DY 67: Poster: Active Matter, Microswimmers

Time: Thursday 15:30–18:00 Location: Poster A

DY 67.1 Thu 15:30 Poster A

Topology of active nematics and dimensionality — •Joscha Tabet and Marco G. Mazza — Max-Planck-Institut für Dynamik und Selbstorganisation, Göttingen, Germany

The complex interplay of topology, viscous dissipation, and active motion leads to stunning nonequilibrium behavior in active nematic fluids. We study the effect dimensionality has on these dynamics. Thus far, the research in this area has mostly been limited to different 2D-topologies. By employing a novel model for nematodynamics based on the stochastic rotation dynamics framework we extend this point of view to quasi-2D and full 3D simulations. Our bottom-up approach reproduces the hydrodynamic equations in a computationally efficient way while maintaining statistical fluctuations. We analyze the topology of active nematics and its coupling with the fluid motion. This method opens up new ways to understanding the dynamics of actin filaments in the cell and the cytoskeleton.

DY 67.2 Thu 15:30 Poster A

Active systems learning at the microscale — •Santiago Muiños-Landin[1], Keyan Ghazi-Zahedi[2], and Frank Cichos[1] — [1]Molecular Nanophotonics. University of Leipzig. Institut for Experimental Physics I — [2]Information Theory of Cognitive Systems, Max Planck Institute for Mathematics in the Sciences

Information exchange makes a collectivity stronger. Different species use interactions between members of a group in order to share information optimizing the solution of problems. These interactions usually rely on sensing mechanisms that individuals also use in order to improve their own knowledge in a feedback loop. Such improvements let them evolve in their behavior through decision making or a learning process. Here we propose a microswimmer collective behavior mechanism based on our previous work, where information exchange is possible through the definition of artificial interactions and behavior evolution is reached via reinforcement learning. We combine these two ideas with swarm algorithms to show how intelligent active behavior is possible in a well defined collective of artificial microswimmers.

DY 67.3 Thu 15:30 Poster A

Probability fluxes for self-propelled particles in strong confinement — •Jan Cammann, Fabian Jan Schwarzendahl, Tanya Ostapenko, Oliver Bäumchen, and Marco G. Mazza — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Active Brownian particles, such as bacteria and motile algae frequently encounter boundaries in their natural habitats. Experimental observations suggest that a wide range of microswimmers seem to spend a significant amount of time close to such boundaries as opposed to staying in the bulk. Experiments on individual cells of the model organism Chlamydomonas reinhardtii in strong confinement show that the probability to find the algae near a boundary is increased with curvature. Additionally local gradients in boundary curvature result in probability fluxes not only bound to the wall, but forming loops that can reach into the bulk and have significant influence on the global behaviour. By describing the particles shape as an asymmetric dumbbell with steric wall interactions, we show that confined active Brownian particle simulations can reproduce the experimental results. This minimal model is capable of reproducing the probability distribution in positional space, as well as the fluxes in probability found in experiments with very good agreement.

DY 67.4 Thu 15:30 Poster A

Dynamics of a nematic microswimmer in aqueous surfactant solution — •Shubhadeep Mandal and Marco G. Mazza — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

The study of self-propelled motion of microswimmers in fluidic environments is of paramount importance to understand modern day applications, such as targeted drug delivery and lab-on-a-chip technologies. In this study, we investigate the dynamics of an artificial microswimmer consisting of nematic liquid-crystal droplet in a surfactant solution. Recent experiments have shown that a nematic droplet suspended in an aqueous surfactant solution not only self-propels, but also exhibits curling or helical motion depending on the physical dimensionality. We perform numerical simulations using stochastic rotational dynamics (SRD) to study the interaction between the nematic swimmer and the surfactant solution. An outstanding question regarding the dynamics of self-propel motion of nematic microswimmers that we address here is the coupling of Marangoni flow and nematic director field. Our first goal is to understand the importance of miceller and molecular solubilization towards the genesis of the self-propelled motion of nematic swimmers. The second objective of the present study is to investigate the symmetry breaking phenomenon towards the curling or helical motion of nematic swimmers.

DY 67.5 Thu 15:30 Poster A

Collective Dynamics of Squirmers in Poiseuille Flow — •Shahajhan Sorathiya and Holger Stark — Institut für Theoretische Physik, TU Berlin, Hardenbergstr. 36, 10623 Berlin, Germany.

Bacteria in microfluidic Poiseuille flow show interesting collective dynamics such as pronounced centerline depletion [1]. We conduct a parametric study using the squirmer microswimmer model and multi-particle collision dynamics by varying squirmer volume fraction (C), the ratio of fluid flow strength (v_f) to squirmer swimming speed (v_0), and squirmer type β.

The most pronounced feature is a global axial polar order, which develops since squirmers collectively swim upstream against the flow. At $v_f/v_0 = 1$ it is highest for neutral squirmers and also increases with volume fraction C. Pushers show the least polar order while the alignment of pullers lies in between. For large flow speeds $v_f/v_0 > 1$, alignment against the flow decreases strongly for all three squirmer types due to the onset of tumbling [2]. In parallel, for $v_f/v_0 = 1$ the axial velocity profiles of pullers and neutral squirmers are directed against the fluid flow, while for $v_f/v_0 = 4$ the profiles of all squirmers are identical and directed with the fluid flow. Finally, the lateral density profiles for neutral and puller squirmers reveal enrichment in the channel center at all speed ratios and $C < 20\%$, while pusher squirmers develop increased density in the center for $v_f/v_0 > 1$.

[1] R. Rusconi, J. S. Guasto, and R. Stocker, Nature Phys. **10**, 212 (2014).
[2] A. Zöttl and H. Stark, Phys. Rev. Lett **108**, 218104 (2012).

DY 67.6 Thu 15:30 Poster A

Mode-Coupling Theory for Active Particles in Shear Flow — •Julian Reichert and Thomas Voigtmann — Deutsches Zentrum für Luft- und Raumfahrt e.V., Linder Höhe, 51147 Köln

We use the Integration through transients formalism to derive a Green-Kubo relation for non-equilibrium transport coefficients of active Brownian hard disks under shear flow, starting from a microscopic kinetic description. This approach has already proven to be successful in calculating the non-equilibrium swim velocities of active Brownian hard disks without shear and uses the Fourier transformed transient non-equilibrium density-density correlation function as an input. The transient density-density correlation function can be approximated by making use of the Mode-coupling theory (MCT) and plays an important role in the context of glass-forming-liquids. MCT has successfully been applied to passive Brownian particles under homogeneous steady shear flows and for active Brownian particles without shear. Our tak is now to combine both theories by what we hope to learn more about the interplay of the intrinsic active forces and the external flow.

References

1. Liluashvili, A., Ónody, J., and Voigtmann, Th., Mode Coupling Theory for Active Brownian Particles, Phys. Rev. E in press, arXiv:1707.07373 (2017).

2. Fuchs, M., Cates, M.E., A mode coupling theory for brownian particles in homogeneous steady shear flow, Journal of Rheology, 53 (957) (2009).

DY 67.7 Thu 15:30 Poster A

Discriminating collective motion mechanisms using correlations and information measures — •Yinong Zhao[1], Zhangang Han[2], Pawel Romanczuk[1], and Cristian Huepe[2,3,4] — [1]ITB, Humboldt-Universität zu Berlin, 10115 Berlin, Germany — [2]School of Systems Science, Beijing Normal University, Beijing 100875, China — [3]CHuepe Labs, 954 West 18th Place, Chicago, IL 60608, USA — [4]Northwestern Institute on Complex Systems and ESAM, Northwest-

ern University, Evanston, IL 60208, USA

Collective motion is an emergent phenomenon observed in a variety of living systems. Although a variety of models have been introduced that can achieve collective motion in the presence of noise, it is still unclear which, if any, of these algorithms is followed by different animal groups.

We consider different measures that use individual heading and are based on correlations and information theory. We show that these measures can discriminate among various minimal models of collective motion. The models include different types of interactions, either metric or topological and based on either relative heading angles or positions. We show that under a high-noise environment, position-based model shows better collective performance than velocity-based model.

Given their ability to discriminate between different simple models, these measures could be used to help infer the underlying mechanism that leads to collective motion in different experimental systems.

DY 67.8 Thu 15:30 Poster A

Collective Motion of Topologically Interacting Particles in Heterogeneous Media — •Parisa Rahmani[1,2], Fernando Peruani[3], and Pawel Romanczuk[2] — [1]Department of Physics, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan, Iran — [2]Department of Biology, Institute for TheoreticalBiology, Humboldt Universität zu Berlin, Germany — [3]Laboratoire J. A. Dieudonné, Université de Nice Sophia Antipolis, France

Collective motion of animals is a fascinating phenomenon occurring in bird flocks, fish schools, and other social animals. Modeling of collective motion is a tool for the understanding of the possible evolutionary benefits and costs associated to group living. An important aspect of collective motion is the impact of environmental heterogeneities. Chepizco et. al. [1] showed that in a model based on metric interaction network, there is an optimal noise which maximizes collective motion in the presence of obstacles. But, observations on animal groups revealed that the Voronoi interaction network outperforms the metric one [2]. Therefore, we study emergence and robustness of collective motion in a group of agents interacting with their topological neighbors in heterogenous media. We show that in this case there is no optimal noise. Topological interaction network is much more robust against obstacles, and even in high obstacle densities ordered phases are observed.

[1] O. Chepizhko et. al., Phys. Rev. Lett., **110** (2013), 238101(1-5)
[2] A. Strandburg-Peshkin et. al., Current Biology, **23** (2013), R709-R711

DY 67.9 Thu 15:30 Poster A

Bead-spring modelling of the triangular three-sphere swimmer — •Sebastian Ziegler[1], Jens Harting[2], Alexander Sukhov[2], and Ana-Sunčana Smith[1] — [1]PULS Group, Department of Physics and Cluster of Excellence: EAM, Friedrich-Alexander University Erlangen-Nürnberg, Nägelsbachstr. 49b, Erlangen, Germany — [2]Helmholtz Institute Erlangen-Nürnberg for Renewable Energy, Fürther Straße 248, Nürnberg, Germany

A customary approach to model mechanical micropropulsion is to impose the swimming stroke. However, with this approach, the hydrodynamic features of the motion are in essence smoothed over and the problem becomes a purely geometrical one. The alternative approach, yet significantly more demanding, is to specify not the swimming stroke itself but the forces which drive the swimming motion. The swimming stroke then emerges in response to the various forces acting in the system. We use this latter approach to study the behaviour of a triangular-shaped bead-spring microswimmer under the influence of external magnetic field under the condition of no net external force and torque. This swimmer evolves in a versatile manner in dependence of its own geometry and its parameters (viscosity of the fluid, spring constant, shape) and exhibits a resonant behaviour for varying driving frequency.

DY 67.10 Thu 15:30 Poster A

Modeling the interaction of magnetically capped colloidal particles — •Anna Eichler-Volf[1], Sibylle Gemming[1,2], Aaron Tobias Strobel[2], Maximilian Neumann[2], Gabi Steinbach[1,2], and Artur Erbe[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Institute of Physics, Technische Universitaet Chemnitz, Chemnitz, Germany

Colloidal self-assembly bears significant potential for the bottom-up fabrication of advanced materials and micromechanical structures. For analyzing correlations between the anisotropy at the particle level and the shape of the assembly, simplified theoretical models have been developed to simulate the self-assembly and resulting structures. Here, we concentrate on particles that interact via polar fields, which are intrinsically anisotropic. Additional anisotropy may be introduced by an asymmetric distribution of the polar material, e.g. in a cap. Observed self-assembled structures can be reproduced by models of dipolar spheres, where the dipole is shifted away from the particle center. The three-dimensional model proposed here represents the extended magnetization distribution by a conductive coil enclosed in a hard sphere. The radius of the coil controls the width of the magnetization distribution. The position, or shift, of the coil inside the sphere determines the magnetic asymmetry.

DY 67.11 Thu 15:30 Poster A

Elongated microswimmers: Influence of hydrodynamics — •Arne W. Zantop and Holger Stark — Institute of Theoretical Physics, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Particles that constitute active matter are often elongated in shape, as for instance bacteria or active filaments. The shape and stiffness influence both their individual and collective dynamics and pattern formation. Previous work has already revealed many insights into, for example, the spontaneous formation of dynamical structures such as vortices or active turbulence [1,2]. Though it still remains to completely identify the interactions that lead to the emergence of these fascinating phenomena and, in particular, to identify the role of long-ranged hydrodynamic interactions [2].

Here, we present an approach for simulating hydrodynamically interacting elongated microswimmers in a fluid environment using multi-particle collision dynamics. To form microswimmers rods, we rigidly bind overlapping spherical squirmers to each other. The single squirmers propel themselves with an imposed surface flow at their no-slip boundaries [3]. We present first results of our simulation study on the role of hydrodynamic interactions in phases of active matter with elongated constitutes.

[1] Dunkel *et al.*, PRL 110.22 (2013): 228102.
[2] Wensink *et al.*, PNAS 109.36 (2012): 14308-14313.
[3] Downton *et al.*, J. of Ph.: Cond. Mat. 21.20 (2009): 204101.

DY 67.12 Thu 15:30 Poster A

A path-integral approach to active matter — •Thomas Schindler, Sebastian Kapfer, and Patrick Ketzko — Friedrich-Alexander Universität, Erlangen, Deutschland

The statistical physics of active particles are a rapidly evolving field with many unsolved problems. One of them is the discrepancy of definitions of thermodynamic observables. In equilibrium systems e.g. the pressures, defined via the derivative of the free energy and defined via the force per area on the container of a gas, always yield equivalent results. This is not true for nonequilibrium systems [1]. Here we use a path integral approach where we study an ensemble of one dimensional trajectories in discrete time steps of diffusing particles with drift velocity. These particles mimic active Brownian particles, but from the ensemble we can define a partition function and hence a free energy of the system. The free energy can be written down explicitly and is amenable to numeric evaluation by Markov-chain Monte Carlo methods. The diffusion is modelled by Gaussian transition probabilities between time steps. The direction of the drift is prescribed by an Ising-like spin variable with predefined temporal correlations which models directional diffusion of the particles.

[1] A. P. Solon, Y. Fily, A. Baskaran, M. E. Cates, Y. Kafri, M. Kardar, and J. Tailleur, Nat. Phys. 11, 673 (2015)

DY 67.13 Thu 15:30 Poster A

Multicomponent Systems of Self-Propelled Particles — •Thomas Bissinger and Matthias Fuchs — Universität Konstanz, Fachbereich Physik, 78457 Konstanz

Self-propelled particles (SPPs) have been studied intensely for more than two decades now, with interests ranging from physics to biology and social sciences.

Our work is on the Vicsek model (VM) in 2D, for which we use a generalization to mixtures of particle species. We investigate motility induced phase separation (MIPS) for a binary mixture of SPPs. MIPS occurs when the absolute particle velocity decreases with increasing density, leading to slowly moving clusters with fast particles crossing between clusters.

Besides particle-based numerical simulations, we treated the system theoretically with a generalization of Ihle's phase space approach [1], which utilizes a Chapman-Enskog expansion to arrive at hydrodynamic equations for the binary VM. An alternate approach followed is based on a description by correlation functions.

[1] Ihle, Thomas. "Kinetic theory of flocking: Derivation of hydrodynamic equations." *Physical Review E* **83.3** (2011): 030901.

DY 67.14 Thu 15:30 Poster A

Micro-Swimming with Inertia in Bulk and on Interfaces — •Oleg Trosman[1], Jayant Pande[1], Alexander Sukhov[2], Maxime Hubert[3], Galien Grosjean[3], Nicolas Vandewalle[3], Jens Harting[2], and Ana Sunčana Smith[1] — [1]PULS Group, Department of Physics and Cluster of Excellence: EAM, FAU Erlangen-Nürnberg — [2]HI ERN - Helmholtz-Institut Erlangen-Nürnberg — [3]GRASP, Université de Liège, Belgium

Most theoretical research in the field of micro-swimming from the past few decades addressed the domain of negligible Reynolds number *Re*, ignoring inertia. For an intermediate range of *Re*, however, before turbulences arise, the inertial effects become important. In this work we conduct a theoretical study of how this regime emerges, extending the swimmer model by Golestanian and Najafi by inclusion of the beads' masses. After combining the Oseen-Stokes equations for the coupled motion of distant spheres in a fluid with Newton's force-mass relations we obtain a closed-form expression for the velocity of the swimmer with an explicit inertia dependence. This velocity expression compares considerably better to results obtained from lattice-Boltzmann simulations, for intermediately high bead masses or driving forces, than the inertia-free model of Golestanian and Najafi. Furthermore we perform an additional study on the Stokes law alteration for spheres being dragged along a contact surface of two different fluids using lattice-Boltzmann simulations in order to compare our model with with data obtained from an experimental realisation of the Golestanian-Najafi swimmer on fluid-air interface.

DY 67.15 Thu 15:30 Poster A

Collective motion of self-propelled rods with velocity-reversal — •Robert Grossmann[1], Fernando Peruani[1], and Markus Bär[2] — [1]Université Côte d'Azur, Nice, France — [2]Physikalisch-Technische Bundesanstalt, Berlin, Germany

We review progress in the theory of self-propelled rods. In the first part, diffusion properties of rods with velocity reversal are discussed. In particular, we show that their diffusivity is maximal for an optimal rotational noise amplitude. The relevance of this theoretical finding for microbiological systems is corroborated by an explicit comparison to experimental data. The second part addresses collective properties of active rods. At first, a microscopic justification of alignment-interactions with nematic symmetry is presented based on a realistic model for the repulsive interaction of anisotropic rod-shaped particles. Subsequently, the large-scale properties of rods are analyzed within a hydrodynamic theory that can be systematically derived from the microscopic Langevin dynamics via the corresponding mean-field Fokker-Planck equations. Combining analytical methods, numerical continuation and particle-based simulations, the phase-diagram of self-propelled rods is constructed. The rate of velocity reversals turns out to be a central control parameter for the emergent macroscopic pattern-formation. In this regard, our results constitute a proof-of-principle in favor of the hypothesis in microbiology that velocity reversals of bacteria regulates the transitions between various self-organized patterns observed during the bacterial life cycle. [Phys. Rev. E 94 050602 (2016); New. J. Phys. 18 043009 (2016)]

DY 67.16 Thu 15:30 Poster A

Pair Interactions of heat driven Janus particles — •Nicola Söker and Frank Cichos — Molecular Nanophotonics, Institut für Experimentalphysik I, Fakultät für Physik und Geowissenschaften, Universität Leipzig

Heat driven Janus particles as micro swimmers are based on self-thermophoresis, an thus the generation of interfacial flows induced by an optical heating of a hemispherically gold coated polymer particle. This non-equilibrium process adds even more complexity to a fluctuating hydrodynamic description of the motion and the interactions of such particles with the environment. In this work an ensemble of heat driven 1mu Janus particles in a thin film of water was observe to get statistics of the noise dominated pair interactions between two active Janus particles in the overdamped limit. Those interactions are split into two contributions. At first the additional heat flow from the other particle altering the overall temperature field and hence the thermos-osmotic forces exerted on the fluid at the particle boundary. And second, hydrodynamic effects, mainly the presence of a second swimmer and its constraints on the fluid flow field. The splitting is done by a comparison with another experiment where only the former contribution is present.

DY 67.17 Thu 15:30 Poster A

Modeling of amoeboid swimmer in confined channel — •Swapnil Dalal, Alexander Farutin, and Chaouqi Misbah — Laboratoire interdisciplinaire de physique (LIPHY), CNRS and Université Grenoble Alpes, F-38000 Grenoble, France

Several micro-organisms (Euglena, Eutreptiella Gymnastica), eukaryotic cells (neutrophils, leukocytes, fibroblasts and cancer cells) undergo shape deformation in order to propel themselves. This self propulsion strategy is referred as amoeboid swimming. We study amoeboid swimming by modeling swimmer as deformable body with an inextensible membrane subjected to local distribution of active forces such that total force and torque acting on swimmer vanishes. This instantaneous local distribution of active force used in this study is dependent on the instantaneous swimmer shape. The active forces applied on the swimmer should instigate its locomotion based on its non reciprocal cyclic deformation in the Stokes flow regime. The active forces in this study are described using correlation function obtained using instantaneous local deformation of swimmer and is time independent. This gives rise to autonomous amoeboid swimmer that adapts itself based on surrounding environment. We study effect of confinement on self adapting amoeboid swimmer. Due to shape dependent active forces, the stroke period of swimmer is a function of confinement and it increases with confinement strength. The swimmer velocity exhibits nonmonotonic behaviour as a function of confinement. The swimmer behaviour averaged over one swimming cycle exhibits pusher nature at lower confinement while it shows puller characteristics at higher confinement.