BP 12: Active Matter II (joint session BP/CPP/DY)

Time: Tuesday 9:30–13:00 Location: H 1028

BP 12.1 Tue 9:30 H 1028

Disorder-induced cooperative behaviour in aligning self-propelled particle systems — •Eloise Lardet and Thibault Bertrand — Imperial College London, London, UK

In 1995, Vicsek et al. wrote a seminal paper describing a simple model that displays a transition from disorder to collective ordered behaviour. It describes a system of self-propelled point particles that align with their neighbours within a certain radius. This minimal model displays rich nonequilibrium behaviours such as flocking and banding. Inspired by the random couplings of spin glass models, I present numerical findings of introducing Gaussian distributed pairwise couplings into a self-propelled particle system. Through adding further disorder by increasing the standard deviation of the Gaussian distribution that the couplings are drawn from, we are able to observe the emergence of global polar order in systems where the majority of couplings are anti-aligning.

BP 12.2 Tue 9:45 H 1028

Swarming of self-steering and responsive active particles — •Rajendra Singh Negi, Roland G. Winkler, and Gerhard Gompper — Theoretical Physics of Living Matter, Institute of Biological Information Processing (IBI-5), Forschungszentrum Jülich, 52425 Jülich, Germany

The collective behavior of self-propelled agents emerges from the dynamic response of individuals to various input signals [1,2]. In our model of intelligent active Brownian particles (iABPs), information about the position and orientation of neighboring particles, obtained through directed visual and isotropic perception, respectively, is used to adjust the propulsion direction. The maneuverability due to visual signal and polar alignment determines the self-organization. Several non-equilibrium structures like worms, milling, compact, and dispersed clusters are obtained at different parameter sets [2]. As the strength of polar alignment increased compared to visual maneuverability, worm structures dominate over compact structures. Our results help to understand the collective behavior of cognitive self-propelled particles, like animal herds and micro-robotic swarms.

[1]. R. S. Negi, R. G. Winkler, and G. Gompper, Emergent collective behavior of active Brownian particles with visual perception, Soft Matter **18**, 6167 (2022).

[2]. R. S. Negi, R. G. Winkler, and G. Gompper, Collective behavior of self-steering particles with velocity alignment and visual perception, (2023) arXiv:2308.00670 .

BP 12.3 Tue 10:00 H 1028

Effect of cell-cell interactions on the collective behaviour of gliding *Chlamydomonas* populations — •Alexandros Fragkopoulos, Justin Nevells, Timo Völkl, and Oliver Bäumchen — University of Bayreuth, Experimental Physics V, 95447 Bayreuth, Germany

Cilia and flagella represent universal tools enabling cells and microbes to propel themselves in diverse environments. In the case of the unicellular biflagellated microbe *Chlamydomonas reinhardtii*, the flagella are used not only to swim in the surrounding medium, but also to adhere to surfaces. In this adhered state, a second flagella-mediated motility mode is observed, during which the cells glide along the surface. This is achieved by means of force transduction through an intraflagellar transport machinery. We recently showed that gliding *C. reinhardtii* cells form weak clusters, most likely assisted by mechanosensing of their flagella [1]. Here we show that *Chlamydomonas noctigama*, a close relative of *C. reinhardtii*, exhibits significantly stronger cell-cell interactions, resulting in pronounced cell clustering even at low densities. In addition, we observe that *C. noctigama* preferentially attach nearby other cells. Finally, we use morphological tools to quantify and compare the clusters to *C. reinhardtii*. By understanding the changes of the cell-cell interactions between the species, we aim to dissect their contribution to the observed cell clustering.

[1] Till et al., *Phys. Rev. Res.* **4**, L042046 (2022).

BP 12.4 Tue 10:15 H 1028

Magnetic colloidal crystals activated by light-driven bacteria — •Helena Massana-Cid[1], Claudio Maggi[1,2], Giacomo Frangipane[1], and Roberto Di Leonardo[1,2] — [1]Department of Physics, Sapienza University of Rome, Rome, Italy — [2]NANOTEC-CNR, Institute of Nanotechnology, Rome, Italy

Active solids, or self-propelling units elastically coupled on a lattice, are recently of growing interest and are predicted to show emerging out-of-equilibrium behaviour, while they can inspire the design of numerous applications. We show for the first time an experimental realisation of a large ordered active solid with activity and confinement tuneable in-situ and on-command. This two-dimensional active solid is composed of repulsive magnetic particles activated by a photokinetic bacterial bath. The bacteria induce active motion into the crystal by pushing its particles and, in a simplified picture, this can be described by an equilibrium state with a higher effective temperature. Nevertheless, this framework breaks down qualitatively because of the active fluctuations time correlations due to the persistent motion of bacteria. We explore the emerging dynamics of this active solid for different values of activity, controlled by the applied light, and repulsion strength, determined by the external magnetic field. Furthermore, we show how we can melt the crystal by increasing activity. Our findings pave the way to unveil the properties of a novel out-of-equilibrium system, an active colloidal solid, which presents questions vastly interesting from a statistical mechanics point of view.

BP 12.5 Tue 10:30 H 1028

Billiards with Spatial Memory — Thijs Albers, Stijn Delnoij, Nico Schramma, and •Mazi Jalaal — Institute of Physics, University of Amsterdam, Amsterdam, The Netherlands

It has been proposed that spatial memory can lead to more efficient navigation and collective behaviour in biological systems. This raises important questions about the fundamental properties of dynamical systems with spatial memory. We present a framework based on mathematical billiards in which particles remember their past trajectories and react to them. Despite the simplicity of its fundamental deterministic rules, such a system is strongly non-ergodic and exhibits highly-intermittent statistics, manifesting in complex pattern formation. We show how these self-memory-induced complexities emerge from the temporal change of topology and the consequent chaos in the system. We study the fundamental properties of these billiards and particularly the long-time behaviour when the particles are self-trapped in an arrested state. We exploit numerical simulations of several millions of particles to explore pattern formation and the corresponding statistics in polygonal billiards of different geometries. Our work illustrates how the dynamics of a single-body system can dramatically change when particles feature spatial memory and provide a scheme to further explore systems with complex memory kernels.

BP 12.6 Tue 10:45 H 1028

Chemical communication in suspensions of active particles — •Nils Göth and Joachim Dzubiella — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany

Chemical communication of bacteria plays an important role in their individual and collective behavior. Here, we study how a simple form of interparticle communication influences a system of colloidal particles. We employ two-dimensional Brownian dynamics simulations of a model of Responsive Colloids, in which the particle size and the internal proton concentration are explicit internal degrees of freedom. The communication between the particles is modeled as a chemical field around each particle to which the other particles respond by changes in their size. We find a rich behavior of structures, including pseudo-regular oscillations and longitudinal waves.

15 min. break

BP 12.7 Tue 11:15 H 1028

Structural Colour from Collective Gliding Bacteria Motion — •Junwei Wang[1], Marina Portoghese[2], Laura Caton[2], Colin Ingham[3], and Silvia Vignolini[1] — [1]Max Planck Institute of Colloids and Interfaces, Potsdam, Germany — [2]University of Cambridge, Cambridge, UK — [3]Hoekmine BV, Utrecht, Netherland

We report a type of marine, non-pathogenic, gliding bacteria, Flavobacterium Iridescent 1 (IR1), that grows into a dense active liquid crystal colony, exhibiting structural colour. We demonstrate different crystalline phases arising from collective bacteria motility correlate with varied optical appearances of the colony. We show the hierarchical collective motions of the rod-like bacteria that organize into clusters, monolayer, multi-layers and finally into large scale vortices. We also illustrate how the bacteria colony adapts to confinement of different geometries.

BP 12.8 Tue 11:30 H 1028

Chiral active molecules in traveling activity waves — •Bhavesh Valecha[1] and Abhinav Sharma[1,2] — [1]Institute of Physics, University of Augsburg, 86159 Augsburg, Germany — [2]Leibniz-Institut für Polymerforschung Dresden, Institut Theorie der Polymere, 01069 Dresden, Germany

Directed motion is crucial for the survival and maintenance of life-supporting functions of numerous biological systems, e.g., motion of sperms towards the egg during fertilisation or movement of immune cells to fight-off an infection. While systematic studies of chiral active molecules simulating crucial aspects of these systems in stationary activity gradients do exist [1-3], the majority of physical scenarios revolve around activity fields that vary with time. So, in this project we study the simplest possible case of an active molecule, the active dimer, in a propagating activity wave. We show that this simple molecule can show very rich emergent tactic behaviour using a cooperative mechanism between the two active chiral particles. In particular, this dimer can, on average, move along with the wave, against the wave motion or not move at all depending on the magnitude of chiral torque and the wave speed. We believe that this study can provide important insights into the design principles of hybrid bio-molecular devices of the future.

[1] P. L. Muzzeddu, H. D. Vuijk, H. Löwen, J.-U. Sommer, and A. Sharma, J. Chem. Phys. **157**, 134902 (2022)

[2] H. D. Vuijk, S. Klempahn, H. Merlitz, J.-U. Sommer, and A. Sharma, Phys. Rev. E **106**, 014617 (2022)

[3] H. Merlitz et al., J. Chem. Phys. **148**, 194116 (2018)

BP 12.9 Tue 11:45 H 1028

Physical principles of space allocation in an active biofluid — •Sebastian W. Krauss, Mithun Thampi, Pierre-Yves Gires, and Matthias Weiss — Experimental Physics I, Bayreuth, Germany

Living matter has the remarkable ability to self-organize into distinct cellular entities that ultimately form the building blocks of organisms. The organisation in multi-cellular systems emerges by replicating a single fertilized oocyte as template structure in multiple division cycles. In contrast, recent studies on Xenopus egg extracts have shown that an active biofluid that is devoid of template structures and genetic material can spontaneously self-organize into compartments in an ATP-driven fashion even when protein synthesis is blocked. The emerging compartments (protocells) are distinct, lack a confining membrane envelope, and vanish after all ATP has been consumed. Here, we show that protocell geometry is determined by a random-packing process with a coarse-graining dynamics that is similar to two-dimensional foams [Development 150, dev200851 (2023)]. Protocell sizes are seen to be tunable by altering the dynamics of microtubules while preserving geometric features of the pattern. Confining the self-organizing fluid in ellipsoidal microfluidic cavities, i.e. mimicking natural confinements like those in embryos, pattern formation is seen to adapt to the confinement, exhibiting a surprising similarity to spatial compartmentalization in early embryos. Further, we observe that an increasing aspect ratio of the chamber results in the formation of smaller protocells. Our results indicate that mechanical cues and simple self-organization principles are key ingredients in many developmental processes.

BP 12.10 Tue 12:00 H 1028

Foams Come to Life — •Ivan Maryshev[1], Filippo De Luca[1,2], and Erwin Frey[1] — [1]Ludwig-Maximilians-Universität München, München, Germany; — [2]University of Cambridge, Cambridge, United Kingdom

Recent experiments on active filament mixtures revealed a new non-equilibrium phase called active foam, consisting of a continuously reconfiguring network of bilayers [1]. The existence of similar structures was previously predicted in phenomenological models [2]. Here we introduce a microscopic model for microtubule-motor mixtures and rigorously derive a hydrodynamic theory that recapitulates the experimental observations. We explain the observed instabilities and associated mechanisms. Finally, we discuss various forms of foam that can be realized in different active matter systems and classify them according to the symmetry and order parameters involved. This research contributes to our understanding of the complex behavior exhibited by active foams and provides insights into their dynamics.

[1] B. Lemma, N. P. Mitchell, R. Subramanian, D. J. Needleman, and Z. Dogic (2022). Active microphase separation in mixtures of microtubules and tip-accumulating molecular motors. Phys. Rev. X 12(3), 031006.

[2] I. Maryshev, A. Morozov, B. Goryachev, and D. Marenduzzo (2020). Pattern formation in active model C with anchoring: bands, aster networks, and foams. Soft Matter 16(38), 8775-8781.

BP 12.11 Tue 12:15 H 1028

Modelling cancer metastasis with active nematics — •Josep-Maria Armengol-Collado[1], Luca Giomi[1], Oleksandr Chepizhko[2], Stephanie Alexander[3], Esther Wagena[3], Bettina Weigelin[3], Peter Friedl[3], Stefano Zapperi[4], and Caterina A.M. La Porta[5] — [1]Instituut-Lorentz, Universiteit Leiden, P.O. Box 9506, 2300 RA Leiden, The Netherlands — [2]Faculty of Physics, University of Viena, Boltzmanngasse 5, Viena, Austria — [3]Department of Medical Biosciences, Sciences, Radboud University Medical Centre, 6525 GA Nijmegen, The Netherlands — [4]Center for Complexity and Biosystems, Department of Physics, University of Milan, via Celoria 16, 20133 Milan, Italy — [5]Center for complexity and Biosystems, Department of Environmental Science and Policy, University of Milan, via Celoria 10, 20133 Milan, Italy

Tumor invasion is characterized by the coordinated movement of cancer cells through complex tissue structures. Here, we focus on recent in vivo experiments where metastasis is observed through the dermis of a living mouse, and low-cohesive modes of collective migration have been identified. Interestingly, local rotational patterns give rise to antiparallel flow tracks that deform the extracellular matrix and establish a sustained flow of cells. To model this phenomenon, we employ the framework of nematic liquid crystals in the so-called "active turbulence" regime. Analysing the effects of confinement and the role of topological defects we provide significant insights to better understand the underlying mechanisms of cancer cell migration.

BP 12.12 Tue 12:30 H 1028

Flow Localization on Active Ordered Surfaces — •Rushikesh Shinde[1], Raphael Voituriez[2], and Andrew Callan-Jones[1] — [1]Laboratoire de Matière et Systèmes Complexes, Université de Paris Cité and CNRS, Paris, France — [2]Laboratoire de Physique Théorique de la Matière Condensée, Sorbonne Université and CNRS, Paris, France

During morphogenetic processes, active flows occur in the plane of curved tissues. Tissues often exhibit orientational order, and topological defects arise during tissue development. We have studied the behavior of a $+1$ defect in a film of active ordered fluid on a curved axisymmetric surface. We find strikingly different physics compared with the flat-space variant of the problem, in which extensile activity causes vortex-like or aster-like integer defects to undergo spiral ordering and rotational motion. We focus in particular on the influence of extrinsic curvature in the elastic free energy, usually neglected in theories of ordered fluids on curved surfaces. We consider two biologically-relevant surfaces: a capped-tube-like rigid surface, similar to epithelial tubes; and a bump on an otherwise flat plane. In the first case, we find that the activity threshold for instability becomes independent of system size, and spontaneous rotational flows become localized. In the latter case, we find that an aster can be passively unstable towards a spiral state, and as a result, contractility-driven active flows are thresholdless and localized. High contractility extinguishes the flow and restores the aster. Surprisingly, for high enough saddle curvature, the spiral to aster transition shifts from continuous to discontinuous.

BP 12.13 Tue 12:45 H 1028

Self-Organization in Quorum-Sensing Active Matter: The Interplay between Nonreciprocity and Motility — •Yu Duan[1], Jaime Agudo-Canalejo[1], Ramin Golestanian[1,2], and Benoît Mahault[1] — [1]Max Planck Institute for Dynamics and Self-Organization (MPI-DS), 37077 Göttingen, Germany — [2]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

Over the past years, the generation of interactions breaking action-reaction symmetry has emerged as new paradigm for active matter. The generalization of the Cahn-Hilliard theory of phase separation to nonreciprocal mixtures predicts the emergence of traveling states that break time reversal symmetry when intra-species attraction leads to demixing while chasing inter-species interactions are present. Here, we study a minimal model of active phase separation involving two species of particles regulating their self-propulsion speed via quorum-sensing rules, and identify a mechanism for dynamical pattern formation that does not rely on the standard route of intra-species effective attractive interactions. Instead, our results reveal a highly dynamical phase of chasing bands induced only by the combined effects of self-propulsion and nonreciprocity in the inter-species couplings. Turning on self-attraction, we find that the system may phase separate into a macroscopic domain of such chaotic chasing bands coexisting with a dilute gas. We show that the chaotic dynamics of bands at the interfaces of this phase-separated phase results in anomalously slow coarsening.