BP 31: Microswimmers DY II (joint session DY/CPP/BP)

Time: Thursday 10:00–13:15 Location: BH-N 243

BP 31.1 Thu 10:00 BH-N 243

Dynamical density functional theory for swarms of active microscopic circle swimmers — Christian Hoell, Hartmut Löwen, and •Andreas M. Menzel — Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

The study of self-propelled particles and active microswimmers is an intensely growing field. However, mostly straight-propelling objects are addressed. In contrast to that, typical real objects are imperfect and show persistently bent trajectories, as investigated in the present case.

Recently, we introduced a first dynamical density functional theory to describe swarms of straight swimming microswimmers suspended in a fluid [1]. The theory includes all basic ingredients, namely, self-propulsion, hydrodynamic as well as steric interactions between the swimmers, and confinement by external potentials. We have now extended this theory to statistically characterize the collective behavior of microscopic circle swimmers [2].

To illustrate the statistical consequences of circle swimming [2], we consider confinement by a spherical trap. While straight-swimming objects tend to push outward against the confining barriers and only by spontaneous symmetry breaking collectively move around the trap, circle swimmers show a deterministic tendency of rotating around the confinement. An increasing tendency of circle swimming leads to localization of the swimmer density in the center of the trap. We have investigated both pusher- and puller-type swimming mechanisms.

[1] A. M. Menzel et al., *J. Chem. Phys.* **144**, 024115 (2016).
[2] C. Hoell et al., *New J. Phys.* in press (2017).

BP 31.2 Thu 10:15 BH-N 243

Memory-induced transition to persistent rotational motion for active colloids in viscoelastic media — •Narinder Narinder[1], Clemens Bechinger[1,2], and Juan Ruben Gomez-Solano[1] — [1] *2.Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany* — [2] *Max-Planck-Institute for Intelligent Systems, Heisenbergstrasse 3, 70569 Stuttgart, Germany*

Life in nature is strongly conjoined with viscoelastic fluids, such as human blood and mucus. Thus, understanding the behavior of artificial microswimmers [1] in such fluids holds the potential for applications such as targeted drug delivery and cargo transport. Motivated by this, we study the dynamics of active colloids in a viscoelastic fluid. Investigating the fluid in the linear rheological response regime, with the increase in propulsion speed, a strong enhancement of the rotational diffusion of the particles is observed [2]. Further increase in the propulsion velocity of the particles leads to the emergence of a new behavior, in which particles describe well defined circular trajectories. Characterization of these orbits, reveals a non-linear dependence of the angular speed on the propulsion speed. We propose that these circular trajectories, absent in Newtonian fluids, originate from a persistent torque acting on the particles which stem from the strong coupling of particles directed motion to microstructural relaxation of the fluid.

[1] J. R. Gomez-Solano et al., Sci. Rep. 7, 14891 (2017).
[2] J. R. Gomez-Solano et al., Phys. Rev. Lett. 116, 138301 (2016).

BP 31.3 Thu 10:30 BH-N 243

Mesoscale turbulence in active suspensions subjected to orienting external fields — •Henning Reinken[1], Sebastian Heidenreich[2], Markus Bär[2], and Sabine H. L. Klapp[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Berlin, Germany — [2]Mathematische Modellierung und Datenanalyse, Physikalisch-Technische Bundesanstalt, Berlin, Germany

Active fluids show a variety of self-sustained non-equilibrium phenomena. An intriguing example is the emergence of a turbulent state in bacterial suspensions, denoted as mesoscale turbulence [1]. Recent publications have shown that a fourth order field theory for the collective microswimmer velocity describes the main features of mesoscale turbulence, including the emergence of a typical vortex size [2,3]. This theory couples the polar order parameter of the microswimmers to the solvent velocity and can be derived from a microscopic Langevin model including hydrodynamic and steric interactions via the Fokker-Planck equation [3,4]. In this work, we extend the theory towards the impact of orienting external fields (e.g. for magnetotactic bacteria or gravitactic algae cells). Using linear stability analysis and weakly nonlinear analysis, we investigate the influence of such external fields on the emerging structures. In addition, we verify our results via numerical solution of the equations.

[1] M. Marchetti et al., Rev. Mod. Phys. **85**, 1143 (2013).
[2] J. Dunkel et al., New J. Phys. **15**, 045016 (2013).
[3] S. Heidenreich et al., Phys. Rev. E **94**, 020601(R) (2016).
[4] H. Reinken et al., in preparation.

BP 31.4 Thu 10:45 BH-N 243

Cluster formation of microswimmers with individually controlled motility — •Tobias Bäuerle[1], Andreas Fischer[2], Thomas Speck[2], and Clemens Bechinger[1] — [1]Universität Konstanz, Germany — [2]Johannes Gutenberg Universität Mainz, Germany

One of the most interesting aspects of microswimmers is their ability to form dynamical clusters even in the absence of long-ranged interactions. Previous experiments and simulations have demonstrated the occurrence of phase separation into large clusters and a dilute gas phase when the density and motility of the particles is sufficiently high. In contrast to previous studies, where the particle motility was kept constant in space and time, in our experiments we are able to control the motility of each single microswimmer depending on its surrounding, e.g. the local density and configuration of microswimmers. Using a light-activated system, such individual motility control is achieved by a feed-back system consisting of a rapidly scanned laser beam and a real-time particle detection algorithm. By introducing appropriate interaction-rules we demonstrate that formation of clusters can occur already at very small particle densities and that their shape and density can be modified by small variations in the interaction rules.

BP 31.5 Thu 11:00 BH-N 243

Optimal decision making for sperm chemotaxis in the presence of noise — •Justus A. Kromer[1], Steffen Märcker[2], Steffen Lange[3], Christel Baier[2], and Benjamin M. Friedrich[3] — [1]Stanford University, Stanford CA, USA — [2]TU Dresden, Dresden, Germany — [3]cfaed/TU Dresden, Dresden, Germany

Navigating agents such as biological cells rely on noisy sensory input. In cells performing chemotaxis, such noise arises from the stochastic binding of signaling molecules at low concentrations. We theoretically address the classic problem of chemotaxis towards a single target. As application example, we study chemotaxis of marine sperm towards the egg. Recent experiments revealed that these cells are able to dynamically switch between slow and fast chemotactic steering. The benefit of this decision making remains open.

We reveal an inherent coupling between the speed of chemotactic steering and the strength of directional fluctuations that result from the amplification of noise in the chemical input signal. This implies a trade-off between slow, but reliable, and fast, but less reliable steering. By formulating optimal navigation in the presence of noise as a Markov decision process, we show that dynamic switching between slow and fast steering substantially increases the probability to find the egg. This decision making is most beneficial, if chemical signals are above detection threshold, yet signal-to-noise ratios of gradient measurements are low. This situation generically arises at intermediate distances from the egg, thus defining a 'noise zone' that cells have to cross.

15 min. break

BP 31.6 Thu 11:30 BH-N 243

Crowd localisation and cohesion of micro-swimmers with perception-dependent motility — •Francois Lavergne, Hugo Wendehenne, and Clemens Bechinger — Department of Physics, University of Konstanz, 78464 Konstanz, Germany

The origin of crowd formation and cohesion in natural contexts remains an important question of collective dynamics, especially in the absence of taxis, communication, confinement, or attractive forces between the individuals. In this work, we show that the mere variation of the motility depending on the perception of other individuals is enough to induce such behaviour. We introduce a long-range indicator of crowd perception that only assumes the ability of an individual to count others within its vision cone. When this quantity exceeds a certain threshold for a given individual, its velocity is increased. This simple rule is applied in an experiment involving photo-responsive colloidal micro-swimmers, whose velocities can be individually varied by live-tuning the intensity of laser spots directed onto them. We observe that initially very dilute ensembles of these micro-swimmers localise into isolated groups, with virtually empty surroundings in unbound space, in sharp contrast with the long-time diffusive behaviour expected in the case of a constant motility. These groups remain cohesive, despite the activity of individuals within them and the absence of alignment, due to a kinetic stabilisation mechanism stemming from the modulation of the motility upon the non-reciprocal perception.

BP 31.7 Thu 11:45 BH-N 243

Maximum in density heterogeneities of active swimmers — •Fabian Jan Schwarzendahl and Marco G. Mazza — Max-Planck-Institute for Dynamics and Self-Organization, Göttingen, Germany

Suspensions of unicellular microswimmers such as flagellated bacteria or motile algae exhibit spontaneous density heterogeneities at large enough concentrations. Based on the relative location of the biological actuation appendages (i.e. flagella or cilia) microswimmers' propulsion mechanism can be classified into two categories: (i) pushers, like E. coli bacteria or spermatozoa, that generate thrust in their rear, push fluid away from them and propel themselves forward; (ii) pullers, like the microalgae Chlamydomonas reinhardtii, that have two flagella attached to their front, pull the fluid in and thereby generate thrust in their front. We introduce a novel model for biological microswimmers that creates the flow field of the corresponding microswimmers, and takes into account the shape anisotropy of the swimmer's body and stroke-averaged flagella. We characterize the nonequilibrium phase diagram, as the filling fraction and Péclet number are varied, and find density heterogeneities in the distribution of both pullers and pushers, due to hydrodynamic instabilities. We find a maximum degree of clustering at intermediate filling fractions and at large Péclet numbers resulting from a competition of hydrodynamic and steric interactions between the swimmers. We develop an analytical theory that supports these results. This maximum might represent an optimum for the microorganisms' colonization of their environment.

BP 31.8 Thu 12:00 BH-N 243

Chemotactic interactions in systems of active and passive colloids — •Julian Stürmer[1], Dhruv Singh[2], Maximilian Seyrich[1], Peer Fischer[2], and Holger Stark[1] — [1]Institut für Theoretische Physik, TU Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]MPI-IS, Heisenbergstr. 3, 70569 Stuttgart, Germany

Self-propelled particles exhibit a variety of self-assembled dynamic structures. In particular, mixtures of active and passive colloids crystallize into 2D clusters as a result of chemotactic interactions [1]. The active colloids represent Janus particles that move while creating sinks in a chemical concentration field. The passive colloids react to the corresponding chemical gradients in form of a diffusiophoretic drift velocity towards the active particles. We model the mixtures using Langevin equations and a diffusion equation for the chemical field extending our approach in [2]. With increasing interaction strength, we observe a gaslike state, an oscillatory and finally a collapsed state. We study the clustering dynamics by quantifying the cluster growth and measuring the cluster velocity as a function of cluster size.

In a similar approach, we model a system of solely active colloids that interact via translational and rotational diffusiophoresis. Here, we take into account the asymmetric character of the Janus particles by including dipole contributions in the chemical concentration field. This asymmetry gives rise to interesting collective phenomena, e.g. the formation of chains that has been observed in recent experiments.

[1] D. P. Singh et al., Adv. Mater. 1701328 (2017)
[2] O. Pohl et al., Phys. Rev. Lett. 112, 238303 (2014)

BP 31.9 Thu 12:15 BH-N 243

Modular microswimmers formed by ion-exchange particles — •Andreas Fischer, Ran Niu, Thomas Palberg, and Thomas Speck — Institut für Physik, Johannes-Gutenberg-Universität Mainz, Germany

Colloidal ion exchange particles generate solvent flow due to a combination of electroosmosis and electrophoresis, which induces long-range attractive interactions between the colloidal particles [1]. These interactions lead to the formation of colloidal "molecules" of varying size and structure. By breaking reciprocality, these molecules can be made active. Depending on their composition, we observe passively diffusing, linearly and circularly moving molecules with different propulsion velocities. We develop a model based on conservative interactions, which makes quantitative predictions about the swimmers' motion that we compare to the experimental results.

BP 31.10 Thu 12:30 BH-N 243

The droplet divisome — Kyle A. Baldwin, Babak Vajdi Hokmabad, and •Corinna C. Maass — MPI für Dynamik und Selbstorganisation Göttingen

Active emulsions of nematic liquid crystals in micellar surfactant solutions are a flexible and well controlled model system for microswimmers, exhibiting a wealth of features like helical swimming, convection driven clustering, chemotaxis and autochemotaxis. Their propulsion is driven by Marangoni stresses caused by self-supporting instabilities in the interfacial surfactant coverage. Generally, such surface tension variations should deform the droplet interface, but we have not seen measurable deviations from a spherical shape for $50\mu m$ droplets in Hele-Shaw cells due to strong capillary forces. However, in experiments using squeezed droplets, i.e. larger, more disk-shaped objects in strong two-dimensional confinement, capillary forces are weakened due to an effective switch from areal to line tension and a decrease of the deformable interface to volume ratio. We have observed multipolar Marangoni instabilities, visible deformation during self propulsion and a spontaneous self division cascade for arrested droplets.

BP 31.11 Thu 12:45 BH-N 243

Dynamical arrest in active emulsions — •Babak Vajdi Hokmabad and Corinna C. Maass — MPI für Dynamik und Selbstorganisation Göttingen

Liquid crystal (LC) droplets self-propel in an aqueous surfactant solution due to Marangoni flow at the droplet's interface. This propulsion is sustained by micellar solubilization of the LC phase. The solubilization leads to a secretion of filled surfactant micelles in the trail of the swimming droplet. This causes depletion of empty micelles in the trail and thereby trail avoidance. We have directly imaged the secretion and spreading of the filled micelles by adding fluorescent dye to the LC phase. The decay of the extracted Gaussian profiles in time is consistent with the theoretical diffusive spreading. Using this technique, we are able to visualize the chemotactic interaction of a swimmer with a trail. To study the collective dynamics of this autochemotaxis-dominated system we track individual swimmers in dense droplet ensembles in 2D and 3D. Results show that in a crowded system, a potential landscape is formed with local minima between the trails. We report on dynamical arrest of the swimmers in transient cages formed inside these local minima.

BP 31.12 Thu 13:00 BH-N 243

Active Double Emulsions — •Kyle A. Baldwin, Babak Vajdi Hokmabad, and Corinna C. Maass — MPI für Dynamik und Selbstorganisation, Göttingen

Active emulsions – solutions containing self-propelling microscopic droplets – display a rich variety of solo and collective swimming behaviours, from self-avoiding helices to collective raft formation, which are strongly influenced by factors such as wall proximity, autochemotaxis, and liquid crystal (LC) structure. Here, we report on the formation and swimming behaviour of active water-oil-water (WOW) double-emulsions; swimming LC oil droplets which carry a secondary inner water droplet. We observe new periodically oscillating swimming modes, and find that shell stability is strongly influenced by nematicity, which inhibits coalescence of the aqueous phases. The utility of these double emulsion swimmers as cargo carriers, and the ability to release this cargo on-demand, makes this system an ideal mechanism for chemical delivery to localised, switchable reaction sites, with prospects for drug delivery.