CPP 21: Active Matter III (joint session BP/CPP/DY)

Time: Tuesday 9:30–12:30 Location: TOE 317

CPP 21.1 Tue 9:30 TOE 317

Gliding motility and reorientation of flagellated microbes on curved surfaces — •Alexandros Fragkopoulos[1], Nicolas Fares[1,2], and Oliver Bäumchen[1] — [1]University of Bayreuth, Experimental Physics V, 95447 Bayreuth, Germany — [2]University of Bordeaux, CNRS, LOMA, UMR 5798, 33400 Talence, France

The model organism *Chlamydomonas reinhardtii*, a unicellular biflagellated microalga, can adhere and colonize almost any surface under particular light conditions. Once the cells attach to a surface, an intraflagellar transport machinery translocates the cell body along the flagella, which are oriented in a 180° configuration. This motion is known as gliding motility. Even though the cells firmly adhere to surfaces, they are able to reorient through different physical mechanisms [1]. With the use of the orientation autocorrelation function, we find that cells exhibit large reorientation events shortly after their initial attachment to a surface, while at longer time scales they are primarily constrained to 1D motion. On cylindrical surfaces, the large reoriations cause the cells to predominantely align in the direction of the minimum principle curvature. We quantify the curvature-induced alignment using the nematic order parameter and reveal that the minimum surface curvature required for cell alignment is comparable to the static flagella curvature.

[1] S. Till, et al., *Phys. Rev. Res.*, (Accepted)

CPP 21.2 Tue 9:45 TOE 317

Efficiency of navigation strategies for active particles — •Lorenzo Piro[1], Ramin Golestanian[1,2], and Benoit Mahault[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford, United Kingdom

Optimal navigation in complex environments is a problem with multiple applications ranging from designing efficient search strategies to engineering microscopic cargo delivery. When motion happens in presence of strong external forces, route optimization is particularly important as active particles may encounter trapping regions that would substantially slow down their progress.

Here, considering a self-propelled agent moving at a constant speed, we study the efficiency of Zermelo's classical solution. Investigating both cases of motion on the plane and on curved surfaces, we focus on the regime where the external force exceeds self-propulsion in finite regions. There, we show that, despite the fact that most trajectories following the trivial policy of going straight get arrested, the Zermelo policy allows for a comprehensive exploration of the environment.

However, our results also indicate an increased sensitivity of the Zermelo strategy to initial conditions, which limits its robustness and long-time efficiency, particularly in presence of fluctuations. These results suggest an interesting trade-off between exploration efficiency and stability for the design of control strategies to be implemented in real systems.

CPP 21.3 Tue 10:00 TOE 317

Run with the Brownian Hare, Hunt with the Deterministic Hounds — •Davide Bernardi[1] and Benjamin Lindner[2,3] — [1]Italian Institute of Technology, Ferrara, Italy — [2]Bernstein Center for Computational Neuroscience, Berlin, Germany — [3]Institut für Physik, Humboldt-Universität zu Berlin

Pursuit and evasion are vital to most animal species and play an important role in many human activities. Traditionally, chase-and-escape models have been studied in the framework of game theory, or in detailed models that can be studied only through numerical simulations and that lack generalization power.

Here, we present analytic results for the mean time and energy used by a pack of deterministic hounds to capture a prey that undergoes Brownian diffusion. Depending on the number of chasers, we find that the mean capture time as a function of the prey's diffusion coefficient can be monotonically increasing, decreasing, or attain a minimum at a finite value. Furthermore, an optimal speed and number of chasing hounds exist, that depend on the baseline power consumption and drag coefficient of each chaser.

The present model can be seen as an analytically tractable basis for the theoretician's perspective on the growing field of smart microswimmers and autonomous robots.

CPP 21.4 Tue 10:15 TOE 317

Function of Morphodynamics in Foraging *Physarum polycephalum* — •Lisa Schick[1], Mirna Kramar[2], and Karen Alim[1] — [1]School of Natural Sciences, Technical University of Munich, Germany — [2]Institute Curie, Paris, France

How network-forming fungi structure and reorganize their network morphology and thereby the carbon flows in the soil is key to understanding climate - yet hidden from us due to the long time scales of network dynamics and the soil itself. Here, the network-forming slime mold *Physarum polycephalum* serves as a model of network dynamics of a foraging network-forming life. We follow and quantify the network migration velocity and morphology of foraging *P. polycephalum*. We identify three distinct morphological states characterized by network compactness and density of moving fronts. Estimating the energetic cost of distinct states, we find that morphological variability allows the organism to balance the energetic costs of foraging and search strategy. Our observations allow us to project how resource availability might shift the balance and thereby affect network extension in foraging network-forming organisms.

CPP 21.5 Tue 10:30 TOE 317

Unraveling the migratory behavior of a large single-celled organism — •Lucas Tröger, Florian Goirand, and Karen Alim — School of Natural Sciences, Technical University of Munich, Germany

Many cells face search problems, such as finding food, conspecifics, or shelter, and different search strategies can provide different chances for success. In contrast to most single-celled organisms the slime mold *Physarum polycephalum* forms a giant network-shaped cell while foraging for food. Which advantage does the giant cell at the verge to multicellularity provide? We experimentally investigate and quantify the long-time migratory behavior of small networks of *P. polycephalum* in the absence and in the presence of food, and develop a simple mechanistic model that successfully describes its migration. We find that *P. polycephalum* performs a run-and-tumble-like motion modified by self-avoidance to achieve superdiffusive migration. Furthermore, it tunes its short-time dynamics in order to adapt to environments with different amounts of available nutrients, while its long-time dynamics remain unchanged. This work shows how *P. polycephalum* controls the inherent stochasticity of its movement by simple rules, which may represent an evolutionary advantage.

15 min. break

CPP 21.6 Tue 11:00 TOE 317

Controlling active turbulence by activity patterns — •Arghavan Partovifard, Josua Grawitter, and Holger Stark — Institute of Theoretical Physics, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Active fluids exhibit spontaneous and chaotic flow patterns which are known as active turbulence [1]. One of the current challenges in active matter is controlling and harnessing these flow patterns for powering processes at small scales [2]. As a simple realization of an active fluid, we consider a semi-dilute solution of active rods and study it within a numerical simulation of the governing equations that are formulated in terms of velocity and the orientational order tensor parameter fields.

We find that for a solution of pusher active rods there is a critical magnitude of activity above which the initially isotropic solution develops locally varying nematic order and turbulent-like fluid flow. Aiming to control the turbulent flow state, we pattern the activity with a square lattice of circular inactivity spots. We find that for a specific range of lattice parameters the flow field develops lanes of unidirectional flow with alternating directions while between them a row of corotating vortexes emerges; We call this state the laning state and it is multistable since different realizations of the random initial state of rods lead to different configurations of the laning state with various widths of the lanes. In this state, the director field develops nematic domains oriented toward the Leslie angle with respect to the flow.

[1] Wensink *et al.*, Proc. Natl. Acad. Sci. **109**, 14308-14313 (2012)
[2] Bowick *et al.*, Phys. Rev. X **12**, 010501 (2022)

CPP 21.7 Tue 11:15 TOE 317

Active matter: From spontaneous to controlled phenomena.

— •Daniel Pearce — University of Geneva

Active matter is the study of materials able to move themselves. During this talk I will discuss how we can take advantage of the interplay between topological defects, geometry and topology to exercise control over active materials. By studying active nematic fluids on a curved surface, we can influence the position and orientation of topological defects according to their charge. This means specific nematic textures can be generated. By studying active contractile actomyosin gels, it is possible to show that only active topological defects with charge +1 can generate curvature, and the sign is related to the phase of the defect. This frees the process from the constraints of the Poincare-Hopf theorem and allows complex surfaces to be generated. This is demonstrated by recreating the shape of a freshwater hydra from the positions of the topological defects

CPP 21.8 Tue 11:30 TOE 317

Nucleation of chemically active droplets — •Noah Ziethen and David Zwicker — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Liquid-liquid phase separation emerged as a crucial organizing principle inside biological cells giving rise to a plethora of intracellular compartments. Unique to the cellular context, these condensates can consist of only a few hundred molecules and are affected by non-equilibrium processes. In particular, active chemical conversion between condensate material and proteins in the surrounding cytoplasm can control multiple aspects of the condensates. Yet, it is unclear how these reactions affect the spontaneous nucleation and dissolution associated with low particle numbers. Here, we investigate the influence of chemical reactions on the bistable region of active droplets using a stochastic field theory. We find an effective increase in the energy barrier and thus decelerated transitions between the homogeneous and the droplet state. Using classical nucleation theory, we approximate the full dynamics by diffusion in a free energy potential described by an analytical expression only depending on droplet radius and reaction rate. This analogy also allows us to determine the equivalence of the binodal line, so we can propose an extension of the equilibrium phase diagram to capture driven chemical reactions. Cells might use these effects to control the nucleation of intracellular droplets.

CPP 21.9 Tue 11:45 TOE 317

Hydrodynamic description and transport coefficients in a model of active cellular aggregates — •Subhadip Chakraborti[1,2] and Vasily Zaburdaev[1,2] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Max-Planck-Zentrum für Physik und Medizin, Erlangen, Germany

Complex multicellular aggregates consisting of a large number of interacting cells are ubiquitous in biology, ranging from bacterial biofilms to organoids, cell spheroids, and tumors. We consider colonies of *N. gonorrhoeae* bacteria as a prototypical example of cells that use retractile cell appendages to actively interact with a substrate and with each other. We construct a microscopic model on a 1D lattice taking into account the non-equilibrium bacterial motility driven by two crucial forces – cell-substrate and cell-cell interactions. We observe a phase transition from a homogeneous state to a clusterized state upon tuning the density and activity parameters. Using macroscopic fluctuation theory (MFT), we analytically derive hydrodynamics for the model system and calculate two density-dependent transport coefficients – the bulk-diffusion coefficient and the conductivity. The behavior of these transport coefficients successfully explains the non-equilibrium phase transition. We support our analytical findings with the results obtained numerically. Our theory provides a general framework for studying the non-equilibrium collective behavior of other dense cellular aggregates also, in the context of dynamics and their transport properties.

CPP 21.10 Tue 12:00 TOE 317

Flocking of unfriendly species: The two-species Vicsek model — •Swarnajit Chatterjee[1], Matthieu Mangeat[1], Chul-Ung Woo[2], Heiko Rieger[1], and Jae Dong Noh[2] — [1]Saarland University, Saarbrücken, Germany — [2]University of Seoul, Seoul, Korea

We consider the two-species Vicsek model (TSVM) consisting of two kinds of self-propelled particles, A and B, that tend to align with particles from the same species and to anti-align with the other. The model shows a flocking transition that is reminiscent of the original Vicsek model [1]: it has a liquid-gas phase transition and displays micro-phase separation in the coexistence region where multiple dense liquid bands propagate in a gaseous background. The novel feature of the TSVM is the existence of two kinds of bands, one composed of mainly A-particles and one mainly of B- particles and the appearance of two dynamical states in the coexistence region: the PF (parallel flocking) state in which all bands of the two species propagate in the same direction, and the APF (anti-parallel flocking) state in which the bands of species A and species B move in opposite directions. When PF and APF states exist in the low-density part of the coexistence region they perform stochastic transitions from one to the other. The system size dependence of the transition frequency and dwell times shows a pronounced crossover that is determined by the ratio of the band width and the longitudinal system size. Our work paves the way for studying multispecies models with heterogeneous alignment interactions.

[1] T. Vicsek, A. Czirók, E. Ben-Jacob, I. Cohen, and O. Shochet, Phys. Rev. Lett. 75, 1226 (1995).

CPP 21.11 Tue 12:15 TOE 317

Two-potential model for molecular motors — •Sophie Klempahn and Helmut Schiessel — Cluster of Excellence Physics of Life, Technical University of Dresden, Germany

Molecular motors are highly efficient biological machines, which drive systems away from equilibrium and realise key biological processes. For the description of the molecular motor action, discrete jump processes as well as energy barriers with height differences can be used. However, these models are based on symmetric conditions or unidirectional motion and therefore do not capture real biological systems with fuel gradients or where the motion is not unidirectional. To predict the effect of molecular motors on the density distribution of cargo particles in one dimension, we introduce a two potential model. This model represents the cargo particles as active particles, in which the binding of molecular motors to the cargo particle causes the active part of motion. Furthermore, we use two different energy landscapes for jumps to the left or right side, to include motors moving back- and forward, asymmetric environment or two different molecular motors acting on the same cargo particle in different directions. The solution of a master equation with different energy landscapes for jumps to the left and right side results in specific extremal points in the probability density of the cargo particles and shows a ratchet effect in case of periodic potentials.