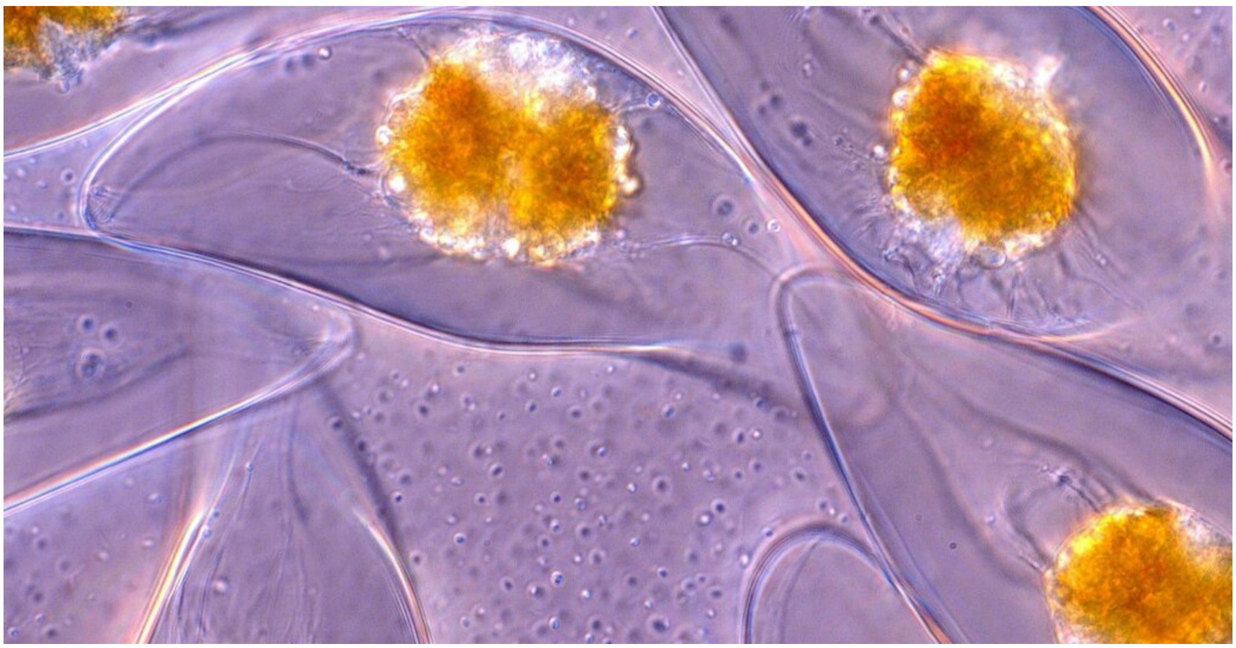
Flashes bright when squeezed tight: How single-celled organisms light up the oceans

July 6 2020



Researchers showed how a single-celled organism of the species Pyrocystis lunula produces a flash of light when its cell wall is deformed by mechanical forces. Through systematic experimentation, they found that the brightness of the flash depends both on the depth of the deformation and the rate at which it is imposed. Credit: Maziyar Jalaal/University of Cambridge

Research explains how a unicellular marine organism generates light as a response to mechanical stimulation, lighting up breaking waves at night.

Every few years, a bloom of microscopic organisms called dinoflagellates transforms the coasts around the world by endowing breaking waves with an eerie blue glow. This year's spectacular bloom in southern California was a particularly striking example. In a new study published in the journal *Physical Review Letters*, researchers have identified the underlying physics that results in light production in one species of these organisms.

The international team, led by the University of Cambridge, developed unique experimental tools based on micromanipulation and high-speed imaging to visualize light production on the single-cell level. They showed how a single-celled organism of the species Pyrocystis lunula produces a flash of light when its cell wall is deformed by mechanical forces. Through systematic experimentation, they found that the brightness of the flash depends both on the depth of the deformation and the rate at which it is imposed.

Known as a 'viscoelastic' response, this behavior is found in many complex materials such as fluids with suspended polymers. In the case of organisms like Pyrocystis lunula, known as dinoflagellates, this mechanism is most likely related to ion channels, which are specialized proteins distributed on the cell membrane. When the membrane is stressed, these channels open up, allowing calcium to move between compartments in the cell, triggering a biochemical cascade that produces light.

"Despite decades of scientific research, primarily within the field of biochemistry, the physical mechanism by which fluid flow triggers light production has remained unclear," said Professor Raymond E. Goldstein, the Schlumberger Professor of Complex Physical Systems in the Department of Applied Mathematics and Theoretical Physics, who led the research.

"Our findings reveal the physical mechanism by which the fluid flow triggers light production and show how elegant decision-making can be on a single-cell level," said Dr. Maziyar Jalaal, the paper's first author.

Bioluminescence has been of interest to humankind for thousands of years, as it is visible as the glow of night-time breaking waves in the ocean or the spark of fireflies in the forest. Many authors and philosophers have written about bioluminescence, from Aristotle to Shakespeare, who in Hamlet wrote about the 'uneffectual fire' of the glow-worm; a reference to the production of light without heat:

"...
To prick and sting her. Fare thee well at once.
The glowworm shows the matin to be near,
And 'gins to pale his uneffectual fire.
Adieu, adieu, adieu. Remember me."

The bioluminescence in the ocean is, however, not 'uneffectual.' In contrast, it is used for defense, offense, and mating. In the case of dinoflagellates, they use light production to scare off predators.

The results of the current study show that when the deformation of the cell wall is small, the light intensity is small no matter how rapidly the indentation is made, and it is also small when the indentation is large but applied slowly. Only when both the amplitude and rate are large is the light intensity maximized. The group developed a mathematical model that was able to explain these observations quantitatively, and they suggest that this behavior can act as a filter to avoid spurious light flashes from being triggered.

In the meantime, the researchers plan to analyze more quantitatively the distribution of forces over the entire cells in the fluid flow, a step towards understanding the light prediction in a marine context.

Other members of the research team were postdoctoral researcher Hélène de Maleprade, visiting students Nico Schramma from the Max-Planck Institute for Dynamics and Self-Organization in Göttingen, Germany and Antoine Dode from the Ècole Polytechnique in France, and visiting professor Christophe Raufaste from the Institut de Physique de Nice, France.

More information: Stress-Induced Dinoflagellate Bioluminescence at the Single Cell Level, *Physical Review Letters* (2020). DOI: 10.1103/PhysRevLett.125.028102

Provided by University of Cambridge