspondence. In particular, I will go beyond the level of analogy by explicitly constructing the QFT corresponding to a class of networks encompassing both vanilla feedforward and recurrent architectures. The resulting theory closely resembles the well-studied O(N) vector model, in which the variance of the weight initializations plays the role of the 't Hooft coupling. In this framework, the Gaussian process approximation used in machine learning corresponds to a free field theory, and finite-width effects can be computed perturbatively in the ratio of depth to width, T/N. These provide corrections to the correlation length that controls the depth to which information can propagate through the network, and thereby sets the scale at which such networks are trainable by gradient descent. If time permits, I will discuss more recent work incorporating layerwise permutation symmetry. This analysis provides a non-perturbative description of networks at initialization, and opens several interesting avenues to the study of criticality in these models.

DY 58.3 Fri 10:15 GÖR/0226

Online Learning Dynamics and Neural Scaling Laws for a Perceptron Classification Problem — •Yoon Thelge, Marcel Kuhn, and Bernd Rosenow — Institute for Theoretical Physics, University of Leipzig, 04103 Leipzig, Germany

Understanding neural scaling laws and emergence of power law generalisations remains a central challenge in learning dynamics. A natural setting for analysing this behaviour is the online-learning dynamics of a perceptron trained in a teacher*student scenario, where in the thermodynamic limit, the generalisation error exhibits characteristic power-law decay. In realistic classification problems, the teacher is a discrete classifier, while standard gradient-based training requires the student to have continuous outputs. Thus, in practically relevant settings the student is necessarily mismatched to the discrete teacher, a regime that is less well understood. We study this regime for a perceptron with a sign-activation teacher and an error-function student. We

derive coupled differential equations for the evolution of the relevant order parameters and verify them via numerical integration and SGD simulations. For fixed learning rates, the generalisation error converges to zero as a power-law with respect to the number of training examples with an exponent of -1/3. The onset of this asymptotic regime shifts with the learning rate, and the generalisation at the onset scales with exponent -1/2, motivating the use of learning-rate schedules to enhance the effective asymptotic decay.

DY 58.4 Fri 10:30 GÖR/0226

Power-Law Correlations in Language: Criticality vs. Hierarchical Generative Structure — •Marcel Kühn[1,2], Max Staats[1,2], and Bernd Rosenow[2] — [1]ScaDS.AI Dresden/Leipzig, Germany — [2]Institute for Theoretical Physics, University of Leipzig, 04103 Leipzig, Germany

Natural language shows power-laws beyond Zipf: the mutual information between words as a function of separation — a two-point correlation — decays approximately as a power-law, a constraint for predictive language models. In autoregressive architectures like transformers, the softmax temperature of the output controls how sharply next-word probabilities concentrate, acting as a thermodynamic knob that might tune correlations. Since phase transitions are a well-known mechanism that generate such scale-free correlations, we ask whether the observed power-law mutual information requires tuning to a critical softmax temperature. Analyzing a Markov (bigram) model, we show that, in a large-system limit, power-law mutual information emerges only at a fine-tuned critical temperature, below correlations decay exponentially. Motivated by the fact that faithful language models must go beyond bigrams and that hierarchical generative processes introducing long range interactions are more representative, we analyze an autoregressive model that perfectly emulates a specific probabilistic context-free grammar. We demonstrate that simple versions of this model preserve power-law mutual information without temperature fine-tuning, and we discuss the generality of this result for variants of the model in which deviations from the grammatical rules may occur.

DY 58.5 Fri 10:45 GÖR/0226

Dynamics of neural scaling laws in random feature regression — •Jakob Kramp[1,2], Javed Lindner[1,2], and Moritz Helias[1,2] — [1]Institute for Advanced Simulation (IAS-6), Computational and Systems Neuroscience, Jülich Research Centre, Jülich, Germany — [2]Department of Physics, RWTH Aachen University, Aachen, Germany

Training large neural networks reveals signs of universality that hold across architectures. This holds also for overparameterized networks which converge to effective descriptions in terms of Gaussian process regression. Those simplified models, already show one ingredient of universality in form of neural scaling laws. An important ingredient are power-law distributed principal component spectra of the training data.

Past work has therefore studied the dynamics of deterministic gradient flow in linear regression with and without consideration of power-law distributed spectra. Previously, dynamics of gradient flow with power law data in a type of linear random feature model were able to mimic effects of feature learning. Our work differs from the former by presenting an approach that holds for Bayesian inference on Gaussian processes obtained by stochastic Langevin training as well as for deterministic gradient flow with or without regularization by weight decay. We obtain interpretability from an effective mean-field theory that requires fewer order parameters than previous works.

15 min. break

Invited Talk DY 58.6 Fri 11:15 GÖR/0226

Creativity in generative AI — •matthieu wyart — JHU & EPFL

Is AI creative? Generative AI such as chatGPT or diffusion models can create new texts or images from a finite training set of examples. I will argue that AI can achieve this magical by learning how compose observed low-level elements into a new whole. I will discuss the type of correlations the model can exploit to do so, how many data are needed for that, and how it relates to a hierarchical construction of latent variables. The analysis is based on the introduction of synthetic languages, and comparison with experiments performed on modern AI architectures trained on real text and images.

DY 58.7 Fri 11:45 GÖR/0226

Understanding Generative Models via Interactions — •Claudia Merger[1,2,3], Alexandre Rene[2,4], Kirsten Fischer[2,3], Peter Bouss[2,3], Sandra Nestler[2,3], David Dahmen[2], Carsten Honerkamp[3], Moritz Helias[2,3], and Sebastian Goldt[1] — [1]SISSA, Trieste, Italy — [2]Jülich Research Centre, Jülich, Germany — [3]RWTH Aachen University, Aachen, Germany — [4]University of Ottawa, Ottawa, Canada

Generative models have become remarkably powerful at reproducing complex data distributions. They can infer the characteristic statistics of a system from comparatively small datasets and even generate new, realistic samples. Yet, our understanding of what these models learn remains limited: which statistics do they capture, and how accurately? To address the first question, we translate the statistics learned by generative models into a central concept of statistical physics: interactions between degrees of freedom that describe how pairs, triplets, and higher-order groups coact to produce the observed statistics of a system. Using invertible neural networks, we extract these interactions directly from trained models, providing a microscopic description of their learned data structure. To assess how accurately these interactions are learned, we use an analytic theory of diffusion models that predicts the precision with which pairwise interactions can be inferred from finite datasets, quantifying how generalization depends on sample size, data hierarchy, and regularization. Together, these results provide a framework grounded in statistical physics to interpret and predict the behavior of modern generative models.

DY 58.8 Fri 12:00 GÖR/0226

From Kernels to Features: A Multi-Scale Adaptive Theory of Feature Learning — •Javed Lindner[1,2], Noa Rubin[5], Kirsten Fischer[1,6], David Dahmen[1], Inbar Seroussi[4], Zohar Ringel[5], Michael Krämer[3], and Moritz Helias[1,2] — [1]Institute for Advanced Simulation (IAS-6), Computational and Systems Neuroscience, Jülich Research Centre, Jülich, Germany — [2]Department of Physics, RWTH Aachen University, Aachen, Germany — [3]Institute for Theoretical Particle Physics and Cosmology, RWTH Aachen University, Aachen, Germany — [4]Department of Applied Mathematics, School of Mathematical Sciences, Tel-Aviv University, Tel-Aviv, Israel — [5]he Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem, Israel — [6]RWTH Aachen University, Aachen, Germany

Feature learning in neural networks is crucial for their expressive power and inductive biases, moti- vating various theoretical approaches. Some ap- proaches describe network behavior after train- ing through a change in kernel scale from initial- ization, resulting in a generalization power com- parable to a Gaussian process. Conversely, in other approaches training results in the adapta- tion of the kernel to the data, involving directional changes to the kernel. The relationship and respective strengths of these two views have so far remained unresolved. This work presents a theo- retical framework of multi-scale adaptive feature learning bridging these two views. Using methods from statistical mechanics, we derive analytical expressions for network output statistics which are valid across scaling regimes and in the continuum between them.

DY 58.9 Fri 12:15 GÖR/0226

Statistical physics of deep learning: Optimal learning of a multi-layer perceptron near interpolation — Jean Barbier[1], Francesco Camilli[1], Minh-Toan Nguyen[1], Mauro Pastore[1], and •Rudy Skerk[2] — [1]The Abdus Salam International Centre for Theoretical Physics, Strada Costiera 11, 34151 Trieste, Italy — [2]International School for Advanced Studies, Via Bonomea 265, 34136 Trieste, Italy

We address a long-standing question in statistical physics by analysing the supervised learning of a multi-layer perceptron, beyond narrow models and kernel methods. Crucially, (i) the width scales with input dimension, making the model more prone to feature learning than ultra-wide networks and more expressive than narrow ones; and (ii) we work in the interpolation regime where trainable parameters and data are comparable, forcing task-specific adaptation. In a matched teacher-student setting we establish the fundamental limits for learning random deep-network targets and identify the sufficient statistics that an optimally trained network acquires as data increases. A rich phenomenology appears with multiple learning transitions: with enough data optimal performance arises via model "specialisation", yet practical algorithms can be trapped in theory-predicted suboptimal solutions. Specialisation occurs inhomogeneously across layers, propagating from shallow towards deep ones, but also across neurons in each layer. The Bayesian-optimal analysis thus clarifies how depth, nonlinearity and finite (proportional) width shape feature learning, with

implications beyond this idealised setting.

DY 58.10 Fri 12:30 GÖR/0226

Phase Transitions as Rank Transitions: Connecting Data Complexity and Cascades of Phase Transitions in analytically tractable Neural Network Models — •Björn Ladewig, Ibrahim Talha Ersoy, and Karoline Wiesner — Institute of Physics and Astronomy, University of Potsdam, Germany

Tuning the L2-regularization strength in neural networks can result in a cascade of (zero-temperature) phase transitions between regimes of increasing accuracy. This phenomenology was previously numerically observed and linked to a basin structure of the error landscape formed by the underlying data [1]. At the level of analytically tractable models, we (i) establish the existence of cascades of transitions for those models, (ii) give meaning to the transitions in terms of the ordered onset of "learned eigendirections" of the underlying data distribution; and (iii) link the phase transitions and corresponding accuracy regimes to saddle points of the error landscape.

[1] I. Talha Ersoy and Karoline Wiesner. Exploring l2-phase transitions on error landscapes. In ICML, Workshop on High-dimensional Learning Dynamics 2025. https://openreview.net/forum?id=AkQNtAw09u

DY 59: Quantum Chaos and Coherent Dynamics (joint session DY/TT)

Time: Friday 9:30–12:45 Location: HÜL/S186

DY 59.1 Fri 9:30 HÜL/S186

Time reversal invariance breaking in quantum chaotic scattering — •Ahmed Aldabag, Nils Gluth, and Thomas Guhr — Universität Duisburg Essen

A. Aldabag, N. Gluth and T. Guhr, Universität Duisburg-Essen

Scattering theory is a key tool for the investigation of quantum systems. Often, the systems are stochastic or in a broad sense chaotic. Using Random Matrix Theory, our group recently derived the distributions of off-diagonal scattering matrix elements and cross sections with the Supersymmetry Method. We did that for the three Dyson classes which are distinguished by the presence or absence of time-reversal invariance in the system. In some important physics situations, time-reversal invariance is weakly broken. We succeeded in analytically calculating the corresponding effects on the universal behavior of the mentioned distributions. Our results provide new tools to analyze time-reversal invariance breaking in data from scattering experiments.

DY 59.2 Fri 9:45 HÜL/S186

Normalization of resonance states in chaotic scattering systems — •Florian Lorenz, Jan Möseritz-Schmidt, and Roland Ketzmerick — TU Dresden, Institut für Theoretische Physik, Dresden, Germany

The normalization of resonance states in scattering systems poses a challenge due to their divergent asymptotic behavior. As a consequence, they cannot be normalized by the usual norm, but instead, by the overlap between left and right resonance states. For dielectric cavities, we demonstrate that this left-right overlap can be computed efficiently using a boundary integral, avoiding divergent integrands. This result provides a practical numerical tool for resonance state normalization. For example, this allows for exact time evolution of wave packets based on resonance states.

DY 59.3 Fri 10:00 HÜL/S186

How exceptional points conduct mode dynamics in optical microcavities — Tom Simon Rodemund[1], Chang-Hwan Yi[2], Jung-Wan Ryu[2], Síle Nic Chormaic[3], and •Martina Hentschel[1] — [1]Institut für Physik, TU Chemnitz, Germany — [2]PCS, IBS, Daejeon, Korea — [3]OIST, Okinawa, Japan

Optical microcavities confine light through total internal reflection, making them inherently open, non-Hermitian systems. Their resonances have a real and an imaginary part, both of which depend on external parameters such as the resonator geometry or the refractive index. When scanning the parameter space, resonances can coincide and when they do so in their real and imaginary part, they form an exceptional point. We illustrate their occurrence and consequences in mesoscopic optics in two examples. First, we consider two coupled two-dimensional microcavities over coupling distances of several resonance wavelengths. Their mode dynamics is determined by a chain of exceptional points that exhibit a periodicity of approximately the wavelength [1]. The second example is a three-dimensional truncated cone. We investigate the interaction between the two mode polarizations, TE and TM, and find that the mode character changes smoothly, with TE and TM coinciding at exceptional points [2]. We confirm this behavior in phase space by generalizing the concept of Husimi functions to three dimensions. [1] C.-H. Yi, J.-W. Ryu, T.S. Rodemund, and M. Hentschel, Phys. Rev. A 112, L031501 (2025). [2] T.S. Rodemund, S. Li, S. Nic Chormaic, and M. Hentschel, Phys. Rev. A 112, 033528 (2025).

DY 59.4 Fri 10:15 HÜL/S186

Describing the spectral behavior around higher-order exceptional points with "periodic orbits" — •Daniel Grom[1], Julius Kullig[1], Malte Röntgen[2], and Jan Wiersig[1] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg, 39016 Magdeburg, Germany — [2]Laboratoire d'Acoustique de l'Université du Mans, 72085 Le Mans, France

Coupled optical microrings can deliver a simple and robust scheme to generate higher-order exceptional points (EPs), where multiple eigenvalues and -modes coalesce. A feature of an EP of order n, is the high sensitivity of the eigenvalues to small perturbations. Two types of perturbations can be classified. The generic behavior, where the eigenvalue response is proportional to the nth root and the non-generic type with a different eigenvalue response.

We present a graph theoretical perspective on the spectral characterization of perturbed higher-order EPs. It turns out that specific "periodic orbits" within the graph picture of the non-chaotic system govern the eigenvalue behavior.

DY 59.5 Fri 10:30 HÜL/S186

Dynamic origin of quantum chaos signatures in the zeros of the Riemann zeta function by means of periodic orbit theory — •Andreas Hötzinger, Sebastian Hörhold, Juan Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

In the 90's, Berry and Keating [1] provided a qualitative, semiclassical analogy to the counting function of the nontrivial Riemann zeros, i.e. the zeros of the famous zeta function (ZF) $\zeta(s)$. Similar to Gutzwiller's trace formula they obtain a result in which the primes play the role of periodic orbits and argue that the so-called Riemann dynamics, underlying the primes, should be chaotic. It is speculated that this system is the classical limit of a Hermitian quantum Hamiltonian which has eigenvalues coinciding with the nontrivial zeros of $\zeta(1/2 + \mathrm{i}t_n)$.

Recently, a promising candidate for such a Hamiltonian has been proposed [2], which has the potential to advance research toward a proof of the Riemann hypothesis. Based on these results, we use a related and simpler, yet non-Hermitian Hamiltonian and consider its semiclassical regime by employing methods from periodic orbit theory.

In this talk, we present our progress in the study of the classical limit of this operator and its dynamics in a complexified phase space. Through this, we hope to unveil a deeper relation between quantum chaos signatures of number theory encoded in the ZF with classical phase space structures.

[1] M. V. Berry and J. P. Keating, SIAM Review 41.2 pp. 236-266
[2] E. Yakaboylu, arXiv:2408.15135

DY 59.6 Fri 10:45 HÜL/S186

Semiclassical geometry of entanglement — •Maximilian Kieler and Peter Schlagheck — CESAM research unit, University of Liège, B-4000 Liège, Belgium

We propose a semiclassical perspective on entanglement in the form of a geometric Schmidt decomposition of regular states, e.g., states associated with invariant tori. Utilizing WKB quantization techniques and classical geometry, we derive the Schmidt spectrum and the corresponding Schmidt states. This framework allows for the reduction of the complexity in many-body states by decomposing them into lower-dimensional components.

15 min. break

Invited Talk DY 59.7 Fri 11:15 HÜL/S186

Anyon dynamics in driven topologically ordered quantum systems — •Francesco Petiziol — Technische Universität Berlin, Institut für Physik und Astronomie, Hardenbergstr. 36, 10623 Berlin

Quantum systems with topological order exhibit long-range entanglement and host quasiparticle excitations with unconventional quantum statistics – anyons. These features make them of great interest from both fundamental and quantum-technological perspectives. Recent progress in realizing topological order in quantum simulators highlights the importance and the challenge of understanding the behaviour of such systems under non-equilibrium conditions. Focusing on Kitaev's toric code, I will discuss how external driving, either coherent or incoherent, can impact and alter anyon properties. Examples include the emergence of more complex anyon classes from simpler ones, the dynamics of entanglement under driven anyon proliferation, and opportunities for controlled anyon transport.

DY 59.8 Fri 11:45 HÜL/S186

Floquet engineering in lattice systems with a parametrically modulated parabolic potential — •Usman Ali[1], Martin Holthaus[1], and Torsten Meier[2] — [1]Institut für Physik, Carl von Ossietzky Universität, D-26111 Oldenburg, Germany — [2]Department of Physics, Paderborn University, Warburger Strasse 100, D-33098 Paderborn, Germany

We present a route to Floquet engineering in lattice systems that exploits a parabolic potential to generate tunable slowly varying on-site energies. When a selected level spacing in the spectrum of the combined parabolic lattice is brought into near resonance with an external periodic drive, nonlinear resonances emerge in the classical phase space and reorganize quantum eigenstates into families of near-resonant Floquet states. Using a Mathieu-resonance approximation together with numerical Floquet calculations, we construct these states and demonstrate how resonant trap eigenstates transmute into resonance-induced effective ground states [1]. The long-time population and transport dynamics are strongly sensitive to the initial phase of the drive, providing a phase-dependent control knob for engineered tunneling and coherence. We identify parameter regimes accessible to present-day cold-atom experiments and argue that selectively populating these Floquet ground states provides a clean testbed for driven many-body and Floquet-band phenomena, enabling novel lattice dynamics inaccessible in solid-state materials [2]. References: [1] U. Ali, M. Holthaus, and T. Meier, New J. Phys. 26, 123016 (2024) [2] U. Ali, M. Holthaus, and T. Meier, Phys. Rev. Research 5, 043152 (2023)

DY 59.9 Fri 12:00 HÜL/S186

Transport through two Floquet-engineered Impurities in a One-Dimensional System: Coherent Control of Fano Resonances, BICs and Localization — •Vincenzo Bruno[1,2], Ameneh Sheikhan[1], Roberta Citro[2,3], and Corinna Kollath[1] — [1]Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn, Germany — [2]Dipartimento di Fisica "E.R. Caianiello", Università degli Studi di Salerno and INFN, Via Giovanni Paolo II, 132, I-84084 Fisciano (Sa), Italy — [3]CNR/SPIN, Fisciano (Sa), 84098, Italy

Floquet engineering has attracted considerable attention due to its ability to coherently control quantum states, finding successful applications across a wide range of fields such as quantum materials, ultracold atoms, and cavity systems. We investigate particle transport through a one-dimensional system containing two periodically driven impurities. Such a configuration is highly relevant for experimental realizations ranging from ballistic semiconductor wires and electron optics to ultracold atoms, and exhibits remarkably rich transmission properties. A central feature of this system is the emergence of Fano resonances-phenomena arising from the quantum interference between a continuum scattering path and discrete quasi-bound states. We demonstrate how drive parameters can be tuned to dynamically control these resonances. Furthermore, we reveal the existence of Bound States in the Continuum (BICs) and explore the interplay between Fano interference and cavity modes. This interplay leads to a localization mechanism where the system can be switched from a fully localized state to a regime of perfect transparency.

DY 59.10 Fri 12:15 HÜL/S186

Ruelle-Pollicott signatures of unitary quantum systems — •Scott Daniel Linz, Jiaozi Wang, Merlin Füllgraf, and Jochen Gemmer — Department of Mathematics/Computer Science/Physics, University of Osnabrück, D-49076 Osnabrück, Germany

Phenomenological observations demonstrate that unitary quantum systems thermalize and equilibrate. While many concepts have been introduced to describe the equilibrium of a quantum system, the route to this state remains an area of ongoing research. A proposed step towards a general description of this behaviour is that correlation functions of chaotic quantum systems can be described by a superposition of relatively few damped oscillations, where each is weighted and assigned a complex frequency. These frequencies will be called Ruelle-Pollicott signatures after the well-understood Ruelle-Pollicott resonances that govern the decay of correlations in classical chaotic systems featuring dissipation. Following this framework, a deterministic fitting method is applied to the correlation functions of numerical simulations of closed unitary quantum systems. This examination will focus on how the number of frequencies needed to reproduce correlation functions relates to other signatures of quantum chaos.

DY 59.11 Fri 12:30 HÜL/S186

Refinements of the Eigenstate Thermalization Hypothesis — •Elisa Vallini[1], Laura Foini[2], and Silvia Pappalardi[1] — [1]University of Cologne, Köln, Germany — [2]Université Paris-Saclay, France

Understanding how isolated quantum many-body systems reach thermal equilibrium is a central question in nonequilibrium physics. The Eigenstate Thermalization Hypothesis (ETH) provides a powerful framework by linking thermalization to the statistical properties of matrix elements of physical observables in the energy eigenbasis.

In this talk, I will present our recent work, in which we revisit and clarify in detail the ideas that have led to the formulation of full ETH, a generalization of the ETH ansatz that captures multi-point correlation functions. Specifically, using tools from free probability, we explore the implications of local rotational invariance, a property that emerges from the statistical invariance of observables under random basis transformations induced by small perturbations of the Hamiltonian.

This approach allows us to analytically characterize subleading corrections to matrix-element correlations, thereby refining the ETH ansatz. Finally, I will show numerical results from non-integrable Floquet systems that support our analytical predictions.

DY 60: Critical Phenomena and Phase Transitions

Time: Friday 9:30–12:00 Location: ZEU/0114

DY 60.1 Fri 9:30 ZEU/0114

Noise-driven transitions and dynamic restoration in a two-state model under stochastic fields — •Raul Toral[1], Sara Oliver-Bonafoux[1], and Amitabha Chakrabarti[2] — [1]IFISC, Institute for Cross-disciplinary Physics and Complex Systems, UIB-CSIC, Palma de Mallorca, Spain — [2]Physics Department, Kansas State University, Manhattan, Kansas, USA

We study a two-state system influenced by both thermal fluctuations and stochastic external fields to explore how randomness affects non-equilibrium transitions and barrier-crossing dynamics. Using the Ising model in a heat bath as a minimal double-well prototype, we introduce spatially uniform, time-dependent random fields and analyze their impact on phase behavior.

The stochastic driving transforms the usual symmetry-breaking transition of the Ising model into a noise-induced transition between soft-paramagnetic and soft-ferromagnetic phases, where magnetization exhibits broad distributions and dynamical symmetry restoration between ferromagnetic states. For small field amplitudes, the transition coincides with the critical point of the undriven system, while at lower temperatures a genuine ferromagnetic phase emerges, marked by spontaneous state selection and diverging switching times.

These results reveal how stochastic forcing modifies phase behavior in bistable systems, providing new insights into noise-driven symmetry breaking and restoration.

DY 60.2 Fri 9:45 ZEU/0114

The frustrated Ising model on the honeycomb lattice: Metastability and universality — •Denis Gessert[1,2,3], Martin Weigel[3], and Wolfhard Janke[2] — [1]Centre for Fluid and Complex Systems, Coventry University, Coventry, CV1 5FB, United Kingdom — [2]nstitut für Theoretische Physik, Universität Leipzig, IPF 231101, 04081 Leipzig, Germany — [3]nstitut für Physik, Technische Universität Chemnitz, 09107 Chemnitz, Germany

We study the Ising model with competing ferromagnetic nearest- and antiferromagnetic next-nearest-neighbor interactions of strengths $J_1 > 0$ and $J_2 < 0$, respectively, on the honeycomb lattice. For $J_2 > -J_1/4$ it has a ferromagnetic ground state, and previous work has shown that at least for $J_2 \gtrsim -0.2J_1$ the transition is in the Ising universality class. For even lower J_2 some indicators pointing towards a first-order transition were reported. By utilizing population annealing Monte Carlo simulations together with a rejection-free and adaptive update, we can equilibrate systems with J_2 as low as $-0.23J_1$. By means of a finite-size scaling analysis we show that the system undergoes a second-order phase transition within the Ising universality class at least down to $J_2 = -0.23J_1$ and, most likely, for all $J_2 > -J_1/4$. As we show here, there exist very long-lived metastable states in this system explaining the first-order like behavior seen in only partially equilibrated systems.

DY 60.3 Fri 10:00 ZEU/0114

Hardness of the "swap" spin glass ensemble — •Alexander K. Hartmann[1], Leticia Cugliandolo[2], and Marco Tarzia[2] — [1]University of Oldenburg, Germany — [2]Sorbonne University, Paris, France

The "swap" ensemble [1] consist of spin glasses with quenched interaction constants J_{ij}, where the spins $s_i = \sigma_i\tau_i$ with $\sigma_i = \pm 1$ and $\tau_i \in [1 - /\Delta/2, 1 + \Delta/2]$ exhibit varying lengths τ_i. The value $\Delta = 0$ corresponds to the standard Ising case. Inspired by "swap moves" used for simulating structural classes [2], it was observed [1] that when including swaps $\tau_i \leftrightarrow \tau_j$ within Monte Carlo simulations at finite temperature with annealing $T \to 0$, ground states are easier to find. The actual "swap" ensemble samples consist of the bonds $\mathcal{J}_{ij} = J_{ij}\tau_i\tau_j$ obtained at the end of the annealing, respectively. Here, we study for two-dimensional spin glasses, by applying exact ground-state algorithms [3], the probability p_0 that true ground states have been found in the annealing. This allows us to define the hardness of the bond samples. In particular we consider the results as a function of the total number $t_{\rm MC}$ of annealing steps and length variation Δ. Furthermore, by applying domain-wall energy calculations [3], we investigate for various values of Δ and slow annealing ($p_0 \to 1$) whether the $\{\mathcal{J}_{ij}\}$ samples actually behave like spin glasses or rather like ferromagnets.

[1] A. Mirando, L. Cugliandolo and M. Tarzia, Phys. Rev. E **100**, L043301 (2024).
[2] L. Berthier and D. R. Reichman, Nat. Rev. Phys. **5**, 102 (2023).
[3] A.K. Hartmann and A.P. Young, Phys. Rev. B 64, 180404 (2001).

DY 60.4 Fri 10:15 ZEU/0114

Experimental study of dynamic phase transitions in nearly isotropic ferromagnetic films — Juan Marcos Marin Ramirez, Luciano Bravo, and •Andreas Berger — CIC nanoGUNE BRTA, E-20018 Donostia-San Sebastián, Spain

Non-equilibrium phase transitions occur across a wide range of physical systems. A relevant example is the dynamic phase transition (DPT) in ferromagnets, where the time-averaged magnetization Q, the dynamic order parameter, changes sharply under an oscillating field as its amplitude H_0 or period P vary. Hereby, it has also been observed that Q is dependent on the presence of an additional bias field H_b, which turns out to be the conjugate field of Q. Studies of the DPT have yielded important insights into dynamically ordered systems, their phase-space behaviour, and transient properties [1], yet this work has focused almost exclusively on Ising-type systems, restricting our understanding to a single material class [2]. Here, we experimentally investigate the DPT in polycrystalline Co films with very weak anisotropy. Dynamic magnetic states are monitored via real-time magneto-optical Kerr effect measurements across the relevant dynamic phase space. We find that the qualitative features of the dynamic phase diagram closely follow those of uniaxial Ising-type films. However, the metamagnetic anomalies of the paramagnetic dynamic state, ubiquitous in Ising-type films, appear to be significantly weaker in our nearly isotropic films.

[1] P. Riego et al., Phys. B Condens. Matter 549, 13 (2018). [2] M. Quintana and A. Berger, Phys. Rev. Lett. 131, 116701 (2023).

DY 60.5 Fri 10:30 ZEU/0114

Quadrupoling in ferroic materials — •Finja Tietjen and Richard Matthias Geilhufe — Chalmers University of Technology, Gothenburg, Sweden

Quadrupolar ordering has been investigated and characterized experimentally in different materials in recent years, but the theoretical approaches have only focused on special cases so far. We follow a new approach where we describe the quadrupoling as a composite order, arising from the fluctuations of a parent phase. This is in contrast to the conventional approach, where different phases are regarded as competing. We derive a mesoscopic field theory that includes thermal fluctuations. That enables us to find the anisotropy-dependent transition temperature and the free energy of the quadrupolar phase. We identify the phase transition into the quadrupolar phase as first-order and show that it is linked to a tetragonal distortion of the lattice of the material. With this framework, we correctly predict experimental measurements of the distortion in Ba2MgReO6 upon entering its quadrupole phase [1].

[1] D. Hirai, H. Sagayama, S. Gao, H. Ohsumi, G. Chen, T.-h. Arima, and Z. Hiroi, 'Detection of multipolar orders in the spin-orbit-coupled 5d Mott insulator Ba2MgReO6', Physical Review Research 2, 022063 (2020)

DY 60.6 Fri 10:45 ZEU/0114

Out-of-equilibrium intertwining of Landau and time-crystalline orders via collective excitations — •Andras Szabo[1] and Rama Chitra[2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]ETH Zurich, Switzerland

The intertwining of multiple order parameters is a widespread phenomenon in equilibrium condensed matter systems, yet its exploration is often hindered by the complexity of real materials. Here, we present a controlled study of intertwined orders in a minimal and versatile driven-dissipative quantum-engineered platform. We consider a Bose-Einstein condensate at the intersection of two optical cavities, realizing two competing copies of a Z2 symmetry-breaking superradiant phase transition characterized by density wave orders. Using periodic drives that exploit dynamical symmetry reduction, we show that collective excitations can be harnessed to stabilize a variety of novel intertwined orders. Going beyond the conventional phenomenology involving Landau orders, we show the emergence of a larger class of out-of-equilibrium intertwined phases, including intertwining of purely time-crystalline orders, as well as between Landau and time crystal orders. These

results should be observable in state of the art experimental setups

15 min. break

DY 60.7 Fri 11:15 ZEU/0114

Nucleation in the Vicinity of the Spinodal — •Sune Kühne and Marcus Müller — Universität Göttingen Institut für Theoretische Physik Friedrich-Hund-Platz 1 37077 Göttingen

Nucleation plays a central role in initiating phase separation across diverse soft-matter systems, from synthetic polymer blends to biomolecular condensates. Near the spinodal, Cahn-Hilliard nucleation theory (CHNT) predicts that the free-energy barrier vanishes while the size and material excess of the critical nucleus diverge. Forming a large cluster significantly delays nucleation even in the absence of a free-energy barrier in analogy to approaching the spinodal from the unstable region. Yet experiments consistently report a finite rate of phase separation even while crossing the spinodal, challenging the classical CHNT scenario. In this work, we investigate the onset of phase separation in the near-spinodal regime and reveal how thermal fluctuations qualitatively modify the nucleation pathway. Using Monte Carlo simulations, we show that fluctuations can locally and transiently push the system beyond the spinodal threshold, enabling the formation of nuclei on a finite length scale well below the system size. This mechanism produces finite nucleation times and naturally explains the experimentally observed smooth crossover from nucleation-dominated to spinodal-like dynamics. By analyzing the free-energy landscape as well as the structure and dynamics of the density fluctuations that eventually become critical, we identify the key physical principles governing phase selection in metastable mixtures.

DY 60.8 Fri 11:30 ZEU/0114

Self-Assembly as a Topological Entropic Transition: Geometry, Connectivity and the Emergence of Molecular Order — •Vicente Domínguez Arca — Biosystem and Bioprocesses Engineering, IIM-CSIC, Spain — Physical and Biophysical Chemistry, Bielefeld University, Germany

Self-assembly in soft-matter systems is traditionally explained through intermolecular forces acting at short metric ranges. Here we propose a radically different view: aggregation emerges from a topological-entropic transition in the geometry of accessible microstates. Using a connectivity-based model of amphiphilic micellization, we show that aggregation reduces the degeneracy of solvent configurations, collapsing a manifold of equivalent states into a confined thermodynamic paraboloid.

This reorganization generates effective forces without invoking pairwise attractions, as entropic gradients arise from the curvature of the configuration manifold itself. The hydrophobic effect thus appears not as a fundamental interaction, but as a solvent-mediated constraint that selects ordered states by maximizing accessible degrees of freedom. This framework explains micellization as a connectivity threshold and rationalizes enthalpy-entropy compensation as a geometric projection of the same curvature tensor. Self-assembly therefore emerges as a topological transition driven by entropy, revealing order as a consequence of state-space geometry rather than microscopic forces.

DY 60.9 Fri 11:45 ZEU/0114

On the adequate and stochastic structure of space in nature and phase transitions in the early universe — •Hans-Otto Carmesin — Universität Bremen, Fachbereich 1, Pf 330440, 28334 Bremen — Studienseminar Stade, Bahnhofstr. 5, 21682 Stade — Gymn. Athenaeum, Harsefelder Str. 40, 21680 Stade

The problem to find an adequate coordinate system (ACS) has been proclaimed by the International Astronomical Union (IAU), and that problem has been solved here. This has far reaching consequences about the structure of space and time: The universal zero of the kinematic time difference δt_{kin} is derived. It corresponds to zero kinetic energy and to the minimum of relativistic energy at a given rest mass. Based on that finding, indivisible volume portions in nature are derived, and homogeneous space is identified as a stochastic average of these indivisible volume portions. With it, gravity and the quantum postulates have been derived. As a consequence, at high density, there occur dimensional phase transitions of space. In the very early universe, there occurred such high densities, and, as a consequence, the corresponding phase transitions took place. This explains the era of 'cosmic inflation', which turns out to be an era of cosmic unfolding.

Carmesin, H.-O. (2025): On the Dynamics of Time, Space and Quanta. Berlin: Verlag Dr. Köster.

Carmesin, H.-O. (2021): Quanta of Spacetime Explain Observations, Dark Energy, Graviton and Nonlocality. Berlin: Verlag Dr. Köster.

DY 61: Brownian Motion and Anomalous Transport

Time: Friday 9:30–11:15 Location: ZEU/0118

DY 61.1 Fri 9:30 ZEU/0118

Quantifying non-Markovianity via entropy production in rotational Brownian motion — •Felix Hartmann[1], Finja Tietjen[2], Matthias Geilhufe[2], and Janet Anders[1,3] — [1]University of Potsdam, Institute of Physics and Astronomy, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany — [2]Department of Physics, Chalmers University of Technology, 412 96 Göteborg, Sweden — [3]Department of Physics and Astronomy, University of Exeter, Stocker Road, Exeter EX4 4QL, UK

Magnetization dynamics is commonly modeled by the stochastic Landau-Lifshitz-Gilbert (LLG) equation, which describes the rotational Brownian motion of a magnetization vector on a spherical surface, and successfully explains and predicts magnetization experiments. On ultrashort timescales ($\sim$ a few picoseconds) an extension of the LLG by an inertial term has been theoretically predicted and experimentally measured. More generally ultrafast magnetization experiments are modeled by an open-system LLG equation, which includes a memory kernel and colored noise. It has previously been reported that if classical entropy production rates become negative, the underlying dynamical evolution is non-Markovian. In this talk we employ this to detect and measure non-Markovianity in the evolution of the magnetization dynamics. We analytically show that the inertial LLG and open-system LLG equation may have temporarily negative entropy production rates. We highlight our findings by numerical calculations of the entropy production rates for the three different LLG equations under different initial conditions and field orientations.

DY 61.2 Fri 9:45 ZEU/0118

Resolving hidden barriers and states form time series of projected observables — •Francesco Malcangi and Aljaz Godec — Mathematical Physics and Stochastic Dynamics, Institute of Physics, University of Freiburg

Single molecule experiments, such as FRET, plasmon ruler, and optical tweezers, probe a low- (often one-) dimensional projection of a higher dimensional dynamics. Unless the hidden degrees of freedom relax faster then the observed ones or they are uncoupled, projection induces memory and hides features of the full dynamics, like the presence of hidden states or energy barriers. In this study we show that the higher-order statistics of appropriately chosen functionals of projected paths can reveal some hidden features directly from the time series. In particular, they can unravel and resolve hidden barriers or states.

DY 61.3 Fri 10:00 ZEU/0118

Intensity countoscope: Quantifying dynamics from intensity correlations in real space — •Sophie Hermann and Sophie Marbach — PHENIX, Sorbonne Université/CNRS, Paris, France

Quantifying the dynamics of particle suspensions is of widespread interest in soft matter, including crystalline aggregates and bacterial colonisation. Here, we develop a new technique to learn about these dynamics directly from microscopy images. The intensity countoscope is based on the analysis of intensity correlations in virtual observation boxes of images. Through colloidal experiments, simulations, and theory, we demonstrate how this method determines equilibrium motion properties, such as self-diffusion coefficients and particle drift. By varying the size of the observation boxes, we can probe dynamics across length scales, disentangling contributions of the particle shape and the point spread function (PSF) from those of the particle motion. The intensity countoscope complements the broad range of existing techniques on interpreting images, such as particle tracking, sitting right in

between dynamical differential microscopy (DDM), and particle number fluctuations (Countoscope). One strength is its applicability to situations where particle tracking is difficult, e.g. at high densities, with fast dynamics or with poor image resolution. Additionally, the entire analysis is performed in real space, which makes the technique computationally cheap as it does not require Fourier transformations. This also enables to find more intuitively physical meaning behind the obtained signals. This simplicity opens up broad perspectives on the study of collective phenomena and of interparticle interactions.

DY 61.4 Fri 10:15 ZEU/0118

Leveraging Interactions for Efficient Swarm-Based Brownian Computing — •Alessandro Pignedoli, Atreya Majumdar, and Karin Everschor-Sitte — University of Duisburg-Essen, CENIDE Center for Nanointegration Duisburg-Essen

Brownian particles naturally explore a system's configuration space through thermal fluctuations, requiring no external energy input. This intrinsic property makes them an energy-efficient basis for addressing optimisation problems [1]. Inspired by swarm intelligence [2], we show that short-range interactions between Brownian quasiparticles induce dynamic clustering around the global minimum of a complex temperature landscape [3,4]. By varying the interaction strength and particle density, we identify a broad range of physical conditions in which collective behaviour enhances optimization accuracy. Our results highlight that the emergent collective dynamics of interacting Brownian particles provide a scalable, energy-efficient framework for unconventional computing.

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

DY 61.5 Fri 10:30 ZEU/0118

Current reversals in periodically driven many-particle colloidal ratchet — •Seemant Mishra[1], David Vorac[2], Artem Ryabov[2], and Philipp Maass[1] — [1]Universität Osnabrück, Institut für Physik, Germany — [2]Charles University, Faculty of Mathematics and Physics, Czech Republic

We study a many-particle colloidal ratchet and demonstrate the occurrence of current reversals under a symmetric, time-periodic driving force. An overcrowding of particles in the potential wells of the ratchet causes the current to be mediated by propagating solitary waves [1,2]. The current reversals arise from distinct modes of these waves. By a mapping onto a quasiparticle dynamics [3] and applying a unit-displacement law [4], we develop an analytic theory for the particle currents as function of the driving parameters and explain the occurrence of the current reversals. We further examine the role of hydrodynamic interactions in the system.

[1] A. P. Antonov, A. Ryabov, P. Maass, Phys. Rev. Lett. 129, 080601 (2022).
[2] E. Cereceda-López, A. P. Antonov, A. Ryabov, P. Maass, and P. Tierno, Nat. Commun. 14, 6448 (2023).
[3] S. Mishra, A. Ryabov, P. Maass, Phys. Rev. Lett. 134, 107102 (2025).
[4] A. P. Antonov, A. Vonhusen, A. Ryabov, P. Maass, Nonlinear Dyn. 113, 31529 (2025).

DY 61.6 Fri 10:45 ZEU/0118

Advection-diffusion processes of Brownian particles in a long corrugated channel: mean first passage time approach — •Xiaohan Huang, Paolo Malgaretti, and Jens Harting — Helmholtz Institute Erlangen-Nürnberg for Renewable Energy, Cauerstr. 1, 91058 Erlangen, Germany

Transport of particles in porous media in micro- and mesoscopic scales is of interest in many applications, such as the catalytic transport and nanoparticles separations. In such scenarios, the time that a particle takes to reach a target for the first time, namely the mean first passage time (MFPT), represents a standard indicator. We model the advection-diffusion of a finite size particle in a diluted suspension through a corrugated channel of N varying cross sections elements. Under the fast transverse equilibrium and the slow longitudinal transport, we encode the geometric effect to an effective entropic potential via the Fick-Jacobs approximation [1]. Together with the lubrication approximation, the 2D equation is reduced to 1D, allowing us to solve the moments of MFPT. The resulting data collapse onto a master curve, enabling us to identify the relevant dimensionless numbers: the MFPT without advection and the particle-sensitive effective advection $\tilde{v}$. $\tilde{v}$ is the average velocity of a particle in a single element, accounting for advection, geometry and particle-wall interactions. Thus, 1^{st} and 2^{nd} moment of MFPT are expressed as $f(Pe)$, $Pe = \frac{\tilde{v}NL}{D}$ [2]. The model predicts the particle transport in a long channel, enabling fast parameter studies in porous media design.[1] P. Malgaretti et al. Entropy 2023. [2] X.Huang et al. in preparation.

DY 61.7 Fri 11:00 ZEU/0118

Anomalies in first-passage times and survival profiles of the critical Lorentz gas — •Giorgia Marcelli and Felix Höfling — Institute of Mathematics, Freie Universität Berlin

We investigate the non-equilibrium transport in the three-dimensional Lorentz gas, which is a paradigm of tracer motion in crowded environments and heterogeneous porous media [1]. The model exhibits critical slowing down and the emergence of anomalous diffusion as the porosity approaches the percolation threshold, where the void space loses connectivity [2,3]. Based on large-scale molecular dynamics simulations for transport across a finite sample, we discuss the statistics of first-passage times (FPT) covering a wide dynamic window [4]. Upon decreasing the porosity, the tail of the FPT density $p(\tau)$ broadens beyond the diffusive law, $p(\tau) \sim \tau^{-3/2}$, and attains a critical power law.

The picture is complemented by a discussion of the spatially resolved survival probability $\rho(x,t)$, which, at low obstacle densities, varies almost linearly in the distance x to the finish line, as expected for normal diffusion, but develops a broad interior plateau near the threshold.

The hazard rate, quantifying the likelihood of an arrival to occur at the next moment, becomes strongly time dependent, signalling a non-Poissonian statistics. We test the consistency of our results against the well-known subdiffusive scaling of the equilibrium transport.

[1] F. Höfling and T. Franosch, Rep. Prog. Phys. **76**, 046602 (2013).
[2] F. Höfling, T. Franosch, and E. Frey, PRL **96**, 165901 (2006).
[3] M. Spanner et al., PRL **116**, 060601 (2016).
[4] G. Marcelli and F. Höfling, in preparation.

DY 62: Active Matter VI (joint session DY/BP)

Time: Friday 9:30–12:15 Location: ZEU/0160

Invited Talk DY 62.1 Fri 9:30 ZEU/0160

Morphogenesis, transport, and computation in micro-scale swarms — •Akira Kakugo — Division of Physics and Astronomy, Graduate School of Science, Kyoto University, Kyoto, Japan

Collective behavior at the microscale offers a powerful route to creating adaptive and functional materials. In this talk, I present a series of studies in which microtubule/kinesin active matter is treated as an ensemble of active agents, and swarming is engineered through DNA-mediated interactions. By introducing programmable dipole-dipole like binding via designed DNA motifs, we establish tunable microscale swarms with controllable cohesion. First, I describe how external mechanical stimuli trigger diverse modes of morphogenesis within these swarms, leading to the emergence of ordered structures and pattern transformations. Next, I introduce a DNA-programmable transport system in which a swarm of millions of active agents cooperatively captures, carries, and releases microscale cargo, enabling light-controlled, spatiotemporally precise transport. Finally, I demonstrate how such active swarms can function as a physical reservoir, where their high-dimensional, nonlinear dynamics are directly harnessed for computation within an active-matter ensemble.

DY 62.2 Fri 10:00 ZEU/0160

Learning effective hydro-phoretic interactions in active matter — •Palash Bera, Aritra K. Mukhopadhyay, and Benno Liebchen — Technische Universität Darmstadt, Darmstadt, Germany.

In the quest to understand collective behaviors in active matter systems, the complexity of hydrodynamic and phoretic interactions remains a fundamental challenge. Despite the substantial progress in identifying effective models, existing approaches often rely on minimalistic approximations, neglecting many-body interactions and the near-field contributions to the full interaction dynamics. We propose a machine learning-based framework to systematically learn hydro-phoretic interactions among active colloids from first principles. By combining high-fidelity simulations with symmetry-preserving descriptors and neural network architectures, our approach captures the effective representations of both near- and far-field interactions. This framework bridges the gap between microscopic continuum models and coarse-grained active matter simulations, enabling scalable many-particle modeling without explicitly resolving the fluid flow or concentration fields. Built on two-body interactions, the coarse-grained model captures clustering phenomena consistent with those observed experimentally in active matter systems. We envision that the principles and tools developed here will have broad applicability across a wide range of active and nonequilibrium systems, including driven colloids, active gels, and field-responsive materials, providing a robust framework for modeling emergent behaviors in living and life-like systems.

DY 62.3 Fri 10:15 ZEU/0160

Interactions between Janus particles in optical tweezers — •Arnaud Compagnie[1], Abhimanyu Nowbagh[2], Ivo Buttinoni[2], and Hartmut Löwen[1] — [1]Institute for Theoretical Physics II, Heinrich Heine University Düsseldorf, 40225 Düsseldorf, Germany — [2]Institute for Experimental Physics of Condensed Matter, Heinrich Heine University Düsseldorf, 40225 Düsseldorf, Germany

Janus particles, by using their asymmetric properties to self-propel due to phoretic effects, are the most prominent artificial active colloids at the microscale. Their ability to extract energy from their surroundings and to self-assemble are used to perform specific tasks. However, due to the vast amount of types of Janus particles and the complex systems they evolve in, the way they interact with their environment remains poorly understood. Optical tweezers can be used to trap them and control their behaviour. By studying how a trapped Janus particle affects the movements of another one in a separate trap, we aim to identify the main physical phenomena - optics, hydrodynamic fluxes, and phoretic fields - that influence the interactions between them. We establish and simulate physical models in order to derive the characteristic dynamical properties of the Janus particles thanks to the comparison with experimental data.

DY 62.4 Fri 10:30 ZEU/0160

Programmable Hydrodynamic Reconfiguration of Active Particles — •Lisa Rohde, Gordei Anchutkin, and Frank Cichos — Molecular Nanophotonics Group, Peter-Debye-Institute for Soft Matter Physics, University Leipzig, Leipzig, Germany

Self-propelled microparticles generate hydrodynamic flow fields that govern their interactions with boundaries and neighbouring particles. The long-range behavior of the flow patterns classifies them as either pushers, pullers or neutral swimmers - each exhibiting fundamentally different collective behaviours. In nature, some microorganisms can adaptively switch between swimming modes in response to their environment. However, in synthetic matter, the hydrodynamic signature is fixed during fabrication constraining our ability to study how switching between modes might enable new emergent behavior. Here, we demonstrate a novel approach for real-time switching of the hydrodynamic character of the microswimmer. By illuminating the particle with a structured light field, we create tailored temperature gradients that drive controllable slip flows on the particle*s surface. This effectively allows control over the swimmer*s flow field and enables mode switching by dynamically changing the illumination pattern on demand. The ability to alter the propulsion characteristics established a versatile platform for experimentally investigating swimming efficiency, adaptivity, and collective behavior.

DY 62.5 Fri 10:45 ZEU/0160

From Passive to Active: Active Particles in Coatings Formulation and Film Formation — •Jan Cammann[1], Karnika Singh[1], Luka Burduli[1,2], Edgar Espinosa Rodriguez[3], Franck D'Agosto[3], Muriel Lansalot[3], and Ignacio Martin-Fabiani[1] — [1]Loughborough University — [2]Constructor University Bremen — [3]Universite Claude Bernard Lyon

Coatings are widely used in protective and functional applications but are fundamentally limited by the passive nature of their formulation ingredients. This leads to a critical lack of control over the spatial distribution of ingredients and prevents the optimization of key functional properties. Addressing this challenge, we propose a paradigm shift towards active coatings formulation. We introduce active Janus particles in coatings formulations and demonstrate how they overcome sedimentation and chemical gradients to accumulate at both the top and bottom coating interfaces. To achieve this programmable microstructure, we balance the timescales of active particle fuel depletion and evaporation induced assembly. We find that Janus particles at the top coating surface have an orientational bias, with the sub-equatorial orientation being the most common. This work lays the foundation for future studies developing functional coatings with programmable microstructures and dual functionalities enabled by orientation-biased active particles.

15 min. break

DY 62.6 Fri 11:15 ZEU/0160

Critical Dynamics of Active, Isotropic Systems — •Emir Sezik and Gunnar Pruessner — Imperial College London

A central result of field theory and renormalisation group (RG) is the concept of universality classes. Systems with different microscopic properties display the same physics near a continuous phase transition as they share the same symmetries. In equilibrium critical dynamics, where systems relax to a thermal steady state, Hohenberg and Halperin have provided the authoritative catalogue, which however, does not immediately extend to critical active matter systems. As they display exciting and new phases by their breaking of detailed balance, we have every reason to attempt to identify the relevant terms and to catalogue these non-equilibrium, critical systems. Motivated by this, in this work, we study an active version of Model A by including the relevant terms that are allowed by symmetry in the coarse-grained description. We show that this universality class encompasses diverse systems including spins with vision-cone interactions and Malthusian flocks. Finally, using field-theoretic RG, we perform a 1-loop calculation, approaching the critical point from the disordered regime, and elucidate the effects of activity on the Wilson-Fisher fixed point.

DY 62.7 Fri 11:30 ZEU/0160

Conservation laws and slow dynamics determine the universality class of interfaces in active matter — •Raphael Maire[1], Andrea Plati[1], Leonardo Galliano[2,3], Frank Smallenburg[1],

Ludovic Berthier[2], and Giuseppe Foffi[1] — [1]Université Paris-Saclay, Laboratoire de Physique des Solides, 91405 Orsay, France — [2]Gulliver, ESPCI Paris, PSL Research University, 75005 Paris, France — [3]Dipartimento di Fisica, Università di Trieste, Strada Costiera 11, 34151, Trieste, Italy

While equilibrium interfaces display universal large-scale statistics, interfaces in phase-separated active and driven systems are predicted to belong to distinct non-equilibrium universality classes. Yet, such behavior has proven difficult to observe, with most systems exhibiting equilibrium-like fluctuations despite their strongly non-equilibrium microscopic dynamics.

We introduce an active hard-disk model that is far from equilibrium but lacks self-propulsion. Contrary to self-propelled models, it displays clear non-equilibrium interfacial scaling and allows the first observation of the $|\boldsymbol{q}|$KPZ and wet-$|\boldsymbol{q}|$KPZ universality classes while revealing a new, previously overlooked universality class arising in systems with slow crystalline or glassy dynamics. We also show that hyperuniformity in the bulk suppresses accordingly the fluctuations of the interface. These distinct classes are selected by conservation laws and slow hydrodynamic modes.

Our model can be experimentally realized in vibrated granular systems and offers a new route to study far from equilibrium interfaces.

DY 62.8 Fri 11:45 ZEU/0160

Spontaneous emergence of solitary waves in active flow networks — Rodrigo García[1], •Gonçalo Antunes[2,3], Jens Harting[2,4], Holger Stark[3], Chantal Valeriani[1], Martin Brandenbourger[5], Juan Mazo[1], Paolo Malgaretti[2], and Miguel Ruiz-García[1] — [1]Universidad Complutense de Madrid, Madrid, Spain — [2]Helmholtz-Institut Erlangen-Nürnberg für Erneuerbare Energien (IET-2), Erlangen, Germany — [3]Technische Universität Berlin, Berlin, Germany — [4]Friedrich-Alexander-Universität Erlangen-Nürnberg, Nürnberg, Germany — [5]Aix Marseille Université, Marseille, France

Flow networks like animal/plant vasculature and power distribution grids can encode, transmit, and transform information embodied in the spatial and temporal distribution of their flows. To study these emergent dynamics, we focus on a minimal yet physically grounded system which supports information transmission. The system is composed of a one-dimensional network of active units that pump fluid via phoresis and elastic units that store volume. We coarse-grain the elastohydrodynamics to an active flow network model. We show that the pressure field can develop solitary waves, resulting in the spontaneous creation and transmission of localized packets of information stored in the physical properties of the flow. We show how the shape and speed of these waves depend on the physical parameters. When the elastic units are coupled to their neighbors, a critical size emerges, below which the solitary waves have a finite lifetime.

DY 62.9 Fri 12:00 ZEU/0160

Instabilities and turbulence in extensile swimmer suspensions — •Purnima Jain[1], Navdeep Rana[3], Roberto Benzi[4,5], and Prasad Perlekar[2] — [1]Leibniz-Institut für Polymerforschung Dresden, Germany — [2]Tata Institute of Fundamental Research, Hyderabad, India — [3]Max Planck Institute for Dynamics and Self-Organization (MPIDS), Göttingen, Germany — [4]Hangzhou International Innovation Institute, Beihang University, Hangzhou, China — [5]Department of Physics and INFN, Tor Vergata University of Rome, Via della Ricerca Scientifica 1, Rome, Italy

Swimmers moving in the same direction form an ordered state of living matter. However, this ordered state is not always stable to ambient disturbances. This may lead to chaotic flows characterized by the presence of topological defects, a phenomenon known as active turbulence. The ordered state of microswimmers can be destroyed by an instability created by their swimming stresses. For slightly larger swimmers, where viscous and inertial forces are comparable, an instability due to the fluctuations in the concentration of swimmers destroys the order [1].

In this talk, I will discuss about the instabilities and turbulence in weakly inertial suspensions of extensile swimmers, where the defect turbulent state transitions to the concentration-wave turbulent state. These findings reveal new ways in which living matter may get organized in nature.

[1] P. Jain et. al., Phys. Rev. Lett. 133, 158302 (2024). [2] P. Jain et. al., Phys. Rev. Fluids 10, 114602 (2025).

DY 63: Nonlinear Stochastic Systems

Time: Friday 11:30–12:45 Location: ZEU/0118

DY 63.1 Fri 11:30 ZEU/0118

Stochastic Dynamics of Noisy Oscillators under Eigenfunction Transformation — •Georg Podhaisky[1,2], Alberto Pérez-Cervera[3], and Benjamin Lindner[1,2] — [1]Bernstein Center for Computational Neuroscience, Berlin, Germany — [2]Humboldt University, Berlin, Germany — [3]Universitat d'Alacant, Alicante, Spain

Stochastic oscillations are observed for a wide range of systems in biology and physics. Although their dynamics may vary drastically, a simple approach for a unified description exists. As recently demonstrated by Pérez-Cervera et al. (PNAS 120, 2023), the first non-trivial eigenfunction $Q_1^*(\mathbf{x})$ of the Kolmogorov backward operator, which is obtained from the adjoint Fokker-Planck equation, can be used as a particularly useful transformation rule: This eigenfunction maps the trajectories of a given stochastic oscillator to a complex-valued domain. In this domain the autocorrelation statistics as well as the system's linear response are characterized by simple and qualitatively universal functions, regardless of the original dynamics. Here we study the stochastic dynamics in the $Q_1^*(\mathbf{x})$ domain, specifically, a number of two-dimensional systems including the Stuart-Landau oscillator and the harmonic oscillation with damping and thermal noise.

DY 63.2 Fri 11:45 ZEU/0118

Impact of heavy-tailed synaptic strength distributions on self-sustained activity in networks of spiking neurons — •Ralf Tönjes — Humboldt Universität, Berlin, Deutschland

We analyze states of stationary activity in randomly coupled quadratic integrate-and-fire neurons using stochastic mean-field theory. Specifically, we consider the two cases of Gaussian random coupling and Cauchy random coupling, which are representative of systems with light- or with heavy-tailed synaptic strength distributions. For both, Gaussian and Cauchy coupling, bistability between a low activity and a high activity state of self-sustained firing is possible in excitable neurons. In the system with Cauchy coupling we find analytically a directed percolation threshold, i.e., above a critical value of the synaptic strength, activity percolates through the whole network starting from a few spiking units only. The existence of the directed percolation threshold is in agreement with previous numerical results in the literature for integrate-and-fire neurons with heavy-tailed synaptic strength distribution. However, we have found that the transition can be continuous or discontinuous, depending on the excitatory-inhibitory imbalance in the network. Networks with Gaussian coupling and networks with Cauchy coupling and additional additive noise lack the percolation transition in the thermodynamic limit.

DY 63.3 Fri 12:00 ZEU/0118

Stochastic thermodynamics of bifurcations in all-to-all interacting systems — •Ankita Gupta[1] and Aljaž Godec[1,2] — [1]Mathematical Physics and Stochastic Dynamics, Institute of Physics, University of Freiburg, 79104 Freiburg im Breisgau, Germany — [2]Mathematical bioPhysics Group, Max Planck Institute for Multidisciplinary Sciences, Am Fassberg 11, 37077 Göttingen, Germany

All-to-all interacting systems provide a fundamental framework for understanding cooperative behavior and synchronization. Here, we examine the stochastic thermodynamics of such systems in continuous space as they are driven across bifurcation. Our analysis centers on the total entropy production rate (tEPR), which quantifies the thermodynamic cost of maintaining or transitioning between different dynamical phases. Focusing on the microscopically reversible Desai-Zwanzig model and irreversible Bonilla-Casado-Morillo models, we investigate how the tEPR depends on microscopic parameters-including interaction strength, temperature, and external driving. Leveraging recent advances on the Onsager-Machlup functional for McKean-Vlasov stochastic differential equations, we study path measures and char-

acterize dynamical fluctuations near criticality. Through a combination of phase-plane methods and numerical simulations, we reveal the structure and nature of the bifurcations across a range of parameter regimes.

DY 63.4 Fri 12:15 ZEU/0118

Estimation of typical time scales in a Langevin-type model for wind turbine power conversion — •Martin Wagner and Joachim Peinke — Carl von Ossietzky Universität Oldenburg, School of Mathematics and Science, Institute of Physics, ForWind - Center for Wind Energy Research, Küpkersweg 70, 26129 Oldenburg, Germany

In the recent years, a data-driven and computationally efficient Langevin approach has been successfully used to detect physically reasonable fixed points in the short-term power conversion dynamics of wind turbines [1]. In our contribution, we aim to use this model to describe the multi-body interaction and possible synergy effects of the power production of many turbines in a wind farm. Additionally to the fixed points, this requires the extraction of the typical inertial time scales of the power conversion from the stochastic model. We find that this is difficult, since the model does not fulfil the Markov property due to a projection that induces a memory kernel to the stochastic differential equation according to the Mori-Zwanzig formalism [2]. Nevertheless, we show that upper boundary estimates for the typical inertial time scales of a wind turbine can be extracted from the stochastic model. In the future, this is a first step towards the stochastic modelling of many turbines, e.g. to model a grid-supportive power production of a whole wind farm.

[1] Milan P, et al. Phys Rev Lett. 2013;110(13):138701.

[2] Zwanzig R. Nonequilibrium Statistical Mechanics. Oxford University Press; 2001. p. 149 ff.f.

DY 63.5 Fri 12:30 ZEU/0118

Universal Kardar-Parisi-Zhang scaling in non-equilibrium magnon condensates — •Alexander Wowchik and Achim Rosch — Institute for Theoretical Physics, University of Cologne, Zülpicher Str. 77, 50937 Köln, Germany

Extensive studies in the past decade have unveiled how driven-dissipative condensates in one and two dimensions can form a unique non-equilibrium phase of matter characterized by a Kardar-Parisi-Zhang (KPZ) equation for the emergent Goldstone modes. We investigate whether the condensation of magnons, as demonstrated in Yttrium Iron Garnet (YIG) films when driven with microwave radiation, is a suitable candidate to study such phenomena. Via micromagnetic simulations of a corresponding system, we show that, after strong initial pumping, the dynamical autocorrelation function of the magnon field exhibits the universal scaling exponent predicted by the KPZ equation.

DY 64: Closing Talk (joint session CPP/BP/DY)

Time: Friday 13:15–14:00 Location: HSZ/0002

Invited Talk DY 64.1 Fri 13:15 HSZ/0002

Biomolecular Condensates: Challenges for Polymer Physics — •Jens-Uwe Sommer — Leibniz-Insitut für Polymerforschung Dresden, Bereich Theorie der Polymere,Hohe Straße 6, 01069 Dresden, Germany — TU Dresden, Insitut für Theoretische Physik, Zellescher Weg 17, D-01069 Dresden, Germany

Biomolecular condensates (BMCs) constitute an emerging paradigm in the understanding of biological functions. They shift the focus from individual biochemical processes toward the collective behavior of biopolymers, in which phase-separation mechanisms and intrinsically disordered proteins lacking canonical enzymatic roles play central and often decisive functions. Consequently, universal principles of complex (bio)polymer solutions gain relevance, and several classical questions in the physics of living matter can now be revisited from this polymer-physics perspective. In this talk, I will discuss theoretical approaches and concepts that are based on universal principles, with a particular emphasis on current challenges in the field.