CPP 19: Microswimmers (joint session BP/CPP/DY, organized by DY)

Time: Tuesday 9:30–13:00 Location: H47

Invited Talk CPP 19.1 Tue 9:30 H47

Amoeboid swimming — •Chaouqi Misbah — CNRS and Univ. Grenoble, France

Microorganisms, such as bacteria, algae, or spermatozoa, are able to propel themselves forward thanks to flagella or cilia activity. By contrast, other organisms employ pronounced changes of the membrane shape to achieve propulsion, a prototypical example being the Eutreptiella gymnastica. Cells of the immune system as well as dictyostelium amoebas, traditionally believed to crawl on a substratum, can also swim in a similar way. We develop a model for these organisms. It is shown that fast propulsion can be achieved with adequate shape adaptations. We investigate the effect of confinement. A complex picture emerges. In particular it is found that optimal swimming can be obtaiend for a special confinement, and that the nature (pusher or puller) of the swimmer depends on confinement. The swimmer is often found to excecute ample excursion (navigation) in the channel.

CPP 19.2 Tue 10:00 H47

Meandering liquid crystal droplet swimmers — •Carsten Krüger, Corinna Maass, Christian Bahr, and Stephan Herminghaus — Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Göttingen, Germany

Liquid crystal microswimmers immersed in an aqueous surfactant solution at concentrations above the critical micelle concentration show self-propelled motion. The droplets dissolve into surfactant micelles [1], producing an inhomogeneous surfactant distribution in the continuum, propelling the droplets via Marangoni flows at the interface [2,3].

Below the nematic-isotropic transition we observe regular meandering trajectories, which change to a persistent random walk when the droplets are made isotropic by heating. This offers a unique possibility to tune the swimming behavior. We observe a distortion of the nematic director field, with the central defect pulled towards the droplet apex, but angled away from the direction of motion. This is consistent with a constant torque caused by a distortion of the defect pattern by the external and internal flow fields, acting against the elastic field associated with the nematic order. It also gives rise to the twofold symmetry break required for helical motion, as proposed by theory, e.g. in [4].

We use polarized microscopy to observe defect structures, PIV to image flow fields and are able to track freely moving droplets in 3D with a light sheet setup. [1] K. Peddireddy et al., Langmuir 28, 12426 (2012). [2] S. Herminghaus et al., Soft Matter 10, 7008 (2014). [3] C. C. Maass et al., Annu. Rev. Cond. Mat. 7, in press (2016). [4] H. Crenshaw, Amer. Zool. 36, 608 (1996).

CPP 19.3 Tue 10:15 H47

Dynamical density functional theory of microswimmers — •Andreas M. Menzel, Arnab Saha, Christian Hoell, and Hartmut Löwen — Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

Microswimmers are found in nature in the form of self-propelling microorganisms, or they can be realized artificially, e.g. as Janus particles propelling due to self-induced phoretic effects. To describe and predict the collective behavior of many such interacting microswimmers on the mesoscopic level, statistical approaches are necessary.

Along these lines, we here report on a newly established dynamical density functional theory (DDFT). This theory includes steric as well as hydrodynamic interactions between individual swimmers within dilute and moderately concentrated suspensions of microswimmers. Minimal model microswimmers are considered. They self-propel by setting the surrounding fluid into motion, which leads to additional hydrodynamic interactions. Both pusher and puller swimming mechanisms are taken into account.

Via numerical simulations, our DDFT is demonstrated to reproduce effects recently observed in agent-based simulations. In a spherical trapping potential, this includes the formation of density rings and the self-organization in a symmetry-breaking state that resembles a hydrodynamic fluid pump. An additional instability is predicted that destabilizes the pumping state.

CPP 19.4 Tue 10:30 H47

Dynamics of a single self-propelled particle — •Christina Kurzthaler, Sebastian Leitmann, and Thomas Franosch — Department for Theoretical Physics, University of Innsbruck, Innsbruck, Austria

The dynamics of a single self-propelled particle in two dimensions is analyzed in terms of the intermediate scattering function, i.e. the characteristic function of the random displacements. Its analytical solution is derived by solving the Fourier transform of the Fokker-Planck equation which has the form of a complex Mathieu equation. Exact expressions for the mean-square displacement and non-Gaussian parameter are obtained as derivatives of the intermediate scattering function. For large wave numbers, oscillations in the intermediate scattering function reflect the persistent swimming motion, whereas at small wave numbers diffusive behavior emerges with an effective diffusion coefficient depending on the velocity and rotational diffusion of the swimmer.

CPP 19.5 Tue 10:45 H47

Droplet swimmers in complex geometries: Autochemotaxis and trapping at pillars. — •Chenyu Jin, Corinna Maass, Carsten Krüger, and Stephan Herminghaus — MPI for Dynamics and Self-Organization, 37077 Göttingen, Germany

Many organisms communicate by trail mediated signalling or autochemotaxis: their motion is influenced by their own emission of a chemical attractant or repellent, diffusing slowly compared to typical agent velocities. This causes gradient forces acting both on themselves as well as on other individuals. Meanwhile, geometrical confinement also influences the behaviour of microswimmers, e.g., pusher-type swimmers attach to curved interfaces depending on the interplay of hydrodynamic interaction and trajectorial persistence. It is of high biological relevance to have a well-controlled, tunable artificial model system exhibiting these traits.

A promising candidate are self-propelling liquid crystal droplets in an aqueous surfactant solution. They gain propulsion energy by micellar solubilisation, with filled micelles acting as a chemical repellent. We can tune the key parameters swimmer size, velocity and persistence length. We use microfluidic pillar arrays of variable radii to provide a convex wall to attract the swimmer, bend its trajectory and to force it to revert to its own trail. Hence, we investigate the interplay of wall attraction, persistence of motion, and negative auto-chemotaxis. We observe repulsion for highly curved surfaces, stable trapping at large pillars, and a narrow transition region, where negative autochemotaxis makes the swimmers detach after a single orbit.

15 min break

CPP 19.6 Tue 11:15 H47

Dimensionality matters in the collective behaviour of active emulsions — •Corinna Maass, Carsten Krüger, and Stephan Herminghaus — MPI for Dynamics and Self-Organization, 37077 Göttingen, Germany

Microswimmer systems like plankton constitute an important part of our ecosystem. The description of such systems is complex, as it involves large numbers of agents, long range hydrodynamic interactions and nontrivial boundary conditions like turbulent flows and complex interfaces. They exhibit rich and sometimes puzzling behaviour like the high species diversity referred to in the Plankton Paradox, or self organised bioconvection of gravitactic bacteria. This complexity makes them hard to treat analytically and numerically. Large scale simulations usually have dimensional restrictions or exclude hydrodynamic interactions, which has to be considered in comparisons with natural systems. Simple, tunable artificial swimmer systems can help bridging this gap.

Our experimental system consists of an active emulsion of self propelling liquid crystal droplets under variable microfluidic confinement and with tunable buoyancy. While changing the system's geometry from a quasi 2D confinement to a full 3D bulk reservoir, we observe a pronounced transition from only transient local aggregation over line formation to a large scale clustering phase stabilised by self-generated convection patterns. We studied this clustering behaviour in more detail with respect to reservoir height and buoyancy.

CPP 19.7 Tue 11:30 H47

Quantification of modular phoretic micro-swimmers — •Ran

Niu, Christopher Wittenberg, Julian Weber, Denis Botin, and Thomas Palberg — Institut f. Physik, JGU Mainz, Staudingerweg 7, D-55128 Mainz, Germany

We have studied the swimming behavior of modular phoretic 2D micro-swimmers with particular focus on collective and cooperative effects[1,2]. These were exploited to proceed from isolated electrolyte releasing particles, driven by electro-osmotic flow field across a charged substrate, to multi-component complex, capable of self-generated, self-directed motion, transport and release of cargo and mutual long ranged interactions. Using optical techniques, such as microscopy and super-heterodyne laser doppler velocimetry, we accurately measured and characterized the swimmer properties and dynamics. From PH gradient measurements and particle tracking, we quantified the electric field and flow field around electrolyte releasing particle. The dependence of field strength on time and the size of electrolyte releasing particle were also determined. This provides the base for the quantitative understanding and establishing of a reliable model.

[1] T. Palberg, H. Schweinfurth,T. Koller,H. Muller,H.J. Schope, and A Reinmuller, European Physics Journal Special Topics 2013, 222:2835-2853. [2] A. Reinmuller, H.J. Schope, and T. Palberg, Langmuir 2013, 29:1738*1742.

CPP 19.8 Tue 11:45 H47

Confinement of Single Microswimmers in Circular Microfluidic Chambers — •Tanya Ostapenko, Thomas Böddeker, Christian Kreis, Fabian Schwarzendahl, Marco G. Mazza, and Oliver Bäumchen — Max Planck Institute for Dynamics and Self-Organization (MPIDS), Am Fassberg 17, 37077 Göttingen, Germany

The characteristics of active fluids, such as suspensions of biological microswimmers, may not only originate from the mutual interactions between the constituents, but also from interactions with interfaces and confining walls. In fact, the natural habitats of many living organisms are complex geometric environments, rather than bulk situations. The influence of interfaces on the dynamics was recognized as an important factor, and there are differences in the way that pusher-type swimmers (e.g. *E. coli*) and puller-type swimmers (e.g. *C. reinhardtii*) behave close to flat interfaces. Using experiments and simulations, we report on the dynamics of single puller-type swimmers in 2D circular microfluidic chambers. We find that the radial probability distribution of trajectories displays a characteristic wall hugging effect, where swimmers remain trapped at a concave interface for decreasing chamber size. For trajectories in the vicinity of the concave wall, an alignment of the local swimming direction with the local wall tangent is observed. In contrast, the swimmers tend to scatter off convex interfaces with short interaction times. Based on geometric arguments involving the swimmer's persistence length, we explain this entrapment effect at concave interfaces.

CPP 19.9 Tue 12:00 H47

Tumbling of an E. coli: role of rotation-induced polymorphism and external shear — •Tapan Chandra Adhyapak and Holger Stark — Institut für Theoretische Physik, Technische Universität Berlin, D - 10623 Berlin, Germany

Many multiflagellated bacteria such as E. coli adopt a run-and-tumble strategy to detect and direct themselves in chemical gradients in their surroundings. Tumbles are events which mark nearly abrupt changes in the direction of straight runs of the bacterium. Reversal of rotation of one or more of the flagella, which under normal rotation act as the propelling part of the bacterium, initiates these tumbles. Simultaneously, flagella that are reverse rotated are observed to undergo a series of polymorphic transitions between different flagellar states [1].

To understand the need, if there is any, of these transitions for an effective tumbling event has remained a long-standing problem. We present here a detailed numerical investigation unraveling the correlation between flagellar conformational changes and an efficient tumbling strategy for E. coli. Importance of these transitions in comparison to the contribution from hydrodynamic and steric interactions [2] will be addressed. At the end the nature of a tumbling event in sheared environment will also be discussed.

[1] R. Vogel and H. Stark, Phys. Rev. Lett. **110**, 158104 (2013).
[2] T.C. Adhyapak and H. Stark, Phys. Rev. E **92**, 052701 (2015).

CPP 19.10 Tue 12:15 H47

Sperm Cells in Structured Microchannels — •Sebastian Rode, Jens Elgeti, and Gerhard Gompper — Theoretical Soft Matter and Biophysics, Institute of Complex Systems (ICS-2) , Forschungszentrum Jülich, 52425 Jülich, Germany

At low Reynolds numbers and in confinement, the directed motion of a self-propelled microswimmer is strongly influenced by steric and hydrodynamic surface interactions [1-2]. Our mesoscale hydrodynamics simulation allow the study of various flagellated and ciliated microorganisms in this environment, ranging from a single flagellated sperm cell to multiciliated microswimmers. In particular, we have studied the motion of sperm in geometrically structured (zig-zag) microchannels. This is an interesting geometry for the manipulation and sorting of sperm cells. In general, sperm swim along the channel walls, but can be deflected from the wall at sharp bends. We found that the effective adhesion of a sperm cell to a curved surface depends both on the envelope of its sinusoidal beating shape and on the orientation of its beating plane. We present a heuristic argument explaining this dependence by an interplay of steric and hydrodynamic surface interactions. Our results are in qualitative agreement with recent microfluidic experiments and might provide a better insight in the mechanisms of sperm navigation under strong confinement.

[1] J. Elgeti et al., Rep. Prog. Phys. 78, 056601 (2015)
[2] J. Elgeti et al., Biophys. J. 99, 1018 (2010)

CPP 19.11 Tue 12:30 H47

Cross-stream transport of asymmetric particles driven by oscillating shear — •Matthias Laumann[1], Paul Bauknecht[2], Stephan Gekle[2], Diego Kienle[1], and Walter Zimmerman[1] — [1]Theoretische Physik I, Universität Bayreuth, 95440 Bayreuth, Germany — [2]Biofluid Simulation and Modeling, Universität Bayreuth, 95440 Bayreuth, Germany

We study the dynamics of asymmetric, deformable particles in oscillatory, linear shear flow. By simulating the motion of a dumbbell, a ring polymer, and a capsule we show that cross-stream migration occurs for asymmetric elastic particles even in linear shear flow if the shear rate varies in time. The migration is generic as it does not depend on the particle dimension. Importantly, the migration velocity and migration direction are robust to variations of the initial particle orientation, making our proposed scheme suitable for sorting applications of various elastic Janus-like particles.

CPP 19.12 Tue 12:45 H47

Calibration method for pH measurements with spatial and temporal resolution — •Julian Weber — Staudingerweg 7, 55128 Mainz

According to the framework of modular microswimmers, the field flow around involved particles is of great interest and can be measured by Doppler velocimetry. Here I present a special method for measuring the pH gradient around a cationic exchange resin. First gradient measurements are demonstrated.