CPP 46: Active Matter IV (joint session DY/BP/CPP)

Time: Thursday 9:30–13:00 Location: ZEU 160

Invited Talk CPP 46.1 Thu 9:30 ZEU 160

Acoustically propelled nano- and microparticles: From fundamentals to applications — •Raphael Wittkowski — Institut für Theoretische Physik, Center for Soft Nanoscience, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

Among the existing types of artificial active colloidal particles, acoustically propelled nano- and microparticles have a particularly high potential for future applications in fields like medicine and materials science. However, despite intensive research on this type of motile particles in recent years, the understanding of their properties is still very limited. A reason for the limited understanding is that the previous research has mostly been experimental and that it is difficult to study the dependence of certain system parameters on the propulsion of the particles in experiments since the parameters can often not be varied independently of the other parameters and in ranges of reasonable size. In this talk, I will give an overview about our theoretical investigation of the properties of acoustically propelled nano- and microparticles and the challenges that remain for future research.

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CPP 46.2 Thu 10:00 ZEU 160

Force on probe in a confined active fluid — Shuvojit Paul[1], •Ashreya Jayaram[2], N Narinder[1], Thomas Speck[2], and Clemens Bechinger[1] — [1]Fachbereich Physik, Universität Konstanz, 78464 Konstanz, Germany — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany

When immersed in a dispersion of smaller "depletants", a colloidal particle experiences depletion forces in the presence of another colloidal particle or under confinement. While the nature of these forces is well-established for passive systems, much less is known about the consequence of making the depletants self-propelled or "active". In this work, we consider a large, optically trapped probe under circular confinement surrounded by smaller active Janus particles. We find that the force experienced by the probe varies non-monotonically as the distance between the colloid and the confinement is increased. To rationalize this observation, we relate the measured force to the active stress and, subsequently, to the microstructure of the surrounding active fluid. Going beyond synthetic active matter, our work could shed light on the organization of intracellular entities in biological systems.

CPP 46.3 Thu 10:15 ZEU 160

Symmetry-breaking refractive index profiles as a propulsion mechanism for active Brownian particles — •Julian Jeggle[1], Matthias Rüschenbaum[2], Cornelia Denz[2], and Raphael Wittkowski[1] — [1]Institut für Theoretische Physik, Center for Soft Nanoscience, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany — [2]Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

Active Brownian particles (ABPs) have been realized with various propulsion mechanisms such as self-diffusiophoresis, self-electrophoresis or acoustic scattering. Typically, these mechanisms induce flow fields around the particles that represent a deviation from the "pure" ABP model. Here, we present a novel implementation of ABPs in the form of transparent microswimmers with a symmetry-breaking refractive index gradient. Utilizing the momentum transfer associated with light refraction as the driving force induces no flow fields beyond Stokes flow. Unlike optothermally driven particles, this archetype of ABPs also allows for sensitivity to the phase and polarization of the driving light field thus improving the spatio-temporal control of light-based propulsion mechanisms. Using non-light-absorbing particles enables bulk volume systems and allows the introduction of feedback loops, therefore making this approach a promising foundation for adaptive matter systems.

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CPP 46.4 Thu 10:30 ZEU 160

The interaction-expansion method: a systematic derivation strategy for active field theories* — •Michael te Vrugt[1,2], Jens Bickmann[1,2], Stephan Bröker[1,2], Tobias Frohoff-Hülsmann[1], Eyal Heifetz[3], Michael E. Cates[4], Uwe Thiele[1,5,6], and Raphael Wittkowski[1,2,5] — [1]Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany — [2]SoN, Westfälische Wilhelms-Universität Münster — [3]Porter School of the Environment and Earth Sciences, Tel Aviv University, 69978 Tel Aviv, Israel — [4]DAMTP, Centre for Mathematical Sciences, University of Cambridge, Cambridge CB3 0WA, United Kingdom — [5]CeNoS, Westfälische Wilhelms-Universität Münster — [6]CMTC, Westfälische Wilhelms-Universität Münster

Field-theoretical models have made enormous contributions to our understanding of the collective dynamics of active matter. In this contribution, we introduce the interaction-expansion method (IEM) [1], which allows for a systematic derivation of active field theories from the microscopic dynamics of individual particles. We then discuss some recent applications of the IEM to particles with orientation-dependent propulsion speed [2] and particles with inertia [3].

[1] M. te Vrugt et al., in preparation (2022)
[2] S. Bröker et al., arXiv:2210.13357 (2022)
[3] M. te Vrugt et al., Nature Communications (provisionally accepted), arXiv:2204.03018 (2022)

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CPP 46.5 Thu 10:45 ZEU 160

Entropy production in active turbulence — •Byjesh Nalini Radhakrishnan, Thomas Schmidt, and Etienne Fodor — Department of physics and material science, University of Luxembourg

Active particles like bacteria and sperm cells sustain a continuous intake and dissipation of energy. Consequently, they are intrinsically out of equilibrium which leads to a non-vanishing entropy production rate (EPR) even in steady states. Quantifying how the EPR varies in different collective phases is crucial in developing a thermodynamic framework for active matter. In this work, we look at the EPR in active turbulence. We use Active Model H, a continuum model for active particles in a momentum-conserving fluid, to study turbulence in contractile scalar active systems. We measure the local EPR in numerical simulations, which unveils the role of the noise and activity parameters on the EPR in active turbulent systems.

15 min. break

CPP 46.6 Thu 11:15 ZEU 160

Phase transitions in multicomponent active matter: a quantitative kinetic theory — •Jakob Mihatsch[1], Thomas Ihle[1], Rüdiger Kürsten[2], and Horst-Holger Boltz[1] — [1]Institute for Physics, University of Greifswald, Greifswald, Germany — [2]Departament de Física de la Matèria Condensada, University of Barcelona, Barcelona, Spain

We consider a multicomponent model of self-propelled particles with Kuramoto-type alignment interactions. Starting from the N-particle Fokker-Planck equation we observe that the usual factorization Ansatz of the probability density, often called Molecular Chaos approximation, predicts a relaxation behavior which qualitatively disagrees with agent-based simulations. Therefore, we develop a kinetic theory which takes the time-evolution of the two-particle correlation function explicitly into account, i.e. goes beyond the mean-field approximation. We show that this theory predicts the relaxation behavior of the system as well as the order-disorder transition with high precision in certain parameter ranges. In particular, the dependence of the transition threshold on the particle speed is predicted correctly.

CPP 46.7 Thu 11:30 ZEU 160

Emergent collective behaviour due to virtual interactions between robotic swimmers — •Samudrajit Thapa[1,2], Bat-El Pinchasik[1,3], and Yair Shokef[1,2,3] — [1]School of Mechanical Engineering, Tel Aviv University, Tel Aviv 69978, Israel — [2]Sackler Center for Computational Molecular and Materials Science, Tel Aviv University, Tel Aviv 69978, Israel — [3]Center for the Physics and Chemistry of Living Systems, Tel Aviv University, 69978, Tel Aviv, Israel

Many organisms in nature use local interactions to realize global collective behaviour. Here we study how simple two body distance-based interactions between active Brownian particles results in collective motion. The interactions are not physical but virtual, wherein each par-

ticle senses the presence of other particles nearby and changes its behaviour accordingly. We study the radial distribution function to quantify the emergent interactions for both social and anti-social behaviour. Using Langevin dynamics simulations, we discover that under certain conditions positive correlations of the motion can emerge even in the case of anti-social behaviour. Our results might be potentially useful for designing robotic swimmers that can swim collectively just based on sensing the distance to their neighbours.

CPP 46.8 Thu 11:45 ZEU 160

Kinetic Event-Chain Algorithm for Active Matter — •Nico Schaffrath, Thevashangar Sathiyanesan, Tobias Kampmann, and Jan Kierfeld — Physics Department, TU Dortmund University, 44221 Dortmund, Germany

We present a cluster kinetic Monte-Carlo algorithm for active matter systems of self-propelled hard particles. The kinetic event-chain algorithm is based on the event-chain Monte-Carlo method and is applied to active hard disks in two dimensions. The algorithm assigns Monte-Carlo moves of active disks a mean time based on the mean and variance of the move length in force direction. This time is used to perform diffusional rotation of their propulsion force. We show that the algorithm reproduces the motility induced phase separated region in the phase diagram of hard disks correctly and efficiently.

CPP 46.9 Thu 12:00 ZEU 160

Emergent pattern formation in communicating active matter — •Robert Grossmann[1], Zahra Mokhtari[2], Robert I.A. Patterson[3], and Felix Höfling[2,4] — [1]Institut für Physik und Astronomie, Universität Potsdam — [2]Institut für Mathematik, Freie Universität Berlin — [3]WIAS Berlin — [4]Zuse Institut Berlin

Inspired by trail formation as observed in colonies of driver ants, for example, we study ensembles of agent particles that communicate via deposition and sensing of pheromones. These chemical traces are produced by the agents themselves and encode their current position and walking direction. Other agents passing by will then tend to align with the orientation inscribed in the pheromone traces. In the limit of short pheromone lifetime, the dynamics of this system reduces to the seminal Vicsek model and, thus, yields the formation of transversally moving bands. In the opposite limit, the effective agent-agent interaction represents a form of delayed feedback and yields the spontaneous formation of macroscopic, persistent trails, which are followed and reinforced by the agents [New J. Phys. **24** 013012 (2022)]. In this talk, we present large-scale simulations of the agent model and establish the phase diagram as function of the lifetime of pheromones. We rationalize our findings by analyzing mean-field equations that are systematically derived from the stochastic particle model. Combining numerical solutions of these order parameter equations and a linear stability analysis, we show how transversal bands, common in the Vicsek model, are destabilized, giving rise to the formation of "longitudinal" trails, pointing in the mean direction of motion.

CPP 46.10 Thu 12:15 ZEU 160

Binary Mixture of Deforming Particles — •Yiwei Zhang, Alessandro Manacorda, and Etienne Fodor — DPhyMS, University of Luxembourg, Luxembourg, Luxembourg

Phase separation occurs in miscible liquids where components have distinct properties. In reactors, components undergo stochastic change in their properties which affect the liquid composition. While phase separation and reaction-diffusion have already been studied extensively as separate ingredients, how they combine in non-ideal reactors remains poorly understood. To bridge this gap, we consider repulsive particles with fluctuating size subject to one-body landscape and nonequilibrium synchronisation. The landscape features minima which, regarding size as reaction coordinate, distinguish three states: Particles with finite size, either A- or B-type, and point particles. In this context, synchronisation penalizes A particles in B-rich phases, and vice versa, so that the system eventually accommodates a uniform state. We report the phase diagram depending on the stability of each state and the corresponding particle sizes. Combining hydrodynamic and phenomenological arguments, we recapitulate how metastability regulates the interplay between synchronisation and repulsion. Our results reveal the role of nonequilibrium kinetic factors at play in non-ideal reaction-diffusion systems.

CPP 46.11 Thu 12:30 ZEU 160

Self-organization of model catalytic cycles — •Vincent Ouazan-Reboul[1], Jaime Agudo-Canalejo[1], and Ramin Golestanian[1,2] — [1]Max Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, D-37077, Göttingen, Germany — [2]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, OX1 3PU, Oxford, UK

We study analytically and numerically a model metabolic cycle composed of an arbitrary number of species of catalytically active particles. Each species converts a substrate into a product, the latter being used as the substrate by the next species in the cycle. Through a combination of catalytic activity and chemotactic mobility, the catalytic particles develop effective interactions with particles belonging to neighbouring species in the cycle. These interactions, being fully out-of-equilibrium, show some unusual features, in particular being non-reciprocal. We find that such model metabolic cycles are able to self-organize through a macroscopic instability, with a strong dependence on the characteristics of the cycle. For instance, cycles containing an even number of species are able to minimize repulsion between their component particles by aggregating all even-numbered species in one cluster, and all odd-numbered species in another. Such a grouping is not possible if the cycle contains an odd number of species, which can lead to oscillatory steady states in the case of chasing interactions.

CPP 46.12 Thu 12:45 ZEU 160

Reentrant condensation transition in a model of driven scalar active matter with diffusivity edge — Berx Jonas[2], •Bose Aritra[1], Mahault Benoit[1], and Golestanian Ramin[1,3] — [1]Max Planck Institute for Dynamics and Self-Organization, 37077 Göttingen, Germany — [2]Institute for Theoretical Physics, KU Leuven, B-3001 Leuven, Belgium — [3]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

A class of scalar active matter for which the effective diffusivity vanishes beyond a certain density threshold, hereby referred to as diffusivity edge, triggers the formation of a condensate when confined in a harmonic potential. The condensation transition exhibits remarkable similarities with a Bose-Einstein Condensation (BEC). Here we study the effect of a diffusivity edge in a system of scalar active matter confined by a periodic potential and driven by an external force.

We find that this system shows qualitatively distinct stationary regimes depending on the amplitude of the driving force with respect to the potential barrier. For small driving, the diffusivity edge induces a condensation analogous to the BEC-like transition reported for the nondriven case, which is characterised by a density-independent steady state current. Conversely, large external forces lead to a qualitatively different phase diagram where condensation is not possible below a density threshold and the associated transition at moderate densities above the threshold the transition is reentrant due to the existence of a subsequent evaporation transition at low effective temperatures.