Mathematical models of active phase separation and droplet dynamics

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Active phase separation gives rise to striking phenomena, such as the suppression of coarsening and the spontaneous growth and division of droplets, that sharply contrast with the behavior seen in classical systems. Whereas classical phase separation favors the growth of larger domains at the expense of smaller ones, chemically active mixtures can sustain a stable population of droplets with finite size. These dynamics have been proposed as a model for protocells, shedding light on the emergence of self-organized prebiotic structures and the transition from non-living to living matter.

In this talk, I will present a mathematical framework for modeling the dynamics of active droplets, using both the phase-field formulation (via the Cahn–Hilliard equation) and the sharp-interface limit (described by the Mullins–Sekerka free-boundary problem). I will explore the connection between these two approaches and discuss the well-posedness and stability of the resulting models, focusing on planar and radial configurations. Finally, I will present numerical simulations that support the asymptotic analysis and highlight complex behaviors such as droplet division and shell formation.