CPP 8: Active Matter I (joint session BP/DY/CPP)

Time: Monday 9:30–13:00 Location: HÜL 386

Invited Talk CPP 8.1 Mon 9:30 HÜL 386

Spontaneous and driven active matter flows — •Eric Clement — PMMH-ESPCI-Sorbonne University, Paris, France

Understanding the individual and the macroscopic transport properties of motile micro-organisms in complex environments is a timely question, relevant to many ecological, medical and technological situations. At the fundamental level, this question is also receiving a lot of attention as fluids loaded with swimming micro-organisms has become a rich domain of applications and a conceptual playground for the statistical physics of active matter. The existence of microscopic sources of energy borne by the motile character of micro-swimmers is driving self-organization processes at the origin of original emergent phases and unconventional macroscopic properties leading to revisit many standard concepts in the physics of suspensions. In this presentation, I will report on a recent exploration on the question of collective motionspontaneous formation, in relation with the rheological response of active suspensions. I will also present new experiments showing how the motility of bacteria can be controlled such as to extract work macroscopically.

CPP 8.2 Mon 10:00 HÜL 386

Light-regulated motility of microbial suspensions induces phase separation in confinement — •Alexandros Fragkopoulos[1], Jeremy Vachier[1], Johannes Frey[1], Flora-Maud Le Menn[1], Michael Wilczek[1], Marco Mazza[1,2], and Oliver Bäumchen[1] — [1]Max Planck Institute for Dynamics and Self-Organization (MPIDS), D-37077 Göttingen, Germany — [2]Department of Mathematical Sciences, Loughborough University, Loughborough, Leicestershire LE11 3TU, United Kingdom

A highly concentrated suspension of self-propelled particles can form large-scale concentration patterns, separating into regions of high and low particle concentrations, due to the activity of the particles and their mutual interactions. However, such a phenomenon has so far been rarely seen in biological systems. Here, we present that a sufficiently concentrated suspension of *Chlamydomonas reinhardtii* cells, a model organism of puller-type microswimmers, forms such large-scale aggregations under confinement in specific light conditions. We find that cell-cell interactions need to be dominated by collisions for the aggregation to form, resulting to a generic coupling of the cell's motility and local cell density. In addition, the cell's motility decreases with decreasing light intensity, which regulates the cell aggregation. Through active Brownian particle simulations, we show that for our system the change of the motility is sufficient to induce the aggregation. Finally, we provide evidence that the photosynthetic activity controls the cell's motility, and consequentially, the separation of the active suspension into regions of high and low cell density.

CPP 8.3 Mon 10:15 HÜL 386

Motility induced transport in microbial environments — •Jayabrata Dhar, Arkajyoti Ghoshal, and Anupam Sengupta — Physics of Living Matter Group, Department of Physics and Materials Science, University of Luxembourg, 162 A, Avenue de la Faencerie, L-1511, Luxembourg City, Luxembourg

Despite their minuscule size, microbes mediate a range of processes in ecology, medicine and industry due to high local concentrations. Studies in aquatic ecosystems have demonstrated nutrient mixing via bioconvection by high concentrations of motile microbes [1] potentially impacts species distributions in natural settings. However, to date, we lack a systematic framework to capture the role of microbial traits (for instance, morphology or motility) on the onset and progression of bioconvection. Here, using different bloom-forming algal species as model organisms, we study how microbial traits underpin the onset of bioconvection and modulate mass transfer due to local density changes. Combining micro-PIV analysis of dispersed particles and auto-fluorescence imaging of algal cells, we quantify the emergent transport properties in real-time, revealing a plume-driven primary convective field. Interestingly, our results further capture relatively weak, secondary eddies that create local mixing patches with short lifetimes. Thus, bioconvection may alter the chemical environment of the microbes through distinct modes, impacting the distribution of nutrients, toxins or secondary metabolites, all of which could be vital for large-scale phenomena like harmful algal blooms.

[1] T. Sommer, et al., Geophysical Research Letters 44, 9424, 2017.

CPP 8.4 Mon 10:30 HÜL 386

Reactivation of isolated axonemes by light-driven ATP regeneration system — Raheel Ahmed[1], Christin Kleinberg[2], Tanja Vidakovich-Koch[2], Kai Sundmacher[2], Eberhard Bodenschatz[1], and •Azam Gholami[1] — [1]MPI for Dynamics and Self-Organization — [2]MPI for Dynamics of Complex Technical Systems

Cilia and flagella are slender cellular appendages whose regular beating pattern pumps fluids, for example the mucus in mammalian airways, or propels unicellular organisms such as the green algae Chlamydomonas reinhardtii. Cilia and flagella have a microtubule-based structure called axoneme which performs whip-lash-like motion to provide motility. This oscillatory motion is powered by dynein molecular motors that generate active stresses for ciliary beat in the presence of ATP. In this work, we have successfully integrated light-driven energy module for continuous generation of ATP. This light-driven ATP regeneration system is built through bottom-up assembly of FOF1- ATP synthase and bacteriorhodopsin into two different types of artificial hybrid membranes based on a diblock copolymer (PBd-PEO) and a graft copolymer (PDMS- g-PEO). After illumination of the energy module with light, we mixed it with axonemes isolated from Chlamydomonas reinhardtii and observed actively beating axonemes for many hours. Interestingly, the axonemes beat even at low concentrations of ATP well below 50 μM.

CPP 8.5 Mon 10:45 HÜL 386

Chemotaxis strategies of bacteria with multiple run-modes — •Zahra Alirezaeizanjani[1,2], Robert Grossmann[1], Veronika Pfeifer[1], Marius Hintsche[1], and Carsten Beta[1] — [1]Institute of Physics and Astronomy, University of Potsdam, 14476 Potsdam, Germany — [2]Max Planck Institute of Colloids and Interfaces, 14476 Potsdam, Germany

Bacterial chemotaxis – a fundamental example of directional navigation in the living world – is key to many biological processes, including the spreading of bacterial infections. Many bacterial species were recently reported to exhibit several distinct swimming modes – the flagella may, for example, push the cell body or wrap around it. How do the different run modes shape the chemotaxis strategy of a multimode swimmer? Here, we investigate chemotactic motion of the soil bacterium *Pseudomonas putida* as a model organism. By simultaneously tracking the position of the cell body and the configuration of its flagella, we demonstrate that individual run modes show different chemotactic responses in nutrition gradients and thus constitute distinct behavioral states. Based on an active particle model, we demonstrate that switching between multiple run states that differ in their speed and responsiveness provide the basis for robust and efficient chemotaxis in complex natural habitats.

30 min. coffee break

CPP 8.6 Mon 11:30 HÜL 386

Synthetic minimal active cilia — •Isabella Guido — Max Planck Institute for Dynamics and Self-Organization, Goettigen, Germany

Cilia and flagella are microtubule based filamentous organelles that protrude into the extracellular environment from the surface of many cells for promoting fluid transport or propelling organisms in fluids by producing rhythmic bending waves. The main contribution to their beating is due to motor proteins that drive sliding of the microtubule doublets. However, the fundamental mechanism of the motor-microtubule interaction is still a puzzle. Here we present a synthetic minimal active cilium, a two-filaments system, in which the beat is initiated by a buckling instability in one of the filaments. The system presents continuous beating through association and dissociation cycles, similar to the sliding of a pair of doublet microtubules observed in a Chlamydomonas flagellum. The analysis of the conformational dynamics gives us a quantification of dynein force, motor density and bending energy. We develop a theoretical model to study the dynamics of active elastic filaments induced by internal force in which the attachment and detachment kinetics of motors play as important a role as their force generation. The active stroke of the synthetic cilium occurs due to a buckling instability between two clamped filaments, while the recovery stroke follows a "catastrophic failure" of the bound motors.

This work is in collaboration with Prof. Ramin Golestanian and Dr. Andrej Vilfan.

CPP 8.7 Mon 11:45 HÜL 386

Chiral stresses in nematic cell monolayers — •Ludwig A. Hoffmann[1], Koen Schakenraad[1,2], Roeland M. H. Merks[2,3], and Luca Giomi[1] — [1]Instituut-Lorentz, Leiden University, The Netherlands — [2]Mathematical Institute, Leiden University, The Netherlands — [3]Institute of Biology, Leiden University, The Netherlands

Recent experiments on monolayers of spindle-like cells have provided a convincing demonstration that certain types of collective phenomena in epithelia are well described by active nematic hydrodynamics. While recovering some of the predictions of this framework, however, these experiments have also revealed unexpected features that could be ascribed to the existence of chirality over length scales larger than the typical size of a cell.

We elaborate on the microscopic origin of chiral stresses in nematic cell monolayers and investigate how chirality affects the motion of topological defects, as well as the collective motion in stripe-shaped domains. We find that chirality introduces a characteristic asymmetry in the collective cellular flow, from which the ratio between chiral and non-chiral active stresses can be measured. Furthermore, we find that chirality changes the nature of the spontaneous flow transition under confinement and that, for specific anchoring conditions, the latter has the structure of an imperfect pitchfork bifurcation.

CPP 8.8 Mon 12:00 HÜL 386

Self-organization of active surfaces — •Alexander Mietke[1,2,3,4,7], V. Jemseena[5], K. Vijay Kumar[5], Ivo F. Sbalzarini[2,3,4,6], and Frank Jülicher[1,3,6] — [1]MPI for the Physics of Complex Systems — [2]Faculty of Computer Science, TU Dresden — [3]Center for Systems Biology Dresden — [4]MPI of Molecular Cell Biology and Genetics — [5]ICTS-TIFR — [6]Cluster of Excellence PoL, TU Dresden — [7]Department of Mathematics, MIT, Cambridge, MA

Self-organization of morphogenetic events often arises through a feedback loop in which active forces, by inducing deformations and material flows, indirectly affect their own mechano-chemical regulation. In recent years, the existence of generic mechano-chemical patterning mechanisms in simple, fixed geometries has been demonstrated theoretically and experimentally. However, the interplay of mechano-chemical processes with the surface geometry remains to be explored. In our work, we employ the theory of active gels in complex geometries to study the properties of dynamically evolving active surfaces. Within those surfaces, diffusive and advective transport processes can redistribute molecules responsible for local stress generation. This resembles the interplay between active forces, the shape changes they imply and the effects this has on their regulation. Within our framework, a contractile ring formation, as well as the peristaltic motion of active tubular structures can be understood as natural emergent phenomena. Our approach provides novel opportunities to explore different scenarios of mechano-chemical self-organization and can help to better understand the role of shape as a regulatory element in morphogenetic processes.

CPP 8.9 Mon 12:15 HÜL 386

Thin-Film Model of Resting and Moving Active Droplets — •Fenna Stegemerten[1], Sarah Trinscheck[1,2], Karin John[2], and Uwe Thiele[1,3] — [1]Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster, Münster, Germany — [2]Université Grenoble-Alpes, CNRS Laboratoire Interdisciplinaire de Physique, Grenoble, France — [3]Center for Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, Münster, Germany

We propose a long-wave model for free-surface drops of polar active liquid on a solid substrate. The coupled evolution equations for the film height and the local polarization profile are written in the form of a gradient dynamics supplemented with active stresses and fluxes. A wetting energy for a partially wetting liquid is incorporated allowing for motion of the liquid-solid-gas contact line. This gives a consistent basis for the description of drops of dense bacterial suspensions or compact aggregates of living cells on solid substrates. As example, we analyze the dynamics of active drops and demonstrate how active forces compete with passive surface forces to shape droplets and drive contact line motion. We perform parameter continuation in the activity parameters discussing both, resting and moving droplets. Additional direct time simulations investigate transitions from non-uniformly to uniformly polarized states.

CPP 8.10 Mon 12:30 HÜL 386

Fast vs. gradual death in assemblies of immotile growing cells — •Yoav G. Pollack, Philip Bittihn, and Ramin Golestanian — Max Planck Institute for Dynamics and Self-Organization (MPI-DS), Göttingen, Germany

Cell life-cycle processes such as growth, division and death, often all happen on a similar timescale, as do the resultant mechanical and dynamical responses of the cell assembly (such as a colony, biofilm or tissue). An archetypal example is *E. Coli* where growth, division and the subsequent relative motion of the daughter cells all happen at roughly the same rate. However there are also examples of another type of system showing abrupt processes, including 'snapping' cell division in *Actinobacteria* and 'explosive' bacterial lysis.

Here we test whether going from the first type of system to the other by introducing a second *fast* timescale in one of the microscopic processes can affect the macroscopic mechano-dynamics, such as the homeostatic pressure. Specifically we simulate a closed 1D channel of cells that grow and divide to fill up the channel and are removed (via death or extrusion) when pressure builds up. We focus on varying the timescale of the cell removal process, keeping growth and division timescales fixed. We show a clear distinction in the macroscopic system properties between abrupt vs. gradual cell removal, such as a significant increase in the homeostatic pressure.

CPP 8.11 Mon 12:45 HÜL 386

Simulations of an active surface immersed in viscous fluids — •Lucas D. Wittwer and Sebastian Aland — Faculty of Informatics / Mathematics, University of Applied Science Dresden, Germany

Mechanochemical processes play a crucial role during morphogenesis, the formation of complex shapes and tissues out of a single cell. On the cellular level, the actomyosin cortex governs shape and shape changes. This thin layer of active material underneath the cell surface exerts an active contractile tension, the strength of which being controlled by the concentration of force-generating molecules. Advective transport of such molecules leads to a complex interplay of hydrodynamics and molecule concentration which gives rise to pattern formation and self-organized shape dynamics.

In this talk, we present a novel numerical model to simulate an active surface immersed in viscous fluids. We show the resulting patterning and cell shape dynamics for different parameter configurations as well as the flow profiles in the surrounding fluids and compare it to results from other models.