Non-Equilibrium Droplets: Mathematical Approaches to Active Phase Separation

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Active phase separation gives rise to remarkable behaviors, including suppressed coarsening and the spontaneous growth and division of droplets, which sharply contrast with those observed in classical phase separation. While traditional systems tend to favor the growth of larger domains at the expense of smaller ones, chemically active mixtures can maintain a stable population of finite-sized droplets. These distinctive dynamics have been proposed as models for protocells, offering insight into the self-organization of prebiotic structures and the emergence of life from non-living matter.

In this talk, I will introduce a mathematical framework for describing active droplet dynamics, employing both the phase-field approach via the Cahn–Hilliard equation and its sharp-interface counterpart, the Mullins–Sekerka free-boundary problem. I will examine the relationship between these formulations and address questions of well-posedness and stability, particularly in planar and radially symmetric settings. The presentation will conclude with numerical simulations that complement the asymptotic analysis and reveal rich phenomena, including droplet division and shell-like structure formation.