DY 38: Microswimmers (joint session DY/CPP)

Time: Wednesday 15:30–18:00 Location: H19

DY 38.1 Wed 15:30 H19

Orientational ordering and collective motion in (semi-)dilute suspensions of active microswimmers — Christian Hoell, Giorgio Pessot, Hartmut Löwen, and •Andreas M. Menzel — Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

Polar orientational ordering in crowds of self-propelled particles is connected to the emergence of collective motion. We study orientational ordering in suspensions of active microswimmers. These objects propel by setting the surrounding fluid into motion. Since we focus on (semi-) dilute suspensions, such hydrodynamic effects dominate the swimmer interactions. For simplicity, we concentrate on planar arrangements of so-called pushers and pullers, which induce different flow fields.

In such a situation, our simulations indicated polar orientational ordering for puller microswimmers, in contrast to pushers [1]. Thus, we analyzed the behavior of binary pusher–puller mixtures. Interestingly, we found that smaller amounts of pusher microswimmers can show a larger degree of orientational order than surrounding puller microswimmers in an ordered suspension of mainly pullers [1]. Increasing the amount of pushers makes the orientational order break down.

To further quantify these phenomena, we performed a linear stability analysis of a corresponding dynamical density functional theory for pusher and puller suspensions [2]. Indeed, we found homogeneous polar orientational order to arise from a linear instability of disordered suspensions of strong pullers, in contrast to pushers.

[1] G. Pessot et al., *Mol. Phys.* **116**, 3401 (2018).
[2] C. Hoell et al., *J. Chem. Phys.* **149**, 144902 (2018).

DY 38.2 Wed 15:45 H19

Maximum in density heterogeneities of active swimmers — •Fabian Jan Schwarzendahl[1] and Marco G. Mazza[1,2] — [1]Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany — [2]Interdisciplinary Centre for Mathematical Modelling and Department of Mathematical Sciences, Loughborough University, Loughborough, Leicestershire LE11 3TU, United Kingdom

Suspensions of unicellular microswimmers such as flagellated bacteria or motile algae can exhibit spontaneous density heterogeneities at large enough concentrations. We introduce a novel model for biological microswimmers that creates the flow field of the corresponding microswimmers, and takes into account the shape anisotropy of the swimmer's body and stroke-averaged flagella. By employing multiparticle collision dynamics, we directly couple the swimmer's dynamics to the fluid's. We characterize the nonequilibrium phase diagram, as the filling fraction and Péclet number are varied, and find density heterogeneities in the distribution of both pullers and pushers, due to hydrodynamic instabilities. We find a maximum degree of clustering at intermediate filling fractions and at large Péclet numbers resulting from the competition of hydrodynamic and steric interactions between swimmers. We develop an analytical theory that supports these results. This maximum might represent an optimum for the microorganisms' colonization of their environment.

DY 38.3 Wed 16:00 H19

Stabilization of a square vortex lattice in microswimmer suspensions by periodic arrays of obstacles — •Henning Reinken[1], Sebastian Heidenreich[2], Igor S. Aranson[3], Markus Bär[2], and Sabine H.L. Klapp[1] — [1]Technische Universität Berlin, Berlin, Germany — [2]Physikalisch-Technische Bundesanstalt, Berlin, Germany — [3]Pennsylvania State University, University Park, PA 16802, USA

Bacterial suspensions, a paradigmatic example of an active fluid, are known to exhibit a state denoted as mesoscale turbulence which is characterized by chaotic dynamics of vortices of a characteristic size. In a recent experiment, these vortices have been stabilized into a square lattice with antiferromagnetic order by geometrically constraining the bacterial suspension using periodic arrays of obstacles with a spacing in the range of the unconstrained vortex size [1]. Interestingly, the vortices are consistently located in the gaps between the obstacles rather than forming around them [1]. We aim to reproduce the patterns observed in the experiment using a recently derived fourth-order field theory for a vectorial order parameter representing an effective microswimmer velocity [2]. In this continuum theoretical framework, we numerically explore different implementations of the constraints: Obstacles that favor negatively charged topological defects straightforwardly reproduce the observed vortex lattice configuration. For topologically neutral defects, higher order nonlinear effects are required to break the topological symmetry and stabilize a certain configuration.

[1] D. Nishiguchi et al., Nat Commun. **9**, 4486 (2018).
[2] H. Reinken et al., Phys. Rev. E **97**, 022613 (2018).

DY 38.4 Wed 16:15 H19

Complex dynamic response of magnetocapillary swimmers — •Alexander Sukhov[1], Sebastian Ziegler[2], Ana-Suncana Smith[2], and Jens Harting[1,3] — [1]Helmholtz Institute Erlangen-Nuernberg for Renewable Energy (IEK-11), Forschungszentrum Juelich GmbH, 90429 Nuernberg, Germany — [2]Institute for Theoretical Physics, Friedrich-Alexander University Erlangen-Nuernberg, 91054 Erlangen, Germany — [3]Department of Applied Physics, Eindhoven University of Technology, P.O. Box 513, NL-5600MB Eindhoven, The Netherlands

Using the lattice Boltzmann method and the Shan-Chen model for multiple fluid components we simulate an interface with several rigid magnetic particles floating on it. The stability of the system is reached when the attractive capillary forces resulting from the weights of the particles are balanced by the repulsive magnetic forces induced by an external static magnetic field applied perpendicularly to the interface. The particles can propel themself at the interface when a smaller oscillating magnetic field of the right frequency is applied in the plane of the interface. We aim at understanding the contributions of interparticle and hydrodynamic interactions as well as that of the interface to the dynamic response of the swimmer when simulating a single, two and three particles at the interface separately.

DY 38.5 Wed 16:30 H19

Microswimmers in an axisymmetric vortex flow: from Hamiltonian dynamics to clustering — •José-Agustín Arguedas-Leiva and Michael Wilczek — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Microswimmers appear in a wide variety of settings, ranging from phytoplankton in the ocean to bacteria in laboratory flows, and are known to give rise to many physically interesting phenomena. One such phenomenon is the clustering of otherwise neutrally buoyant particles. Its occurrence, and in particular the importance of physical parameters such as particle shape and swimming velocity, are currently not fully understood.

Here, we study the the distribution and clustering of swimmers in a two-dimensional axisymmetric vortex flow. Due to its simplicity, this system allows for a number of insights: We find that spherical swimmers follow phase-space preserving Hamiltonian dynamics, excluding the possibility for clustering. Interestingly, changing the particles' shape breaks the Hamiltonian structure of the dynamics, and clustering can occur. Based on this observation we identify a single control parameter: an effective swimming velocity, which takes into account both the particles' shape and velocity. By characterizing the topology of the underlying phase space our results help to clarify the role of motility and shape-dependent hydrodynamic interactions.

15 min. break

DY 38.6 Wed 17:00 H19

Oscillatory dynamics of swimming E. coli bacteria in wall-bounded Poiseuille flow — •Andreas Zöttl[1,2], Arnold Mathijssen[1,3], Nuris Figueroa-Morales[2], Gaspard Junot[2], Éric Clément[2], and Anke Lindner[2] — [1]University of Oxford, UK — [2]ESPCI Paris, France — [3]Stanford University, USA

Swimming microorganisms respond to flows in highly diverse and complex environments, at scales ranging from open oceans to narrow capillaries. The combined effects of fluid flow and boundaries lead to preferred swimmer orientation breaking the up/down-stream and left/right symmetry. To date, this so-called bacterial surface rheotaxis has been quantified by measuring instantaneous orientation distributions or average transport velocities, but a complete picture is still missing.

We investigate the time-resolved orientation dynamics of E.coli bacteria, theoretically and experimentally, as a function of applied shear close to walls. With increasing flow, we identify four regimes separated by critical shear rates: (I) circular swimming with a bias along the direction of vorticity; (II) upstream swimming without oscillations; (III) oscillatory motion, increasingly more to the left; (IV) coexistence of swimming to the left and to the right, with dynamical switching between these states. By modeling bacterial rheotaxis comprehensively - accounting for their chiral nature, hydrodynamic and steric interactions, elongation, fore-aft asymmetry and activity - we assess the relative importance of these contributions throughout a trajectory, and explain the full dynamics.

DY 38.7 Wed 17:15 H19

Polarization of Brownian swimmers with spatially heterogeneous activity — •Sven Auschra[1], Nicola Söker[2], Paul Cervenak[1], Viktor Holubec[1], Klaus Kroy[1], and Frank Cichos[2] — [1]Institute for Theoretical Physics, University of Leipzig, 04103 Leipzig, Germany — [2]Peter Debye Institute for Soft Matter Physics, University of Leipzig Leipzig, 04103 Leipzig, Germany

Janus particles fuelled by laser heating are paradigmatic autophoretic microswimmers. Their dynamics under constant driving has been well characterized [1-3]. We consider situations in which the particles' propulsion strength fluctuates in space and time, due to a variable fuel supply. Specifically, we analyze their spatial and orientational distribution experimentally, realizing prescribed spatial and temporal activity variations via the laser heating. We find depletion in regions of higher activity and polarization in activity gradients. Using Brownian dynamics simulations and a powerful numerical solver for Fokker-Planck equations [4], we can reproduce the experimental observations. A simple run-and-tumble process captures the observed features, qualitatively, and provides some analytical insights.

[1] A. Bregulla and F. Cichos: Faraday Discuss. 184, 381-391 (2015)
[2] H. Jiang, N. Yoshinaga, and M. Sano: PRL 105, 268302 (2010)
[3] A. Würger: Rep. Prog. Phys. 73, 126601 (2010)
[4] V. Holubec, K. Kroy and S. Steffenoni: arXiv:1804.01285v2 (2018).

DY 38.8 Wed 17:30 H19

Efficiency limits of the three-sphere swimmer in viscous fluids — •Babak Nasouri[1], Andrej Vilfan[1,2], and Ramin Golestanian[1,3] — [1]Max Planck Institute for Dynamics and Self-Organization (MPIDS), Göttingen, Germany — [2]J. Stefan Institute, Ljubljana, Slovenia — [3]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford, United Kingdom

We consider a swimmer consisting of a collinear assembly of three spheres connected by two slender rods. This swimmer, as first shown by Najafi and Golestanian (Phys. Rev. E 69, 062901 2004), can propel itself forward by varying the lengths of the rods in a way that is not invariant under time reversal. Although any non-reciprocal strokes of the arms can lead to a net displacement, the energetic efficiency of the swimmer is strongly dependent on the details and sequences of these strokes. We define the efficiency of the swimmer using Lighthill's criterion, i.e., the power that is needed to pull the swimmer by an external force at a certain speed, divided by the power needed for active swimming with the same average speed. Here, we determine numerically the optimal stroke sequences while limiting the maximum extension of the rods. Our calculation takes into account both far-field and near-field hydrodynamic interactions. We specifically show that the swimming efficiency initially rises by increasing the maximum allowable extension of the rods, and then converges to a maximum value.

DY 38.9 Wed 17:45 H19

Actuation of particles in modulated Poiseuille flow — •Winfried Schmidt[1,2], Matthias Laumann[1], Eva Kanso[2], and Walter Zimmermann[1] — [1]Physikalisches Institut, Universität Bayreuth, 95440 Bayreuth, Germany — [2]Aerospace and Mechanical Engineering, University of Southern California, Los Angeles, USA

What is the dynamical behavior of micro-particles in Poiseuille flow with oscillating flow direction at low Reynolds number? We investigate the overdamped motion of bead-spring models, e.g., capsules and red blood cells. We predict net motion of the particles, despite vanishing mean flow. This effect is generic as it does not depend on the model and is explained by a broken symmetry. The mean actuation velocity of passive particles is caused by their varying shape in both half periods. Since the net velocity depends also on the size and the elasticity of the particles, this novel actuation mechanism is appropriate for particle sorting. The system is also explored for active particles.