Passive hydrodynamic adaptations of *Euplectella aspergillum*

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Abstract

Euplectella aspergillum, a deep-sea hexactinellid sponge that is often called Venus' flower basket, has long intrigued biologists and engineers for its remarkable skeletal architecture and survival strategies in harsh abyssal environments. This presentation is organized in two consequent steps. First, we summarize published work by our group on passive adaptations of the skeletal motifs of this organism to local hydrodynamic conditions. Second, we present preliminary results on hydrodynamic interactions between multiple sponges to explore the broad question about hydrodynamic advantages of life in a group for sessile deep-sea organisms. Both these efforts are supported by state-of-the-art computational mechanics research through the Lattice Boltzmann method. Specifically, we conduct high-performance computing (HPC) simulations on digital twins of *E. aspergillum* with sub-millimeter resolution at different Reynolds numbers. Each simulation resolves more than 10 Giga lattice sites and exploits hybrid CPU-GPU parallelization on Leonardo supercomputing facility. The first set of results have been published in three recent papers (Falcucci et al. Nature 595.7868 (2021): 537-541; Falcucci et al. Nature 603.7902 (2022): E26-E28; Falcucci et al. Physical Review Letters 132.20 (2024): 208402.). Overall, these studies show that the complex, beautiful structure of the Venus' flower basket is not just for mechanical strength as previous research suggests, but also an incredible example of biomimetic fluid dynamics optimization. The porous, hierarchical structure significantly reduces the overall drag force exerted by the surrounding flow on the sponge, helping it withstand the deep-sea environment. The skeleton's design supports the formation of coherent internal recirculation patterns within the body cavity, even at low flow velocities. These flow patterns are crucial for the sponge's ability to live in the low-nutrient abyss, as they are beneficial for selective filter feeding and sexual reproduction by increasing the residence time of water and particles inside the body. One can argue that the sponge is

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some form of highly efficient passive flow-diverting machine that ensures a steady supply of nutrients and gametes with minimal energy expenditure. The second set of results is ongoing work on two different two-sponge layouts: in-line, where an organism lies downstream of another, and side-by-side, where specimens are aligned with respect to the fluid flow. Our preliminary simulations uncover a striking form of hydrodynamic entanglement that arises from purely passive interactions. In the in-line configuration, the upstream sponge generates an extended low-velocity wake that envelopes the downstream sponge. Contrary to expectations, this shielding does not impair internal recirculation within the upstream sponge and the downstream sponge experiences dramatic gains. Hydrodynamic loading is equally affected. While upstream and side-by-side organisms experience a hydrodynamic drag comparable to isolated specimens, the downstream sponge undergoes a remarkable drag reduction. Side-by-side arrangements exhibit milder but still positive hydrodynamic consequences: gap flow between organisms increases water admission in both sponges, with limited impact on hydrodynamic loads.