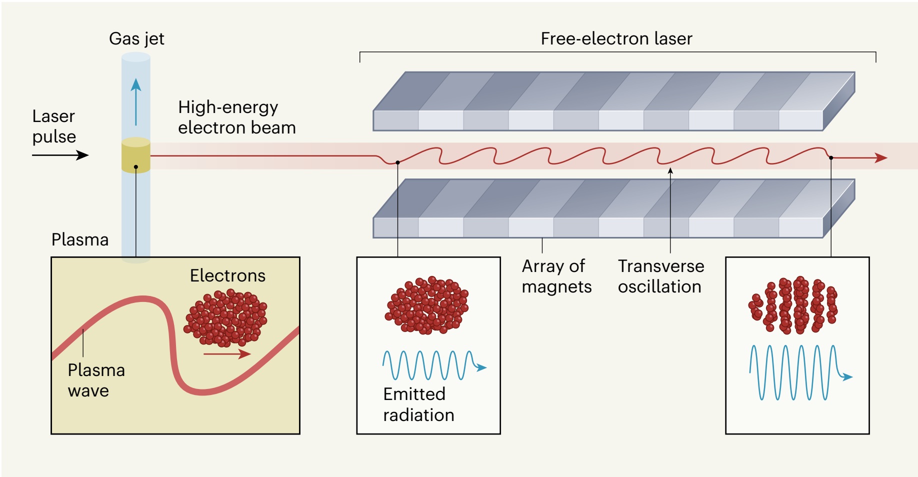

Figure 1 | A free-electron laser driven by electrons accelerated in a laser-excited plasma wave. Wang *et al.*[5] fired a laser pulse at a gas jet to produce an ionized gas called a plasma. Electrons in the plasma were accelerated as they 'surfed' an electromagnetic wave known as a plasma wave. The authors directed the resulting high-energy electron beam into a light source called a free-electron laser, which comprises an array of magnets of alternating polarity (indicated by the two shades of grey). These magnets caused the beam to oscillate transversely and emit radiation. Initially, the electrons were randomly distributed and generated low-amplitude light. However, when leaving the magnets, the electrons were bunched into regions about the size of the radiation wavelength and emitted high-amplitude light. This demonstration shows that high-energy electron beams for free-electron lasers can be produced in compact set-ups (Wang and colleagues' set-up was about 12 metres long), rather than requiring particle accelerators several hundred metres to a few kilometres in length.

centimetres instead of a few kilometres.

A plasma wave can be excited by a laser pulse or the electron beam itself. Indeed, it is possible to shape the beam current in such a way that one part of the beam excites the wave, which then accelerates a second part of the same beam. Both approaches were explored previously, and enormous field strengths, similar to those predicted[6], were demonstrated[7,8]. But one of the missing ingredients to drive FELs successfully using these beams concerned the beam quality. Specifically, the energy difference between the electrons was too large, and the emitted radiation behaved as though generated by randomly distributed electrons, rather than by electrons bunched into regions about the size of the radiation wavelength, for which the light amplification is several orders of magnitude larger.

Various teams are concentrating on finding the conditions for stable and reliable acceleration of an electron beam that is sufficiently monochromatic for FEL amplification[9]. Wang *et al.* have demonstrated, for the first time, that this amplification can be achieved using electrons accelerated in a laser-excited plasma wave (Fig. 1). The authors produced the plasma wave by firing a laser pulse at a gas jet that had a diameter of only 6 mm. By manipulating the density of the gas, they shaped the plasma density along the acceleration direction and loaded electrons from the plasma into the accelerating phase of the plasma wave. This technique ensured that the generated beam, with an energy of about 0.5 GeV, was of sufficient quality to amplify radiation in an extreme-ultraviolet FEL at an output wavelength of 27 nm.

The performance of Wang and colleagues' FEL cannot yet match that available in existing FEL facilities that produce radiation at similar wavelengths[1,10]. However, this laser represents a technological breakthrough, and its stability, reproducibility and efficiency in transferring energy from the electron beam to the radiation will probably be improved in the future. The authors' experiment paves the way for FELs driven by extremely compact accelerators[11], which could be managed in university-scale facilities. One of the requirements for a new tool that will favour discoveries is its availability, and this work promises to increase the availability of FEL light in the world.

Luca Giannessi is at the FERMI FEL facility, Elettra Synchrotron Trieste, 34149 Basovizza, Trieste, Italy, and at the National Institute for Nuclear Physics, National Laboratory of Frascati, Frascati, Italy.
e-mail: luca.giannessi@elettra.eu

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Biomechanics

Fluid flow through Venus's flower basket

Laura A. Miller

Sophisticated numerical simulations reveal that the beautiful structure of a sponge known as Venus's flower basket reduces hydrodynamic drag, and probably aids the capture of food particles, as well as sperm for sexual reproduction. **See p.537**

The deep-sea sponge *Euplectella aspergillum*, also known as Venus's flower basket, is celebrated for its intricate glass skeleton. This structure provides remarkable mechanical support and has inspired a generation of strong, lightweight bridges and skyscrapers[1]. Water is continuously drawn into and out of the sponge's central body cavity through pores, to filter food particles and exchange gases. Although the mechanical properties of the sponge's skeleton are well documented, little is known about the detailed fluid flows around and through the organism. On page 537, Falcucci *et al.*[2] use state-of-the-art fluid-dynamics simulations to resolve these flows. Their results show that the sponge's structural elements reduce the impact of hydrodynamic forces on the organism and generate internal circulation patterns that might be used for feeding and sexual reproduction.

The skeleton of *E. aspergillum* consists of a regular square lattice that is diagonally reinforced and forms scaffolding for the sponge's hollow cylindrical body[3] (Fig. 1). In addition, external ridges spiral around

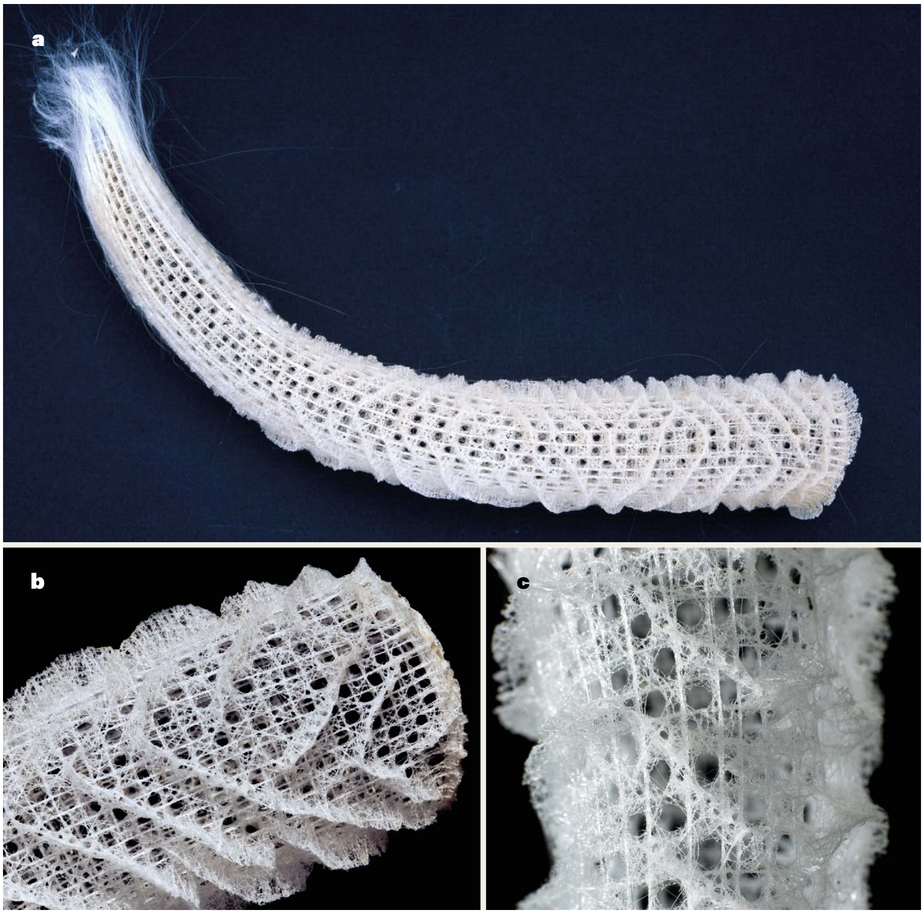

Figure 1 | Venus's flower basket. a, Falcucci *et al.*[2] used sophisticated fluid-dynamics simulations to study fluid flows through and around the intricate skeleton of a deep-sea sponge known as Venus's flower basket. The tubular skeleton can be up to 250 millimetres long. **b**, External ridges spiral around the main body of the sponge. The authors found that these ridges generate low-speed flow structures in the body cavity that probably enhance the capture of food particles. **c**, The ridges are superimposed on a regular square lattice that is diagonally reinforced. Falcucci and colleagues discovered that this porous skeleton reduces hydrodynamic drag, boosting the organism's robustness to strong ocean flows.

A, J. M. BARRES/ALAMY; B, DIRK WIERSMA/SPL; C, SPL/ALAMY

the main body and are superimposed on the lattice. To deconstruct the effect of each skeletal component on the fluid flows, Falcucci and colleagues generated several idealized models of the sponge for comparison. These models included a plain solid cylinder, a solid cylinder with helical ridges, a hollow cylindrical lattice and a hollow cylindrical lattice with helical ridges.

Determining the fluid flows for these different models required extremely accurate fluid-dynamics simulations. These can simultaneously resolve a level of detail from the microscopic flows around the skeleton all the way up to the bulk flows around the entire organism. To make these *in silico* experiments feasible, Falcucci *et al.* numerically solved the equations that govern such flows using a method that lends itself particularly well to parallel computing on electronic circuits called graphics processing units[4]. Moreover, the authors ran the simulations on Marconi100, one of the most powerful supercomputers in the world (see go.nature.com/3hzrzjp).

It is well documented that, in water flows of 1–10 centimetres per second or more, solid cylinders roughly the size of *E. aspergillum* undergo vortex shedding[5] — a process in which repeating patterns of swirling vortices form on the downstream side of an object. This phenomenon results in large velocity fluctuations in the wake of the cylinder, as well as varying and increased hydrodynamic drag. Falcucci and colleagues' *in silico* experiments showed that a hollow cylindrical lattice acts as a porous object that suppresses such velocity fluctuations and decreases drag. Given that hydrodynamic forces can be powerful enough to dislodge a sea sponge, reduced drag improves the organism's robustness in the presence of strong flows.

The authors also found that the inclusion of helical ridges generates low-speed vortical structures in the cylinder's central cavity. For *E. aspergillum*, such flow structures probably improve the capture of food particles by increasing the rate of encounters between plankton and the sponge's body cavity. Similarly, these structures could increase the contact between free-swimming sperm and retained eggs, thereby boosting reproductive efficiency.

Although these *in silico* experiments have greatly advanced what is known about fluid flow through *E. aspergillum*, there is still much that is not understood. For instance, Falcucci *et al.* were able to show that the sponge's external helical ridges increase the residence time of particles in the central cavity. However, the extent to which this aids food uptake and gas exchange has not been quantified. Future work should consider how the low-speed vortical structures in the cavity might selectively filter particles of specific shapes and sizes.

Furthermore, it is not yet understood how cells that actively drive fluid flow through the sponge by beating their hair-like extensions (flagella) interact with the environmentally driven flows. The *in silico* experiments also assumed that the oncoming flow is steady and that the sponge is rigid. Deformations of the sponge in unsteady currents probably produce hydrodynamic forces that are different from the simplified case considered by the authors.

This work provides a striking example of how state-of-the-art numerical simulations can be used to explore problems in areas such as biomechanics, fundamental fluid dynamics and bioinspired design. Falcucci and colleagues' results suggest that many of the complex structures seen in marine invertebrates and other organisms have non-intuitive consequences for fluid dynamics. The authors' approach could be applied to a vast array of puzzles in nature related not only to food filtering, gas exchange and drag reduction, but also to pollen capture and heat loss. For example, such multiscale flow simulations could be used to understand the hydrodynamics of gas exchange through coral reefs[6], or the aerodynamics of pollen capture[7].

Moreover, this study of Venus's flower basket reveals how complex geometries can manipulate fluid flow for multiple functions, including drag reduction, mechanical support and particle filtering. The lessons learnt from this organism could inspire improved multifunctional engineering structures, such as sampling and filtering devices.

Laura A. Miller is in the Departments of Mathematics and Biomedical Engineering, University of Arizona, Tucson, Arizona 85721, USA.
e-mail: lauram9@math.arizona.edu

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