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

Time: Monday 9:30–13:00 Location: TOE 317

Invited Talk BP 2.1 Mon 9:30 TOE 317

Emergent properties in motile active matter — •Roland G. Winkler — Theoretical Physics of Living Matter (IBI-5/IAS-2), Forschungszentrum Jülich, Jülich

Motile active matter systems, ranging from assemblies of bacteria, self-organized bio-polymers such as the cytoskeleton of living cells, to schools of fish and flocks of birds, exhibit intriguing emerging structural and dynamical out-of-equilibrium properties, even with reminiscence to classical turbulence. Their spatiotemporal dynamics is controlled by the propulsion of the active agents in combination with various direct interactions. The latter are typically anisotropic and emerge from different sources, such as elongated agent shapes, intrinsic flexibility and constraints, microswimmer flow fields etc. By analytical theory and mesoscale simulations, we study the physical aspects of motile active matter, ranging from propulsion of bacteria and linear filaments to large-scale collective properties of active agents, and unravel its generic features. Studies on individual polymers reveal fundamental differences in their dynamical and conformational properties depending on their propulsion mechanism, which is illustrated for polymers either tangentially driven or composed of active Brownian particles. In the latter case, hydrodynamic interactions additionally affect the conformational properties, in contrasts to passive polymers. Moreover, hydrodynamic interactions determine the activity-induced phase behavior. For spherical microswimmers (squirmers), hydrodynamics suppresses motility-induced phase separation, but enhances collective turbulent-like large-scale flows.

BP 2.2 Mon 10:00 TOE 317

High-resolution mapping of odd fluctuations and oscillations in living chiral crystals — •Jinghui Liu[1,2], Lisa Lin[1], Yuchao Chen[1], Yu-Chen Chao[1], and Nikta Fakhri[1] — [1]Department of Physics, Massachusetts Institute of Technology — [2]Center for Systems Biology Dresden

It has been shown that active crystals formed by self-assembling clusters of swimming starfish embryos exhibit signatures of odd mechanics, such as self-sustained chiral waves. How are these observed chiral waves and oscillations are actuated and how their dynamics couple to the formation and dissolution of the living chiral crystal? Here, we report the use of vibrational mode decomposition to dissect various non-equilibrium phases of the crystal dynamics. By analyzing embryo cluster trajectories over the time course of crystal formation and dissolution, we identify the spatial modes responsible for the collective actuation of an oscillatory active crystal both in spontaneous and mechanically excited conditions. We also report a direct extraction of dispersion relation from fluctuations of confined crystals to infer odd elastic moduli. Taken together, our results unveil the complex spatiotemporal origin of mechanical waves in non-reciprocal materials and provide insight on the design principles of collective phases of active metamaterials.

BP 2.3 Mon 10:15 TOE 317

Self-organized chemotaxis of coupled cell populations — •Mehmet Can Ucar and Edouard Hannezo — Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg, Austria

Many processes in development and disease such as tissue morphogenesis, cancer invasion and immune response rely on collective directional movement of cells. In a wide array of systems this collective motility is driven locally by self-generated chemokine or stiffness gradients, as opposed to pre-patterned, global guidance cues. While recent studies have explored migration mechanisms of a single species of cells, the role of self-generated gradients navigating multiple cell types remains largely untested. Here we address this issue by introducing a theoretical framework for self-organized guidance of chemotactically coupled cell populations. Combining analytical theory and simulations with experiments on immune cell populations, we discover a diverse spectrum of collective migration patterns controlled by single-cell properties. We find that differential chemotactic sensitivity leads to efficient colocalization of distinct cell types, and show that this coupling also depends on the geometry and initial configuration of the dynamical system. We finally outline conditions for robust, sustained multicellular interactions relevant for physiological settings such as during immune response.

BP 2.4 Mon 10:30 TOE 317

Geometry-induced patterns in collective cell migration — •David Brückner — Institute of Science and Technology, Am Campus 1, 3400 Klosterneuburg, Austria

The coordinated migration of cell collectives is increasingly well understood at the level of large two-dimensional confluent monolayers. However, many physiological migration processes rely on small polarized cell clusters and their responses to external confining geometries, such as 2D channels and 3D curved environments. How active motion and cell-cell interactions interplay with such external boundaries remains poorly understood. I will discuss how external geometries can induce patterns in collective cell migration, using two examples. First, we show that the migration efficiency of 2D confined cell clusters is determined by the contact geometry of cell-cell contacts that are either parallel or perpendicular to the direction of migration. Our minimal active matter model reveals how cell-cell interactions determine a geometry-dependent supracellular stress field that controls this response to external boundaries. Secondly, we show how the interplay of curvature and active flocking dynamics of 3D cell spheroids induces a collective mode of cell migration manifesting as a propagating velocity wave. Together, these approaches provide a conceptual framework to understand how cell-cell interactions interplay with 2D and 3D geometries to determine the emergent dynamics of collective cell migration.

BP 2.5 Mon 10:45 TOE 317

Shape primed AC-electrophoretic microrobots — •Florian Katzmeier and Friedrich C. Simmel — Technical University of Munich, Munich, Germany

Second-order electrokinetic flow around colloidal particles caused by concentration polarization electro-osmosis can be utilized to controllably move asymmetric particle dimers in AC electrical fields. To demonstrate this actuation mechanism, we created particle dimers from micron-sized silica spheres with sizes 1.01 μm and 2.12 μm by connecting them with DNA linker molecules. The dimers can be steered along arbitrarily chosen paths within a 2D plane by controlling the direction of the AC electric field in a fluidic chamber with the joystick of a gamepad. Further utilizing induced dipole-dipole interactions, we demonstrate that particle dimers can be used to controllably pick up monomeric particles and release them at any desired position, and also to assemble several particles into groups. Systematic experiments exploring the dependence of the movement direction and velocity on buffer composition, frequency, and field strength further elucidate the underlying physical mechanism, and provide operational parameter ranges for our micro robotic swimmers which we termed 'SPACE-bots'.

15 min. break

BP 2.6 Mon 11:15 TOE 317

Rodrolls: self-rolling rods powered by light and chemical gradients — •Ann Rosna George[1], Martin Wittmann[2], Antonio Stocco[1], Igor M. Kulić[1], and Juliane Simmchen[2] — [1]CNRS, Institute Charles Sadron, Strasbourg, France — [2]Physical chemistry, TU Dresden, Germany

The self-rolling motion upon spontaneous symmetry breaking is demonstrated by certain rod-shaped microorganisms like viruses. Hence it is imperative that we understand the mechanism of this symmetry breaking triggering the active rolling motion. This behaviour has also been demonstrated on the macroscopic scale by rod-like objects. It is very interesting to try and replicate this on a microscopic scale. The main aim of the project is to create a new class of active rods that exhibit rolling activity under chemical and optical gradients. To achieve this, it is important to understand the mechanism of activity of rod-like objects under chemical and optical stimuli.

Experiments conducted using silica Janus rods with a Platinum layer in an aqueous solution of H2O2 give interesting results and exhibit different kinds of activity when parameters like concentration of H2O2 and aspect ratio of rods are changed. Under specific conditions, particles are capable of switching their direction of motion. Experiments done using rods covered in gold nanoparticles under an optical gradient also reveal promising results of being able to make the rods roll upon providing sufficient energy to break the symmetry and fine-tuning certain parameters.

BP 2.7 Mon 11:30 TOE 317

Active Nematic Multipoles: Flow Responses and the Dynamics of Defects and Colloids — •Alexander J. H. Houston[1,2] and Gareth P. Alexander[1,3] — [1]Department of Physics, Gibbet Hill Road, University of Warwick, Coventry, CV4 7AL, United Kingdom — [2]Department of Physics, University of York, Heslington, York YO10 5DD, United Kingdom — [3]Centre for Complexity Science, Zeeman Building, University of Warwick, Coventry, CV4 7AL, United Kingdom

Two fundamental questions in active nematics are how to extract useful work from their non-equilibrium dynamics and how to extend the topological defect-based description of dynamics that has proved useful in two dimensions to three dimensions, in which the defects form geometrically-complex loops. We introduce a general description of localised distortions in active nematics using the framework of 'active nematic multipoles'. We give the Stokesian flows for arbitrary multipoles in terms of differentiation of a fundamental flow response and describe them explicitly up to quadrupole order. This allows the identification of the dipolar and quadrupolar distortions that generate self-propulsion and self-rotation respectively and serves as a guide for the design of arbitrary flow responses. Our results can be applied to both defect loops in three-dimensional active nematics and to systems with colloidal inclusions. They reveal the geometry-dependence of the self-dynamics of defect loops and provide insights into how colloids might be designed to achieve propulsive or rotational dynamics, and more generally for the extraction of work from active nematics.

BP 2.8 Mon 11:45 TOE 317

Structure and Dynamics of Active Polymer — •Sunil Pratap Singh — Indian Institute of Science Education and Research Bhopal, India, 462066

In this talk we are going to present structural and dynamical properties of a self-propelled filament using coarse-grained Brownian dynamics simulations. We consider two kinds of self-propulsion force on polymers, in case one force is applied tangent to the filament and in another model direction of active force is considered to be random. Case one shows that chain's stiffness and radius of gyration monotonically decrease. Moreover, the radius of gyration of the filament shows universal scaling for various bending rigidities with flexure number. In the latter model, where monomers are assumed to be active Brownian particle (ABP), displays a non-monotonic behaviour of end-to-end distance with activity strength. We will discuss here the role of many-body interactions on its structure and relaxation behavior. Additional we talk about the rheological behavior of chain under linear shear-flow. Our simulations reveal that active polymer's zero-shear viscosity varies in non-monotonic fashion with the active noise. More-importantly the viscosity decreases in the intermediate regime, that is followed by an increase in the more extensive Pe regime. We attribute the decrease of the zero-shear viscosity in the intermediate regime is due to many-body interactions among chain monomers.

BP 2.9 Mon 12:00 TOE 317

Pumping, Mixing, and Signal Transmission in Active Pores — •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, Cauer Str. 1, 91058 Erlangen, Germany — [2]Max–Planck–Institut für Intelligente Systeme, Heisenbergstr. 3, 70569 Stuttgart, ,Germany — [3]IV. Institut für Theoretische Physik, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [4]Department Chemie- und Bioingenieurwesen und Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Fürther Straße 248, 90429 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. An intriguing technique to manipulate fluid flows in a pore is diffusioosmosis. We show both numerically and analytically that a corrugated catalytic pore can act as a micropump even when it is fore-aft symmetric. This phenomenology is possible due to a spontaneous symmetry breaking which occurs when advection rather than diffusion is the dominant mechanism of solute transport. Relaxing the condition of Stokes flow leads to unsteady flow, and persistent oscillations with a tunable frequency appear. We further include the inverse chemical reaction that consumes solute and introduces an additional timescale. Finally, we find that the flow may lose its axial symmetry and hence promote mixing in the low Reynolds number regime.

BP 2.10 Mon 12:15 TOE 317

Interacting particles in an activity landscape — •Adam Wysocki[1], Anil Kumar Dasanna[1,2], and Heiko Rieger[1,2] — [1]Department of Theoretical Physics and Center for Biophysics, Saarland University, Saarbrücken, Germany — [2]INM-Leibniz Institute for New Materials, Saarbrücken, Germany

We study interacting active Brownian particles (ABPs) with a space-dependent swim velocity. We find that, although an equation of state exists, a mechanical equilibrium does not apply to ABPs in activity landscapes. The pressure imbalance originates in the flux of polar order across the interface between regions of different activity. An active-passive patch system is mainly controlled by the smallest global density for which the passive patch can be close packed. Below this density a critical point does not exist and the system splits continuously into a dense passive and a dilute active phase with increasing activity. Above this density and for sufficiently high activity the active phase may start to phase separate into a gas and a liquid phase caused by the same mechanism as motility-induced phase separation of ABPs with a homogeneous swim velocity.

BP 2.11 Mon 12:30 TOE 317

Active phase fluctuations of Chlamydomonas axonemes — •Abhimanyu Sharma[1], Benjamin M. Friedrich[2], and Veikko F. Geyer[1] — [1]B CUBE - Center for Molecular Bioengineering, TU Dresden, Dresden, Germany — [2]Cluster of Excellence Physics of Life, TU Dresden, Dresden, Germany

Cilia and eukaryotic flagella generate periodic beat patterns by the activity of dynein motors. Earlier studies revealed active fluctuations in the ciliary beat arising presumably from small number fluctuations in the collective dynamics of the molecular motors that drive the beat. A theoretical model of the beating cilium as a system of coupled motors predicts that the fluctuations measured in terms of the quality factor of the oscillations scale with the number of beat-generating-motors.

To measure those fluctuations experimentally, we use in situ reactivated axonemes, the mechanical core of motile cilia isolated from the green alga Chlamydomonas. To modulate the number of motors in beating axonemes, we make use of motor mutants or partially extract molecular motors biochemically.

Using shape mode analysis and limit-cycle reconstruction, we characterize the phase fluctuations in the beat and report for the first time the relation between beat parameters and the motor number in Chlamydomonas axonemes. We experimentally infer scaling relations for the beat frequency, mean beat amplitude, and the quality factor. Further, using mass spectrometry, we identify specific dynein motors and infer their role in regulating the beat fluctuations.

BP 2.12 Mon 12:45 TOE 317

Lattice dynamics of pulsating active particles — •Alessandro Manacorda and Étienne Fodor — University of Luxembourg

Cells in epithelial tissues can drastically deform their shapes and volume giving rise to collective behavior such as size oscillation and wave propagation. These phenomena have a strinking impact in many biological contexts such as embryonic development, cardiac arrhythmias and uterine contraction.

The theoretical models describing the emergence of contractile waves so far consider the cells as motile particles, where activity is represented by self-propulsion; however this ingredient is questionable in dense systems where particles barely move. We therefore introduce a novel class of active matter where the activity is the ability to change an internal degree of freedom at the single-particle level e.g. particles' size. The collective behavior of active particles is investigated in a lattice model, where the interplay between pulsation and synchronization gives rise to emergent behavior such as wave propagation. Fluctuating hydrodynamic equations can be obtained from microscopic dynamics and their predictive power is shown in comparison with numerical simulations.

We highlight the minimal ingredients needed for the complex behavior above-mentioned and point out future directions in the growing field of pulsating active matter.