Collective behavior of self-steering polar microswimmers

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“Cognitive” biological microswimmers and synthetic microbots are characterized by their ability to sense the environment, process this information, and adapt their motion accordingly. We aim to develop minimal models of such intelligent active agents [1,2,3], and analyze their emergent behavior. For the collective behavior of self-propelled particles, the adaptation of motion by alignment with neighbors has been shown to lead to long-range polar order in dry systems. However, in wet systems, hydrodynamic interactions between the active agents can destabilize both nematic and polar order. To unravel the self-organization and emergent dynamics of wet polar active matter, we propose a hydrodynamic extension of the Vicsek model in three dimensions, where microswimmers align by self-steering via adaptive actuation. We employ a mesoscale hydrodynamic simulation method, the multiparticle collision dynamics approach (MPC), where embedded microswimmers are modeled by self-steering squirmers with adaptive surface flow fields [3]. In contrast to dry polar systems with long-range order, our wet systems show only short-range polar order even for strong self-steering alignment [4]. Instead, the self-steering polar microswimmers exhibit chaotic dynamical patterns, characterized by a power-law decay in their kinetic energy spectra. Specifically, the systems of rear-actuated squirmers (pushers) feature active turbulence with suppressed density fluctuations and a Gaussian velocity distribution. In contrast, suspensions of front-actuated squirmers (pullers) exhibit a strong tendency for cluster formation as well as non-Gaussian velocity and vorticity distributions with fat tails, demonstrating that the chaotic advection of pullers is not active turbulence. Moreover, vortex rings and fluid jets emerge and decay in time [4]. Our results demonstrate that self-steering gives rise to novel collective phenomena.

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