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Hydrodynamic Performance of *Euplectella aspergillum*: Simulating Real Life Conditions in the Abyss

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Abstract. We detail some of the understudied aspects of the flow inside and around the Hexactinellid Sponge *Euplectella aspergillum*. By leveraging the flexibility of the Lattice Boltzmann Method, High Performance Computing simulations are performed to dissect the complex conditions corresponding to the actual environment at the bottom of the ocean, at depths between 100 and 1,000 m. These large-scale simulations unveil potential clues on the evolutionary adaptations of these deep-sea sponges in response to the surrounding fluid flow, and they open the path to future investigations at the interface between physics, engineering and biology.

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Key words: Lattice Boltzmann method, fluid-structure interaction, sponge hydrodynamics, high performance computing, complex boundary conditions.

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1 Introduction

Discovered at the end of the XIX Century [1, 2], the silica sponge *Euplectella aspergillum* has seized the attention of scientists ever since, for its remarkable structural properties and mesmerizing beauty. The skeletal system of this hexactinellid sponge, in fact, is characterized by a regular and hierarchical cylindrical lattice, which confers flexibility and resistance, notwithstanding its composition of amorphous hydrated silica [3–6]. Despite such a long-standing interest in the structural properties of these dwellers of the abyss, the study of the hydrodynamic fields surrounding the glass sponge has remained largely unexplored until very recently, [7].

In [8], some of these authors have conducted massively-parallel fluid dynamic simulations [9] using the Lattice Boltzmann Method (LBM) [10], to explore the role of the sponge skeletal structure for different values of the external velocity, corresponding to different Reynolds numbers. For the first time, compelling evidence was provided that the skeletal structure of *E. aspergillum* delivers a twofold benefit to the organism, by reducing the hydrodynamic drag and increasing the residence time inside the sponge body cavity, thereby enhancing the possibility of selective filter feeding and sexual reproduction.

In this paper, we provide additional details to the investigation in [8] along three main directions: i) we present new insights on the local, micro-scale features of the flow through *E. aspergillum* skeleton; ii) we clarify the possibility of employing different characteristic residence times within the body cavity; and iii) we offer further evidence to the complexity of the fluid motion within the body cavity and its connection to the technical literature on deep-sea sponges. The proposed results unveil potential clues on the evolutionary strategy that has led to the formation of such a complex structure, driven by stimuli from the surrounding hydrodynamic environment.

2 Reconstruction of *E. aspergillum* skeletal structure

E. aspergillum exhibits a remarkably beautiful skeletal structure, characterized by a complex hierarchical architecture, [3], which can be schematized in four main parts: i) the bottom bulb, which anchors the sponge to the sea floor, ii) the main cylindrical body, iii) a curved section connecting the two, and iv) the sieve plate at the top of the structure, called *osculum* (see Fig. 1(a)). In [8], we accurately described the process of creating five digital mock-ups: one corresponding to the complete geometry of the deep-sea sponge and four simplified models derived from its main body.

The complete geometry has been rendered with a resolution of 200 μm, reproducing the primary and secondary patterns of external ligaments and the helical ridges that decorate its outer surface. Concerning the four simplified models, two solid (a smooth cylinder and a cylinder with helical ridges) and two porous (hollow cylindrical lattice and hollow cylindrical lattice with helical ridges) geometries were generated, as reported in Fig. 1(b).