DY 30: Focus Session: New Trends in Nonequilibrium Physics – Conservation Laws and Nonreciprocal Interactions II

Nonequilibrium phase transitions and pattern formation are known from numerous examples of open systems, where external reservoirs and gradients prevent relaxation to thermodynamic equilibrium. In recent years, related research in biology and soft matter systems in physics and chemistry has increasingly focused on active matter, where energy is injected locally. This often involves mass conservation constraints and, in many cases, in addition non-reciprocal interactions of the involved entities, such as macromolecules or cells. Both have far reaching consequences on the universal dynamical behavior of a wide range of nonequilibrium systems and require classical concepts of nonlinear and statistical physics, such as phase transitions, to be reconsidered and developed further. For example, well-known approaches to nonequilibrium pattern formation require substantial extensions to address conserved systems. Thus, recent theoretical studies in this field have revealed many novel phenomena, such as arrested coarsening, odd elasticity, oscillatory phase separation, persistent wave dynamics, and active turbulence. Many of these aspects have by now been confirmed by experimental findings, for example, in intracellular pattern formation or collective dynamics in colloidal systems. This symposium will provide a well-balanced overview of experimental and theoretical progress in this new, exciting area.

Organized by Markus Bär (Berlin) and Carsten Beta (Potsdam)

Time: Wednesday 15:00–16:30 Location: BH-N 243

Invited Talk DY 30.1 Wed 15:00 BH-N 243

Continuum Approach for Studying Morphological Deformations of Multiple-Phase Renewable Energy Devices — •Arik Yochelis — Swiss Institute for Dryland Enviremental and Energy Research, Ben-Gurion University of the Negev, Sede Boqer Campus, Midreshet Ben-Gurion 8499000, Israel — Department of Physics, Ben-Gurion University of the Negev, Be'er Sheva 8410501, Israel

Optimizing the morphological properties of soft-matter renewable energy devices is not only challenging technologically but also reveals novel physical and mathematical puzzles. For example, recent experimental studies of bulk heterojunction (BHJ) organic photovoltaics (OPV) show that phase separation can surprisingly inhibit morphological changes in three-phase (donor/mixed/acceptor) constellations. Motivated by BHJ observations, the development of a continuum model (dissipative parabolic-elliptic PDEs) that undertakes the coupling between the spatiotemporal evolution of the material and generated charge dynamics along with charge transfer at the device electrodes, will be presented. Model analysis in the spirit of reaction-diffusion-type mechanisms uncovers the bending (zigzag mode) and the pinching (cross-roll mode) of the donor/acceptor stripes, where the latter leads to the formation of disconnected domains and hence to loss of charge flux near the electrodes. In the end, a similar approach is applied to renewable Ni (Edison-type) batteries in which charge/discharge electrochemical reactions and capacity are associated with fingering instability between the multiplicity of Ni phases.

DY 30.2 Wed 15:30 BH-N 243

Collective behavior of cohesive, aligning particles — •Jeanine Shea and Holger Stark — Technische Universität Berlin, Institut für Theoretische Physik, Hardenbergstr. 36, 10623 Berlin, Germany.

Collective behavior is all around us, from flocks of birds to schools of fish. These systems are immensely complex, which makes it pertinent to study their behavior through minimal models. We introduce a minimal model for cohesive and aligning self-propelled particles. In contrast to former models of this type, we establish group cohesion through non-reciprocal torques [1] as opposed to attractive forces. These torques cause constituents to effectively turn towards one another. We additionally incorporate an alignment torque. By changing the strength and range of these torque interactions, we uncover a vast array of dynamics ranging from long filaments to pear-shaped clusters. We present state diagrams to identify these different dynamic states.

[1] Knežević, M., Welker, T. and Stark, H. Collective motion of active particles exhibiting non-reciprocal orientational interactions. Sci Rep 12, 19437 (2022).

DY 30.3 Wed 15:45 BH-N 243

Aligning self-propelled particles beyond mean-field: the active Boltzmann equation — Jakob Mihatsch[1], •Horst-Holger Boltz[1], Rüdiger Kürsten[2], and Thomas Ihle[1] — [1]Universität Greifswald, Greifswald, Deutschland — [2]Universitat de Barcelona, Barcelona, Spanien

Models of active matter are commonly discussed within mean-field approaches. Going beyond mean-field by assuming one-sided molecular chaos, we show that it is possible to explicitly account for the finite duration and range of actual interactions in particular active matter leading to the active Boltzmann equation. One principle outcome is a derivation of the entropy production.

We demonstrate the quantitatively accurate realization of this methodology, both analytically and numerically, for ensembles of Vicsek-style self-propelled particles with finite-ranged alignment interactions. For anti-aligning interactions in the absence of noise, this system displays deterministically chaotic dynamics under the existence of an additional conservation law that affects the large-scale statistics.

We use an asymptotically exact solution to predict a novel flocking transition in heterogeneous systems wherein all couplings are anti-aligning, which we corroborate by agent-based direct simulations, and show how the formalism can successfully be expanded to non-reciprocal interactions.

References: Ihle, Kürsten, Lindner (2023) arXiv:2303.03354, 2303.03357; Kürsten, Mihatsch, Ihle (2023) arXiv: 2304.05476

DY 30.4 Wed 16:00 BH-N 243

Formation of trails and bands of signaling active particles — •Zahra Mokhtari[1], Robert Grossmann[2], Robert Patterson[3], and Felix Höfling[1,4] — [1]Institut für Mathematik, Freie Universität Berlin — [2]Institut für Physik und Astronomie, Universität Potsdam — [3]WIAS Berlin — [4]Zuse Institute Berlin

To shed light on pattern formation of active particles with nonreciprocal interactions, we study self-propelled agents that interact via self-generated fields: individual particles deposit traces of pheromones which encode their current walking direction, in turn influencing the direction of motion of passing agents. In contrast to direct binary alignment interactions, the communication via self-generated fields constitutes a type of time-delayed, non-reciprocal feedback. The system exhibits different stable patterns: the collective dynamics is of the Vicsek type in the limit of short-lived traces, thus forming transversely moving bands. For prolonged pheromone lifetime, particles are found to gather along macroscopic narrow trails along the direction of motion. To elucidate the transitions between these states, we derive hydrodynamic equations within a mean-field approximation, unraveling a nuanced phase diagram dependent on pheromone lifetime. Combining numerics and a linear stability analysis reveals that transversal bands are destabilized in favor of the emergence of *longitudinal* trails. Thereby, this work provides a first steps towards an understanding of the role of nonreciprocal, delayed feedback interactions for the symmetry and structure of a novel type of emergent patterns forming under nonequilibrium conditions.

DY 30.5 Wed 16:15 BH-N 243

Two-species Janus colloids with non-reciprocal interactions — •Gennaro Tucci, Suropriya Saha, and Ramin Golestanian — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

We are examining two interacting populations of Janus colloids, each distinguished by their catalytic caps and mobility. The dynamics of these colloids are characterized by their position and orientation, influencing and being influenced by the density distribution of a single chemical substrate. Specifically, the particles can produce or consume the chemical and interact with its concentration gradient through chemotaxis. This chemically-mediated coupling gives rise to an effective non-reciprocal interaction between the two colloid species, resulting in novel configurations of instability. We derive the equation of motion for both density and the polar order parameter through a systematic coarse-graining of the microscopic dynamics. Subsequently, a linear stability analysis of the reference state, featuring constant densities and disordered polarity, allows us to elucidate the mechanisms by which it may become unstable. Initially, we demonstrate how the system exhibits one-species-like behavior in a certain parameter subspace. Finally, we explore phases that can be obtained through the non-reciprocal nature of the two-species interaction.