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The artistry of dinoflagellate bioluminescence[☆]

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Abstract

Dinoflagellates are unicellular organisms responsible for many spectacular displays of coastal bioluminescence. This phenomenon is both scientifically interesting and aesthetically beautiful. As part of my efforts to communicate my science to the general public, I developed an Artist-in-Residence program, offering artists the opportunity for direct collaborations to develop creative approaches for displaying bioluminescence. I provide the resources of my laboratory, including space, living organisms, camera equipment, and scientific equipment as appropriate. The artist benefits from my expertise in working with dinoflagellates, and I mentor the resident artist in techniques most effective for a particular project. The results of these collaborations have included works that involved photography, video, and live installations, with exhibits in Paris, Los Angeles, and Milan. Art and science aim to help us experience and understand the world around us. An artistic approach for science outreach provides an aesthetic experience that highlights the beauty of nature and creates opportunities to teach science.

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1. Introduction

"... on one very dark night, the sea presented a wonderful and most beautiful spectacle. There was a fresh breeze, and every part of the surface, which during the day is seen as foam, now glowed with a pale light. The vessel drove before

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her bows two billows of liquid phosphorus, and in her wake she was followed by a milky train. As far as the eye reached, the crest of every wave was bright, and the sky above the horizon, from the reflected glare of these vivid flames, was not so utterly obscure, as over the rest of the heavens." Charles Darwin, December 1833 [1].

The bioluminescence of marine dinoflagellates, common unicellular organisms, is known all over the world and commonly seen from ships and along the shore. In some places, like the bioluminescent bays of Puerto Rico, these displays can be spectacular and persist throughout the year. In Southern California, when dinoflagellates are abundant they can cause events called red tides, coloring the water by day and creating beautiful bioluminescence at night.

The ecological function of dinoflagellate bioluminescence is to startle a potential predator or act as a light alarm to attract a predator of the dinoflagellate predator, as in a burglar alarm. But any flow condition with sufficient levels of mechanical force will stimulate their bioluminescence [2]. So waves, flow along moving objects, or surge contain sufficient forces to stimulate bioluminescence [3]. Our previous research has examined the levels of mechanical forces required to stimulate bioluminescence, first using populations of cells within fully characterized flow conditions [4-6] and more recently for individual cells studied using microfluidics and atomic force microscopy [7, 8]. Light originates from microsources within each dinoflagellate cell called scintillons, vesicles containing the luminescent chemistry [9, 10]. The chemical reaction producing the light is activated by a rapid and complex series of biochemical and electrical steps that comprise the bioluminescence signaling pathway. The entire pathway, from mechanical stimulation to light production, is extremely rapid with a duration of less than 20 ms [7, 11, 12]. Our current research is investigating the signaling proteins involved in this pathway, in the process identifying elements of mechanical sensing that have been conserved in higher organisms [13].

In our research we were inspired by the work of Leonardo da Vinci, who more than 500 years ago examined the flow of moving water by throwing grass seeds to visualize the intricacies of the flow. Now we use dinoflagellate bioluminescence to visualize flows. In one project we used dinoflagellate bioluminescence to examine forces within breaking waves [14]. Individual waves were created in a flow channel at Scripps Institution of Oceanography. By seeding the volume with dinoflagellates, the breaking wave created flow conditions that stimulated bioluminescence, as imaged by a low light camera system mounted on a robotic sled that tracked the moving wave. From this and related work [15] it was possible to determine the mechanical forces within breaking waves, and the contribution of bubbles created in the air cavity of the spilling wave.

In another project we used bioluminescence to visualize the flow around moving dolphins [16]. Based on video images of trained dolphins, we were able to study the boundary layer properties of the dolphin, telling us how streamlined was the animal based on the amount of stimulated bioluminescence. When the study was published, the cover image featured our image of the dolphin stimulated bioluminescence, along with a copy of the 1923 woodcut print *Dolphins in Phosphorescent Sea* by the Dutch artist M. C. Escher showing his representation of dinoflagellate bioluminescence caused by dolphins swimming by the bow of a boat.

Other artists have depicted bioluminescence, including Andrew Wyeth in a 1944 painting *Night Hauling* showing bioluminescence stimulated by the hauling of a lobster trap, and *Phosphorescence* by Mindy Dwyer depicting the luminescent wake of a boat.

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