Seminar

Institute for Plasma Research

Title : Collective dynamics of active or self-propelled particles

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Abstract :

Plasma is known for its collective behavior, thanks to the electro-magnetic nature of its constituent charged species. Interestingly, collective behavior is abundant in biological systems as well. For example, a group of birds fly together and, sometimes, perform fascinating areal display. Other well known collective behavior in biological domain are the motion of cytoskeletal filaments inside eukaryotic cells, movement of cells during wound healing, pattern formation in bacterial colonies, circular gyration of large ant colonies, motion of a collection of fish in oceans, migration of heard of zebras, lane formation of human crowd while passing over a narrow bridge. The above mentioned fascinating collective behavior span over an extensive range of scales, for instance, from nano to meter scales. These systems are also known as active matter in literature to differentiate them from conventional passive physical systems, such as plasma. Active matter can be thought of as self-driven or self-propelled systems, where the energy is injected in the smallest scales, unlike energy injection at the large scales in passive driven systems. In recent times a great amount of effort has been put to understand the observed collective properties in active systems. For example, several simplified nontrivial models have been proposed for active systems to understand the universality of the emergence properties in active systems. Effort is being put in making a connection between passive and active system via generalized physical principles of non-equilibrium statistical mechanics and more. Apart from fundamental interest, active systems has a great potential for applications in solving some of the key problems that mankind is currently facing, such as in healthcare, environmental sustainability, climate changes, security, to name a few.

In this Thesis, several problems in active matter physics have been addressed employing minimal models in two dimensions using an in-house developed GPU version of the Molecular Dynamics solver MPMD. We begin by considering a small system of point-like, repulsively interacting model of active or self-propelled particles with finite mass. In the first part of the Thesis, the importance of inertia or mass of a homogeneous system of under-dense self-propelled particles is investigated. It is shown that, unlike their passive counterpart, active particles can be at a temperature very different in magnitude from its surrounding medium or heat bath. Motility or self-propulsion is known to induce a phase separation into low and high density regions. In the second part of the Thesis, considering a large system of finite size self-propelled particles, it is demonstrated that the softness and effective size are the key parameters to understand the phase diagram of motility induced phase separation (MIPS), which was hitherto unrealized. In the above said system, existence of strong velocity correlation is seen, even though the physics of alignment, commonly found in active particles, is absent. In the later part of the Thesis, the importance of alignment dynamics between active particles is addressed. In particular, a non-reciprocal alignment mechanism is proposed in Thesis that produces two fundamentally different phenomena, namely MIPS and flocking, with variation in the sign of the alignment interaction. In the last part, a mixture of active and passive particles are considered together and the effect of active particle dynamics on passive collective modes such as shear flows is addressed. Several unsolved problems within and without the Thesis are identified, some of which will be highlighted. Possibilities of realizing synthetic active particles in plasma experiments is also discussed.