Mechanics of Polar Active Solids

Olivier Dauchot*[1]

[1]Gulliver, CNRS, ESPCI Paris, PSL Research University – Gulliver, CNRS, ESPCI Paris, PSL Research University – France

Abstract

Polar active solids are composed of polar active units embedded in an elastic matrix. Such active solids have recently been explored in a model system composed of polar active agents that are free to reorient, but are trapped at the nodes of a periodic lattice. The generic presence of a non-linear elasto-active coupling between the orientation of the active forces and the elastic strain is responsible for a transition between a disordered phase and a collective actuation phase, where the orientations all rotate synchronously. In the present talk, we will discuss the mechanical properties of the disordered phase of such solids. First, analyzing the correlation matrix of the displacements, we find that the vibrational eigenmodes of the solid being coupled, an energy flow from the high-frequency to the low-frequency modes leads to a condensation of energy at low-frequency, which can be reinterpreted into a strong effective softening of the solid eventually leading to vanishingly small elastic moduli. Second, when put under traction, the polar active solids exhibits a variety of strongly anomalous response. At low activity, one recovers the softening of the solid, expected from the analysis of the fluctuations. Increasing the activity, this softening becomes so strong that the elastic modulus indeed vanishes, and an oscillating instability sets in.

*Speaker

Evidence of robust, universal conformal invariance in living biological matter

Amin Doostmohammadi*[1]

[1]Niels Bohr Institute [Copenhagen] – Denmark

Abstract

Collective cellular movement plays a crucial role in many processes fundamental to health, including development, reproduction, infection, wound healing, and cancer. The emergent dynamics that arise in these systems are typically thought to depend on how cells interact with one another and the mechanisms used to drive motility, both of which exhibit remarkable diversity across different biological systems. I will discuss recent findings, where we report experimental evidence of a universal feature in the patterns of flow that spontaneously emerges in groups of collectively moving cells. Specifically, I demonstrate that the flows generated by collectively moving dog kidney cells, human breast cancer cells, and by two different strains of pathogenic bacteria, all exhibit conformal invariance. Remarkably, not only do the results show that all of these very different systems display robust conformal invariance, but we also uncover that the precise form of the invariance in all four systems is described by the Schramm-Loewner Evolution (SLE), which allows us to reveal the universality class. A continuum model of active matter can recapitulate both the observed conformal invariance and SLE form found in experiments. The presence of universal conformal invariance reveals that the macroscopic features of living biological matter exhibit universal translational, rotational, and scale symmetries that are independent of the microscopic properties of its constituents. The results show that the patterns of flows generated by diverse cellular systems are highly conserved and that biological systems can unexpectedly be used to experimentally test predictions from the theories for conformally invariant structures.

*Speaker

Barrier crossing and rare fluctuations of active particles

Peter Sollich*[1]

[1]Institute for Theoretical Physics, University of Goettingen – Germany

Abstract

We study barrier crossing processes for active particles. Using a low-noise Kramers limit we derive the effective activation barriers for three standard descriptions: active Brownian (ABP), active Ornstein-Uhlenbeck (AOUP) and run-and-tumble particles (RTP). We find that, because barrier crossing is dominated by rare fluctuations, there are significant qualitative differences between these, opening the way to e.g. designing potentials that could sort active particles according to their self-propulsion mechanism. For ABPs one key result is that, for potentials with a symmetry axis, activity can generate optimal escape paths that break this symmetry.

*Speaker

Emergent polar order in nonpolar mixtures with nonreciprocal interactions

Giulia Pisegna*[1], Suropriya Saha[1], and Ramin Golestanian[1]

[1]Max Planck Institute for Dynamics and Self-Organization – Germany

Abstract

Self-organization in living and active systems arises from simple microscopic interactions, often leading to collective behavior through spontaneous symmetry breaking. To study these phenomena, we employ a field-theoretical approach that predicts large-scale properties based on fundamental features such as symmetries and conservation laws. While these principles are typically inherent to the constituents, new phenomena can emerge when composite units related to emergent symmetries dominate the system's behavior.

We present a generic class of active matter models with two scalar fields that represent the concentration of molecular species interacting non-reciprocally. When non-reciprocity crosses a critical threshold, the system transitions from a phase-separated equilibrium configuration to an out-of-equilibrium stationary state, where parity and time-reversal symmetries are broken. The two species system evolves into a traveling-wave state, with one density field chasing the other in a spontaneously chosen direction. This is a striking example of polar order arising from non-polar particles, contrarily to many active matter models that assume polarity at a microscopic level.

We study analytically and numerically the stability of the ordered state and demonstrate the existence of true long-range orientational order in two dimensions and higher. We go beyond a linear approximation and perform a Renormalization Group analysis to study the effect of non-linearities. We show that the dynamics of concentration fluctuations around the ordered state map onto the Kardar-Parisi-Zhang universality class. This classification allows us to prove a conclusive violation of the Mermin–Wagner theorem and to predict the large-scale behavior of systems with non-reciprocal interactions at any dimension.

*Speaker

Stability of Discrete and Continuous-Symmetry Flocks

Yariv Kafri*[1]

[1]Technion - Israel Institute of Technology [Haifa] – Israel

Abstract

The talk will discuss the stability of flocking phases which exhibit symmetry breaking. For models which break a discrete symmetry, both an active Ising model and a hydrodynamic description will be used to show that droplets of particles moving in a direction opposite to that of the ordered phase nucleate and grow ballistically in all directions. The results imply that, in the thermodynamic limit, discrete-symmetry flocks are metastable in all dimensions. Following this the ordered phase of a flocking model which breaks a continuous symmetry will be considered and argued to be stable in parts of the phase diagram. This implies that in flocking models, in contrast to equilibrium systems, breaking a continuous symmetry is easier than a discrete one.

*Speaker

Active colloidal mixtures: clustering, seggregation and collective motion

Laura Alvarez*[1,2]

[1]Centre de Recherche Paul Pascal – Université de Bordeaux, Institut de Chimie - CNRS Chimie, Centre National de la Recherche Scientifique – 115 Avenue du Dr Albert Schweitzer, 33600 Pessac, France, France

[2]Université de Bordeaux – CNRS, Univ. Bordeaux, CRPP, 115 avenue du Dr A. Schweitzer, 33600 Pessac 33600 – France

Abstract

In nature, the complex interactions driving collective motion lead to fascinating out-of-equilibrium self-organization processes. Cells of the same and/or different species coordinate their movement to enhance environmental exploration, achieving efficient navigation and maximizing survival through emergent cooperative and competitive behaviors. Group dynamics are often explored with dense suspensions of active colloids as synthetic model systems. While significant progress has been made in understanding collective behavior in single-species systems (1,2,3), active mixtures of different motilities remain largely unexplored. Here, we present a system of active colloids that exhibit flocking and spatial segregation driven by external electric fields, with particles having distinct motilities and independently tunable interactions (4). We experimentally and numerically report on the formation of highly dynamic polar clusters of both species of particles, with alignment occurring regardless of their propulsion speed. In dense binary mixtures, effective segregation emerges, with the dynamics of fast and slow particles influenced by interspecies interactions. These results highlight synergistic effects in the self-organization of active mixtures, offering insight into designing systems with advanced group dynamics (5).

(1) Boudet, et.al. Science Robotics 6, (2021)
(2) Theurkauff, et.al, Phys. Rev. Lett. 108, 268303466 (2012).
(3) Nkayama, et.al., Proceedings of the National Academy of Sciences (2023)
(4) L. Alvarez, E.Sesé-Sansa, D. Levis, et.al. (in preparation)
(5) C. van Baalen, L. Alvarez, et.al. (submitted)

*Speaker

Non-equilibrium phenomena via exact hydrodynamic analysis of active matter models

Robert Jack*[1]

[1]Department of Applied Mathematics and Theoretical Physics – United Kingdom

Abstract

We discuss lattice models of self-propelled particles for which the large-scale hydrodynamic behaviour can be derived exactly, see for example (1). First we consider a model of with flocking behaviour (2) where we impose thermodynamic consistency in that self-propulsive forces are the only source of external work. These modelling assumptions lead to significant changes in the phase diagram and the entropy production rate, compared to previous models. Second, we consider a mixture of active and passive particles where non-reciprocal effective interactions generate dynamical patterns (3). (1) M Kourbene-Hossene, C Erignoux, T Bodineau, J Tailleur, Phys Rev Lett 120, 268003 (2018).
(2) T Agranov, RL Jack, ME Cates, and E Fodor, New J Phys 26, 063006 (2024).
(3) J Mason, RL Jack, and M Bruna, arXiv:2408.03932.

*Speaker

Active granular matter with bristlebots: how far from equilibrium ?

Thomas Barois*[1], Jean-François Boudet , Juho S. Lintuvuori , and Hamid Kellay

[1]Laboratoire Ondes et Matière d'Aquitaine (LOMA) – Université de Bordeaux, Centre National de la Recherche Scientifique, Centre National de la Recherche Scientifique : UMR5798, Université de Bordeaux : UMR5798 – Université de Bordeaux, PAC Talence, bât. A4N, 351 Cours de la Libération, 33405 TALENCE CEDEX, France

Abstract

Bristlebots are centimeter-sized granular particles that are self-propelled by an internal vibration mechanism. Assemblies of such particles are obviously out-of-equilibrium systems but the question we would like to address here is how far from equilibrium such systems are? In some situtations, bristlebots show dynamial states that are somehow similar to equilibirum states with order/disorder transitions for example. This is the case when a set of brisltebots is placed in a circular rigid arena. At low surface densities, the particles mostly behave as a gas and for higher surface densities, the particles form boundary ordered clusters that coexist with the particle gas state.

However, if some physical parameters are modified such as the softness/mobility of the arena boundary or the chiral properties of the particles, some collective states can emerge that have no equivalent in equilibrium statistical mechanics.

In this talk, I would like to review some of the experimental results we have with bristlebots and try to give some illustrations of what out-of-equilibirum can mean for active granular matter.

*Speaker

Dynamical steady states with macroscopic currents in nonreciprocal systems

Sarah Loos*[1]

[1]Department of Applied Mathematics and Theoretical Physics – United Kingdom

Abstract

Nonequilibrium conditions often break the symmetry between actions and reactions, giving rise to effective nonreciprocal couplings. In this talk, I discuss the emergence of dynamical steady states with macroscopic currents due to nonreciprocal interactions. First, I consider fluctuating field theories with conserved dynamics describing travelling waves in nonreciprocal fluid mixtures. We find that close to PT-symmetry breaking phase transitions, fluctuations not only inflate, as is known from equilibrium criticality, but also become increasingly irreversible. Second, I consider single-species disordered spin systems, where we find that nonreciprocal interactions lead to dynamical states with coherent oscillations but incoherent phases, but can also give rise to chaotic phases and suppress or enhance glassy behaviour.

*Speaker

Active crystals and the XY model with persistent noise

Hugues Chaté*[1]

[1]CEA Saclay – Commissariat à l'énergie atomique et aux énergies alternatives – France

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.

*Speaker

Bacterial glass transition

Martin Maliet , Nicolas Fix-Boulier , Ludovic Berthier , and Maxime Deforet*[1]

[1]Laboratoire Jean Perrin – CNRS : UMR8237, Sorbonne Université UPMC Paris VI – France

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.

*Speaker

Active colloids climbing up a wall

Cécile Cottin-Bizonne*[1]

[1]Université Claude Bernard Lyon 1 - Faculté des sciences – Université Claude Bernard Lyon 1 – France

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.

*Speaker

Kinetic theory of decentralized learning for smart active matter

Gerhard Jung*[1], Misaki Ozawa[1], and Eric Bertin[1]

[1]Laboratoire Interdisciplinaire de Physique (LIPHY), Grenoble – UGA-CNRS – France

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.
REFERENCES
(1) C. Kaspar et al., The rise ofintelligent matter, Nature 594 (2021) 345.
(2) H. Levine and D. I. Goldman, Physics of smart active matter: integrating active matter andcontrol to gain insights into living systems, Soft Matter 19 (2023) 4204.
(3) G. Jung, M. Ozawa and E. Bertin, Kinetic theory of decentralized learning for smart activematter, arXiv:2501.03948(2025)

*Speaker

Non-reciprocal active matter at small scales

Ramin Golestanian*[1,2]

[1]Max Planck Institute for Dynamics and Self-Organization – Germany
[2]Rudolf Peierls Centre for Theoretical Physics – United Kingdom

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.

*Speaker

Optimal closed-loop control of active particles

Rosalba Garcia Millan*[1,2], Janik Schuettler[2], Michael Cates[2], and Sarah Loos[2]

[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.

*Speaker

Hydrodynamic Hamiltonians of active two-dimensional fluids

Naomi Oppenheimer*[1]

[1]Tel Aviv University – Israel

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.

*Speaker

Anti-chemotactic flocking in active biomimetic colloids

Guillaume Duclos*[1]

[1]Brandeis University – United States

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.

*Speaker

Phase coexistence and chiral flows in systems of spinning disks

Demian Levis*[1]

[1]Condensed Matter Physics Department, University of Barcelona – Spain

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.

*Speaker

Emergence of collective oscillations in massive human crowds

Denis Bartolo*[1]

[1]Département de Physique [ENS Lyon] – Ecole Normale Supérieure de Lyon – France

Abstract

Though a combination of field observations, measurements and theory I will show how spontaneous chiral oscillations emegerge in ultra dense crowds. I will then explain this unanticipated dynamics showing that packed human crowds realize a form of odd active matter.

*Speaker

Dynamic Scaling of Two-Dimensional Polar Flocks

Alexandre Solon*[1] and Hugues Chaté[2]

[1]Laboratoire de Physique Théorique de la Matière Condensée – Sorbonne Universités, UPMC, CNRS – France

[2]Service de Physique de l'Etat Condensé, CEA, CNRS Université Paris-Saclay, CEA-Saclay, 91191 Gif-sur-Yvette, France – CEA-Saclay, Gif-sur-Yvette, France – France

Abstract

We propose a hydrodynamic description of the homogeneous ordered phase of polar flocks. Starting from symmetry principles, we construct the appropriate equation for the dynamics of the Goldstone mode associated with the broken rotational symmetry. We then focus on the two-dimensional case considering both "Malthusian flocks" for which the density field is a fast variable that does not enter the hydrodynamic description and "Vicsek flocks" for which it does. In both cases, we argue in favor of scaling relations that allow one to compute exactly the scaling exponents, which are found in excellent agreement with previous simulations of the Vicsek model and with the numerical integration of our hydrodynamic equations.

*Speaker

Discontinuous transition to active nematic turbulence

Ricard Alert*[1]

[1]Max Planck Institute for the Physics of Complex Systems, Dresden – Germany

Abstract

Active fluids exhibit chaotic flows at low Reynolds number known as active turbulence. I will discuss the nature of the transition from laminar to turbulent flows. Through simulations of a minimal model of unbounded active nematics, we find that the transition to active turbulence is discontinuous. The transition features a jump in the mean-squared velocity, as well as bistability and hysteresis between laminar and chaotic flows. From distributions of finite-time Lyapunov exponents, we identify the transition at a value $A^* \approx 4900$ of the dimensionless activity number. Below the transition to chaos, we find subcritical bifurcations that feature bistability of different laminar flow patterns. These bifurcations give rise to oscillations and to chaotic transients, which become extremely long close to the transition to turbulence. Altogether, our finding of a discontinuous transition contrasts with the continuous transition previously found in channel confinement. We propose that, without confinement, the transition to turbulence is discontinuous because the long-range hydrodynamic interactions of Stokes flow suppress the spatial coexistence of turbulent puffs and laminar flow.

*Speaker

Emergence of mesoscale flows under non-equilibrium drive in crowded environments

Juliane U. Klamser*[1], Ludovic Berthier[2,3], Robert L. Jack[4,5], and Yann-Edwin Keta[6]

[1]Laboratoire Charles Coulomb UMR5221 – CNRS, Université de Montpellier – France
[2]Gulliver (UMR 7083) – CNRS, ESPCI Paris, PSL Research University – France
[3]Laboratoire Charles Coulomb UMR5221 – CNRS, Université de Montpellier – France
[4]Department of Applied Mathematics and Theoretical Physics [University of Cambridge] – United Kingdom
[5]Yusuf Hamied Department of Chemistry, University of Cambridge – United Kingdom
[6]Instituut-Lorentz for Theoretical Physics, Universiteit Leiden – Netherlands

Abstract

When non-equilibrium driving at the particle level competes with crowding at high densities in overdamped particle systems, spontaneous velocity correlations can give rise to mesoscale flows resembling turbulence. We demonstrate that such flows can originate not only from the persistent self-propulsion forces of active particles, such as active Ornstein-Uhlenbeck particles, but also from non-reciprocal inter-particle forces.
The emergence of turbulent-like flows in various experimental active systems has inspired numerous theoretical studies. However, none of these theories capture the unique flow characteristics observed in our systems. Strikingly, we find significant similarities between the flows generated by activity and those arising from non-reciprocal interactions, suggesting common underlying principles. Moreover, tuning the respective control parameters–persistence time for active particles or the degree of non-reciprocity–allows the time and length scales of these flows to grow arbitrarily large.
In the non-reciprocal system, this scaling behaviour is linked to a non-equilibrium phase transition to absorbing states, where particle positions self-organise such that every particle experiences identical forces, abruptly halting the turbulent-like flows. The critical exponents we measure are consistent with the conserved directed percolation universality class.

*Speaker

Collective dynamics of confined droplet microswimmers

Corinna Maass*[1]

[1]Physic of Fluids, University of Twente – Netherlands

Abstract

Autophoretic droplets are a versatile microswimmer prototype that can be easily synthesized in large numbers with high uniformity. They exhibit rich emergent dynamics like mutual signalling and aggregation effects, which can be compared to elementary active matter models. Based on experiments in confined microfluidic geometries, I will discuss in which cases essential dynamics can be understood using pure chemical ('dry') or hydrodynamic interactions, and where a full chemohydrodynamic modelling is necessary.

*Speaker

State-dependent temperature and fluctuation(-dissipation) relation out of equilibrium

Rémi Goerlich*[1], Benjamin Sorkin[2], Dima Bosiskovsky[1], Cyriaque Genet[3], Benjamin Lindner[4], and Yael Roichman[1]

[1]Raymond Beverly Sackler School of Chemistry, Tel Aviv University, Tel Aviv 6997801, Israel – Israel
[2]Department of Physics, Princeton University – United States
[3]University of Strasbourg and CNRS, CESQ and ISIS, UMR 7006 – CNRS – France
[4]Humboldt-Universität zu Berlin = Humboldt University of Berlin = Université Humboldt de Berlin – Germany

Abstract

Building a consistent thermodynamic framework for non-equilibrium systems is a major challenge. For such systems, even the generalization of state variables like temperature is problematic. Here, we take the bet of applying a transformation on a non-equilibrium state, rather than focusing on steady-state. Doing so, we reveal a surprisingly consistent ensemble of state variables and thermodynamic relations. More precisely, an optically trapped microparticle is driven into a non-equilibrium state using an engineered correlated stochastic force. We investigate the thermodynamic response of the microparticle to a stiffness change of the potential. First, we derive a fluctuation-dissipation relation, which allows us to differentiate between equilibrium and non-equilibrium states, and to further resolve the origin of effective temperatures, whether arising from white or colored noise. Second, we investigate the stochastic thermodynamics of the microparticle during a state-to-state transformation. We define a state-dependent effective temperature with which the Second Law of thermodynamics is recovered. This temperature further allows us to derive a new fluctuation theorem that we confirm experimentally. This consistent thermodynamic framework far from equilibrium offers new tools to describe and control active and driven systems.

*Speaker

Active nematics : Investigations of texture in 3D systems

Aparna Baskaran*[1]

[1]Brandeis University – United States

Abstract

In this talk, I will briefly review Active nematic hydrodynamics and some experimental and numerical results on structure of disclination loops in 3D fluids. I will present an analysis framework for nematic structure from 3D data and use it to illustrate the influence of nematogen stiffness and boundary patterning on the topological properties of nematic textures in the active fluid.

*Speaker

Single active particle engine utilizing a nonreciprocal coupling between particle position and self-propulsion

Grzegorz Szamel*[1]

[1]Department of Chemistry, Colorado State University – United States

Abstract

A self-propelled particle is formally equivalent to a system consisting of two sub-systems interacting with their own heat reservoirs and coupled by a nonreciprocal (violating Newton's third law) interaction. We previously showed that this approach allows us to generalize stochastic thermodynamics to systems of active particles. Here we argue that the nonreciprocal coupling can be used to extract useful work from a single self-propelled particle maintained at constant temperature. We demonstrate one way to achieve this extraction, through manipulating correlations between the particle's position and self-propulsion using an externally controlled aligning interaction. We analyze quantitatively the work extracted, the power and the efficiency of the resulting single active particle engine. Finally, we investigate an information engine based on the same principles.

*Speaker

Turing Foams and Active Foams

Erwin Frey*[1]

[1]Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universitaet Muenchen, Theresisenstrasse 37, D-80333 Muenchen – Germany

Abstract

Non-equilibrium protein pattern formation and the self-organization of motor-filament mixtures, driven by NTPase cycles, are crucial mechanisms for cellular processes like division and polarization. Despite their distinct physical origins, both systems can form remarkably similar structures. Protein diffusion-reaction dynamics lead to foam-like patterns, which we termed "Turing foams," that follow non-equilibrium interface laws similar to equilibrium foams(1). Motor-filament mixtures similarly self-organize into supramolecular structures, including micelles, bilayers, and foams, driven by instabilities (2). This talk will discuss the shared non-equilibrium principles governing these systems, focusing on interface laws linked to thermodynamic-like relations.

(1) Deciphering the Interface Laws of Turing Mixtures and Foams, Henrik Weyer, Tobias A. Roth, and Erwin Frey, (arXiv:2409.20070).

(2) Supramolecular assemblies in active motor-filament systems: micelles, bilayers, and foams, Filippo De Luca, Ivan Maryshev, and Erwin Frey, Physical Review X 14, 031031 (2024).

*Speaker