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"Digital Moon": information system for distribution, visualization and analysis of lunar data

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Abstract

In the last decade, there has been a sharp increase in the amount of data obtained by planetary missions, as well as the rapid growth of existing planetary data archives, for example, a lot of spacecraft from different countries have been exploring the Moon lately. Remote sensing data of the Moon, like any spatial planetary data, include arrays of images and digital relief models, which are characterized by diversity, significant volumes and high complexity. Processing and analysis of such data requires specialized approaches, including online processing, various methods of categorizing and data integration. For decision of these tasks we developed a distributed communication environment using new software architecture [1]. The proposed approach is based on ensuring the possibility of a comprehensive use of heterogeneous data within a single unified information environment. This is of great importance for establishing planetary research at a qualitatively new level, where expert analysis and automated approaches to data processing are complementary and are based on the use of existing standards used in planetary studies.

The Moon exploration is essential for the Russian space program. During next few years several launches are planned: the landing missions Luna-Glob (Luna-25, 27, 28) to the sub-polar areas [2] and an orbital mission Luna-Resource (Luna-26) [3], which is aimed at a global topographic mapping of the Moon. So, we also expect large amount of data: for example, a spacecraft in the quasi-polar circular orbit at an altitude of 50-100 km above the surface makes 12 flights around the Moon during the earth's day, obtaining about 5,000 images per day or about 150,000 images per month, assuming typical lunar data transfer rate [4].

To solve the problems of joint analysis of heterogeneous lunar data obtained from different sources we have proposed concept of "Digital Moon" for the integration of existing information as well as new data to be obtained in future. We are developing information system, including solutions for storage, archiving, joint processing, access, distribution, visualization and analysis of lunar data that can be used for implementation of an advanced front-end for Russian segment of the planetary archive to plan, to collect and to manage data from future missions [5]. Using proposed software architecture, we have developed a various applications for the processing, analysis, and three-dimensional visualization of lunar data. For example, to support image shooting planning we have developed web instrument "OrbitCalc" (http://cartsrv.mexlab.ru/orbitcalc/). Another applications for interactive terrain modeling, translation of spatial context in teleconferencing mode, intelligent search of lunar data in external sources) will be presented at the conference.

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SpectroLab: a planetary test bench for spectroscopic analysis in a CubeSat

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1. Introduction

Spectroscopic analysis of soil samples provides precious information about the nature and composition of the rocks.

2. SpectroLab

The idea of SpectroLab is to build an easy-to-move test bench, which could be used in different environments: on a Lunar lander, with a robotic arm to bring the samples to analyse, or in extra-terrestrial facilities etc.
To do so, the format of SpectroLab is inspired by a 2U CubeSat. The spectrometer is located in the top unit, with a lamp and a camera to monitor the state of the system. In the lower unit, the sample holder is shaped as a drawer which can be pulled out to place the sample, and then in to analyse it. When the drawer is open, a calibration target faces the aperture of the spectrometer to allow the best precision of measures.

Figure 1 - SpectroLab 1.0

3. Different test configurations

There are two configurations: the “Lab mode” and the “Lander mode”.

In the “Lab mode”, we consider that the user is close to the SpectroLab. SpectroLab is plugged to a laptop, on which the user runs the spectro analysis. The operator activates the opening of the sample holder, place the sample and closes it.
In the “Lander mode”, SpectroLab is embedded on the ExoGeoLab lander (EuroMoonMars robotic test bench). Using the equipment on board the lander, the user can control SpectroLab remotely: open the sample holder, store the flat field, close the drawer and acquire the spectrum of the sample. The user will also have access to a live view of the sample holder, to allow him to check the functioning of it all, the illumination of the sample, etc.

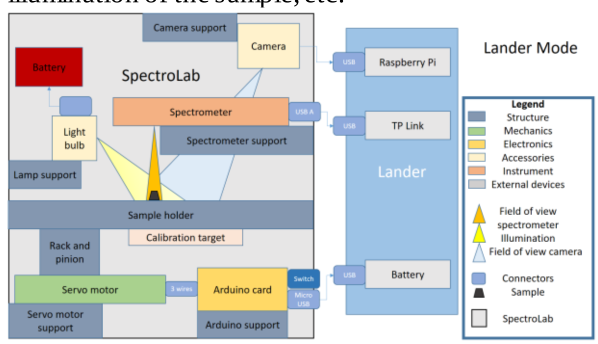

Figure 2 - SpectroLab architecture in Lander Mode

4. Development of SpectroLab

The development of SpectroLab is still ongoing. Figure 1 shows the first version of the test bench; it still lacks the servomotor and control system of the drawer as well as the camera and the illumination system. It is the simplest configuration allowing to run spectro tests.
We 3D printed the structure at ESTEC, in the EuroMoonMars ExoHabitat.

5. Future uses

This SpectroLab is a prototype for a future planetary spectroscopic test bench. To make the design adapted to extra-terrestrial use, it would of course need to be either made of a more resistant material, or 3D printed once arrived on location.

6. Scientific aspect

The work on SpectroLab also has a more scientific part, dedicated to the data analysis. We are developing a detailed method allowing to get spectra with as little noise as possible in the 700nm – 880nm range for characterisation of Moon and Mars minerals, as well as a database of spectra of Moon/Mars analogue minerals.

Acknowledgements:

We would like to thank the International Lunar Exploration Working Group (ILEWG) and acknowledge the help Alexander Zaklinsky provided by lending us his 3D printer.

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Telecontrol of ExoGeoLab lander

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1. Introduction

ESA-ESTEC and the International Lunar Exploration Working Group (ILEWG) developed the ExoGeoLab Lander. This pilot prototype intends to prove the utility of common use of instruments by astronauts and remotely. Its aluminum structure can be equipped with payloads, such as telescopes, spectrometers, controllable cameras, drills, etc. Anyone of them can be remotely controlled, in short range by a dedicated computer, which can in turn be remotely controlled for long-range manipulations.

1.1 Goals

A set of computerized instruments, such as telescopes or spectrometers could be used in the frame of Moon/Mars habitats to obtain scientific results, such as astrophysics or soil analysis, but also for cooperation with astronauts, such as the monitoring of distant Extra-Vehicular Activities (EVAs). The remote operation of such scientific instruments has already been demonstrated with this lander [1-5], so we are now working on the improvement of the reliability of the technologies and the capabilities of our instruments, and especially the telescope.

1.2 Known advantages

The Lunar surface has obvious advantages for astrophysical studies, because of the low-seismic activity, the absence of an atmosphere or even the low and very predictable orbital rotation [6].

2. Modifications and architecture improvements

To improve the robustness of our control system, which is made of off-the-shelf components, we worked on the developments of dedicated drivers. The mainly problematic system remains the telescope, because of communications issues between the mount and the controller. To avoid troubles due to motions out of the safe range, we developed a monitoring systems made of controllable cameras broadcasting real-time images of the lander and its telescope, while looking into the communication issue itself. This system and the drivers mentioned above are the main improvement made since last year.

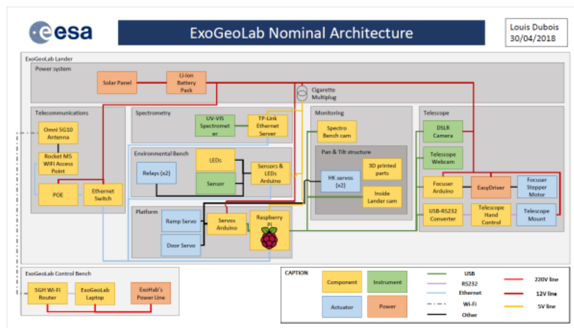

Figure 1 Architecture of the ExoGeoLab lander

3. Preliminary results

The EuroMoonMars team organized on the 19th and 20th of April a two-day workshop. We ran two analogue simulations with experienced and beginner participants, and let them use the lander. This field test gave us feedback on the user-friendliness of our systems, its robustness, etc.

Figure 2 Analogue astronauts practicing remote control and target acquisition before simulation

So far, because of the communication issue between the embedded computer and the telescope, we cannot perform any kind of alignment. However, manual motion control remains doable, and thanks to a webcam mounted on the telescope's tube, we already managed to perform fully remote astrophysical observations.

Figure 3 Image of the Moon taken with ExoGeoLab's telescope from ESTEC

4. Expected Improvements:

We are now working on the solving of the communication issue described above, which precludes alignment. Once this problem solved, we will be able to align the telescope, to automatically target at stars from databases and even program automated observations. Then we would be able to acquire usable data remotely from a distant facility, as astronauts could do from their habitat. We are also working on the ability to orientate and target automatically at non-astronomical marks. Such a capacity would allow, as explained earlier, to follow distant EVAs from the habitat, but also to target some interesting areas in order to send manned or unmanned exploring systems, like rovers or drones.

Figure 4 Contour and centre detection on a picture of the Moon

5. Acknowledgements

We would like to thank ILWEG, Elise Clavé, Germaine van der Sanden and former EuroMoonMars trainees for their help, and all participants of our simulations.

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Environmental ethics in outer space - Long term sustainability of the human species

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Abstract

This project integrates environmental ethics in the emerging field of astrobioethics, to obtain an ethical foundation for long term sustainability of the human species beyond Earth. Becoming a multiplanetary species represents a permanent alteration of human life, from an environment we developed from to one where we will be foreigners. I argue that we need to exceed from asking *what* we can do and *how* we can do it, to how we *should* do it. Consider this question: What kind of psychological and social being will a human be that has no relation to or experience of other forms of life, or solely of an artificially introduced environment? The question of what we want to bring along and what we want to leave behind gets a significantly different meaning when we change our vocabulary from expedition and exploration to settlement and exploitation. I argue that we need to define what sustainability is in outer space.

1. Introduction

The dominant discourse on space settlement is currently narrated as a continuation of the exploiting, economically driven definition of progress. Contemporary environmental philosophy argues for the Western cosmology's conception of humans as somewhat separated from and superior to the natural environment, as the major contributor to the current environmental crisis, through its fostering of an ethic lacking the resources to state why environmental harmful behaviour is wrong [1]. Environmental philosophy, as numerous natural sciences, argue for the physical and psychological relationship dependency of humans to a natural environment. If we embark on this adventure armed with the same ethic, I argue that long term human survival beyond Earth is unlikely. I propose that we must base our expansion on ethics that acknowledges the limitations, risks and pitfalls of pure anthropocentrism, and includes a more ecocentric understanding of ourselves and the environments that would be housing us, and thus a guideline for behavior for the benefit of all life and non-life.

2. Rationale

I argue for three specific reasons why spreading Earth-life in the universe is both a necessity and a desire from a human perspective. The first is an acknowledgement of life's *conatus*, the second is for long term survival, and the third is for the cosmic value of life as potentially something exceptional. Progress is linked to *conatus* and thus not easily tamed. The definition of progress however is in our power to redefine. An alteration in the ethical foundation is hoped to positively affect also our treatment of Earth, as arguably should be of priority, but due to the fact that these plans are, if possible, going to be executed simply due to existing interests such as SpaceX, this project focuses on the destination in order to bring critical questions to the table in time. By basing my research on the *Sustainability Solution* to the Fermi Paradox [2] which implies that a civilization must stay within the carrying capacity of its ecosystem to obtain long term survival, I argue that sustainability of a supporting ecosystem is a prerequisite, and that the source to obtain it lies in a reconstruction of the Western ethic of dualism and human superiority.

3. Main themes

The project consists of five correlating main themes:

1. *Ethics concerning how we should relate to extraterrestrial environments.* Settling beyond Earth will entail compromises between human interests and the need for a supporting ecosystem, versus the new environment. I argue for a need to remember critical aspects of past Earth colonization and exploitation, and acknowledge both that we will be intruders, and our limitations in analyzing possible risks for both the new world and for ourselves. By which principles should we relate to possible indigenous life and non-

life on that world? How can we fulfill our own *conatus* in a way that does not threaten either new environments or ourselves? Which efforts and impacts of terraforming can be ethically justified in order to secure human well-being?

2. *Which value-system will apply in space.* The hierarchy-based value system with utility for humans as the pinnacle, born from our current Western ethics is, as demonstrated over the last centuries, unsustainable. In a less hospitable environment than our home planet, a direct transfer of current values are unlikely to function for both the human inhabitants and the environment. Think of Mars One's worm experiments for Mars agriculture [3], how valuable would not a worm be on Mars in the early days of settlement? So which values will these future humans be guided by?

3. *Ethics concerning human physical, psychological and technological adaptation.* Settling beyond Earth is currently narrated as an expedition, however an expedition is a relatively short term event under extreme conditions, not sustainable or desirable for the participants in the long run. As a first step, living under expedition conditions will be necessary, but as an expedition is about survival, a permanent relocation is about improving life, thriving, developing and defining new goals and dreams. How will this future human think, feel and behave? What physical and psychological environment will he or she live in? Will he or she have pets?

4. What the socio-political system among humans at an extraterrestrial body could be and its relation to Earth. An initial Mars-settlement is likely to have some socio-political relation to organs on Earth, currently guided by the arguably outdated Outer Space and Moon Treaties. As our extraterrestrial settlements grow, the questions of socio-political and economic structures are more questionable to be directed from Earth. Haqq-Misra's call for liberating Mars presents many of the decisions in need of settling, preferably in advance of settlement [4]. What collective humanity will these humans be part of? Is 'colonization' the concept we want to apply, or should we rethink our past methods for expansion?

5. *Ethics concerning our universal role and legacy as an intelligent species*. If we are to spread in the Universe, I argue that it should be in our interest to consider our universal role and legacy. Whether we take on the role as guardians of life, as discussed by Chon-Torres [5], I argue that our one ability which sets us apart from other life on Earth, our reflexive self-consciousness, is followed by a responsibility, exactly because it enables us to comprehend, reflect, and thus make choices. What values do we want to represent as an intelligent species?

4. Method and components

The project will visualize the complex correlation of the physical and psychological relationship between human beings and the natural environment, by merging social sciences such as environmental philosophy, ecopsychology, geo- and bioethics and astrobioethics in a framework of natural sciences such as evolutionary biology- and psychology, ecology, astrophysics, geology and astrobiology. Ethical implications of past events in the history of humanity as well as both the iconic imagined and the actually planned future scenarios are analyzed, in order to reach an ethical foundation coinciding with the Sustainability Solution. The project will thus take the overall shape of a qualitative thought experiment of normative futurology.

5. Conclusion

In order to secure our own survival, acknowledgement of our *conatus*, and improve our universal legacy, I argue that an alteration of our current ethic is needed as we intend to expand beyond Earth. This entails defining what is sustainable in outer space, and constructing an ethic that merges sustainability with our desires to take on a new role in the name of humanity. To reach such goals we need to think, comprehend and act in accordance with the scope of the dream, and evolve that dream accordingly through a process of feedback learning. As we physically expand our known world, so must our ethical perspectives grow accordingly.

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Four Centuries of European Planetary Mapping: Towards Mapping for New Human Surface Operations

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Abstract

We have attempted to map the complete professional planetary mapping scene from the beginnings to today and compiled a catalog of over 2200 standalone planetary maps published between 1600 and 2017 internationally, including the USA, Soviet Union/Russia and European countries (especially Germany's DLR/TU/FUB map production outputs). The motivation for the creation of this catalog is that recent advancement in international cooperation and national space programs outside the United Stations, in particular in Europe and China, led to a proliferation of planetary maps that are published uncoordinated, without a central repository. Several of these recently produced planetary maps are not even available online. Our catalog aims to inform the planetary community about the recently completed maps worldwide, to aid planetary geologists in finding the appropriate previously published maps for their analysis. This database stems from the Integrated Database of Planetary Features [1]

1. Introduction

Europe is where planetary mapping began and after a long decline in producing original materials, in the last decade Europe returned to the planetary mapping field with a rich variety of map products and a number of maps reaching those produced in the USA. On the other hand, the USGS is still the single publisher for *peer-reviewed*, professionally edited planetary geologic maps that are *published in a coordinated manner*, since 1961 [2]. The production of USGS planetary maps are supported by NASA's different elements of the Planetary Science Research Program where individual researchers or groups of researchers produce maps that are edited and published by USGS. *In Europe*, however, ESA policy is not supporting planetary mapping unless it is part of an ongoing mission or the planning of a future mission. Even if workers find support, European planetary researchers do not have any publishing house that would take the responsibility to coordinate or publish European-produced planetary maps. This has led to map publications distributed in a variety of journals, online platforms, creating difficulties in finding the published maps and a variety of standards, formats, and qualities of works. Standalone mapping efforts have become more common in recent years and the number of published major (large-size) planetary geologic maps in journals are now comparable to those released by USGS [3]. International cooperation within single space missions, such as Dawn and Cassini, resulted in mapping tasks distributed over groups in different nations, according to the origin of suppliers of cameras or other instruments aboard the spacecraft [11]. The need to quickly publish geologic maps during the active missions also generated geologic maps outside the slower peer-review process [4,5]. European plans for landing or flying their missions also resulted in the publications of various geologic and geomorphic maps [6]. Chinese scientists have begun producing their own lunar maps [e.g., 7].

1.1 Historic aspect

Previous map catalogs could not quantify the total map production. Our catalog contains data that can be filtered to authors, year, country, scale, etc., which can reveal long-term trends in planetary mapping and in general, planetary science activities [10] (Fig. 1). Although this is mostly of historical interest, this catalog also can keep track of recent dramatic changes in planetary map production internationally. Our catalog is available through the website of the ICA Commission on Planetary Cartography [9] and is being updated regularly with both newly resurfaced historic maps (especially commercially published maps in which field the catalog is far from complete) and new additions. On longer term, we plan to add maps that have been published in journal articles (perhaps with the help of A.I.-based search methods) and also to digitize the feature location information on those maps that are only available in non-GIS formats. It is still under consideration how we can include and compare GIS layer maps to formerly formally published map sheets in the database statistics.

2. An overview of planetary maps published in 2017

New planetary maps are distributed online and many are produced for online use. We classified recent maps into *Web Map Services* (WMS), *geologic maps*, *base maps* and *citizen maps*. WMS's and citizen maps are new developments in planetary mapping. WMSs are changing how we access, use and produce maps. WMSs are organized into map layers, which allow the user to view and analyze the terrain in detail. Highlights include the MoonTrek by NASA/JPL/Caltech, the Solar Atlas System created by ESRI, Space Maps by Google with original photomosaics, and the European initiative of OpenPlanetaryMap (OPM), which is the first attempt to create a vector-based Mars base map. Classic geologic maps with large-sized sheet layout completed in 2017 mostly represent the Martian geology [8, 9], however, there are also Mercury [6] and Ceres projects [5]. In 2017 there were also ongoing projects of other celestial bodies (Moon, Charon, Europa) that remain to be finished in the future. New Horizons, Dawn and Cassini spacecrafts provided materials for new base maps of Pluto, Ceres, and Mimas. End products include the Pluto color photomosaic image, while Ceres and Mimas are shown in classical cartographic sheets, produced at DLR in Germany. The largest group of maps produced in 2017 came from citizen scientists.

3. Challenges

Maps are used for mission planning, surface operation and post mission analysis. Maps serve as the interface between humans and the spatial infrastructure data. In the near future maps will be key components of planning and operating new human missions, e.g., Moon villages. These would require large-scale maps and the development of new digital mobile map interface simulated in a number of analog missions [12]. Observable is an evolution of planetary mapping from traditional static (print) layouts to forms more adjusted to the digital, dynamic online medium. We live in a transition period where static maps that characterized the last 400 years may soon become extinct and new, dynamic digital map services and GIS layers for scientific use could, or already did, replace them. This has major consequences on the art aspect of cartography in which online and dynamic applications provide new opportunities.

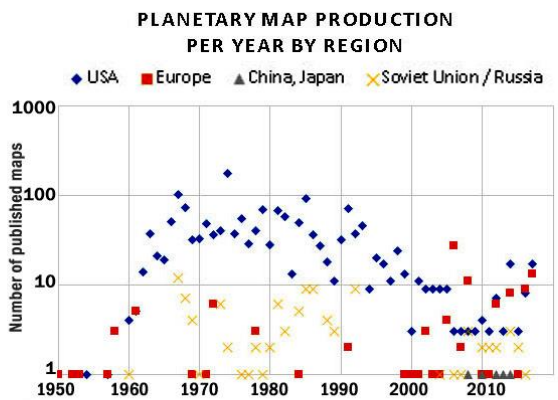

Figure 1: Planetary maps of all types published by professionals in map sheets or atlases, since 1950. Note logarithmic scale for the number of maps.

4. Acknowledgements

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Moon and Mars habitation in lava tubes: The first explorers will be cave men again. Stefánshellir test site in Iceland

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4th Planet Logistics (4PL) is establishing a lava tube test site for expeditions to the Moon and Mars. The cave, called Stefánshellir, is situated in western Iceland, in the Hallmundarhraun lava field, (figure 1).

The project focuses on the development needed to establish facilities on the Moon and Mars, utilizing naturally occurring lava tubes which will serve as habitable zones for human exploration (figure 2). The cave will provide a development test site suitable for work with robots, materials, equipment and inflatable habitats with the aim of providing key data for future human missions to the Moon and Mars.

Figure 1: Inside Stefánshellir lava tube, West Iceland. Credits Björn Hróarsson.

Lava tubes offer future explorers a way to greatly reduce the time, resources and effort needed to initially construct safe and practical habitats and other pressurized support facilities such as greenhouses and maintenance enclosures.

Lava tubes will protect these explorers from harmful radiation, extreme temperature changes and deadly meteorites. Besides that, vestigial or fossil life forms on Mars will most likely be found in caves.

Iceland has been selected for this development test site as it has many parallels to the Moon and Mars, including a barren landscape, rocky soils, limited accessibility, and naturally stable lava tubes.

Thanks to an international team of experts in logistics, geology, engineering and expedition planning, as well as a broad network within the country and to the exclusive right to access a major lava tube, 4PL is also able to assist and support projects of various kinds and magnitude proposed by third parties.

Moreover, 4PL focuses on educational outreach programs supporting and developing different projects, including a museum exhibit in Húsavík, Iceland, with aims to produce additional exhibits in continental Europe.

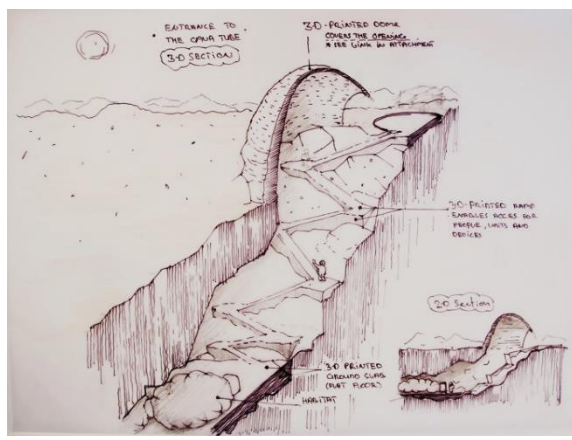

Figure 2: Drawing of a possible outlook of a lava tube habitat, by architect Dmitry Zhuikov, zaarchitects.com, advisory board of 4th Planet Logistics.

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Homepage 4th Planet Logistics: 4thplanetlogistics.com

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LOGOS: Lunar Organisms, GeoMicrobiology and Organic Compound Space Experiment

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Abstract

LOGOS is a concept designed for *in situ* science on the Moon or in its orbit. Measurement operations on an exposure platform as well as within a micro-greenhouse device are part of this concept. The goal is to investigate the use of lunar resources as well as to analyze the stability of biomolecules as potential biosignatures serving as reference for future space exploration missions to Mars and the icy ocean moons in the outer solar system.

1. Introduction

Astrobiological exploration of the solar system is a priority research area such as emphasized by the European Astrobiology Roadmap (AstRoMap) [1]. It is focusing on several research topics, such as "Habitability" and on "Biomarkers for the detection of life". Therefore, "space platforms and laboratories", such as the EXPOSE setup installed outside the ISS [2],[3], are essential to gain more knowledge on space- and planetary environments, which might be an essential basis for improvement of the robotic and human interplanetary exploration (Moon, Mars, Encedalus, Titan and Europa). In reference to these exposure platforms a new generation of hardware is needed to be installed in the lunar orbit or directly on the Moon. LOGOS is such a concept combining the life detection topics with topics relevant to autonomous life supporting systems. A combination of a sample exposure device and a micro-habitat for plants and microorganisms could address a tremendous number of questions from astrobiology and life sciences.

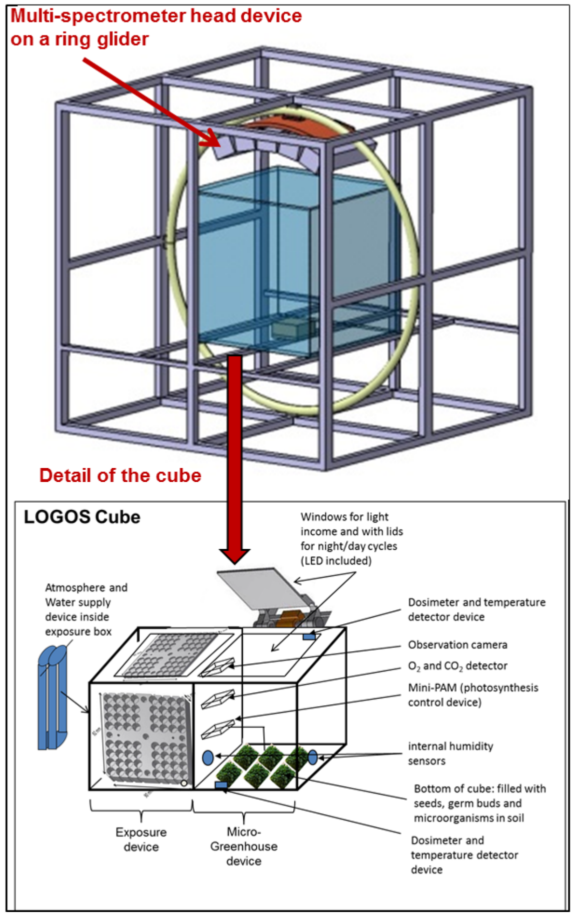

Figure 1: The LOGOS concept for multipurpose use

2. The main objectives

In focus of LOGOS are:

- *In situ* measurements by spectroscopy methods (such as Raman, IR, UV/VIS-spectroscopy) for analysis of biosignatures and their stability (future support of life detection missions on Mars and the icy moons in the outer solar system)
- *In situ* measurements of environmental conditions (radiation, pressure/vacuum, temperature, pH, humidity) in micro-modules / compartments in reference to planned micro-habitat experiments placed on the Moon or incorporated on an exposure facility in orbit

- *In situ* measurements of microorganisms' activity in micro-modules / compartments in reference to planned micro-habitat experiments placed on the moon or incorporated in the exposure facility in orbit

3. Summary and Conclusions

The Moon is an excellent platform to operate different space experiments which will be of relevance for astrobiology, life sciences and human space missions. LOGOS tries to fulfill a large number of scientific works in reference to these disciplines. The lunar environment is much harsher compared to Mars; and tests on biomolecules in this environment could provide information on their stability and therefore on the value to be used as reference for future space missions to Mars or the icy ocean moons in the outer solar system. Resources of the Moon such as the regolith or the freely available radiation on the surface could be tested by using them in a micro-greenhouse. Within this greenhouse different filters could test the optimal spectra range of the radiation.

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Future Low-Cost Lunar and Planetary Missions Enabled by Commercial Space Companies

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Abstract

Science missions to the Moon need not be seen as rare and expensive opportunities. Affordable, repeated access to lunar orbit and/or the lunar surface is being made possible by innovations by commercial space companies.

Moon Express' vision is to open the lunar frontier with turn-key payload, data and services for missions to the Moon for a wide range of customers globally, including governments, NGO's, commercial enterprises, universities, and consumers.

Like the Earth, the Moon has been enriched with vast resources through billions of years of bombardment by asteroids and comets. Unlike the Earth, these resources are largely on or near the lunar surface, and therefore relatively accessible. Moon Express is blazing a trail to the Moon to seek and harvest these resources to support a new space renaissance, where economic trade between countries will eventually become trade between worlds. All Moon Express expeditions will prospect for materials on the Moon as candidates for economic development and in-situ resource utilization.

One of the greatest practical space discoveries of our generation is the presence of vast quantities of water on the Moon. Water not only supports life but its constituents, hydrogen and oxygen, are energetic and clean rocket fuel. The discovery of water on the Moon is a game changer, not just for the economic viability of lunar resources, but for the economics of humans reaching Mars and other deep space destinations. Water is the oil of the solar system, and the Moon can become a gas station in the sky to fuel human space exploration, development and settlement of the solar system. Moon Express will begin prospecting for water resources on the Moon with its very first expedition.

1. The MX family of spacecraft

Moon Express has developed a family of flexible, scalable robotic explorers that can reach the Moon and other solar system destinations from Earth orbit. The MX spacecraft architecture supports multiple applications, including delivery of scientific and commercial payloads to the Moon at low cost using a rideshare model, or charter science or commercial expeditions to distant worlds.

The MX robotic explorer spacecraft are optimized for launch on existing and emergent rocket systems. The payload masses quoted below assume no launcher constraints.

MX-1: A single stage spacecraft capable of delivering up to 30kg to the lunar surface.

MX-2: A dual-stage spacecraft that doubles the capability of the MX-1 and can reach the moons of Mars.

MX-5: A cis-lunar workhorse spacecraft that can deliver up to 150kg to lunar orbit or 50kg to the surface.

MX-9: A lunar prospector/harvester that can deliver up to 500kg to the lunar surface, including an embedded MX-1R spacecraft that can launch from the lunar surface and return lunar samples to Earth.

The MX spacecraft architecture supports multiple applications, including delivery of scientific and commercial payloads to the Moon at low cost using a rideshare model, or charter science expeditions to distant worlds.

Designed for Scout Class exploration capabilities starting from low Earth orbit, MX-1 delivers flexibility and performance to revolutionize access to the Moon and cis-lunar space.

Figure 1: MX-1 Spacecraft

Dual stage flexibility drives more payload to the lunar surface or extends the reach to deep space. Compatible with existing and emergent launch vehicles, the MX-2 delivers Scout Class possibilities for exploration and commerce at low cost.

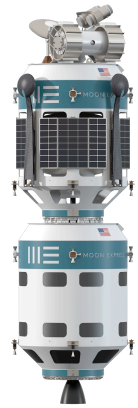

Figure 2: MX-2 Spacecraft

Designed as a workhorse that can deliver 150kg to low lunar orbit from low Earth orbit, with a range of configurations to support lunar landing and cis-lunar operations, the MX-5 can also be outfitted with MX-1 or MX-2 staged systems that can bring the entire solar system within reach. Available in orbiter, lander, deep space probe and sample return configurations.

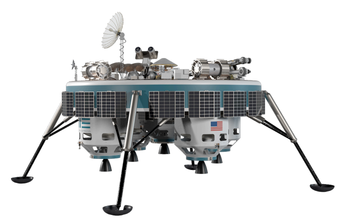

Figure 3: MX-5 Spacecraft

Designed for Frontier Class exploration capabilities, MX-9 will support robust lunar sample return operations. Like it's MX-5 little brother, the MX-9 can also be outfitted with MX-1 or MX-2 staged systems that can deliver over 10kms ΔV and extend its reach to span the solar system, and beyond.

Figure 4: MX-9 Spacecraft

2. Currently-Planned Lunar Missions

Our first expedition will utilize our MX-1E robotic explorer to deliver a diverse manifest of scientific and commercial payloads to the lunar surface. Our customers for this mission include the International Lunar Observatory Association, the University of Maryland, The National Laboratories of Frascati, Celestis and Google.

Following our initial "Lunar Scout" expedition next year, we will offer payload accommodations on future voyages, planned at the rate of one per year. But we can also scale up and increase the frequency of our lunar flights to meet market demand and opportunity.

Our second expedition in 2020, "Lunar Outpost", will enable the first commercial presence and exploration of the lunar South Pole. It may in fact be the first-ever soft-landing at a lunar pole. The primary goals of this mission are to set up the first lunar research outpost at a "peak of eternal light", prospect for water and useful minerals, and accommodate a variety of research instruments for our expedition partners.

Our third expedition, "Harvest Moon", will take place by 2021 and includes the first commercial sample return, beginning our business phase of lunar resource prospecting and harvesting. The samples brought back will be the only privately obtained lunar materials on Earth, and will be used to benefit science as well as commercial purposes.

3. Collapsing the cost of lunar missions

The paradigm of what it takes to fly a lunar mission has begun to shift. Launch costs are rapidly decreasing with emerging commercial launch providers. Commercial operators can reduce the cost of orbiters and landers by re-using designs and by innovating in ways that national space agencies are not mandated to do.

Although the current architectures for Moon Express missions involve going from Low Earth Orbit directly to Lunar orbit, then Lunar surface, or to other destinations in the solar system, integrating the MX family spacecraft into an architecture that involves the Lunar Orbital Platform (LOP) presents new and exciting opportunities for science and for cis-lunar operations in general.

Mission concepts that assume that the LOP is available as a hub of operations in Lunar orbit can enable much larger landed masses on the lunar surface and/or continuous shuttle service for assets on the surface or for returned samples to LOP.

Moon Express has been able to collapse the cost of Lunar missions, and the incorporation of LOP into mission scenarios enable even lower mission costs with a workhorse for small payloads to and from the surface of the Moon, and from the Lunar Orbital Platform itself.

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Dealing with a physically disabled crew member: Lessons learned by the crew of the ICAres-1 mission

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Abstract

The standard for designing manned missions today is to assume that a crew flying to the Moon or to Mars is healthy and physically fit – and remains healthy and fit during the duration of the mission. However, common sense predicts that it is just a matter of time until the first accidents occur during planetary surface missions, accidents that may handicap crew members temporarily or even permanently.

For this reason, the former Laboratory of Extreme Medicine at the University of Medical Sciences in Poznan has conducted the first ever analog mission with one physically disabled crew member. This mission with the name ICAres-1 (short for Innovative Concepts Ares) took place at the Polish LUNARES habitat in the October of 2017 and initially comprised a tri-national 6-person crew, 3 males and 3 females, which was reduced to 5 crew members a few days into the mission due to circumstances unrelated to the mission.

One crew member, an engineer by training, had lost eyesight and the greater part of their two hands about 10 years prior to the mission. Consequently, unlike most missions which simulate first arrival on Mars, ICAres-1 is set long after the first arrival, up to perhaps 10 years, which shifts the mission scenario to a near-permanent settlement.

Members of the crew will present here the lessons they learned during the 2-week simulation. In particular, we will discuss the necessarily made adjustments to schedules provided by mission support, the influence of a physically disabled crew member on group dynamics, and ways in which architectures of surface habitats can be improved to accommodate injured or disabled astronauts.

1. Introduction

ICAres-1 is the first analog mission in which one crew member is physically disabled. The name ICAres derives from Innovative Concepts Ares, and the overarching goal of ICAres-1 is to study the effects of "everything that can go wrong on Mars". Beside the disability of one of the ICAres-1 crew members, the mission included a number of experiments aimed at enabling a crew on Mars to reacting to various worst-case scenarios.

The crew was subjected to various simulated incidents, but also experienced several unforeseen events. In the case of these off-nominal occurrences, ICAres-1 aimed to find and understand good reaction strategies by both the crew and mission control.

2. Mission Details

ICAres-1 took place form October 8th to 22nd, 2017. Initially, the crew comprised 6 crew members, of which one was forced to leave on mission day 4 due to reasons beyond the control of the ICAres-1 team. The remaining crew consisted of three females (D,F,PL) and two males (both PL).

In particular, one of the Polish crew members had suffered an accident 10 years prior to the simulation in which he had lost eyesight and both his hands except for the thumb and index of his right hand.

While it is questionable that a base on Mars would have the capacity to treat the injuries from that accident similarly as they were treated on Earth, we believe that the type of accident and following incapacitation should be within the scope of risk management for Mars, especially for near-permanent missions.

Due to the long-term nature of this mission scenario, the size of mission control was kept to a minimum, with the team only comprising a Flight Director and Flight Surgeon, plus the team of researchers leading varies experiments conducted by the crew.

As is customary with most Mars simulations, the crew was allowed to leave the habitat only when wearing a simulated spacesuit, and then only into the hangar. During the mission, the crew received two cargo drops that had to be transferred to the habitat with an EVA.

Communication with the outside world was limited to e-mail, and internet access was restricted. Contact with Mission Control was to take place via the specially designed HabitatOS, which also enforced a 20-minute delay in messaging in each direction. A similar limitation for internet access and normal email communication had been planned, but was not implemented until the end of the mission. Resources such as food and water were limited, but with a comfortable margin.

Mission control and the crew managed life and work with a physically disabled crew member, which lead to significant adjustments in the crew schedule and many activities. Additionally, the crew learned many lessons for the architecture of a Mars base and how to improve its usability for the event of an incapacitating accident of one of the crew members. Moreover, the crew dealt with the loss of one crew member (including the subsequent “funeral”), communication difficulties, a simulated food shortage and a number of equipment failures.

On the plus side, the crew tested various stress relief and crew bonding methods, including exercising and spending leisure time together and organizing EVAs together – with the limitations of the disabled crew member.

3. Summary

We will present the outcomes of the ICAres-1 mission, the first mission with a physically disabled crew member, with a special focus on the lessons learned by the crew to help future missions to prepare better for and react to disastrous events.

Acknowledgements

The authors would like to thank L. Poulet, S. Rubczynski, Z. Sobiak and M. Harasymczuk for making this challenging mission possible.

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Updated Design Concepts of the Moon and Mars Base Analog (MaMBA)

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Abstract

Surface habitats are among the many technical challenges for human space flight to commence beyond low Earth orbit. Dozens of test habitats have been built around the world in the past few decades. These habitats typically serve training purposes, psychological studies, and/or tests of specific pieces of hardware. However, all habitats that exist to date are of rather low fidelity, i.e. they would not function on the surface of either Moon or Mars. The project Moon and Mars Base Analog (MaMBA) aims to close this gap. Here, we will present the updated design concept for both the overall habitat and its scientific core, the science module. Construction of the mock-up or first iteration of the habitat laboratory is scheduled to begin later this year.

1. Introduction

With the International Space Station having been operational for almost 18 years, ESA is promoting the Moon Village concept and NASA leading preparations for human exploration even further away, most notably the Deep Space Gateway and the integrated SLS rocket and Orion spacecraft.

However, no concrete plans exist yet for the time when astronauts reach the surface of the Moon or the proposed next step, Mars. A number of test habitats have been built during the last decades and inhabited for various durations, among them the American experiments HI-SEAS [1] and HESTIA [2,3], or the Chinese Lunar Palace 1 [4,5], to name a few. However, these and similar habitats are primarily equipped for studies on human factors and would not function in an extraterrestrial environment.

In particular, existing habitats share the following flaws (in varying combinations):

They
- are built for terrestrial simulations and often rely to some extent on the resupply of resources (air, water)
- sit at the surface, that is they possess no means of shielding against space radiation
- consist of either a single module or rely on a central module
- use space inefficiently
- become unusable by injured astronauts (some even provoke accidents)
- contain an ineffective laboratory (scientific objectives were usually added after the end of the design phase).

Project MaMBA (Moon and Mars Base Analog) aims to build the first functional habitat, drawing from lessons learned at existing habitats. The habitat will serve as testbed for mission critical technologies such as life support, power systems, and interplanetary communication, among others.

2. Goals and Updated Timeline

As a consequence of the above stated problems, we aim to build a habitat that would be functional under extraterrestrial conditions.

2.1 Long-term

In particular, the goal of project MaMBA is to create a base that
- consists of six separable modules that can house consecutive crews of 6 for 10 years (see fig. 1 for a rough sketch of the base layout)
- can be inhabited if/when placed on Moon or Mars, i.e. is adequately shielded from radiation, provides air, water, and energy to the astronauts, fosters their physical and mental health, etc.
- enables meaningful biological and geological analyses, plus studies that could lead to a permanent human presence on Moon and Mars
- remains usable after accidents (this includes damage to both crew and habitat)

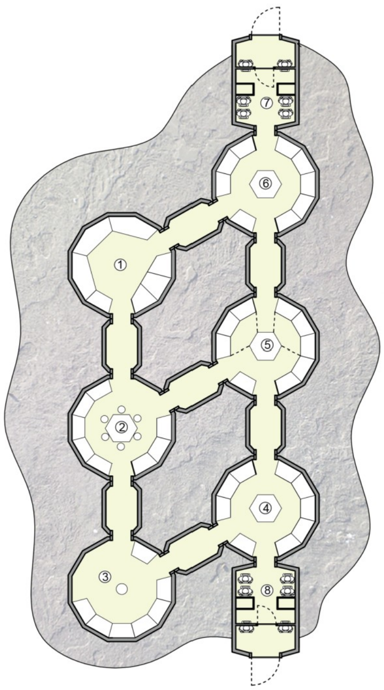

Figure 1: Floorplan of the six-module habitat: 1 - sleeping + hygiene module, 2 - kitchen module, 3 - window and leisure module, 4 - greenhouse and exercise module, 5 - science module, 6 - workshop and storage module, 7+8 - airlocks.

2.2 Mid-term

Being the core of any scientific surface mission, the science module will be the central module. This not only means that the module will be at the center of the habitat, but it will also be the first to be developed and tested. Moreover, the science module will serve as the blueprint for the other modules, in particular with respect to the outer shell design and integrated life support system components.

It should be noted here that the project team is *not* planning to develop all critical system components, but rather to integrate existing systems where possible and to provide an infrastructure for high fidelity tests of said components. Collaborators for these subsystems are sought both in academia and industry.

2.3 Current status

We are currently in the process of developing the outer shell and interior layout of the science module. Construction of a mock-up or first iteration of the module design (that will not yet be fully functional) is scheduled for the late fall this year and will take approximately half a year.

Following construction and outfitting, we will run a series of short-duration simulations (several hours each) to test the usability of the habitat laboratory. The occupants will be scientists performing geological and biological analyses, using the on-board equipment and resources.

Acknowledgements

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EuroMoonMars 2018 Workshop: Hands-on demonstration and practice before analogue simulations.

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1. Introduction

On the 19th and 20th of April 2018, the International Lunar Exploration Working Group (ILEWG) and ESA-ESTEC organized the annual *EuroMoonMars* Workshop and gathered speakers and participants involved or interested in the Moon-Mars Villages topic. The second day of the Workshop consisted of analogue simulations and we therefore used the first day to demonstrate, teach and train the analogue astronauts for the operations and tests they would run.

2. Device usage – Spectrometer and analysis

One of the main leads for investigation on the ExoGeoLab lander is spectroscopic analysis. In the end, the aim is to have a spectroscopic test bench on the lander, which could be operated remotely. During the Workshop, we could not run the test remotely yet, but we showed the attendees the operating of the spectrometer and the different results it allows to obtain. We first made a general presentation to everyone, before letting the analogue astronauts of the following day, and those interested in learning more about the operating, run the test themselves. It was an interesting activity: people who wanted to know more about spectroscopy and obtain some spectra themselves did so quite successfully, using different light sources and samples.

3. Operating ExoGeoLab lander's instruments

During the simulations, analogue astronauts had access to the ExoGeoLab lander. As the participants were not members of the *EuroMoonMars* project, they needed instructions, demonstrations and practice, even though they were provided with detailed procedures to guide them through the operation. Because of the complexity of the system, the first part of this demonstration consisted of a walkthrough of the procedure to take the control of the lander and proceed the settings. Attendees could thus follow up the different steps thanks to the visual streaming, while *EuroMoonMars* team members gave real time advice. The idea here was to allow analogue astronauts to have a first overview of their task, without presenting too many details for non-participant attendees. In a second place, participants had time to practice and carrying out the task themselves or in small groups. With the help of the procedures and the team, attendees managed quite well to take control of the different devices.

Figure 1 Volunteers practicing on the control of the ExoGeoLab lander

4. Radio-communication rules

For the sake of realism, all communications between analogue astronauts and "Ground Support" during the simulations were gathered, normalized and codified. Consequently, communication protocols needed to be presented to future participants. These protocols, based on the use of normalized keywords and speaking priorities, were strongly inspired by aeronautic rules for radio communication, but adapted for the specific technology used for simulations. In the first place, *EuroMoonMars* team members presented the basic rules and applied them to an easy scenario, and then let attendees practice through a few unscripted scenarios.

Acknowledgements

We would like to thank the International Lunar Exploration Working Group (ILEWG), all the speakers and attendees who participated to the workshop and all the analogue astronauts who helped us to prepare and carry out the simulations.

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EuroMoonMars 2018 Workshop: Lunar Analogue Simulations.

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1. Introduction

On the 19th and 20th of April 2018, the International Lunar Exploration Working Group (ILEWG) and ESA-ESTEC held the annual *EuroMoonMars* Workshop and gathered speakers and participants involved or interested in the Moon-Mars Villages topic. On the second day of the workshop, we ran two Lunar Analogue simulations. Three teams were involved: two crews and the Ground Control Center (GCC).

2. Objectives of the simulations

Terrestrial simulations offer great insight into what it takes the human species to inhabit Space.
The first simulation was result oriented, to demonstrate the functioning of different technologies on the ExoGeoLab lander (robotic test bench) and in the ExoHabitat (Hab). The second simulation was to allow attendees to discover the concept of analogue simulations or train them for other campaigns.

3. Preparation of the simulations

The team spent some time preparing detailed procedures and schedules for the different activities and tests to be ran during the simulations, to allow analogue astronauts to perform their tasks with as much autonomy as possible. Astronauts could also train in the handling of the equipment and the communication protocols on the first day of the workshop, during a session of technical demonstrations and master classes.

Figure 1 - Attendees learning to control ExoGeoLab lander remotely

4. The facilities

The simulations took place in the EuroMoonMars facilities at ESTEC: the Habitat module called ExoHab and the laboratory module: the Exobiology Laboratory (ExoLab). The activities in the former were more technology oriented whereas in the latter, they were more about science (biology, human health etc.).

Figure 2 -ExoHabitat with origami tunnel

5. ExoHabitat

In the ExoHabitat, there were three crewmembers in the morning simulation and four in the afternoon one: the Hab Commander, the Scientific Officer, the Engineer and the Journalist. The Hab Commander was in charge of communication with the Ground Control Center, controlled the lander remotely and ran some spectroscopic analysis. The Scientific Officer and Engineer performed Extra Vehicular Activities (EVAs) such as exploring and sample collecting. The Journalist was in charge of uploading the logbook during the mission and record important events.
During the first simulation, the astronauts accidentally introduced a few changes in scenario and not all planned activities were successfully ran. However, the lander was successfully set up, astronauts performed remote control to carry out visual check-up of the facilities and monitor EVAs. Because of the unplanned changes in the scenario, they also performed other tasks, such as detailed spectro-

analysis of the collected samples or sky- and satellite-surveillance.

Figure 3 - ExoHabitat astronauts on Extra Vehicular Activity, checking on ExoGeoLab lander

The second simulation went very smoothly and the different tests were successfully implemented.

6. ExoLaboratory

The Lab Commander, the Scientific Officer, Biomedical Engineer, Food Designer and the Visual Artist constituted the crew of the ExoLaboratory. The crew ran different experiments in the Lab and in Extra Vehicular activities such as a study of the growth of plant in Martian-like environment, a demonstration of guided medical assistance during emergency in EVA.

Figure 4 - ExoLaboratory crew running different tests

The first simulation went very well, except for a slight problem with communication: communications with the Ground Control Center and the astronauts on EVA were on the same device, and therefore in case of emergency, the Lab could not let GCC know as the same time as guiding astronauts on EVA through what to do.

During the second simulation, an important communication problem occurred and the Lab crew has been out of the waves for a significant duration. This event led to interesting situations of emergency, and forced participants involved in GCC and ExoHab to build up and carry out urgent rescue missions. These missions resulted eventually in a recover for the ExoLaboratory of the communications. In the meantime, the crew had very efficiently followed the schedule and performed their tasks.

Figure 5 - Sketch of lab crew during second simulation by Anastasia Izotova, Visual Artist of the second crew

Acknowledgements:

We would like to thank the International Lunar Exploration Working Group (ILEWG) and acknowledge the analogue astronauts who participated in the simulations: Maria Grulich, Anna Sitnikova, Ilaria Cinelli, Alexander Zaklinsky, Yulia Akisheva, Bram de Winter and Jocelino Rodrigues, Daniel Michalik, Mark Ijzerman, Anastasia Izotova and Isa Andersson. We would also like to thank those who got involved in the Ground Control Center, Csaba Jeger and Hugo Schravesande particularly.

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EuroMoonMars 2018 Workshop: Ground Control Center during Analogue Simulations

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1. Introduction

On the 19th and 20th of April 2018, the International Lunar Exploration Working Group (ILEWG) and ESA-ESTEC held the annual *EuroMoonMars* Workshop and gathered speakers and participants involved or interested in the Moon-Mars Villages topic. The second day of the Workshop consisted of two analogue simulations. Three teams were involved: two crews and the Ground Control Center (GCC).

2. Objectives of the Ground Control Center

The team consisted of the *Flight Director*, the *Capcom* (responsible for communication with the crews), the *Public Affairs Officer* and different experts. Their aim was to assist the crews in performing their different activities successfully.

3. Communication with the crews

One of the main issues in analogue simulation is often communication, and for the Ground Control team it is indeed essential. Without proper and efficient communication, the *Flight Director* does not know how his astronauts are doing, and thus the Ground Control Center cannot fulfil his aim of assisting the crews in need. During our simulation, communication between the crews and Ground Control was via a single-channel communication system allowing audio and chat communication. It also allows sharing screens and live videos with Ground Control to keep them informed. It was quite efficient; however, it was a challenge for the Capcom to manage the two communication channels (vocal with one crew and through chat with the other) at the same time.

It was very interesting for the team in Ground Control to have live views from the facilities and the lander. Thus, they could follow the activities of the astronauts and be better prepared to assist on a specific task.
At the beginning of the second simulation, there were some communication problems: one crew was left with no mean to communicate with the Ground Control Center for some time, but it was eventually dealt with and the rest of the simulation went very well.
When astronauts used the communication protocols, exchanges where efficient. That is why it is so important to train all astronauts to communication protocols before the beginning of the simulation.

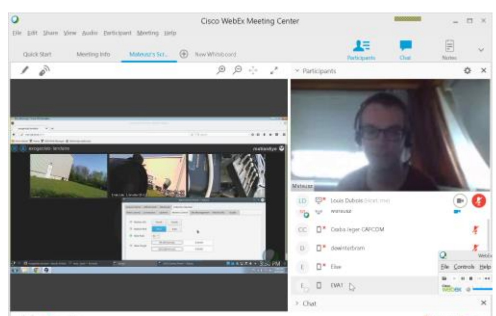

Figure 1 -WebEx interface for communication with crews. The system provided GCC with images of the astronauts inside the facilities as well as the surroundings of the base thanks to cameras on the lander.

4. Technical assistance

The morning simulation was “result oriented”: the crewmembers had experience either as analogue astronauts or in the operating of the different instruments. Therefore, they did not require much technical assistance. However, the afternoon crew was less used to the running of the different tests and thus often asked guidance to the Ground Control team, who provided it efficiently every time. From that point of view, the second simulation was a great success.

4. Participation of guest attendees

While our astronauts were performing their different activities in the lunar analogue facilities and Ground Control team assisted, other attendees were all given a role in the Ground Control Center and asked to give their opinion, ask questions and assist the team. Some raised very interesting points about religion in space and the place of women, for example.

Acknowledgements

We would like to thank the International Lunar Exploration Working Group (ILEWG), all the attendees who participated to the workshop and all the analogue astronauts who helped us to prepare and carry out the simulations. We give special thanks to Csaba Jeger and Hugo Schravesande who took active parts in the GCC during the simulations.

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NASA's Solar System Exploration Research Virtual Institute: Building Collaboration Through International Partnerships

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Abstract

The NASA Solar System Exploration Research Virtual Institute (SSERVI) is a virtual institute focused on research at the intersection of science and exploration, training the next generation of lunar scientists, and community development. As part of the SSERVI mission, we act as a hub for opportunities that engage the larger scientific and exploration communities in order to form new interdisciplinary, research-focused collaborations.

This talk will describe the international partnership program, research efforts and how we are engaging the international science and exploration communities through workshops, conferences, online seminars and classes, student exchange programs and internships.

1. Introduction

NASA's Solar System Exploration Research Virtual Institute (SSERVI) represents a close collaboration between science, technology and exploration that will enable deeper understanding of the Moon and other airless bodies as we move further out of low-Earth orbit. The Institute is centered on the scientific aspects of exploration as they pertain to the Moon, Near Earth Asteroids (NEAs) and the moons of Mars. The Institute focuses on interdisciplinary, exploration-related science centered around all airless bodies targeted as potential human destinations. Areas of study reported here will represent the broad spectrum of lunar, NEA, and Martian moon sciences encompassing investigations of the surface, interior, exosphere, and near-space environments as well as science uniquely enabled from these bodies.

We will provide a detailed look at research being conducted by our ten international partners. In addition, we will discuss the process for developing international partnerships with SSERVI.

2. Summary and Conclusions

As the Institute's teams continue their proposed research, new opportunities for both domestic and international partnerships are being generated that are producing exciting new results and generating new ideas for scientific and exploration endeavours. SSERVI enhances the widening knowledgebase of planetary research by acting as a bridge between several different groups and bringing together researchers from: 1) scientific and exploration communities, 2) multiple disciplines.

Acknowledgements

The authors would like to thank the hard work and dedication to all SSERVI Team members and International Partners that work diligently to create an innovative and collaborative Institute.

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NASA SSERVI: Merging Science and Human Exploration

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Abstract

The NASA Solar System Exploration Research Virtual Institute (SSERVI) is a virtual institute focused on research at the intersection of science and exploration, training the next generation of lunar scientists, and community development. As part of the SSERVI mission, we act as a hub for opportunities that engage the larger scientific and exploration communities in order to form new interdisciplinary, research-focused collaborations.

This talk will describe the research efforts of the thirteen domestic teams that constitute the U.S. complement of the Institute and how we will engage the community through workshops, conferences, online seminars and classes, student exchange programs and internships.

1. Introduction

NASA's Solar System Exploration Research Virtual Institute (SSERVI) represents a close collaboration between science, technology and exploration, and was created to enable a deeper understanding of the Moon and other airless bodies. SSERVI is supported jointly by NASA's Science Mission Directorate and Human Exploration and Operations Mission Directorate. The institute currently focuses on the scientific aspects of exploration as they pertain to the Moon, Near Earth Asteroids (NEAs) and the moons of Mars, but the institute goals may expand, depending on NASA's needs, in the future.

We will provide an overview at research being conducted by each of the 13 domestic US teams. The research profile of the Institute integrates investigations of plasma physics, geology/ geochemistry, technology integration, solar system origins/evolution, regolith geotechnical properties, analogues, volatiles, ISRU and exploration potential of the target bodies.

NASA anticipates additional team selections in early 2019 with a further Cooperative Agreement Notice (CAN) likely to be released in 2017. Calls for proposals are issued every 2-3 years to allow overlap between generations of institute teams, but the intent for each team is to provide a stable base of funding for a five-year period. SSERVI's mission includes acting as a bridge between several groups, joining together researchers from: 1) scientific and exploration communities, 2) multiple disciplines across a wide range of planetary sciences, and 3) domestic and international communities and partnerships.

2. Summary and Conclusions

As the Institute's teams build upon their proposed research, new opportunities for both domestic and international partnerships will be generated that will produce exciting new results and generate new ideas for scientific and exploration endeavours. SSERVI enhances the widening knowledgebase of planetary research by acting as a bridge between several different groups and bringing together researchers from: 1) scientific and exploration communities, 2) multiple disciplines across the full range of planetary sciences, and 3) domestic and international communities and partnerships.

Acknowledgements

The authors would like to thank the hard work and dedication to all SSERVI Team members and International Partners that work diligently to create an innovative and collaborative Institute.

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As our closest celestial neighbour, the Moon has captured the imagination of the world for centuries. America benefitted both politically and academically from the inspirational value of the Apollo programme, and there is a huge opportunity for Europe to take the lead with inspiring the next generation of scientists, engineers and artists (and more) with a renewed focus on the Moon. Educational, multimedia and traditional media campaigns can be used to tell the story of a new era of exploration, developed hand-in-hand with private companies.

PTScientists GmbH is an aerospace engineering company and unique in Europe as the only privately owned and funded SME that is developing a commercial lunar payload delivery system. The company was founded in 2008 and has been developing its spacecraft and lander concept, ALINA-autonomous landing and navigation module, since 2010 with a goal of showing that lunar exploration is commercially viable.

PTScientists is already working on a highly innovative technology demonstration mission that aims to be the first private mission to land on the Moon. "Mission to the Moon" will include several key proof-of-concept elements, with a view to developing a sustainable lunar transport and communications infrastructure, which may also be used to further humanity's exploration ambitions.

The company is headquartered in Berlin, Germany with 45 fixed employees and a team of part-time contributors. The team behind the mission also features some senior engineers of the original Apollo program such as Jack W. Crenshaw who was in charge of the flight trajectories for Apollo. Technical cooperation partners include Audi AG, Vodafone Germany and Nokia Bell Labs, the German Aerospace Center (DLR), the European Space Agency (ESA) as well as technical universities in Germany and Austria.

The team composition does not only include technicians and engineers, but also a1000 m2 assembly hall for our lunar lander (ALINA) and ALQ rover components and a test bed with sand analogous to moon regolith to be able to carry out tests with the moon rover. This sand's composition is similar to lunar regolith and the maximum slope and grip of the wheels can be simulated.

In our own mechanical workshop, we can perform cutting metalworking's, have an electronic laboratory, a large integration room as well as a test facility for a climate control. Our professional clean room will be ISO class 8 and is currently under construction.

PTScientists is also developing its own mission control centre (MCC) and ground segment software in partnership with SCISYS, and guidance, navigation and control (GNC) software with the University of Würzburg and the German space agency (DLR). Our onboard software for ALINA and the Audi lunar quattro rovers runs on the RODOS operating system, selected for its ability to facilitate redundancy. We are using AI Solution's FreeFlyer as a base framework for programming our mission simulations for orbital determination and flight dynamics. Thus, our Partner for video broadcasting and test procedures of voice in the loops simulation is RIEDEL.

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Conceptual design and development of Lunar Mobile Habitat for exploration of Moon

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Moon has always been a dream location for space exploration. Humans have only set foot on moon amongst the other planetary bodies and have further plans to establish a settlement in form a basecamp. The existing design setup of Moon village is a brilliant concept and has many advantages but it limits humans from getting mobile for a longer distance and duration of time and thereby reduce the capability of humans in exploring the far side of the moon. It is impossible for individual humans to perform all the activities on Moon, therefore the usage of rovers in exploration is highly appreciated and human-robotic missions are always a key consideration when missions are planned. Being limited with rovers and only short EVAs will not be sufficient to fulfill the quest for the search for vital things on moon. The aim is not only to explore the surface and help in the colonization of moon. The Author's vision for the future Lunar exploration of humans is to establish a mobile habitat module for human beings which shall help in assessing remote locations easily and effectively. Usage of mobile habitats will not only help humans in exploring the Moon at a faster rate but will make them nomads of the Moon and help increase the probability of finding and establishing better understanding of various locations on Moon. The mobile habitat will consist of all the facilities as the regular habitat base in terms of power, water storage, sleeping pods, living room, kitchen etc. The conceptual design of the habitat which includes all the required facilities for travelling on moon shall be taken care and presented at the conference.

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HERACLES – Exploring the Moon in an International Context

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Abstract

The HERACLES (Human-Enhanced Robotic Architecture and Capability for Lunar Exploration Science) project is currently under study at ESA as a way to enable lunar science in an international context, in particular in collaboration with JAXA, CSA, while NASA and Russia participate as observers.

1. Introduction

HERACLES is designed to demonstrate key elements and capabilities for sustainable human exploration of the Moon and human-robotic exploration of Mars while maximizing opportunities for unprecedented scientific knowledge gain. To enable human lunar exploration, which is one of the four cornerstones of the European Exploration Envelope Program, it is planned to launch a sub-scale demonstration mission in the mid-2020's timeframe to test key components of lunar vehicles, including a lander, rover and ascent vehicle. ESA will coordinate and undertake the study of the ascent module, JAXA will study the lander, and CSA will investigate the rover element. In parallel, we are developing surface operational scenarios that reflect the input from the international lunar science community. This will include the selection and characterization of a potential landing site with a large scientific potential and return of lunar samples of high scientific value before conducting a long distance traverse that will provide further opportunities for science and exploration. The coordination of the planning of science opportunities is performed by the multi-agency HERACLES Science Working Group. This working group is also responsible for developing a mission science management plan to describe science team and science payload selection processes, and data and sample policies. In the next steps, we will engage the science communities of the study agencies and install an international HERACLES Science Definition Team (HSDT). The HSDT will generate a prioritized list of investigations and will provide input for landing site selection. In the initial phase of mission planning, the HERACLES study team developed a nominal scenario with Schrödinger basin as the reference landing site. On the basis of this preliminary study, Schrödinger basin might be a potential landing site that could satisfy may science objectives (Tab. 1) although other sites may also be considered.

2. Preliminary Mission Scenario

The current mission planning foresees a 70-day surface sample return mission, followed by a 1-year traverse encompassing one or more additional potential human exploration landing sites in the south pole region. We plan to return 25kg of samples, including the sample container. In 2017, the Science Working Group defined a set of mission science objectives in response to the ISECG Science White Paper (Tab. 1). A possible mission scenario to accomplish these objectives is shown in Fig. 1. The first HERACLES mission starts with the launch of a mid-sized launch vehicle (baseline Ariane 64) to lunar transfer orbit (LTO). The lunar desent element (LDE) main engine performs the lunar orbit insertion (LOI). In LLO, descent is preceded by a periselenium lowering manoeuvre and more tracking to initialise the LDE GNC for descent. It is assumed that the landing is to occur during daylight conditions During descent, the LDE controls the vehicle attitude to follow the descent profile to a high gate arrival ~1km above the lunar landing site. The part of the mission after High Gate Arrival is referred to as the final descent, and comprises of the reduction of remaining velocity and altitude. The final approach ends in a hovering phase, the goal of which is to precisely

Table 1: Initial HERACLES Science Objectives (unprioritised)	
Responding to ISECG Science Theme: Understanding our place in the universe	
S1	Constrain the impact chronology of the Earth-Moon system and test the cataclysm hypotheses by determining absolute ages for major impact events based on surface geological features
S2	Understand the Earth-moon impact flux by determining the abundance, composition and isotopic nature of impactor remnants in regoliths of various ages
S3	Enhance understanding of dynamic processes on airless bodies by measuring the processes of space weathering, solar wind and magnetosphere interactions and the exosphere
S4	Enhance understanding of the origin and evolution of the moon by determination of structural layering of the highland crust and mantle through in situ geophysical networks, and determination of compositional layering and solidification age through sample return
S5	Understand volcanic processes on the moon through obtaining eruption information, composition and age of silicic domes, scoria cones and holes and youngest and oldest mare material.
S6	Enhance understanding of cratering processes on the moon through study of impacts of different size, age and complexity
S7	Understand the origins of lunar volatiles trapped in ancient rock
S8	Understand solar and galactic evolution by measuring the abundance of cosmic ray generated isotopes in minerals of various exposure ages
S9	Contribute to understanding the origin of life and prebiotic chemistry through constraining Solar System Conditions when life first arose
Responding to ISECG Theme: Living and Working in Space	
L1	Determine the physical and chemical properties of dust and its toxicity
L2	Determine the composition and abundance of minerals in regolith as resources
L3	Identify the effects of exposure to the lunar radiation environment on DNA stability, mutation rates of exploration relevant microorganisms, including human cell analogues

acquire the reference altitude, to steer clear of any inacceptable terrain (rocks or steep slopes), to zero out any horizontal motion, and to perform main engine cut-off (MECO) for final ballistic descent to the surface. On the surface, the Rover egresses the LDE and starts the surface campaign. Initial exploration of the surface by the Rover is supported by ground control and time-tagged commanding until the crew arrives on the LOP-G. Once the crew is present, the crew-supported surface mobility operations will start. The rover then is commanded to drive, to perform sample collection and to transfer the sample container to the Lunar Ascent Element (LAE). The sample collection phase can take multiple lunar day-night cycles and ends with the deposition of the samples into the LAE. The LAE ascends into an initial orbit with the aposelenium at the altitude of the intermediate circular LLO and the periselenium high enough such that the initial orbit will not lead to an impact on the surface for at least two weeks. Eventually, the LAE initiates the transfer to the LOP-G. The sample container will be removed from the LAE by the LOP-G robotic arm. HERACLES's rover remains functional on the surface and is driven by ground-control along the planned traverse to demonstrate long-life, long-range surface mobility and exploration activities (in-situ investigations and sampling).

3. Summary

HERACLES is an exiting mission concept that enables Europe to gain access to the Moon and to play a leading role in the international exploration of the Moon. The concept is ambitious but offers enormous benefits particularly by the combination of human and robotic assets on the LOP-G. The mission will also allow excellent science from orbit, on the surface, and in terrestrial laboratories once the samples have been returned.

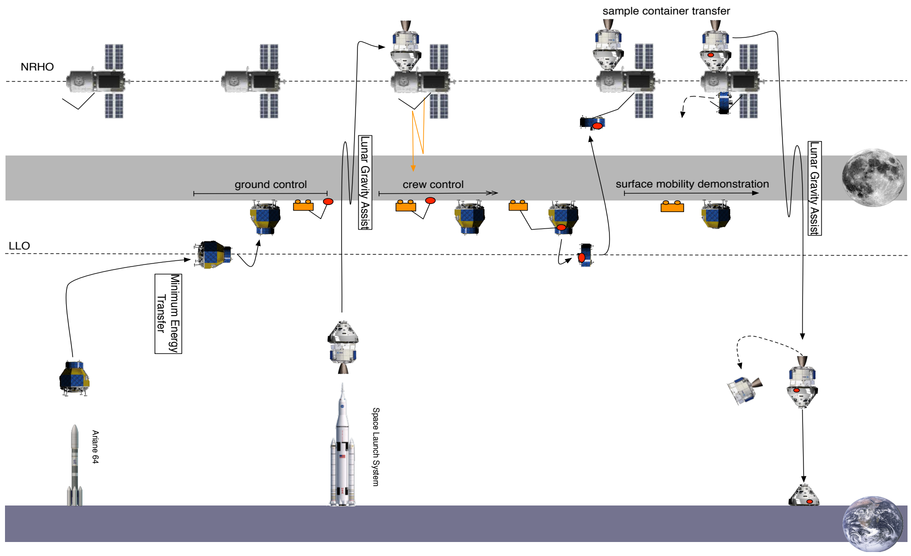

Fig 1: Baseline Mission Operations Scenario (left to right)

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Surface characterization of potential lunar polar landing sites with accuracy up to 7 meters

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Abstract

The landing site selection method primarily developed by our team for Luna-25 mission allowed us to identify several scientifically interesting and safe for landing locations in the Polar Regions of the Moon. These locations can be considered as possible landing sites for future lunar missions.

1. Introduction

Russian space agency is planning to launch two lunar landers in the upcoming years – Luna-25 and Luna-27. Instruments installed on board the landers are designed to study volatiles and water ice, lunar exosphere, dust particles and regolith composition. As primary scientific interest is concentrated in the polar region, the landing sites for both landers are selected there.

2. Data and Methods

The landing site selection method primarily developed by our team for Luna-25 mission allowed us to select the main and reserved landing sites in the South Polar Region of the Moon [2]. Furthermore the method provided us with several scientifically interesting and safe for landing locations in the Polar Regions of the Moon. These locations can be considered as possible landing sites for future lunar lander missions.

The method of map overlaying developed for landing sites selection [2] combines the input maps and estimates the optimal locations for landing based on the spacecraft characteristics. Input maps depict the scientific criteria for the mission success and engineering constraints of the spacecraft. In this study we used data from LEND [4], LROC [6], Diviner [5] instruments as well as LOLA data [7] to create the input maps of surface slopes, roughness, temperatures, water content, etc. and the analysis area extended from the latitudes of 85° up to the Poles on the near side of the Moon. The spatial resolution of the data varied from about 10 km for LEND data [4] up to 7 m for the LOLA SLDEM2013 dataset [1]. The minimum size of the resulting area was set up to 1 km corresponding to the possible high-precision landing technique. The method with the parameters set as described above provided us with about 15 areas suitable for landing and surface operations in both Polar Regions of the Moon.

Further detailed analysis of the areas included estimation of such parameters as mean surface slope, mean sun illumination, mean earth visibility and mean water equivalent hydrogen content of the regolith for each area as well as understanding its geologic context [3]. Then multi-parameter prioritization based on the estimated parameters was performed and the top three areas in each Polar Region were determined. Their main features will be discussed.

3. Conclusions

The performed analysis of the Moon polar surface indicated an extensive area suitable for landing (with the 1 km precision) and surface operations in both North and South Polar Regions of the Moon.

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Near surface environment specifications for Lunar South Pole exploration sites

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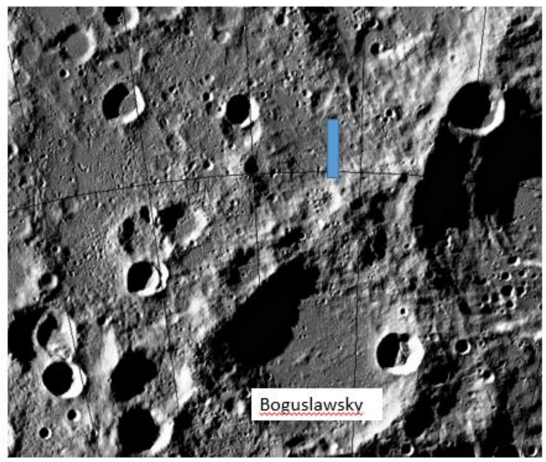
Abstract

Lunar exploration scenarii such as ROSCOSMOS Luna 25 to 29 landers planned between 2019 and 2030 include landing in the Lunar South Pole regions in order to characterize trapped volatiles and usable resources, study the lunar dusty exosphere, plasma and radiation environments, and prepare for the future deployement of robotic and humans explorers and humans infrastrucutres. In the years to come some steps will be undertaken to test technologies for landing, communication, and resources charachterization in a collaborative frame between ROSCOMOS and ESA [1,2].

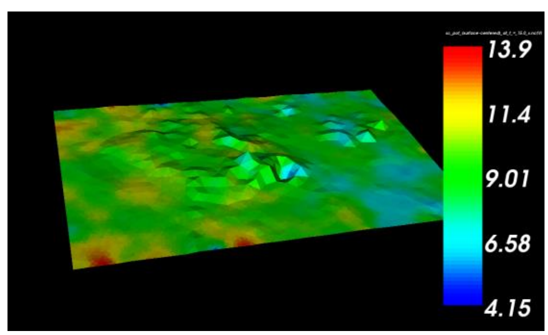
Those activities will benefit from a better understanding of both the lunar regolith properties as well as close lunar surface environment characteristics at scales relevant to habitat, and surface operations. Here we present some predicted effects due to the Solar Wind plasma and Solar EUV illumination interactions with the lunar surface such as regolith surface charging, topology driven fields and potential surface dust mobilization.

We explore a range of environmental parameters corresponding to varying Moon location as well as Solar activity while specific to the South Pole Region of the Moon at a possible area of interest North of the Boguslawsky crater (72.9°S, 43.3°E, ~100 km in diameter), a region of interest for future landers such as Luna Glob[3]. In particular we have used a LRO based DTM on a restricted (~100mx100m) 69.545°S, 43.544°E centered area of interest where some topological variations can be identified (see Figure 1).



. Figure 1: context map (LRO/WAC) showing the area container (blue rectangle North of Boguslawsky crater).

A coupled PIC-Monte Carlo approach is used to calculate surface potential (e.g. Figure 2) and lunar dust charging and near surface transport.



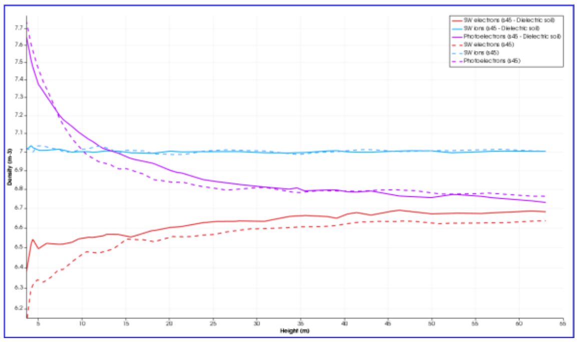


Figure 2: top : surface potential map associated with a DTM of a 130mx90m lunar surface patch (with reduced resolution) at 60 illumination angle in the solar wind. Bottom : density profiles of plasma species and dust

This provides an illustration of possible study cases that can be performed for specific landers, rovers and payloads scenarios at the lunar surface.

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FDOA-based method to enhance TOF method for Position Determination of Lunar Exploration Rovers

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Abstract

In this paper, a method for position determination of robotic rovers in a Lunar exploration scenario is presented. A survey on the different position determination methods and techniques for mobile robots is included, based in a number of assumptions, which are defined considering mission, operational and environmental aspects. The advantages of including information about robot velocity to the position determination, calculated by a Multilateration TOF procedure are reported and discussed.

1. Introduction

Although there are different methods and technologies to determine the position of autonomous agents in a given environment [1], the decision about which of these methods to implement is not trivial as it is a key factor to guarantee the success of the mission. For a lunar exploration mission, the advantages of a cooperative multi-robot system over a single robot approach include increasing robustness, reliability, area researched versus rover mass and power budget etc. Nevertheless, effective mapping and navigation mechanisms must be implemented.

Previous to navigation and other high-level functionalities, a precise and efficient method for mobile robots location is necessary to support local navigation processes as well as the organization of the robotic system as a whole. For this, Frequency Difference of Arrival (FDOA) methods based in Doppler shift for velocity determination can contribute to improve the position estimation [2], in combination with absolute (i.e. non incremental) position determination by, for instance, multilateration Time-of-Flight (TOF) procedures. This work proposes a system to implement such functionality with minimum hardware and software requirements.

2. Materials and Methods

The next figure shows the system proposed. The exploration system consists in a hybrid robotic system formed by large robots providing the communications and navigation infrastructure (Tracking stations) and a number of smaller robots carrying instrumentation (mobile nodes) intended to travel across the research area.

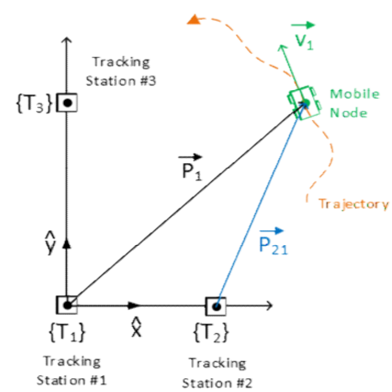

Figure 1: Multirobot system proposed for Lunar Exploration.

The system is configured as a hybrid heterogenous robotic system in order to comply with complex mission requirements and to be scalable and reusable (the large tracking station could be used by future robotic missions or enhanced by further missions). Therefore, a concept of upgradeable robotic exploration infrastructure is presented, making possible the enhancement of the system functionalities with successive missions.

The exploration area is assumed to be 1000 x 1000m, limited and small enough to assume a flat non-geodetic surface [3]. Numerical formulation of the multilateration and velocity determination from the range via Time-Of-Flight measurements and Doppler frequency shifts respectively is presented and discussed, including analysis of computational load yielding to the solving of the resulting algebraic equations systems, generally inconsistent and overdetermined.

3. Summary and Conclusions

The advantages of an heterogeneous robotic system for lunar exploration were explained, and the combination of Doppler shift-based velocity estimation with Time-of-Flight absolute position determination of exploration rovers was demonstrated to enhance position information, necessary for effective navigation across the exploration scenario.

Acknowledgements

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On the need to consider the dynamics of future governmental and cooperate space travel and their effects on the non-biological environment in the planetary system.

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During the last 200 years, driven by the accelerating technological capabilities, human societies leave an exponentially increasing environmental footprint. The realization of this massive impact spreads into nearly every aspect of human behaviour. It appears that humans are setting out for a new age of space exploration and exploitation. Thus, human activities will expand into "pristine" environments beyond the realm of life confined to a thin skin on the surface of Earth; i.e., the atmosphere, hydrosphere and crust of Earth.

The technological achievements and its use by societies develops in a non-linear way, making predictions of future applications difficult. For the first aviation pioneers the sky likely appeared as endless space. Only 70 years after the pioneering air plane flight by the brother Wright the first commercially operated super-sonic air plane travelled between Europe and Amerika. Today 4 billion passengers travel with air planes and substantial efforts are required to minimize plane collisions. Similarly, the first rockets reached and empty orbital space around Earth only 70 years ago. Today the increasing number of space debris may soon lead to a runaway process (Kessler Syndrome) that will turn parts of this orbital space into dangerous ground. These negative developments continue despite the immense economical and strategical importance of the orbital space around Earth. Realizing the speed and dynamics of such a developments shows that human activity will also change the "non-biological" environment dramatically.

Due to the increasing governmental and private space activities it is important to not only consider the technical possibilities but also the social and economic dynamics. While previous space endeavours were initially motivated by the desire to expand the final frontier, most of the governmental support steamed from the intention to advertise and demonstrate political superiority and to finance technological advances. Today space travel is increasingly of economic and strategic interests, expanding form satellites in the Earth to other private activities related to space travel as exemplified by sending a car for public and shareholder interests on a trajectory beyond Mars.

Thus, in order to understand the future impact of advancing space travel requires a combination between technological, and planetary natural scientist and a wide range of human sciences such as economics, law, ethics and social sciences. Discussing protection space and planetary environments is getting less science fiction especially as there will be many conflicts of interests and different expectations in visiting, using, or appreciating the Moon. For example recently the Google x-Price encouraged a visit near the Apollo landing site, thus endangering Niels Armstrong first footprint on the Moon, a possible cultural heritage. The Moon, and ideas of a lunar village present a playground to bringing people with different expertise and views together to discuss on how humans want to develop into a multi planet species.

Considering a World Wide treaty for the Moon similar to the Antarctic treaty would present a starting point to regulate our impact on the pristine space environment and how we pass it over to the next generation.

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EuroMoonMars Workshop 2018: a pilot study on a semi-autonomous laboratory module for analogue simulations

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Introduction: On the 19th and 20th of April 2018, the International Lunar Exploration Working Group (ILEWG) and ESA-ESTEC held its annual EuroMoonMars Workshop. The 19th of April focused on technical demonstrations to prepare interested participants for the simulations, held on the 20th of April.

Terrestrial analogues can offer great insight into what it takes for the human species to inhabit Space. *EuroMoonMars* is a pilot research programme that functions as one of the small building blocks towards human or robotic habitation of the Moon, Mars, Phobos, or asteroids. Its annual program is concerned with the development of its Robotic Test Bench (ExoGeoLab), Habitation module (Exohab) and Laboratory module (Exolab) at the European Space Research and Technology Centre of the European Space Agency, Noordwijk, NL (ESA-ESTEC).

EuroMoonMars2018 Laboratory module: The laboratory module functioned as a sub-system in a bigger-picture with the ExoGeoLab, the Exohabitat, and the Ground Control Center. The laboratory crew consisted of a crew commander, scientific officer, biomedical engineer, food designer and visual artist. The laboratory is a prototype for functional experimentation. There were internal functions and scientific experiments. In addition, there was also an ExtraVehicular Activity (EVA) to demonstrate guided biomedical advice during emergency situations and to collect astro-biological samples - later to be analyzed with the Visual Near Infra-Red spectrometer.

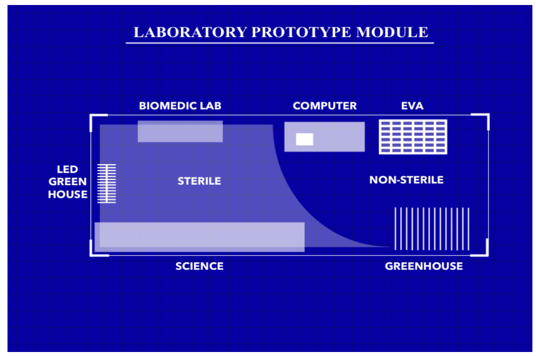

Figure 1: The layout of the laboratory module at ESA ESTEC, Noordwijk, NL.

Plant Laboratory: Long-duration human spaceflight into deep space will increasingly rely on the production of carbon-based biomass. Thorough on-going research into plant growth in space will enable the food provision of edible-fresh products. Within the Plant Laboratory a small-scale pilot study on plant growth in Martian simulant soil with the help of a generic chemical fertilizer in cultivation pots was executed. We had a number of seeds that were carefully selected based on plant research in space e.g. romaine lettuce and red curly lettuce.

In the non-sterile area of the lab there was a greenhouse compartment that could function as a fresh food source, oxygen supply and extraction of pollutants from the atmosphere. The food designer was taking care of the plant health of the greenhouse and the processing of food, in particular hot sauce. This product in particular was chosen because of the known alteration in tastes when humans live for a prolonged time in space.

Figure 2: A photo taken during the first simulation in the laboratory.

Medical Emergency during EVA: During the ExtraVehicular activity one astronaut suffered a physical breakdown. Telecommunication contact with the biomedical engineer enabled guided CPR. One of the EVA astronauts practiced CPR on the other astronaut, based on the instructions from the biomedical expert. **Public Affairs and Outreach:** The Visual Journalist was in close contact with the Public Affairs Officer in Ground Control Center. This allowed direct output from simulation to public. **Lessons learned:** The main issues during the simulation occurred within the communication. During the first simulation there was a communication problem with Ground Control Center that could have been solved by splitting up the communication device. The second simulation suffered from inadequate information on the WebEx code to enter the meeting, therefore they were out of communication for 50% of the simulation. In order to execute the functions well enough during the simulation it is of requisite that the crewmembers are well informed on their tasks before the simulation starts.

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Acknowledgements: I would like to thank all the participants and speakers of the EuroMoonMars 2018 workshop. And in particular the terrestrial laboratory astronauts: Angelo Vermeulen, Anna Sitnikova, Anastasia Izotova, Daniel Michalik, Ilaria Cinelli, Isa Andersson and Mark Ijzerman.

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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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Synergies between geological laboratory analyses on the Moon and Mars

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Abstract

Human spaceflight opens up vast possibilities of scientific research on planetary bodies, such as the moon and Mars. While there is some debate as to which should be the first goal, the consensus is that both will be visited in the mid-term future. To ensure that manned missions to either Moon or Mars will yield a maximum scientific outcome, it is necessary to start the debate about what the scientific community would like to achieve on the moon and Mars, and what equipment would be required to meet these goals. Here, we will look at the most pressing open questions in the field of lunar and Martian geology and how to address them.

1. Introduction

Significant progress has recently been made in launch systems that could bring humans to the moon and to Mars in the not-so-distant future, and several institutes work on systems and system components to support human life on the surface of either planetary body. One of these activities is project MaMBA (short for Moon and Mars Base Analog) which is located at the ZARM in Bremen and dedicated to creating a full-scale, functioning habitat. One core element of MaMBA is the lab supporting geological analyses, among others.

Some analyses are best performed in-situ, during a surface EVA, and others require a sample return to Earth. Nevertheless, it is expected that the first surface habitats will contain a geology laboratory, which could be used for sample analyses, including for the purpose of improving sample quality, and the classification of which samples should be sent to Earth for more in-depth analysis. Previous sampling of lunar materials during the Apollo missions has been with the view of making all analyses back on the Earth.

Including a geology laboratory at a lunar or Martian base would face certain limiting factors such as weight of equipment, energy supply, need of consumables (e.g., gases, liquids), and qualification of the staff. However, the objective of this study is to give a general overview of what can be considered minimum requirement of instrumentation to achieve the necessary first order results.

The laboratory can be compared with what would be considered a well-equipped geology laboratory at a university or research institute with the difference that we will apply some limits concerning equipment size and staff requirements. We will focus on equipment that already has reached some minimization, for instance for robotic missions, and does not require whole teams of trained personnel.

2. Lunar Geology

The Moon is one of the most studied planetary objects; however there are still several major open questions about its formation, evolution, and geology [1]. In situ and continuous investigation of the moon interior structure, volcanic material, and regolith physical and chemical characteristics would help us answer those questions. The moon surface offers a prime analysis possibility of its own impact cratering history and consequently other inner planetary objects. Lunar regolith offers a record of a few Ga of space weathering which would not only increase our knowledge about regolith formation, but also about the sun and cosmic rays variation since the formation of the moon. A geology laboratory, would, in addition, allow a close study on the past volcanic activities.

3. Martian Geology

After four decades of orbital exploration of Mars surface, we have now clear evidence of the past presence of liquid water on the Martian surface [2]. In addition to the observation of fluvial valleys and crater lakes, aqueous minerals and evaporites have, as well, been widely detected on the surface. The presence of these minerals reveals that the climate and surface conditions at the time of their formation must have been different from the current one. In situ investigation of the surface and near surface material

would be crucial for increasing our understanding of the history of liquid water on Mars, which has direct implication on the search for life on the red planet.
Understanding the stratigraphical relation between various geological units, their chemical composition and mineralogy, the formation environment of the aqueous minerals and evaporites in addition to the chronology of surface events, and the interior structure of Mars are our main study goals for a laboratory situated on the Martian surface.

4. Lab Equipment for Moon and Mars

Given the aforementioned broader science questions for the moon and Mars, and bearing in mind the concept of the lab as a place for swift determinations before more detailed analysis of selected samples can be made on Earth, here we suggest the lab to be equipped with, at least, the following:

- First, for selection outside:

1. Visual inspection: high resolution portable camera in order to document the morphology and texture of areas of interest in close-up as well as landscapes. This would enable the possibility of further investigating the ROI in the lab. Tools for sampling, e.g., hammers, chisels, hand-operated core drillers, and lens, as well as sample bags and containers.
2. Cartography equipment such as mapping camera and GPS equivalent which would allow a wide geological investigation in combination to the orbital data.
3. Hand-held petrophysical tools such as susceptimeters.
4. IR spectrometer: for mineralogy characterization and identification of the igneous, hydrated, and evaporite minerals, in addition to comparison with remote sensing results.
5. GPR: to investigate the subsurface layers and potentially composition of material, in higher resolution than already obtained by remotely sensed data.

- Secondly, inside the lab:

6. Visual analysis: binocular magnifiers, with tools such as fluorescent light etc.
7. Capacity to cut and polish rocks of up to hand specimen dimensions (i.e., a cubic dm).
8. Equipment for semi-automated thin section production; for the analysis of thin sections and cut-and-polished rock slabs optical microscopes for both translucent and reflected light.
9. Mineralogy and microstructures: Scanning Electron Microscope coupled with an Energy Dispersive X-Ray (SEM-EDX).
10. VIS+IR imaging spectrometer: to examine crushed samples, their composition and grain size.
11. Raman laser spectrometer: To identify mineral phases at a small scale in a prepared sample.

5. Field equipment

The above mentioned list of instruments would serve as a generic “base lab” for answering a variety of geologic questions. In addition, some of the objectives above would require more specialized equipment installed outside of the habitat:

- Seismometer, heat measurement instrument.

As the moon and Mars have significant differences in term of exogenic surface processes, following separates field equipment between the moon and Mars.

- First, in case of the Moon:

  - Space Weathering: Small particle counter to quantify the micrometeorite flux on the lunar surface over time; portable ASD-type.
  - Lunar volatile content: To monitor the local volatile quantity and avoid contamination in a terrestrial lab, volatile abundances could be measured directly on the Moon, using Secondary Ion Mass Spectrometers (SIMS).

- Second, in case of Mars:

  - A weather station including measurement of wind, pressure, atmospheric composition, and composition variation.
  - Dust collector for later lab experiments on the composition and grain size.

6. Summary

We suggested a list of equipment that could help future astronauts perform geological analyses on the surfaces of the moon and Mars. Much of the equipment is very similar, with only minor differences between the two planetary bodies, meaning that instrumentation developed for the moon could be re-used on a mission to Mars.

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The JULES VERNE 2028 project

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Abstract

The aim of the JULES VERNE 2028 project, proposed for a FET-Open 2018 Horizon 2020 EU funding, is to update the 'polymath'-like global approach, similar to that of the great naturalists of the 19th and 20th centuries, and progressively abandoned with the hyper-specialisation of modern scientists. Together with specialists in cognitive science, researchers from various domains will share and compare their protocols during field investigations and evaluative workshops dedicated to different environments then proposed new and innovative technologies and methodologies permitting to define the ideal protocols to explore new worlds, both on Earth and elsewhere in the Solar System.

1. Introduction

Space exploration of rocky bodies in the Solar System is arriving at the end of a cycle and at the beginning of a new one. Following the upcoming missions to Mars – ExoMars 2020 (ESA-Roscosmos) and Mars 2020 (NASA) – future missions will either focus on other bodies, such as Europa, the icy moon of Jupiter, or on the human exploration of Mars and the Moon. Humanity will thus enter into a new period comparable with the Age of Discovery. In this adventure, explorers will be assisted by new technologies, instrumentation and robotics. To be scientifically pertinent, the investigation of these new worlds must be conducted based upon a global interdisciplinary approach, similar to that of the great naturalists of the 19th and 20th centuries, in order to link very precise measurements to their general context, taking into account the role of the chemical, biological, geological, etc. history of the sample.

Unfortunately, this notion of a 'polymath'-like global approach has been progressively abandoned with the hyper-specialisation of modern scientists, and recent technologies have followed the same trend, becoming more and more specialised and adapted to very specific topics.

The aim of the JULES VERNE 2028 project is thus to update the global naturalist's approach based on new and innovative technologies coming from various domains, and to define the ideal protocols to explore new worlds, both on Earth and elsewhere in the Solar System.

2. Toward a universal protocol

To understand and describe the process of discovery of an unknown place through a spectrum of different scientific domains, field trips will be undertaken with a focus on atmospheres, surfaces, subsurfaces, icy environments and aqueous environments (Fig.1). These will be followed by environment-specific workshops bringing together scientists and instrumentation companies to define a list of the critical data that must be obtained and to identify missing technologies. The field investigations and workshop discussions will be conducted together with specialists in behavioural and cognitive analysis, who will appraise and compare approaches and protocol. This has the aim of discovering the congruent data of crucial relevance for interdisciplinary purposes.

Figure 1: The different environments considered in the JULES VERNE 2028 project.

3. Universal guidebooks

The fieldtrips and workshops will permit to obtain the critical data that would be of paramount interest to measure *in situ*, or in laboratories, for each of the different domains. This will allow the construction of the "perfect" protocol permitting the full interdisciplinary description of any environment during the second stage of the project and the redaction of the 2028 UNIVERSAL GUIDEBOOK OF THE SCIENTIFIC EXPLORER and its SPACE EDITION proposing ideal protocols and instrumentation for future space missions.
Until now, mission payloads have been designed prior to the definition of the missions, producing fragmented scientific results with knowledge gaps. This should be avoided in the future by providing integrated instruments and protocols that minimize these gaps. For example, instrumental constraints are mostly discussed prior to defining the target of the mission (i.e., the landing site). It is the principal aim of the JULES VERNE 2028 project to ensure that scientific objectives are prioritized, optimising protocols and instrumental payloads accordingly.

4. Toward a new technology

The JULES VERNE 2028 project will establish the optimal way for exploring different environments in order to obtain a universal protocol describing the workflow for the interdisciplinary characterization of unknown areas and their associated samples. This will be an ultimate global protocol that could not be achieved with current technology.
The originality of the JULES VERNE 2028 project is to not limit ourselves by being technique-, instrument- or domain-specific; the ultimate goal is not to improve contemporary instruments but to propose a proof of concept for new technology. Major science-to-technology breakthroughs will be achieved throughout the course of the project. The project will conclude with the proposition of requirements specifications for new technology: THE POLYMATH. This could be developed by laboratories, start-ups, and existing private companies and SMEs during or immediately following the project.

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Planetary Science in Analogs in Lunares habitat.

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Introduction

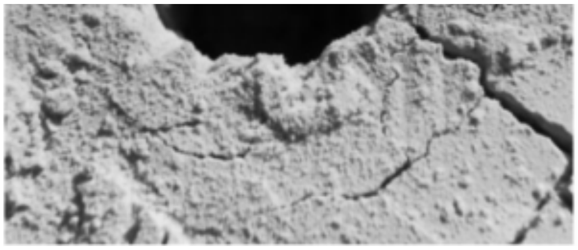
Lunares base was established in 2017 by Space Garden (www.lunares.space) (**Fig. 1**). It was created by space enthusiasts, who sponsored the design, materials, equipment and building of the facility as well as organization of scientific and exploratory missions. Lunares name derives from LUNA (Moon), and ARES (Mars), to highlight ability to run two types of environmental analogs: lunar and martian ones. EVA terrain connected by airlock (**Fig. 2**), together with laboratories inside the habitat were designed to perform planetary science experiments during analog missions. Actually, we study: (1) growing plants on regolith simulants; (2) water and magnetic particles extraction; (3) robotic operations in simulated lava tubes.

Fig. 1. The habitat has 8 functional modules around social area called Atrium (108 square meters): Dormitory with 6 private chambers, Biolab with hydroponics and bioreactors, Analytic lab, Kitchen, Operations room, Storage, Sanitary Modules, Airlock module connected to isolated EVA terrain inside the hangar (photos: Space Garden).

Fig. 2. Airlock module connecting the habitat with EVA terrain. Sterilization area with UV light is activated every time whenever doors are opened. Green and red signaling for “stop” and “go” commands are both located inside the habitat and in the airlock (photos: Space Garden).

1.Regolith simulants

150 square meters of Moon surface was made using small basalt rocks and powder. Another 150 square meters of red rocky surface simulated martian terrain. Both surfaces were shaped with volcanoes and craters. This unique terrain is used for extravehicular activities in isolated from external environment hangar, with various types of lighting modes, communication, navigation and environmental conditions such temperature and humidity. On this rocky surface analog astronauts search for original meteorite samples and regolith simulants. Several regolith simulants were used (**Fig. 3**), for example Lunar analogue AGK-2010 [1]. We cordially invite planetary scientist to test Lunares platform as well as multiple regolith simulants.



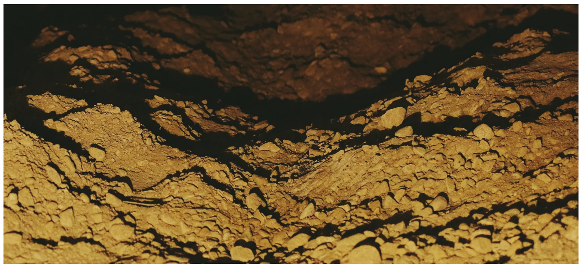
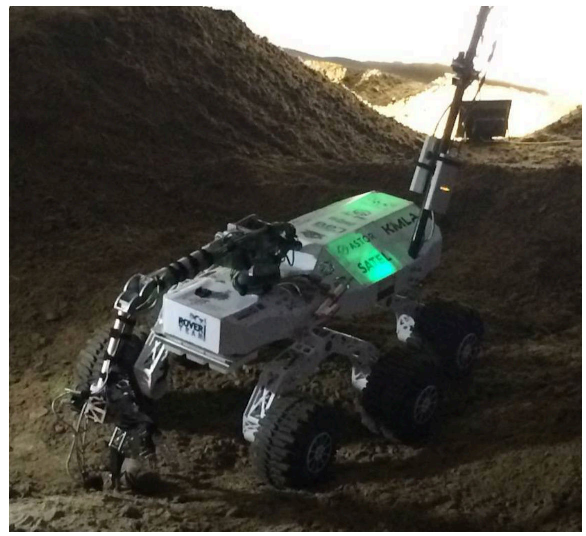


Fig. 3. Lunar analogue AGK-2010 [1] and martian soil (up). Martian and lunar EVA terrain in Lunares hangar (down).

2. Operations

We developed two different habitat manuals and procedure types, specified for lunar and martian conditions. Schedules and communication modes are running on two different timing systems: Lunar Standard Time (LST) for lunar missions [2], and Mars24 Sunclock [3] for martian analogs. Every time two analog astronauts go for 2 hour EVA walks. During this time 3rd astronaut controls EVA from the habitat. Analog astronauts communicate via radio and wifi connection. EVAs can be fully autonomous using rovers and landers (**Fig. 4**), controlled by astronauts crew, or controlled fully remotely from the Mission Control Centers.

Fig. 4. ExoGeoLab lander from ILEWG equipped with VIS/IR spectrometer and telescope ready for use during EVA operations (**up**). Telerobotic operations using Modernity Rover (**down**).



Acknowledgements

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