

CPP 5: Active Matter I (joint session BP/CPP/DY)

Time: Monday 9:30–12:45

Location: H 1028

CPP 5.1 Mon 9:30 H 1028

Active Colloids as Tunable Swarmalators — ●VEIT-LORENZ HEUTHE^{1,2} and CLEMENS BECHINGER^{1,2} — ¹Fachbereich Physik, Universität Konstanz — ²Centre for the Advanced Study of Collective Behaviour, Universität Konstanz

The complexity and functional advantages in various systems from groups of organisms to robotic swarms and digital networks hinge on spatiotemporal patterns arising from the interactions of their constituents. One approach to gain understanding of how these patterns emerge are so-called swarmalators. In this conceptual framework, individual entities exhibit both oscillatory behavior and translational motion, coupled based on their relative phase and position, yielding a diverse array of complex patterns. Here, we introduce a system of active colloids that both oscillate and translate and are coupled to each other in both speed and phase through hydrodynamic interactions. Despite the physical nature of the interactions, the system retains tunability, enabling us to systematically study the behavior of swarmalators in a real system.

CPP 5.2 Mon 9:45 H 1028

Electric field driven active colloids moving in polymeric environments — ●VENKATA MANIKANTHA SAI GANESH TANUKU, PETER VOGEL, and THOMAS PALBERG — Institute of Physics, Johannes Gutenberg University

A dilute suspension of Janus particles (JPs) in a dense viscoelastic fluid, forms a natural setting to study their dynamics in surrounding doped with macromolecules such as polymers is crucial, as most of the target application media are complex in nature. In this study, we investigate the motion of AC electric field driven SiO₂-Au JPs in the presence of concentrated amounts of poly (ethylene glycol) (PEG). The transport of active particles is strongly influenced by the viscous medium and shows a dynamical jamming transition as a function of activity and medium density. For low activity, the active particle gets self-trapped in a cavity of its own making. Conversely, higher activity causes JP to push through the fluid, leaving behind a porous trail. At the given concentration of the PEG studied within these experiments two intriguing outcomes emerge: firstly, a JP can be immobilized and secondly, when two JPs move in the same direction, an unusual attraction occurs, causing the trailing JP to eventually catch up with the leading one in finite time.

CPP 5.3 Mon 10:00 H 1028

Lorentz reciprocal theorem in fluids with odd viscosity — ●YUTO HOSAKA¹, RAMIN GOLESTANIAN^{1,2,3}, and ANDREJ VILFAN^{1,4} — ¹Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Göttingen, Germany — ²Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom — ³Institute for the Dynamics of Complex Systems, University of Göttingen, 37077 Göttingen, Germany — ⁴Jozef Stefan Institute, 1000 Ljubljana, Slovenia

The Lorentz reciprocal theorem – that is used to study various transport phenomena in hydrodynamics – is violated in chiral active fluids that feature odd viscosity with broken time-reversal and parity symmetries. Here we show that the theorem can be generalized to fluids with odd viscosity by choosing an auxiliary problem with the opposite sign of the odd viscosity [1]. We demonstrate the application of the theorem to two categories of microswimmers. Swimmers with prescribed surface velocity are not affected by odd viscosity, while those with prescribed active forces are. In particular, a torque-dipole can lead to directed motion.

[1] Y. Hosaka, R. Golestanian, and A. Vilfan, *Phys. Rev. Lett.* 131, 178303 (2023).

CPP 5.4 Mon 10:15 H 1028

A Stochastic Bubble Model in MIPS Active systems — ●MINGQI YAN^{1,2,3,4}, ERWIN FREY^{1,4}, MARCUS MÜLLER^{2,4}, and STEFAN KLUMPP^{3,4} — ¹Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, Department of Physics, Ludwig-Maximilians-Universität München, Theresienstraße 37, D-80333 München, Germany — ²Institut für Theoretische Physik, Department of Physics, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, D-37077 Göttingen, Germany — ³Institut für Dy-

namik komplexer Systeme, Department of Physics, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, D-37077 Göttingen, Germany — ⁴Max Planck School Matter to Life, Hofgartenstraße 8, D-80539 München, Germany

Motility-Induced Phase Separation (MIPS) is a notable phenomenon in which self-propelled particles undergo phase separation solely due to their intrinsic motility. This behavior starkly contrasts with passive systems, where active systems constantly form bubbles in liquids. Here, we introduce a stochastic bubble model to elucidate the changes in bubble area within Active Brownian Particle systems. We demonstrate that the bubble-area evolution can be described by a Langevin equation. Notably, this equation characterizes a unique category of stochastic systems: while it possesses an absorbing state, it concurrently maintains a stable nonequilibrium steady state distribution of areas.

CPP 5.5 Mon 10:30 H 1028

Dynamics and phase separation of active Brownian particles on curved surfaces and in porous media — ●PRIYANKA IYER, ROLAND WINKLER, DMITRY FEDOSOV, and GERHARD GOMPPER — Theoretical Physics of Living Matter (IBI-5/IAS-2), Forschungszentrum Jülich

In biophysical systems, active particles are often exposed to curved geometries and confinement. This prompts a crucial question: How does curvature influence the emergent collective behavior of active particles? We study this question by considering the effect of curvature on an ensemble of repulsive active Brownian particles (ABPs) moving on a spherical surface. Surface curvature affects the dynamics of ABPs, as it introduces a new time scale $\tau = R/v_0$, with curvature radius R and propulsion velocity v_0 , in addition to the rotational diffusion time τ_r . The time scale τ is related to a stop-and-go motion caused by the recurrent alignment of the propulsion direction with the surface normal. This implies that motility-induced phase separation (MIPS) disappears for large curvature. Moreover, the phase-separation boundary at low area fraction ϕ attains a turning point for small R , allowing for the possibility of a re-entrant behavior. The findings also have implications for understanding how curvature influences ABP dynamics in porous media, as demonstrated through a paradigmatic example involving two connected pores. Surprisingly, it is found that the different curvatures of the two pores can facilitate particle flux towards regions of high particle density and induce transient MIPS states.

[1] Iyer et al. *Phys. Rev. Res.* 5, 033054 (2023).

CPP 5.6 Mon 10:45 H 1028

Giant Activity-Induced Stress Plateau in Entangled Polymer Solutions — DAVIDE BREONI¹, CHRISTINA KURZTHALER², BENNO LIEBCHEN³, HARTMUT LÖWEN², and ●SUVENDU MANDAL³ — ¹Institut für Theoretische Physik II: Weiche Materie, Heinrich Heine-Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf, Germany — ²Max Planck Institute for the Physics of Complex Systems, Nöhnitzer Straße 38, 01187 Dresden, Germany — ³Technische Universität Darmstadt, Karolinenplatz 5, 64289 Darmstadt, Germany

Highly entangled active polymer solutions play vital roles in various biological processes, spanning from the intricate mechanisms of cell mitosis to the regulation of genetic transcription. We study the viscoelastic properties of highly entangled, flexible, self-propelled polymers using Brownian dynamics simulations. Our results show that the active motion of the polymer increases the height of the stress plateau by orders of magnitude due to the emergence of grip forces at entanglement points. Identifying the activity-induced energy of a single polymer and the ratio of polymer length to self-propulsion velocity as relevant energy and time scales, we find the stress autocorrelation functions collapse across Peclet numbers [1]. We predict that the long-time viscosity scales with polymer length squared, in contrast to equilibrium counterparts that scale with the cube of the polymer length [1]. These insights offer prospects for designing new materials with activity-responsive mechanical properties.

[1] D. Breoni, C. Kurzthaler, B. Liebchen, H. Löwen, and S. Mandal, <https://doi.org/10.48550/arXiv.2310.02929>

15 min. break

CPP 5.7 Mon 11:15 H 1028

Gravitactic bioconvection drives emergent transport and mixing in harmful algal blooms — ●SOMITREE MISHRA¹ and ANUPAM SENGUPTA^{1,2} — ¹Physics of Living Matter Group, Department of Physics and Materials Science, University of Luxembourg — ²Institute for Advanced Studies, University of Luxembourg

Bioconvection, the active self-sustaining transport phenomenon triggered by the accumulation of motile microbes, has been long studied. Yet, if and how this collective behavior, driven by competing physico-chemical cues, impacts ecological processes including Harmful Algal Blooms (HABs) remains unexplored. Here, using a bloom-forming model phytoplankton, we present a comprehensive mechanistic study on the biophysical factors governing the emergent collective patterns and capture the eco-physiological implications of bioconvective flows. Leveraging our Ocean-On-Chip platform, together with particle tracking velocimetry (PTV) and particle image velocimetry (PIV), we uncover flow fields around isolated self-organized microbial plumes, using which we extract the spatial range of active transport. Using data-backed fluid dynamic simulations, we extract the Lyapunov exponents, revealing the mixing capacity of such plumes in confined environments. Our findings significantly advance our understanding of bioconvection's functional role in ecological contexts[1], providing a novel playground where ecology meets active matter. [Reference 1] Bioconvection mediates transport and mixing dynamics within harmful algal blooms: S. Mishra & A. Sengupta (manuscript in preparation).

CPP 5.8 Mon 11:30 H 1028

Energetic cost of microswimmer navigation: the role of body shape — ●LORENZO PIRO^{1,2}, ANDREJ VILFAN^{1,3}, RAMIN GOLESTANIAN^{1,4}, and BENOÎT MAHAULT¹ — ¹Max Planck Institute for Dynamics and Self-Organization (MPI-DS), 37077 Goettingen, Germany — ²Department of Physics and INFN, University of Rome Tor Vergata, Via della Ricerca Scientifica 1, 00133 Rome, Italy — ³Jozef Stefan Institute, 1000 Ljubljana, Slovenia — ⁴Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

We study the energetic efficiency of navigating microswimmers by explicitly taking into account the geometry of their body. We show that, whereas arguments based solely on propulsion efficiency lead to the conclusion that needle-like swimmers are most energetically efficient, disk-like swimmers rotated by flow gradients naturally follow time-optimal trajectories. The coupling between body geometry and hydrodynamics thus leads to a generic trade-off between the energetic costs associated with propulsion and navigation, which is accompanied by the selection of a finite optimal aspect ratio. We derive from optimal control theory the steering policy ensuring overall minimum energy dissipation and characterize how navigation performances vary with the swimmer shape. Our results highlight the important role of the swimmer geometry in realistic navigation scenarios.

CPP 5.9 Mon 11:45 H 1028

Optimal motility strategies for self-propelled agents to explore porous media — ●CHRISTOPH LOHRMANN and CHRISTIAN HOLM — Institute for Computational Physics, University of Stuttgart, 70569 Stuttgart, Germany

Micro-robots for, e.g., biomedical applications, need to be equipped with motility strategies that enable them to navigate through complex environments. Inspired by biological microorganisms we recreate motility patterns such as run-and-reverse, run-and-tumble or run-reverse-flick applied to active rod-like particles in silico. We investigate their capability to efficiently explore disordered porous environments with various porosities and mean pore sizes ranging down to the scale of the active particle. By calculating the effective diffusivity for the different patterns, we can predict the optimal one for each porous sample geometry. We find that providing the agent with the ability to sense position for a certain time and to make a decision based on its observation yields a motility pattern outperforming the biologically inspired patterns for all investigated porous samples[1].

[1] Lohrmann, Holm: Optimal motility strategies for self-propelled agents to explore porous media, arXiv:2302.06709, 2023

CPP 5.10 Mon 12:00 H 1028

Chemotaxis of an active particle attached to a semiflexible cargo — ●SHASHANK RAVICHANDUR¹, ABHINAV SHARMA^{2,1}, and JENS-UWE SOMMER¹ — ¹Leibniz-Institut für Polymerforschung, Dresden, Germany — ²Universität Augsburg, Augsburg, Germany

The chemotaxis of synthetic active particles in activity gradients, achieved by connecting them to other active/passive particles to form simple dimers, has been demonstrated in recent studies. These studies have been extended to synthetic active particles connected to each other to form polymer chains, which also exhibit chemotaxis. However, the study of these polymer chains in activity gradients has been limited to the Rouse model, wherein the particles are connected to each other via springs, and the excluded volume interactions are ignored. To obtain a more realistic description, we consider an active synthetic particle connected to a passive tail that is semiflexible. In such a system, the configuration of the passive tail affects the motion of the active particle. Using Langevin dynamics simulations, we show that these polymers also exhibit chemotaxis in activity gradients despite the coupling between the active particle and the passive tail. We also study the effects of the chain length and bending rigidity on the chemotactic behavior.

CPP 5.11 Mon 12:15 H 1028

How cell shape guides gliding motility — ●LEON LETTERMANN¹, FALKO ZIEBERT¹, MIRKO SINGER¹, FRIEDRICH FRISCHKNECHT², and ULRICH S. SCHWARZ² — ¹IPT & Bioquant, Heidelberg University — ²CIID, Heidelberg University

Cell motility comes in many different types, including swimming, crawling and gliding. The latter term denotes movement on surfaces or through tissues without appreciable changes in cell shape and is usually based on some kind of surface flow. Gliding motility is often used by cells that need to accomplish high speeds, including myxobacteria as well as eukaryotic parasites from the phylum apicomplexa, in particular the causative agents of malaria and toxoplasmosis. We have developed an active particle theory which connects the self-organized surface dynamics to the global motility patterns of the glider. Our theory demonstrates that the resulting trajectories depend strongly on glider shape. Our analytical solutions and numerical simulations show that straight motion to get from A to B is unstable and predict the rotational and helical trajectories which are observed experimentally for gliding bacteria and apicomplexan parasites.

CPP 5.12 Mon 12:30 H 1028

Impact of non-reciprocity on the self-aggregation of an anisotropic colloidal system — ●SALMAN FARIZ NAVAS and SABINE H.L. KLAPP — ITP, Technische Universität Berlin, Germany

Non-reciprocal interactions have been demonstrated to introduce interesting collective behaviour in many-body systems[1]. Recent studies involving non-reciprocal colloidal particle systems have shown to induce propulsion mechanisms[2] and cause enhanced diffusion of tracer particles[3]. Such effects can have an impact on aggregation mechanisms as well[2]. Here, we introduce non-reciprocal interactions to a self-aggregating colloidal system with direction dependent, field-induced interactions[4]. In stark contrast to the passive (reciprocal) case, non-reciprocity induces a propulsion mechanism when a pair of particles belonging to different species come in contact. We show that at low degrees of non-reciprocity the aggregation is accelerated. At higher degrees of non-reciprocity, the system even tends to phase separate leading to the coexistence of dilute, freely moving particles and dense clusters.

[1] M. Fruchart, R. Hanai, P. B. Littlewood, and V. Vitelli, *Nature* 592, 363 (2021).

[2] S. Fehlinger and B. Liebchen, *Phys. Rev. Research* 5, L032038 (2023).

[3] A. Benois, M. Jardat, V. Dahirel, V. Démery, J. Agudo-Canalejo, R. Golestanian, and P. Illien, *Phys. Rev. E* 108, 054606 (2023).

[4] F. Kogler, O. D. Velev, C. K. Hall, and S. H. L. Klapp, *Soft Matter* 11, 7356 (2015).