CPP 38: Active Matter IV (joint session DY/BP/CPP)

Time: Thursday 9:30–13:00   Location: BH-N 334

Invited Talk   CPP 38.1   Thu 9:30   BH-N 334
Flocking by turning away — •RICARD ALERT — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Flocking, as paradigmatically exemplified by birds, is the coherent collective motion of active agents. As originally conceived, flocking emerges through alignment interactions between the agents. Here, I will show a new mechanism of flocking based on interactions that reorient agents away from each other. Combining simulations, kinetic theory, and experiments, we demonstrate this mechanism of flocking in self-propelled Janus colloids with stronger repulsion on the front than on the rear. We show that, unlike for alignment interactions, the emergence of polar order from turn-away interactions requires particle repulsion. The polar flocking state is stable because particles achieve a compromise between turning away from left and right neighbors. These findings could help to reconcile the observations that cells can flock despite turning away from each other via contact inhibition of locomotion. Overall, our work shows that flocking is a very robust behavior that arises even when the orientational interactions seem to prevent it.

CPP 38.2   Thu 10:00   BH-N 334
Metastability of ordered phase in discretized flocking — •SWARNAJIT CHATTERJEE[1], MINTU KARMAKAR[2], MATTHIEU MANGEAT[1], RAJA PAUL[2], and HEIKO RIEGER[1] — [1]Center for Biophysics & Department for Theoretical Physics, Saarland University, 66123 Saarbrücken, Germany. — [2]School of Mathematical & Computational Sciences, IACS, Kolkata – 700032, India.

Polar flocks are observed in a large class of active matter systems and have been considered robust to fluctuations. However, recent studies have argued that liquid polar flocks are metastable to the presence of small obstacles [1] or to the nucleation of opposite-phase droplets [2]. In this work, we study the stability of the ordered phase in flocking models with q-fold symmetry under the influence of counter- or transversely-propagating droplets. We observe that the liquid phase is more susceptible to a transversely-propagating droplet than a counter-propagating droplet. Also, for droplet counter-propagation, system morphology is dominated by a novel *"sandwich state"* of the liquid state and the droplet state rather than a reversal of the liquid phase. Here spatial anisotropy plays a crucial role. Metastability of the liquid phase in a discretized Vicsek model shows a strong dependency on the noise strength where the anisotropy parameter q does not significantly affect the reversal dynamics. Our study further investigates the influence of droplet size, density, and other control parameters on liquid stability.
[1] Codina et al., PRL 128, 218001 (2022).
[2] Benvegnen et al., arXiv:2306.01156 (2023).

CPP 38.3   Thu 10:15   BH-N 334
Emergent Metric-like States of Active Particles with Metric-free Polar Alignment — YINONG ZHAO[1], CRISTIAN L. HUEPE[2], and •PAWEL ROMANCZUK[3,4] — [1]Shanghai Jiao Tong University, Shanghai, PR China — [2]Northwestern University, Chicago, USA — [3]Department of Biology, Humboldt Universität zu Berlin, Germany — [4]Excellence cluster "Science of Intelligence", Berlin

We study a model of self-propelled particles interacting with their k-nearest neighbors through polar alignment. By exploring its phase space as a function of two nondimensional parameters (scaled alignment strength g and Peclet number Pe), we identify two distinct order-disorder transitions. One appears to be continuous, occurs at a low critical g value independent of Pe, and resembles a mean-field transition with no density-order coupling. The other is discontinuous, depends on a combined control parameter involving g and Pe, and results from the formation of small, dense, highly persistent clusters of particles that follow metric-like dynamics. These dense clusters form at a critical value of the combined control parameter Pe/g^α, with $\alpha \approx 1.5$, which appears to be valid for different alignment-based models. Our study shows that models of active particles with metric-free interactions can produce characteristic length-scales and self-organize into metric-like collective states that undergo metric-like transitions.

CPP 38.4   Thu 10:30   BH-N 334
Strong Casimir-like Forces in Flocking Active Matter —
•GIUSEPPE FAVA[1,2], ANDREA GAMBASSI[3], and FRANCESCO GINELLI[1,2] — [1]Dipartimento di Scienza e Alta Tecnologia and Center for Nonlinear and Complex Systems, Università degli Studi dell'Insubria, Como, Italy — [2]INFN sezione di Milano, Milano, Italy — [3]SISSA International School for Advanced Studies and INFN, via Bonomea 265, 34136 Trieste, Italy

Confining in space the equilibrium fluctuations of statistical systems with long-range correlations is known to result into effective forces on the boundaries.

In this work we demonstrate the occurrence of Casimir-like forces in the non-equilibrium context provided by flocking active matter. In particular, we consider a system of aligning self-propelled particles in two spatial dimensions, which are transversally confined by reflecting or partially reflecting walls. We show that in the ordered flocking phase this confined active vectorial fluid is characterized by extensive boundary layers, as opposed to the finite ones usually observed in confined scalar active matter. A finite-size, fluctuation-induced contribution to the pressure on the wall emerges, which decays slowly and algebraically upon increasing the distance between the walls.

We explain our findings which display a certain degree of universality within a hydrodynamic description of the density and velocity fields.

Ref: "Strong Casimir-like Forces in Flocking Active Matter", arXiv:2211.02644

CPP 38.5   Thu 10:45   BH-N 334
Collective Dynamics in Dense Systems of Active Polar Disks — •YATING ZHENG[1,2], WEIZHEN TANG[3], AMIR SHEE[4], PAWEL ROMANCZUK[1,2], and CRISTIAN HUEPE[4] — [1]Humboldt-Universität zu Berlin — [2]Research Cluster of Excellence 'Science of Intelligence' — [3]Beijing Normal University — [4]Northwestern University

We study a general model of a dense system of active polar disks with repulsive linear interactions, confined by a circular boundary. Each disk advances with a preferred self-propulsion speed and changes heading by turning around an axis of rotation located at a distance R behind its barycenter. We characterize the emerging phases and collective states as a function of R, density, and noise, for disks with isotropic and anisotropic damping disks, and a smooth or rough boundary. We find a rich phase space that combines transitions from solid to fluid states with novel R-dependent transitions from a collective state displaying localized disk rotation to a milling state around a common centre of rotation. These transitions are related to the formation of vortices that follow simple or complex dynamics depending on the boundary properties and system size. Our results demonstrate generic collective states that are expected to be observed in experimental dense systems of natural or artificial active agents in confined spaces.

CPP 38.6   Thu 11:00   BH-N 334
Cooperative resetting exhibits a delocalisation phase transition — •FELIX J. MEIGEL and STEFFEN RULANDS — Arnold Sommerfeld Center for Theoretical Physics, Department of Physics, Ludwig-Maximilians-Universität, München, Germany

In the realm of biology, many non-equilibrium systems are inherently noisy, while their proper functioning relies on the adept control of fluctuations. Stochastic resetting processes, where the state of a system is reset to its initial condition at random times, provide a framework for the control of the accumulation of fluctuations over time. Yet, in this framework, resetting is externally imposed. Here, we demonstrate that a constraint of fluctuations can also be achieved in a self-organized manner by cooperative resetting in many-particle systems. Specifically, we demonstrate that many-particle systems, wherein pairs of particles are reset to their respective average positions, exhibit a second-order phase transition as a function of the resetting rate. This transition delineates a regime where particles localize, thereby controlling fluctuations, and another regime where particle positions become unbounded. Our research showcases that cooperative resetting enables adaptation to external perturbations and enhances the optimization of search tasks compared to extrinsic resetting. We showcase the versatility of self-organized fluctuation control through cooperative resetting, with applications ranging from biological systems, such as intracellular vesicle dynamics and the fitness advantages of genetic recombination,

to technical domains like the optimization of shared mobility services.

15 min. break

Invited Talk   CPP 38.7   Thu 11:30   BH-N 334
Growth and division as drivers of complex dynamics in dense cellular matter — •Philip Bittihn — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — Institute for the Dynamics of Complex Systems, University of Göttingen, Germany

Cells in systems such as tissues, bacterial aggregates, embryonic development or tumors self-organize on large scales to fulfil their biological functions. Many such collective behaviors have been studied in the broader context of active matter, where they emerge from the intrinsic non-equilibrium activity of the constituent particles. Growth and division as drivers of activity have received less attention, although they are defining features of life and often play indispensable roles.

Here, I will describe some of our recent theoretical efforts in characterizing their effects in dense cellular matter. Using minimal models of mechanically interacting particles, we investigate scenarios in which growth and division either lead to large-scale flows and volume expansion or total volume is conserved. By developing statistical descriptions suited for non-conserved particle numbers, we find that certain components of particle motion follow simple scaling laws that can be related to macroscopic flows or to classical active particle models. Other features of the dynamics reveal new phenomena and transitions due to growth-induced pressure, confinement and anisotropic particle shapes. If time permits, I will outline interactions with motility or chemical activity. Overall, our results aim to establish universal physical principles as a baseline for experimental observations and provide design strategies for bio(technological) applications or artificial systems.

CPP 38.8   Thu 12:00   BH-N 334
Motility-induced clustering of active particles under soft confinement — •Timo Knippenberg[1], Ashreya Jayaram[2], Thomas Speck[2], and Clemens Bechinger[1] — [1]FB Physik, Universität Konstanz, Deutschland — [2]Institute for theoretical physics IV, Universität Stuttgart, Deutschland

In the field of active matter, motility-induced phase separation (MIPS) is one of the most widely studied subjects. This phenomenon, characterized by a phase transition from a homogeneous phase into a densely clustered state with a gaseous surrounding, occurs at sufficiently high density and active particle (AP) velocity. However, most of these studies focus on APs in bulk or near hard walls, while research on APs in soft confinement is scarce. The latter promises insights into the dimensionality-dependent aspects of MIPS, as gradually increasing the confinement strength provides a way to approach the 1-dimensional limit, where MIPS is known to be absent.

To address this topic, here we experimentally investigate the structural and dynamical properties of APs confined in a soft annulus-shaped channel. Depending on the strength of the confinement and the AP velocity, we observe a novel re-entrant phase behavior. We can explain our measurements by the strong coupling between velocity and the effective confining dimensionality in such soft systems.

In addition to highlighting the important influence of soft boundaries on APs, our research has implications for future applications in micro-robotics.

CPP 38.9   Thu 12:15   BH-N 334
Emergent memory from tapping collisions in active granular matter — •Lorenzo Caprini, Anton Ldov, René Wittmann, Christian Scholz, and Hartmut Löwen — Heinrich-Heine University of Düsseldorf

In an equilibrium thermal environment, random elastic collisions between the background particles and a tracer establish the picture of Brownian motion fulfilling the Einstein relation between diffusivity and mobility. In nature, environments often comprise collections of autonomously moving objects, termed active matter, which exhibit fascinating phenomena. We investigate experimentally the impact of an active environment on a passive tracer by using active granular particles, i.e. vibrationally excited inertial self-propelled units termed vibrobots. They display multiple correlated tapping collisions with the tracer, by bouncing and sliding on its surface. As a consequence, the tracer displays a persistent memory and is described by a generalized active Einstein relation that constrains fluctuations, dissipation, and effective activity due to the tracer memory. Since the resulting persistence can be tuned by the environmental density and motility, our findings can be useful for engineering properties of various active systems in biomedical applications and swarm robotics.

CPP 38.10   Thu 12:30   BH-N 334
Stationary particle currents in sedimenting active matter wetting a wall — •Matthieu Mangeat, Shauri Chakraborty, Adam Wysocki, and Heiko Rieger — Saarland University, Saarbrücken, Germany

Recently it was predicted, on the basis of a lattice gas model, that scalar active matter would rise against gravity up a confining wall in spite of repulsive particle-wall interactions [PRL 124, 048001 (2020)]. We confirm this prediction with sedimenting active Brownian particles (ABPs) in a box and elucidate the mechanism leading to the formation of a meniscus rising above the bulk of the sedimentation region. The height of the meniscus increases algebraically with the activity, and the formation of the meniscus is determined by a stationary circular particle current centered at the base of the meniscus. The origin of these vortices can be traced to the confinement of the ABPs in a box: already the stationary state of non-interacting ABPs without gravitation displays highly symmetric circular currents. Gravitation distorts this vortex configuration downward, leaving two major vortices at the two side walls, with a strong downward flow along the walls. Repulsive interactions between the ABPs change this situation only as soon as motility induced phase separation (MIPS) sets in and forms a dense, sedimented liquid region at the bottom, which pushes the center of the vortex upwards towards the liquid-gas interface. Self-propelled particles therefore represent an impressive realization of scalar active matter that forms stationary particle currents being able to perform visible work against gravity, which we predict to be observable experimentally.

CPP 38.11   Thu 12:45   BH-N 334
Velocity-density scaling for active particles in an external field — •Colin-Marius Koch and Michael Wilczek — Theoretical Physics I, University of Bayreuth, Germany

Active particles in external fields can show diverse aggregation phenomena. The emerging collective phenomena and their statistics can thereby depend on microscopic details of active constituents' interactions. Here, we investigate how different steric interactions and self-propulsion mechanisms affect the aggregation of active particles in an external field. While density and velocity profiles individually differ between the studied cases, they consistently scale inversely with each other, when the instantaneous velocity projected onto the particle orientation is considered. The observed velocity-density scaling is robust for relatively dilute systems in which no strong aggregation, i.e. motility-induced phase separation, is present. We conclude that different microscopic details can result in the same statistics of collective behaviour in systems that are dilute enough.