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## Let There be Light: Evolution of Bioluminescence on Pandora

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### Abstract

James Cameron's, *Avatar* [1], is set on a fictional moon, Pandora, which orbits the planet Polyphemus in the Alpha Centauri system. The movie depicts the majority of Pandora's biota to be bioluminescent. Although the movie itself never presents the evolutionary basis for this trait, later publications attempt to make sense of this phenomenon. This paper aims to explain whether the theories that arose as an explanation for the development of bioluminescence are plausible and the likelihood of this trait emerging in the majority of living organisms. Ultimately, it asks whether Pandora's biodiversity is a rare feat of evolution or a fancy trick for the cameras.

**Keywords:** *Film; Biology; Evolution; Bioluminescence; Avatar (James Cameron)*

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### Introduction

On Earth, animals develop bioluminescence for multiple reasons, including attracting mates, warning predators, or for camouflage. On Pandora [1], this same phenomenon can be seen. However, what sets it apart from the organisms on Earth is that this trait is almost universally shared across all organisms on Pandora. Since bioluminescence is metabolically taxing, it is extremely unlikely that most life on Pandora would develop bioluminescence unless there was a real evolutionary incentive where this trait served as a real advantage.

### The Chemistry of Bioluminescence

Bioluminescence is a chemical reaction within a living organism that produces light. For this chemical reaction to take place, either luciferase or photoprotein enzymes are required to bind to luciferin [2], producing oxyluciferin and light [3]. However, the production of light comes at a cost. O<sub>2</sub> and ATP are required to catalyse luciferin. *Figure 1* shows the full mechanism of luciferase catalysis of luciferin. All known living cells require ATP as their primary source of energy [4]. All organisms depend on their ability to acquire and appropriately distribute their energy [5]. Spending this vital energy on emitting light indicates that being bioluminescent is crucial to their survival.

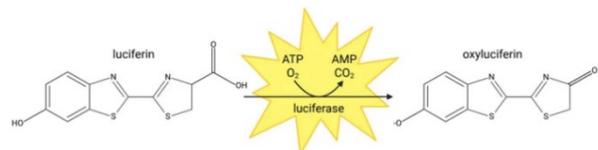


Figure 1 – Simplified luciferin reaction: luciferin being catalysed by luciferase with cofactors ATP and O<sub>2</sub>, releasing light [4].

### Why the need to Glow?

The book, *The Science of Avatar* [6], hypothesises that many of the functions of bioluminescence on Pandora are comparable to those observed on Earth, but its ubiquitous presence is driven by the moon's orbital dynamics within the Alpha Centauri system, specifically Alpha Centauri A and B (αCA and αCB). The most favoured hypothesis suggests that, due to its orbit between two sources of light, Pandora rarely experiences true darkness. *Figure 2* illustrates Pandora's night and day cycles as it orbits αCA. To survive the short periods of total darkness, natural selection favoured bioluminescence as a means of maintaining ambient illumination during the brief intervals of darkness. In this instance, organisms could avoid the cost of developing alternative traits to navigate in the dark, such as enhanced night vision or echolocation. This is because these traits only serve as an alternative to vision, whilst

bioluminescence can be used for a multitude of reasons [7].

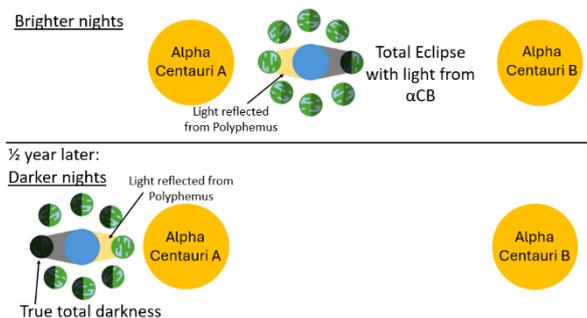


Figure 2 – Diagram (not to scale) showing different phases of the moon, Pandora, depending on its position in its orbit around Polyphemus, with respect to  $\alpha CA$  and  $\beta CA$  (created by author).

However, this explanation does not account for the presence of bioluminescence in flora. Additionally, light emission would significantly increase visibility to predators, imposing serious selective disadvantages; raising the question: if the environment around you glows, why would individual organisms not reduce or suppress their own light output to avoid predation? To answer this question, we can turn to examine evolutionary drivers here on Earth.

### Biology on Earth

Bioluminescence has developed multiple times, on Earth, with an estimated 75% of marine organisms producing light [8]. This bioluminescence developed independently on at least eight separate occasions [9], making a clear example of convergent evolution, where similar features are developed in unrelated lineages in response to similar environmental pressures.

Visual perception plays a critical role in survival, enabling organisms to navigate their environment, hunt prey and avoid predation. As a result, 96% of extant animal species possess some form of eye or light-sensing organ [10]. Whilst eyes vary widely in structure and function, all eyes share a unity in the genes used to build them [11], leading to the widely supported view that vision can be traced back to a single ancestral organism. Given that the ancestors of these bioluminescent organisms already possessed vision, natural selection favoured the refinement of eyes better suited to

the darkness or features that enhance visibility in darkness, such as bioluminescence. Knowing this, it is possible to deduce what the most probable evolutionary route organisms on Pandora followed.

### Biology on Pandora

To explain why bioluminescence is so prevalent in Pandora's biology, it is most likely that, like eyes on Earth eyes, vision and bioluminescence developed early in Pandora's history. Organisms relied heavily on vision due to the moon's sustained illumination, and natural selection drove organisms to expend energy maintaining those levels of light rather than to adapt other traits that would only be useful for short bursts. Since all animals possess bioluminescence, it's most probable that this trait arose from a common ancestor. Had bioluminescence developed later through convergent evolution, most organisms would not need to develop it, as their environment would provide ambient lighting. This can also explain why it has not been lost presently, as developing bioluminescence early would allow more time for animals to rely on this trait for other reasons, aside aiding with vision, as discussed by Baxter [6]. Considering the moon's mostly constant state of illumination, it can be reasoned that bioluminescence does not provide many disadvantages since survival mechanisms built to survive during daylight can also serve during the night, where light is provided by organisms instead.

However, for flora, another explanation is needed. The most probable explanation is that through convergent evolution, plants developed their bioluminescence separately due to the similar environmental factors they inhabit. This phenomenon is known as plant mimicry and could serve multiple purposes [12].

### Conclusion

Overall, the most likely explanation for Pandora's ubiquitous bioluminescence among organisms is that fauna initially acquired it through a common ancestor early in Pandora's evolution to combat short periods of darkness. Later, through convergent evolution, flora adopted this trait to use their already glowing surroundings to their own advantage.

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