DY 16: Active Matter 2 (joint session DY/BP/CPP)

Time: Tuesday 10:00–13:00 Location: H18

DY 16.1 Tue 10:00 H18

Density fluctuations in bacterial binary mixtures — •Silvia Espada Burriel, Victor Sourjik, and Remy Colin — Max Planck Institute for Terrestrial Microbiology, Karl-von-Frisch-strasse 10, 35043 Marburg & Center for Synthetic Microbiology (SYNMIKRO), Karl-von-Frisch-strasse 14, 35043 Marburg

In wild environments, bacteria are found as mixtures of motile and sessile species, which interact physically and chemically to give rise to complex community organization. Very little is understood of the role of physical interactions in these processes: Numerical works on dry active matter and experiments on colloidal systems have shown that the activity of the active particles may affect the spatial distribution of passive particles with which they are mixed. However, the physical behavior of binary mixtures of bacteria remains largely unexplored. In our study, we present a novel phenomenon in which non-motile bacteria form large density fluctuations when mixed with motile bacteria, distinct from the aforementioned behaviors. We systematically explored the phase diagram of the mixtures in experiments combining microfluidics, fluorescence (confocal) microscopy, quantitative image analysis and parameter tuning by genetic engineering. Our experimental results show that the emergence of these large density fluctuations of the non-motile cells in presence of motile cells is controlled by hydrodynamic interactions between the motile and non-motile cells and by the sedimentation of the non-motile cells, possibly because it breaks the systems symmetry.

DY 16.2 Tue 10:15 H18

Pulsating Active Matter — •Yiwei Zhang and Etienne Fodor — 0 Av. de la Faiencerie, 1511 Luxembourg

Active matter features the injection of energy at individual level keeping the system out of equilibrium, which leads to novel phenomenologies without any equilibrium equivalents. So far, most active matter models assign a velocity to each particle, whilst we herein consider a system of pulsating soft particles where the activity sustains particles' periodic deformation instead of spatial displacement. At sufficiently high density, we reveal the existence of wave propagation independent of any particle migration, and derive the corresponding phase diagram. We study the character of phase transitions, and investigate the underlying physical mechanisms, using both particle-based simulations and hydrodynamic analysis.

DY 16.3 Tue 10:30 H18

Long-Range Nematic Order in Two-Dimensional Active Matter — •Benoît Mahault[1] and Hugues Chaté[2,3] — [1]MPIDS, 37077 Göttingen, Germany — [2]SPEC, CEA-Saclay, 91191 Gif-sur-Yvette, France — [3]CSRC, Beijing 100193, China

Studies of active matter continue to flourish, exploring more and more complex situations in an increasingly quantitative manner. Evidence has accumulated that shows active matter exhibits properties that are impossible in thermal equilibrium or even in driven systems. In spite of all this progress, important fundamental questions remain open. Such a long-standing issue is whether true long-range nematic order can emerge in two space dimensions. In this talk, we will present theoretical and numerical results obtained from minimal models of self-propelled polar particles aligning nematically. Our study shows that the orientational order emerging from such systems is quasi-long-ranged beyond the scale associated to induced velocity reversals, which is typically extremely large and often cannot even be measured. On scales where particle motion is ballistic, nematic order appears truly long-range. A hydrodynamic theory for this de facto phase is derived, and we show that its structure and symmetries differ from conventional descriptions of both polar flocks and active nematics. Our analysis of this field theory predicts π-symmetric propagative sound modes and the scaling form of space-time fluctuations. Finally, numerical results confirm the theory and allow us to estimate all scaling exponents.

DY 16.4 Tue 10:45 H18

Collective behavior of repulsive chiral active particles with non-reciprocal couplings — •Kim L. Kreienkamp and Sabine H. L. Klapp — Technische Universität Berlin, Germany

Mixtures of chiral active particles [1] as well as non-reciprocal systems [2] show intriguing collective behavior like pattern formation and traveling waves. The combination of both – non-reciprocal couplings in mixtures of chiral active particles – promises a rich variety of collective dynamics.

Here, we investigate how non-reciprocal couplings and naturally occurring repulsive interactions due to finite particle sizes affect the collective behavior in a mixture of two species of particles. We analyze the effects due to non-reciprocity and finite size individually as well as their interplay based on a field description of the system in terms of the particle concentration and director field, measuring the overall orientation of particles at a certain position.

We derive the field equations under the mean-field assumption by coarse-graining microscopic Langevin equations for individual chiral particles, which are modeled as self-propelling circle swimmers with soft repulsive forces, comprising the finite size effects. Particles of the two species rotate with different intrinsic frequencies and align with near-by particles. Focusing on non-reciprocity, we use a non-mutual alignment between the particles.

[1] D. Levis and B. Liebchen, Phys. Rev. E 100, 012406 (2019)
[2] M. Fruchart, R. Hanai, P. B. Littlewood, and V. Vitelli, Nature 592, 363-369 (2021)

DY 16.5 Tue 11:00 H18

Memory-induced chirality in self-freezing active droplets — •Aritra K. Mukhopadhyay[1], Kai Feng[2], José Carlos Ureña Marcos[1], Ran Niu[2], Qiang Zhao[2], and Benno Liebchen[1] — [1]Technische Universität Darmstadt, 64289 Darmstadt, Germany. — [2]Huazhong University of Science and Technology, 430074 Wuhan, China.

We experimentally realize and numerically model a new type of self-propelled droplet swimmer which exhibits chiral motion due to self-induced memory effects without requiring any explicit symmetry breaking caused by specific droplet geometries or complex environments. The droplets are composed of a binary polymer mixture that solidifies over time, simultaneously emitting certain polymers into their environment. A spontaneous asymmetry of the emitted polymer concentration along the stationary droplet surface induces Marangoni flows which cause the droplet to initially self-propel ballistically. However, the emitted polymers diffuse slowly and form long-lived trails with which the droplet can self-interact in the course of time and this leads to a dynamical transition from ballistic to chiral motion. The droplets persistently exhibit chiral motion with the same handedness until at even later times a second transition occurs when the droplets confine themselves leading to self-trapping over the timescale of our experiments and simulations. Our results exemplify a new route to realizing synthetic active particles whose dynamics can be controlled via the pronounced self-induced memory effects.

15 min. break

DY 16.6 Tue 11:30 H18

Role of advective inertia in active nematic turbulence — •Colin-Marius Koch and Michael Wilczek — Theoretical Physics I, University of Bayreuth, Bayreuth

Suspensions of active agents with nematic interactions can exhibit complex dynamics such as mesoscale turbulence. Continuum descriptions for such systems are inspired by the hydrodynamic theory of liquid crystals and feature an advective nonlinearity which represents inertial effects. The typically low Reynolds number of such active flows raises the question whether and under which conditions the active stresses present in these systems can excite inertial flows. To address this question, we investigate mesoscale turbulence in a two-dimensional model for active nematic liquid crystals. In particular, we compare numerical simulations with and without nonlinear advection and frictional damping of the flow field. Studying the nondimensionalized equations of motion, we find that inertia can trigger large-scale motion even for small microscopic Reynolds numbers if the active forcing is sufficiently large and the Ericksen number is sufficiently low. Performing a spectral analysis of the energy budget, we identify an inverse energy transfer caused by inertial advection, whose impact is small in comparison to active forcing and viscous dissipation but accumulates over time. We additionally show that surface friction, mimicked by a linear friction term, dissipates the transported energy and suppresses the large-scale motion. We conclude that, without an a priori knowledge of model parameters matching experiments, including inertia and friction may be necessary for consistent modeling of active nematic turbulence.

DY 16.7 Tue 11:45 H18

Pumping in active microchannels — •Goncalo Antunes[1,2,3], Paolo Malgaretti[1,2,3], Siegfried Dietrich[2,3], and Jens Harting[1,4] — [1]Helmholtz-Institut Erlangen-Nürnberg für Erneuerbare Energien (IEK–11), Forschungszentrum Jülich, Erlangen, Germany — [2]Max–Planck–Institut für Intelligente Systeme, Stuttgart, Germany — [3]Universität Stuttgart, Stuttgart, Germany — [4]Friedrich-Alexander-Universität Erlangen-Nürnberg, Nürnberg, Germany

Much attention is currently being given to the problem of manipulating fluids at the microscale, with successful applications to fields such as 3D fabrication and biomedical research. Often micropumps are a fundamental component of these microfluidic systems. An intriguing technique to manipulate fluid flows in a channel is diffusioosmosis. Fluid flow is obtained upon imposing an inhomogeneous concentration of some solute, which generates flow in a boundary layer around the channel walls. This inhomogeneity is the result of a spatially inhomogenous production rate of solute inside the channel.

We show that a solute-producing, corrugated, active channel can act as a micropump even when it is fore-aft symmetric. This result is obtained by coupling the Stokes equation with an advection-diffusion equation for the solute concentration, which we solve analytically in the limit of thin, weakly-corrugated channels. Lattice Boltzmann simulations further support the existence of the symmetry-breaking. Our calculations are also valid for left-right asymmetric channels, and provide a tool to optimize the pumping rate of an active microchannel by tuning its shape or its solute production rate.

DY 16.8 Tue 12:00 H18

Active Refrigerators Powered by Inertia — •Lukas Hecht[1], Suvendu Mandal[1], Hartmut Löwen[2], and Benno Liebchen[1] — [1]Institut für Physik kondensierter Materie, Technische Universität Darmstadt, Hochschulstr. 8, D-64289 Darmstadt, Germany — [2]Institut für Theoretische Physik II - Soft Matter, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany

We present the operational principle for a refrigerator which uses inertial effects in active Brownian particles (ABPs) to locally reduce the (kinetic) temperature by two orders of magnitude below the environmental temperature. This principle requires two ingredients: First, we need the feature of inertial ABPs to undergo motility-induced phase separation into coexisting phases with different (kinetic) temperatures and second, a mechanism which localizes the dense phase in the targeted cooling domain is required.

Here, we exploit the peculiar but so-far unknown shape of the phase diagram of inertial ABPs to initiate motility-induced phase separation in the targeted cooling domain only. Remarkably, active refrigerators operate without requiring isolating walls separating the cooling domain from its environment. This feature opens the route towards using active refrigerators to systematically absorb and trap substances such as toxins or viruses from the environment.

DY 16.9 Tue 12:15 H18

The influence of motility on bacterial accumulation in a microporous channel — •Christoph Lohrmann[1], Miru Lee[2], and Christian Holm[1] — [1]Institute for Computational Physics, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]Institute for Theoretical Physics, Georg-August-Universität Göttingen, 37073 Göttingen, Germany

Swimming microorganisms are often encountered in confined geometries where also an external flow is present, e.g. in filters or inside the human body. To investigate the interplay between microswimmer motility and external flows, we developed a model for swimming bacteria based on point coupling to an underlying lattice Boltzmann fluid. Random reorientation events reproduce the statistics of the run-and-tumble motion of the bacterium E. coli. We present the application of the model to the study of bacterial dynamics in a channel with a single cylindrical obstacle. In accordance with experimental measurements, simulations show asymmetric accumulation behind the obstacle only when the bacteria are active and an external flow is present.

Lee, Miru *et al.*, *Soft Matter* **17**, 893-902 (2021)

DY 16.10 Tue 12:30 H18

Inertial dynamics of an active Brownian particle* — •Jonas Mayer Martins and Raphael Wittkowski — Institut für Theoretische Physik, Center for Soft Nanoscience, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

Active Brownian motion commonly assumes spherical overdamped particles. However, self-propelled particles are often neither symmetric nor overdamped yet underlie random fluctuations from their surroundings. Active Brownian motion has already been generalized to include asymmetric particles. Separately, recent findings have shown the importance of inertial effects for particles of macroscopic size or in low-friction environments. We aim to consolidate the previous findings into the general description of a self-propelled asymmetric particle with inertia. We derive the Langevin equation of such a particle as well as the corresponding Fokker-Planck equation. Furthermore, a formula is presented that allows to reconstruct the hydrodynamic resistance matrix of the particle by measuring its trajectory. Numerical solutions of the Langevin equation show that, independent of the particle's shape, the noise-free trajectory at zero temperature starts with an inertial transition phase and converges to a circular helix. We discuss this universal convergence with respect to the helical motion that many microorganisms exhibit.

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DY 16.11 Tue 12:45 H18

Stochastic motion under active driving due to inverted dry (solid) friction — •Andreas M. Menzel — Otto-von-Guericke-Universität Magdeburg, Magdeburg, Germany

It has become common to describe the motion of actively driven or self-propelled objects using a driving force of constant magnitude. We assume that this driving force always acts along the current velocity direction. Moreover, we consider objects featuring a nonpolar axis, along which driving and propagation occur [1].

In that case, spontaneous symmetry breaking decides on the heading of propagation, that is, “forward” or “backward” along the nonpolar axis. Stochastic effects may reverse the velocity and thus the direction of the driving force.

As it turns out, active driving under these circumstances corresponds to inverted dry (solid) friction of the Coulomb type. Corresponding tools of theoretical analysis can thus be adopted, mapping the velocity spectrum to the one of a quantum-mechanical harmonic oscillator subject to a repulsive delta potential. In this way, the diffusion coefficient can be calculated analytically. We evaluate velocity and displacement statistics. Outward propagating displacement maxima emerge under increased active driving. The trajectories feature pronounced cusps when velocity reversals occur.

Our results should apply, for instance, to certain types of vibrated nonpolar rods and swimming bacteria that may reverse their propagation direction.

[1] A. M. Menzel, submitted.