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Advances in Low Earth Orbit Experiments

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Abstract. Advance in low Earth orbit experiments are described.

1. Introduction

The prebiotic chemistry under radiative conditions received a great attention in the last years in order to evaluate the mechanism of synthesis and degradation of molecules of biological relevance, as well as to identify libraries of possible molecular markers for the remnant presence of trace of life. Since the pivotal experiments carried out by Kuzikeva, Simakov and coworkers onboard of the Salyut 7 station (Kuzicheva et al. 1989), and of the satellite BION-11 (Simakov et al. 2002), high energy space conditions emerged as a benign environment for the synthesis of biomolecules from pre-formed chemical precursors. These experiments have been revisited as part of the PROCESS experiment of the European EXPOSE-E mission on board the International Space Station, focusing on the photodegradation of selected organics under filtered extraterrestrial solar electromagnetic radiation (Noblet et al. 2012). In this latter case, the attention in monitoring the degradation of the starting material did not provided information on the occurrence of possible synthetic processes. Which of the two pathways, synthesis versus degradation, is expected to prevail in spatial conditions? Recent studies demonstrated that the total balance of the process is strictly dependent from the specific environment in which the reaction occurs. The irradiation of widely diffused C-1 containing chemical precursors, as simple as HCN and formamide, fueled by high energy proton beam mimicking the Solar Wind, irremediably furnish a robust chemical framework for the increase of the chemical complexity in the presence of meteorites. A large panel of biomolecules is obtained, including the main components of the pre-genetic and pre-metabolic apparatuses, the regio- and stereoselectivity of the transformation being controlled by the occurrence of heterogeneous catalysis (Saladino et al. 2018). This chemistry is of particular relevance in the case of polymerization processes, being a synthetic entry for the formation of high molecular weight polymers which resemble the insoluble organic matter (IOM) in terms of elemental composition and physical and chemical properties (d'Ischia et al. 2019). Recently, the combined effect exerted by meteorite of the chondrite type (remnant of the origin of the Solar System) and the Solar Wind in the oligomerization of simple poly-aromatic hydrocarbon (PAH) has been reported and discussed in relation to previously unrevealed relationship between melanin like polymers and IOM (Bizzarri et al. 2020). Thus, a novel perspective overlooks for Low Earth Orbit experiments, that is the attention for the modelling of synthetic processes in addition to the degradative counterpart. Most probably, the next ROSCOMOS BIOPAN satellite mission in 2023 will expose for the first time this type of experiments. Moving from molecular evolution to existing life, irradiation irremediably works towards the simplification of complexity, the degradative process (mutagenesis and cell death) being fortunately balanced by Darwinian evolution.

2. First low Earth orbit experiments

The exposure of microorganisms to outer space started almost with the human space exploration in the 1960s. The first facilities were installed outside the Gemini 9 and 12 modules and allowed a few-hour exposure of bacterial and fungal spores (Bacillus subtilis and Penicillium) to the space environment. The survival of bacterial and fungal spores was further challenged during the journey back to Earth of the Apollo 16 mission by using the Microbial Ecology Evaluation Device (MEED) facility that exposed the spores to space vacuum and radiation for 1.3 h. A few-day experiment in the outer space was carried out in 1983 by using an exposure tray accommodated in the cargo bay of the Spacelab SL1. Then in 1992 Bacillus subtilis spores and dried cells of the bacterium Deinococcus radiodurans were exposed to space for 327 day using the European REtrivable Carrier (EURECA) satellite that was launched with the space shuttle Atlantis and recovered during the space shuttle Endeavour mission. The longest exposure of Bacillus subtilis spores to space was of about 6 years (1984-1990) and occurred during the NASA Long-Duration Exposure Facility (LDEF) mission; indeed, the retrieval was scheduled after 11 months but it was delayed due to the dramatic loss of shuttle Challenger in 1986. From 1990 to 2007, other opportunities for short-duration exposure experiments (10 to 12 days) were provided by the ESA BIOPAN facility, a container with a deployable lid mounted on the descent module of a Russian Foton satellite. In 2005, in addition to bacterial and fungal spores, for the first time a complex organism, a dried lichen (a symbiotic association between a fungus and algae) expended our knowledge on the survival potential of terrestrial life forms (H.Cottin et al. 2017; Horneck et al. 1994).

3. Current and future astrobiological experiments

In recent years (2004, 2009, 2014) joint announcements coordinated by ESA, NASA, JAXA and CSA, entitled International Life Science Research Announcement, were released to select astrobiological experiments. Indeed, in the last fifteen years microorganisms were exposed for more than one year to low Earth orbit using in three space missions the ESA EXPOSE facility installed outside the International Space Station (ISS). The EXPOSE-E, named after its final destination on the European Columbus module of the ISS, allowed a 584-day exposure (2008-2009), the EXPOSE-R, installed on the Russian external module Zvezda, exposed a selection of microorganisms to outer space for 682 days (2009-2011), followed by a 696-day exposure during the EXPOSE-R2 (2014-2106) space mission. The EXPOSE facility allowed only a passive exposure of dried samples to space and Mars-like condition simulated in low Earth orbit. Therefore, a selection of extremophiles able of drying without dying, the so called anhydrobiotes, was used for these experiments, including archaea, bacteria, cyanobacteria, fungi, lichens and bryophytes. Post-flight analyses were performed on the exposed samples after their retrieval back to Earth and rehydration under optimal laboratory-growth conditions. The response of microorganisms to the space conditions was investigated during the NASA Organism/Organic Exposure to Orbital Stresses (O/OREOS) cubesat that was launched in November 2010 into an orbit of 650km altitude. In this experiment after 14 and d 97 days in space, Bacillus subtilis spores were allowed to germinate by adding a nutrient medium. The effects of deep space will be monitored on dried cells of the budding yeast Saccharomyces cerevisiae that will be rehydrated in orbit using the NASA nanosatellite BioSentinel mission planned to fly on the Space Launch System's first Exploration Mission (EM-1) (H.Cottin et al. 2017; Horneck et al. 1994). Indeed, microbial survivability under space conditions until rehydration in orbit, is a crucial endeavor for future astrobiology experiments beyond low Earth orbit, namely the future lunar orbital platform-Gateway or the Moon surface. The exposure of metabolically active organisms will allow the achievement of a new horizon into the adaptation potential of astrobiology model systems that have been investigated so far only for survival potential and biomarker detectability after exposure in the dried state to space and Mars-like conditions (Billi 2019).

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