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Considerations on instruments for astrobiological investigations in a Moon/Mars laboratory

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Abstract

Mankind may be only decades away from establishing a long-term presence on our moon and on Mars. With the right equipment, this presence can lead to immense advances in diverse scientific fields. We here discuss how laboratories on the Moon and Mars could be equipped to answer astrobiological questions pertaining (among others) to: i) the limits for life beyond Earth, ii) the search for extraterrestrial life, iii) the origins and early development of life, iv) biological life-support systems (BLSS), and v) microbiome evolution and containment.

1. Introduction

We, as a species, are likely to walk on the Moon and Mars in the next decades. We will probably establish long-term bases in these environments and potentially beyond [1,2]. While astrobiological investigations on our natural satellite would be reduced in scope compared to those to be performed on the red planet; it would serve as a test-bed for missions farther away [3]: we could for instance test search-for-life instruments and protocols, develop efficient BLSS, and monitor the inner microbiome. Thus, a lunar and a Martian laboratory could have a lot in common in terms of general design and instrumentation.

2. Astrobiology on the Moon

The uniqueness of the Moon as an astrobiology target comes, first, from its proximity to Earth: a considerable quantity of material could be sent to and from it. Second, it comes from its potential as a reservoir of prebiotic molecules (indigenous or brought by, e.g., meteorites). Samples could be characterized directly on the Moon, or screened and preselected for a return to Earth.

Being outside of the Earth's magnetic field protection, the Moon also has a remarkable potential as an astrobiology platform for testing instrumentation and carrying life resistance studies, in support of the search for extant or extinct life on Mars and other bodies of interest [4,5]. Indeed, facilities currently available on Earth and in low Earth Orbit (LEO) cannot reproduce accurately all conditions found farther away, notably extraterrestrial radiation spectra [6]. Conducting exposure experiments on the surface of the Moon would therefore allow for a much deeper understanding of the limits of terrestrial life in space and planetary environments, a crucial endeavor for both habitability and planetary protection investigations. Studying the behavior of selected biomolecules exposed to more damaging conditions than in LEO would also help select the remnants of life to search for in our solar system.
Biological organisms imported from Earth could play a key role, a part of BLSS, in both enabling a long-term human presence beyond Earth and significantly reducing its costs. On the other hand, Earth microorganisms evolving in extraterrestrial habitats for a prolonged period of time could create health and safety hazards [7,8]. Testing and optimizing BLSS, and documenting the evolution of microbiomes, can be performed on the Moon where evacuation can be prompt and planetary protection constraints are mild. This would be a valuable preparation for crewed Mars missions [9].

3. Astrobiology on Mars

Mars is the obvious choice for an astrobiology laboratory beyond Earth. After more than 50 years of robotic exploration, we are closer than ever to being able to answer the question whether Mars is—or has been—inhabited [10,11]. However, robots are far from equalling humans in the field and, as for the Moon, the search for organic matter and potential signs of life on Mars would be significantly enhanced by the presence of dedicated instrumentation in a surface, crewed laboratory [12].

A Martian BLSS would greatly benefit from technologies developed on the Moon. However, Mars has more potential for coupling *in situ* resources and BLSS to make the latter sustainable and expandable [13]. Laboratory studies on site will be critical to monitor the efficiency of BLSS, and its evolution, under Martian gravity and when fed with Martian resources. In the same way as for a Moon base, the inner microbiome would need to be monitored and controlled to avoid both health and safety hazards [7,8], and outbound contamination: contrary to the Moon, Mars is subject to strict planetary protection rules—although those will have to be redefined for crewed exploration [10].

4. A Lunar/Martian astrobiology laboratory

We here consider examples of instruments and laboratory configurations relevant to answer the astrobiology questions described above. Many of them would be shared between different disciplines, so as to reduce the payload represented by a lunar or Martian laboratory. To reduce it further, supplies' reusability should be increased and hardware miniaturized. The latter should also work under, and resist, the physical constraints of both the local environments and inbound trips. Equipment design will greatly benefit from past endeavours in LEO, such as on-board the ISS (e.g. [14]). A sterilisable and contained workplace (e.g., a glove box [15]) will be needed to work with potentially pathogenic organisms or unknown extraterrestrial materials.

4.1 Exposure experiments and the search for life

Exposure experiments on a lunar base could proceed passively, *via* external platforms linked to the habitat (or *via* telemetry) with *in situ* instrumentation [5]. However, an active astrobiological laboratory would be needed to investigate meteorites and particles on the Moon, and various samples on Mars. It would share analytical instruments with other disciplines, such as: microscopes (optical, fluorescence, confocal, potentially SEM and others), spectrometers (UV-Vis-IR, Raman), gas and liquid chromatographs coupled with mass spectrometers (GC/MS and LC/MS), and biosensor arrays (or biochips) [16–18]. Environmental sensors (e.g., for temperature, radiation, and humidity) will be needed to characterize exposure conditions and monitor experiments.

4.2 Active biology experiments

Monitoring the inner-station microbiome (including human flora), or testing the responses of organisms used in BLSS, to lunar and Martian conditions will require culturing, RNA/DNA sequencing, and an array of environmental sensors in addition to those mentioned above. In recent years, the size and weight of sequencers, as well as other relevant biology hardware, have been dramatically reduced [19,20].

5. Summary and Conclusions

We suggested equipment and instruments to answer astrobiological questions on future Moon and Mars bases. We believe that developers should aim for similar instrumentation at both locations, so that a Martian laboratory can benefit from lessons learned on the Moon.

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