BP 12: Microswimmers I (Joint Session DY/BP)

Time: Tuesday 9:30–13:00 Location: HÜL 186

Invited Talk BP 12.1 Tue 9:30 HÜL 186

Tactic Response of Synthetic Microswimmers in Gravitational and Optical Fields — •Clemens Bechinger — 2. Physikalisches Institut, Universität Stuttgart

Numerous motile organisms have developed intriguing steering mechanisms allowing them to orientate and navigate within gravitational, chemical or light fields. Such tactic response strongly promotes e.g., the search for food, reproduction and/or escape from unfavorable ambient conditions and is therefore an essential aspect of life. Unlike living systems, where tactic behavior is typically achieved by complex internal signal pathways, it is not obvious how this can be imposed on synthetic microswimmers which are distinguished by rather simple internal structures. Using light-activated self-propelled particles, we demonstrate that autonomous steering in gravitational fields and light gradients can be achieved without invoking a complex internal machinery but simply by the combination of viscous forces and torques which naturally arise during self-propulsion in liquids. These findings, which are confirmed by theory and simulations, make the use of artificial swimmers as micro-shuttles for targeted drug delivery to appear promising.

1. Lozano, Hagen, Löwen, Bechinger, Nat. Comm. 7, 12828 (2016).
2. Hagen, Kümmel, Wittkowski, Takagi, Löwen, Bechinger, Nat. Comm. 5, 4829 (2014).

BP 12.2 Tue 10:00 HÜL 186

Fission and fusion of microswimmer clusters — •Andreas Kaiser[1], Francisca Guzmán-Lastra[2], and Hartmut Löwen[2] — [1]Materials Science Division, Argonne National Laboratory, 9700 South Cass Ave, Argonne, Illinois 60439, USA — [2]Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany

Fission and fusion processes of particles clusters occur in many areas of physics and chemistry from subnuclear to astronomic length scales. Here we study fission and fusion of magnetic microswimmer clusters [1] as governed by their hydrodynamic and dipolar interactions. Rich scenarios are found which depend crucially on whether the swimmer is a pusher or a puller.

A linear magnetic chain of pullers is stable while a pusher chain shows a cascade of fission processes as the self-propulsion velocity is increased. Contrarily, magnetic ring clusters show fission for any type of swimmer. Moreover, we find a plethora of possible fusion scenarios if a single swimmer collides with a ringlike cluster and two rings spontaneously collide [2].

[1] A. Kaiser, K. Popowa, and H. Löwen, Phys. Rev. E 92, 012301 (2015)

[2] F. Guzmán-Lastra, A. Kaiser, and H. Löwen, Nature Commun. 7, 13519 (2016)

BP 12.3 Tue 10:15 HÜL 186

Optimal decision making in sperm chemotaxis — •Justus A. Kromer and Benjamin M. Friedrich — cfaed, TU Dresden

Sperm cells follow dilute chemical gradients to find the egg in a process termed chemotaxis. To evaluate local concentrations of chemoattractant, sperm detect single attractant molecules, while moving along helical paths. This noisy chemical input signal regulates the flagellar beat to steer the cell up-gradient. Recent experiments showed that sperm cells can switch between two distinct steering modes in a situation-specific manner [1]. While swimming up-gradient, cells employ a mode of conservative steering, characterized by slow bending of the helical swimming path towards the direction of the concentration gradient. In contrast, if a cell accidentally swims down-gradient, it responds with a vigorous steering maneuver, characterized by fast helix bending.

Here, we present a theoretical description of this cellular decision making, formulated as a Markov decision process in the framework of a stochastic single-player game. We predict that decision making would provide no benefit in a hypothetical noise-free world, but substantially increases the chances to find the egg at physiological levels of sensing noise. Our work exemplifies the fundamental trade-off choice between responding accurately or responding fast for navigating cells.

[1] JF. Jikeli et al. Nature Communications **6**, 7985 (2015)

BP 12.4 Tue 10:30 HÜL 186

Lattice Boltzmann study of magnetocapillary microswimmers — •Alexander Sukhov[1], Qingguang Xie[2], and Jens Harting[1,2] — [1]Helmholtz Institute Erlangen-Nürnberg for Renewable Energy (IEK-11), Forschungszentrum Jülich GmbH, Fürther Straße 248, 90429 Nürnberg, Germany — [2]Department of Applied Physics, Eindhoven University of Technology, P.O. Box 513, NL-5600MB Eindhoven, The Netherlands

Magnetocapillary swimmers - a system of three or more paramagnetic beads trapped at a fluid-gas interface - attracted recently considerable theoretical [1] and experimental attention [2]. Due to an interplay of attractive capillary and repulsive magnetic dipole-dipole interactions the swimmer can be stabilized. By applying a set of a static and a time-dependent magnetic field its position and the velocity direction can also be well manipulated. The last makes the swimmers potentially interesting for multiple applications ranging from a controlled cleaning of liquid interfaces to even a drug delivery or other medical applications *in vivo*.
Using a hybrid lattice Boltzmann and discrete element method we show a sharp dependence of the average speed of the swimmer on the frequency of the time-dependent magnetic field, demonstrate the control of the direction of the swimmer motion using B-fields and also analyze the obtained results analytically. [1] R. Chinomona, J. Lajeunesse, W.H. Mitchell, Y. Yao and S.E. Spagnolie, Soft Matter **11**, 1828 (2015). [2] G. Grosjean, G. Lagubeau, A. Darras, M. Hubert, G. Lumay and N. Vanderwalle, Sci. Rep. **5**, 16035 (2015).

BP 12.5 Tue 10:45 HÜL 186

Swimming *Bacillus subtilis* with different number of flagella — •Javad Najafi[1], Florian Altegoer[2], Thomas John[1], Gert Bange[2], and Christian Wagner[1] — [1]Experimental Physics, Saarland University, 66123 Saarbruecken, Germany — [2]LOEWE Center for Synthetic Microbiology (Synmikro), Philipps-University Marburg, Marburg, Germany

Microorganisms generally use so called flexible appendages known as flagella to swim in aqueous media. Different species have various flagellar number and while single flagellum is enough for swimming, it is not understood well why some bacteria synthesize several flagella. We statistically investigate the swimming of multi-flagellated bacteria by characterizing the influence of flagellar number of genetically manipulated strains of *Bacillus subtilis* on diverse swimming parameters. We find that while numerous flagella are not significantly advantageous in terms of propulsion speed, it slightly changes running time and angular quantities. In a homogeneous medium, the strain with more flagella has an increased rotational diffusion and turning angle after tumbling. Consequently, the cells with more flagella tend to turn in larger angles that causes smaller translational diffusion coefficient and localized motion. We use Langevin simulation based on experimental parameters which enables us to disentangle the effect of turning angle and rotational diffusion on translational diffusion.

BP 12.6 Tue 11:00 HÜL 186

Intermediate scattering function of an anisotropic circle swimmer — •Christina Kurzthaler and Thomas Franosch — Institut für theoretische Physik, Universität Innsbruck, Technikerstraße 21A, 6020 Innsbruck, Austria

A plethora of active agents ranging from biological microswimmers to artificially synthesized self-propelled particles exhibit peculiar dynamical behavior while moving in aqueous media at low Reynolds number. These active particles are intrinsically out of equilibrium and their transport properties are highly sensitive to their body shape, the symmetry of the propulsion mechansim, and also interactions with interfaces, which all have shown to induce a chiral swimming pattern. Here, we theoretically characterize the oscillatory dynamics of these Brownian circle swimmers in terms of the directly measurable intermediate scattering function (ISF), i.e. the characteristic function of the random displacements [1]. We identify different spatiotemporal regimes reflecting the bare translational diffusion at large wavenumbers, the persistent circular motion at intermediate wavenumbers and an enhanced effective diffusion at small wavenumbers. In particular, the circular motion of the particle manifests in characteristic oscillations of the ISF away from zero in contrast to oscillations around zero that can be traced back to the persistent swimming motion only. Furthermore, we obtain an exact expression for the non-Gaussian parameter, which displays oscillations at intermediate times mirroring the chiral swimming pattern of these active agents. [1] C. Kurzthaler, S. Leitmann, T. Franosch, Scientific Reports 6, 36702 (2016).

15min. break

Invited Talk BP 12.7 Tue 11:30 HÜL 186

Emergent structures in actuated magnetic and active colloidal suspensions — •Ignacio Pagonabarraga — University of Barcelona, Barcelona, Spain

Actuated and autocatalytic colloids constitute systems that are intrisically out of equilibrium. As a result fo their dynamic interactions, they can show a rich variety of self assembly scenarios. The observed self assembled structures make these systems very sensitive to external forcing, hence making actuated and active matter a fertile ground to explore and develop mechanically tunable materials.

I will analyze the basic physical mechanisms that control the collective behavior of two kinds of colloidal particles that move in a liquid medium. Confined magnetic colloids can rectify their motion when actuated with a rotating magnetic field, acting as a hydrodynamic conveyor belt. Self assembled chains of rotors propel faster than individual ones, reaching a saturation speed at distances where induced-flow additivity vanishes. The development of Janus colloids has opened the possibility to create synthetic microrobots that can move due to the chemical reacions they catalyze on their heterogeneous surfaces. The motion of chemically powered colloids is intricate because of the interplay between chemical and hydrodynamic interactions. These dynamic interactions have a strong impact in the collective behavior of these suspensions. I will describe the analogies and specificities in the hydrodynamic coupling that characterize these two types of systems.

BP 12.8 Tue 12:00 HÜL 186

Phase diagram of microswimmers in bulk — •Fabian Jan Schwarzendahl, Stephan Herminghaus, and Marco G. Mazza — Max Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, 37077 Göttingen, Germany

The hydrodynamic flow field of microswimmers such as bacteria or algae can be classified into two categories: pushers and pullers. Bacteria like *E. coli* create a force dipole pushing the fluid away at their front and rear. On the other hand algae like *Chlamydomonas reinhartii* create a force dipole that pulls the fluid towards them at the front and rear. We study the bulk behaviour of both types using a combination of molecular dynamic (MD) and stochastic rotational dynamic (SRD) simulations. Here, we use a minimal model for the swimmers accounting for hydrodynamic (SRD) as well as steric (MD) interactions. We find a rich phase diagram showing clustering as well as nematic states.

BP 12.9 Tue 12:15 HÜL 186

Collective migration under hydrodynamic interactions - a computational approach — •Axel Voigt and Wieland Marth — Institut für Wissenschaftliches Rechnen, TU Dresden, Germany

Substrate-based cell motility is essential for fundamental biological processes, such as tissue growth, wound healing and immune response. Even if a comprehensive understanding of this motility mode remains elusive, progress has been achieved in its modeling using a whole cell physical model. The model takes into account the main mechanisms of cell motility - actin polymerization, substrate mediated adhesion and actin-myosin dynamics and combines it with steric cell-cell and hydrodynamic interactions. The model predicts the onset of collective cell migration, which emerges spontaneously as a result of inelastic collisions of neighboring cells. Each cell here modeled as an active polar gel, is accomplished with two vortices if it moves. Open collision of two cells the two vortices which come close to each other annihilate. This leads to a rotation of the cells and together with the deformation and the reorientation of the actin laments in each cell induces alignment of these cells and leads to persistent translational collective migration. The effect for low Reynolds numbers is as strong as in the non-hydrodynamic model, but it decreases with increasing Reynolds number.

BP 12.10 Tue 12:30 HÜL 186

Swimming by buckling: low Reynolds number swimming by shape hysteresis — •Horst-Holger Boltz[1,2] and Jan Kierfeld[2] — [1]Institut für nichtlineare Dynamik, Fakultät Physik, Georg-August-Universität Göttingen, Göttingen, Deutschland — [2]Fakultät Physik, Technische Universität Dortmund, Dortmund, Deutschland

We present a low Reynolds number swimming concept based on an oscillatory change in a parameter controlling a hysteretic shape transition, which converts the time-reversible parameter changes into non-time-reversible shape changes leading to a net swimming motion. As realization of this general concept we propose and investigate the swimming locomotion of a spherical elastic capsule that undergoes repeated hysteretic buckling under a time-reversible periodic volume change. We show analytically and by numerical simulation based on the boundary integral method that the hysteretic switching gives rise to net locomotion at low Reynolds numbers. We characterize the swimming mechanism and its efficiency in dependence on the elastic properties capsule and derive the characteristic behaviour of the net swimming velocity.

BP 12.11 Tue 12:45 HÜL 186

A kinetic theory for dynamics of self-propelled magnetic suspensions — •Fabian Rouven Kössel and Sara Jabbari-Farouji — Johannes Gutenberg-Universität - Institut für Physik

Inspired by novel dynamical behaviour of magnetotactic bacteria, we present a minimal kinetic model for dilute suspensions of magnetic self-propelled particles. Our kinetic theory couples a Fokker-Planck equation of active particles in an external magnetic field to a Stokes-flow equation. Including the hydrodynamic stress contributions due to self-propulsion and magnetic torque in the Stokes flow we investigate the interplay between internal and external drives on the dynamics and effective viscosity of active suspensions. Through the linear stability analysis and full numerical simulations of our model, we examine the role of the external magnetic field on stability of aligned suspensions and their complex flow patterns.