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Swimming among the stars: an alternative perspective on the murderers from Kamchatka - dinoflagellates

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Due to the massive death of marine life in Kamchatka, unicellular algae dinoflagellates acquired the reputation of microscopic Jack the Ripper. But in reality, they are not bloodthirsty murderers at all! These tiny creatures, with their intricate structure and ability to glow in the dark, were objects of worship and heroes of legends. They were sourses of inspiration for writers and scientists, and they still are. It's just not a part of common public knowledge.

Well, it's time to change that!

Preamble

"Environmental disaster" - this is the name the journalists came up with to describe the events in Kamchatka in the fall of 2020. And this is not an exaggeration! How else can you call such a massive death of marine life? The beaches are covered with dead bodies, and people who have come into contact with seawater have reported symptoms of poisoning.

Although scientists have yet to fully understand the situation, the bad reputation has gone to dinoflagellates - microscopic unicellular algae with the ability to produce toxins. It is assumed that the abnormal abundance of these algae in the seawater caused the death of the animals[1].

But could nature really harm itself like that?

Outbreaks of uncontrolled proliferation of dinoflagellates are called "red tides". It is due to the algae's pigments, that give the water unusual shades: from brown to purple. Red tides occurred repeatedly both in Kamchatka and other places and indeed led to the poisoning of biota[2,3]. And the reason is not just toxins. Algae breathe like animals, which leads to a lack of oxygen in the water when the number of algae reaches a certain point. As a result, other organisms simply suffocate[4,5].

However, it must be clear: the possible role of dinoflagellates in these events does not take the responsibility from humans.

It was shown that the reasons behind the rapid rises in the dinoflagellates' numbers can be anthropogenic. Reproduction is facilitated by waste leaks[6], an abundance of phosphates in sewage[7], the transfer of dinoflagellates to new habitats by ships[7], climate change and ocean acidification caused by massive emissions of carbon dioxide[3,8,9].

It is not surprising that people associate dinoflagellates with poison, death, and stench after seeing photos from Kamchatka. But this impression is completely wrong.

Dinoflagellates are quite harmless. If there is something devilish in them, it is just luciferase. It only takes a single look from a different angle to be convinced.

Everyone who has looked up into the sky over the sea is familiar with a strange mixture of feelings, coming from the very depths of the soul. One can fully enjoy this beauty on a deserted beach, far from the smog of cities and the lights of civilization. In these moments comes a sudden understanding of how huge the world around us is.

But in some rare special places, it is not the sky that shines - it is the sea! As if some of the stars fell down from heaven into the seawater! No, these lights are not moon paths or reflections - they come from the depths of the ocean. Billions of tiny sparkles flash wherever the water moves: along underwater currents, around swimming fish, or stones that were thrown into the water.

Surely, such a phenomenon could not go unnoticed. Since ancient times, various sailors have been describing the glow of the seas[10]. In Crimea, people can tell a legend about these lights[11]. Once upon a time, the Greeks wanted to conquer the peninsula: they sailed at night, hoping to come ashore unnoticed. But the water under their ships turned into blue flame! Warriors of Crimea noticed the attackers thanks to the help of the sea. Thus, they were able to defend their territory.

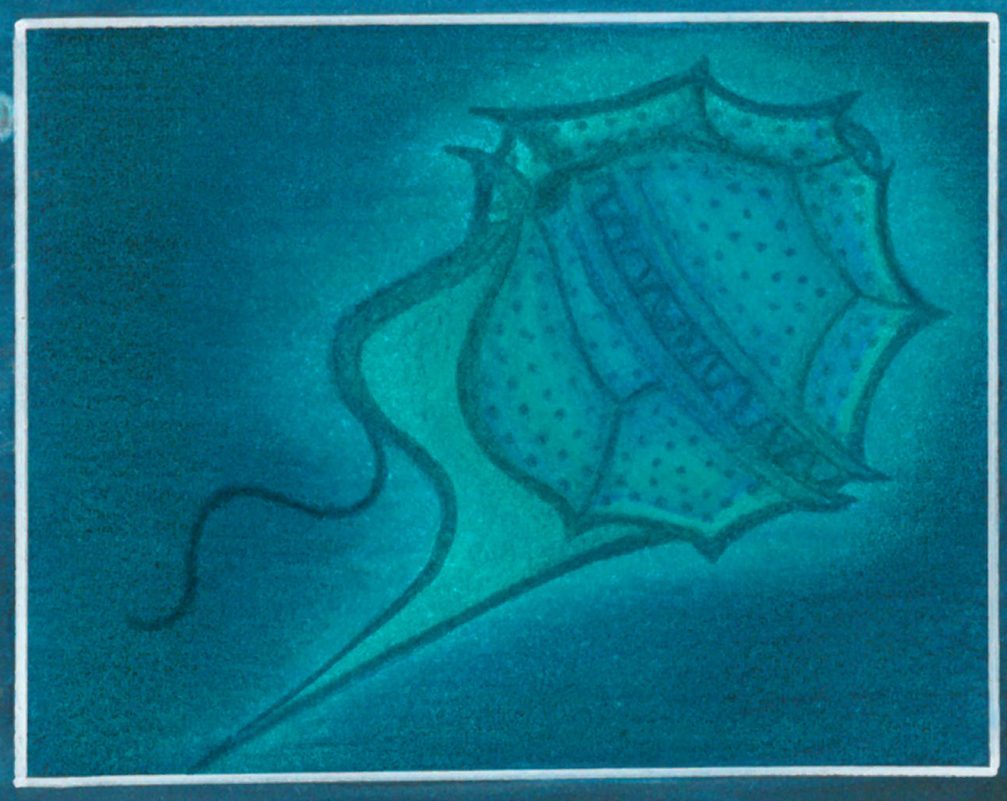
However, not everywhere people were favorable to the glow of the sea. There is another legend, about Spanish sailors, who created the Mosquito Bay in Puerto Rico. The sailors greately feared the unknown nature of the lights in the Caribbean sea. They attributed the glow of the to the intrigues of the devil himself! Thus, sailors tried to control the spread of the cursed waters, cut them off using boulders[12]. Their efforts only increased the glow though, and now Mosquito Bay is a popular tourist attraction.

But what is the actual reason behind this illumination?
The answer was found in 1980[13]. It turned out, that the sources of light are

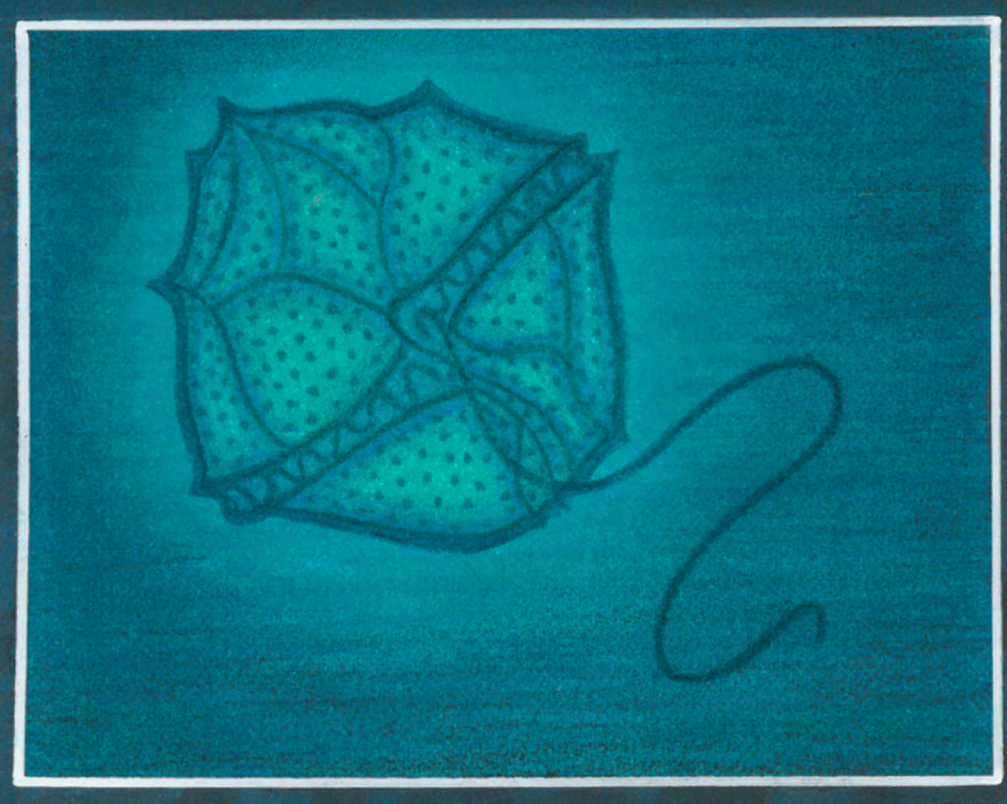
DINOFLAGELLATES

Microscopic unicellular algae with two flagella and a cellulose shell. Some of them are capable of bioluminescence: emission of blue or green light in response to mechanical stress of moving water.

Noctiluca scintillans saved Crimea from the Greeks. Unlike most dinoflagellates, *N. scintillans* does not have a shell. It is also not capable of photosynthesis, and therefore it feeds on other inhabitants of plankton[14]



Pyrodinium Bahamense is the one glowing in Mosquito Bay[15]. There really is something from the devil in it: *P. Bahamense* is one of those toxic dinoflagellates that cause red tides and the death of marine life[16]



The best-studied dinoflagellate is *Lingulodinium Polyedra*. Despite it also being toxic[17], *L. Polyedra* is often used as a model organism in research. That includes the search for an answer to the most intriguing question: how do dinoflagellates glow?

How do they glow?

Any movement of water (caused by a fish or a current) pushes and stretches the membrane of the dinoflagellates. Stretching activates special proteins, these proteins activate other proteins - and so on. As a result, ions appear in a special place in the cell - the scintillon - while under normal conditions these ions are kept somewhere else. In scintillon ions trigger a chemical reaction aimed to produce glowing molecules. But this is just a simplified overview - much more details are known about this process!

1

Mechanical stress localy increases the fluidity of the cytoplasmic membrane[18]

2

In response to the change in membrane properties heterotrimeric G-proteins are activated (directly or through coupled receptors)[18]

3

G-proteins activate phospholipase C, which hydrolyses PIP_2, producing IP_3 and DAG - small signaling molecules[19]

4

IP_3 and DAG open calcium channels: calcium enters the cell from the surroundings and also gets freed from storage compartments inside the cell[19]

5

An increase in calcium concentration sends a signal (action potential) along vacuole membrane[20]

6

Action potential opens hydrogen channels, and hydrogen ions escape vacuoles and enter scintillones. Scintillones are special pockets, where all necessary ingredients for bioluminescence are stored[21,22]

7

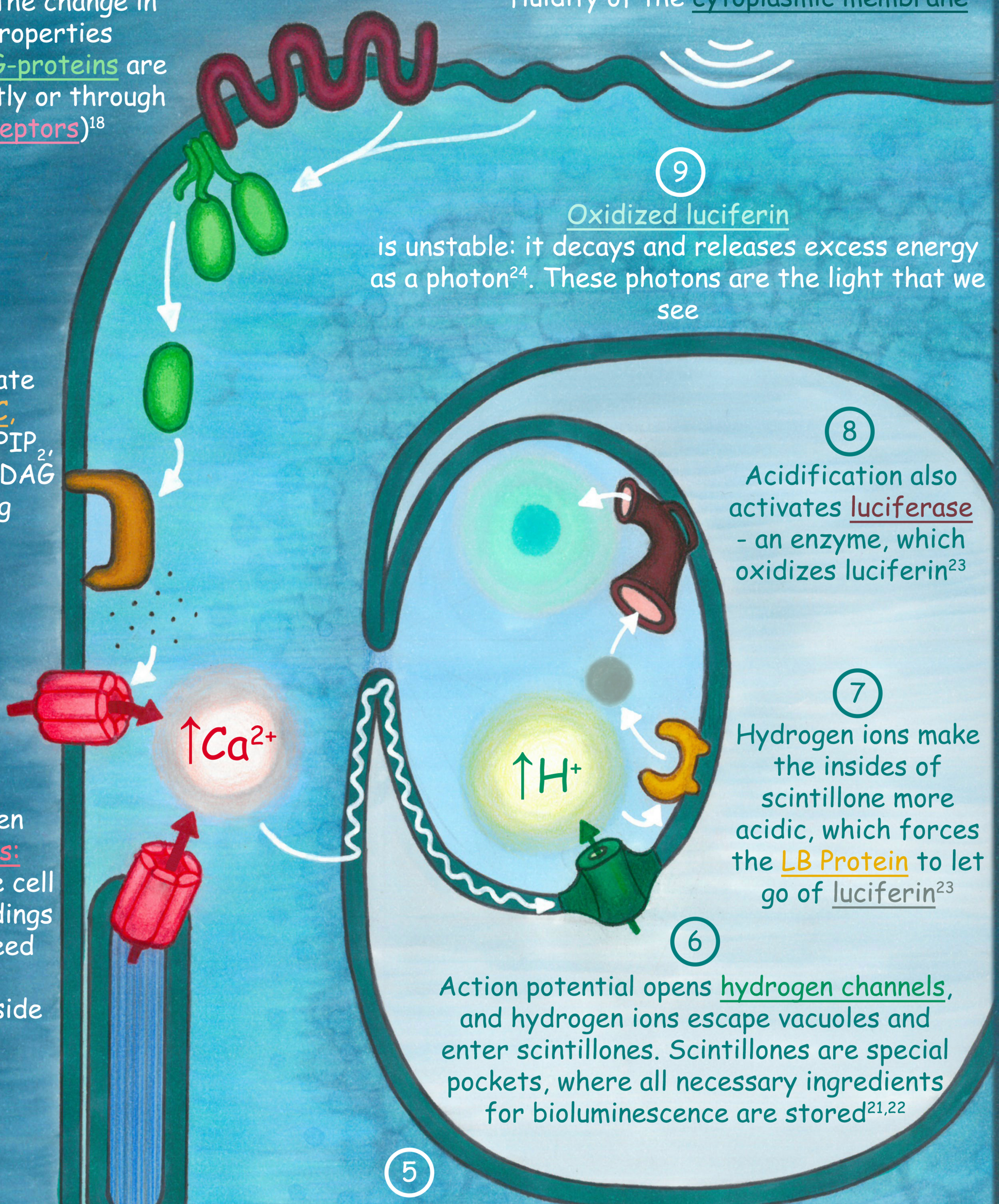
Hydrogen ions make the insides of scintillone more acidic, which forces the LB Protein to let go of luciferin[23]

8

Acidification also activates luciferase - an enzyme, which oxidizes luciferin[23]

9

Oxidized luciferin is unstable: it decays and releases excess energy as a photon[24]. These photons are the light that we see

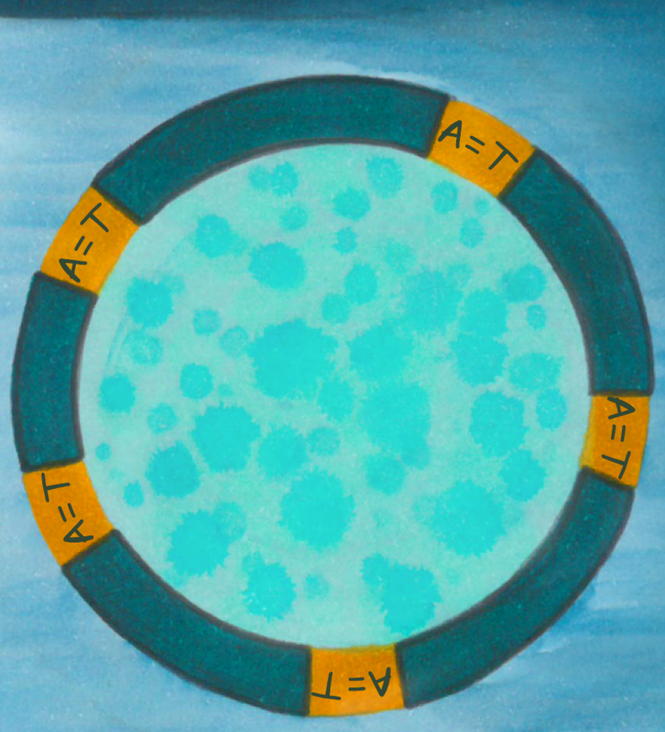


But why do they glow?

1. The glow scares off predators that feed on dinoflagellates. For example, shrimp and shellfish[17]

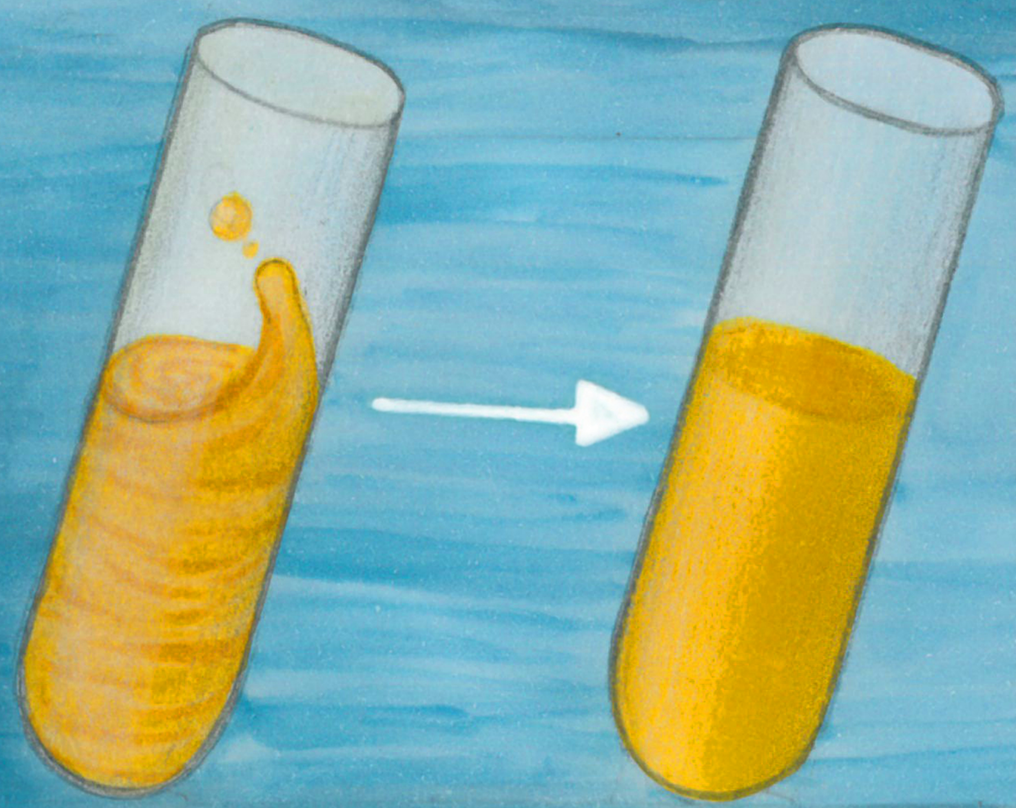
2. The glow attracts larger predators that feed on shrimp and shellfish[17,25]

3. The glow is a source of inspiration for scientists!



In 2020, a team from the University of Friborg developed microscopic mechanosensitive vesicles - polymersomes. The developers observed, how the scintillon membrane in dinoflagellates becomes temporarily permeable under mechanic stress and decided to give similar properties to the membranes of their polymerosomes[26]. The membrane was built of synthetic lipid-like molecules with incorporated nucleobases (nucleobases are building blocks of our and any other DNA). Under normal conditions, nucleobases are bound together by hydrogen bonds. However, these bonds are easily broken by mechanical impact. Thus, the pores are formed in the membrane through which the contents of the bubble-polymersome can escape. And the best thing is: the contents can be anything!

For example, the researchers loaded polymersomes with luminescent molecules and pushed them through a tube with a constriction. Due to increased pressure and turbulent water flow in that area, molecules left the polymersomes and their glow could be detected. Scientists believe that such mechanosensitivity can be used for more efficient drug delivery to fight vasoconstriction in atherosclerosis patients[27].



One can also load polymersomes with polymerization-inducing reagents. This way solutions can be created with the ability to solidify upon shaking or applying pressure. For example, 3D printing inks could rapidly harden while squeezing through the thin spout of a 3D pen. In general, the prospects for using such technologies are as limitless as our imagination![28]

The idea of mechanosensitive polymersomes is not the only contribution of dinoflagellates to science. Dinoflagellates can be used as model organisms to study certain proteins. As some of them did not change much during evolution, this could give helpful insights on the function of these proteins in humans[29]. The bioluminescence of dinoflagellates made it possible to optimize the operation of bioreactors in a way, that the cells grown in them were subjected to minimum mechanical stress upon stirring of the culture medium[30]. What is also curious, is that some dinoflagellates glow only at night - during the day this mechanism is turned off to save resources. This makes them useful in the research of circadian rhythms[31]. Dinoflagellates visualize the movement of seawater, thereby helping oceanographers[32]. Sometimes the glow of the sea is even visible from space[33]! True, so far these phenomenons are attributed to glowing bacteria, not algae. But who knows, maybe dinoflagellates will one day direct their light from the ocean to the stars?

A few words from the author

On vacation, my friends and I decided to swim in the sea before going to bed. This adventure became one of the brightest impressions of my entire life. What can possibly be compared to the feeling of floating in the night sky, summoning starlight with your own hands? A photo could never convey this subtle magic, and it is quite a challenge to describe the whole range of feelings with words. So I have decided to draw it. I didn't have to spend time searching for inspiration for this work.

I would like to thank my friends from the Usrak Nilicitzo group for sharing this supernatural adventure with me, thank my parents and Oleg Khlebnikov for their support and the right New Year gift (alcohol-based markers), as well as every reader for their interest.

Thank you!

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