IONIZING RADIATION ON THE SURFACE OF EUROPA: IMPLICATIONS FOR THE SEARCH FOR EVIDENCE OF LIFE.

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Introduction: Europa's subsurface ocean is a possible abode for life, but it is inaccessible with current technology. However, 'Chaos' regions on the surface might provide direct access to materials originated from shallow pockets of liquid water within the ice shell, or even the subsurface ocean itself [1–6]. These would be ideal locations to search for possible evidence of life, such as organic biomarkers. The best case environment for such evidence would be the orbital "upstream" hemisphere, shielded from much of Jupiter's radiation belt flux, but where galactic cosmic rays (GCRs) still interact with surface materials.

GCRs that strike unimpeded Europa's surface produce ionizing radiation in the form of high-energy electrons, protons, gamma rays, neutrons and muons. The effects of ionizing radiation in matter always involve the destruction of chemical bonds and the creation of free radicals. Both can destroy organic biomarkers over time [7, 8].

Using ionizing radiation transport codes, we recreated the most-favorable radiation environment on the surface of Europa, and evaluated its possible effects on organic biomarkers within the shallow ice-shell.

Methods: We performed a full Monte-Carlo simulation of the nuclear reactions induced by the Galactic cosmic rays hitting Europa's surface using the Planetcosmic code (http://cosray.unibe.ch/~laurent/planetocosmics/) [9]. This code is based on the GEANT-4 toolkit for the transport of particles through matter.

The computational domain was comprised of 20 m of water ice. To model the GCR primary spectra for Z = 1-26 (protons to iron nuclei) we assumed the CREAME96 model under solar minimum [https://creme96.nrl.navy.mil/].

Results: Our preliminary results show that the flux of ionizing radiation as a function of depth in Europa's ice shell is similar in magnitude to that estimated for the surface on Mars for pure ice [10], see Figure 1. As expected, pure ice results in an extensive environment of energetic neutrons, protons, electrons, muons and gamma rays, whose flux is highest within the top few meters. The flux of ionizing radiation can be converted into dosage at the molecular level using a a "biologically-weighted" scheme [10]. The derived radiation dose at 1 meter depth is 0.3 Gy/year. We emphasize that these results likely represent a best-case scenario for Europa, an estimation of the radiation environment resulting from galactic cosmic rays alone. Further work will focus on also taking into account the Jovian radiation environment. However, previous work has shown that this radiation environment is less penetrative (decimeters) [4]. We also expect that the presence of Jupiter will create anisotropies in the distribution of the GCR radiation environment.

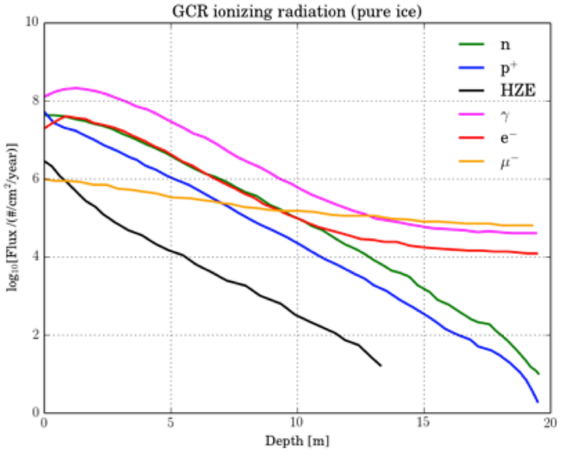

Fig. 1. Attenuation of ionizing radiation fluxes with depth for neutrons (n), protons (p$^+$), High charge/high-energy (HZE), photons (gamma), electrons (e$^-$) and muons (mu$^-$).

Discussion: Our results indicate that dormant microorganisms within the top 1 meter of regolith of the most *favorable Europan hemisphere* would likely be killed in less than 150 kyr due to cumulative radiation damage. This survival time applies to radiation-resistant organisms such as *Deinoccocus radiodurans*. More importantly, organic biomarkers such as complex biomolecules (i.e. proteins) would be severely damaged by ionizing radiation (either directly or indirectly) within the top 1 meter in time scales of 1-2 million years. For example, the immunoresponse (an indicator of molecular integrity) of several biological polymers, including proteins and exopolyssacharides, diminishes by >90% after exposure to 500 kGy of electron radiation, equivalent to 1.6 Myr exposure at 1 meter depth in Europa's ice-shell. Even smaller doses are sufficient to break the backbone of proteins into smaller fragments. Smaller organic molecules of astrobiological interest, such as amino acids, would also be affected by ionizing radiation. The D_{10} value for the radiolytic decomposition of glycine and alanine is reached after exposure to 20-30 MGy [8], equivalent to 60-90 Myr exposure at 1 meter depth in Europa's ice shell.

Our preliminary results indicate that even the best-case Europan radiation environment, created by galactic cosmic rays alone, biomolecules would be heavily damaged quickly. Complex organic molecules, including biomarkers, could become heavily processed in the top 1 meter in time scales >1 million years, and smaller organic molecules such as amino acids could be severely damaged in time scales <100 million years. Model age estimates of Europa's surface range between 60 and 100 million years [11], which would place serious limits on the preservation of organic biomarkers near the surface. However, age estimates of Chaos regions are lacking, and might be critical to the success of life detection missions. Hence, a better constraint on the surface age of Chaos regions on Europa might be critical to the success of such missions. If surface ice deposits are fresh and young, biomarkers may be preserved. For this reason it is important to confirm the existence of putative plumes of icy particles at Europa, such as exist at Enceladus. Such fresh particles, very recently erupted from deep liquid reservoirs, might be relatively undamaged and more likely to bear intact biomarkers. On the other hand, such particles are exposed to the full brunt of the Jovian radiation environment.

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