BP 19: Active Matter III (joint session DY/BP/CPP)

Time: Wednesday 9:30–13:00 Location: BH-N 334

Invited Talk BP 19.1 Wed 9:30 BH-N 334

Emergent chemotaxis in synthetic active matter — •Abhinav Sharma[1,2], Hidde Vuijk[1], Pierluigi Muzzeddu[3], Holger Merlitz[2], and Jens-Uwe Sommer[2] — [1]Universität Augsburg, 86159 Augsburg — [2]Leibniz Institute für Polymerforschung, Dresden — [3]SISSA, Trieste, Italy

Active particles with their characteristic feature of self-propulsion are regarded as the simplest models for motility in living systems. The accumulation of active particles in low activity regions has led to the general belief that chemotaxis requires additional features and at least a minimal ability to process information and to control motion. We show that self-propelled particles display chemotaxis and move into regions of higher activity if the particles perform work on passive objects, or cargo, to which they are bound. The origin of this cooperative chemotaxis is the exploration of the activity gradient by the active particle when bound to a load, resulting in an average excess force on the load in the direction of higher activity. In fact chemotaxis should emerge in all those structures which allow cooperative exploration of the activity landscape. We demonstrate this in simple assemblies of active molecules, which show robust chemotaxis both under static and dynamic activity landscapes.

BP 19.2 Wed 10:00 BH-N 334

Active particles interacting via phase-separating chemicals — •Dennis Schorn, Aritra K. Mukhopadhyay, and Benno Liebchen — Institut für Physik Kondensierter Materie, Technische Universität Darmstadt, Germany

Synthetic active particles self-propel by catalyzing a certain chemical reaction and moving up or down the resulting concentration gradient. In this talk, we present our study of the collective dynamics of chemotactic active particles which interact via self-produced chemicals that have an intrinsic tendency to phase separate. When the chemical interactions are attractive (chemoattraction), the particles aggregate to form a large cluster. In contrast, chemorepulsive particles exhibit two distinct patterns: a stationary foam-like structure and an oscillating stripe pattern. We explain the origins of these structures through a comprehensive linear stability analysis of our system. Our findings underscore that the intricate interplay between chemical phase separation and particle chemotaxis induces new instabilities, leading to the formation of unique patterns.

BP 19.3 Wed 10:15 BH-N 334

Towards the cybernetics of active matter — •Alexander Ziepke[1], Ivan Maryshev[1], Igor S. Aranson[2], and Erwin Frey[1,3] — [1]Arnold Sommerfeld Center and CeNS, LMU, Munich, Germany — [2]Dept. Biomed. Eng., Penn State University, University Park, PA, USA — [3]Max Planck School Matter to Life, Munich, Germany

Cybernetics describes the self-organized behavior of collectives of individual units in response to their environment, often taking inspiration from biological processes. Different organisms have developed various communication strategies to control such collective responses. For instance, social amoeba use chemical signaling to form localized aggregates in response to starvation, insects such as ants secrete pheromones for navigation, and bats and birds employ acoustic signals to form cohesive swarms. Our research focuses on how chemical and acoustic communication enables the formation of collective states with cooperative functionality, a targeted specification of the units, and the control of a coordinated response. In particular, we show that acoustic signaling of oscillatory agents leads to the formation of synchronized localized clusters and collectively propagating snake- and larva-like structures with distinct acoustic signatures. By emitting acoustic waves, these emergent structures are able to sense environmental changes, such as approaching reflective objects, and respond with a coordinated change in phenotype. This study provides insights into design principles for unsupervised microrobots, able to form adaptive, multi-functional structures with population-level cognitive capabilities (Ziepke, Maryshev, Aranson, Frey., Nat Commun 13, 6727 (2022)).

BP 19.4 Wed 10:30 BH-N 334

Active Spaghetti: Collective Organization in Cyanobacteria — •Jan Cammann[1], Mixon K. Faluweki[2,3], Lucas Goehring[2], and Marco G. Mazza[1] — [1]Loughborough University, UK — [2]Nottingham Trent University, UK — [3]Malawi Institute of Technology

Filamentous cyanobacteria can show fascinating examples of nonequilibrium self-organization, which, however, are not well understood from a physical perspective. We investigate the motility and collective organization of colonies of these simple multicellular lifeforms. As their area density increases, linear chains of cells gliding on a substrate show a transition from an isotropic distribution to bundles of filaments arranged in a reticulate pattern. Based on our experimental observations of individual behavior and pairwise interactions, we introduce a nonreciprocal model accounting for the filaments large aspect ratio, fluctuations in curvature, motility, and nematic interactions. This minimal model of active filaments recapitulates the observations, and rationalizes the appearance of a characteristic length scale in the system, based on the Péclet number of the cyanobacteria filaments.

Reference: M. Faluweki, J. Cammann, et al. Phys. Rev. Lett. 131, 158303 (2023)

BP 19.5 Wed 10:45 BH-N 334

Collective dynamics and pair-distribution function of active Brownian ellipsoids* — Stephan Bröker[1], •Michael te Vrugt[2], and Raphael Wittkowski[1] — [1]Institut für Theoretische Physik, Center for Soft Nanoscience, Universität Münster, 48149 Münster, Germany — [2]DAMTP, Centre for Mathematical Sciences, University of Cambridge, Cambridge CB3 0WA, United Kingdom

While the collective dynamics of spherical active Brownian particles is relatively well understood by now, the much more complex dynamics of nonspherical active particles still raises interesting open questions. Previous work has shown that the dynamics of rod-like or ellipsoidal active particles can differ significantly from that of spherical ones. In this work [1], we obtain the full state diagram of active Brownian ellipsoids depending on the Péclet number and packing density via computer simulations. The system is found to exhibit a rich state behavior that includes cluster formation, local polar order, polar flocks, and disordered states. Moreover, we obtain numerical results and an analytical representation for the pair-distribution function of active ellipsoids. This function provides useful quantitative insights into the collective behavior of active particles with lower symmetry and has potential applications in the development of predictive theoretical models.

[1] S. Bröker, M. te Vrugt, and R. Wittkowski, arXiv:2307.15535 (2023)

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BP 19.6 Wed 11:00 BH-N 334

Flow and orientational properties of active nematic liquid crystals under an electric field — •Yutaka Kinoshita and Nariya Uchida — Department of Physics, Tohoku University, Sendai, Japan

Active nematic liquid crystals are materials where each constituent has nematic symmetry and produces dipolar flow along its axis. Examples include microtubule-kinesin suspensions and actomyosin networks. Because of the input of energy into the system, the state is driven out of thermodynamic equilibrium and shows a chaotic flow called active turbulence. The flow patterns are controlled by external field, confinement, and friction. An external field induces reorientation of the active elements and suppresses chaotic flow. Here we numerically simulate the effects of an electric field on the dynamics of two-dimensional active nematics [1].

We found transitions among three states that are characterized by the degree of flow anisotropy: the active turbulence, laning state, and uniformly aligned state. The average flow speed and its anisotropy are maximized in the laning state. We also found localization of vortices and topological defects associated with periodic shifts between active turbulence and laning state, which is similar to experimentally observed oscillations in a friction-controlled system. Our results might lead to a further understanding of the dynamical states of active nematics under an external field.

[1] Y. Kinoshita and N. Uchida, Phys. Rev. E **108**, 014605 (2023)

15 min. break

BP 19.7 Wed 11:30 BH-N 334

From Active Chiral Particles to the Active Model B + — •Erik Kalz[1], Abhinav Sharma[2,3], and Ralf Metzler[1,4] — [1]University of Potsdam, Germany — [2]University of Augsburg, Germany — [3]Leibniz-Institute for Polymer Research, Dresden, Germany — [4]Asia Pacific Centre for Theoretical Physics, Pohang, Republic of Korea

A first-principles approach for active chiral hard disks is presented, that explicitly accounts for steric interactions on the two-body level. With a handle on the full derivation, we explicitly point out the necessary assumptions to derive the field-theoretical description for Active Chiral Particles. By considering different regimes of the Péclet number, the well-known models in active matter can be obtained through our consideration. Explicitly, we derive the phenomenological Model B. By going to higher orders in the closure scheme, we show that this first-principles approach results in the recently introduced Active Model B +, a natural extension of Model B for active processes. Contrary to systems without chirality and to previous derivations, we find that chirality can change the sign of the characteristic activity parameters. This has profound consequences for the already shown effects in the Active Model B +. Finally, we draw a connection between Active Chiral Particles and Odd Diffusion, a phenomenon that has attracted considerable attention recently, and for which Active Chiral Particles are handled as an exemplary system.

Ref: E. Kalz, A. Sharma, and R. Metzler: *arXiv preprint arXiv:2310.16691*, 2023

BP 19.8 Wed 11:45 BH-N 334

Phase Behaviour of a Minimal Chiral Active Ising Lattice Model — •Boyi Wang[1,3], Frank Jülicher[1,4,5], and Patrick Pietzonka[2,1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom — [3]Institute of Physics, Chinese Academy of Sciences, Beijing, China — [4]Center for Systems Biology Dresden (CSBD), Dresden, Germany — [5]Cluster of Excellence, Physics of Life, TU Dresden, Dresden, Germany

We introduce chiral activity into a lattice model with Ising interactions, achieved by locally rotating a random selected 2×2 neighbourhood of lattice site each time step only in clockwise direction. Monte Carlo simulations at low temperature reveal a path to condensate formation, marked by the evolution of the droplet's edge into a particular tilted orientation relative to the square lattice. This tilt angle depends on the local rotation direction, thus reflecting the chirality of the model on a macroscopic scale.

Furthermore, we investigate the stability of the chiral tilted angle in the droplet's lattice field. We identify a persistent edge current flowing along the droplet's interface. By an equivalent 1D model, we also quantify this current-angle dependence, allowing us to identify the angles that emerge in the stationary state.

Our findings provide a novel perspective on chiral non-equilibrium systems in a discrete and analytical framework, expanding our understanding of how chiral driving forces influence the formation and interface behaviour of active droplets.

BP 19.9 Wed 12:00 BH-N 334

Long-range fluctuation-induced forces in chiral active fluids — Hashem Fatemi[1], Hamidreza Khalilian[1], Jalal Sarabadani[1], and •Reza Shaebani[2] — [1]Institute for Research in Fundamental Sciences (IPM), Iran — [2]Department of Theoretical Physics, Saarland University, Germany

We study long-range fluctuation-induced (FI) interactions in chiral active matter systems. We show that the combination of self-rotation and self-propulsion can lead to large FI forces, depending on the elongation of active particles. Such strong forces can contribute to self-organization of chiral active matter into dynamic structures and patterns. We numerically measure the FI forces between intruders immersed in chiral active fluids and find that the influence of chirality depends on the particle elongation in the active bath. For round active objects, the FI force monotonically decreases with increasing chirality since the active bath structure gradually changes from rotating flocks and vortices to localized spinners. Contrarily, for elongated active objects there is an optimal chiral angle at which the magnitude and range of the FI interaction are maximized. We explain how the balance of collisions around the intruders varies with chirality and separation between the intruders.

BP 19.10 Wed 12:15 BH-N 334

Self-Solidifying Active Droplets Showing Memory-Induced Chirality — •Aritra K. Mukhopadhyay[1], Kai Feng[2], José Carlos Ureña Marcos[1], Ran Niu[2], Qiang Zhao[2], Jinping Qu[2], and Benno Liebchen[1] — [1]Technische Universität Darmstadt, 64289 Darmstadt, Germany. — [2]Huazhong University of Science and Technology, 430074 Wuhan, China.

Synthetic microswimmers have yet to achieve the autonomy and versatility of their biological counterparts, particularly in terms of energy supply and motion diversity. Here, we introduce an all-aqueous droplet swimmer that shows remarkable autonomy and rich dynamics without any external driving mechanism [1]. Comprising a surface tension-lowering polyelectrolyte mixture, the droplets undergo self-solidification on acidic water surfaces, gradually emitting polyelectrolytes into the surroundings. A spontaneous asymmetry of the emitted polyelectrolyte concentration along the droplet surface induces Marangoni flows, which causes the droplet to self-propel. The slowly diffusing polyelectrolytes form long-lived chemical trails creating memory effects that drive a dynamic transition from linear to chiral motion. This showcases the droplet's ability to navigate its environment in a persistent, directional manner requiring no externally imposed symmetry breaking. Practical applications are highlighted through the droplets' highly efficient uranium removal from wastewater. Our results provide a route to fueling self-propelled agents that can autonomously perform chiral motion and collect toxins.

[1] K. Feng et al., Advanced Science 10, 2300866 (2023).

BP 19.11 Wed 12:30 BH-N 334

Optimising transport of active magnetic particles with finite internal magnetic anisotropy — Andrey Kuznetsov[1], Ekaterina Novak[2], Vladimir Zverev[2], Tatyana Belyaeva[2], and •Sofia Kantorovich[1] — [1]University of Vienna, Vienna, Austria — [2]Ekaterinburg, Russia

In recent years, we have observed a rapid development in synthesis techniques that opens up new avenues for tailoring magnetic nanoparticles, including their size, shape, and internal anisotropy. The concept of creating magnetically controllable colloids with finely tuneable rheological properties on the nano- or micro-scale has sparked significant experimental and theoretical efforts but remains not fully realised. In this contribution, we employ molecular dynamics computer simulations to investigate the interplay between internal particle magnetic relaxation dynamics and particle self-propulsion. Our findings demonstrate that optimal transport can be achieved by selecting the strength of an applied magnetic field based on the particle's material and size. This, in turn, opens up an avenue for active magnetic particle sorting.

BP 19.12 Wed 12:45 BH-N 334

The Role of Anisotropy in Pulsating Active Matter — •Luca Casagrande, Alessandro Manacorda, and Etienne Fodor — University of Luxembourg, Department of Physics and Material Science

Contraction waves have been observed in different biological systems where contractile tissues are present. Some examples can be found in embryonic development, cardiac arrhythmogenesis and uterine contraction. Recently, a particle-based model reproducing the spontaneous emergence of contraction waves has been proposed. In this model, a dense system of active particles is considered, where each particle features isotropic repulsion with neighbors, and has an internal drive that periodically changes its size.*However, it is well know that cells in tissues are not isotropic. Therefore, we consider an additional degree of freedom which embodies the ability of particles to change their eccentricity. It enables us to investigate the role of particle anisotropy in pulsating collective dynamics. The resulting dynamics are studied through numerical simulations. Also an analytical hydrodynamics approach is used through coarse-graining methods. We present the full phase diagram that illustrates the stationary regime as a function of the control parameters of the model. Our model elucidates the interplay between nematic order and phase synchronization in pulsating active matter, and it paves the way towards studying how to control the emergence of contractile waves in biological tissues.