BP 14: Active Matter 3 (joint session BP/CPP/DY)

Time: Wednesday 9:30–12:30 Location: H16

BP 14.1 Wed 9:30 H16

Collective foraging of microrobots trained by reinforcement learning — •Robert C. Löffler[1], Emanuele Panizon[2], and Clemens Bechinger[1] — [1]Fachbereich Physik, Universität Konstanz, Konstanz, Germany — [2]Department of Quantitative Life Science, International Centre for Theoretical Physics, Trieste, Italy

From bacteria to mammals, collective behavior can be observed on all scales in nature. It is generally driven by the benefit to individuals when cooperating with others. However, the exact motivation of individuals to participate is challenging to investigate, as biological creatures are complex systems theirself. At the same time engineers seek to create collective groups of autonomous systems to perform dedicated tasks by cooperation.

Here we present an experimental model system of feedback-controlled microswimmers which are trained with multi agent reinforcement learning in an actor-critic scheme. A group of active particles is situated in a 2D environment containing a virtual food source which is changing position over time. Despite being rewarded individually for being inside the food source, particles show cohesive collective motion forming flocks and swirls. This is driven by the benefit of social information and collision avoidance, resulting in faster migration to a relocated food source. Understanding those mechanisms behind the emergence of collective behavior is of biological interest as well as to understand human crowd behavior and to design future robotic systems.

BP 14.2 Wed 9:45 H16

Collective response of microrobotic swarms to external threats — •Chun-Jen Chen[1] and Clemens Bechinger[1,2] — [1]Fachbereich Physik, Universität Konstanz, 78464 Konstanz, Germany — [2]Centre for the Advanced Study of Collective Behaviour, Universität Konstanz, 78464 Konstanz, Germany

Many animal species organize within groups to achieve advantages compared to being isolated. Such advantages can be found e.g. in collective responses which are less prone to individual failures or noise and thus provide better group performance. Inspired by social animals, here we demonstrate with a swarm of microrobots made from programmable active colloidal particles (APs) that their escape from a hazardous area can originate from a cooperative group formation. As a consequence, the escape efficiency remains almost unchanged even when half of the APs are not responding to the threat. Our results not only confirm that incomplete or missing individual information in robotic swarms can be compensated by other group members but also suggest strategies to increase the responsiveness and fault-tolerance of robotic swarms when performing tasks in complex environments.

BP 14.3 Wed 10:00 H16

Soft robots powered by magnetically driven active particles — •Hongri Gu and Clemens Bechinger — Fachbereich Physik, University of Konstanz, Germany

Active matter describes systems of a large number of self-driving particles that convert surrounding energy into active motion. Many of the emergent behaviors resemble life-like behaviors in nature. However, it is still unclear how one can utilize such active collective motions for engineering and robotic applications. In this talk, we would like to bridge the research fields of active matter and soft robots by designing soft machines powered by active matter. The main objective is to investigate the general interactions between swarm active particles and soft structures and use this knowledge to design a new type of soft robots that are driven by swarm active particles. To facilitate the investigation, we built a highly customizable fabrication process for magnetic composite soft structures at mesoscales based on two-step micromolding. We also built a modular magnetic actuation system based on rotating permanent magnets. This new experimental platform has an enormous design space for magnetic soft matters with the capability to tune individual system parameters. By carefully designing these parameters, it is possible to precisely tune the local magnetic, elastic, and hydrodynamic interactions between active particles and soft structures. This new type of soft machine can potentially take advantage of the robust dynamic states of the active matter, which can recover their functions from extreme mechanical deformations.

BP 14.4 Wed 10:15 H16

Microswimmers in viscosity gradients — •Sebastian Ziegler[1], Maxime Hubert[1], and Ana-Sunčana Smith[1,2] — [1]PULS Group, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [2]Division of Physical Chemistry, Ruder Bošković Institute Zagreb, Croatia

Regions of variant viscosity are ubiquitous in both inanimate systems as well as in living systems. It is therefore of great interest to understand the effect of viscosity gradients on the mobility of both passive particles as well as on active systems. We firstly study a system of passive spheres and provide a general expression for the asymptotic mobility matrix in small viscosity gradients. We apply this result to linear viscosity gradients, where we unveil the existence of radially constant flows and elaborate on the effect of asymmetry of the particle position within the finite-size gradient, which hitherto has not been considered.

These results are subsequently applied to bead-spring microswimmers as model systems for self-propelling active matter. In contrast to the common approach of prescribing the stroke of the swimmer, we here employ a force-based swimmer model, allowing for an adaption of the swimming stroke to the environment, and reveal the rich viscotactic properties of such a microswimmer. We also construct a simple swimmer inspired by the Chlamydomonas algae and compare the viscotactic behavior of the biological swimmer to ours.

15 min. break

BP 14.5 Wed 10:45 H16

Noisy pursuit of active Brownian particles — •Segun Goh, Roland G. Winker, and Gerhard Gompper — IBI-5, Forschungszentrum Jülich, 52425 Jülich, Germany

Many biological and artificial agents are not only motile, but also capable of adjusting their motion based upon information gathered from their environment. This study considers sensing of a target and as a consequence reorientation of the direction of self-propulsion, which enables active pursuit. Specifically, an active Brownian particle is employed as a model agent to investigate pursuit dynamics in two dimensions, for both stationary as well as moving targets. We discuss how the interplay between intrinsic persistent self-propulsion and active reorientation by sensing gives rise to unexpected complex behaviors. In particular, the noise plays a pivotal role with both positive and negative influences on the success of pursuit. Numerical simulations and analytical calculations reveal that strong motility results in overshooting of the target, while pursuers cannot approach the target effectively at low Péclet numbers. Moreover, we propose a strategy to sort active pursuers according to their motility and reorientation capability by employing particular target trajectories.

BP 14.6 Wed 11:00 H16

Rheotaxis of the ciliate — •Takuya Ohmura[1], Yukinori Nishigami[2], and Masatoshi Ichikawa[3] — [1]Biozentrum, University of Basel, Switzerland — [2]Research Institute for Electronic Science, Hokkaido University, Japan — [3]Department of Physics, Kyoto University, Japan

Rheotaxis, a property of organisms to move against an external flow, has a crucial role to stay in living environment. For instance, freshwater fishes in rivers swim upstream to avoid being swept away to the sea. Interestingly, recent studies reported that not only fish but also swimming cells show rheotaxis. We elucidated the rheotaxis of the ciliate, Tetrahymena, a well-known single-celled freshwater microorganism swimming by cilia [1]. While that microorganism doesn*t have a sensor to detect flow direction and micrometer-sized particles are swept away downstream in a viscous flow, what dynamics underlie the rheotaxis of the ciliate? Our experiments revealed that the ciliate slid upstream along a wall, which indicates that the cells receive rotational torque from shear flow to align swimming orientation. To evaluate the shear torque, we performed a numerical simulation with a hydrodynamic model swimmer adopting cilia dynamics in a shear flow. The result suggests that the ciliate automatically slides upstream by using cilia-stalling mechanics.

[1] T. Ohmura, et al., Science Advances, 7(43), eabi5878 (2021).

BP 14.7 Wed 11:15 H16

Analytical study of active semiflexible ring polymer — •Christian A. Philipps, Gerhard Gompper, and Roland G. Winkler — Forschungszentrum Jülich, Jülich, Germany

Nature provides a variety of active matter systems, with self-propelled agents consuming internal energy or extracting it from their vicinity for locomotion [1]. Examples on the cellular level are self-propelled semiflexible actomyosin ring-like filaments driven by myosin motors in the cytoskeleton. We present a theoretical study of an active ring polymer [2] with tangential propulsion applying the continuous Gaussian semiflexible polymer model [3]. By a normal-mode expansion, the ring polymer conformational and dynamical properties, emerging by the homogeneous active force, and its interplay with rigidity are determined. Remarkably, the ring conformations are unaffected by activity for any rigidity. In contrast to linear filaments, the center-of-mass motion is independent of propulsion. However, activity strongly influences the internal dynamics with an activity enhanced diffusive for the flexible and a ballistic regime for the semiflexible ring polymer. Furthermore, a dominant rotational mode over several orders of magnitude in time emerges for high activities, which implies a rotational motion of the entire ring polymer. [1] R. G. Winkler, G. Gompper, J. Chem. Phys. 153, 040901 (2020); [2] M. Mousavi, R. G. Winkler, G. Gompper, J. Chem. Phys. 150, 064913 (2019); [3] T. Eisenstecken, G. Gompper, R. G. Winkler, Polymers 8, 304 (2016).

BP 14.8 Wed 11:30 H16

Dynamical Renormalization Group approach to the collective behavior of natural swarms — Andrea Cavagna[1], Luca Di Carlo[1], Irene Giardina[1], Tomas Grigera[1,3], •Giulia Pisegna[1,2], and Mattia Scandolo[1] — [1]Sapienza Università di Roma, Roma IT — [2]Max Planck Institute for Dynamics and Self-Organization, Goettingen DE — [3]IFLYSIB, La Plata, Argentina

Recent data on strongly correlated biological systems showed the validity of scaling laws as one of the fundamental traits of collective behaviour. Experiments on natural swarms of insects unveiled traces of critical dynamics, with inertial features and a dynamical critical exponent z=1.2. To rationalize this evidence, we develop an inertial active field theory in which the velocity is coupled to its generator of internal rotations, namely the spin, through a mode-coupling interaction. We study its near-critical regime with a one-loop Renormalization Group approach under the assumption of incompressibility. The presence of friction in the dynamics of the spin rules a paramount crossover between two fixed points: the unstable underdamped fixed point with z=1.3 and the stable overdamped fixed point with z=1.7, where dissipation takes over. We show how finite-size systems with weak dissipation, such as swarms, can actually exhibit the critical dynamics of the unstable fixed point thus providing a theoretical result which is in fair agreement with experimental data.

15 min. break

BP 14.9 Wed 12:00 H16

Dynamics and rheology of active suspensions in viscoelastic media — •Akash Choudhary[1], Sankalp Nambiar[2], and Holger Stark[1] — [1]Institute of Theoretical Physics, Technische Universität Berlin, 10623 Berlin, Germany — [2]Nordita, KTH Royal Institute of Technology and Stockholm University, Stockholm 10691, Sweden

Active suspensions are systems of motile organisms or active motors that are driven out of equilibrium through self-propulsion. This localized energy-work conversion imparts rich phenomenology and anomalous macroscale properties that are in stark contrast to passive suspensions and polymeric fluids. Motivated by the ubiquitous microbial systems in biological fluids, we analyse the impact of non-Newtonian fluids on the rheological response of active suspensions to steady shear flows.

We first study the suspension at an individual scale and show that elongated pushers (representative of *E. coli*) and pullers (*C. reinhardtii*) exhibit diverse orbital dynamics in a viscoelastic fluid. We find that the active stresses not only modify the Jeffery orbits, well-known for viscous fluids, but microswimmers can even resist flow-induced rotation and align themselves at an angle with the flow. To analyze the impact of such behavior on the bulk rheological response, we study an ensemble of a dilute suspension of such swimmers in the presence of stochastic noise from bacterial tumbling and rotary diffusion. In comparison to Newtonian media, the polymeric elastic stresses substantially and non-monotonically amplify the swimmer-induced viscosity, in particular, the superfluid transition of pusher solutions.

BP 14.10 Wed 12:15 H16

Intercellular transport in *Chara corallina* — •Florian von Rüling[1], Anna Alova[2], Alexander Bulychev[2], and Alexey Eremin[1] — [1]Otto von Guericke University Magdeburg, Germany — [2]Moscow, Russia

We explore the kinetics of the intercellular transport between the giant cells of characean algae. The transport involves advection via cytoplasmic streaming and diffusion through the plasmodesmata, pores that penetrate the cell walls. Using fluorescent dye as a tracer, we measure the permeation through the node of tandem cells. The permeability is extracted from the experimental data using an advection-diffusion model. The current work is focused on the roles of cytoplasmic streaming and the nodal cells in the transport mechanism. To separate the diffusive permeation from the advective contribution, cyclosis was temporarily inhibited using action potentials. Streaming cessation results in dye accumulation in the vicinity of the node. The shape of regions with high dye concentration indicates that action potentials may induce closure of the plasmodesmata in central nodal cells.