BP 41: Active Matter I (Joint Session DY/BP/CPP)

Time: Wednesday 15:00–19:00 Location: HÜL 186

BP 41.1 Wed 15:00 HÜL 186

Flocking ferromagnetic particles — •Andreas Kaiser, Alexey Snezhko, and Igor S. Aranson — Materials Science Division, Argonne National Laboratory, 9700 South Cass Ave, Argonne, Illinois 60439, USA

Suspensions of microswimmers, show fascinating collective behaviours like clustering, flocking and turbulence [1]. Here, we demonstrate the discovery of ferromagnetic flocking colloids. The self-propulsion is an outcome of the spontaneous rotation of a ferromagnetic colloidal sphere in a vertical alternating (AC) magnetic field [2]. Depending on the frequency of this magnetic field, a sequence of transitions can be observed: from gas-like motion of individual particles to the onset of flocking and global rotation followed by a reentrant flocking and gas-like state for increasing frequency [3]. We also emphasize a subtle role of rotational noise: While the low-frequency flocking appears to be noise-insensitive, the reentrant flocking happens to be noise-activated. Moreover, we uncover a new relation between collective motion and synchronisation.

[1] T. Vicsek, A. Zafeiris, Physics Reports 517, 71 (2012)

[2] G. Kokot, D. Piet, G.M. Whitesides, I.S. Aranson, A. Snezkho, Scientific Reports 5, 9528 (2015)

[3] A. Kaiser, A. Snezkho, I.S. Aranson, Science Advances (submitted)

BP 41.2 Wed 15:15 HÜL 186

Unexpected enhancement of rotational dynamics of self-propelled particles in a colloidal glass — •CELIA LOZANO[1,2], JUAN RUBEN GOMEZ-SOLANO[1], and CLEMENS BECHINGER[1,2] — [1]2. Physikalisches Institut, Universitaet Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Max-Planck-Institute for Intelligent Systems, Heisenbergstrasse 3, 70569 Stuttgart, Germany

It has been recently demonstrated that the glass transition of dense colloidal suspensions is progressively shifted by increasing activity of embedded self-propelled particles (SPP) [1]. However, it is not clear yet how the dynamics of such SPP becomes affected by the surrounding glassy environment. We experimentally investigate the active motion of spherical Janus particles within a cage created by a binary mixture of colloidal particles. We observe a dramatic enhancement of the rotational diffusion of active particles with increasing particle velocity and the density, in a similar fashion as SPP in semi-dilute polymer solutions [2]. This experimental approach allows us to measure, in parallel, the temporal evolution of the active particle and the passive colloidal suspension. Our findings suggest that these effects originate from the coupling between the thermal fluctuations of the particle and the surrounding heterogeneities, which displays large relaxation times of several seconds.

[1] Ni, R., Stuart, M. A. C. & Dijkstra, M. Nature communications 4, 2704 (2013). [2] Gomez-Solano, J. R., Blokhuis, A. & Bechinger, C. Phys. Rev. Lett. 116, 138301 (2016).

BP 41.3 Wed 15:30 HÜL 186

Motility-Induced Phase-Separation of Microswimmers: Hydrodynamics and Phase-Equilibria — •Johannes Blaschke and Holger Stark — Institut für Theoretische Physik, Technische Universität Berlin, Hardenberg Str. 36, 10623 Berlin, Germany

Active motion of microorganisms and artificial microswimmers is relevant both to real world applications as well as for posing fundamental questions in non-equilibrium statistical physics. Microswimmers are often modelled as active Brownian particles, neglecting hydrodynamic interactions between them. However, real microswimmers, such as ciliated microorganisms, catalytic Janus particles, or active emulsion droplets, employ propulsion mechanisms reliant on hydrodynamics. Therefore, we use multi-particle collision dynamics to explore the influence of hydrodynamics on the collective behavior of spherical microswimmers in quasi-two-dimensional geometry [1].

A striking feature of the collective motion of microswimmers is that for sufficiently strong self-propulsion they phase-separate into dense clusters coexisting with a low-density gas phase. Here we examine the influence of hydrodynamic interactions on this motility-induced phase separation. The most striking difference with the phase diagram of active Brownian particles is that a larger mean density results in a lower density of the coexisting dilute phase, which is a clear signature of hydrodynamics. Furthermore, we find that pushers or pullers suppress phase separation by increasing the critical Péclet number.

[1] J. Blaschke, M. Maurer, K. Menon, A. Zöttl, and H. Stark, *Soft Matter* (2016), DOI:10.1039/C6SM02042A.

BP 41.4 Wed 15:45 HÜL 186

Synthetic Janus microswimmers moving under confinement in viscoelastic media — •Juan Ruben Gomez Solano[1], Mahsa Sahebdivani[1], and Clemens Bechinger[1,2] — [1]2. Physikalisches Institut, Universitaet Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Max-Planck-Institut fuer Intelligente Systeme, Heisenbergstrasse 3, 70569 Stuttgart, Germany

The motion of many natural microswimmers, e.g. bacteria and spermatozoa, commonly takes place in viscoelastic media and under confinement close to solid walls. Recent experiments demonstrate that active colloids in Newtonian liquids can be hydrodynamically and phoretically trapped or guided by solid walls depending on the surrounding flow field and on the geometry of the confinement [1-3]. In our work, using spherical Janus microswimmers activated by light in a semidilute polymer solution [4], we experimentally investigate how viscoelasticity affects the motion of such self-propelled particles when approaching or leaving a flat wall. Unlike self-propulsion in Newtonian fluids, we find a strong particle-wall repulsion induced by the surrounding viscoelastic liquid over large distances from the wall. We show that this phenomenon has dramatic consequences for the particle translational and rotational dynamics in more complex confined geometries, as well as for collective motion in crowded environments.

[1] G. Volpe et al., Soft Matter 7, 8810 (2011). [2] D. Takagi et al., Soft Matter 10, 1784 (2014). [3] J. Simmchen, Nat. Comm. 7, 10598 (2016). [4] J. R. Gomez-Solano, A. Blokhuis, and C. Bechinger, Phys. Rev. Lett. 116, 138301 (2016).

BP 41.5 Wed 16:00 HÜL 186

Dynamics of microswimmer molecules — Sonja Babel, Niklas Küchler, Hartmut Löwen, and •Andreas M. Menzel — Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany

In recent years, the dynamical properties of individual microswimmers have been investigated intensively. The same applies for their collective dynamical behavior in dilute and dense suspensions. Here we address an intermediate level. We study the dynamics of compound objects of coupled swimmers that we term "microswimmer molecules" [1,2].

First, we address three spherical magnetic microswimmers connected by elastic springs to a straight object [1]. The magnetic interactions support the straight arrangement. However, with increasing active drive, hydrodynamic interactions destabilize the straight shape. Technically, this occurs via a subcritical Hopf bifurcation. The oscillatory feature of this bifurcation is connected to a cork-screw-like motion of the molecule.

Second, we consider an active microswimmer coupled by elastic springs to one or more passive swimmers [2]. The dynamics of this type of molecule in an external planar swirl flow is investigated, while hydrodynamic interactions are neglected to lowest order. Because of the finite extension and deformability of these molecules, interesting dynamical features arise. They comprise an expulsion from or undertow into the swirl, rotations of the deformed trajectories, and changes in the sense of the trajectory rotations.

[1] Babel et al., *EPL (Europhys. Lett.)* **113**, 58003 (2016).

[2] Küchler et al., *Phys. Rev. E* **93**, 022610 (2016).

BP 41.6 Wed 16:15 HÜL 186

Microscopic derivation of the hydrodynamics of active-Brownian-particle suspensions — Stefano Steffenoni[1], •Gianmaria Falasco[2], and Klaus Kroy[2] — [1]Max planck for the mathematics in the science, leipzig — [2]Institute for theoretical physics, leipzig

We derive the hydrodynamic equations of motion for a fluid of active particles described by under- damped Langevin equations that reduce to the Active-Brownian-Particle model, in the overdamped limit. The contraction into the hydrodynamic description is performed by locally averaging the particle dynamics with the non-equilibrium many-particle probability density, whose formal expres- sion is found in the physically relevant limit of high-friction through a multiple-time-scale analysis. This approach permits to identify the conditions under which self-propulsion can be subsumed into the fluid stress tensor and thus to define systematically and unambiguously the local pressure and surface tension of the active fluid.

15 min. break

BP 41.7 Wed 16:45 HÜL 186

Determination of the phase behavior and the critical point in systems of active particles in depletants — •Jonathan Tammo Siebert[1], Benjamin Trefz[1,2], Thomas Speck[1], Kurt Binder[1], and Peter Virnau[1] — [1]Department of Physics, Johannes Gutenberg University of Mainz, D-55128 Mainz, Germany — [2]Graduate School Materials Science in Mainz, D-55128 Mainz, Germany

We study a modified, active variant of the well-known Asakura-Oosawa model for colloid-polymer mixtures. Activity is introduced as Vicsek-like self-propulsion. This system already undergoes phase separation in case of zero propulsion. In the driven case, the binodal lines are shifted towards lower densities.

Building on earlier results for the binodal line, we completed the phase diagram by determination of the critical point, using a subsystem-block-density distribution analysis. In addition to understanding critical phenomena in this specific system far from equilibrium, the proposed method can serve as a recipe to find critical points and the associated exponents for other types of active particles.

BP 41.8 Wed 17:00 HÜL 186

Clustering of nematic active particles in low Reynolds number Navier-Stokes flow — •Rebekka Breier, Cristian C. Lalescu, Devin Waas, Michael Wilczek, and Marco G. Mazza — Max-Planck-Institut für Dynamik und Selbstorganisation, Göttingen

Large groups of self-propelled particles are ubiquitous in nature, from flocks of starlings and herds of wildebeests down to schools of fish and groups of bacteria or algae. Many of these creatures exist in (possibly mildly) turbulent habitats, like motile plankton in the pycnocline of the ocean. We study large systems of self-propelled, nematically aligning, hard core particles by means of molecular dynamic simulations which inhabit a turbulent environment. We investigate the active dynamics and compare the results from kinematic simulations ("synthetic turbulence") with direct numerical simulations of the turbulent background field. We find a "sweet spot" for clustering, that is, an optimal strength of turbulence leads to very dense small-scale clusters. We explain the mechanism that induces clustering. Moreover, we investigate the effect of hard cores compared to point particles, and also give the appropriate dimensionless numbers to describe the dynamic transitions.

BP 41.9 Wed 17:15 HÜL 186

Reinforcement learning of artificial microswimmers — •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

Reinforcement Learning (RL) is a special area of the Machine Learning discipline which consist in the search of an optimal policy in the context of Markovian Decision Processes (MDP). Learning is based on the interaction of the system with its environment and is guided by sparse rewards. In RL a policy is a function that connects the available actions that an agent can execute with the states where this agent can be located at. MDPs were already proposed as a model for the navigation of natural microswimmers. Here we present now a method that uses this RL in order to achieve an autonomous explorative behavior from a self-thermophoretic microswimmer. We implement it experimentally by photon nudging to reach reinforcement learning of a symmetric microswimmer.

BP 41.10 Wed 17:30 HÜL 186

Self-propelled motion of an extra particle in a two-dimensional plasma crystal — •Ingo Laut, Christoph Räth, Sergey K. Zhdanov, Volodymyr Nosenko, Gregor E. Morfill, and Hubertus M. Thomas — Deutsches Zentrum für Luft- und Raumfahrt, Forschungsgruppe Komplexe Plasmen, 82234 Weßling, Germany

Plasma crystals consist of charged microparticles that levitate in a weakly ionized gas. In these nonequilibrium systems the particle interaction is nonreciprocal due to flowing ions. Plasma crystals were successfully used to study dynamical effects in liquids and solids at the kinetic level and have the potential to also enable the study of active particles.

Here, we analyze in simulations and theory the self-propelled motion of an "extra" particle in a two-dimensional plasma crystal. Experimental observations [1] showed that the extra particle is confined in a channel of two neighboring rows of particles and moves persistently through the crystal. We use the simple model of a pointlike ion wake charge to reproduce this intriguing effect in simulations. We show that the nonreciprocity of the particle interaction, owing to the plasma flow, is responsible for a broken symmetry of the channel that enables the self-propelled motion of the extra particle [2].

[1] C.-R. Du, V. Nosenko, S. Zhdanov, H. M. Thomas, and G. E. Morfill, Phys. Rev. E **89**, 021101(R) (2014)
[2] I. Laut, C. Räth, S. K. Zhdanov, V. Nosenko, G. E. Morfill, and H. M. Thomas, accepted for publication in Phys. Rev. Lett.

BP 41.11 Wed 17:45 HÜL 186

Dynamics of model bacteria in dense polymer suspensions and networks — •Andreas Zöttl and Julia M Yeomans — Rudolf Peierls Centre for Theoretical Physics, University of Oxford, UK

Swimming bacteria, such as Helicobacter pylori, Pseudomonas aeruginosa and sperm cells, move through viscoelastic fluids, such as mucus, in vivo. Theoretical models for these complex fluids are typically based on continuum equations which assume a constant density of sufficiently small polymers, homogeneously embedded in a Newtonian fluid. However, real viscoelastic fluids are more structured when considered on the length scale of a microswimmer: they can consist of heterogeneously distributed, up to micrometer long, macromolecules such as mucin polymers.

Here we present results of coarse-grained hydrodynamic simulations of a flagellated bacterium swimming in explicitly modeled macromolecular polymer solutions and cross-linked networks. We find a remarkable increase in the bacterium's swimming speed at high polymer density. We further discuss the effect of polymer properties such as length, stiffness and cross-linking. We also report the flow fields and the local polymer properties in the vicinity of the bacterium, which can be strongly influenced by its motion.

BP 41.12 Wed 18:00 HÜL 186

Rheology and shear-induced dynamics of passive and active anisotropic colloids — •Henning Reinken and Sabine H. L. Klapp — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

We investigate the rheology of passive and active fluids focusing on shear-induced instabilites and emerging spatiotemporal structures. Prominent examples of active matter, which is composed of self-driven units converting energy into motion on the microscopic scale, are anisotropic colloidal particles with polar or nematic interactions. Already in the passive case, these systems show very interesting rheological properties including oscillatory orientational states and shear banding [1]. Introducing activity into the system modifies the rheology and leads to additional instabilities [2].

We study the rheological properties via the Doi-Hess theory [1], a continuum theoretical approach. In this framework, the orientational order parameter is coupled to the flow via the stress tensor, which can be extended to include an active stress [2]. In particular, we focus on parameter regimes where interesting spatiotemporal structures like banded states or active turbulence [3] emerge and discuss the differences between active and passive systems.

[1] R. Lugo-Frías, H. Reinken, S. H. L. Klapp, Eur. Phys. J. E **39**: 88 (2016).
[2] M. C. Marchetti et al. Rev. Mod. Phys. **85**, 1143 (2013).
[3] S. Heidenreich, J. Dunkel, S. H. L. Klapp, M. Bär, Phys. Rev. E **94**, 020601(R) (2016).

BP 41.13 Wed 18:15 HÜL 186

Effective interactions of active particles: interfacial phase behavior and swim pressure — •René Wittmann, Abhinav Sharma, and Joseph Brader — Departement für Physik, Universität Fribourg, 1700 Fribourg, Schweiz

We employ classical density functional theory to study the self-organization in active systems. Using a first-principles approach, we map the self-propulsion onto an effective pair interaction potential, which has been shown [1] to account for the motility-induced phase separation (MIPS) observed for active Brownian particles. We further introduce an effective external potential and investigate inhomogeneous situations.

Solely as a result of their activity, we predict [2] that active (Brownian) particles undergo a variety of interfacial phase transitions, e.g., wetting and capillary condensation in purely repulsive systems or drying and capillary evaporation of attractive colloids. We explain why the effective thermodynamic pressure and interfacial tension do not coincide with the mechanical results, which we recover by embedding the presented effective-potential approach within a more general (dynamical) framework. Finally, we comment on situations with a non-vanishing particle current [3].

[1] T. F. F. Farage, P. Krinninger and J. M. Brader, Phys. Rev. E **91**, 042310 (2015).
[2] R. Wittmann and J. M. Brader, Europhys. Lett. **114**, 68004 (2016).
[3] A. Sharma, R. Wittmann, J. M. Brader, arXiv:1611.03897 (2016).

BP 41.14 Wed 18:30 HÜL 186

Patterns in chemically interacting microswimmers: Do they really exist? — •Benno Liebchen[1], Davide Marenduzzo[1], and Michael E. Cates[2] — [1]SUPA, School of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3FD, United Kingdom — [2]DAMTP, Centre for Mathematical Sciences, University of Cambridge, Cambridge CB3 0WA, United Kingdom

Chemotaxis is the directed motion of particles in response to a gradient in a chemical signal. It allows micro-organisms, like bacteria, to find food and to escape from toxins. Some micro-organisms can produce the species to which they respond themselves and use chemotaxis for signalling. Remarkably, artificial Janus colloids that swim by catalysing reactions in a bath naturally feature chemical interactions and thereby provide a synthetic analogue to signalling micro-organisms. While, it is well known that cases where these interactions are attractive lead to clustering and phase separation, we have recently demonstrated that the purely repulsive case does not simply stabilize the uniform phase but creates a versatile new route to pattern formation in active systems.

In this talk, I will briefly review our work on chemorepulsive pattern formation and will focus the question on how generic and realistic these patterns are for Janus colloids. Our work unveils a fundamental link between autophoresis and chemotaxis leading to a massive collapse of parameter space and generic instability criteria which we confirm using particle based simulations.

BP 41.15 Wed 18:45 HÜL 186

Kinetic theory of self-propelled particles: von Mises distribution and Chapman-Enskog expansion — •Rüdiger Kürsten and Thomas Ihle — Institut für Physik, Ernst-Moritz-Arndt Universität Greifswald

We consider Vicsek-type models [1] with multi-particle interactions and discrete time dynamics. Starting from the exact evolution equation for the N-particle probability distribution, an Enskog-like kinetic equation is derived. Recently, the von Mises distribution and an geometric series ansatz were proposed to treat this nonlinear integral equation [2,3]. We critically assess them for a Vicsek-model with bounded-confidence interactions. Both approaches recover the qualitative behavior of the system but the von Mises distribution causes large deviations in certain parameter regions [4]. We extend the von Mises approximation by an additional term that leads to much better agreement. The geometric series ansatz for the Fourier modes of the probability density is typically very accurate but fails for very weak noise. We therefore suggest an alternative approach – a Gaussian ansatz – for the higher modes, which is robust at all noises. Furthermore, we present a non-standard Chapman-Enskog expansion with a fast time scale. This expansion is used to derive the macroscopic transport equations from the microscopic collision rules. We discuss the expressions for the transport coefficients, which become simple in the limit of infinite density.

[1] Phys. Rev. Lett. 75 (1995) 1226 [2] J. Stat. Mech. (2015) P10017
[3] Phys. Rev. E 90 (2014) 063315 [4] arXiv:1611.00624