Active crystals and the XY model with persistent noise

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Abstract

Two-dimensional crystals made of active particles can sustain very strong large scale spontaneous deformations without melting, in a clear departure from the bounds set by the equilibrium KTHNY theory on the decay of correlations. This can be traced back to the persistence in time of the active forces exerted by each particle. Indeed, a passive 2D crystal immersed in a bath of active, persistent, particles also displays fast-decaying correlations without melting. I will briefly recall these recent results. I will then follow the above ideas to the end of their logic and study an XY model where the spins are subjected to some persistent noise. I will show that this model can resist spinwave fluctuations stronger than in equilibrium and remain quasi-ordered. The BKT transition is shifted along the line of fixed points, with some scaling exponents varying continuously with the persistence time of the noise. It is thus likely that the melting of 2D active crystals, when continuous, follows the KTHNY scenario but only qualitatively.

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*Speaker

Bacterial glass transition

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Abstract

Dense bacterial assemblies, such as colonies and biofilms, are dynamic systems that present unique opportunities to study the physics of active matter. As their density increases, these assemblies transition from fluid-like to solid-like states, exhibiting phenomena reminiscent of glassy behavior in equilibrium systems, despite their active and far-from-equilibrium nature. In this work, we use monolayers of *Pseudomonas aeruginosa* to investigate the interplay between density, activity, and geometry in active glassy dynamics. By employing a novel deep-learning-based segmentation and tracking method, we monitor the motion and orientation of thousands of cells across a wide range of surface fractions, generating high-resolution datasets spanning multiple orders of magnitude in time and space.

Our results demonstrate a dynamical slowdown as the system approaches a critical density, with correlation times for both orientation and position diverging at the same critical density. We observe growing spatial heterogeneities in displacements near the transition, consistent with theoretical predictions of active glassy systems, but find no evidence of decoupling between orientational and positional relaxation, even across different strains and motility modes.

Our findings provide experimental insights into active glass transitions in biological systems, where self-propulsion and structural disorder interplay to drive emergent behavior. This study also provides high-quality datasets, unprecedented in their resolution and scale, that could serve as a benchmark for theoretical and computational studies of active glasses.

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*Speaker

Active colloids climbing up a wall

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Abstract

Active matter systems, composed of self-propelled particles, display intriguing dynamic properties. In this study, we focus on active interfaces by considering a sediment of self-propelled Janus colloids and exploring whether wetting-type effects manifest in such an active fluid. We explore a parallel to the classical capillary rise effect in the context of active matter. Specifically, we examine how a non-phase separated sediment of self-propelled Janus colloids behaves upon contact with a vertical wall.

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*Speaker

Kinetic theory of decentralized learning for smart active matter

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Abstract

Active matter has emerged as a new central field within statistical physics. A defining characteristic of active matter is its capacity to harness energy to facilitate self propulsion. Usual active matter, however, remains inherently 'dead', lacking the capability to learn and process information and to adapt to its environment beyond predetermined policies. Consequently, the notion of 'smart' matter has recently sparked much attention (1,2).
I will introduce a new statistical physics perspective on smart matter, which can dynamically adjust its interaction parameters, or policy, to maximize a given reward function and thus reach a target collective state. Learning is achieved in a decentralized approach in which agents can teach their acquired policy to neighbors (see figure below). Based on a kinetic theory framework, wherein the learning process is encoded as a reward-dependent interaction rule, I will demonstrate how to analytically derive hydrodynamic equations for the policy dynamics, therefore characterizing the learning of smart agents (3).

Using the kinetic theory we can explain results of agent-based simulations in space-dependent environments wherein agents must continually adapt to evolving surroundings to sustain optimal reward levels. In such complex environments the introduction of mutations, i.e. a certain randomization in the learning process, is key for efficient adaptation. Furthermore, we can identify 'uncertainty relations' connecting adaptation speed with the strength of fluctuations around the target state. Consequently, our theoretical framework lays the groundwork for an analytical comprehension of smart matter.

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*Speaker

Non-reciprocal active matter at small scales

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Abstract

Non-reciprocal interactions (NRIs) are quite natural among higher organisms including humans, as we all know that the way two humans act towards each other does not derive from a mutual "interaction potential" that gives rise to action=-reaction. This is because the interactions arise from a combination of cognitive abilities, processing and decision making abilities, as well as feedback mechanisms that enable the organisms to put the decisions into actions. It is, however, a big surprise that NRIs can exist at the microscopic scale among brain-less particles, when they are catalytically active, i.e. under non-equilibrium conditions. In this talk, I will introduce the topic and discuss some of its non-trivial consequences, following the recent developments in the field.

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*Speaker

Optimal closed-loop control of active particles

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[1]King's College London – United Kingdom
[2]University of Cambridge – United Kingdom

Abstract

Minimising the energetic cost of moving an active particle in a confining trap over a target distance is a fundamental problem of optimal control of active matter. The control is a closed-loop protocol if it involves information about the particle state, such as its initial position or self-propulsion, and it is an open-loop protocol otherwise. In this talk, I will present recent analytical results where we derive the optimal time-dependent protocol that minimises its associated average work (arXiv:2407.18542 (2024)). I will show that, while the optimal open-loop protocol is independent of the particle's activity, the optimal closed-loop protocol utilises the initial self-propulsion to lower the overall accumulated work. Depending on parameters, the associated work becomes negative, indicating that the activity of the particle can be harvested to extract work from the system. Moreover, the extractable work reaches a maximum at a finite persistence time. I will further present a minimal active information engine based on a periodic optimal closed-loop protocol and compare its performance when run by a Run and Tumble Particle or by an Active Ornstein-Uhlenbeck Particle. While the average work is identical in both cases, the work distribution, its fluctuations and the information efficiency of the engine are advantageous when the engine is run by a Run and Tumble Particle.

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*Speaker

Hydrodynamic Hamiltonians of active two-dimensional fluids

Naomi Oppenheimer*[1]

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Abstract

I will describe two biologically inspired systems that can be analyzed using the same hydrodynamic Hamiltonian formalism. The first is ATP synthase proteins, which rotate in a biological membrane. The second is swimming micro-organisms such as bacteria or algae confined to a two-dimensional film. I will show that in both cases, the active systems self-assemble into distinct structural states — the rotating proteins rearrange into a hexagonal lattice, whereas the micro-swimmers evolve into a zig-zag configuration with a particular tilt. While the two systems differ both on the microscopic, local interaction, as well as the emerging, global structure, their dynamics originate from similar geometrical conservation laws applicable to a broad class of fluid flows. Time permitting, I will show experiments and simulations in which the Hamiltonian is perturbed, leading to different and surprising steady-state configurations.

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*Speaker

Anti-chemotactic flocking in active biomimetic colloids

Guillaume Duclos*[1]

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Abstract

Competition for resources is a fundamental constraint that guides the self-organization of natural, biological, and human systems, ranging from urban planning and ecosystem development to intracellular pattern formation. Here, we investigate the collective dynamics that emerge in a population of colloids propelled by actin treadmilling, an out-of-equilibrium process where filaments grow from one end while shrinking from the other. Using a combination of experiments and theory, we show that symmetry-breaking, self-propulsion, and flocking naturally emerge from local competition for actin monomers. We demonstrate that beads propelled by actin treadmilling are anti-chemotactic and spontaneously generate asymmetric self-sustained actin gradients that trigger directed motility. Flocking emerges from the combined effects of anti-chemotaxis and local competition from monomers. The flocks are highly dynamic and have a stereotypical "U" shape resulting also from local competition for monomers. The flocking transition depends on reaction, diffusion, and motility whose interplay controls the emergence of short-range attractive interactions between the colloids. Our findings demonstrate that active stress generation coupled to reaction-diffusion is a generic mechanism that can lead to a multiscale cascade of behaviors when active agents can remodel the activity landscape they are in. Actin treadmilling offers a platform to study how motile agents interacting through a field self-organize in novel dynamical phases, with potential applications in non-reciprocal and trainable active matter.

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*Speaker

Phase coexistence and chiral flows in systems of spinning disks

Demian Levis*[1]

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Abstract

I will discuss the phase behaviour and collective dynamics of a system of Brownian particles, driven by an externally rotating field, spinning them at a fixed rate. Experimentally, this is motivated by suspensions magnetic colloids driven by a rotating magnetic field. At the fundamental level, the addition of chiral torques breaks parity and time reversal symmetry of a quiescent particle suspension, giving rise to odd stresses and steady flows, which have been observed experimentally and described by continuum models. Here, I'll model such chiral fluids as assemblies of Lennard Jones disks interacting via non-conservative transverse forces. The system exhibits a phase separation between a chiral liquid and a dilute gas phase that can be characterized by its equations of state. We find that the surface tension controls interface corrections to the coexisting pressure predicted from the equal-area construction and that transverse forces generate edge currents at the liquid-gas interface. At higher densities chirality can break the solid phase, giving rise to a dense fluid made of rotating hexatic patches. I'll then deiscuss the shear rheology of such chiral fluid, that exhibits shear thinning induced by transverse forces, acting as a local shear that explains the yielding of the 2d solid upon spinning.

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*Speaker