GALACTIC COSMIC RAYS, EXOPLANETS AND HABITABILITY. D. Atri[1], [1]Blue Marble Space Institute of Science, 1200 Westlake Ave N Suite 1006, Seattle, WA 98109, USA (dimitra@bmsis.org)

Introduction: What are the physical conditions that make a planet habitable? The answer to this question depends on the definition of habitability. One way to approach this problem is to study the Earth and estimate the range of physical conditions which can support an Earth-like biosphere. These include the astrophysical conditions such as the stellar spectrum and flux and also the properties of the planetary atmosphere for climate modeling. There is a tremendous interest in the search for signatures of life on planets around stellar systems which can support liquid water on its surface [1]. However, here we focus on a different approach, where we estimate the range of physical conditions for which the radiation dose can permit a stable Earth-like biosphere. We explore various physical conditions that give rise to increased radiation dose on an exoplanet's surface. The radiation environment of a planet consists not only of the photon and proton flux from the host star, but also the galactic cosmic ray (GCR) flux consisting of charged nuclei (mostly protons). Although the flux of GCRs is only a small fraction of the radiation flux from the host star, the average energy of individual GCR particles is higher by several orders of magnitude than photons and protons from the host star. The GCR flux depends on (1) the magnetic moment of the planet, and (2) the location of the planetary system at a particular time in the galaxy. GCR secondary particles comprise of the most penetrating ionizing radiation and its biological effects have been discussed extensively [2][3][4].

Mechanism: GCRs are energetic particles of astrophysical origin, which strike the planetary atmosphere and produce secondary particles, including muons, which are highly penetrating. Some of these particles reach the planetary surface and contribute to the radiation dose. Along with the magnetic field, another factor governing the radiation dose is the depth of the planetary atmosphere. The higher the depth of the planetary atmosphere, the lower the flux of secondary particles will be on the surface. If the secondary particles are energetic enough, and their flux is sufficiently high, the radiation from muons can also impact the sub-surface regions, such as in the case of Mars. If the radiation dose is too high, the chances of sustaining a long-term biosphere on the planet are very low.

Computational modeling: In order to model the interaction of GCR particles with the planetary atmosphere, we will use CORSIKA (COsmic Ray SImulations for KAscade), which is a widely used Monte Carlo tool to model cosmic ray induced air showers from primaries in a wide energy range [5]. The code is regarded as a gold standard in simulating the propagation of GCRs in the atmosphere. The model is continuously tested against data from a number of experiments around the globe and updated frequently with new physics results. Simulations were carried out using CORSIKA v6990, a stable version of the code with updated interaction models. The code has already been demonstrated to reproduce air shower data with high accuracy [2].

Radiation dose and habitability of exoplanets: Based on modeling particle fluxes and their atmospheric interactions, we found that although the magnetic field shielding is an important factor deciding the radiation dose on the surface, the atmospheric thickness is the dominating factor. If the atmosphere is sufficiently thick, such as in case of the earth, the radiation levels only increase a factor of ~2 even in case of no magnetic shielding. On the other hand, the GCR induced dose increase is very large, ~ 1600, when the atmospheric thickness is ~ 10% that of the Earth. Comparing with the total annual natural background radiation (2.4 mSv/yr), the increase in radiation dose is by a factor of 230. Although, it is hard to assess the long-term impact of radiation dose, lethal doses calculated for Earth-based life can be taken as a reasonable upper limit. A total radiation dose of 4 Sv is considered to be lethal, resulting in a 90% probability of death (United States Nuclear Regulatory Commission, 2013). A planet with 100 gcm-2 atmosphere and less than 15% of the Earth's magnetic moment would cross this limit in less than 10 years. Such radiation is certainly not suitable for a sustained habitat for Earth-like life. In addition to the liquid water habitability criteria, biological radiation dose should also be considered as an important factor in constraining the habitability of a planet [6].

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