DY 33: Statistical Physics of Biological Systems I (joint session DY/BP)

Time: Wednesday 9:30–12:45 Location: ZEU/0114

DY 33.1 Wed 9:30 ZEU/0114

Metastability in the mixing/demixing of two species with reciprocally concentration-dependent diffusivity — •Benjamin Lindner[1,2], Alexander B. Neiman[3,4], and Xiaochen Dong[2] — [1]Department of Physics, Humboldt University Berlin, Berlin, Germany — [2]Bernstein Center for Computational Neuroscience Berlin — [3]Department of Physics and Astronomy, Ohio University, Athens, OH, United States — [4]Neuroscience Program, Ohio University, Athens, OH, United States

It is known that two species of diffusing particles can separate from each other by a reciprocally concentration-dependent diffusivity: the presence of one species at a certain location amplifies the diffusion coefficient of the respective other one in this location, causing the two densities of particles to separate spontaneously. In a minimal model, Schimansky-Geier et al. (2021) observed this with a quadratic dependence of the diffusion coefficient on the density of the other species. Here, we consider a sigmoidal dependence in the form of a logistic function on the other particle's density averaged over a finite sensing radius. The sigmoidal dependence leads to a new regime in which a homogeneous disordered (well-mixed) state and a spontaneously separated ordered (demixed) state coexist, forming two long-lived metastable configurations. In systems with a finite number of particles, random fluctuations induce repeated transitions between these two states. By tracking an order parameter that distinguishes mixed from demixed phases, we measure the corresponding mean residence in each state.

DY 33.2 Wed 9:45 ZEU/0114

Phase separation in a mixture of proliferating and motile active matter — Lukas Hupe[1], Joanna M. Materska[2], David Zwicker[1], Ramin Golestanian[1,3], Bartlomiej Waclaw[2,4], and •Philip Bittihn[1] — [1]MPI for Dynamics and Self-Organization, Göttingen, Germany — [2]Dioscuri Centre for Physics and Chemistry of Bacteria, Institute of Physical Chemistry, Warsaw, Poland — [3]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, United Kingdom — [4]School of Physics and Astronomy, The University of Edinburgh, United Kingdom

Proliferation and motility are ubiquitous drivers of activity in biological systems. Here, we study a dense binary mixture of motile and proliferating particles with exclusively repulsive interactions, where homeostasis in the proliferating subpopulation is maintained by pressure-induced removal. Using large-scale simulations, we show that this heterogeneous active matter undergoes spontaneous phase separation at high density and weak enough self-propulsion. We recapitulate this behavior using an effective Active Brownian Particle model that incorporates the emergent effects of the proliferating matrix on motile particles: enhanced diffusion, renormalized self-propulsion, reduced persistence, and an effective attraction between motile particles. Our results establish a new type of phase transition and reveal how mechanical activity from growth can mediate non-equilibrium interactions and fluctuations. This mechanism provides a conceptual framework to reinterpret the physics of dense pattern-forming cellular populations, such as bacterial colonies or tumors, as systems of mixed active matter.

DY 33.3 Wed 10:00 ZEU/0114

Reentrant phase separation and critical behaviour in cellular aggregates — •Subhadip Chakraborti[1,2] and Vasily Zaburdaev[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Max-Planck-Zentrum für Physik und Medizin, Erlangen, Germany

We study pili-mediated bacterial colonies as a paradigm for attractive cellular aggregates. The interplay between inherent motility and intercellular attraction leads to a reentrant phase separation between attraction-induced and motility-induced phase separation separated by a homogenous state. Using finite-size scaling of the largest cluster we characterise these two transitions and thereby determine the associated critical lines in terms of the control parameters - density, pili lifetime and attraction strength. We further evaluate critical exponents corresponding to two transitions in the parameter space and from their relations determine the respective universality classes.

DY 33.4 Wed 10:15 ZEU/0114

Phase separation with non-local interactions — Filipe C. Thewes, Yicheng Qiang, Oliver W. Paulin, and •David Zwicker — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Phase separation takes place in many complex systems, notably biological cells. While simple theories predict coarsening until only macroscopically large phases remain, concrete models often exhibit patterns with finite length scales, e.g., caused by chemical reactions, elasticity, membrane interactions, or charge. To unify such models, we here propose a field theory that combines phase separation with non-local interactions. If these interactions are long-ranged, they generally suppress coarsening, whereas systems with non-local short-range interactions additionally exhibit a continuous phase transition to patterned phases. Only the latter system allows for the coexistence of homogeneous and patterned phases, which we explain by mapping to the conserved Swift–Hohenberg model. Taken together, our generic model provides a framework that unifies similar phenomena observed in many complex phase-separating systems.

DY 33.5 Wed 10:30 ZEU/0114

Motile response of bacterial swimmers towards competing chemical signals — •Agniva Datta[1], Robert Grossmann[1], and Carsten Beta[1,2] — [1]Institute of Physics and Astronomy, University of Potsdam, Germany — [2]Nano Life Science Institute (WPI-NanoLSI), Kanazawa University, Kakuma-machi, Kanazawa 920-1192, Japan

Understanding how bacteria navigate in bulk fluid has gained significant interest in the field of active matter and random transport processes in the last few decades. We use the soil bacterium *Pseudomonas putida* as our model organism, the motility pattern of which is characterized by persistent runs, interrupted by random reorientation events (turns). In addition to this, bacteria sense chemical signals and adapt their motility pattern accordingly. Recent experiments show that bacteria can change the frequency of turns (duration of runs) depending on the concentration of nutrients as well as auto-inducer molecules that they themselves produce in the medium. This complex interplay of the dynamics of nutrients, auto-inducers and bacterial density may lead to dynamic instabilities. Combining experiments and theory, we are elucidating the dynamics of bacteria in the presence of these two competing signaling factors.

DY 33.6 Wed 10:45 ZEU/0114

Anisotropic hierarchy decides the fate of an amorphous droplet — •Andrey Zelenskiy, Pietro Caracciolo di Torella, and Martin Lenz — LPTMS, CNRS, Orsay, France

The classical description of ordering, from theories of phase transitions to classical nucleation, typically emphasizes a direct transition from disorder to order. Yet, the majority of systems in nature deviate from this simple description, and often choose indirect pathways to ordering. In particular, complex structures often form via disordered or partially ordered intermediates – the amorphous precursors.

We present a model of self-assembling patchy particles, where the interactions are characterized by a hierarchy of geometric competitions. By tuning the anisotropy, we can stabilize a variety of aggregate morphologies, including crystals, gels, lamellar sheets, and fibers. However, due to geometric frustration, self-assembly proceeds via a dense amorphous intermediate, where the anisotropic interactions are largely averaged out. Our simple framework based on an anisotropic hierarchy sheds light on this non-classical mechanism of particle assembly, and provides a platform for new experimental principles of complex structure design.

15 min. break

DY 33.7 Wed 11:15 ZEU/0114

Improving neuronal information transmission with pathway splitting — •Kolja Klett[1,2] and Benjamin Lindner[1,2] — [1]Humboldt University, Berlin — [2]Bernstein Center for Computational Neuroscience, Berlin

In many organisms sensory information can take different neuronal paths from sensory cells to destinations in the brain. These paths can be made up of neurons serving distinct functions. Often, pathways consisting of neurons coding the increase (ON) or decrease (OFF) of a signal are observed which have be found to improve the transmission

static signals. Here, we consider a simple network of spiking ON and OFF neurons to study the effects of pathway splitting on the transmission of dynamic signals. To that end, we use the coherence function as a frequency-resolved measure of informations transmission. We relate the information transmission of the whole network to that of the constituting neurons by employing response theory leading to approximate relations for the coherence function. For a simple white noise driven integrate-and-fire model of spiking neurons, we find an optimal mixture of ON and OFF neurons which maximizes the coherence function over a broad frequency range. The effect can be attributed to the nonlinear response of the neurons that only becomes relevant for sufficiently strong stimuli.

DY 33.8 Wed 11:30 ZEU/0114

Population sparseness in recurrent spiking neural networks — •Jakob Stubenrauch[1,2], Naomi Auer[3], Richard Kempter[2,3,4], and Benjamin Lindner[1,2] — [1]Physics Department HU Berlin — [2]Bernstein Center for Computational Neuroscience Berlin — [3]Institute for Theoretical Biology HU Berlin — [4]Einstein Center for Neurosciences Berlin

It is long known that in association tasks for neural networks, the fraction of active neurons in patterns to be associated plays an important role. Specifically, the number of patterns that can be simultaneously remembered grows when the information content per pattern is decreased. In binary networks, this content can be constrained by the population sparseness (one minus fraction of active neurons). For neurons with graded activity, population sparseness can be quantified by the Treves-Rolls measure or by the Gini coefficient. Here, we present results on the spontaneous and evoked population sparseness in different variants of recurrent neural networks of integrate-and-fire neurons. We find that the type of competition between neurons plays an important role and discuss that neurons in fully disordered networks can, in a mean field limit, only compete across a low-dimensional effective inhibition hub. We showcase the relevance of our findings for association tasks in spiking neural networks.

DY 33.9 Wed 11:45 ZEU/0114

Minority-triggered reorientation yields macrocscopic cascades and maximal responsiveness in a Vicsek swarm — •Simon Syga[1], Chandraniva Guha Ray[2,3,4], Josué Manik Nava Sedeño[5], Fernando Peruani[6], and Andreas Deutsch[1] — [1]Technische Universität Dresden, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Max Planck Institute of Molecular Cell Biology and Genetics, Dresden, Germany — [4]Center for Systems Biology Dresden, Germany — [5]Universidad Nacional Autónoma de México, Mexico City, Mexico — [6]CY Cergy Paris Université, Paris, France

Collective motion in animals and cells often exhibits bursty reorientations and scale-free velocity correlations associated with criticality. This ensures that information, like the presence of predators, quickly spreads through a group, ensuring an adequate response. To explain this phenomenon, we introduce a simple, biologically plausible mechanism, a minority-triggered reorientation rule: when local order is high, agents sometimes follow a strongly deviating neighbor instead of the majority. This generates heavy-tailed cascades of reorientations and macroscopic spatial correlations over broad parameter ranges, without fine-tuning. Our mechanism preserves cohesion while markedly enhancing collective responsiveness: localized directional cues elicit amplified, group-level reorientation. Our results provide a parsimonious, biologically interpretable route to critical-like fluctuations and high susceptibility in collective motion.

DY 33.10 Wed 12:00 ZEU/0114

Noise structure shapes transitions in cell differentiation processes — •Sara Oliver-Bonafoux[1], Javier Aguilar[1,2], Tobias Galla[1], and Raúl Toral[1] — [1]Institute for Cross-Disciplinary Physics and Complex Systems IFISC (CSIC-UIB), Campus UIB, Palma de Mallorca, Spain — [2]Laboratory of Interdisciplinary Physics, Department of Physics and Astronomy "G. Galilei", University of Padova, Padova, Italy

Stochastic differential equations provide a natural framework to describe dynamical systems influenced by random fluctuations, but they require specifying the structure of the noise term (e.g., additive, demographic, or environmental). In biological systems, the choice of an appropriate noise description remains a matter of debate. Understanding how stochastic fluctuations shape biological dynamics is a central challenge in biophysics and systems biology.

We address this question in the context of a model of cell differentiation, the process by which an unspecialised cell commits to a specialised cell type with a specific structure and function. Both the undifferentiated state and differentiated states are stable, and transitions between them are induced by noise. A recent study has provided theoretical evidence that different noise structures can give rise to substantially distinct differentiation paths. Here, we use stochastic bridges to sample differentiation paths under different types of noise and for varying noise intensity.

DY 33.11 Wed 12:15 ZEU/0114

Darwin's paradox of the peacock tail: a stochastic perspective on sexual selection — •Ian Magalhaes Braga — CASUS, Gorlitz, Germany

Many species show male traits that are extravagant, costly, and seemingly disadvantageous, yet they evolve and persist. Classical explanations especially deterministic versions of Fisher's runaway struggle to fully account for this pattern, mostly because they ignore the inherent randomness of evolutionary processes. In this work, I propose that stochasticity is not a secondary detail but the key element that reshapes the dynamics of trait preference coevolution. Treating sexual selection at the microscopic, probabilistic level reveals a simple but unexpected idea: in finite populations, a costly trait can actually support the evolution of female preference. I refer to this effect as the cost advantage. The basic picture is that stochastic fluctuations change the timing of fixation events, creating conditions under which preference benefits from the very cost that penalizes the trait. Using large-scale simulations across multiple evolutionary architectures, I show that this behavior is general and does not depend on specific modelling choices. The results suggest that costly ornaments are not paradoxical after all they may simply reflect the true stochastic nature of evolutionary change.

DY 33.12 Wed 12:30 ZEU/0114

Local equations for the generalized Lotka-Volterra model on sparse asymmetric graphs — •David Machado Pérez[1,2,3], Pietro Valigi[1], Tommaso Tonolo[4,5], and Maria Chiara Angelini[6] — [1]Physics Department, Sapienza University of Rome, Rome I-00185, Italy — [2]Department of Theoretical Physics, Physics Faculty, University of Havana. CP10400, Havana, Cuba — [3]CNR-NANOTEC, Rome Unit, Rome I-00185, Italy — [4]Gran Sasso Science Institute, 67100 L'Aquila, Italy — [5]INFN-Laboratori Nazionali del Gran Sasso, 67100 Assergi (AQ), Italy — [6]INFN, Sezione di Roma I, 00185 Rome, Italy

Real ecosystems are characterized by sparse and asymmetric interactions, posing a major challenge to theoretical analysis. We introduce a new method to study the generalized Lotka-Volterra model with stochastic dynamics on sparse graphs. By deriving local Fokker-Planck equations and employing a mean-field closure, we can efficiently compute stationary states for both symmetric and asymmetric interactions. We validate our approach by comparing the results with the direct integration of the dynamical equations and by reproducing known results and, for the first time, we map the phase diagram for sparse asymmetric networks. Our framework provides a versatile tool for exploring stability in realistic ecological communities and can be generalized to applications in different contexts, such as economics and evolutionary game theory.