Adaptive cohesion and pattern formation in pusher-type microswimmer suspensions

Segun Goh[1,2], Elmar Westphal[3], Roland G. Winkler[2], and Gerhard Gompper[2]
[1]*School of Liberal Studies, Sejong University, Korea*
[2]*Theoretical Physics of Living Matter, Institute for Advanced Simulation, Forschungszentrum Jülich, Germany*
[3]*Peter Grünberg Institute and Jülich Centre for Neutron Science, Forschungszentrum Jülich, Germany*

The emergence of dynamic structures and patterns is a hallmark of both biological and artificial active matter systems. Collective behavior in such systems is not solely determined by physical interactions between agents, but often relies on sensing of their environment, information processing, decision making and goal-oriented adaptation, implying the prevalence of non-reciprocal interactions. Here, we demonstrate that non-reciprocal cohesive adaptation, widely used to describe clustering tendencies in active systems, may give rise to long-lived filamentous patterns in pusher suspensions. This is surprising because extensile active stresses generated by self-propulsion are known to promote hydrodynamic instabilities, particularly for aligning particles, which results in chaotic dynamics [1]. Combining mesoscale hydrodynamic simulations with linear stability analysis of a generic model for active suspensions, we show that cohesion can indeed facilitate chain- and ring-like patterns in certain limiting cases. Our findings may provide guidance for controlling and stabilizing complex patterns in active microrobotic systems.

[1] S. Goh, E. Westphal, R. G. Winkler, and G. Gompper, Phys. Rev. Res. 7, 013142 (2025).