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

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

DY 27.1 Wed 15:00 P4

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

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

DY 27.2 Wed 15:00 P4

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

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

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

DY 27.3 Wed 15:00 P4

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

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

DY 27.4 Wed 15:00 P4

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

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

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

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

DY 27.5 Wed 15:00 P4

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

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

DY 27.6 Wed 15:00 P4

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

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

DY 27.7 Wed 15:00 P4

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

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

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

DY 27.8 Wed 15:00 P4

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

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

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

DY 27.9 Wed 15:00 P4

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

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

DY 27.10 Wed 15:00 P4

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

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

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

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

DY 27.11 Wed 15:00 P4

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

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

[1] F. Hensel et al., Frontiers in AI, vol. 4 (2021)

[2] E. Cheng et al., IOP, vol.57 [30] (2024)

[3] S. Yara et al, Journal of Biomedical Informatics, vol. 130 (2022)

DY 27.12 Wed 15:00 P4

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

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

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

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

DY 27.13 Wed 15:00 P4

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

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

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

DY 27.14 Wed 15:00 P4

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

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

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

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