Radioactive Decay Energy Conversion for Biological use in Subsurface Environments on Icy Moons and the Early Earth. Thiago Altair[1], Marcio G B de Avellar[2], Fabio Rodrigues[3] and Douglas Galante[4], [1]Instituto de Física de São Carlos, Universidade de São Paulo, São Carlos/SP, Brazil (thiago.altair.ferreira@usp.br), Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, São Paulo/SP, Brazil (mgb.avellar@iag.usp.br), Departamento de Química Fundamental Instituto de Química, Universidade de São Paulo, São Paulo/SP, Brazil(farod@iq.usp.br) [4]Laboratório Nacional de Luz Síncrotron, Campinas/SP, Brazil (douglas.galante@lnls.br).

Introduction: Photosynthesis is a highly complex mechanism that several life forms on Earth utilize to convert solar energy into biological useful chemical disequilibria. However, biological systems in subsurface regions are isolated from the photosphere, thus incapable of directly utilizing this energy source. Biology explores different alternatives, including radiolysis, as was shown for some microbial litoautotrophic species[1]. Subsurface environments may have had importance for the emergence and maintenance of life on early Earth, during periods of surface stress caused by impacts that would make it virtually sterile, such as during the heavy bombardment period. Besides, these environments on Earth may represent analogues of other celestial bodies, such as the Jovian icy moons.

In the context of icy moons, the oceans under its icy crusts may be biophilic environments[2,3], since the presence of abundant water and several sources of energy are proposed. This includes active geological process in global scale[4], tidal phenomena, and radiolysis induced by radionuclides and galactic cosmic rays[5].

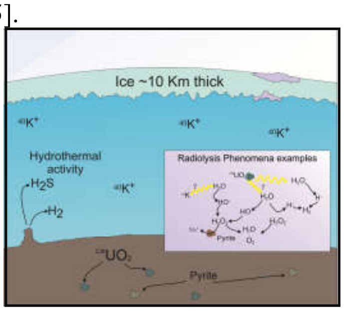

Fig. 1 - Model of Europa emphasizing the uranium radiogenic material and the radiolysis phenomena that can occur below seabed.

In this context, we propose a model for the energy yield due to radiolysis in subsurface environments, such as on the early Earth and on the icy moons of the Solar System, considering that as an alternative source of energy that is biologically useful and independent of the solar input. For this model, we primarily considered the local physico-chemical conditions and the radiogenic effects on this condition of the most abundant radionuclides (Fig 1). As mechanisms of energy transfer from chemical species formed in radiolysis, we use biological metabolic pathways based on modern subsurface species - such as the case of the extremophile *Candidatus Desulforudis audaxviator* [1,5](Fig. 2) – or proposed proto-metabolic pathways – such as a precursor of acetyl-CoA pathway[6]. In this way, we seek to evaluate the effects of radiogenic environments on the habitability of the Solar System and beyond, where non-photosynthetic based ecosystems may be thriving.

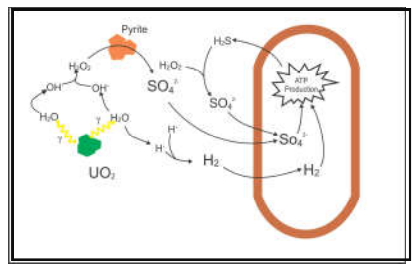

Fig. 2 - Model of a cell of *Ca. D. audaxviator* including the pathway of sulfate reduction.

Additional Information: The authors thank FAPESP, CNPq and CAPES for the financial support.

References:

1. Lin, L.-H. et al. 2006 Long-Term Sustainability of a High-Energy, Low-Diversity Crustal Biome. *Science (80-.).* **314**, 479–482. (doi:10.1126/science.1127376)
2. Cockell, C. S. et al. 2016 Habitability: A Review. *Astrobiology* **16**, 89–117. (doi:10.1089/ast.2015.1295)
3. Chyba, C. F. 2000 Energy for microbial life on Europa. *Nature* **403**, 381–382. (doi:10.1038/35019159)
4. Hand, K. P., Carlson, R. W. & Chyba, C. F. 2007 Energy, Chemical Disequilibrium, and Geological Constraints on Europa. *Astrobiology* **7**, 1006–1022. (doi:10.1089/ast.2007.0156)
5. Atri, D. 2016 On the possibility of galactic cosmic ray-induced radiolysis-powered life in subsurface environments in the Universe. *J. R. Soc. Interface* **13**, 20160459. (doi:10.1098/rsif.2016.0459)
6. Branscomb, E. & Russell, M. J. 2013 Turnstiles and bifurcators: The disequilibrium converting engines that put metabolism on the road. *Biochim. Biophys. Acta - Bioenerg.* **1827**, 62–78. (doi:10.1016/j.bbabio.2012.10.003)