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Instabilities and pattern formation in active particle suspensions[1]

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Suspensions of swimming microorganisms are characterized by complex dynamics involving strong fluctuations and large-scale correlated motions. These motions, which result from the many-body interactions between particles, are biologically relevant as they impact mean particle transport, mixing and diffusion, with possible consequences for nutrient uptake. Using direct numerical simulations, I first investigate aspects of the dynamics and microstructure in suspensions of interacting self-propelled rods at low Reynolds number. A detailed model is developed that accounts for hydrodynamic interactions based on slender-body theory. It is first shown that aligned suspensions of swimming particles are unstable as a result of hydrodynamic fluctuations. In spite of this instability, a local nematic order persists in the suspensions over short length scales and has a significant impact on the mean swimming speed. Consequences of the large-scale orientational disorder for particle dispersion are discussed and explained in the context of generalized Taylor dispersion theory. Dynamics in thin liquid films are also presented, and are characterized by a strong particle migration towards the interfaces. The results from direct numerical simulations are then complemented by a kinetic model, in which the dynamics are captured using a continuity equation for the particle configurations, coupled to a mean-field description of the flow arising from the active stress exerted by the particles on the fluid. Based on this model, the linear stability of both aligned and isotropic suspensions is revisited. In aligned suspensions, the instability observed in the simulations is predicted to occur at all wavelengths, a result that generalizes previous predictions by Ramaswamy et al. (2002). In isotropic suspensions, an instability for the active particle stress is also found to exist, in which shear stresses are eigenmodes and grow exponentially at long scales. Non-linear effects are also investigated using numerical simulations in two-dimensions. The results of the stability analysis are confirmed, and the long-time non-linear behavior is shown to be characterized by strong density fluctuations, which appear to be driven by the active stress instability.

[1]This work is in collaboration with Michael Shelley (NYU)