BP 4: Active Matter DY I (joint session DY/CPP/BP)

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

BP 4.1 Mon 10:00 BH-N 243

Dynamics of sedimenting active particles — •Jérémy Vachier and Marco G. Mazza — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

The collective motion of active particles has attracted enormous interest on account of the technological applications of artificial and biological particles. Even in the simple case of a dilute suspension solely subject to gravity, active particles show interesting behavior. While theoretical studies have addressed this problem with effective theories, a full time-dependent solution of the sedimentation problem has been neglected. Here, we present an analytical solution of the Fokker–Planck equation for the stochastic process which allows us to describe the full dynamics of active particles in three dimensions under an external force. Our results are supported by numerical calculations in which weak hydrodynamics interactions are approximated. We address three cases: active particle under gravity, confinement by reflecting barriers, and the effect of the activity of the particles on their collective motion. Finally, we compare our results with experiments and find a very good agreement.

BP 4.2 Mon 10:15 BH-N 243

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

Living organisms are able to sense and process information about the environment they live in. They are also able to update this information in order to contruct solutions for real life problems such as finding food or avoiding danger. This active adaption process that in the long run drives the evolution of species is the result of a short time scale evolution of the knowledge of an organism that we know as learning. At the microscale the learning is hampered by stochasticity given that the intrinsic Brownian noise makes critical to build a feedback between stimulus and action. Here, we present a system based on a self-themophoretic microswimmer that allows the application of artifical intelligence algorithms at the microscale. Using reinforcement learning we show that even under noise conditions a system is able to learn how to optimize a simple navigation task. We study the influence of noise and the situation where multiple agents can share information to carry out specific tasks. This way we show how adaptation and intelligent collective behavior can be studied in artificial microswimmers systems.

BP 4.3 Mon 10:30 BH-N 243

Collective rotations of active particles interacting with obstacles — •Zahra Mokhtari[1], Timo Aspelmeier[2], and Annette Zippelius[1] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, Germany — [2]Institut für Mathematische Stochastik, Georg-August-Universität Göttingen, Germany

We study the motion of active particles in the presence of static obstacles. We observe accumulation and crystallization of active particles around the obstacles which serve as nucleation sites, a phenomenon that is expected due to the known absorption of active particles at solid boundaries. In the limit of high activity, the crystals start to rotate spontaneously around the obstacle, resembling a rotating rigid body. We explain the occurrence of such rotations through the enhanced attraction of particles to the cluster whose orientation points along its rotational velocity as compared to those whose orientation points in the opposite direction.

BP 4.4 Mon 10:45 BH-N 243

Collective dynamics of squirmers confined to a surface by strong gravity — •Jan-Timm Kuhr, Felix Rühle, Johannes Blaschke, and Holger Stark — Institut für Theoretische Physik, Technische Universität Berlin, Hardenberg Str. 36, 10623 Berlin, Germany

External fields acting on microswimmers are of paramount importance for collective phenomena like bioconvection. In previous work we explored the individual [1] and collective [2] dynamics of squirmer model swimmers under moderate gravity by MPCD simulations. Here, we turn to strong gravity, where microswimmers form a single layer at the bottom surface, while interacting hydrodynamically in 3D.

We find various intriguing phenomena depending on the swimmer type (neutral, pusher, and puller) and area density: Formation of pairs, chains and other metastable bound states, but also collective swarming parallel to the surface.

Neutral squirmers at low area densities repel each other by their self-generated flow fields and thereby arrange in strongly disturbed hexagonal lattices reminiscent of 2D crystals subject to intense fluctuations. For higher densities attractive interactions become important and give rise to pair and chain formation. We characterize these distinct emergent states, compare to melting of 2D colloids, and explore the flow fields, which create hexagonal lattices.

[1] F. Rühle *et al.*, accepted at New J. Phys.
[2] J.-T. Kuhr, J. Blaschke, F. Rühle, and H. Stark, Soft Matter **13**, 7548 (2017).

BP 4.5 Mon 11:00 BH-N 243

Learning agents as a model for collective motion — •Katja Ried[1], Thomas Müller[2], and Hans J. Briegel[1,2] — [1]Institut für Theoretische Physik, Universität Innsbruck, Technikerstraße 21a, 6020 Innsbruck, Austria — [2]Department of Philosophy, University of Konstanz, 78457 Konstanz, Germany

Watching a swarm of fish, birds or insects is mesmerizing, and it inevitably makes one wonder how countless independent individuals can form such a perfectly coordinated whole. A number of theoretical models attempt to answer this question by studying the collective dynamics that arise when individuals interact according to certain rules. However, these rules are often simply postulated ad hoc, and individuals are modelled as featureless points carrying them out. Naturally, such models are unlikely to provide an accurate - or even plausible - account of the individual-level behaviour that ultimately drives the swarm.

I will present a different Ansatz to this problem, wherein individuals are considered as full-fledged agents: distinct entities that can perceive certain (reasonable) features of their surroundings, endowed with a stable internal mechanism for processing these perceptions and deciding how to respond, and capable of modifying these responses as a function of their personal experience. I will illustrate this Ansatz with the example of locusts marching in a one-dimensional arena and discuss what insights agent-based models can offer to the study of collective motion.

15 min. break

BP 4.6 Mon 11:30 BH-N 243

Localized States in an Active Phase-Field-Crystal Model — •Lukas Ophaus, Johannes Kirchner, Svetlana Gurevich, and Uwe Thiele — Institut für Theoretische Physik, WWU, Münster, Germany

The Phase-Field-Crystal (PFC) model provides a simple microscopic description of the thermodynamic transition from a fluid to a crystalline state [1]. The model can be combined with the Toner-Tu theory for self-propelled particles to obtain a model for crystallization (swarm formation) in active systems [2]. Within the resulting active PFC model, resting and traveling crystals can be identified. In the linear regime, we give analytical expressions for the transitions from the liquid state to both types of crystals. In addition, we provide a general semi-analytical criterion for the onset of motion in the nonlinear regime, that corresponds to a drift-pitchfork bifurcation. Like the passive PFC model [3], the active version describes a variety of localized states (LS) besides spatially extended crystals. In the spatially one-dimensional case we explore how the bifurcation structure (slanted homoclinic snaking) is amended by activity. Numerical continuation is applied to follow resting and traveling LS while varying the activity and mean concentration. A fold continuation allows us to determine the area of existence of different states in a two parameter plane. Finally, we look into the scattering behavior of LS through numerical time simulation. [1] M.J. Robbins et al., PRE 85, 061408 (2012). [2] A.M. Menzel and H. Löwen, PRL 110, 055702 (2013). [3] U. Thiele et al., PRE 87, 042915 (2013)

BP 4.7 Mon 11:45 BH-N 243

Turbulence and pattern formation in a minimal model

for active fluids — •Martin James[1], Wouter Bos[2], and Michael Wilczek[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]LMFA, CNRS, Ècole Centrale de Lyon, France

Continuum theories of active fluids display a fascinating range of dynamical states, including stationary patterns and turbulent phases. While the former can be tackled with classical pattern formation theory, the spatio-temporal disorder of active turbulence calls for a statistical description. In this presentation, new results on turbulence and pattern formation in a minimal continuum model for active fluids, which has been recently proposed by Wensink et al. [PNAS 109(36):14308 (2012)], will be discussed. Adopting techniques from turbulence theory, we establish a quantitative description of correlation functions and spectra for active turbulence. We furthermore report on a novel type of turbulence-driven pattern formation far beyond linear onset: the emergence of a dynamic vortex lattice state after an extended turbulent transient, which can only be explained taking into account turbulent energy transfer across scales.

BP 4.8 Mon 12:00 BH-N 243

Emergence of phytoplankton patchiness at small scales in mild turbulence — Rebekka E. Breier, Cristian C. Lalescu, Michael Wilczek, and •Marco G. Mazza — Max Planck Institute for Dynamics and Self-Organization (MPIDS), Am Faßberg 17, 37077 Göttingen

Phytoplankton often encounter turbulence in their habitat. As most toxic phytoplankton species are motile, resolving the interplay of motility and turbulence has fundamental repercussions on our understanding of their own ecology and of the entire ecosystems they inhabit. The spatial distribution of motile phytoplankton cells exhibits patchiness at distances of decimeter to millimeter scale for numerous species with different motility strategies. The explanation of this general phenomenon remains challenging. Furthermore, hydrodynamic cell-cell interactions, which grow more relevant as the density in the patches increases, have been so far ignored. Here, we combine particle simulations and continuum theory to study the emergence of patchiness in motile microorganisms in three dimensions. By addressing the combined effect of turbulent flow conditions, and spatial correlations in the particle positions, we uncover a general mechanism: when motility allows cells to cross the fluid streamlines, the typical length scale associated to the small-scale turbulence selects a characteristic cell-cell interactions scale where strong patches form. Our results shed light on the dynamical characteristics necessary for the formation of patchiness, and complement current efforts to unravel planktonic ecological interactions.

BP 4.9 Mon 12:15 BH-N 243

Critical behavior of active Brownian particles — Jonathan Tammo Siebert, •Florian Dittrich, Friederike Schmid, Kurt Binder, Thomas Speck, and Peter Virnau — Johannes Gutenberg University Mainz, Department of Physics, 55122 Mainz

We propose an improved block-density distribution method, which allows us to determine accurately the critical point of two dimensional active Brownian particles at $\mathrm{Pe}_{\mathrm{cr}} = 40(2)$, $\phi_{\mathrm{cr}} = 0.597(3)$. Based on this estimate we study the corresponding critical exponents β, γ/ν, and ν. Our results are incompatible with the 2D-Ising universality class, thus raising the fascinating question whether there exists a non-equilibrium universality class.

BP 4.10 Mon 12:30 BH-N 243

Pattern Formation and Synchronization of Disk-Shaped Circle Swimmers — •Guo-Jun Liao and Sabine H. L. Klapp — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin

We computationally study a generic model of disk-shaped active Brownian particles using Brownian dynamics simulation. Each particle is driven both by constant propulsion force and torque. We investigate how these two distinct propulsions combine to influence the macroscopic structure of a colloidal system. In the regime of small propulsion torque, the active colloids exhibit motility-induced clustering [1]. As the propulsion torque becomes comparable to thermal energy, the clustering phenomenon is drastically suppressed. Moreover, although all particles are intrinsically assigned to rotate counterclockwise, a novel state of clockwise vortices emerges at an optimal value of propulsion torque. We introduce a gear argument to capture the underlying mechanism of such vortices. To obtain deeper insight into the interplay between active motion and particle alignment, an additional polar interaction is then incorporated into our model. With increasing strength and range of the polar interaction, synchronization behavior is observed. Our model bears some similarity with the Kuramoto model [2], in which oscillators are actively moving over time.

[1] I. Buttinoni *et al.*, Phys. Rev. Lett. **110**, 238301 (2013)
[2] Y. Kuramoto, *Chemical Oscillations, Waves, and Turbulence*, (Springer, Berlin, 1984).

BP 4.11 Mon 12:45 BH-N 243

Pair Creation in Insect Swarms — •Dan Gorbonos and Nir Gov — Weizmann Institute, Rehovot, Israel

The macroscopic emergent behavior of social animal groups is thought to arise from the local interactions between individuals. We proposed a model of acoustic interaction within insect swarms that resemble gravitational attraction. Unlike gravity, the interactions between the insects are adaptive. Sensory mechanisms in biology, from cells to humans, have the property of adaptivity, whereby the sensitivity of the signal produced by the sensor is adapted to the overall amplitude of the signal. Adaptivity reduces the sensitivity in the presence of strong background stimulus, while increasing it when the background is weak. We find that in particular adaptivity is responsible for pairwise interaction that are characterized by higher-frequency nearly harmonic oscillations conducted by two synchronized insects. By comparison, the capture of pairs under normal gravity is extremely rare. We show that such pairs are created in simulations of the "adaptive gravity" model and compare them with pairs that were found in measurements of laboratory midge swarms. In addition we show similarities in density distributions between the simulations and laboratory measurements.

BP 4.12 Mon 13:00 BH-N 243

Dynamically Generated Patterns in Dense Suspensions of Active Filaments — •Prathyusha Kokkoorakunnel Ramankutty[1], Silke Henkes[2], and Rastko Sknepnek[3] — [1]Max Planck Institute of Physics of Complex Systems, Dresden Germany — [2]University of Aberdeen, United Kingdom — [3]University of Dundee, United Kingdom

We use Langevin dynamics simulations to study dynamical behaviour of a dense planar layer of active semi-flexible filaments. Using the strength of active force and the thermal persistence length as parameters, we map a detailed phase diagram and identify several non-equilibrium phases in this system. In addition to a slowly flowing melt phase, we observe that for sufficiently high activity, collective flow accompanied by signatures of local polar and nematic order appears in the system. This state is also characterised by strong density fluctuations. Furthermore, we identify an activity- driven cross-over from this state of coherently flowing bundles of filaments to a phase with no global flow, formed by individual filaments coiled into rotating spirals. This suggests a mechanism where the system responds to activity by changing the shape of active agents, an effect with no analog in systems of active particles without internal degrees of freedom