BP 7: Active Fluids and Microswimmers (joint session DY/BP/CPP)

Time: Monday 15:00–18:30 Location: BH-N 243

Invited Talk BP 7.1 Mon 15:00 BH-N 243

Control of active turbulence — •Holger Stark — Technische Universität Berlin, Institute of Theoretical Physics, Hardenbergstr. 36, 10623 Berlin, Germany

Active turbulence is one of the prominent features of active matter and occurs in diverse systems such as bacterial suspensions, biopolymeric assemblies, and tissues. One of the current challenges is to control these turbulent flow patterns for powering processes at small scales.

In the first part of the talk we rely on a continuum description of active paranematics, the Doi-Edwards theory supplemented by an active stress tensor [1]. We characterize the occuring turbulent flow for extensile active stresses. Then, motivated by the possibility to control the activity of bacteria by light, we consider a square lattice of spots, where activity drops to zero. Depending on the lattice constant and the size of the spots, we identify a trapped-vortex and, most interestingly, a multi-lane flow state. The latter consists of lanes with opposite flow directions separated by a street of vortices. It displays multistability and can also appear transiently.

Second, we perform hydrodynamic simulations of a collection of active or squirmer rods moving in their fluid environment [2]. We classify their dynamic states for the pusher/puller type as a function of density and aspect ratio of the rods and observe clustering and swarming. In particular, pusher rods show active turbulence as a compromise of disordering hydrodynamic and aligning steric interactions.

[1] A. Partovifard and H. Stark, submitted.

[2] A.W. Zantop and H. Stark, Soft Matter **18**, 6179 (2022).

BP 7.2 Mon 15:30 BH-N 243

Entropy production in active turbulence — •Byjesh N. Radhakrishnan, Thomas L. Schmidt, and Etienne Fodor — Department of Physics and Material science, University of Luxembourg

Active particles like bacteria and sperm cells sustain a continuous intake and dissipation of energy. Consequently, they are intrinsically out of equilibrium which leads to a non-vanishing entropy production rate (EPR) even in steady states. Quantifying how the EPR varies in different collective phases is crucial in developing a thermodynamic framework for active matter. In this work, we look at the EPR in active turbulence. We use Active Model H, a continuum model for active particles in a momentum-conserving fluid, to study turbulence in contractile scalar active systems. We measure the local EPR in numerical simulations, which unveils the relation between the magnitude of entropy production and $+1/2$ topological defects in the system. Also, we study how EPR and the properties of defects such as mean square displacement and defect lifetime vary with the activity parameter.

BP 7.3 Mon 15:45 BH-N 243

Active turbulent mixing — •Till Welker[1], Malcolm Hillebrand[2], Ricard Alert[2], and Holger Stark[1] — [1]Institute of Theoretical Physics, TU Berlin, Germany — [2]MPI for the Physics of Complex Systems, Dresden, Germany

Mixing on the mesoscale is crucial for both microfluidic devices and living cells. Experiments backed by simulations show a significant increase in mixing efficiency caused by active turbulence.

Our goal is to enhance the theoretical understanding of active turbulent mixing by transferring theories and concepts originally developed for inertial turbulent mixing. We therefore study a defect-free active nematic model known to show universal scaling of the energy spectrum with a passive chemical diffusing and advecting in the flow.

The efficiency of mixing χ rises with both activity of the nematic A and diffusion coefficient of the chemical D. Intriguingly, as D approaches zero, mixing efficiency converges to a non-zero value $\chi_0(A)$ because smaller D are compensated by larger concentration gradients. This presents an attractive mechanism to mix poorly diffusive substances, and is also observed in inertial turbulent mixing.

The scaling of the concentration spectrum $E_c(q)$ is of great interest and has been extensively studied in the context of inertial turbulence. We demonstrate that Batchelor-Howells-Townsend theory and Batchelor theory for strongly and poorly diffusive substances can be transferred to active turbulence. As a consequence of the universal energy scaling of our active nematic, we predict universal scaling regimes for $E_c(q)$ which we validate in simulations.

BP 7.4 Mon 16:00 BH-N 243

Simultaneous emergence of active turbulence and odd viscosity in a colloidal chiral active system — •Joscha Mecke[1,2], Yongxiang Gao[1], Gerhard Gompper[2], and Marisol Ripoll[2] — [1]Institute for Advanced Study, Shenzhen University, China — [2]Institute of Biological Information Processing and Institute for Advanced Simulation, Forschungszentrum Jülich, Germany

Active fluids display collective phenomena such as active turbulence or odd viscosity, which refer to spontaneous complex and transverse flow. We report the simultaneous emergence of these seemingly separate phenomena in experiment for a chiral active fluid composed of a carpet of standing and spinning colloidal rods, and in simulations for synchronously rotating hard discs in a hydrodynamic explicit solvent (see also Commun. Phys. 6, 324 (2023), https://doi.org/10.1038/s42005-023-01442-3). Stresses among the colloids encompass rotational and odd shear contributions absent in usual fluids. Rotational viscosity couples the colloids' rotation to translation, causing active turbulence. Odd viscosity involves a perpendicular coupling of shear stresses, leading to an effective pressure pointing into or out of the emergent vortices. We quantify the two phenomena in experiments and simulation using the same setup. Both rotational and odd viscosity originate from the same source and the system behaviour hinges on the propagation of odd stresses via long-ranged hydrodynamics. Our findings are relevant for the understanding of biological systems and for the design of microrobots with collective self-organised behaviour.

BP 7.5 Mon 16:15 BH-N 243

Hydrodynamic synchronization of elastic cilia: How flow confinement and boundary conditions determine the characteristics of metachronal waves — Albert von Kenne, •Markus Bär, and Thomas Niedermayer — Physikalisch-Technische Bundesanstalt, Berlin, Germany

We model hydrodynamically interacting cilia by a coupled phase oscillator description by reducing the dynamics of hydrodynamically interacting elastic cilia to the slow time scale of synchronization [1]. In this framework, we determine analytical metachronal wave solutions as well as their stability and perform simulations in a periodic chain setting. The flow confinement at the wall stabilizes metachronal waves with long wavelengths propagating in the direction of the power stroke and, moreover, metachronal waves with short wave lengths propagating perpendicularly to the power stroke. In open chains of phase oscillators, the dynamics of metachronal waves is fundamentally different. Here, the elasticity of the model cilia controls the wave direction and selects a particular wave number: At large elasticity, waves traveling in the direction of the power stroke are stable, whereas at smaller elasticity waves in the opposite direction are stable. In addition, coexistence of waves traveling in opposite directions and irregular, chaotic dynamics are observed. [1] A. von Kenne, M. Bär and T. Niedermayer. Preprint, https://www.biorxiv.org/content/10.1101/2023.10.20.563276v1.full.pdf.

BP 7.6 Mon 16:30 BH-N 243

Pattern formation in non-Newtonian active suspensions — •Henning Reinken and Andreas M. Menzel — Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

Controlling spatiotemporal patterns in active matter is of essential importance in view of prospective applications. In contrast to previous studies utilizing external control such as geometrical constraints [1], we here explore the possibility of controlling suspensions of microswimmers via the internal rheological properties of the suspension. Recent work has focused on the impact of viscoelastic and non-Newtonian behavior on the dynamics of single swimmers [3], but only a limited number of studies explores the consequences for collective motion and emergent patterns. Here, employing a recent continuum model for mesoscale turbulence in microswimmer suspensions [4], we investigate the impact of non-Newtonian behavior on the pattern formation. In particular, we focus on the stabilization of regular vortex structures in otherwise turbulent suspensions without the need for external intervention.

[1] H. Reinken, D. Nishiguchi, S. Heidenreich, A. Sokolov, M. Bär, S. H. L. Klapp, and I. S. Aranson, Commun. Phys. **3**, 76 (2020)

[3] G. Li, E. Lauga, and A. M. Ardekani, J. Non-Newton. Fluid Mech.

297, 104655 (2021)
[4] J. Słomka and J. Dunkel, Eur. Phys. J. ST **224**, 1349 (2015), Phys. Rev. Fluids **2**, 043102 (2017), Proc. Natl. Acad. Sci. U.S.A. **114**, 2119 (2017)

15 min. break

BP 7.7 Mon 17:00 BH-N 243

Bacterial swimming strategies in a shear flow — •Valeriia Muraveva, Agniva Datta, and Carsten Beta — Potsdam University, Potsdam, Germany

By changing the configuration of their flagella, bacterial swimmers can control their direction and speed of locomotion. The soil bacterium Pseudomonas putida pushes itself forward by counterclockwise (CCW) rotation of its flagellar bundle, while clockwise (CW) rotation pulls the cell body in the opposite direction. Additionally, P. putida can wrap its bundle of flagella around the cell body to move in a screw thread fashion. However, the benefits of having different modes of swimming still remain unclear. Here, we used microfluidics in combination with fluorescence microscopy to show how the swimming behavior changes under laminar shear flow conditions. Compared to a fluid at rest, we found that in flow, swimmers prefer the pull configuration over the wrapped one (both emerging under CW flagellar rotation). Moreover, we investigated flow-induced alignment effects and compared the distributions of swimming modes and velocities in the bulk fluid and close to the fluid-substrate interface. Our results provide first insights into how bacteria adapt their swimming strategy under different flow conditions at the single-cell level.

BP 7.8 Mon 17:15 BH-N 243

Artificial Microswimmers in locally-tuneable hydrodynamic flow fields — •Lisa Rohde and Frank Cichos — Molecular Nanophotonics Group, Peter-Debye-Institute for Soft Matter Physics, University Leipzig, Leipzig, Germany

Biological components on the microscale, which constantly consume energy can organize themselves into functional structures through interaction with their environment. Interaction potentials, temperature or composition gradients as well as flow fields play an important role in this structure formation. We would like to transfer such self-organization principles to synthetic active particles, which are a model system to mimic the function of motors in biology, but yet have only limited functionality. Here, we expose thermo-phoretic Janus particles to an environment with tuneable hydrodynamic flow fields generated by local temperature gradients. A heated paramagnetic silica particle acts as a heat source and generates a thermo-osmotic flow field due to a temperature gradient on the substrate. By controlling the temperature of the heat source, we are able to locally change the generated hydrodynamic flow field. We study the orientational dynamics and the distance of the Janus particles relative to the heat source in dependence of temperature and laser intensities. The interplay of the local flow fields with the activity of the Janus particles results in a potential that traps the Janus particles in a configuration around the heat source. We find a polarisation of the Janus particles that align with the flow field having a stable orientation relative to the heat source.

BP 7.9 Mon 17:30 BH-N 243

Run-and-tumble motion of ellipsoidal swimmers — •Gordei Anchutkin[1], Viktor Holubec[2], and Frank Cichos[1] — [1]Molecular Nanophotonics Group, Peter Debye Institute for Soft Matter Physics, Leipzig University, 04103 Leipzig, Germany — [2]Department of Macromolecular Physics, Faculty of Mathematics and Physics, Charles University, CZ-180 00 Praha, Czech Republic

The characteristic motion of bacteria, the so-called "run-and-tumble" motion, is a hallmark of living active particles. It consists of a sequence of linear directional movements and random rotations that constantly alternate based on a biochemical feedback process. In contrast to bacteria, synthetic active particles do not exhibit run-and-tumble motion, except they are forced to do so by sophisticated optical control feedback loops.

In this study, we show that self-thermophoretic Janus ellipsoids can carry out run-and-tumble-like dynamics under strong confinement. Our Janus ellipsoids are propelled along the short axis and exhibit long periods of directed motion before reversing the propulsion direction. We show that a bimodal out-of-plane angular distribution arises at high propulsion velocities, which is mainly the result of hydrodynamic wall interactions. We evaluate hydrodynamic interactions, and gravitational and optical forces to give a quantitative model of the observed dynamics. These interactions together with the slow rotational diffusional dynamics around the short ellipsoid axis provide the basis of the run-and-tumble dynamics.

BP 7.10 Mon 17:45 BH-N 243

Microswimming under a wedge-shaped confinement — •Alexander R. Sprenger and Andreas M. Menzel — Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Universitätsplatz 2, D-39106 Magdeburg, Germany

Microswimmers, both living and artificial, frequently navigate through diverse and often confined environments. Their out-of-equilibrium nature of self-propulsion and associated fluid flows lead to complex hydrodynamic interactions with their surroundings. Understanding the impact of various confinements on the behavior of self-propelled particles is crucial for gaining insights into biological phenomena and motivating advancements in microtechnologies.

In this contribution, we study the low-Reynolds-number dynamics of microswimmers confined within a wedge-shaped free-slip boundary [1]. Such scenarios naturally occur in experiments on inhomogeneously evaporating fluid flows, which form a free-standing confinement between two converging interfaces. Additionally, wedge-shaped environments possess distinctive geometric trapping and guiding properties relevant to various microfluidic applications.

Here, we present an exact solution for the resulting flow fields for various opening angles of the wedge employing the method of images. In this manner, we investigate the hydrodynamic interactions between each swimmer and the confining interfaces. We find either attraction or repulsion towards the tip of the wedge, depending on the propulsion mechanism (pusher or puller) and the opening angle of the wedge.

[1] A. R. Sprenger, A. M. Menzel (submitted).

BP 7.11 Mon 18:00 BH-N 243

AcoDyn: Efficient computer simulations of acoustically propelled microparticles — •Adrian Paskert and Raphael Wittkowski — Institut für Theoretische Physik, Center for Soft Nanoscience, Universität Münster, 48149 Münster, Germany

For future applications in science and engineering, active microparticles have great potential. Acoustically propelled microparticles are particularly advantageous for medical applications because they operate well within medically safe intensity ranges and are generally considered biocompatible. However, due to the complexity of the flow fields generated around these particles and the high computational cost of direct computer simulations even for simple 2D particle geometries, the theoretical understanding of the particles' propulsion and dynamics is still very limited. In this talk, we will give an overview of how these particles can be simulated efficiently to enable the numerical study of complex 3D particles. Moreover, our novel software solution `AcoDyn` will be presented, along with key results we have obtained through its application.

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BP 7.12 Mon 18:15 BH-N 243

Opto-fluidic dynamic patterning of microparticles — •Elena Erben[1], Weida Liao[2], Antonio Minopoli[3], Nicola Maghelli[4], Eric Lauga[2], and Moritz Kreysing[1] — [1]IBCS-BIP, KIT, Karlsruhe, Germany — [2]DAMTP, University of Cambridge, UK — [3]University of Pisa, Pisa, Itlay — [4]Fondazione Human Technopole, Milano, Italy

Techniques for the precise manipulation of microscopic objects bear great potential for application in a wide range of fields, from basic biological research to microfabrication. Our method uses rapid scanning of an infrared laser beam to optically generate thermoviscous flows [1] within a sample. Combined with closed-loop control this enables the automatic positioning of a single microparticle, with a precision of up to 24 nm [2]. Our approach can be multiplexed to manipulate up to 15 particles in a parallel and dynamic fashion. Furthermore, we have found that the positioning of multiple particles can be greatly accelerated by exploiting the complex flow patterns that result from the time-sharing of different laser scan paths. We plan to combine our approach with a full analytical model of the flows [3], which we expect will further increase the precision and speed of this manipulation method, facilitating its translation to applications in the life sciences and beyond.

[1] Weinert et al. Phys. Rev. Lett. 2008; [2] Erben et al. Opt. Express 2021; [3] Liao et al. Phys. Rev. Fluids 2023.