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Andreas Acrivos Dissertation Prize Lecture: Phytoplankton in Flow

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Phytoplankton are small, unicellular organisms that form the base of the marine food web and are cumulatively responsible for half the global oxygen production. While phytoplankton live in an environment characterized by ubiquitous fluid flow, the impact of hydrodynamic conditions on their ecology remain poorly understood. In this talk, I report on two novel biophysical mechanisms based on the interaction between phytoplankton motility and fluid shear. First, I will consider "thin phytoplankton layers," important hotspots of ecological activity that are found meters beneath the ocean surface and contain cell concentrations up to two orders of magnitude above ambient. Using a combination of experiments, individual-based simulations, and continuum modeling, we have shown that layers can form when the vertical migration of phytoplankton is disrupted by hydrodynamic shear. This mechanism - which we call "gyrotactic trapping" - is capable of triggering thin phytoplankton layers under hydrodynamic conditions typical of the environments that often harbor thin layers. Second, I will discuss the potential for turbulent shear to produce patchiness in the spatial distribution of motile phytoplankton. Field measurements have revealed that motile phytoplankton form aggregations at the Kolmogorov scale, whereas non-motile cells do not. We propose a new mechanism for the formation of this small-scale patchiness based on the interplay of gyrotactic motility and turbulent shear. Using laboratory experiments, an analytical model of vortical flow, and isotropic turbulence generated via Direct Numerical Simulations, we found that motile phytoplankton rapidly aggregate, whereas non-motile cells remain randomly distributed. Taken together, these two mechanisms demonstrate that the interaction of cell motility with flow plays a fundamental role in phytoplankton ecology and, as a consequence, can contribute to shape macroscale characteristics of the ocean.