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A multi-step astrobiological approach for supporting life-detection

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Abstract. The next space exploration missions will aim to search for signs of life on other planetary bodies of the Solar System. The research is mainly focused on the search for biogenic molecules (biosignatures) or life form remnants (fossils). However, potential signs of extinct or extant life can be affected by solar radiation as UV and ionizing radiation, heavy ions from galactic radiation, or by vacuum; conditions not experienced on Earth and that can be harmful to organics, preventing their detectability. Currently, one of the best ways to study the effects of space environment is through a combined approach, including the selection of biological sample, preliminary ground-based experiments, and exposure in dedicated platforms outside the International Space Station (ISS), since all the stressing conditions of deep space cannot be simulated even in the best planetary simulation scenario. Here, we described the main stages of multi-step investigations for astrobiological research.

Key words. Astrobiology investigation – extreme environments – ground-based experiments– Low Earth Orbit exposure

1. Astrobiology research

Astrobiology is defined as "the study of the origin, evolution, and distribution of life in the context of cosmic evolution; this includes habitability in the Solar System and beyond" (Hornek et al. 2016). Nowadays, astrobiological research is mainly focused on the exploration of other planets or icy moons in our Solar System, in order to detect signs of extinct or extant life. Particularly, it includes the investigation of the Martian surface and subsurface, since i) the planet hosts carbon, energy sources, and different water forms (Malin & Edgett 2000, 2003; McKay 2004; Rasmussen et al. 2009), and ii) during the first stage of its evolutionary history, it was characterized by warm temperatures, liquid water, and a hydrologically and geochemically active environment (McEwen et al. 2007; Howard 2007; Andrews-Hanna et al. 2007; Gendrin et al.

2005; Bibring et al. 2006). Nowadays, environmental conditions are rather harsh due to the presence of a high radiation flux at the surface (ionizing and non-ionizing radiation; (Hassler et . 2014), oxidizing species as perchlorates and oxygen peroxide (H_2O_2), and a low-pressure CO_2-rich atmosphere. Although these conditions appear hostile for life as we know (McKay 2004), hypothetical life forms might have survived adopting similar strategies to those used by microorganisms in extreme environments on Earth (Schulze-Makuch et al. 2008). Based on this concept, the study of these environments and their inhabiting microorganisms, combined with preliminary ground-based simulation tests and the subsequent exposure of selected microorganisms to real space conditions, are necessary steps for correct astrobiological investigations.

2. A multi-step approach for astrobiological investigations

The detection and identification of hypothetical traces of extant or extinct life on other planetary bodies beyond Earth is one of the most important challenges of our era. Particularly, the ongoing space exploration missions (i.e. the NASA's Mars 2020 and the ESA-Roscosmos's ExoMars 2022), will aim to achieve this purpose by detecting and characterizing those particular features, called biosignatures, which are defined as "an object, substance, and/or pattern whose origin specifically requires a biological agent" (Des Marais et al. 2008). In the context of life-detection missions, experimental procedures and tools need to be settled, and a significant amount of preparation is required to prevent and eliminate bias. Hence, a multi-step approach combining field, laboratory and space research is necessary to perform and support life-detection missions beyond Earth (Fig. 1). Firstly, as Earth is the only planet supporting life that we know thus far, it is reasonable to use terrestrial environments as analogues for studying the ability of life to persist in hostile extraterrestrial environments and how to detect it there. Field research is the first step within an astrobiology investigation (Step 1, Fig.1). It involves the study of an extreme environment, terrestrial (e.g., hot and cold deserts, rivers) as well as marine (e.g., hydrothermal vents, oceanic clathrates, underwater hydrothermal regions) habitats on Earth and the selection of the best inhabiting microorganism (usually an extremophilic organism) to be used as test-organism in simulated space and Low Earth Orbit (LEO) exposure experiments. Besides, it is necessary for validating the experimental procedures and tools to be used in the biosignature analysis, which can be carried out both *in situ* and in laboratories. Since extreme environments on Earth cannot exhibit the whole physico-chemical environmental parameters described on other target planetary bodies, a complementary study integrating laboratory space simulations is required when preparing space exploration missions (Leveille et 2009). Experimental works using planetary simulation facilities represent the following step within an astrobiology investigation. They are designed as ground-based experiments (Step 2, Fig. 1) to discern whether samples (i.e. microorganisms and their biosignatures) could be able to persist in space and planetary conditions. These investigations are conducted through analysis of survivability, resistance, and stability of samples (both materials and biological samples) after their exposure to such complex but well defined simulated environmental conditions that could not be otherwise experienced on Earth. Finally, no laboratory is equipped with facilities that are able to simultaneously test all the conditions that samples could undergo in real space. For studying the different responses of samples in a spectrum of conditions as close as possible to those typical of extraterrestrial environments, exposure to the real harsh space environment (Step 3, Fig. 1) is necessary. When possible, this last preparatory step (Step 3, Fig. 1) within an astrobiology investigation is generally performed in LEO and supported outside the ISS by using exposure facilities. In this context, samples are subjected to an hostile environment, characterized by high vacuum, an intense radiation flux of both solar and galactic origins, extreme temperatures, and microgravity. The choice of the most appropriate exposure facility depends on

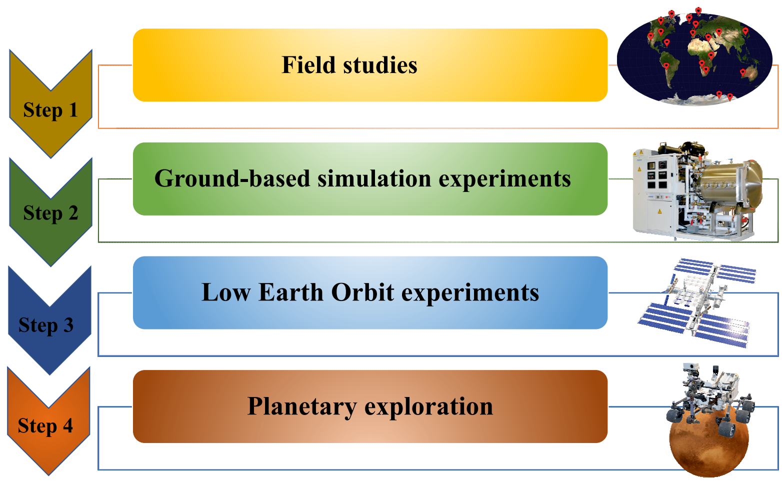

Fig. 1: Schematic representation of an astrobiological multi-step approach

the duration of each experiment. For instance, the BIOPAN payload, a multi-sample facility, has been designed for short-term space experiments (two weeks), allowing the exposure of both biological and non-biological samples of different size to a broad range of space conditions (Cottin et al. 2017). Conversely, all the EXPOSE facilities (EXPOSE-E/-R/-R2) have been used for long-term, interdisciplinary experiments, where samples can be accommodated in small chambers within three different experiment trays (Cottin et al. 2017). Once back on Earth, samples have to be analyzed depending on the study-type and by comparing results with those obtained from the previous ground-based experiments. Finally, all the results are combined together in order to provide support for the future space exploration missions on target planetary bodies. Besides, results deriving from all these three steps can provide a broader and more realistic view of how biosignatures could be and how to detect them on other planets or icy moons (Step 4, Fig. 1) (Carrier et al. 2020).

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