CPP 64: Active Matter III (joint session BP/CPP/DY)

Time: Friday 9:30–12:00 Location: H11

CPP 64.1 Fri 9:30 H11

Dynamics of an active model microswimmer in an anisotropic fluid — •Abdallah Daddi-Moussa-Ider and Andreas M Menzel — Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf, Düsseldorf

Several recent experiments investigate the orientational behavior of self-propelled bacteria and colloidal particles in anisotropic fluids such as nematic liquid crystals. Correspondingly, we study theoretically the dynamics of a simple model microswimmer in a uniaxially anisotropic fluid. The behavior of both puller- and pusher-type swimmers in the anisotropic fluid is analyzed. Depending on the propulsion mechanism as well as the relative magnitude of different involved viscosities, we find alignment of the microswimmer parallel or perpendicular to the anisotropy axis. The observed swimmer reorientation results from the hydrodynamic coupling between the self-induced fluid flow and the anisotropy of the host fluid. Our theoretical predictions are found to be in qualitative agreement with recent experiments on swimming bacteria in nematic liquid crystals. They support the objective of utilizing the anisotropy of a surrounding fluid to guide individual swimmers and self-propelled active particles along a requested path, enabling controlled active transport.

Reference: A. Daddi-Moussa-Ider and A. M. Menzel. Dynamics of a simple model microswimmer in an anisotropic fluid: Implications for alignment behavior and active transport in a nematic liquid crystal, Phys. Rev. Fluids 3, 094102 (2018).

CPP 64.2 Fri 9:45 H11

Dynamics of bottom-heavy squirmers — •Felix Ruehle and Holger Stark — Institut für Theoretische Physik, Technische Universität Berlin, Germany

The self-propulsion of biological or synthetic microswimmers is often influenced by a gravitational field [1,2], where a density mismatch leads to sedimentation and an offset center of mass triggers reorientation along the direction of gravity so that they swim upwards [2]. Combining these passive effects with the non-equilibrium properties of active motion creates novel and interesting dynamics, both in dense and dilute suspensions [3]. In particular, a large variety of dynamical behaviours has been observed for the squirmer microswimmer model [4,5].

In this contribution we focus on bottom-heavy squirmers and determine their state diagram, depending on the gravitational force and acting torque. For strong gravitational forces we observe conventional sedimentation, whereas the density profile is inverted for weaker forces. Additionally, we find stable convective plumes for neutral squirmers that become metastable as the torque increases. We also observe spawning clusters at the bottom if the sedimentation velocity almost equalizes the swimming speed. Spawning clusters and continuous plumes do not occur for pusher and puller type swimmers.

[1] J. Palacci, et al., *Phys. Rev. Lett.* **105**, 088304 (2010).
[2] K. Drescher et al., *Phys. Rev. Lett.* **102**, 168101 (2009).
[3] K. Wolff, A. M. Hahn and H. Stark, *EPJE* **36**, 1 (2013).
[4] J.-T. Kuhr et al., *Soft Matter* **13**, 7548 (2017).
[5] F. Rühle et al., *New J. Phys.* **20**, 025003 (2018).

CPP 64.3 Fri 10:00 H11

Bead-spring modelling of triangular microswimmers — •Sebastian Ziegler[1], Alexander Sukhov[2], Jens Harting[2,3], and Ana-Sunčana Smith[1,4] — [1]PULS Group, Institute for Theoretical Physics, Department of Physics, Friedrich-Alexander Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Helmholtz Institute Erlangen-Nürnberg for Renewable Energy, Germany — [3]Dep. of Applied Physics, Eindhoven University of Technology, The Netherlands — [4]Division of Physical Chemistry, Ruder Bošković Institute Zagreb, Croatia

A customary approach to model mechanical micropropulsion is to prescribe the swimming stroke. However, with this approach, the hydrodynamic features of the motion are in essence smoothed over and the problem becomes a purely geometrical one. The alternative approach, yet significantly more demanding, is to impose not the stroke itself but the forces driving the device. The swimming stroke then emerges as a result of the various forces acting in the system. We use a perturbative approach to examine a triangular swimmer's behaviour in the Stokes regime that is also eligible for general geometries of bead-spring swimmers. The device shows a multifaceted comportment dependent on a number of therefore identified effective parameters. The triangular swimmer is further used as a prototype to study the influence of variations in the viscosity of the surrounding fluid on its motion.

CPP 64.4 Fri 10:15 H11

Simple Swimmers Reverse Direction near a Surface — •Michael Kuron[1], Philipp Stärk[1], Joost de Graaf[2], and Christian Holm[1] — [1]Institut für Computerphysik, Universität Stuttgart, Deutschland — [2]Institute for Theoretical Physics, Universiteit Utrecht, Nederland

The motion of a microswimmer can change substantially in the presence of a surface. Sperm are known to move in circular trajectories near a wall, paramecia move in sinusoidal trajectories through a tube, and chemical swimmers can orbit around spherical obstacles. Spherical squirmers are one of the simplest model microswimmers, commonly defined by the first two Legendre modes of their surface slip velocity. In this talk, we use the squirmer to numerically investigate the effect of the environmental geometry. We discuss how the transition between scattering and orbiting/hovering depends on the strength of the squirmer's hydrodynamic dipole moment. Interestingly, we observe cases where the squirmer orbits/hovers along a surface in a direction opposite to that observed in bulk. This effect is present both in a far-field theoretical model and our lattice Boltzmann calculations, which accurately account for the near-field flow. These results extend the understanding of the effect of geometry on microswimmer motion and show the importance of finite swimmer size and associated near-field effects.

CPP 64.5 Fri 10:30 H11

Bacterial Swarming Dynamics — •Hannah Jeckel[1,2,3], Eric Jelli[1,2], Raimo Hartmann[1], Praveen Singh[1], Rachel Mok[3,4], Jan Frederik Totz[5], Lucia Vidakovic[1], Bruno Eckhardt[2], Jörn Dunkel[3], and Knut Drescher[1,2] — [1]Max Planck Institute for Terrestrial Microbiology, Marburg, Germany — [2]Department of Physics, Philipps-University Marburg, Germany — [3]Department of Mathematics, Massachusetts Institute of Technology, Cambridge, MA — [4]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA — [5]Institute for Theoretical Physics, Technical University Berlin, Germany

Coordinated dynamics of individual components in active matter are an essential aspect of life on all scales. Establishing a comprehensive, causal connection between intracellular, intercellular, and macroscopic behaviors has remained a major challenge due to limitations in data acquisition and analysis techniques suitable for multiscale dynamics. Here, we combine a high-throughput adaptive microscopy approach with machine learning, to identify key biological and physical mechanisms that determine distinct microscopic and macroscopic collective behavior phases which develop as *Bacillus subtilis* swarms expand over five orders of magnitude in space. Our experiments, continuum modeling, and particle-based simulations reveal that macroscopic swarm expansion is primarily driven by cellular growth kinetics, whereas the microscopic swarming motility phases are dominated by physical cell-cell interactions. These results provide a unified understanding of bacterial multi-scale behavioral complexity in swarms.

CPP 64.6 Fri 10:45 H11

Effects of collective bacterial motility on their chemotactic navigation — •Remy Colin and Victor Sourjik — Max Planck Institute for Terrestrial Microbiology, Marburg, Germany

At high cell density, swimming bacteria exhibit collective motility patterns, self-organized through physical interactions of a however still debated nature. Although high-density behaviors are frequent in natural situations, it remains unknown how collective motion affects chemotaxis, the main physiological function of motility that enables bacteria to follow chemical and other gradients in their environment. Here, we systematically investigated this question in the model organism *Escherichia coli*, varying cell density, cell length and suspension confinement. The characteristics of the collective motion indicated that its emergence is dominated by hydrodynamic interactions between swimmers. We observed that moderate increase in cell density enhanced the chemotactic drift of bacteria, whereas it was suppressed at higher

densities, because the collective motion disturbed the choreography necessary for chemotactic sensing. We suggest that this physical hindrance imposes a fundamental constraint on high-density behaviors of motile bacteria, including swarming as well as the formation of multicellular aggregates and biofilms.

CPP 64.7 Fri 11:00 H11

Feedback Control of Active Microswimmers — •Alexander Fischer[1], Haw Yang[2], and Frank Cichos[1] — [1]Uni Leipzig — [2]Princeton University

Collective motion created by the interaction of autonomous individuals plays a major role in flocks of birds, bacterial growth or the motion of robotic swarms. Sensing and reacting to signals is a fundamental issue of life. Microswimmers, which are artificial objects that mimic the active motion of biological systems, do not have such sensing and response features built in yet, but may gain them through an external control of their propulsion. Here we explore an information exchange between artificial microswimmers by computer-controlled feedback processes. We have created a setup where multiple active microswimmers can react to their position in space or their distance to other microswimmers. We investigate the influence of different interaction potentials or a delay in the information exchange. Our results demonstrate so far that particles can be coupled to each other by the used feedback by designed virtual potentials. The collective motion of such coupled particles reveals oscillating modes with emergent features like spontaneous rotation. The experiments shall help to understand the emergence of complex behavior in biological systems.

CPP 64.8 Fri 11:15 H11

Out-of-plane beating components of active axonemes isolated from Chlamydomonas reinhardtii — Azam Gholami[1], •Soheil Mojiri[2], Eberhard Bodenschatz[1], and Jörg Enderlein[2] — [1]Max-Planck Instiute for Dynamics and Self-Organization, Göttingen, Germany — [2]Georg-August Universität, Göttingen, Germany

Cilia and flagella are ubiquitous in the living world. They are essential for micro-scale driven transport of fluids or cells by cilia/flagellar beating. Their slender bodies are composed of a microtubule/molecular motor structure that when taken independently are called an axoneme. Axonemes move by bending waves that emerge from the interplay between internal stresses generated by dynein motor proteins . Here we use the novel multi-plane phase contrast imaging technique to record the three dimensional beating pattern of isolated axonemes from Chlamydomonas reinhardtii that beat in the vicinity of a substrate. We measure the torsion of the axoneme along the contour length with high spatiotemporal resolution. High precision information on out-of-plane beating component of axonemes allows us to check the validity of the resistive-force theory.

CPP 64.9 Fri 11:30 H11

Nanoscale chemotaxis of enzymes and small molecules — •Jaime Agudo-Canalejo[1,2], Tunrayo Adeleke-Larodo[1], Pierre Illien[3], and Ramin Golestanian[4,1] — [1]University of Oxford, Oxford, UK — [2]Penn State University, State College, USA — [3]ESPCI Paris, Paris, France — [4]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

We present a microscopic theory for the observed chemotaxis of enzymes and other small molecules. [1,2] We find that two distinct mechanisms contribute to enzyme chemotaxis: a diffusiophoretic mechanism due to non-specific interactions, and a new type of mechanism due to binding-induced changes in the diffusion coefficient of the enzyme. For a typical enzyme, the two mechanisms compete against each other, one dominating at high substrate concentration, the other at low concentration. The competition between the two mechanisms may be used to engineer nanovehicles that move towards or away from regions with a specific substrate concentration. Finally, we include the effects of anisotropy and flexibility of the enzyme, [3] and show that enzymes can be aligned by gradients, and shape fluctuations lead to corrections in the diffusion and chemotactic mobility of enzymes. [1] Agudo-Canalejo, J., Adeleke-Larodo, T., Illien, P., & Golestanian, R. (2018) Acc. Chem. Res. 51, 2365 [2] Agudo-Canalejo, J., Illien, P., & Golestanian, R. (2018) Nano Lett. 18, 2711 [3] Adeleke-Larodo, Agudo-Canalejo, J., & Golestanian, R. (2018) arXiv:1811.09631

CPP 64.10 Fri 11:45 H11

High-motility visible light-driven Ag/AgCl Janus microswimmers interacting with passive beads — •xu wang[1], larysa baraban[2], vyacheslav r misko[3,4], franco nori[4,5], petre formanek[6], tao huang[2], gianaurelio cuniberti[2], jürgen fassbender[1], and denys makarov[1] — [1]Helmholtz-Zentrum Dresden-Rossendorfe.V., Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]Universiteit Antwerpen, B-2610 Antwerpen, Belgium — [4]RIKEN Cluster for Pioneering Research, 351-0198 Saitama, Japan — [5]University of Michigan, 48109-1040 Michigan, USA — [6]Leibniz-Institut für Polymerforschung Dresden e.V., 01069 Dresden, Germany

Visible light driven nano/micro swimmers typically show mean squared displacement (MSD) values in the range of up to 200 μm^2 (over 10 s) under favorable UV light illumination.[1] Here, we demonstrate Ag/AgCl-based spherical Janus micromotors that reveal an efficient propulsion with a MSD to 3000 μm^2 (over 10 s) in pure H_2O under visible blue light illumination (λ = 450-490 nm).[2] Furthermore, we show the micromotors reveal efficient exclusion effect to their surrounding passive polystyrene beads in pure H_2O experimentally and using numerical simulations of the Langevin equations.[3]

1. Simmchen, J., et al., ChemNanoMat 2017, 3, 65.
2. Wang, X., et al., Small DOI: 10.1002/smll.201803613.
3. Wang, X., et al., Small 2018, 14, 1802537 (Frontispiece paper)