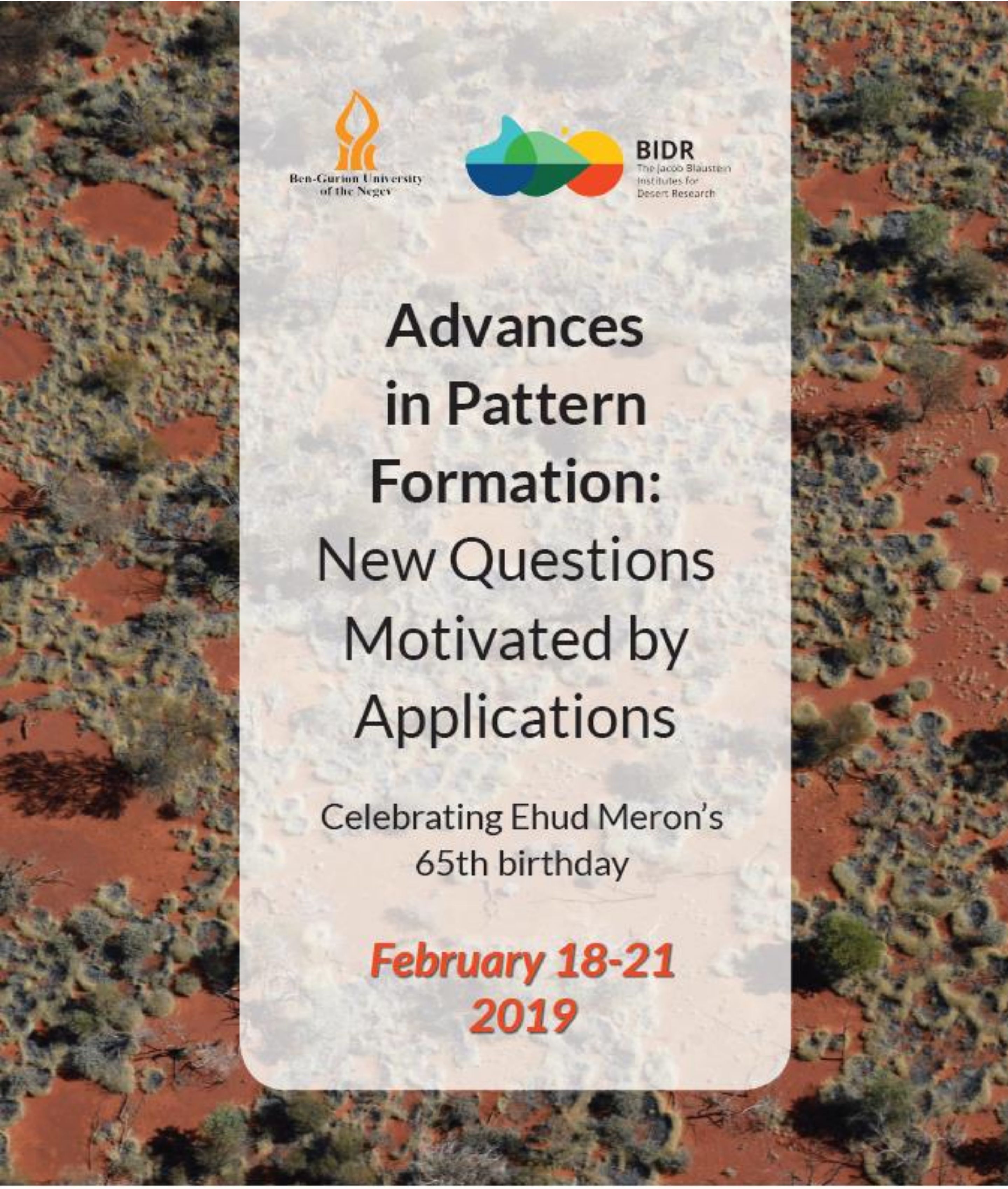

Ben-Gurion University of the Negev

BIDR The Jacob Blaustein Institutes for Desert Research

Advances in Pattern Formation: New Questions Motivated by Applications

Celebrating Ehud Meron's 65th birthday

February 18-21 2019

מרכז קלור לפיסיקה ביולוגית
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ABSTRACTS

Engineering Spatial-temporal Organization of Bacterial Suspensions

Igor ARONSON

Pennsylvania State University

Suspensions of motile bacteria or synthetic microswimmers, termed active matter, manifest a remarkable propensity for self-organization and formation of large-scale coherent structures. Most active matter research deals with almost homogeneous in space systems and little is known about the dynamics of active matter under strong confinement. I will talk on experimental and theoretical studies on the expansion of highly concentrated bacterial droplets into an ambient bacteria-free fluid. The droplet is formed beneath a rapidly rotating solid macroscopic particle inserted in the suspension. We observed vigorous inability of the droplet reminiscent of a supernova explosion. The phenomenon is explained in terms of continuum first-principle theory based on the swim pressure concept. Furthermore, we investigated self-organization of a concentrated suspension of motile bacteria Bacillus subtilis constrained by two-dimensional (2D) periodic arrays of microscopic vertical pillars. We show that bacteria self-organize into a lattice of hydrodynamically bound vortices with a long-range antiferromagnetic order controlled by the pillars' spacing. Our findings provide insights into the dynamics of active matter under extreme conditions and significantly expand the scope of experimental and analytic tools for the control and manipulation of active systems.

Modelling Physarum Microplasmodia as Active Poroelastic Two-Phase Media: Deformation Patterns, Droplet Motion and Comparison to Experiments

Markus BÄR

Physikalisch-Technische Bundesanstalt (PTB) and Technische Universität Berlin

Many processes in living cells are controlled by biochemical substances regulating active stresses. We argue that deformation patterns and waves in microplasmodia of Physarum polycephalum are an intriguing example of this. In order to model these structures, we employ a description of an active poroelastic material, where we incorporate the active stress into a two-phase model of the cytoplasm which accounts for the spatiotemporal dynamics of the cytoskeleton and the cytosol. The cytoskeleton is described as a solid matrix that together with the cytosol as an interstitial fluid constitutes a poroelastic material. We find different forms of mechanochemical waves including traveling, standing, and rotating waves even in this model [1]. A complete description of Physarum microplasmodia requires, however, a coupling of an active poroelastic medium to a reaction-diffusion dynamics, that can describe temporal oscillations as well as the regulation of the free calcium concentration in the cytosol [2,3]. Recent findings on the influence of the passive material properties on the dynamics of such patterns in active solids and fluids are presented [4]. The model for Physarum microplasmodia [2] is revisited and critically assessed in light of a plethora of recent experimental papers providing new insights into the material properties of Physarum cytoplasm as well as the pattern dynamics in stationary and moving microplasmodia. Motivated by recent experiments, we also have modelled the flow-driven amoeboid motility that is exhibited by protoplasmic droplets of Physarum. Here, the feedback loop between a chemical regulator, active mechanical deformations, and induced flows described above gives not only rise to spatio-temporal contraction patterns but also results in directed motion of microplasmodia. This in line with experimental observations of contraction patterns in these droplets. Here, we present an approach that includes free boundary conditions [5], nonlinear friction between droplet and substrate and a nonlinear reaction kinetic for the regulator to model the movement of these droplets. We find deformations of the droplet boundary as well as oscillatory changes in the droplets position with a net motion in each cycle. References: [1] M. Radszuweit, S. Alonso, H. Engel, and M. Bär, Phys. Rev. Lett. 2013. [2] M. Radszuweit, H. Engel, and M. Bär, PLoS One 2014. [3] S. Alonso, U. Strachauer, M. Radszuweit, M. Bär, and M. Hauser, Physica D 2016. [4] S. Alonso, M. Radszuweit, H. Engel, and M. Bär, J. Phys. D: Appl. Phys. 2017. [5] D. A. Kulawiak, J. Löber, M. Bär, and H. Engel, J. Phys. D: Appl. Phys. 2019.

Recent News About Bacterial Swarming

Avraham BE'ER
Ben-Gurion University of the Negev

Bacterial swarming is a biophysical phenomenon describing collective motion of thousands of self-propelled cells. During swarming, the cells interact and form long-lived jets and vortices, thought to be governed by short-range steric forces and long-range hydrodynamic effects. How exactly, and whether they indeed take decisions is not really clear, but the exact evolutionary advantage of swarming in bacteria is definitely unknown. In the talk I will describe the experiments we perform in details, and will present some of the recent results we have obtained in the last five years. For instance, I will show results for (1) Levy Walk statistics of individual bacteria migrating among their siblings in the crowded swarm, (2) puzzling swimming of cells against their own collective flow, and (3) the influence of cell aspect ratio, and rotational diffusion on swarming.

Somitogenesis: The Segmentation of the Antero-posterior Axis in Vertebrates

David BENSIMON
École Normale Supérieure Paris

Somitogenesis is the process by which the antero-posterior axis is segmented in vertebrate giving rise to the spinal cord and defining the coordinate system around which the limbs and organs are organised. This process involves the interaction between a segmentation clock in the tail and a posterior moving morphogenetic wavefront. In this talk I will describe a series of experiments aimed at testing a model of the wavefront. While our experiments in zebrafish are consistent with the predictions of our model, the model makes further predictions that could be tested in other model organisms.

Dynamical Wave Patterns in the Cortex of Motile Amoeboid Cells

Carsten BETA

University of Potsdam

The actin cytoskeleton provides the basis for shape dynamics and motility of eukaryotic cells that play a central role in processes such as wound healing, embryonic morphogenesis, or cancer metastasis. In cells of the social amoeba Dictyostelium discoideum, a well-established model organism for cell motility and chemotaxis, dynamic ring-shaped actin waves spontaneously emerge in the cell cortex. To image the large-scale dynamics of these patterns independently of boundary effects, we produced giant cells by electric-pulse-induced cell fusion. In these cells we observed that actin waves are coupled to the border of phosphatidylinositol (3,4,5)-trisphosphate (PIP3)-rich bands. These composite structures display a constant width, they propagate across the ventral plasma membrane with undiminished speed, and display typical features of an excitable system, such as mutual annihilation upon collision. Here we present results that show how wave formation impacts shape dynamics and motility. We also explored various approaches to manipulate the dynamics of actin waves, such as micropipette aspiration and microchannel confinement. We compared our experimental observations to numerical solutions of a model that combines a noisy reaction-diffusion system with a dynamic phase field for the cell shape and identify key factors that control the interplay of subcellular actin waves and cell shape dynamics.

Ecological Pattern Formation in Trait and Physical Space

Bernd BLASIUS

University of Oldenburg

Pattern formation is a fundamental process in ecology. As every individual is characterized not only by its position in space but also by quantitative traits (e.g. body size or resource affinities) that define its interaction to others, ecological pattern formation arises in two different flavours: it may shape the distribution of spatial positions or of trait values. This led to two independent bodies of research. One the one hand, 'classic' pattern formation theory has been applied to describe the spatial structure of populations of individuals. On the other hand, trait-based models predict the emergence of lumped trait distributions due to the effect of non-local competitive or feeding interactions. In this presentation I revisit ecological theory that aims to combine these two approaches. I will present a simple model of a trait-based metacommunity in a spatially continuous landscape. Each species is described by a functional trait on a niche axis and lives along an environmental gradient, characterized by a spatial coordinate. Growth rates and species interactions are determined by the position and relative distances in this space. Without dispersal species will be sorted along optimal environmental positions, but with the onset of dispersal species are displaced into unfavourable positions (source-sink dynamics) leading to complex model outcomes, such as species lumping in trait and physical space and non-monotonous response of diversity to changes in dispersal strength. I will apply this framework to spatial resource competition and zonation of salt marsh plants on an elevation gradient.

Nonlinear Dynamics of the Auditory System

Dolores BOZOVIC

University of California at Los Angeles (UCLA)

The inner ear constitutes a remarkable biological sensor that exhibits nanometer-scale sensitivity of mechanical detection. The first step in auditory processing is performed by hair cells, which act as transducers that convert minute mechanical vibrations into electrical signals that can be sent to the brain. The hair cells operate in a viscous environment, but can nevertheless sustain oscillations, amplify incoming signals, and even exhibit spontaneous motility. The thermodynamic requirements of this indicate the presence of an underlying active process that pumps energy into the system. Hair bundle motility has been described using dynamic systems theory, which has shown that proximity to different bifurcations can be used to explain different aspects of this sensory system. Our experiments explore the physical mechanisms behind the detection of very weak signals, and describe them using models based on nonlinear dynamics theory. We demonstrate the presence of chaos in the innate motility of active bundles, and show both theoretically and experimentally that it enhances the sensitivity of detection. Secondly, we show that stimulation of the efferent neurons, which synapse onto the hair cell bodies, strongly impacts the innate motility of the bundles. We further demonstrate that the sensitivity of the mechanical response in vitro is reduced by efferent activity, indicating that these neurons modulate the biological control parameter that fine-tunes the dynamics of the hair cell.

The Busse Balloon as Organizing Center in Pattern Formation

Arjen DOELMAN

Leiden University

Fritz Busse introduced the concept of, what we now call, the Busse balloon in the context of convection: it determines the region in (parameter, wave number)-space for which a system exhibits stable spatially periodic patterns (the convective `rolls' in the original setting). Mathematical studies of models of (singularly perturbed) reaction-diffusion(-advection) type indicate the relevance of the Busse balloon in the ecological process of desertification -- that is driven by the dynamics of vegetation patterns. This point of view was recently confirmed by observations of the distributions of the wave numbers of striped vegetation patterns, as function of the local (terrain) slope, in two areas in Somalia: these indicate that the Busse balloon indeed plays an organizing role in this setting. In this talk we will discuss various aspect of the Busse balloon for (singularly perturbed) reaction-diffusion(-advection) equations. Studies of the dynamics of multi-pulse patterns (in `semi-strong interaction') show that the Busse balloon can often be seen as an attractor: randomly distributed pulses typically evolve towards an equidistant setting -- either or not by `shedding' a number of pulses in a slow/fast coarsening process. This raises fundamental questions about the nature of the Busse balloon as first step towards fully developed turbulence (the role played by the balloon in convection): what kind of bifurcations occur as the system crosses through the boundary of the Busse balloon? When does it yield more complex dynamics -- as in convection -- and when does it lead to `morphothanatos', `the death of patterns', the opposite of Turing's morphogenesis -- as in desertification? What kind of general insights can be developed in the -- sometimes remarkably intricate -- boundary of the Busse balloon in singularly perturbed reaction-diffusion systems?

Chiral Dynamics of Protein Filaments on Supported Membranes

Mario FEINGOLD

Ben Gurion University of the Negev

The primary protein of the bacterial Z ring guiding cell division, FtsZ, has recently beens shown to engage in intriguing self-organization together with one of its natural membrane anchors, FtsA. When co-reconstituted on flat supported membranes, these proteins assemble into dynamic chiral vortices whose diameters resemble the cell circumference. These dynamics are due to treadmilling polar FtsZ filaments, supposedly destabilized by the co-polymerizing membrane adaptor FtsA, thus catalysing their turnover. We show that FtsA is in fact dispensable and that the phenomenon is an intrinsic property of FtsZ alone when supplemented with a membrane anchor. The emergence of these chiral dynamic patterns is critically dependent on GTP concentration and FtsZ surface densities, in agreement with theoretical predictions. The interplay of membrane tethering, GTP binding, and hydrolysis promotes both, the assembly and the destabilization of FtsZ polymers, leading to the observed treadmilling dynamics. Notably, the vortex chirality is defined by the position of the membrane targeting sequence (mts) and can be inverted when attaching it to the opposite end of FtsZ. This reveals a so far unknown vectorial character of these cytomotive filaments, comprising three orthogonal directions: Filament polarity, curvature, and membrane attachment.

Tipping Phenomena in Ecological Systems

Ulrike FEUDEL
University Oldenburg

Many ecological systems possess different stable states such as e.g. different community compositions or different spatial patterns of vegetation for given environmental conditions. These stable ecological states are subject to perturbations acting either on state variables and/or on internal parameters and external drivers. Sudden changes in the qualitative dynamics in nonlinear dynamical systems are known as tipping points. Such tippings related to bifurcations and the impact of noise have been studied for a long time in mathematics and physics and have been successfully applied in ecology. Here we discuss two other types of tipping, one related to single large perturbations acting as shocks, the other one related to a slow change in environmental conditions following a trend. In the first case of shock tipping (S-tipping) we develop an algorithm to compute the smallest single shock which is able to destabilize the desired ecological regime, in which all species coexist. This algorithm corresponds to the computation of ecological resilience introduced by Holling in 1993. We apply this method to plant-pollinator networks to unravel the relationship between stability with respect to shocks and network topology. In the second case of a trend we demonstrate a rate-induced critical transition (R-tipping) leading to a collapse of a predator-prey system in face of a very slow decline of resources.

Self-assembly in high-order PNP-type systems

Nir GAVISH
Technion – Israel Institute of Technology

The Poisson-Nernst-Planck (PNP) theory is one of the most widely used analytical methods to describe electrokinetic phenomena for electrolytes. The model, however, considers isolated charges and thus is valid only for dilute ion concentrations. The key importance of concentrated electrolytes in applications has led to the development of a large family of generalized PNP models. However, the wide family of generalized PNP models fails to capture key phenomena recently observed in experiments and simulations, such as self-assembly and under-screening in concentrated electrolytes. In this talk, we present a thermodynamically consistent mean-field model for concentrated solutions that goes beyond the PNP framework. We show that the model describes bulk and interfacial pattern-formation, map the parameter regimes of distinct self-assembly behaviors and the relevant bifurcation associated with them, and consider their effect on electrostatic screening and transport. In particular, we reveal a novel mechanism of under-screening, and consider relevance to gating phenomena.

Pattern Formation in Optical Microresonators for Frequency Comb Generation

Damia GOMILA
Institute for Cross-Disciplinary Physics and Complex (IFISC)

A frequency comb is a light source whose spectrum consist of a series of discrete equally spaced frequency lines. Frequency combs are crucial for metrology applications as they allow to measure the optical part of the electromagnetic spectrum with very high precision. Recently nonlinear optical microresonators have proved to be a reliable source of frequency combs as a result of a Turing instability. In this talk, I will discuss how the formation and stability of patterns and localized states determine the properties of the frequency combs at the output of a cavity. Different instabilities and nonlinear dynamics of spatial structures will be reviewed in this context.

Model-Free Network Control

Gemunu GUNARATNE
University of Houston

Coupled networks can be used to represent biological processes in cells, interactions within social groups, communications in wireless networks and in many other complex systems. One major goal of network analyses is to design methods to control these systems to pre-specified target states. For example, in cellular processes, we may inquire if damaging consequences of genetic mutations or chromosomal rearrangement can be circumvented through external intervention. The evident approach is to start from a realistic model of the underlying network; unfortunately, this is an extremely difficult task. In intra-cellular processes precise quantitative form of interactions between biomolecules is unlikely to be available. In this talk, I will introduce a model-free approach for control. The “state” of the network is defined using the experimentally accessible gene expression profile. Interestingly, controlling the system to a pre-specified state only requires knowledge of “response surfaces,” which consists of the system responses to a specific set of perturbations. Analyses of model systems and nonlinear electrical circuits show that a target state can be approached by external control of the levels of a few nodes. This approach can prove useful in many contexts including in reprogramming cellular states.

From Vegetation Patterns to Global Climate Modeling

Jost von HARDENBERG

Institute of Atmospheric Sciences and Climate at Turin

Soil water-vegetation feedback mechanisms allow the formation of both regular and irregular vegetation patters in drylands and bistability of different patterned states and of uniform states under the same climatic conditions, with important important local ecohydrological implications. Less is known about the impact of vegetation patterns on vegetation-atmosphere interactions. In particular, recent studies have shown an impact of the spatial vegetation pattern dynamics on evapotranspiration fluxes, with possible impact on local climate. The question to what extent such local phenomena could be of relevance also for climate modeling at large scales remains open. To discuss this point I will present briefly the case of bistability of tropical forests with grasslands and savannas (tropical grassy biomes) under similar climatic conditions, whose dynamics is controlled crucially also by local phenomena such as fires. Both results from satellite observations and Dynamic Global Vegetation Models (as implemented in state-of-the-art global earth system models) will be discussed.

Underwater Pattern Formation in Marine Plants

Emilio HERNANDEZ-GARCIA

Institute for Cross-Disciplinary Physics and Complex (IFISC)

Factors such as competition for water or nutrients or interactions with herbivores drive spatial instabilities in landscapes of terrestrial plants, resulting in pattern formation phenomena that have been a subject of intense research in the last years. Observations from air and side-scan sonar data have recently revealed analogous pattern forming phenomena in submerged vegetation in the Mediterranean Sea [1], mainly in meadows of seagrasses such as Posidonia oceanica and Cymodocea nodosa. Starting from growth rules of these clonal plants, we have derived a macroscopic model for the plant density that is able to provide an explanation to the observed submarine patterns of isolated ‘fairy circles’, and landscapes of spots and stripes. The essential ingredient is a competitive interaction at a distance of 20-30m. Beyond a qualitative description of the observed patterns, and their prevalence under different meadow conditions, the model fits well measurements of the population density of Posidonia, which show great variability close to the coast, where patterns typically appear. Work done in collaboration with D. Ruiz, D. Gomila, T. Sintes, N. Marbà and C. Duarte. [1] D. Ruiz-Reynés, D. Gomila, T. Sintes, E. Hernández-García, N. Marbà and C.M. Duarte, Fairy circle landscapes under the sea, Science Advances 3, e1603262 (2017).

Delayed Hopf Bifurcations in Reaction-diffusion Equations

Tasso KAPER
Boston University

Based on joint work with Theo Vo, this talk will focus on the discovery of delayed loss of stability due to slow passage through Hopf bifurcations in reaction-diffusion equations, thereby extending to spatially-extended systems the DHB phenomenon previously known for analytic ODEs since the early work of Shishkova and Neihstadt. DHB in PDEs will be illustrated on paradigm systems in the field of pattern formation, such as the Hodgkin-Huxley system, the cubic CGL equation, the Brusselator, and a spatially-extended model of a pituitary clonal cell line. The delayed loss of stability impacts the frequencies and amplitudes of the observed oscillations. In addition, we identify buffer curves in the space-time plane near which solutions must leave the neighborhoods of the repelling states, thereby generalizing the concept of buffer points in delayed Hopf bifurcations in ODEs to these PDEs.

Coupled Oscillators and Chaos in Gene Regulation

Mogens H. JENSEN
Niels Bohr Institute

Oscillating patterns with periods of 2-5 hours have been observed for transcription factors in single cells. The oscillations appear as a response to DNA damage and other induced stresses. We have identified the central feed-back loops leading to oscillations and formulated genetic networks in terms of mathematical equations. By applying an external periodic protein signal, it is possible to lock the internal oscillation of a transcription factor to the external signal [1]. We have observed that the two signals lock when the ration between the two frequencies is close to basic rational numbers [1] which can be mapped out as Arnold tongues. When the tongues start to overlap we may observe mode hopping and chaotic dynamics in the concentration of proteins [1]. We investigate how this influences gene productions through stochastic simulations by Gillespie algorithm. In the chaotic regime, genes with high affinity decreases their production with increased external amplitude, while genes with low affinity increases their production [2]. [1] M.L. Heltberg, R. Kellogg, S. Krishna, S. Tay and M.H. Jensen, "Noise-induced NF-kB Mode Hopping Enables Temporal Gene Multiplexing" Cell Systems 3, p. 532–539 (2017). [2] M.L. Heltberg, S. Krishna and M.H. Jensen, "Chaotic Dynamics in Transcription Factors: Enhancement of Low Affinity Genes, Efficient Protein Complex Formation and Generation of Population Heterogeneity", Nature Communication (2018).

Spatial Localization in Conserved and Nonconserved Systems

Edgar KNOBLOCH

University of California at Berkeley

In this talk I will describe recent progress in understanding spatial localization in nonconserved systems and compare and contrast the resulting behavior with that found in conserved systems. I will focus on two prototypical systems, the bistable Swift-Hohenberg equation (characteristic of nonconserved systems) and the conserved Swift-Hohenberg equation (characteristic of conserved systems). I will describe snaking in both systems and discuss the different types of depinning and front propagation that arise in these systems. I will conclude with some implications of this work for models of vegetation growth.

Emergent Behavior in Ensembles of Globally Coupled Oscillators: From Cluster Patterns to Chimera States

Katharina KRISCHER

Technische Universität München

Globally coupled Stuart-Landau oscillators are a generic model system for the study of collective behavior in oscillatory systems beyond the weak coupling limit. In this talk we will address two fundamental questions concerning emergent behavior in globally coupled Stuart-Landau networks: 1) How is clustering behavior in minimal networks linked to clustering dynamics in large ensembles of oscillators. 2) Which symmetries are realized in states with partially broken symmetry, also called chimera states. In both cases, we start out by considering a minimal system of four globally coupled oscillators. To answer the first question, we elaborate how 2-cluster states crowd when increasing the number of oscillators. Furthermore, using persistence, we discuss how this crowding leads to a continuous transition from balanced cluster states to synchronized solutions via the intermediate unbalanced 2-cluster states. These cascade-like transitions emerge from what we call a cluster singularity. As for the second question, we demonstrate that when the four mean-coupled Stuart-Landau oscillators form states with partially broken symmetry, states with different set-wise symmetries in the incoherent oscillators may arise, some of which are and some are not invariant under a permutation symmetry on average. We conclude our report with a discussion of how in the two cases the results apply to spatially extended systems.

Cellular Pattern Formation via Notch Signaling

Herbert LEVINE
Northeastern University

One of the best-studied intercellular signaling systems used in developmental biology relies on the Notch pathway. In its canonical form, this pathway leads to lateral inhibition and thereby to spatial organization of differentiated tissue. During cancer progression, this pathway can shift to a lateral induction mode that may play a key role in metastasis. Here we survey various models of the Notch pathway and place its dynamics within the general mathematical framework of non-equilibrium pattern formation. We argue that the results may be helpful in resolving outstanding issues regarding pattern regularity and pattern flexibility.

Multiple-scale Structures: From Faraday Waves to Soft-matter Quasicrystals

Ron LIFSHITZ
Tel Aviv University

Current research is now actively exploring the formation of quasicrystals in a variety of soft materials, including systems of macromolecules, nanoparticles and colloids. Much effort is being invested in understanding their thermodynamic properties in order to predict and possibly control the structures that form, and hopefully to shed light on the broader yet unresolved general questions of quasicrystal formation and stability. Moreover, the ability to control the self-assembly of soft quasicrystals may contribute to the development of novel photonics or other applications based on self-assembled metamaterials. Here a path is followed, leading to quantitative stability predictions [1], that starts with a model developed two decades ago [2] to treat the pattern formation of multiple-scale quasiperiodic Faraday waves (standing wave patterns in vibrating fluid surfaces), and which was later mapped onto systems of soft particles, interacting via multiple-scale pair potentials [3,4]. I shall review the quantitative predictions of these models, present new analytical methods for treating them, and show a number of newly found stable quasicrystalline structures that they support. 1. S. Savitz, M. Babadi, R. Lifshitz, IUCrJ, 5, (2018), 247-268. 2. R. Lifshitz, D. Petrich, Phys. Rev. Lett., 79, (1997), 1261-1264. 3. K. Barkan, H. Diamant, R. Lifshitz, Phys. Rev. B, 83, (2011), 172201. 4. K. Barkan, M. Engel, R. Lifshitz, Phys. Rev. Lett., 113, (2014), 098304.

Pattern Formation: New Questions Motivated by Applications

Ehud MERON
Ben Gurion University of the Negev

Advances in pattern formation have largely been made using relatively simple experimental-model systems, such as the Rayleigh-Bénard setup of thermal convection or the Belousov-Zhabotinsky chemical reaction, and simple mathematical models, such as the Swift-Hohenberg equation, the CGL equation or the FitzHugh-Nagumo model. These advances have resulted in a well-established theory, but the application of this theory to living systems often fall short of explaining observed behaviors or addressing new questions motivated by functional aspects of these systems. In this talk I will focus on dryland ecosystems as a case study of pattern formation in complex living systems.

In the first part of the talk I will review the progress that has been made in understating self-organized vegetation patchiness by applying pattern formation theory to models of dryland vegetation. Three distinct pattern-forming feedbacks between vegetation growth and water transport will be introduced, and their large-scale effects, in terms of existence and stability of uniform, periodic and localized solutions, will be explained. Realizations of these solutions in natural ecosystems will be further discussed with a focus on the fascinating phenomenon of fairy circles, observed in western Namibia and north-western Australia.

In the second part of the talk I will address several new questions motivated by the complex nature of dryland ecosystems and their function in variable environments. These questions include the interplay between different vegetation-water feedbacks and the implications to multi-scale patterns, the roles of front instabilities in reversing desertification and inducing self-recovery, and sustainable human intervention in ecosystem dynamics based on the exploration of unstable states. Parallels to other pattern-forming living systems will be drawn.

Control and Balance in Living Neuronal Networks

Elisha MOSES
Weizmann Institute of Science

Living neuronal networks offer a reductionist view of biological computation. While individual neurons retain their physiological characteristics , the structure and connectivity in the network are considerably simpler to measure and analyze than they are in the real brain. We demonstrate that the activity of the network is strongly regulated by tuning of the connectivity, in a manner that is much like a feedback mechanism. A constant behavior of the network is maintained over a broad range of parameters by a precise handling of the inhibitory versus the excitatory input connection strengths.

Mathematical Modeling of Cyclic Population Dynamics

Alexander NEPOMNYASHCHY
Technion – Israel Institute of Technology

We discuss deterministic models for three-species ecological systems exhibiting cyclic (rock-paper-scissors) dynamics, which account for delay or/and spatial nonlocality in interspecies competition. The biological origin of the temporal and spatial nonlocalities is the secretion of a toxin lethal to another species in the environment. The dynamics of spatially homogeneous states is described by ODE models, which allow for three classes of stable limit solution: (i) steady coexistence solutions; (ii) limit cycles; (iii) stable heteroclinic cycles. PDE models allow to describe the nontrivial spatial structure and dynamics of fronts between domains occupied by homogeneous states, as well as regular and irregular spatio-temporal dynamical regimes.

Spontaneous Recovery of Loop Structure and a Role of Post-inhibitory Rebound in Multistate Network Systems

Yasumasa NISHIURA
Tohoku University

We propose a class of directed network systems that spontaneously initiates and completes loop searching against the removal and attachment of connection links. Network nodes are either the Morris-Lecar model, FitzHugh-Nagumo model, or group oscillator model. The self-recovery process emerges out of only local interactions between the nodes without introducing a feedback function representing the global state of the system. A sudden external perturbation like removal or attachment of links in general breaks a loop structure, but at the same time it causes unleashing of inhibition of neighboring nodes and the resulting new firing (post-inhibitory rebound) becomes an onset of searching a new loop. This shows an automatic attractor switching triggered by external perturbation. The searching time depends on the topology of network, for instance, scale-free networks have shorter searching time than random networks. The concept of the model construction is applicable to a wider class of nonlinear systems including chemical reactions and neural networks. This is a joint work with K.I. Ueda (Toyama University).

Patterning and Deformation of Nematic Elastomers

Len PISMEN
Technion – Israel Institute of Technology

Liquid crystal elastomers, made of cross-linked polymeric chains with embedded mesogenic structures, combine orientational properties of liquid crystals with shear strength of solids. Their flexibility and sensitivity to chemical and physical signals comes close to that of biological tissues. Transition to a deformed polarized state may be frustrated in constrained geometry leading to the formation of defects. A novel strategy of biomimetic patterning and actuation of nematic elastomers that does not require inscribing the texture directly is based on varying the dopant concentration that, beside shifting the phase transition point, affects the nematic director field via coupling between the gradients of concentration and nematic order parameter. Rotation of the director around a point dopant source causes topological modification manifesting itself in a change of the number of defects. A variety of shapes, dependent on the dopant distribution, are obtained by anisotropic deformation following the nematic--isotropic transition.

Oscillatory Instabilities in Strained Frictional Granular Matter

Itamar PROCACCIA
Weizmann Institute of Science

Frictional granular matter is shown to be fundamentally different in its plastic responses to external strains from generic glasses and amorphous solids without friction. While regular glasses exhibit plastic instabilities due to a vanishing of a real eigenvalue of the Hessian matrix, frictional granular materials can exhibit a previously unnoticed additional mechanism for instabilities, i.e the appearance of a pair of complex eigenvalues leading to oscillatory exponential growth of perturbations which are tamed by dynamical nonlinearities. This fundamental difference appears crucial for the understanding of plasticity and failure in frictional granular materials. The relevance to earthquake physics will be discussed in the context of the amplification or remote triggering.

Spontaneous Activity and Transient Response in the Actin Cytoskeleton of Chemotactic Cells

Alain PUMIR
École Normale Supérieure Lyon

The motion of cells towards external sources of chemo-attractant is ultimately related to the polymerization activity of the actin cytoskeleton. Experiments show that, in the absence of any stimulation, some Dictyostelium discoideum cells exhibit noisy self-sustained oscillations. I will discuss the nature of these oscillations, and show that they can be described by a generic nonlinear oscillator model with noise. The quantitative role of the noise can be described by a single dimensionless, experimentally accessible parameter that also characterizes the variability of a population of cells. I will also discuss the transient polymerization activity, induced by a short pulse of chemoattractant (cAMP) in cells with oscillatory polymerization dynamics. The stimulation induces first a large response over a short time scale (~25 sec), followed by a longer transient response, of reduced amplitude and frequency, compared to the activity at rest. The duration of this transient widely varies, over a range of 3 to 14 polymerization cycles. The phenomenon can be described by an extension of the noisy oscillator model, by introducing an inhibitory variable that acts as a timer for the transient phase activated by the binding of the chemoattractant to the receptor. The model takes into account the intrinsic cell to cell variability present in the populations of cells, and reproduces the most important features of the response of the actin cytoskeleton to cAMP. The range of time scales is consistent with the known properties of the signaling cascade.

Dynamics of Fronts in 1D Allen-Cahn Equations Coupled to Large Scale Components

Jens RADEMACHER
University of Bremen

When weakly coupling the classical one-dimensional Allen-Cahn interface model to slow large scale fields, the dynamics drastically changes. For linear coupling this can be rigorously analysed in a rather explicit way. Combining various methods allows to detect and unfold degenerate Takens-Bodganov points for the interface dynamics. This features various periodic, homoclinic and heteroclinic solutions. This is joint work with Martina Chirilus-Bruckner, Peter van Heijster and Hideo Ikeda, and earlier with Arjen Doelman.

Partial Synchronization Patterns and Chimera States in Complex Networks

Eckehard SCHÖLL

Technische Universität Berlin

Chimera states are an intriguing example of partial synchronization patterns emerging in networks of identical oscillators. They consist of spatially coexisting domains of coherent (synchronized) and incoherent (desynchronized) dynamics. We show that a plethora of chimera patterns arise if one goes beyond the Kuramoto phase oscillator model, and considers coupled phase and amplitude dynamics, and more complex topologies than a simple one-dimensional ring network, e.g., fractal connectivities or multi-layer structures. For the FitzHugh-Nagumo system, the Van der Pol oscillator, and the Stuart-Landau oscillator with symmetry-breaking coupling various multi-chimera patterns including amplitude-mediated phase chimeras, amplitude chimeras, chimera death, and coherence resonance chimeras occur. We review the control of chimera patterns by a subtle interplay of dynamics, topology, noise, and delay.

Vegetation Pattern Formation and Cross-level Interactions in Ecological Systems

Moshe SHACHAK

Ben Gurion University of the Negev

Ecological systems are hierarchical structures organized by cross levels interactions among individuals, populations, communities, ecosystems, and landscapes. My main assertion is that in order to integrate vegetation pattern formation as the main agent controlling ecological systems' structure and function, vegetation patterns should be viewed both as products and regulators of cross level interactions in ecological systems. Vegetation pattern formation is an emerged property initiated by individual-level processes of soil –plant feedbacks and plant-plant interactions. It is a bottom-up process that produces a landscape-level structure. Vegetation pattern formation, however, is affected by landscape-scale processes, such as rainfall variability, which feedback on lower-level processes. An important class of such top-down effects is ecosystem engineering that modulates geodiversity, in terms of micro-topography and soil functions, and thereby regulate water, soil and nutrients fluxes. The ecosystem engineering effects of pattern formation involve top-down cross-level interactions, whereby landscape modulation is cascading to the ecosystem level by regulating fluxes that control population dynamics, community assemblage, and food-web functions. By presenting pattern formation in the context of bottom up and top down cross-level interactions I propose to integrate the study of pattern formation as an important element in understanding ecosystem structure and function. This comprehensive view of vegetation patterns as both a product and regulators of cross levels interactions is crucial in the Anthropocene where humans' activities limits the potential of nature to self-organize. In my presentation, I will suggest a theoretical framework, with examples from water-limited systems, on the link between pattern formation and the functions of natural and human-made ecological systems.

Propagating Chemical Waves as an Engine for Autonomous Flapping Sheets

Eran SHARON
The Hebrew University of Jerusalem

Autonomous actuation of soft tissues is common in a wide variety of natural systems, both on cellular and macroscopic scales. The success in mimicking such systems in manmade structures is limited. We present the first autonomous shape transforming sheet and suggest a framework for its analysis and design. Thin sheets made of NIPA- Ruthenium copolymer gel are placed in a solution of the Belousov-Zhabotinsky (BZ) reactants, leading to the spontaneous periodic propagation of chemical fronts within the gel. These front lead to local contraction and expansion of the gel, driving its periodic buckling into 3D evolving shapes. Using the theory of incompatible elastic sheets, we describe the system as a non-Euclidean plate. The reference metric of the plate varies in time and space according to the BZ field evolution. We obtain a connection between the BZ field and the 3D configurations and confirm it experimentally

Populations and Communities in Fluctuating Environment

Nadav SHNERB
Bar-Ilan University

Noise and fluctuations are ubiquitous features of living systems. In particular the reproductive success of individuals is affected by many random factors. Some of these factors, like the local availability of nutrients or accidental encounters with predators, act on the level of a single individual (demographic stochasticity). Others, like fluctuations in temperature and precipitation rates, affect entire populations (environmental stochasticity). Environmental stochasticity is known to be the dominant mechanism when the population is large, but demographic noise becomes important close to extinction/fixation points. Accordingly, one must take account of both in order to calculate the chance of fixation, the time to extinction/fixation, or the species richness that reflects a balance between the pace of extinction and the pace of entrance of new types (via mutation, speciation, migration from a regional pool and so on) . I will present results for a few generic models of a single population, two competing populations and high diversity assemblages, where stochasticity is superimposed on time-independent selective forces. A particular attention will be given to the possibility of noise-induced stabilization (storage effect), where stochasticity enhanced biodiversity/polymorphism. The relevance of the results to population viability analysis (PVA) and to the general modern coexistence theory (MCA) will be discussed.

Topographic Probes of Dryland Vegetation Arcs

Mary SILBER

University of Chicago

Some of the most beautiful examples of spontaneous pattern formation occur in drylands, where the spatial distribution of vegetation may appear as a remarkably self-organized patchiness on a scale spanning kilometers. Arced bands of vegetation, which alternate rhythmically with bare soil, occur in different drylands around the globe, with the first examples reported when aerial photographs accompanied hydrological survey work in the Horn of Africa, dating to the 1940s. These self-organized, community scale vegetation bands rely on harvesting water from the region surrounding them, and hence the gentle topography plays an important role. We explore this relationship within the type of conceptual framework of water-biomass models that was pioneered by Ehud Meron and his group. We examine the shape of the bands, and their location on the underlying terrain, as probes of the resilience of these fragile ecosystems, and also as probes of the models.

Dip Coating as a Pattern Formation Phenomenon

Uwe THIELE

Universität Münster

First, we review situations where the dynamics of moving three-phase contact lines creates structures, e.g., dewetting or dip coating of simple and complex liquids, and Langmuir-Blodgett (LB) transfer of surfactants from a bath onto a moving plate [1,2]. After presenting typical hydrodynamic thin-film models we rewrite them as gradient dynamics for an underlying energy functional that accounts for wettability and capillarity. This allows for many consistent extensions, e.g., towards solute-dependent wettability and the incorporation of surfactant phase transitions. Next, such models are employed to investigate the out-of-equilibrium process of the deposition of line patterns at receding contact lines for evaporatively dewetting solutions/suspensions [3] and in Langmuir Blodgett transfer [4]. Similarities and differences of the occuring local and global bifurcations are discussed. Although, most results focus on one-dimensional patterns, i.e., the deposition of line patterns, an outlook is given towards the fully two-dimensional case. Different ways to control these patterns are presented as well [5,6]. [1] U. Thiele, Advances in Colloid and Interface Science 206, 399-413 (2014). [2] M. Wilczek, W. B. H. Tewes, S. V. Gurevich, M. H. Köpf, L. Chi and U. Thiele, Math. Model. Nat. Phenom. 10, 44-60 (2015). [3] L. Frastia, A. J. Archer and U. Thiele, Soft Matter 8, 11363-11386 (2012). [4] M.H. Köpf and U. Thiele, Nonlinearity 27, 2711-2734 (2014). [5] M. Wilczek, J. Zhu, L. Chi, U. Thiele, S. V. Gurevich, J. Phys.: Condens. Matter 29, 014002 (2017). [6] P.-M. T. Ly, U. Thiele, L. Chi and S. V. Gurevich, unpublished (2018).

Basics of pde2path (and some advanced features)

Hannes UECKER

University of Oldenburg

pde2path is a Matlab package for numerical continuation and bifurcation analysis of partial differential equations. Its main design goals are flexibility (to be able to treat large classes of problems), easy usage, and hackability (easy customization). It is based on the finite element method and arclength continuation. Currently, it can handle branches of steady solutions and time periodic orbits for various classes of systems of PDEs, and the associated bifurcation. We first briefly review the basic setup using the Allen-Cahn equation as a simple example, and then explain some more advanced features such as bifurcations of higher multiplicity and bifurcation from relative periodic orbits, and also some applications in distributed optimal control.

On Possible Connections Between Rogue Waves and Solitons

Yair ZARMI

Ben-Gurion University of the Negev

Two possible ways for connecting rogue waves and solitons will be presented. The first possibility exploits the existence of a “special polynomial” - a differential polynomial in the soliton solution of an integrable evolution equation, which vanishes identically on the single-soliton solution. On multi-soliton solutions of the same equation, this polynomial is a hump that is localized around the intersection region of the solitons. The original evolution equation is extended into a system of two equations, in which the multi-soliton solution and the rogue wave are coupled. The second possibility exploits the non-uniqueness of the τ-functions, from which a soliton solution of an integrable evolution equation is constructed. In the case of a multi-soliton solution, an equivalent τ-function is constructed, from which an entity that is localized around the soliton interaction region is obtained. This hump serves as a source, from which the soliton solution is constructed. This second approach has a side benefit, in that it facilitates uncovering the fate of an N-soliton solution when two wave numbers in the solution are made to coincide. It is traditionally accepted that the solution degenerates into one with $(N-1)$ solitons. However, the structure of the equivalent τ-function shows that, more often, solutions degenerate into ones with $(N-2)$ solitons.

Active Phase Separation - A Universal Approach

Walter ZIMMERMANN

Universität Bayreuth

We identify active phase separation as a generic demixing phenomenon in non-equilibrium systems with conservation constraints. Examples range from cell polarization to cell populations communicating via chemotaxis and from self-propelled particle communities to mussels in ecology. We show that system-spanning properties of active phase separation in non-equilibrium systems near onset are described by the classical Cahn-Hilliard (CH) model. This result is rather suprising since the CH equation is famous as a model for phase separation at thermal equilibrium. We introduce a general reduction scheme to establish a unique mathematical connection between the generic CH equation and system-specific models for active phase separation. This approach is exemplarily applied to models for cell-polarization of cells and models for chemotactic cell communities. The approach is also nonlinearly exended to include the next higher order terms in the case of mobility induced phase separation. We also validate this approach by comparing solutions of the reduced and basic models.

[1] Chaos and Levy Walks in Swarming Bacteria

Gil ARIEL
Bar-Ilan University

Bacterial swarming is a collective mode of motion in which cells migrate rapidly over surfaces. Swarming is typically characterized by densely packed groups moving in coherent patterns of whirls and flows. Recent experiments showed that within such dense swarms, bacteria are performing super-diffusion that is consistent with a Levy walk. We present a simple model of a spheroidal, self-propelled particle, moving in the effective, vortex-like flow generated by all other bacteria. Mathematically, the model presents a new mechanism for Levy walks in chaotic maps that are reversible but not volume preserving. Levy walking emerges from sticking close to regular, fractal-like areas with multiscale periodicities. A period doubling bifurcation separates a chaotic, super-diffusive regime and a regular, ballistic one. Biologically, it explains how cells can fine-tune the geometric properties of their trajectories.

[2] Ecosystem Engineering, Collectively, in Space

Matthieu BARBIER
The French National Center for Scientific Research (CNRS)

Ecosystem engineering and its spatial consequences are often considered from the perspective of a single engineer species or low-dimensional system. Very little theoretical work has been done on collective aspects, with many species able to enact small changes in similar or different directions. I will present some modeling efforts and some ongoing work on connecting them with data.

[3] Long-distance Seed Dispersal Affects the Resilience of Banded Vegetation Patterns in Semi-deserts

Jamie BENNETT
Ben-Gurion University of the Negev

Landscape-scale vegetation stripes (tiger bush) observed on the gentle slopes of semi-arid regions are useful indicators of future ecosystem degradation and catastrophic shifts towards desert. Mathematical models like the Klausmeier model---a set of coupled partial differential equations describing vegetation and water densities in space and time---are central to understanding their formation and development. One assumption made for mathematical simplicity is the local dispersal of seeds via a (local) diffusion term. In fact, a large amount of work focuses on fitting dispersal 'kernels', probability density functions for seed dispersal distance, to empirical data of different species and modes of dispersal. We address this discrepancy by analysing an extended Klausmeier model that includes long-distance seed dispersal via a non-local convolution term in place of diffusion, and assessing its effect on the resilience of striped patterns.

[4] On System-spanning Demixing Properties of Cell Polarization

Fabian BERGMANN
Universität Bayreuth

A number of mathematical models have been suggested to describe cell polarization in eukaryotic cells. One class of models takes into account that certain proteins are conserved on the time scale of cell polarization and may switch between a fast and a slow diffusing state. We raise the question whether models sharing this design feature can be condensed into one system-spanning model. We show exemplarily for the mass-conserved reaction-diffusion model of Otsuij et al. (Otsuij M et al. (2007) PLoS Comput Biol 3(6):e108) that cell polarization can be classified as active phase separation. This includes a fundamental connection between a number of non-equilibrium demixing phenomena such as cell polarization to phase separation. As shown recently, generic properties of active phase separation close to its onset are described by the Cahn-Hilliard model. By a systematic perturbation analysis we directly map the basic cell polarization model to the universal Cahn-Hilliard model. Comparing the numerical solutions of the polarization model and the Cahn-Hilliard equation also provides the parameter range where the basic cell polarization model behaves like other systems showing active phase separation. Polarization models of the active phase separation type cover essential properties of cell polarization, e.g. the adaptability of cell polarity to the length of growing cells. Our approach highlights how basic principles of pattern formation theory allow the identification of common basic properties in different models for cell polarization.

[5] Labyrinth Ice Pattern Formation Induced by Ice Selective Near-infrared Irradiation

Ido BRASLAVSKY

The Hebrew University of Jerusalem

Pattern formation in ice is mostly known as the dendritic growth of crystals. Tyndall figures are water melting dendritic patterns that emerge from ice that was superheated by infrared radiation. Here, we describe a new ice/water pattern formation, termed Labyrinth Ice, which induced by near-infrared irradiation that heats one phase more than the other in a two-phase system. The pattern forms during irradiation of tens of microns thick ice crystals in solution near equilibrium. This led to the development of dynamic holes and micro-channel labyrinths at specific regions and with a typical distance of few microns between melted points. Addition of minute amounts of absorbing ink to the melted phase, that increase the light absorption of the liquid phase reduces significantly the development of the pattern. We also noted fast time oscillations in the water ice system under radiation at some experimental conditions. We concluded that the differential absorption of water and ice was the driving force for this pattern formation. Melting of ice by laser absorption might be useful in applications such as cryopreservation of biological samples. Reference: Labyrinth Ice Pattern Formation Induced by Ice Selective Near-infrared Irradiation, S. Guy Preis, H. Chayet, A Katz, V. Yashunsky, A. Kaner, S. Ullman, I Braslavsky, in revision, Science Advances. Funding: Israel Science Foundation grant no. 930/16.

[6] Comb-like Turing Patterns Embedded in Hopf Oscillations

Paulino Monroy CASTILLERO

Ben-Gurion University of the Negev

A generic mechanism for the emergence of spatially localized states embedded in an oscillatory background is demonstrated by using a 2:1 frequency locking oscillatory system. The localization is of Turing type and appears in two space dimensions as a comb-like state in either π phase shifted Hopf oscillations or inside a spiral core. Specifically, the localized states appear in absence of the well known flip-flop dynamics (associated with collapsed homoclinic snaking) that is known to arise in the vicinity of Hopf-Turing bifurcation in one space dimension. Derivation and analysis of three Hopf-Turing amplitude equations in two space dimensions reveal a local dynamics pinning mechanism for Hopf fronts, which in turn allows the emergence of perpendicular (to the Hopf front) Turing states. The results are shown to agree well with the comb-like core size that forms inside spiral waves. In the context of 2:1 resonance, these localized states form outside the 2:1 resonance region and thus extend the frequency locking domain for spatially extended media, such as periodically driven Belousov-Zhabotinsky chemical reactions. Consequently, the study suggests distinct control and design features to spatially extended oscillatory systems.

[7] Shaping the Asymmetry of Localized Frequency-locking Waves by a Generalized Forcing and Implications to the Inner Ear

Yuval EDRI

Ben Gurion University of the Negev

Frequency locking to an external forcing is a well-known phenomenon. In the auditory system, it results in a localized traveling wave, the shape of which is essential for efficient discrimination between incoming frequencies. An amplitude equation approach is used to show that the shape of the localized traveling wave depends crucially on the relative strength of additive versus parametric forcing components; the stronger the parametric forcing, the more asymmetric is the response profile and the sharper is the traveling-wave front. The analysis qualitatively captures the empirically observed regions of linear and nonlinear responses and highlights the potential significance of parametric forcing mechanisms in shaping the resonant response in the inner ear.

[8] How does Rainfall Intermittency Affect Semi-arid Vegetation Pattern

Lukas EIGENTLER

Heriot Watt University and The University of Edinburgh

A characteristic of many semi-arid regions is patterns of vegetation. The limiting resource in these ecosystems is water, which is added to the system through short and intense rainfall events that cause a pulse of biological processes such as plant growth and (nonlocal) seed dispersal. Based on the extended Klausmeier reaction(-advection)-diffusion model on flat ground I present a model that considers the combination of such pulse-type mechanisms with processes that occur continuously in time. This impulsive model which couples a set of partial differential equations with a set of integrodifference equations is used to analytically investigate the effects of rainfall intermittency on the onset of patterns. I show that a lower frequency of precipitation pulses inhibits the formation of patterns but increases the total amount of water required for plants to persist. Unlike in the Klausmeier reaction-diffusion model, patterns are not solely caused by a diffusion-driven instability. Instead an additional condition based on the length of the drought periods between precipitation pulses needs to be satisfied. I further present that the introduction of pulse-type seed dispersal weakens the influence of the plant dispersal kernel on the onset of patterns. Joint work with Jonathan A. Sherratt.

[9] Nonlinear Analysis of Dissipative Systems with a Conservation Law

Tobias FROHOFF-HULSMANN
Westfälische Wilhelm-Universität 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.

[10] Water Transport in Models of Dryland Vegetation Patterns

Punit GANDHI
Ohio State University

I will discuss aspects of the surface/subsurface water dynamics in dryland ecoystems that exhibit banded pattern formation. Capturing these hydrological processes on appropriate timescales may allow us to better utilize observational data as we work to identify the dominant mechanisms underlying the pattern formation and understand how environmental factors influence pattern characteristics. This work is in collaboration with Sara Bonetti (ETH Zurich), Sarah Iams (Harvard), Amilcare Porporato (Princeton) and Mary Silber (U Chicago).

[11] Similarities between the Mass Distribution of Insect Swarms and Star Clusters

Dan GORBONOS

Weizmann Institute of Science

Swarming is a form of collective animal behavior that has caught the attention of physicists, as a self-organized non-equilibrium system that remains cohesive although it exhibits no clear order parameter, as opposed to "flocking" behavior. Such behavior is observed in a variety of species, such as fish, bats and flying insects. We proposed a model whereby the interactions between the flying insects (midges) are mediated by acoustics due to the sound they emit while flying, and this gives rise to long-range (power-law) interactions. In particular, we showed that the effective interaction between the midges seems to decay as the inverses square of the distance between the noise-emitting midges. Furthermore, the response of the midges was proposed to be adaptive, as most sensory systems in biology are. We demonstrate that the adaptive-gravity interaction model can reproduce the observed large-scale organization within the midge swarm. This result is calculated using the same methodology used to calculate the morphology of star clusters held by regular gravity. In particular, we compare between adaptive-gravity and regular gravity, and find that adaptive-gravity gives a new class of mass distributions, which are not found for gravitationally bound systems.

[12] The Stochastic Gray Scott System

Erika HAUSENBLAS

Montanuniversitaet Leoben

Reaction and diffusion of chemical species can produce a variety of patterns, reminiscent of those often seen in nature. The Gray Scott system is a coupled equation of reaction-diffusion type, modelling this kind of patterns. Depending on the parameter, stripes, waves, cloud streets, or sand ripples may appear. These systems are the macroscopic model of microscopic dynamics. Here, in the derivation of the equation, the random fluctuation of the molecules are neglected. Adding a stochastic noise, the inherent randomness of the microscopic behaviour is modelled. In particular, we add a time-homogenous spatial Gaussian random field with a given spectral measure. The main result of our presentation about the stochastic Gray Scott system. In addition, we introduce and explain an algorithm for its numerical approximation by an operator splitting method. Finally, we present some examples illustrating the dynamical behaviour of the stochastic Gray Scott system.

[13] Continuum Model for Active Polar Fluids with Density Variations

Vasco WORLITZER and Sebastian HEIDENREICH

Physikalisch Technische Bundesanstalt Berlin

The collective behavior of swarming bacteria is an intriguing example of an active polar fluid which forms large scale patterns ranging from vortex lattices to mesoscale turbulence. For dense Bacillus subtilis suspensions (wild type) many of these phenomena are sufficiently well modeled via an effective polar field theory with up to forth-order derivatives using the assumption of constant swimmer density. For lower densities or non-wild type strains recent experiments reveal an anomalous velocity statistics in contrast to simulation results of the theory. In our contribution, we present an extension of the phenomenological theory that incorporates density variations. We show that these density variations result in an anomalous velocity statistics as observed in experiments. We demonstrate the emergence of an anomalous velocity statistics in the suspension of Bacillus subtilis is related to the formation of small regions of dense and less motile bacteria.

[14] Mathematical Tales of Fairy Circles II

Olfa JAIBI

Leiden University

Dryland ecosystems exhibit intriguing self-organising mechanisms in order to account for the strong plant competition for limited resources, especially water. These mechanisms typically manifest themselves in the form of vegetation patterns, ranging from bare-soil gaps in uniform vegetation to vegetation stripes and vegetation spots. A fascinating example of gap patterns is the so-called fairy circle phenomenon, found in Namibia and recently in Australia. Fairy circles are circular barren gaps in grasslands of significant size, a few meters in diameter, that form nearly-periodic patterns on large, landscape scales. Mechanisms for the appearance of this phenomenon in Namibia and in Australia, and corresponding mathematical reaction-diffusion models, have recently been proposed by Zelnik et al. [PNAS(2015)] and by Getzin et al. [PNAS(2016)]. The underlying mathematical model that describes these patterns is of (singularly perturbed) reaction-diffusion type. Unlike the more widely studied (homoclinic pulse-type) banded vegetation patterns, fairy circles have an underlying multi-front structure. We present a mathematical analysis of the model proposed for Namibian fairy circles. The mathematical approach is along the lines of dynamical systems theory (particularly geometric singular perturbation theory) and is accompanied by numerical simulations of the full model and proofs for the existence and stability of the different patterns exhibited by the model.

[15] Autonomously-actuated non-Euclidean sheets

Ido LEVIN

The Hebrew University of Jerusalem

Autonomous shape-shifting soft structures are common in a wide variety of natural systems and scales: from cellular membranes of embryos, through plant leaves and up to invertebrates. These organisms utilize external energy sources to alter their shape via local plastic deformations, prescribing a dynamical intrinsic geometry. Even though their flexibility and versatility are desired properties in man-made structures, so far only rudimentary examples were fabricated, focusing mostly on uni-axial deformations triggered by an external stimuli. In this work we build a completely autonomous soft-tissue that periodically changes its shape due to intrinsic transport-processes fueled by chemicals from its environment. We use environmentally-sensitive gel with equilibrium volume that is coupled to the Belousov-Zhabotinsty (BZ) chemical reaction. This reaction in a two-dimensional medium generates spatio-temporal patterns, resulting in a sheet whose intrinsic geometry is non-uniform and changes over time. The outcome is a gel that utilizes chemicals in its environment to autonomously change its shape, similarly to biological organisms. To account for the evolving intrinsic geometry, incompatible elastic models are used, allowing us to study and predict the evolving three-dimensional shape of the gel. The shape and the phase of the BZ-reaction are measured using a stereoscopy apparatus. The experimental results are also compared to numerical elastic solutions.

[16] Cell Adhesion and Fluid Flow Jointly Initiate Genotype Spatial Distributions in Biofilms

Ricardo MARTINEZ-GARCIA

Princeton University

Biofilms are microbial collectives that occupy a diverse array of surfaces. It is well known that the function and evolution of biofilms are strongly influenced by the spatial arrangement of different strains and species within them, but how spatiotemporal distributions of different genotypes in biofilm populations originate is still underexplored. In this presentation, I will introduce recent results on the origins of biofilm genetic structure by combining model development, numerical simulations, and microfluidic experiments with the human pathogen Vibrio cholerae. Using spatial correlation functions to quantify the differences between emergent patterns of cell lineage segregation, I will show that strong adhesion often, but not always, maximizes the size of clonal cell clusters on flat surfaces. Counterintuitively, the model predicts that, under some conditions, investing in adhesion can reduce rather than increase clonal group size. Remarkably, these results emphasize that a complex interaction between fluid flow and cell adhesiveness can underlie emergent patterns of biofilm genetic structure. This structure, in turn, has an outsize influence on how biofilm-dwelling populations function and evolve.

[17] Analytical Thin-film Solutions Driven by Surface Acoustic Wave

Kevin David Joachim MITAS
Westfälische Wilhelm-Universität Münster

The behaviour of a meniscus of a partially wetting newtonian liquid that is transfered from a bath onto a moving plate is well studied. We are interested in a related system, namely, the behaviour of such a meniscus under the influence of a Rayleigh surface acoustic wave that propagates in the substrate. This Landau-Levich-type problem is analysed with a thin-film equation that combines SAW driving (employed in [1] for wetting liquid) with the standard dragged-film problem for partially wetting liquid [2] to account for SAW driving in the case of partially wetting liquids. First, we use the numerical path-continuation package pde2path [3] to obtain bifurcation diagrams for one-dimensional steady profiles and also discuss the corresponding stationary velocity profiles. This allows us to analyse the transitions that occur when increasing the plate velocity. Next, we briefly discuss time-periodic states corresponding to the deposition of line patterns. Finally, we present results for truly two-dimensional states that are not transversally invariant. [1] M. Moronov and O. Manor. J., Fluid Mech., 810:307--322, 2017; [2] M. Galvagno., D. Tseluiko, H. Lopez and U. Thiele, Phys. Rev. Lett., 112:137803, 2014; [3] H. Uecker, D. Wetzel and J.D.M. Rademacher, Numerical Mathematics: Theory, Meth. and Appl., 7(1):58--106, 2014.

[18] From Bilateral to Trilateral Relations -3D Morphology of Nanoparticles

Yasumasa NISHIURA
Tohoku University

Diblock copolymers involve different chemical species bound by covalent bonding. When these dual units interact with one another in large numbers, the interplay between attractive and repulsive forces gives rise to a plethora of self-organized morphologies. Three-dimensional confinement of these systems further restricts the degrees of freedom, resulting in novel morphologies. A model based on finding the steepest direction of descent of an appropriate free energy leads to a set of Cahn-Hilliard equations that describe morphologuies and the dynamical transformation of between different phases. TEMT observations of nanoparticles made of polystyrene-polyisoprene copolymer is also presented. Additionally, self-assembled particles made of three of non-interacting homopolymers are also discussed.

[19] TBD

Lukas OPHAUS

Westfälische Wilhelm-Universität Münster

The conserved Swift-Hohenberg equation (or Phase-Field-Crystal [PFC] model) provides a simple microscopic continuum description of the thermodynamic transition between fluid and crystalline states. Combining it with elements of the Toner-Tu theory for self-propelled particles, Menzel and Löwen obtained a model for crystallization (swarm formation) in active systems [1]. Here, we study the occurrence of resting and traveling localized states, i.e., crystalline clusters, within the resulting active PFC model [2]. Based on linear stability analyses and numerical continuation of the fully nonlinear states, we present a detailed analysis of the bifurcation structure of periodic and localized, resting and traveling states in one and two spatial dimensions. This allows us, for instance, to explore how the slanted homoclinic snaking of steady localized states found for the passive PFC model is amended by activity. A particular focus lies on the onset of motion, where we show that it occurs either through a drift-pitchfork or a drift-transcritical bifurcation. A corresponding general analytical criterion for the onset of motion is derived. [1] A.M. Menzel and H. Löwen, Phys. Rev. Lett. 110, 055702 (2013) [2] L. Ophaus, S.V. Gurevich, U. Thiele, Phys. Rev. E 98, 022608 (2018).

[20] Dynamics of Interacting Growth-Driven Systems Inspired by Plant Tropisms

Amir PORAT

Tel Aviv University

A variety of biological systems are not motile, but sessile in nature, relying on movement resulting from growth. Groups of sensory-growth organisms can form complex structures, such as the functional architecture of growing axons, or the adaptive structure of plant root systems. These processes are not yet understood, however the decentralized growth dynamics bear similarities to the collective behavior observed in self-propelled active matter. Equivalent growth mechanisms make these systems amenable to a theoretical framework inspired by tropic responses of plants, where growth is considered implicitly as the driver of the observed bending. We analytically and numerically investigate the 2D dynamics of single organs responding to point signals fixed in space, and pairs of organs which interact by sensing each other's signals. For attractive interactions, we find that apical sensing yields stable dynamics, while local sensing can yield unstable dynamics in certain cases. The rich dynamics resulting from these pairwise interactions suggest the emergence of complex collective dynamics in systems of multiple interacting organs. This work sets the stage towards a theoretical framework for the investigation and understanding of systems of interacting growth-driven individuals.

[21] Size Matters for Nonlinear (Protein) Wave Patterns

Lisa RAPP

University of Bayreuth

Pattern formation and selection are fundamental, omnipresent principles in nature - from small cells up to geological scales. In E. coli bacteria, for example, self-organized pole-to-pole oscillations of Min proteins - resembling a short standing wave - ensure correct positioning of the cell division site. The same biochemical reaction leads to traveling protein waves on extended membranes in in vitro experiments. Are these seemingly contradictory observations of system-spanning importance? We show that a transition of nonlinear traveling wave patterns to reflection-induced standing waves in short systems is a generic and robust phenomenon. It results from a competition between two basic phenomena in pattern formation theory. We confirm the generic findings for the cell-biological Min reaction and for a chemical reaction-diffusion system. These standing waves show bistability and adapt to varying system lengths similar as pole-to-pole oscillations in growing E. coli. Our generic results highlight key functions of universal principles for pattern formation in nature.

[22] Sulfide Concentration as a Mechanism for Pattern Formation in Posidonia Oceanica Meadows

Daniel RUIZ-REYNES

Institute for Cross-Disciplinary Physics and Complex (IFISC)

The meadows of Posidonia oceanica, a clonal plant predominant in the Mediterranean, have been identified as a remarkable example of pattern formation phenomena. The ecosystem formed by this marine plant provides important benefits such as, great biodiversity, CO2 absorption or shoreline protection. Under the present circumstances of important loss mainly due to anthropogenic factors, pattern formation theory have shown its potential, not only explaining spatial distribution of vegetation but as diagnostic tool to identify ecosystems at risk. However, the biological mechanism giving rise to these vegetation patterns is still unclear. Different hypothesis have been considered based on different mechanisms of interaction. However, the spatial scale involved in the competition, necessary to produce pattern formation, is around 30 m. This fact makes hypothesis related with water movement such as, interactions through toxic compounds like sulfide concentration or hydrodynamics by itself the most plausible candidates. In this work we explore the possibility of interaction through excessive sulfide concentrations generated by organic matter decomposition. We introduce the dynamics of sulfides coupled with the growth of plant density showing that this mechanism reproduces the formation of patterns in agreement with experimental data. In addition, oscillatory behaviors are predicted, including new dynamical behaviors to the systems.

[23] Pattern Formation Aspects of Electrically Charged Tri-stable Media with Implications to Bulk Heterojunction in Organic Photovoltaics

Alon SHAPIRA

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A common thread in designing electrochemically-based renewable energy devices comprises materials that exploit nano-scale morphologies, e.g., supercapacitors, batteries, fuel cells, and bulk heterojunction organic photovoltaics. In these devices, however, Coulomb forces often influence the fine nano-details of the morphological structure of active layers leading to a notorious decrease in performance. By focusing on bulk heterojunction organic photovoltaics as a case model, a self-consistent mean-field framework that combines binary (bi-stable) and ternary (tri-stable) morphologies with electrokinetics, is presented and analyzed, i.e., undertaking the coupling between the spatiotemporal evolution of the material and charge dynamics along with charge transfer at the device electrodes. Particularly, it is shown that tri-stable composition may stabilize stripe morphology that is ideal bulk heterojuction. Moreover, since the results rely on generic principles they are expected to be applicable to a broad range of electrically charged amphiphilic-type mixtures, such as emulsions, polyelectrolytes, and ionic liquids.

[24] Grazing Away the Resilience of Patterned Ecosystems

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In this presentation I show how foraging behavior, herbivore migration and grazing management, influence the response of spatially patterned ecosystems to climate change. Vegetation can locally exhibit positive density dependence by facilitating the availability and uptake of water resources. But vegetation can also exhibit negative density dependence by competing for these resources at larger distances, the interplay between these density dependencies drives dryland vegetation pattern formation. The formation of these patterns helps to retain vegetation density when rainfall decreases. So what about grazing in patterned ecosystems? Grazing by mobile herbivores can also generate positive density dependence or negative density dependence within vegetation. The authors contrast existing models, without density dependence due to grazing, to two types of grazing by mobile herbivores, elucidating the effects of grazing by mobile herbivores. Grazing by mobile herbivores is shown to hamper the ability to smoothly respond to changing environmental conditions, leading to regime shifts and hysteresis.

[25] Motion of Fronts and Clusters in an Active Allen-Cahn Model

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Active matter is composed of many particles which are able to transform different types of energy into motion. This may result in motility-induced clustering or directed collective motion. Such phenomena are observable for swarming in fauna as well as for artifical microswimmers. The collective structures may consist of disordered or well ordered arrangements and are referred to as active clusters and active crystals, respectively. In order to understand aspects of the behaviour of active clusters we employ a rather simple model for active matter, namely, the active Allen-Cahn (aAC) equation: The passive Allen-Cahn equation is coupled to a polarization field similar to the active phase field model (aPFC) in [1]. We then study occurring clusters and the motion of fronts in aAC. In particular, we provide bifurcation diagrams and show that the onset of motion occurring with increasing activity corresponds to a drift-ptichfork bifurcation similar to the case of aPCF [2]. Additionally, we we find that motion is not only controlled by the activity parameter but is also affected by the chemical potential. We track the drift-pitchfork bifurcation in the corresponding parameter space. Finally, we show that depending on the chemical potential the passive AC equation generates pulled and pushed fronts and discus their existence in the active case. [1] A. M. Menzel and H. Löwen Phys. Rev. Lett. (2013) [2] L. Ophaus, et al. Phys. Rev. E (2018).

[26] Melt Ponds as Metastable States of Arctic Sea Ice

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The melting of Arctic sea ice is a phase transition phenomenon, from solid to liquid, albeit on large regional scales and over a period of time that depends on environmental forcing and other factors. The sea ice surface undergoes a remarkable transformation to a complex mosaic of melt ponds. The complexity of the geometry of pond patterns increases rapidly through a transition phase. To describe this complexity, we use the nonlinear ODE model of energy balance in this system as well as the statistical mechanics model, where the binary variable assigned as frozen state or melting state. Both models reveal that such pond patterns exhibit metastable states of the system.

[27] Localized States in Heterogeneous Media

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We investigate the formation and dynamical properties of localized states in systems with spatial inhomogeneities. The theoretical investigation of inhomogeneities and their effect on pattern forming systems is necessary, since small spatial inhomogeneities are unavoidable in any real experimental setup ranging from biology to nonlinear optics. However, even small heterogeneities change the symmetry properties of the system and can therefore have drastic implications on the formation and the dynamics of its solutions. We therefore consider paradigmatic pattern forming systems described by Swift-Hohenberg and Lugiato-Lefever equations with additional inhomogeneities and analyze their influence on the regime of existence of localized states by deploying numerical continuation techniques. We show, that small inhomogeneities can drastically widen the parameter regime, in which localized states exist, which can be beneficial for the experimental investigation of localized states. Furthermore we show, that an inhomogeneity can act attracting or reppelling on a localized state depending on other system parameters. We introduce a semi-analytical model to determine the influence of an inhomogeneity, where we show that the localized structure in the vicinity of the inhomogeneity can be treated as an overdamped particle in a potential well. Finally, we consider time-delay induced dynamics in the presence of inhomogeneities. Especially in nonlinear optics, time-delayed feedback provides a promising control mechanism for intra-cavity pattern formation. In particular, we show that the presence of inhomogeneities changes the induced dynamics drastically by breaking the underlying translational symmetry of the system and therefore changing the eigenmodes that become destabilized by time-delayed feedback.

[28] Modelling of Surfactant-Driven Front Instabilities in Spreading Bacterial Colonies

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The spreading of bacterial colonies at solid-air interfaces hinges on physical processes connected to the properties of the involved interfaces. The production of surfactant molecules by the bacteria is one strategy that allows the bacterial colony to efficiently expand over a substrate. The surfactant molecules affect the surface tension which results in an increased wettability as discussed in [1] as well as in outward-pointing Marangoni fluxes that promote spreading. These fluxes may cause an instability of the circular colony shape and the subsequent formation of fingers. We discuss the front instability of bacterial colonies at solid-air interfaces induced by surfactant production in the framework of a passive hydrodynamic thin-film model which is extended by bio-active terms. We show that the interplay between wettability and Marangoni fluxes determines the spreading dynamics and decides whether the colony can expand over the substrate. We observe four different types of spreading behaviour, namely, arrested and continuous spreading of circular colonies, slightly modulated front lines and the formation of pronounced fingers [2]. [1] S. Trinschek et al. PRL 119.7 (2017): 078003 [2] S. Trinschek et al. Soft Matter 14.22 (2018): 4464-4476

[29] Period-doubling as an Early Warning Signal for Critical Transitions

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Much research effort has been devoted recently to identifying early warning signals for ecosystems that approach tipping points. These signals, however, are inadequate for assessing the collapse of ecosystems far from tipping points as a result of climate extremes. Such an assessment calls for the identification of new signals based on processes that precede the collapse. Using a mathematical model of dryland vegetation we show that ecosystems subjected to strong seasonal variability exhibit a period-doubling route to chaos that precedes the collapse to bare soil. We further find that plants that invest in fast growth go through period-doubling sooner than plants that invest in tolerance to droughts. We suggest that tracing signatures of period-doubling in spectral densities can indicate vulnerability to desertification by climate extremes, and that plants' functional traits associated with strong biomass response to seasonal variability may contain significant information about potential vulnerability to desertification.

[30] Pattern Formation in Agroforestry Systems

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The development of sustainable agricultural systems in drylands is currently an important issue in the context of mitigating the outcomes of population growth under the conditions of climatic changes. The need to meet the growing demand for food, fodder, and fuel under the threat of climate change, requires cross-disciplinary studies of ways to increase the livelihood while minimizing the impact on the environment. Practices of agroforestry systems, in which herbaceous species are intercropped between rows of woody species plantations, have shown to increase land productivity. As vegetation in drylands tends to self-organize in spatial patterns, it is important to explore the relationship between the patterns that agroforestry systems tend to form, and the productivity of these system in terms of biomass, their resilience to droughts, and water use efficiency.

A spatially-explicit vegetation model for two species that compete for water and light and may exploit soil layers of different depths will be introduced. Spatially-uniform and periodic solutions, and their stability properties, will be presented for different scenarios of species and environmental conditions. The implications for optimal intercropping in terms of biomass productivity, water use efficiency, and resilience to environmental changes, will be discussed.

[31] The Effect of Heterogeneity on the Dynamics of Localized Patterns

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The interplay between 1D traveling pulses with oscillatory tails and heterogeneities of Dirac type is studied for a generalized three component FitzHugh Nagumo equation. We first deduce the dynamics of a pulse in the vicinity of the drift-bifurcation. Starting from the reduced dynamics, penetration, oscillatory pinning and rebounding states are investigated. We use Melnikov's method to derive the bifurcation value in a limit case. The result is compared to solutions of the underlying reaction-diffusion system, which shows good agreement.

[32] The Three Regimes of Spatial Recovery

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Identifying the drivers of ecosystem and population stability is a fundamental aspect of ecology. In an spatially explicit context, the basic ingredients to consider are the spatial structure of the landscape, the local dynamics of species, and their dispersal behavior which mediates between the former two. Numerous studies has looked at each of these components as a driver of stability, but little is known on the interplay between them. Missing has been a more integrative approach, able to map and identify the possible dynamical regimes which determine the response to perturbations, i.e. the stability properties of ecosystems and populations. We focus on a simple, yet relatively general, scenario: the recovery of a homogeneous metapopulation from a single, spatially localized pulse disturbance. We find that the response can take one of three forms, each representing one of three dynamical regimes: Isolated, Interplay and Mixing. Using dimensional analysis we can predict the transition points between these regimes, and how these change with basic system properties such as its total area and the nonlinearities of local dynamics. We deduce a framework which enables us to address pertinent questions for ecology such as the effect of habitat fragmentation, which effectively pushes systems towards the Isolated regime, or of global change which may slow down local dynamics as conditions deteriorate, pushing systems towards the Mixing regime. Finally, we can also better position other studies that address various questions, from the stabilizing effect of disturbances on populations prone to synchrony-induced extinctions, to the mechanisms underlying biomass productivity in metacommunities.