# Towards controlled assembly in active matter

Shashi Thutupalli,[1,2,3,4,*] Delphine Geyer,[3] Rajesh Singh,[5,6] Ronojoy Adhikari,[5,6] and Howard A. Stone[3]

[1] *Simons Centre for the Study of Living Machines, National Centre for Biological Sciences, GKVK Campus, Bellary Road, Bangalore 560065, India*

[2] *International Centre for Theoretical Sciences, Tata Institute of Fundamental Research, Bangalore 560012, India*

[3] *Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ 08544, USA*

[4] *Joseph Henry Laboratories of Physics, Princeton University, Princeton, NJ 08544, USA*

[5] *The Institute of Mathematical Sciences-HBNI, CIT Campus, Chennai 600113, India*

[6] *DAMTP, Centre for Mathematical Sciences, University of Cambridge, Wilberforce Road, Cambridge CB3 0WA, UK*

We describe our efforts towards constructing synthetic active particle systems capable of tunable assemblies and organised structures. Active particles, including swimming microorganisms, autophoretic colloids and droplets, are known to self-organize into ordered structures at fluid-solid boundaries. The entrainment of particles in the attractive parts of their spontaneous flows has been postulated as a possible mechanism underlying this phenomenon. Here, combining experiments, theory and numerical simulations, we demonstrate the validity of this flow-induced ordering mechanism in a suspension of active emulsion droplets. We show that the mechanism can be controlled, with a variety of resultant ordered structures, by simply altering hydrodynamic boundary conditions.

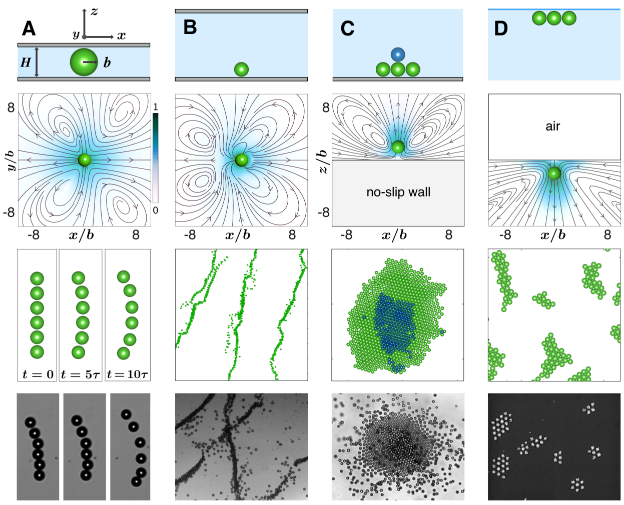


FIG. 1. The role of boundaries in determining the collective behaviour of active particles (particles). Top row: Schematic of confinement. Second row: The exterior flow field produced by the active particles in each boundary condition considered. Third and fourth (bottom) rows, respectively, contain snapshots from simulations and experiments.

Thus, for flow in Hele-Shaw cells, metastable lines or stable traveling bands can be obtained by varying the cell height. Similarly, for flow bounded by a plane, dynamic crystallites are formed. At a no-slip wall the crystallites are characterised by a continuous out-of-plane flux of particles that circulate and re-enter at the crystallite edges, thereby stabilising them. At an interface where the tangential stress vanishes the crystallites are strictly two-dimensional, with no out-of-plane flux. We rationalize these experimental results by calculating, in each case, the slow viscous flow produced by the droplets and the dissipative, long-ranged, many-body active forces and torques between them. The results of numerical simulations of motion under the action of the active forces and torques are in excellent agreement with experiments. Our work [1] elucidates the mechanism of flow-induced phase separation (FIPS) in active fluids, particularly active colloidal suspensions, and demonstrates its control by boundaries, suggesting new routes to geometric and topological phenomena in active matter.

States of self-organization maintained by entropy production were studied in the past by the Brussels school and were given the name *dissipative structures* [2]. Self-organization in active particles, as shown here, appears to be an example of a dissipative structure but one in which the dissipative mechanism and the resultant forces and torques are unambiguously identified.

* Corresponding author: shashi@ncbs.res.in

[1] Thutupalli S, Geyer D, Singh R, Adhikari R, and Stone H A (2018) Flow-induced phase separation of active particles is controlled by boundary conditions *Proc. Nat. Acad. Sci.* **115 (21)**, 5403-5408.

[2] Kondepudi, D & Prigogine, I. (1998) *Modern Thermodynamics: From Heat Engines to Dissipative Structures.* (John Wiley & Sons).