Research Statement

Research accomplishments

Overview. My research has focused on understanding the impact of flow physics on the biological and ecological functions of cilia and ciliated systems. Using analytical and computational methods, I develop mathematical models for ciliary motion in microorganisms and analyze how cilia interactions with the surrounding fluid dictate the performance of the microorganism in generating feeding currents and transporting nutrients and dissolved particles. I am currently seeking a postdoctoral position that allows me to delve more into studying the physics of biological systems.

Comparative Study of Nutrient Acquisition Strategies in Single-cell Cilites. Nutrient acquisition is crucial and challenging for oceanic microbes, particularly given the sporadic distribution of nutrient particulates within oceanic environments. Some oceanic protists enhance their feeding rates by coordinating the motion of their hair-like appendages, such as cilia and flagella. These protists face an evolutionary dilemma: whether to actively swim towards nutrient-rich regions or to attach themselves to substrates and create feeding currents to capture prey. Both ”swim” and ”stay” strategies are observed in different species within natural communities, with previous studies suggesting each strategy as an optimal nutritional approach. To address this debate from a fluid dynamics perspective, I explore the following questions: **(Q1)** What are the flow features around a sessile ciliates compared to motile ciliates? **(Q2)** How do cilia-driven flow affect the nutrient transport and consequently the feeding rate of ciliated microorganisms? **(Q3)** Do model predictions align with natural biological observations?

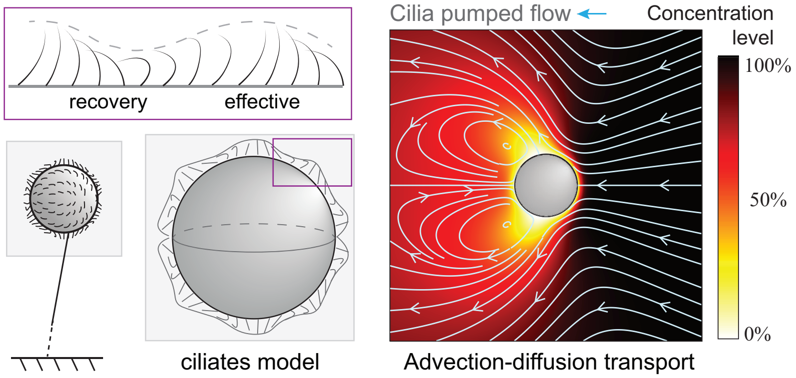

Figure 1: **Model sessile ciliates.** Streamlines (arrow lines) of surrounding fluid flow and the corresponding nutrient concentration field (colormap) by advection-diffusion transport.

(Q1) I developed a mathematical model for sessile ciliated microorganisms based on the classic Blake's envelope model. This model considers the organism as a spherical shape with periodic surface velocity (see Fig.1). The surrounding flow field is analytically obtained by solving the Stokes equation and analyzed through decomposition in spherical harmonics. **(Q2)** The surrounding nutrient concentration field is modeled by an advection-diffusion process, and the feeding rate is estimated by using Fick's law for diffusion phenomena. Through asymptotic analysis and numerical computations, I explored feeding behavior under extreme Péclet numbers to determine the optimal cilia-driven surface motion that maximizes feeding rates. This result is consistently confirmed by a backward PDE-constrained optimization problem using the adjoint method [1]. **(Q3)** I conducted a comprehensive review of biological data to validate model predictions against real ciliate shapes and flow data. Notably, I found that feeding rates are asymptotically equivalent at high Péclet numbers for both motile and sessile ciliates, providing insights into the optimal nutrient acquisition strategy [2]. Additionally, I compared established models such as the Stokeslet model and rigid sphere model to investigate