BP 2: Active Matter I (joint session DY/BP/CPP)

Time: Monday 9:30–12:45 Location: H37

BP 2.1 Mon 9:30 H37

Odd dynamics and pattern formation in mixtures of magnetic spinners and passive colloids — •Dennis Schorn[1], Stijn van der Ham[2], Hanumantha Rao Vutukuri[2], and Benno Liebchen[1] — [1]Technische Universität Darmstadt, 64289 Darmstadt, Germany — [2]MESA+ Institute, University of Twente, 7500 AE Enschede, The Netherlands

Starfish embryos aggregate into chiral crystals exhibiting odd elasticity (Tan *et al.* Nature **607**, 287 (2022)). Similar structures have been recently observed in externally driven magnetic colloids. In this talk, I present experiments and simulations of binary mixtures of magnetic spinners and passive colloids. We develop a model to predict the phase diagram of the system, which comprises four distinct phases that can be systematically reproduced in experiments. In particular, our simulations and experiments show a phase where the passive particles form a gel-like network featuring significant holes filled with self-organized rotating chiral clusters made of spinners. This phase can be reversed by changing the system's composition and magnetic field strength, featuring a system spanning spinner phase with embedded counter-rotating chiral clusters made of passive colloids. Our system may open the route towards a new type of viscoelastic active chiral matter involving nonreciprocal interactions between both species.

BP 2.2 Mon 9:45 H37

Symmetry breaking in active non-reciprocal systems — •Kim L. Kreienkamp and Sabine H. L. Klapp — TU Berlin, Germany

Non-reciprocity significantly impacts the dynamical behavior in mixtures. One of its particularly striking consequences is the spontaneous emergence of time-dependent phases that break parity-time symmetry [1-3]. Here, we study a paradigmatic model of a non-reciprocal polar active mixture with completely symmetric repulsion [4,5]. Using a combination of field theory and particle-based simulations, we identify two qualitatively distinct regimes of non-reciprocity-induced dynamics. In the regime of weak intra-species alignment, non-reciprocity leads to asymmetric clustering in which only one of the two species forms clusters. Notably, the asymmetric density dynamics is driven alone by non-reciprocal orientational couplings [4,5]. In contrast, in the strongly coupled regime, the corresponding field theory exhibits exceptional points that have been associated with the emergence of chiral phases where the polarization direction rotates over time [2]. Our simulations confirm that spontaneous chirality arises at the particle level. In particular, we observe chimera-like states with coexisting locally synchronized and disordered regions. At the coupling strengths associated with exceptional points, the spontaneous chirality peaks.

[1] Z. You et al., PNAS 117, 19767 (2020).
[2] M. Fruchart et al., Nature 592, 363 (2021).
[3] K. L. Kreienkamp and S. H. L. Klapp, NJP 24, 123009 (2022).
[4] K. L. Kreienkamp and S. H. L. Klapp, to appear in PRE (2024).
[5] K. L. Kreienkamp and S. H. L. Klapp, to appear in PRL (2024).

BP 2.3 Mon 10:00 H37

Emergent phases in a discrete flocking model with non-reciprocal interaction — •Swarnajit Chatterjee, Matthieu Mangeat, and Heiko Rieger — Center for Biophysics & Department for Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany

Non-reciprocal interactions arise in systems that seemingly violate Newton's third law "actio=reactio". They are ubiquitous in active and living systems that break detailed balance at the microscale, from social forces to antagonistic interspecies interactions in bacteria. Non-reciprocity affects non-equilibrium phase transitions and pattern formation in active matter and represents a rapidly growing research focus in the field. In this work, we have undertaken a comprehensive study of the non-reciprocal two-species active Ising model (NRTSAIM), a non-reciprocal discrete-symmetry flocking model. Our study uncovers a distinctive *run-and-chase* dynamical state that emerges under significant non-reciprocal frustration. In this state, A-particles chase B-particles to align with them, while B-particles avoid A-particles, resulting in B-particle accumulation at the opposite end of the advancing A-band. This run-and-chase state represents a non-reciprocal discrete-symmetry analog of the chiral phase seen in the non-reciprocal Vicsek model. Additionally, we find that self-propulsion destroys the oscillatory state obtained for the non-motile case, and all the NRTSAIM steady-states are metastable due to spontaneous droplet excitation and exhibit motility-induced interface pinning. A hydrodynamic theory supports our simulations and confirms the reported phase diagrams.

BP 2.4 Mon 10:15 H37

Emergent phases in a discrete flocking model with reciprocal interaction — •Matthieu Mangeat[1], Swarnajit Chatterjee[1], Jae Dong Noh[2], and Heiko Rieger[1] — [1]Saarland University, Saarbrücken, Germany — [2]University of Seoul, Seoul, Korea

We have undertaken a comprehensive study of the two-species active Ising model (TSAIM), a discrete-symmetry counterpart of the continuous-symmetry two-species Vicsek model, motivated by recent interest in the impact of complex and heterogeneous interactions on active matter systems. In the TSAIM, two species of self-propelled particles undergo biased diffusion in two dimensions, interacting via local intraspecies alignment and reciprocal interspecies anti-alignment, along with the possibility of species interconversion. We observe a liquid-gas phase transition, exhibiting macrophase-separated bands, and the emergence of a high-density parallel flocking state, a feature not seen in previous flocking models. With species interconversion (species-flip dynamics), the TSAIM corresponds to an active extension of the Ashkin-Teller model and exhibits a broader range of steady-state phases, including microphase-separated bands that further enrich the coexistence region. We also find that the system is metastable due to droplet excitation and exhibits spontaneous motility-induced interface pinning, preventing the system from reaching long-range order at sufficiently low noise. A hydrodynamic theory complements our computer simulations of the microscopic model and confirms the reported phase diagrams.

BP 2.5 Mon 10:30 H37

Emergent collective behavior from cohesion and alignment — •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. To explore their basic characteristics, we introduce a minimal model for cohesive and aligning self-propelled particles in which group cohesion is established through additive, non-reciprocal torques [1]. These torques cause constituents to effectively turn towards one another, while an additional alignment torque competes in the same spatial range. By changing the strength and range of these torque interactions, we uncover six states which we distinguish via their static and dynamic properties. These states range from disperse particles to closely packed worm-like formations. A number of the states generated by this model exhibit collective dynamics which are reminiscent of those seen in nature.

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

Invited Talk BP 2.6 Mon 10:45 H37

Collective behavior of photoactive macroscopic particles — •Iker Zuriguel — University of Navarra, Pamplona, Spain

Active matter refers to systems of interacting, self-propelled agents that convert energy into mechanical motion, representing a nice example of out-of-equilibrium systems. In this work, a novel type of active particles is introduced. These are active granular (i.e. they interact solely through physical contacts) and photoactive, meaning that they self-propel using energy from light. Therefore, by means of a programmable LED panel, we are able to change the illumination pattern and, consequently, the particle activity in space and time, allowing a precise exploration of a variety of scenarios related to collective behavior. This possibility has been exploited in microscopic systems but is genuinely new in macroscopic ones.

First, we will present the clustering behavior of these agents under homogeneous illumination. By varying the illumination intensities and changing the population size, we observed a power-law-like distribution for both the cluster sizes and durations. We identified a transition from unstable to stable clusters, as indicated by the divergence of average cluster durations. Higher particle activities and smaller populations led to the creation of small unstable clusters, while lower particle activities and larger populations result in big, stable clusters that persist over time. This transition is explained with the help of a simple model capturing the most important processes involved in cluster dynamics. In the last part of the talk, the collective behavior under inhomogeneous illumination patterns will be introduced.

15 min. break

BP 2.7 Mon 11:30 H37

Swarming model with minority interaction exhibits temporal and spatial scale-free correlations — •Simon Syga[1], Chandraniva Guha Ray[2,3,4], Josué Manik Nava Sedeño[5], Fernando Peruani[6,7], and Andreas Deutsch[1] — [1]Technische Universität Dresden — [2]Max Planck Institute for the Physics of Complex Systems — [3]Max Planck Institute of Molecular Cell Biology and Genetics — [4]Center for Systems Biology Dresden — [5]Universidad Nacional Autónoma de México — [6]Université Côte d'Azur, Nice — [7]CY Cergy Paris Université

Collective motion is a widespread phenomenon in social organisms, from bird flocks and fish schools to human crowds and cell groups. Swarms of birds and fish are particularly fascinating for their coordinated behavior and rapid escape maneuvers during predator attacks. Critical motion is hypothesized as an optimal trade-off between cohesive group behavior and responsiveness to well-informed individuals. However, traditional models only show criticality at the phase transition between ordered and unordered motion. Here, we extend the Vicsek model with a minority interaction, where individuals primarily follow neighbors but can switch to follow a defector moving against a well-aligned group. This triggers cascades of defections, leading to rich dynamics, including large-scale fluctuations, scale-free velocity distributions, and a scale-free return time distribution of the order parameter. Our model underscores the biological importance of minority interactions in swarming and their role in critical behavior.

BP 2.8 Mon 11:45 H37

'Predator-prey' driven swarmalator systems — •Ginger E. Lau, Mario U. Gaimann, and Miriam Klopotek — Stuttgart Center for Simulation Science (SimTech), Cluster of Excellence EXC 2075, University of Stuttgart, Germany

Swarmalators are an active matter system of oscillators which exhibit swarming and collective motion in physical space, as well as synchronization behavior in an additional phase variable space, originally introduced by O'Keeffe *et al.* (*Nat. Commun.* 8(1), 1504, 2017). Such systems with bidirectional couplings in space and phase can be observed in nature, such as in the chorusing behavior of Japanese tree frogs characterized by Aihara *et al.* (*Sci. Rep.* 4(1), 3891, 2014). The interplay between attraction, repulsion, and phase synchronization provides several distinct regimes of self-organizational behavior. Akin to biological swarm systems responding to predator interactions, swarmalators can respond collectively to external perturbations by a repulsive driver. In previous work, driving was realized with a mobile 'pacemaker' by Xu *et al.* (*Chaos* 34(11), 113103, 2024). The present study introduces a new 'predator-prey' driven swarmalator model showing rich adaptive behavior. This could have a wide variety of potential future applications, from biological physics to swarm robotics to nature-inspired learning algorithms and methods of inference.

BP 2.9 Mon 12:00 H37

Inertial active matter governed by Coulomb friction — •Alexander Antonov[1], Lorenzo Caprini[2], and Hartmut Löwen[1] — [1]Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany — [2]University of Rome La Sapenzia, Rome, Italy

Coulomb, or dry friction, is a common phenomenon that can be encountered in various systems, such as granular matter or Brownian motors. The Coulomb friction force resists the motion and, unlike the friction in wet systems, is almost independent of the relative velocity. We show that this characteristic feature of Coulomb friction leads to emergence of dynamical states when subjected to active, or self-propelled motion [1]. At low activity levels, the dynamics resembles Brownian motion, while at greater activity, a dynamic Stop & Go regime emerges, marked by continuous switching between diffusion and accelerated motion. At even higher activity levels, a super-mobile regime arises, characterized by fully accelerated motion and an anomalous scaling of the diffusion coefficient with activity. Near the transition between the Stop & Go and super-mobile regimes, we reveal a novel activity-induced phase separation in collective behavior [2]. Our theoretical findings have been also demonstrated in experiments, where vibrobots on a horizontal surface are activated by vertical oscillations generated using an electromagnetic shaker.

[1] A.P. Antonov, L. Caprini, A. Ldov, C. Scholz, and H. Löwen, Phys. Rev. Lett. 133, 198301 (2024)

[2] A.P. Antonov et al., in preparation.

BP 2.10 Mon 12:15 H37

Active nematic turbulence with substrate friction — •Peter A. E. Hampshire[1,2] and Ricard Alert[1,2,3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Center for Systems Biology Dresden, Dresden, Germany — [3]Cluster of Excellence Physics of Life, Dresden, Germany

Active nematics with high activity exhibit turbulent-like flows, characterized by vortices, spatio-temporal chaos and power laws in the energy spectra [1-3]. Continuum models have been successfully used to predict the scaling of the energy spectra with the wavevector. Most theoretical work has focused on free-standing, active nematic films. However, in several experimental realisations, such as bacterial colonies and epithelial monolayers, the active nematic is in contact with a solid substrate. We generalised a 2D, incompressible active nematic model to include substrate friction, and studied its impact on the transition to turbulence and the energy spectra of the turbulent-like flows. We find a variety of dynamic states including flow in lanes, stable vortices and both isotropic and anisotropic turbulence. At high activity and moderate friction, we found a power-law scaling in the kinetic energy spectrum $E(q) \sim q^3$, where q is the wavevector, at low wavevectors. The exponent of 3 can be justified with a power-counting argument. Overall, we have developed a model for active nematic turbulence on a substrate that can be compared to biological systems. [1] L. Giomi, *Phys. Rev. X* **5**, 031003 (2015). [2] R. Alert, J.-F. Joanny, J. Casademunt, *Nat. Phys.* **16**, 682-688 (2020). [3] B. Martínez-Prat*, R. Alert*, et al., *Phys. Rev. X* **11**, 031065 (2021).

BP 2.11 Mon 12:30 H37

Self-sustained patchy turbulence in shear-thinning active fluids — •Henning Reinken and Andreas M. Menzel — Otto-von-Guericke-Universität Magdeburg

Bacterial suspensions and other active fluids are known to develop highly dynamical vortex states, denoted as active or mesoscale turbulence. We reveal the pronounced effect of non-Newtonian rheology of the carrier fluid on these turbulent states, concentrating on shear thinning. As a consequence, a self-sustained heterogeneous state of coexisting turbulent and quiescent areas develops, which results in anomalous velocity statistics. The heterogeneous state emerges in a hysteretic transition under varying activity. We provide an extensive numerical analysis and find indirect evidence for a directed percolation transition. Our results are important, for instance, when addressing active objects in biological media with complex rheological properties.