DY 22: Active Matter II (joint session BP/DY/CPP)

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

DY 22.1 Tue 9:30 HÜL 386

Sedimentation and Convection of Bottom-Heavy Squirmers — •Felix Rühle, Jan-Timm Kuhr, and Holger Stark — TU Berlin, Institut für Theoretische Physik, Berlin, Germany

Active particles form appealing patterns, in particular, when hydrodynamic interactions are present [1-3]. A fascinating example known from biology is bioconvection of microswimmers under gravity [4]. In order to study such systems, we simulate bottom-heavy squirmers (neutral squirmers, pushers, and pullers) under different gravitational forces and torques. The relevant parameters are the ratio of swimming to bulk sedimentation velocity and the normalized torque.

In the state diagram of these parameters, for neutral squirmers we observe sedimentation at strong gravitational forces and inverted sedimentation at finite torques, when activity dominates. In between, we identify plumes of collectively sinking squirmers that feed convective rolls of circling squirmers at the bottom of the simulation cell. At velocity ratios slightly above one and large torques squirmers form a spawning cluster, which floats above the bottom wall and from which squirmers occasionally escape. For strong pushers and pullers, we find that the dipolar flow fields weaken the formation of plumes and convective rolls.

[1] M. Hennes, *et al.*, PRL **112**, 238104 (2014)
[2] J.-T. Kuhr, *et al.*, Soft Matter **13**, 7548 (2017).
[3] H. Jeckel, *et al.*, PNAS **116**, 1489 (2019).
[4] T.J. Pedley, and J.O. Kessler, Annu. Rev. Fluid Mech. **24**, 313 (1992).

DY 22.2 Tue 9:45 HÜL 386

Sculpting vesicles with active particles — Masoud Hoore[1], Clara Abaurrea-Velasco[1], Hanumantha Rao Vutukuri[2], Thorsten Auth[1], Jan Vermant[2], Gerhard Gompper[1], and •Dmitry Fedosov[1] — [1]Institute of Complex Systems and Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Department of Materials, ETH Zürich, 8093 Zürich, Switzerland

Biological cells are able to generate intricate structures and respond to external stimuli, sculpting their membrane from inside. Simplified biomimetic systems can aid in understanding the principles which govern these shape changes and elucidate the response of the cell membrane under strong deformations. We employ a combined simulation and experimental approach to investigate different non-equilibrium shapes and active shape fluctuations of vesicles enclosing self-propelled particles. Interestingly, the most pronounced shape changes are observed at relatively low particle loadings, starting with the formation of tether-like protrusions to highly branched, dendritic structures. At high volume fractions, globally deformed vesicle shapes are observed. The obtained state diagram of vesicles sculpted by active particles predicts the conditions under which local internal forces can generate dramatic cell shape changes, such as branched structures in neurons.

DY 22.3 Tue 10:00 HÜL 386

Diffusing Activity: Active Particles in Evolving Environments — •Nima H. Siboni, S. Mohsen J. Khadem, and Sabine H. L. Klapp — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany

We study the dynamics of a single active Brownian particle (ABP) and the collective behavior of interacting ABPs in a heterogeneous medium. We apply the idea of the diffusing diffusivity model [1] to mimic the environmental heterogeneity in the equation of motion of the ABPs via a time-dependent activity and diffusivities. In our model, the fluctuations of the environment affect simultaneously and similarly the motility and diffusion coefficients. We obtain analytically the probability distribution function of the particle displacement and its moments and support our results via particle-based simulations. We finally investigate the impact of the introduced fluctuations on the collective behavior of ABPs. We obtain the phase diagram of motility-induced phase separation [2,3] for a wide range of noise strength and compare our results with that for the conventional ABPs [4].

[1] M. V. Chubynsky and G. W. Slater, Phys. Rev. Lett. **113**, 098302 (2014).
[2] I. Buttinoni, J. Bialké, F. Kümmel, H. Löwen, C. Bechinger, and T. Speck, Phys. Rev. L. **110**, 238301 (2013).
[3] J. Stenhammar, A. Tiribocchi, R. J. Allen, D. Marenduzzo, and M. E. Cates, Phys. Rev. L. **111**, 145702 (2013).
[4] S. M. J. Khadem, N. H. Siboni, and S. H. L. Klapp, in preparation.

DY 22.4 Tue 10:15 HÜL 386

Phoretic interactions of two chemically-active particles — •Babak Nasouri[1] and Ramin Golestanian[1,2] — [1]Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Goettingen, Germany — [2]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

Catalytically-coated active particles in a viscous medium interact with one another by altering the chemical and hydrodynamic fields in their surroundings. Such phoretic interactions may drive particles in motion and are strongly dependent on the physico-chemical properties of the system, namely: the response of the particles to the interaction fields, and geometric factors such as inter-particle distances and particle sizes. In this work, we discuss an analytical approach which can accurately capture the dynamical behaviour of two phoretic spherical particles, for any given configuration.

DY 22.5 Tue 10:30 HÜL 386

Axisymmetric spheroidal squirmers and self-diffusiophoretic particles — Ruben Poehnl[1], •Mihail Popescu[2], and William Uspal[1] — [1]Dept. of Mech. Eng., Univ. of Hawai'i at Manoa, 2540 Dole St., Honolulu, HI 96822, USA — [2]Max Planck Institute for Intelligent Systems, Heisenbergstr. 3, 70569 Stuttgart, Germany

By using previously published analytical solutions for Stokes flow around a spheroid, here we investigate the motion of a spheroidal, axisymmetric squirmer in an unbounded fluid and the low Reynolds number hydrodynamic flow induced by the squirmer.

In contrast to the case of a spherical squirmer, for the spheroidal squirmer each slip mode either contributes to the velocity, or contributes to the stresslet. Additionally, and also distinct from the case of a spherical squirmer, each slip mode excites either all of the fore-aft symmetric or fore-aft asymmetric components of the flow field, respectively. Accordingly, with small modifications of the squirming pattern, a microrganism could maintain its velocity unchanged but dramatically alter the topology of the flow around it. This raises the interesting speculative question as whether the spheroidal shape is providing an evolutionary advantage, i.e., a spheroidal squirmer possesses simple means – not available to a spherical one – for acting in hydrodynamic disguise, which can be advantageous as either predator or prey.

The results are straightforwardly extended to the self-phoresis of axisymmetric, spheroidal, chemically active particles with phoretic slip.

DY 22.6 Tue 10:45 HÜL 386

Active particle penetration through a planar elastic membrane — •Abdallah Daddi-Moussa-Ider[1], Benno Liebchen[1,2], Andreas M Menzel[1], and Hartmut Löwen[1] — [1]Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf, Germany — [2]Theorie Weicher Materie, Fachbereich Physik, Technische Universität Darmstadt, Germany

Active penetration of nanoparticles through cell membranes is an important phenomenon which has various biomedical and clinical applications. Using particle-based computer simulations and theory, we study the penetration mechanism of an active or externally driven particle through a planar elastic membrane. We model the membrane as a self-assembled sheet of particles embedded in a viscous fluid. We introduce a coarse-grained model to describe the mutual interactions between the membrane particles. We identify three distinct scenarios, including trapping of the active particle, penetration through the membrane with subsequent self-healing, in addition to penetration with permanent disruption of the membrane. The latter scenario may be accompanied by a partial fragmentation of the membrane into bunches of isolated or clustered particles. Our approach might be helpful for the prediction of the transition threshold between the trapping and penetration states in real-space experiments involving motile swimming bacteria or artificial self-propelling active particles. Reference: Daddi-Moussa-Ider *et al.*, Theory of active particle penetration through a planar elastic membrane, *New J. Phys.* **21**, 083014 (2019).

30 min. coffee break

Invited Talk DY 22.7 Tue 11:30 HÜL 386

Physics of Growth: Another Form of Active Matter — •Jens Elgeti — Foschungszentrum Jülich, Germany Theoretical Soft Matter and Biophysics

Active matter is matter, driven out of equilibrium by its microscopic constituents. Growing mater is also active matter, but activity does not enter via the stress, but in material conservation. The material generates itself – think cells dividing or a tumor growing. Growth implies a change in volume. In physical terms, the conjugate force to volume is pressure. Thus, in order to grow, cells must exert mechanical pressure. In turn, pressure influences growth. This yields to interesting novel phenomena like infinite compressibility, self contracting materials and steady tread-milling states.

We use particle based simulations to study mechanical properties and effects in growing matter. These simulations have been helpful in understanding, interpreting and designing experiments. I will present an overview of the simulation technique, and several examples of how this model helped to gain insight in mechanical processes underlying tissue growth, ranging from growth of cancer spheroids under pressure [1], to *in silico* competition experiments [2-5] and tumor evolution [6].

[1] Montel et al., PRL **107**, 188102 (2011)
[2] Podewitz et al., EPL **109**, 58005 (2016)
[3] Basan et al., Phys. Biol. **8**, 026014 (2011)
[4] Podewitz et al., New J. Physics **18**, 083020 (2016)
[5] Ganai et al., New J. Phys. **21** 063017 (2019)
[6] Büscher et al., arxiv:1910.03263 (2019)

DY 22.8 Tue 12:00 HÜL 386

The effect of hydrodynamic interactions on self-propulsion of multiple swimmers — •Sebastian Ziegler[1], Maxime Hubert[1], Thomas Scheel[2], Jens Harting[2], and Ana-Sunčana Smith[1,3] — [1]PULS Group, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [2]Helmholtz Institute Erlangen-Nürnberg for Renewable Energy, Forschungszentrum Jülich, Germany — [3]Division of Physical Chemistry, Ruder Bošković Institute Zagreb, Croatia

A common theoretical approach to model systems of microswimmers is to prescribe the swimming stroke of each individual. If the system consists of more than one device, such models, however, underestimate the impact of one swimmer's stroke on the stroke of all others, reducing the problem of hydrodynamic interactions to a purely geometric one. Furthermore, a number of experimental systems are associated with imposing the forces driving each of the devices. This situation is, from a theoretical point of view, significantly more demanding and has not been investigated so far for multiple swimmers. This issue is addressed in this presentation where we employ a recently developed perturbative calculation and numerical modeling to study the effects of nearby swimmers on the stroke, swimming speed and direction. Notably, we find that for two swimmers, a significant fraction of the parameter space results in both swimmers experiencing a boost from one another. We identify the key characteristics that yield this effect.

DY 22.9 Tue 12:15 HÜL 386

Active particle scattering in structured and random environments — •Theresa Jakuszeit[1], Samuel Bell[2], and Ottavio A. Croze[1] — [1]Cavendish Laboratory, JJ Thomson Avenue, CB3 0HE, Cambridge, United Kingdom — [2]Laboratoire Physico Chimie Curie, Institut Curie,PSL Research University, CNRS UMR168, 75005 Paris, France

Active propulsion as performed by bacteria and Janus particles, in combination with hydrodynamic interaction at boundaries, can lead to the breaking of time reversibility. One typical example of this is the accumulation of bacteria on a flat wall. However, in microfluidic devices with pillars of sufficiently small radius, self-propelled particles can slide along the surface of a pillar without becoming trapped over long times. Using simulations and theory, we study the impact of different modes of obstacle interaction on the diffusive transport of active particles in a lattice of such obstacles. We find that sliding along obstacles can result in large diffusivities even at high obstacle density, unlike particles that undergo classical specular reflection, as in the Lorentz gas. We introduce a microscopically derived run-and-tumble model, which describes the macroscopic transport for different scattering rules very well, and test it in microfluidic channels for E.coli. Finally, we discuss the role of tumbling in structured and random environments.

DY 22.10 Tue 12:30 HÜL 386

Swimming behavior of squirmer dumbbells and polymers — •Judit Clopés Llahí, Gerhard Gompper, and Roland G. Winkler — Theoretical Soft Matter and Biophysics, Institute for Advanced Sim- ulation and Institute of Complex Systems, Forschungszentrum Jülich, D-52425 Jülich, Germany

Nature provides a plethora of microswimmers, which can be rather elongated, filament- or polymer-like. Examples are bacteria swarmer cells or marine phytoplankton dinoflagellates assembling in a linear fashion. In order to address the relevance of hydrodynamic interactions for the collective behavior of such organisms, we study the swimming properties of linear polymer-like assemblies by mesoscale hydrodynamic simulations, where an active unit (monomer) is described by a spherical squirmer -which can be a pusher, a neutral swimmer, or a puller. We find that the monomer hydrodynamic flow field leads to correlations in the relative orientation of adjacent monomers, and consequently the swimming efficiency differs from that of active Brownian linear assemblies. In particular, puller chains show a pronounced increase in the rotational diffusion coefficient compared to pushers, while for neutral squirmers, the rotational diffusion coefficient is similar to that of active Brownian particles. Hence, the large-scale conformational and dynamical properties depend on the specific propulsion mechanism. Refs.: [1] J. Elgeti, R. G. Winkler, G. Gompper, Rep. Prog. Phys. 78, (2015). [2] R. G. Winkler, J. Elgeti, G. Gompper, J. Phys. Soc. Jpn. 86, (2017). [3] A. Martin-Gomez, T. Eisenstecken, G. Gompper, R. G. Winkler, Soft Matter 15, (2018).

DY 22.11 Tue 12:45 HÜL 386

The step-wise induction of transcription drives morphological changes in aggregates of RNA polymerase II — Agnieszka Pancholi[1], Roshan Prizak[1], Tim Klingberg[2], Weichun Zhang[1], Amra Noa[1], Gerd Ulrich Nienhaus[1,3], Vasily Zaburdaev[2], and •Lennart Hilbert[1] — [1]Karlsruhe Institute of Technology — [2]Friedrich-Alexander University Erlangen-Nuremberg — [3]University of Illinois at Urbana-Champaign

In eukaryotic cells, a main control point of transcription is the transient pausing of engaged RNA polymerase II (Pol II) just before transcript elongation. Paused Pol II forms transient polymeric aggregates that exhibit diverse morphologies. Here, we use super-resolution microscopy in embryonic zebrafish cells to show how entry into and exit from Pol II pausing determines these aggregate morphologies. Instant structured illumination microscopy (iSIM) in live embryos revealed that aggregates initially are morphology complex, round up as they grow, and unfold again when actual transcript elongation begins. Using transcription inhibitors, we confirm that Pol II pausing indeed drives aggregate rounding. Further resolving aggregates by STimulated Emission Double Depletion (STEDD) microscopy, we found a granular fine-structure that suggests clustering aggregation rather than liquid-liquid compartmentalization. We currently develop a theoretical model to explain what underlying macro-molecular interactions could result in the observed morphologies.