DY 31: Microswimmers and Fluid Physics of Life (joint session DY/CPP)

Time: Wednesday 15:00–18:15 Location: MOL 213

DY 31.1 Wed 15:00 MOL 213

Physics of gut motility governs digestion and bacterial growth — •Agnese Codutti[1], Jonas Cremer[2], and Karen Alim[1] — [1]School of Natural Sciences, Technical University of Munich, Germany — [2]Biology Department, Stanford University, USA

Malfunctioning of the small intestine contractility and the ensuing bacterial population therein are linked to a plethora of diseases. We, here, study how the small intestine's variety of contractility patterns impacts nutrient uptake and bacterial population [1]. Our analytical derivations in agreement with simulations identify flow velocity as the key control parameter of the nutrients uptake efficiency and bacterial growth, independently of the specifics of contractility patterns. Self-regulating flow velocity in response to the number of nutrients and bacteria in the gut allows for achieving 100% efficiency in nutrient uptake. Instead of the specifics of intestine contractility, our work points to the flow velocity and its variation in time within the intestine to prevent malfunctioning.

[1] Codutti A., Cremer J., Alim K., "Changing Flows Balance Nutrient Absorption and Bacterial Growth along the Gut" PRL 129, 138101 (2022)

DY 31.2 Wed 15:15 MOL 213

Turbulence induces clustering and arrested phase separation in polar active fluids — Vasco Worlitzer[1,2], Gil Ariel[2], Avraham Beer[3], Holger Stark[4], •Markus Bär[1,4], and Sebastian Heidenreich[1] — [1]Physikalisch-Technische Bundesanstalt, Berlin — [2]Bar-Ilan University, Ramat Gan, Israel — [3]Ben-Gurion University, Beer Sheva, Israel — [4]Technische Universität Berlin

We study a novel phase of active polar fluids, which is characterized by the continuous creation and destruction of dense clusters due to self-sustained turbulence. This state arises due to the interplay between self-advection of the aligned swimmers and their defect topology. The typical cluster size is determined by the characteristic vortex size. Our results are obtained by investigating a continuum model of compressible polar active fluids [1], which incorporates typical experimental observations in bacterial suspensions [2], in particular a non-monotone dependence of speed on density.

[1] V. Worlitzer et al., Soft Matter 17, 10447-10457 (2021)
[2] A. Beer et al., Communications Physics 3, 66 (2020)

DY 31.3 Wed 15:30 MOL 213

Bacterial spreading in complex environments — •Agniva Datta, Sönke Beier, Veronika Pfeifer, Robert Grossmann, and Carsten Beta — Institute of Physics and Astronomy, University of Potsdam, Potsdam, Germany

Elucidating the principles of bacterial motility and navigation is key to understand many important phenomena such as the spreading of infectious diseases and the formation of biofilms. A prime challenge of swimming bacteria is to navigate in their habitat purposefully and efficiently, e.g., in the soil, which is a complex, structured environment. In this talk, we address the question of how bacterial navigation at the microscale relates to their large-scale spreading in heterogeneous environments. We combine experiments with the soil bacterium *Pseudomonas putida* with active particle modeling. In particular, the motility pattern of these bacteria in agar will be discussed with a focus on anomalous transport properties in disordered environments. In contrast to *E. coli*, our analysis reveals transient subdiffusion of bacteria in agar due to intermittent trapping, giving rise to a hop-and-trap dynamics with power-law distributed trap times.

DY 31.4 Wed 15:45 MOL 213

Minimum Entropy Production by Microswimmers with Internal Dissipation — •Andrej Vilfan, Abdallah Daddi-Moussa-Ider, Babak Nasouri, and Ramin Golestanian — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Microswimmers are natural or artificial self-propelled microscale objects moving through a fluid at low Reynolds numbers. The entropy production of microswimmers, related to their dissipated power, consists of two contributions. The external dissipation takes place in the viscous fluid surrounding the microswimmer. Internal dissipation takes place in the propulsive layer on the swimmer's surface. We have previously shown that a lower bound on the external dissipation can be derived with the knowledge of drag coefficients of two bodies of the same shape, one with a no-slip and one with a perfect slip boundary condition [1]. Here, we show that our approach can be generalized to take into account the internal dissipation, which is often the dominant contribution. By combining the Helmholtz minimum dissipation theorem and the principle of linear superposition, we solve the combined minimum dissipation problem for different classes of swimmers including surface-driven viscous droplets, swimmers driven by tangential forces and swimmers driven by normal forces. We show that the minimum entropy production in suspensions of active microswimmers differs fundamentally from particles driven by external forces.

[1] B. Nasouri, A. Vilfan and R. Golestanian, Phys. Rev. Lett., 126, 034503 (2021).

DY 31.5 Wed 16:00 MOL 213

Synchronization of model cilia by time-dependent elastohydrodynamics — •Albert von Kenne[1], Holger Stark[2], and Markus Bär[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), 10587 Berlin — [2]Technische Universität Berlin, 10623 Berlin

Collections of hair-like micro actuators known as cilia are employed in biology to pump extra cellular fluids at low Reynolds number conditions. Their collective dynamics exhibit synchronization and a large scale coordinated motion called metachronal waves. Typically, simple models that characterize the self-organization among hydrodynamically interacting cilia neglect the inertial forces in the fluid against the viscous forces. In this case, the mutual flows are determined instantaneously through the forces exerted by cilia. Consequentially synchronization requires a symmetry breaking external to hydrodynamics, that can come from elastic responses to flow perturbations (*T. Niedermayer et al., Chaos 2008*). Meanwhile, experiments show that inertial forces are significant in microscopic flow at the relevant scales (*D. Wei et al. Phys. Rev. Lett. 2019*). In this situation, the fluid response is explicitly time-dependent and hydrodynamic correlations can lead to synchronization (*M. Theers and R. Winkler, Phys. Rev. 2013*). We derived a simplified phase-oscillator model that describes the leading order coupling between cilia by elastic responses and hydrodynamic correlations. We show that its interrelations don't change the collective state qualitatively. However, the strength of coupling is always increased.

DY 31.6 Wed 16:15 MOL 213

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

Artificial and living microswimmer encounter a large variety of geometric confinements and surfaces in the biological world which alter their motion when nearby. Here, we study the low-Reynolds-number dynamics of a microswimmer enclosed by a wedge-shaped free-slip interface. For various opening angles of the wedge, we derive an exact solution for flow and pressure fields using the method of images. The active swimmer is represented in terms of a superposition of Stokes singularities. In this way, the hydrodynamic interactions between the swimmer and the confining interfaces are examined. In particular, we find attraction or repulsion by the wedge depending on the propulsion mechanism (pusher- or puller-type swimming strokes) and the opening angle of the wedge. For the dynamics of a microswimmer inside the wedge, we present a minimal model in terms of coupled Langevin equations for position and orientation. Our analytic results are evaluated for parameters inspired by common self-propelling microorganisms like *Escherichia coli.*

15 min. break

DY 31.7 Wed 16:45 MOL 213

Role of cohesion in the flow of active particles through bottlenecks — •Timo Knippenberg[1], Anton Lüders[1], Celia Lozano[2], Peter Nielaba[1], and Clemens Bechinger[1] — [1]Fachbereich Physik, Universität Konstanz, Germany — [2]Bosonit, AI Department, La Rioja, Spain

Recently, many studies examined the intermittent flow of granular particles through bottleneck-shaped apertures. A common framework which describes the occurring flow statistics was empirically found for a wide range of such systems reaching from microscopic colloids and macroscopic grains up to sheep herds. However, similar studies with active matter are scarce and do merely consider steric agent interactions. Here, we experimentally and numerically study the flow of programmable, colloidal active Janus swimmers through bottlenecks. Our results confirm the applicability of the above-mentioned statistical framework of granular intermittent flow also on complex-interacting active microswimmers. Moreover, upon increasing the strength of interparticle cohesion, we find a transition from an arch-dominated clogging regime to a cohesion-dominated regime where droplets form at the outlet. The flow-rate only weakly depends on the cohesion strength in the arch-dominated regime, which suggests that cohesion needs not necessarily to hinder particle flow through geometric constrictions or pores.

DY 31.8 Wed 17:00 MOL 213

Self-assembling meso-machines along liquid-air interfaces — •Nicolas Vandewalle, Megan Delens, and Ylona Collard — GRASP, University of Liege, B4000 Liege, Belgium

Magnetocapillary driven self-assembly allows us to create complex structures floating along a liquid-air interface. We show how these structures can be elaborated and how they can be triggered for locomotion. First, the pairwise capillary and magnetic interactions between floating objects are experimentally studied and rationalized through analogies with electrostatics. Then, the combination of capillary attraction and magnetic repulsion will lead to the spontaneous formation of a rich variety of floating structures. Placed in processing magnetic fields, those structures may behave like swimming ciliate organisms and start to move along the liquid-air interface. The conditions to obtain this magnetic powered locomotion are emphasized.

DY 31.9 Wed 17:15 MOL 213

Induced capillary dipoles in floating particle assemblies — •Megan Delens, Ylona Collard, and Nicolas Vandewalle — GRASP, Institut de Physique B5a, Université de Liège, Liège, BE

Capillary-driven self-assembly is a common fabrication method that consists in placing floating particles onto a liquid-air interface. The attractive capillary interaction between particles is due to the local deformations of the interface which can be described via so-called capillary charges. When the particles are spherical and far from each other, the menisci are planar circles and can be described by monopolar capillary charges. The capillary interaction is then approximately found by assuming that the charges carried by individual spheres may be linearly superposed. However, when particles are close together, we experimentally observed that the attraction is enhanced and becomes far more complex. Indeed, the contact lines start to tilt and the superposition principle no longer holds. For these situations, we propose to additionally consider induced capillary dipoles to describe the menisci, therefore, providing an extra attraction between particles at short distances. This effect is enhanced when particles have different sizes such that binary self-assemblies may reveal unusual local ordering.

DY 31.10 Wed 17:30 MOL 213

A Versatile Swarm of Individually Controlled Microparticles for Object Manipulation and Transport — •Veit-Lorenz Heuthe[1], Emanuele Panizon[2], and Clemens Bechinger[1] — [1]Universität Konstanz, Konstanz, Germany — [2]International Centre for Theoretical Physics, Trieste, Italy

Some tasks for robotic systems require many robots to cooperate, similar to ants that join their forces to carry large objects. On a macroscopic scale, many examples for such collective tasks exist, like robot swarms that can assemble objects. However, future potential applications like minimally invasive medicine call for miniaturization of such concepts. On the microscopic scale, one major challenge is the strong thermal noise, that demands for much more robust control. We use a reinforcement learning algorithm to individually steer microswimmers in a swarm that can manipulate and transport a large object. Due to decentralized control, our multi robot system is highly flexible, scalable and robust. With this demonstration we take micro-robot swarms one step further on their way to become tools for manipulating microscopic objects.

DY 31.11 Wed 17:45 MOL 213

New insights into the mechanism of self-phoresis — •Alvaro Domínguez[1], Mihail Popescu[1], and Siegfried Dietrich[2] — [1]Univ. Sevilla, Spain — [2]MPI für Intelligente Systeme, Stuttgart

Chemophoresis describes the displacement of a particle in an ambient fluid due to a gradient in chemical composition. Classic phoresis can be understood through linear–response theory: in the presence of a sufficiently small gradient $(\nabla n)_{\rm ext}$ in concentration, the phoretic velocity of the particle is $\mathbf{V} = \mathcal{L}_{\rm lin}(\nabla n)_{\rm ext}$, in terms of the phoretic coefficient $\mathcal{L}_{\rm lin}$ given by a Green–Kubo expression.

Self-phoretic particles induce a composition gradient $(\nabla n)_{\rm act}$ through catalytic activity and provide a physical realization of artificial swimmers. Experimental observations are then customarily addressed as another instance of classic phoresis, $\mathbf{V} = \mathcal{L}_{\rm lin}(\nabla n)_{\rm act}$.

However, an additional role of the particle's chemical activity has been recently identified [1,2], namely, as responsible for a specific activity–induced response $\mathcal{L}_{\rm act}$, so that one has to write

$$\mathbf{V} = (\mathcal{L}_{\rm lin} + \mathcal{L}_{\rm act})\,[(\nabla n)_{\rm ext} + (\nabla n)_{\rm act}]$$

in the more general scenario. This would mean a change in paradigm as it disproves the claim that "self-phoresis is phoresis in a self-induced gradient".

[1] A. Domínguez, M. Popescu, C. Rohwer, S. Dietrich, Physical Review Letters, **125**, 268002 (2020).
[2] A. Domínguez, M. Popescu, Current Opinion in Colloid & Interface Science, **61**, 101610 (2022).

DY 31.12 Wed 18:00 MOL 213

Orientational 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]KTH Royal Institute of Technology and Stockholm University, Stockholm 10691, Sweden

Active suspensions are systems of motile organisms or active filaments 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 level and show that elongated pushers (representative of *E. coli*) and pullers (*C. reinhardtii*) exhibit diverse orbital dynamics in a weakly viscoelastic shear flow. We find that the active stresses not only modify the Jeffery orbits well-known from Newtonian fluids, but microswimmers can exhibit alignment and shear-plane rotation states. 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 amplify the swimmer-induced viscosity, in particular, the superfluid transition observed in pusher solutions.