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Journal

Materials Today:Proceedings, 4(4A)

Author

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Publication Date

2017



The Living Light Conference 2016

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 working 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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Selection and Peer-review under responsibility of The Living Light Conference (May 4 – 6) 2016, San Diego (USA).

Keywords: art, bioluminescence, dinoflagellate

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.

2. Objectives

These examples demonstrate the artistic interest in bioluminescence, and that our research generated imagery that was aesthetically beautiful. But could art directly contribute to the communication of science? With that goal in mind, I created an Artist in Residence program, with the goal of using art as an approach for communicating science to the public. This involved direct collaboration with artists to develop creative concepts in displaying bioluminescence that went beyond our scientific approaches. I provided 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, using techniques that I have developed over several decades for best obtaining bioluminescence images. The results of these collaborations have included works that involve photography, video, and live installations, with exhibits in Paris, Los Angeles, Venice Italy, and London.

3. Results of artist collaborations

Transdisciplinary artist Erika Blumenfeld was the first Artist-in-Residence in my laboratory. In 2001 Blumenfeld contacted me after learning about my interest in the synergy between art and science. At the time she was investigating the use of single-celled bioluminescent organisms for a large-scale installation and asked if we could start a dialogue. Blumenfeld's art practice up to that point was primarily focused on a reductive approach to imaging light, using a self-built camera without a lens to, as she says, "capture the essence of light as both medium and subject." In Blumenfeld's first residency, her research inquiries were primarily to learn how to work with the organisms and understand their light cycle. Her residency period resulted in initial drawings and animated renderings that illustrated her ultimate vision to produce a live installation. She additionally created a series of works capturing the patterns created by dinoflagellate bioluminescence stimulated by bubbles (Fig. 1). This approach was inspired by my earlier unpublished work with James Case where we examined bioluminescence stimulated by various bubble sizes. Blumenfeld found during her testing that when the machine was nearly turned off and there was only one bubble at a time being produced, the glow from the bioluminescence was more sustained and gradual, producing the effect she was trying to achieve for her work. My research colleagues and I later studied bubble stimulated bioluminescence, quantifying the light production by single bubbles and bubble clouds [17].

Blumenfeld returned for a second residency in 2011. She contacted me with an interest in producing a new series of works for an exhibition that would focus on artists in collaboration with scientists to produce work that related to issues of climate change. Blumenfeld imaged bioluminescence created in a flow agitation chamber used by U.S. Navy oceanographers who survey bioluminescence in the world's oceans. Her interest was focused on wanting to image controlled populations of organisms in motion in order that she could capture the light expression of an individual bioluminescent organism as well as larger concentrations of organisms (Fig. 2). We tested both the speed of the flow through the chamber and the number of organisms within the population in order to achieve her vision. My research colleagues and I later published our scientific results using the identical apparatus [18].

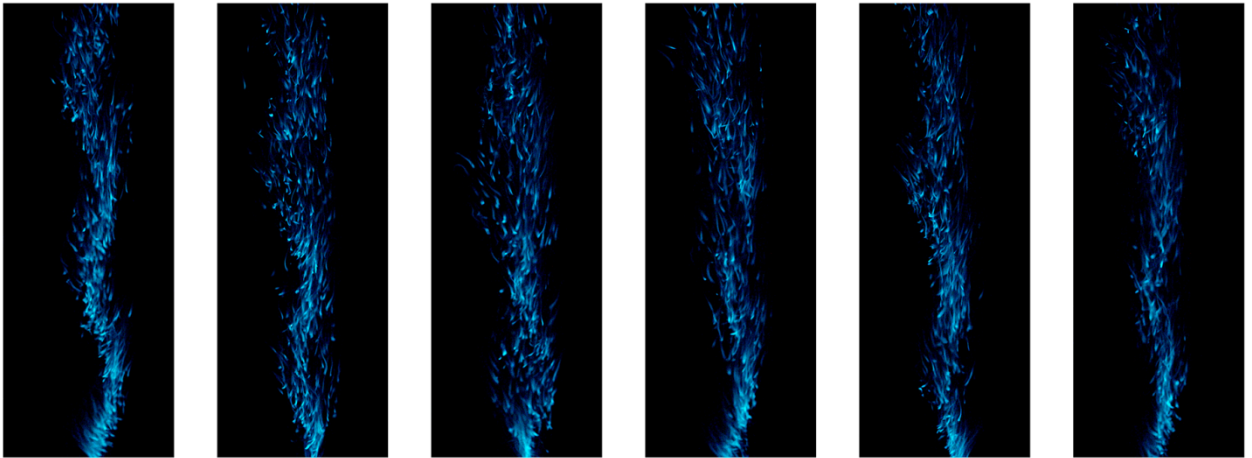


Fig. 1. Erika Blumenfeld, *Living Light No.1 (Pyrocystis Fusiformis)*, 2001/2004, Digital pigment print, 24x60 inches, Published by Santa Fe Editions. Copyright: Erika Blumenfeld. Published with permission.

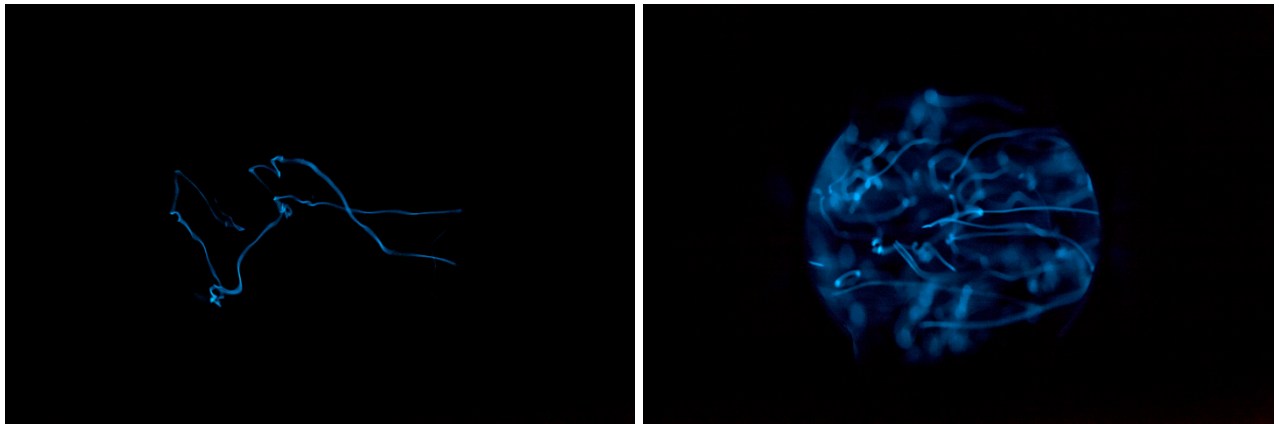


Fig. 2. (Left) Erika Blumenfeld, *Bioluminescence Vol. 1 (Pyrocystis Fusiformis)*, 2011. From a suite of 8 digital pigment prints housed in an embossed handmade portfolio box, 17x22 inches. (Right) Erika Blumenfeld, Still from *Moving Light: Bioluminescence*, 2011. Video installation (00:11:00, looped, silent), Dimensions variable. Copyright: Erika Blumenfeld. Published with permission.

Blumenfeld also created striking images of bioluminescence “galaxies”, showing glowing streaks reminiscent of NASA depictions of the cosmos (Fig. 3). Each image was unique. Those images depicted bioluminescence from within sealed bags stimulated “by the artist’s own hand”, according to Blumenfeld. These bags are used as educational materials by the Birch Aquarium at Scripps and elsewhere, including a bioluminescence exhibit at the Las Cabezas de San Juan nature reserve in Puerto Rico that is adjacent to a bioluminescent bay. Blumenfeld’s photographic and video imagery were shown in 2012 at the Fondation EDF Espace Electra’s exhibition titled “CARBON 12” in Paris, France. Our collaboration focused on bioluminescence as a proxy of phytoplankton, and we discussed the impacts of climate change on global phytoplankton populations and bioluminescent bays. The exhibition culminated in many publications [19-22] as well as a presentation made at a forum at the UNESCO Headquarters in Paris titled “Climate as Culture: Art, Imagination and Social Change.”

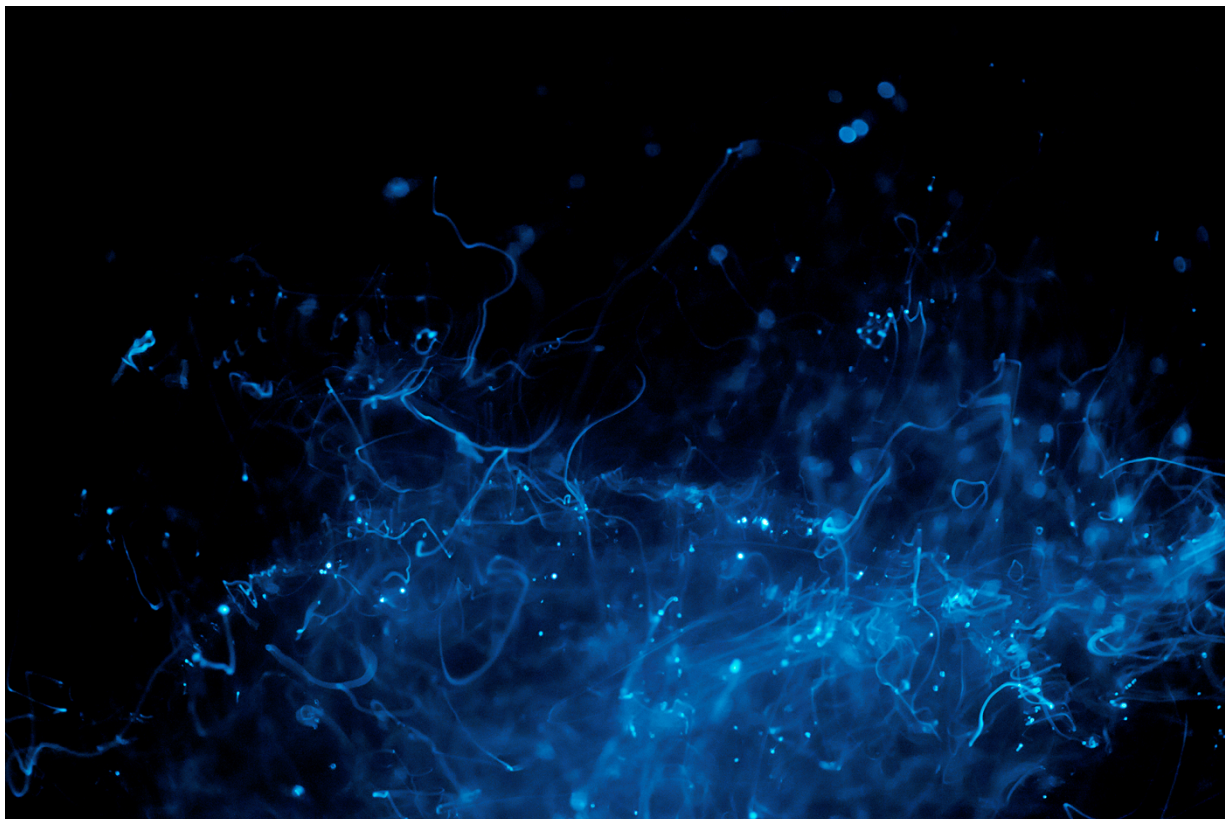


Fig. 3. Erika Blumenfeld, *Living Light No. 4 (Pyrocystis Fusiformis)*, 2011, Digital pigment print, 40x60 inches. Copyright: Erika Blumenfeld. Published with permission.

Glenn Kaino, a Los Angeles based artist who had earlier visited Scripps because of his interest in exploring a live coral-based art piece, contacted me about collaborating on an exhibit for GLOW Santa Monica, a public art festival held around the Santa Monica pier in Los Angeles that attracts hundreds of thousands of people [23]. Kaino was one of 15 artists selected to participate in what was described as “an all-night cultural experience featuring original commissions... [of] thoughtful and participatory artworks”. We decided on a live bioluminescence exhibit, titled *Well*, involving a wishing well made out of transparent acrylic that was filled with luminescent dinoflagellates. So late one afternoon in September of 2013, we filled up the well, located on the beach near the Santa Monica pier, with aquarium grade saltwater and then large volumes of dinoflagellate cultures. A live bioluminescence concept is extremely risky, especially one held outside under the elements and having never been tested before. After we filled up the well we waited for darkness, not knowing how successful the concept would be. It worked like a charm! Throngs of people queued up; when it was their turn people walked up to the well, paused in reflection as though making a wish, and then threw coins into the well. It was as though their wishes were validated by the bright bioluminescence stimulated by the coins as they hit the water and fluttered down to the bottom out of sight. That night we collected several hundred dollars in coins, which were donated to the local conservation group Save the Bay.

London-based artist Iyvone Khoo, after frustrating attempts in trying to work with dinoflagellate bioluminescence on her own, spent several weeks at Scripps as an Artist in Residence in 2014 to obtain imagery for the MEAD Fellowship project installation called *Ara*

Lucidas, described as a light altar consisting of Venetian glass sculpture with projected video including bioluminescence (Fig. 4). The work was a response to the Gothic theme of the 56th Venice Biennale in Glasstress Gotika.



Fig 4. Iyvone Khoo, *Ara Lucidas*, 2015. Venetian glass with lighting and video projection. Copyright: Iyvone Khoo. Published with permission.

Khoo was so inspired by this experience that she returned for a second residency in 2015. For the first time she obtained ultra high definition video of dinoflagellate bioluminescence at high magnification without using a microscope, and through innovative techniques created striking spatial patterns of bioluminescence (Fig. 5). This footage is being incorporated into a ‘sensorial space’ called *Infinity Cube*, consisting of video projections of bioluminescence accompanied by soundscapes. *Infinity Cube* will be displayed at the Birch Aquarium at Scripps in spring 2017.

During her residency, Khoo explored different ways of using sound to stimulate dinoflagellate bioluminescence. The aim of the experiment is to facilitate a hypothetical conversation between man and nature for an interactive viewer experience: “What if we could understand nature’s light language? What if the message is imperative for human survival? How can we facilitate this communication?” Through this residency, Khoo realized that the synergy between art and science allows the right conditions for inspiration and exploration. According to Khoo, “It is both humbling and inspiring to think that 50% of the world’s oxygen originates from tiny, beautiful, precious plankton and I am extremely fortunate to be able to contribute to the promotion of respect and appreciation of our natural world through the work that I do.”

The idea of creating bioluminescence through sound was independently developed by communication design student Jack Smith of Central Saint Martins, University of the Arts

London, who came as an Artist-in-Residence in 2016 after also being frustrated by the difficulty in working with live dinoflagellates in his London flat. “I was first grasped by a vision from synthetic biologists that suggested that genetically engineered trees could replace street lamps as an ecological alternative to electricity. I began to speculate on potential applications for bioluminescence in our future societies. I had been interested in using sound to shape form through cymatic experiments and saw an opportunity to use vibration to stimulate patterns of light. I was curious to know, would the algae dance to the rhythms of music in the same ways which water does? Using synthesizers to gain full control over the visual displays we collaboratively created a series of imagery and films; this enquiry has opened up room for further investigation in to the behavior of the micro-algae and the properties and potential use of bioluminescence for me.” (Fig. 6).

4. Conclusions

These examples demonstrate that art is an effective way to communicate science, showing the aesthetic beauty of nature without the jargon and technical details that tend to limit the effectiveness of scientists in explaining their work. Instead of telling about science, just show the phenomenon and let the viewer decide. Some will ask “what is it?”, others “why?”. Why would such small organisms, one of the ocean’s primary producers that channel the energy of sunlight into the food chain, provide such pyrotechnics? These questions provide an opportunity to educate the curious about science. For others the “wow” factor is sufficient validation that the experience was impactful.

Working with artists is a creative collaboration, not unlike working with other scientists, where each person brings expertise to a project that transcends boundaries. There is great satisfaction in creating something new and unique based on creative input and exploration. And it takes us back to the beginning of our scientific quest, to that original observation that started the whole process of scientific inquiry. I never get tired of seeing bioluminescence, yet it is our fancy instruments that remove us from that sensory experience. Working with artists provides an opportunity to re-explore our scientific roots.

One satisfying outcome of the Artist-in-Residence program has been to increase environmental awareness in the art community. For example, Erika Blumenfeld later went to Antarctica as a participant in the Interpolar Transnational Art Science Constellation (ITASC) with the South African National Antarctic Program (SANAP), obtained a Masters of Science in Conservation Studies from University College London, and is currently the lead scientist on a project at the NASA Johnson Space Center that represents a collaboration between the arts and sciences. As best said by Blumenfeld, “The point at which the wonder of natural phenomena begins to awaken the mind and imagination is the point at which art, science and humanity meet”. Science and art inspire us to understand the natural world and our place within it.

Acknowledgements

I am deeply grateful to the artists and scientists who have inspired me in my study of bioluminescence, as well as to ‘Dr.’ J. Wolf Schlossberg-Cohen for discussions of the common links between art and science, and J. Rohr, E. Blumenfeld, I. Khoo, and J. Smith for comments on the manuscript. My research has been supported by the U.S. Office of Naval Research and the National Science Foundation.

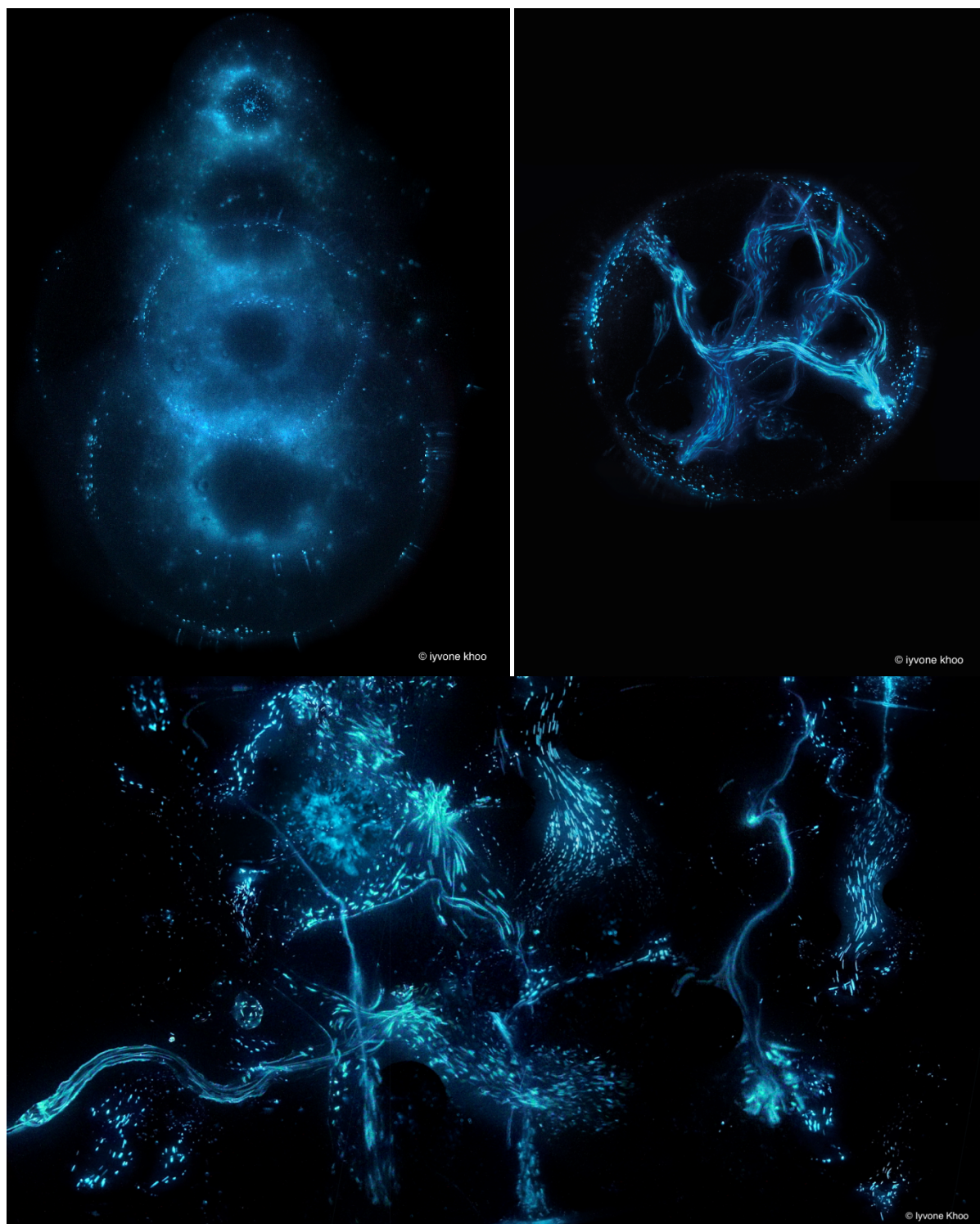
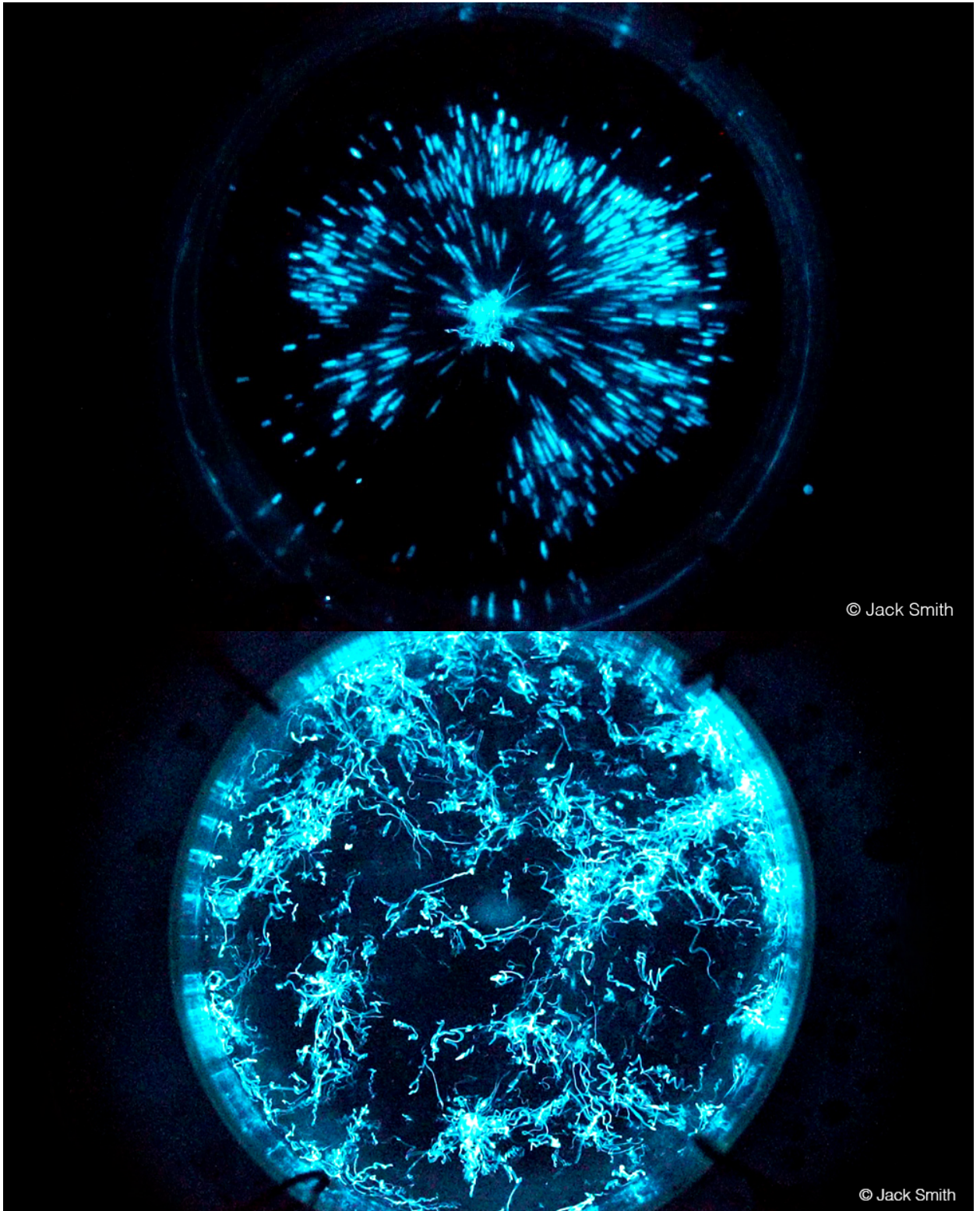


Fig 5. Images of dinoflagellate bioluminescence, by Iyvone Khoo, 2016. (Top left) *Cosmic Island*. (Top right) *Blue Noctorne, Millions of Photons*. (Bottom) *Flow*. Copyright: Iyvone Khoo. Published with permission.



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Fig. 6. Sound stimulation of bioluminescence, by Jack Smith, 2016. Stills from *Tribal Waves*. Copyright: Jack Smith. Published with permission.

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Appendix A. Artist information

More information about the artists can be found on their web sites:

Erika Blumenfeld: <http://erikablumenfeld.com>

Glenn Kaino: <http://kavigupta.com/artist/glennkaino>

Iyvone Khoo: <http://www.iyvonekhoo.co.uk>

Jack Smith: <http://jsmithcreative.co.uk>