EVOLUTIONARY CONSIDERATIONS PERTAINING TO THE CONVERGENT EMERGENCE OF BIOLUMINESCENCE ON EUROPA. C. L. Flores Martinez[1], [1]Centre for Organismal Studies, University of Heidelberg, Im Neuenheimer Feld 234, 69120 Heidelberg, Baden-Wurttemberg, Germany,
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Introduction: This presentation will outline an evolutionary macro-trajectory for putative life on Jupiter's ocean moon Europa. A number of major transitions are assumed to theoretically constrain the nature of biological complexity in the subsurface environment. These include but are not necessarily limited to: 1) an independent origin of life at the seafloor according to the submarine alkaline hydrothermal vent hypothesis [1]; 2) subsequent protocellular evolutionary processes based on horizontal gene transfer leading toward the emergence of integrated cellular entities [2]; 3) initially purely chemoautotrophic microbial organisms pioneering upper strata [3]; 4) globally increasing oxygen concentrations in the ocean due to radiolytic chemistry at the surface [4] and 5) the evolution of bioluminescent systems among uni- and possibly multicellular organisms as an adaptive response to global oxygenation.

Towards a Theory of Convergent Evolution: In the light of a potential discovery of extraterrestrial life through advanced robotic exploration or astronomical observations, a future theory of universal biology, if it exists, should be able to make falsifiable predictions about the kind of biological activity such missions expect to encounter [5]. To do so, current evolutionary thinking has to provide a comprehensive explanation of the convergent emergence of numerous adaptive traits that evolved independently and repeatedly across the tree of life. Prime examples include distinct cellularization events in eubacteria and archaea, endosymbiosis, multicellularity, bioluminescence, echolocation, fusiform shapes and intelligent and social behavior in non-primate species.

Recent studies indicate that convergent evolution is actually occurring on the molecular sequence level and, indeed, genome-wide in some instances. Information and biological systems theory are beginning to reframe the phenomenon of convergent evolution in terms of top-down causation and resulting functional equivalence classes [6]. One instantiation of convergent evolution, bioluminescence, is especially well-suited for studying its underlying informational, genomic, functional and ecological basis.

Biological Light in an Aphotic Environment: Here, the emergence of bioluminescence in Europa's subsurface ocean will be theorized as an evolutionary process of niche construction [7] (as biologically produced light in certain locales of the otherwise dark ocean could potentially create a selection pressure toward light reception).

The proposed emergence of bioluminescence in the subsurface ocean is contingent on radiolytic processing of surface ice due to acceleration of high-energy particles in Jupiter's magnetic field. On Earth, bioluminescence originated after the Great Oxygenation Event as a mechanism for oxygen detoxification and was then co-opted for other biological functions. Thus, analogous oxygenation events on Europa would constitute a top-down causative factor for the emergence of bioluminescence among life forms that previously thrived in anoxic conditions. The existence of functional equivalence classes in light-producing molecular systems is evidenced on Earth by a wide-range of chemical substrates that are catalyzed by individually evolved enzymes across vast phylogenetic depths. A feed-back between light-production and reception has been hypothesized for the most basal bioluminescent animal with a sequenced genome: the comb jelly *Mnemiopsis leidyi* [8]. Blooms of bioluminescent bacteria have been detected in the Mediterranean deep-sea, as well as on the surface in the form of so-called "milky seas" [9, 10]. However, the function of the observed luminescence remains to be determined.

Strategies for Astrobiological Research: Large-scale comparative sequencing of bioluminescent organisms (uni- and multicellular) could help in elucidating the genomic underpinnings of convergent adaptations; the assessment of bioluminescent signalling across marine ecosystems, especially in deep-sea and under-ice habitats, could open up the understanding of an analogous biosphere on Europa; and, finally, advanced robotic systems can be devised for biosignature detection in exploration efforts on Earth and, eventually, the icy abyss of Europa.

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