DY 39: Pattern Formation and Reaction-Diffusion Systems

Time: Thursday 10:00–12:15 Location: H19

DY 39.1 Thu 10:00 H19

Dynamics of tagged particles in a biased $A + A \to \emptyset$ system in one dimension : result for asynchronous and parallel updates — •Reshmi Roy[1], Parongama Sen[1], and Purusattam Ray[2] — [1]University of Calcutta, Kolkata, India — [2]IMSC, Chennai, India

We have studied dynamical features of tagged particles in one dimensional $A + A \to \emptyset$ system, where the particles A have a bias ϵ such that they move towards their nearest neighbour with the probability $0.5+\epsilon$ and move in the opposite direction with probability $0.5-\epsilon$ and annihilate on contact. We found that for $\epsilon > 0$ when asynchronous dynamics is used to update the system, probability distribution $\Pi(x,t)$ of the particles shows a double peak structure with a dip at $x = 0$ and it assumes a double delta form at very late time regime. For any $\epsilon > 0$, there is a crossover at time t^*, below which the particle motions are highly correlated, and beyond t^*, the particles move as independent biased walkers. When we use parallel updating rule, $\Pi(x,t)$ shows a non-Gaussian single peaked structure and the fraction of surviving particle $\rho(t)$ shows a $\ln t/t$ variation. For the deterministic point $\epsilon = 0.5$, we found that an isolated pair of particles, termed as dimers, can survive indefinitely in the system which is exclusive for parallel dynamics. When ϵ is made negative, $\Pi(x,t)$ becomes Gaussian as found in $\epsilon = 0$. A comparative analysis for the relevant quantities using asynchronous and parallel dynamics shows that there are significant differences for $\epsilon > 0$ while the results are qualitatively similar for $\epsilon < 0$.

Journal Ref: J. Phys. A: Math. Theor. 53, 155002 (2020), J. Phys. A: Math. Theor. 53, 405003 (2020), Physica A 97569, 125754 (2021).

DY 39.2 Thu 10:15 H19

Wrinkling in Curved Films — •Megha Emerse and Lucas Goehring — Nottingham Trent University, Nottingham, United Kingdom

Thin films or sheets exposed to external forces can become unstable to drastic shape changes, often forming regular or periodic patterns like wrinkles, folds, creases, etc. This can be distinctly observed when one tries to wrap a world map onto a globe since it is unachievable without creating any wrinkles. Wrinkling is a self-initiated process, spontaneously generating periodic structures out of a uniformly smooth surface and represents a pathway for simply creating regular surface topography. Here, we study thin elastic membranes that form complex wrinkle patterns when put on substrates where there is a mismatch in their inherent shape. Using 3D-printed moulds, we prepare elastic membranes with different curvatures, including cases of positive and negative Gaussian curvature, and shapes with two distinct principal curvatures. Through these, we experimentally investigate the dependence of the amplitude and wavelength of the wrinkles that spontaneously form when these curved membranes are constrained by a flat fluid substrate. We also study how these properties change along the membrane, for example with distance from the film edges.

DY 39.3 Thu 10:30 H19

Exploring Bifurcations in Bose-Einstein Condensates via Phase Field Crystal Models — •Alina B. Steinberg[1], Fabian Maucher[2], Svetlana V. Gurevich[1,3], and Uwe Thiele[1,3] — [1]Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Strasse 9, 48149 Münster, Germany — [2]Departament de Física, Universitat de les Illes Balears \& IAC-3, Campus UIB, E-07122 Palma de Mallorca, Spain — [3]Center of Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, Corrensstrasse 2, 48149 Münster, Germany

To facilitate the analysis of pattern formation and phase transitions in Bose-Einstein condensates as well as to unravel analogies we present an explicit approximate mapping from the nonlocal Gross-Pitaevskii equation with cubic nonlinearity to a model of phase field crystal type. This approximation is valid close to the superfluid-supersolid phase transition and permits us to explore the phase transition through the corresponding bifurcation diagrams obtained via numerical path continuation. Additionally the effects of phenomenological higher order nonlinearities are considered. In passing we discuss the importance of localized states as an indicator of a first order character of the phase transition. A. B. Steinberg, F. Maucher, S. V. Gurevich and U. Thiele, Exploring Bifurcations in Bose-Einstein Condensates via Phase Field Crystal Models, http://arxiv.org/abs/2205.15194 (2022)

DY 39.4 Thu 10:45 H19

Phase Field Crystal model for particles with n-fold rotational symmetry in two dimensions — •Robert F. B. Weigel and Michael Schmiedeberg — Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

We introduce a Phase Field Crystal (PFC) model for particles with n-fold rotational symmetry in two dimensions [1]. The n-fold symmetry of the particles corresponds to the one that can be realized for colloids with symmetrically arranged patches, with the patches being either attractive or repulsive.

Our approach is based on a free energy functional that depends on the reduced one-particle density, the strength of the orientation, and the direction of the orientation, where all these order parameters depend on the position. The functional is constructed such that for particles with axial symmetry (*i. e.* $n = 2$) the PFC model for liquid crystals [2] is recovered. We explain how both, repulsive as well as attractive patches, are described in our model.

We discuss the stability of the functional and explore phases that occur for $1 \leq n \leq 6$. In addition to isotropic, nematic, stripe, and triangular order, we also observe cluster crystals with square, rhombic, honeycomb, and even quasicrystalline symmetry.

[1] arXiv:2204.00051 [cond-mat.soft]
[2] H. Löwen, *J. Phys.: Condens. Matter* **22**, 364105 (2010)

15 min. break

DY 39.5 Thu 11:15 H19

Control-optimisation for spatiotemporal chaos in 2D excitable media through a genetic algorithm — •Marcel Aron[1,2,3], Thomas Lilienkamp[2,4], Stefan Luther[1,2,3,5], and Ulrich Parlitz[2,3,5] — [1]Institute of Pharmacology and Toxicology, University Medical Center Göttingen, Göttingen, Germany — [2]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [3]Institute for the Dynamics of Complex Systems, Georg-August-Universität Göttingen, Göttingen, Germany — [4]Computational Physics in den Life Sciences, Technische Hochschule Nürnberg, Nürnberg, Germany — [5]German Center for Cardiovascular Research (DZHK), Partner Site Göttingen, Göttingen, Germany

The emergence of spatiotemporal chaos (i.e. fibrillation) in the cardiac muscle (an excitable medium) leads to loss of pumping function and sudden cardiac death. Clinically, such episodes are treated with high-energy electric shocks to control (terminate) the chaotic dynamics and restore a regular heart rhythm. However, high shock energies result in increased risk of tissue damage or worsening the overall prognosis. This motivates the search for alternatives, including periodic sequences of low-energy electric pulses of constant field strength, which has seen success in pre-clinical trials on pig hearts.

Here we show that non-uniform pulse energies and time intervals can be used to further optimise the control of spatiotemporal chaos in 2D simulations of homogeneous cardiac tissue. We use a simplified shock-application model and define control-performance metrics to employ a genetic algorithm in the search for more efficient control approaches.

DY 39.6 Thu 11:30 H19

The French flag problem revisited: Creating robust and tunable axial patterns without global signaling — •Stephan Kremser[1], Gabriel Vercelli[1,2], and Ulrich Gerland[1] — [1]Physics Department, Technical University of Munich — [2]MIT Microbiology Program, Massachusetts Institute of Technology

Wolpert's French flag problem conceptualizes the task of forming axial patterns with broad regions in multicellular systems. Wolpert described two different solutions to his problem, the balancing model and thresholding of a morphogen gradient, both of which require global, long-range signaling between cells. Since global signaling becomes challenging in large systems, we computationally explore alternative solutions, which use only local cell-cell signaling and are simple enough to potentially be implemented in natural or synthetic systems. We employ cellular automata rules to describe local signal processing logics, and search for rules capable of robust and tunable axial patterning with evolutionary algorithms. This yields large sets of successful rules, which however display only few types of different behaviors. We introduce a rule alignment and consensus procedure to identify patterning modules that are responsible for the observed behaviors. With these modules as building blocks, we then construct local schemes for axial patterning, which function also in the presence of noise and growth, and for patterns with a larger number of different regions. The regulatory logic underlying these modules could therefore serve as the basis for the design of synthetic patterning systems, and as a conceptual framework for the interpretation of biological mechanisms.

DY 39.7 Thu 11:45 H19

Coupling-Mediated Protein Waves in Mass-Conserved Pattern Forming Systems — •Benjamin Winkler[1], Sergio Alonso Muñoz[2], and Markus Bär[1,3] — [1]Physikalisch-Technische Bundesanstalt — [2]Universitat Politècnica de Catalunya — [3]TU Berlin

The formation of protein patterns inside biological cells is of crucial importance for their spatial organization, growth and division. In many cases these dynamics can be described by coupled, mass-conserving reaction-diffusion equations [Brauns et al., PRX, 2020]. Motivated by the question how the generation of cell polarity is influenced by membrane heterogeneity, we study the behavior of the coupled dynamics of two well-known, mass-conserved systems. System A is therein given by a simplified model [Mori et al., Biophys.J., 2008] for the emergence of cell polarity with a single pair of activated-inactivated proteins M and B. The inactive, fast-diffusing species (B) in the bulk of the cell becomes activated (M) when bound to the cell membrane. When endowed with a positive feedback on the membrane-mediated activation, the system exhibits inherent polarizability. System B is described by the Cahn-Hilliard equation, two membrane species demixing into a pattern of comparatively small, static droplets. We then consider a difference in interaction affinity for M with respect to the two phases of the cell membrane and an additional contribution in the chemical potential of the membrane, depending on the presence of M. In the so coupled system, the emergence of traveling waves can be observed above a finite threshold of coupling strength.

DY 39.8 Thu 12:00 H19

Robustness of *in vivo* Min patterns underlines complex protein interaction motives — •Henrik Weyer, Laeschkir Würthner, and Erwin Frey — Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, Department of Physics, Ludwig-Maximilians-Universität München, Theresienstraße 37, D-80333 München, Germany

The Min protein system organizes the symmetric cell division of E. coli bacteria: Two proteins, MinD and MinE, undergo pole-to-pole oscillations via a reaction–diffusion mechanism, and guide the cell-division machinery towards midcell. In elongated, filamentous cells the pole-to-pole oscillations transition into a standing-wave pattern forming several stripes along the cell. We show that modeling of the latent MinE state, which allows for Min pattern formation over a large range of MinE densities, suppresses standing-wave patterns. This effect is explained to demonstrate a generic mechanism that latent states form a homogeneous reservoir in reaction–diffusion systems. We reason that the MinE–MinD interaction cannot be described as a single hydrolysis step, and that MinE plays a more complex role in the Min protein network, a finding supported by recent experimental evidence.