DY 18: Pattern Formation, Delay and Nonlinear Stochastic Systems

Time: Tuesday 9:30–13:00 Location: BH-N 128

Invited Talk DY 18.1 Tue 9:30 BH-N 128
Phase field method to model single cell locomotion and collective cell interactions — •Sergio Alonso — Group of Computational Biology and Complex Sytems, Department of Physics, Universitat Politècnica de Catalunya, Barcelona, Spain

The interior of the living cells is complex and different types of processes happens simultaneously. Such dynamics are regulated by biochemical reactions and the dynamics of different biochemical components which are commonly modeled by reaction-diffusion equations. Polarization is typically described by Reaction-Diffusion processes and determines the head and the tail of the motion of the cell. Such process has to be connected with cell deformation and cell locomotion. The definition of a dynamical phase field to determinate the interior of the cell is a common tool for biophysical modelers. Here, I will review this technique and note some application in the case of crawling amoebae.

DY 18.2 Tue 10:00 BH-N 128
Influence of physical interactions on spatiotemporal patterns — •Chengjie Luo, Lucas Menou, and David Zwicker — Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany

Complex spatiotemporal patterns are often modeled by reaction-diffusion equations, which combine complex reactions between constituents with ideal diffusion. Such descriptions neglect physical interactions between constituents, which might affect resulting patterns. To overcome this, we investigate the influence of physical interactions on two representative chemical reactions: the Hill-Langmuir equation, generating static Turing patterns for ideal diffusion, and cyclic dominant reactions, like the seminal rock-paper-scissors (rps) game, yielding dynamic spiral waves. In the Hill-Langmuir system, we find that weak repulsion substantially lowers the required differential diffusivity and reaction nonlinearity for Turing pattern formation, while strong interactions induce phase separation. For cyclic-dominant reactions, we discover that weak interactions change the length- and time scales of spiral waves. In contrast, strong repulsive interactions typically generate oscillating lattices, and strong attraction leads to an interplay of phase separation and chemical oscillations. Despite the distinct nature of the two chemical reactions, physical interactions play a crucial role in pattern formation in both cases. We thus suggest that physical interactions are crucial for forming spatiotemporal patterns in nature, so they should be incorporated when modeling realistic systems.

DY 18.3 Tue 10:15 BH-N 128
Flower wave patterns in the CHD-BZ reaction in the presence of spatial heterogeneities — Sangram Gore[1], Binaya Paudyal[1], Oliver Steinbock[2], and •Azam Gholami[1] — [1]New York University, Abu Dhabi, UAE — [2]Florida State University, Tallahassee, Florida, USA

In this work, we investigate the effects of millimeter-sized obstacles on the chemical waves in the CHD-Belosouv-Zabotinsky reaction, in which the classical organic substrate malonic acid is replaced by 1,4-cyclohexanedione (CHD). Our experiments show that an arrangement of cylindrical obstacles can significantly influence the chemical waves in the CHD-BZ reaction. We observed circular waves with a period of about 1 min that started almost synchronously at the pillars and propagated outward. However, after two cycles of outward propagating circular waves, wavefront instability sets in and flower patterns form. Interestingly, the number of petals depends on the pillars diameters and is higher for larger diameters. This instability occurs in an open-lid environment where evaporation plays an important role. In a closed lid environment, the waves remain circular and do not break. These experiments underline the importance of evaporation, which, in addition to the chemical concentration gradient, contributes to the formation of Marangoni currents.

DY 18.4 Tue 10:30 BH-N 128
A universal description of stochastic oscillators — Alberto Pérez-Cervera[1], Boris Gutkin[2], Peter J. Thomas[3], and •Benjamin Lindner[4,5] — [1]Universidad Complutense de Madrid,Spain — [2]Ecole Normale Supérieure - Paris Science Letters University, France — [3]Case Western Reserve University, Cleveland, OH, USA — [4]Institut für Physik, Humboldt-Universität zu Berlin — [5]Bernstein Center for Computational Neuroscience Berlin

Systems in physics and biology exhibit oscillations which are shaped by randomness. Dynamically, such stochastic oscillations can be caused by different mechanisms and are thus described by strongly different mathematical models, e.g. a linear dynamics with a stable focus and noise, limit-cycle systems perturbed by noise, or excitable systems in which random inputs lead to spikes. Here, we introduce a nonlinear transformation of stochastic oscillators to a complex-valued function that greatly simplifies and unifies the mathematical description of the oscillator's spontaneous activity, its response to an external time-dependent perturbation, and the correlation statistics of different, weakly coupled oscillators. The general framework (see Perez-Cervera et al. PNAS 2023) can be applied to the different example dynamics mentioned above but also to higher-dimensional systems such as two damped harmonic oscillators with thermal noise that are strongly coupled.

DY 18.5 Tue 10:45 BH-N 128
Detecting a periodic signal by a population of spiking neurons in the weakly nonlinear response regime — •Maria Schlungbaum[1,2] and Benjamin Lindner[1,2] — [1]Physics Department, Humboldt University Berlin — [2]Bernstein Center for Computational Neuroscience Berlin

Signal detection is a ubiquitous problem in several situations for living organisms. We are specifically interested in detecting a weak signal in the presence of a stronger stimulus and noise – known as cocktail party problem in auditory perception. We simplify this problem here and study the response to two periodic signals by a homogeneous population of stochastic leaky integrate-and-fire (LIF) neurons. Using a threshold-crossing of the population activity as a detection criterion, we show by the means of the receiver operating characteristics (ROC), that the detectability depends strongly on the stimulus amplitude but only weakly on the time window of observation. Interestingly, the detection of a weak periodic signal can be boosted by a strong periodic stimulus. This effect depends on the frequencies of the two signals and the dynamical regime in which the neurons operate. We also present an analytical approximation for the ROC curve based on the weakly nonlinear response theory for a stochastic LIF model.

DY 18.6 Tue 11:00 BH-N 128
Self-organizing patterns in crossing flows of pedestrians — •Pratik Mullick — Wroclaw University of Science and Technology, Wroclaw, Poland

Studying collective dynamics of human crowds are vital for enhancing pedestrian traffic flow, ensuring safety, and effective urban planning. In this research, we focus on the emergence of striped patterns when two streams of pedestrians cross, a manifestation of self-organized collective behavior. Using experimental data, we introduce numerical strategies, such as an edge-cutting algorithm and a Gabor function-based pattern-matching technique to study geometric properties of these patterns. Notably, an invariant property is revealed: stripes in crossing groups are consistently parallel, and perpendicular to the bisector of crossing angle. This work contributes to understanding and modeling crowd behavior, offering insights applicable to diverse scenarios like pedestrian traffic management and crowd safety during mass gatherings. In presenting this research, I aim to share innovative computational methods and findings that advance the comprehension of self-organizing patterns in human crowds.

15 min. break

DY 18.7 Tue 11:30 BH-N 128
Laminar chaos in systems with random delay — •David Müller-Bender[1] and Günter Radons[1,2] — [1]Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany — [2]ICM - Institute for Mechanical and Industrial Engineering, 09117 Chemnitz, Germany

A type of chaos called laminar chaos was found in singularly perturbed dynamical systems with periodically time-varying delay [Phys. Rev. Lett. 120, 084102 (2018)]. It is characterized by nearly constant laminar phases, which are interrupted by irregular bursts, where the intensity levels of the laminar phases vary chaotically from phase to phase.

While laminar chaos, which is observed in systems with a so-called dissipative delay, is a low-dimensional phenomenon, its counterpart called turbulent chaos is a high-dimensional type of chaos, which is typically found in systems with conservative (including constant) delays. In this talk, we demonstrate that laminar chaos can also be found in systems with randomly time-varying delay. Moreover, for short time correlated random delay variations it turned out that laminar chaos and its generalizations are observed in almost the whole delay parameter space spanned by the mean delay and the delay amplitude. This means that introducing such a random delay variation into the considered class of systems typically leads to a drastic reduction of the dimension of the chaotic attractor.

DY 18.8 Tue 11:45 BH-N 128

Temporal localized states in an injected Kerr Gires-Tournois Interferometer: The influence of phase modulation. — •Marc Hunkemöller[1], Thomas Seidel[1], Svetlana Gurevich[1,2], and Julien Javaloyes[3] — [1]Institute for Theoretical Physics, University of Münster, Germany — [2]Center for Nonlinear Science, University of Münster, Germany — [3]Departament de Física & IAC-3, Universitat de les Illes Balears, Spain

We study an injected Kerr Gires-Tournois interferometer (KGTI) in which a periodic modulation of the feedback phase is introduced that can be interpreted as a periodic potential. We investigate the first principle model based upon delay algebraic equations using direct numerical simulations and path continuation techniques. The micro-cavity's dispersion and Kerr effect combined with detuned injection give rise to temporal localized states (TLSs) which live on a continuous wave (CW) background and synchronize with the periodic potential. We show that the Arnold tongues limiting the synchronized regime are realized by a SNIPER bifurcation. Furthermore, we study the movement of the TLSs in the periodic potential, caused by third order dispersion. In the limit of weak injection and small cavity losses the system is compared to the Lugiato-Lefever equation. The linear part is solved by Hermite-Gauss modes therefore a mode decomposition is conducted.

DY 18.9 Tue 12:00 BH-N 128

Temporal localized states in an injected Kerr-Gires-Tournois interferometer in the regime of anomalous dispersion — •Tim Lohmann[1], Thomas G. Seidel[1], Julien Javaloyes[2], and Svetlana V. Gurevich[1,2,3] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9, 48149 Münster, Germany — [2]Departament de Física, Universitat de les Illes Balears and IAC-3, Cra. de Valldemossa, km 7.5, E-07122 Palma de Mallorca, Spain — [3]Center for Nonlinear Science (CeNoS), University of Münster, Corrensstraße 2, 48149 Münster, Germany

We are interested in the dynamics of temporal localized states (TLSs) in an injected Kerr-Gires-Tournois interferometer (KGTI) in the regime of anomalous dispersion. In this regime and in the uniform field limit, the first principle model based upon delay algebraic equations can be approximated by the Lugiato-Lefever partial differential equation, giving rise to the formation of TLSs.Using the combination of numerical simulations and path continuation techniques, we demonstrate that for parameter values far away from the Lugiato-Lefever regime a new form of short high-intensity TLSs emerges.

DY 18.10 Tue 12:15 BH-N 128

Solitons beyond the uniform field limit in injected Kerr resonators — Thomas Seidel[1], Julien Javaloyes[2], and •Svetlana Gurevich[1,3] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9, 48149 Münster, Germany — [2]Departament de Física & IAC-3, Universitat de les Illes Balears, C/ Valldemossa km 7.5, 07122 Mallorca, Spain — [3]Center for Nonlinear Science (CeNoS), University of Münster, Corrensstrasse 2, 48149 Münster, Germany

We elucidate the formation of temporal localized states (TLSs) in an injected Kerr-Gires-Tournois interferometer in the normal dispersion regime and operated far from the uniform field limit (UFL). Our first principle model is based upon time delayed algebraic equations whose uniform validity allows for a systematic exploration of all the parameter space. While in the weakly nonlinear regime the cavity response and the dynamics can be described by the Lugiato-Lefever equation (LLE), such a framework breaks down in the regimes of large detuning and injection. By using a combination of direct numerical simulations and path continuation techniques, we investigate these new regimes that departs from the UFL and find short, high-intensity TLSs which live on a single stable continuous wave (CW) background. In this regime, the previously stable upper CW solution becomes Turing unstable. Further, we analyze the transition between the LLE and the UFL and the change of the shape of the TLSs.

DY 18.11 Tue 12:30 BH-N 128

Stable semivortex solitons in a fermionic condensate — •Pablo Díaz — Departamento de Ciencias Físicas, Universidad de La Frontera, Temuco, Chile

In the present work, we numerically show the existence of semivortex solitons in a two-dimensional fermionic spinor, which has never been previously reported in the literature. This soliton is free of two-dimensional potentials and includes a Rashba-type spin-orbit coupling. The theoretical framework consists of a mean-field theory applied to a Fermi superfluid. We obtain the gap solitons using an ansatz of semivortex type. This approach allows us to reduce the two-dimensional equations to a system of radial equations determined numerically for a parameter space given by the chemical potential and the cross-interaction between the spinors. To test the stability of the soliton solutions, we performed real-time computational simulations using finite differences with the Runge-Kutta 4 method. Our results show that the soliton stability zone only partially coincides with the Vakhitov-Kolokolov linear stability criterion. Interestingly, we have found stable solitons for times much larger than the simulations observed in similar works for bosonic systems. Moreover, this stability was tested by inducing oscillations of a soliton due to a step-like change of the Zeeman parameter. We compute the resulting fluctuations in the spin state of the soliton induced by the transfer of particles between the spinors.

DY 18.12 Tue 12:45 BH-N 128

Modeling 1/f noise using models with overlapping pulses — •Aleksejus Kononovicius and Bronislovas Kaulakys — Institute of Theoretical Physics and Astronomy, Vilnius University, Vilnius, Lithuania

White noise and Brownian motion are well understood types of noise and fluctuations in variety of materials, devices, and other physical and non-physical systems. Universal nature of 1/f noise remains an elusive problem. Earlier we have considered an elementary model with non-overlapping rectangular pulses in a conductive material [1, 2]. We have shown that pure 1/f noise can be obtained only with long pulses and power-law distributed gaps (or vice versa). Taking the point process limit results in perversion of 1/f noise, which suggests that allowing pulses to touch can also cause perversion. Here we show that this intuition is wrong, even a model with overlapping pulses exhibits pure 1/f noise.

[1] A. Kononovicius, B. Kaulakys, PRE 107: 034117 (2023).
[2] A. Kononovicius, B. Kaulakys, arXiv:2306.07009.