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Non-equilibrium pattern formation in active matter

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Active matter, popularized by the collective motion of bird flocks, constitutes a novel and rapidly growing field gathering interests and contributions from very diverse communities. In particular, it offers new promises in organizing elementary units at different scales in ways that are unavailable to equilibrium systems, like clustering and phase separation without attractive interactions, dense fronts of coherently moving entities, etc. At a fundamental level, this new physics emerging in active matter has been mostly understood in terms of simplified particle models, which allow to identify the key ingredients giving rise to such non-equilibrium collective phenomena. However, properly controlling the self-assembly of active particles is still an open challenge.
Here we consider chiral active matter, composed of large assemblies of polar circle swimmers, i.e. polar active particles that follow circular trajectories (like bacteria suspensions in two dimensions or asymmetric L-shaped chiral self-propelled colloids). We show that rotations induce a plethora of new collective behaviors as compared to non-rotating particles and, in particular, they provide a novel generic route to pattern formation. We show that slow rotations induce phase separation while faster rotations result in the emergence of patterns of smaller synchronized structures with self-limited size, such as those observed in suspensions of sperm cells. Most remarkably, we show that the size of these patterns can be directly controlled by the microscopic parameters of the model in a simple way. Moreover, in the presence of a distribution of rotation frequencies, they can synchronize over very large distances, even in 2D, as opposed to non-active oscillators on static or time-dependent networks, usually leading to synchronized domains only. We finally discuss some experimental observations in suspensions of magnetic colloids that can be understood within this framework.

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