DY 15: Pattern Formation

Time: Tuesday 10:00–13:15 Location: H3

DY 15.1 Tue 10:00 H3

Spontaneous center formation in Dictyostelium discoideum — •Estefania Vidal-Henriquez and Azam Gholami — Max Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, D-37077 Göttingen, Germany

Dictyostelium discoideum (D.d.) is a widely studied amoeba due to its capabilities of development, survival, and self-organization. During aggregation it produces and relays a chemical signal (cAMP) which shows spirals and target centers. Nevertheless, the natural emergence of these structures is still not well understood. We present a mechanism for creation of centers and target waves of cAMP in D.d. by adding cell inhomogeneity to a well known reaction-diffusion model of cAMP waves and we characterize its properties. We show how stable activity centers appear spontaneously in areas of higher cell density with the oscillation frequency of these centers depending on their density. The cAMP waves have the characteristic dispersion relation of trigger waves and a velocity which increases with cell density. Chemotactically competent cells react to these waves and create branching aggregation streams even with very simple movement rules. Finally we argue in favor of the existence of a degradation which scales with local density to maintain the wave properties once small cell clusters appear in the high density streams.

DY 15.2 Tue 10:15 H3

Controlling discrete pattern formation with local signals — •Stephan Kremser, Tiago Ramalho, Hao Wu, and Ulrich Gerland — Technical University of Munich

Programmability is a fruitful concept to explore the extent to which a dynamical system can be steered by external inputs or internal feedback signals. Here, we propose a minimal system for studying the programmability of discrete patterning, based on one-dimensional cellular automata, which process discrete local signals to update their internal state according to logical rules. The organization signals are given by individual cells that are located either within the system or at its boundary. This framework is sufficiently general to encompass a broad class of model systems, yet simple enough to permit exhaustive analysis. We study model systems with different update rules and different topologies, to assess their ability to perform programmable pattern formation and their susceptibility to errors. We find that only a small subset of model systems permits local organizer cells to dictate any target pattern. These systems follow a common principle whereby a temporal pattern is transcribed into a spatial pattern. Our results establish a basis for the design of synthetic systems, and for more detailed models of programmable pattern formation closer to real systems.

DY 15.3 Tue 10:30 H3

Effects of time-periodic forcing in a generalized Cahn-Hilliard model for the Langmuir-Blodgett transfer — •Phong-Minh Timmy Ly[1], Uwe Thiele[1], Lifeng Chi[2], and Svetlana V. Gurevich[1] — [1]Westfälische Wilhelms-Universität, 48149 Münster, Germany — [2]Soochow University, 215123 Suzhou, P.R. China

The Langmuir-Blodgett transfer is a surfactant based dip-coating technique where pattern formation occurs via self-organization. In particular, a solid substrate is pulled out of a liquid bath, covered by a monolayer of surfactants. In this setup the transfer velocity is the main control parameter and leads to deposition of different kinds of patterns depending on its magnitude. The procedure excels in through-put in comparison to traditional lithographic methods as means for pattern creation but lacks in terms of uniformity and ways to control the patterns. Therefore, we investigate the effect of a time-periodically modulated velocity on the pattern formation by means of a generalized Cahn-Hilliard equation. 1D and 2D direct numerical simulations reveal various synchronization phenomena as well as the deposition of a variety of complex patterns. Interestingly, it is also possible to influence the system in the spatial direction which is transversal to the direction of the forcing which can lead to the formation of synchronized patterns in two-spatial dimensions.

DY 15.4 Tue 10:45 H3

DNS of liquid films under lateral and normal excitations — •Sebastian Richter and Michael Bestehorn — Department of Theoretical Physics, BTU, 03044, Cottbus, Germany

We investigate the dynamics of a two-dimensional liquid film on a horizontal substrate with free and deformable surface. The system is subjected to a time-periodic gravitation field in normal or lateral direction. We present a finite-difference method on staggered-grids for the full incompressible Navier-Stokes equations. To avoid surface tracking and to reduce the necessary interpolations to a minimum, the time-dependent free surface is mapped to a constant rectangular region using the non-linear transformation $z = h(x, t) \cdot \tilde{z}$ of the vertical coordinate. Taking the continuity equation into account, a sparse linear system for the pressure, whose solution fulfills momentum and mass conservation, can be computed directly from the discretized Navier-Stokes equations allowing us to refrain from applying pressure corrections. We compare our findings to those of a simplified model studied in [1] and [2]. Vertical excitations generate the classic Faraday waves and lateral forces engender the formation of coarsening droplets. A preferred direction of motion of the drops and a non-vanishing mean flow rate is observed for lateral excitations that break the horizontal mirror symmetry $x \to -x$. Our results show good agreement with the model.

[1] M. Bestehorn, "Laterally extended thin liquid films with inertia under external vibrations", Phys. Fluids 25, 114106 (2013)
[2] S. Richter and M. Bestehorn, "Thin-Film Faraday patterns in three dimensions", Eur. Phys. J. Special Topics 226, 1253 (2017)

DY 15.5 Tue 11:00 H3

Simulation of surface evolution beyond the small gradient approximation — •Christoph Kabelitz and Stefan Jakob Linz — Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster

Apart from three-dimensional and discrete models the evolution of surfaces is usually described by spatially two-dimensional PDEs. These models are often derived from small gradient approximations, but the studied surfaces do not fulfill this requirement in all cases. We will explain how to overcome the small gradient approximation. Therefore, we will introduce a method to simulate the evolution of surfaces with respect to local geometric properties. In contrast to traditional PDEs, the resulting geometric PDEs do not depend on the parametrization of the surface [1]. This allow us to simulate surface evolution not only on almost flat surfaces but also on more complex shaped objects. For small gradients the studies of simple model equations show similar results compared to the related PDEs (like the Kuramoto-Sivashinsky equation [2, 3]). For large gradients the results differ fundamentally.

[1] M. Marsili et al, Rev. Mod. Phys., 68, 963 (1996).
[2] Y. Kuramoto and T. Tsuzuki, Progress of Theoretical Physics, 55, 356 (1976).
[3] G. Sivashinsky, Acta Astronautica, 4, 1177 (1977).

DY 15.6 Tue 11:15 H3

Pattern formation in salt playa — •Jana Lasser — Max Planck Institut für Dynamik und Selbstorganisation, Göttingen

Salt pans are geological sinks where evaporation outweighs precipitation. As a result, a continuous salt crust forms, which expresses iconinc hexagonal ridge patterns with a diameter of roughly one meter. We model the process driving the emergence of these patterns as result of an instability in a dynamical process, taking place in the ground below the patterns: Here, the subsurface is composed of a porous medium saturated with salty water. As water evaporates through the surface, a salinity gradient builds below the surface and is prone to a buoyancy-driven convective instability. With this advection-diffusion model, we can explain the onset of convection as well as the length scale of the patterns. We show evidence from experiments, numerical simulations and direct field observations, confirming that convection takes place in the underground, and that convection cells are co-located with the patterns visible on the surface.

15 min. break

DY 15.7 Tue 11:45 H3

Single-Mode Turbulence in Pattern-Forming Protein Systems — •Jonas Denk, Jacob Halatek, Fridtjof Brauns, Korbinian Pöppel, and Erwin Frey — Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität München, Germany

Protein pattern formation often relies on proteins that cycle between a cytosolic bulk and a membrane at which they undergo molecular interactions. On a flat membrane, this cycling can lead to intriguing protein patterns including spiral waves as well as more irregular dynamics such as chemical turbulence. While theoretical approaches have been able to reproduce various experimentally observed protein patterns, the underlying mechanisms for pattern selection remain poorly understood. Motivated by the bacterial Min protein system, we present a spatially reduced reaction-diffusion model to study pattern selection in protein systems with bulk-membrane coupling. Remarkably, we find that already a single-mode instability can lead to turbulent dynamics at the onset of pattern formation. Further away from this onset, we observe a transition from turbulent to coherent patterns, which can be explained on the basis of diffusively coupled local equilibria. Our study yields insights into a novel route to chaos for a widespread class of mass-conserving reaction-diffusion systems with bulk-boundary coupling.

DY 15.8 Tue 12:00 H3

Transition to Chaos: From Small to Large Domains in the Nikolaevskiy Model — •Simon Hartmann, Steffen Richters-Finger, and Stefan J. Linz — Institut für Theoretische Physik, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Straße 9, 48149 Münster

We investigate the dynamics and the transition to spatiotemporal chaos observed in the partial differential equation known as Nikolaevskiy equation in one and two spatial dimensions while applying periodic boundary conditions. In contrast to the generic chaotic solution in large domains, the model exhibits rich possibilities for different chaotic and non-chaotic dynamics if the considered domain size is constrained to only a few characteristic wavelengths. Extending the work by Tanaka [1], we provide an in-depth numerical analysis including maps of several parameter subspaces and results from the numerical continuation of many types of regular dynamics.

[1] Tanaka D., J. Phys. Soc. Jpn., 74, 2223 (2005).

DY 15.9 Tue 12:15 H3

Nonlinear analysis of dissipative systems with a conservation law — •Tobias Frohoff-Hülsmann[1] and Uwe Thiele[1,2] — [1]Institute of Theoretical Physics, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 9, 48149 Münster — [2]Center of Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, Corrensstr. 2, 48149 Münster

We investigate the coupled dynamics of a conserved and a non-conserved order parameter field using the generic example of a Cahn-Hilliard equation coupled to a Swift-Hohenberg equation. Uncoupled, both equations have a gradient dynamics structure and we employ couplings that may preserve or violate this structure. In both cases, the coupled system can show short- and long-scale instabilities. We analytically examine the types of linear instability and the weakly nonlinear behaviour deriving amplitude equations which are generically influenced by the conservation law. The weakly nonlinear results are compared to fully nonlinear bifurcation diagrams obtained with numerical path continuation. Finally, we discuss the generic consequences of a conservation law in variational and nonvariational systems.

DY 15.10 Tue 12:30 H3

Pattern formation of a coupled Turing-polarity model — •Francine Kolley[1], Peter Gross[1], K Vijay Kumar[2], and Stephan W Grill[1] — [1]BIOTEC, TU Dresden, Germany — [2]ICTS, Bangalore, India

Pattern formations are ubiquitous phenomena in nature. It is the ability of non-equilibrium systems to form stable, spatially non-homogeneous states. Such non-equilibrium patterns can emerge via a large class of distinct mechanisms.
Our aim is to couple two different mechanisms, Turing patterns and polarity patterns.
Turing systems are typically described using a diffusion term, which enables to spread out over the space and a reaction term, which couples two different species. These two species can establish Turing patterns under the condition of short-ranged activation and long-ranged inhibition.
In comparison to Turing systems, a central feature of polarity models is mass conservation. As a consequence, the patterned state generally has a singular domain. Furthermore, polarity models can show multistability, where the homogeneous state and the patterned state are both stable to perturbations.
We construct a model that can be gradually shifted from a pure Turing system to a pure polarity system. We investigate the pattern formation properties of this model, with a particular emphasis on the region where the Turing mode and the polarity mode compete.

DY 15.11 Tue 12:45 H3

Nonlinear patterns shape their domain on which they live — •Mirko Ruppert[1], Falko Ziebert[2] und Walter Zimmermann[1] — [1]Theoretical Physics I, University of Bayreuth, Germany — [2]Institute for Theoretical Physics, Heidelberg University, Germany

We investigate nonlinear pattern formation on a finite domain with fixed area but flexible borders. The self-consistent interplay between the stationary stripe pattern of a Swift Hohenberg model and the domain boarders, described by a phase field, may reshape the domain. With increasing amplitude of the stripe pattern the nearly circular domain for a small pattern amplitude deforms with increasing amplitude into an elliptical shaped domain. The behavior of this coupling resembles experimental observations made for vertically vibrated liquid drops. We also couple the Cahn-Hilliard model to a phase field, where the demixing process of a binary emulsion deforms the domain shape.

DY 15.12 Tue 13:00 H3

Boundary driven oscillations in *Dictyostelium discoideum* — •Torsten Eckstein, Estefania Vidal-Henriquez, and Azam Gholami — Max Planck Institute for Dynamics and Self-Organization, Goettingen, Germany

Dictyostelium discoideum amoeba aggregate if deprived of nutrients, producing wave patterns of a chemo attractant called cyclic adenosine monophosphate (cAMP). To successfully produce waves, the role of degradation of cAMP by phosphodiesterase is fundamental, preventing the accumulation of cAMP and producing the gradients necessary for cell detection. The knockout mutant pdsA^{-} can not produce the most active type of phosphodiesterase and therefore does not show pattern formation under normal circumstances. Using a microfliuidic channel, we show how an advective flow can partially recover signaling in this system. Above a minimum flow velocity decaying waves are induced, with a decay length that scales with the applied flow speed. After stopping the advecting flow, the cells continue to signal, showing normal structures and aggregation, although with a wave period much higher than in wild type cells. Extensive numerical simulations showed that these waves have a boundary driven origin, where the lack of cAMP in the upstream flow destabilizes the system. We explored the parameter region where these waves exist and their properties, with good agreement with our experimental observations. The results here presented provide experimental confirmation of the destabilizing effect of the upstream boundary in an otherwise stable reaction-diffusion system.