→ RESEARCH OPPORTUNITIES ON THE DEEP SPACE GATEWAY

responses to the Call for Ideas

European Space Agency

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INTRODUCTION

Research Ideas for the Deep Space Gateway

In the autumn of 2017 the European Space Agency (ESA) opened a Call for Ideas inviting members of the science community in Europe to propose research ideas that could be performed on the Deep Space Gateway, a crewed spaceship in lunar vicinity.

This document contains the ideas received in response to that call and accepted following review by a Science Advisory Team representing the various science working groups that support ESA's activities. Ideas are broadly categorised for the purposes of this document as: life sciences, physical sciences and astronomy, Solar System and Earth sciences, and technology.

It is expected that during the 2020s, the Deep Space Gateway will be assembled and operated in the vicinity of the Moon, where it will move between different orbits and enable the most distant human space missions ever attempted. The Deep Space Gateway will be a testing ground for the challenges of long-duration human missions in the environment of deep space.

The area of space around the Moon can be an effective location from which to travel to other destinations in the Solar System, such as the Moon or Mars. The environment there is also representative of deep space. The gateway could be an enabling infrastructure for human and robotic missions that access the lunar surface and return samples and eventually people to Earth.

The Deep Space Gateway initiative is being led by the International Space Station partners: ESA, NASA, Roscosmos, JAXA, and CSA. Plans are currently at an early stage of definition and envision a power and propulsion system, a small habitat for the crew, a docking capability, an airlock, and a logistics module.

The ideas included in this document demonstrate the research opportunities that can be created and can be used to support preparatory activities for the Deep Space Gateway. These ideas highlight in particular the capabilities that would be needed to enable research, the partnerships that can make it happen and future Announcements of Opportunity for research.

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- Effects of cosmic radiation on human psychoemotional performance and neurological status
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- Lunar environment package

PHYSICAL SCIENCE AND ASTRONOMY

SPACE-COTS SERIES:

RADHARD BY DESIGN MEMORY CELL FOR DEEP SPACE MISSIONS

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Scientific Domain:

The miniaturization of integrated circuits offers new advantages like higher integration but it has also disadvantages especially for harsh radiation environments like in space. For example the well-known Single Event Effect (SEE) is the result of the impact of and energetic particle (Proton, Neutron, Heavy Ion, etc.) in a sensitive area of the circuit. This project focussed to a particular case of SEE so called Single Event Upset (SEU) which are not destructive faults resulting in the change of the content of a memory cell. As the consequence of the charge issued from them impact of the impinging particle. The advances of microelectronics manufacturing technologies lead to new error to the possibility that neighbour memory cells are modified by single particle: MCU (Multiple Cell Upset). If the perturbed cells are in the same memory word the error is called Multiple Bit Upset (MBU) and cannot be detected by traditional error correcting codes (ECC) depending of the multiplicity. To avoid such errors Bit Interleaving (physical neighbour memory cells are not in the same memory word) is a widely used technique.

An alternative solution to deal with MCU, MBU, etc. is the design of Rad-Hard memory cells (Flip-Flops). This cover all kind of digital circuits (processors, FPGAs, etc.). State-of-the-art solutions make the hypothesis that a single transistor of the cell change as the consequence of the impinging particle. However for circuits manufacturing very advanced technologies this hypothesis is not more realistic.

Furthermore, robust electronics are necessary for future Moon and Deep Space missions. Cost is also a very important factor and the cost reduction of electronic components is necessary for future activities. No ITAR and COTS components are more and more relevant for future space missions and one of the most important components is the semiconductor memory. In this project idea Rad-Hard and COTS technologies will be tested and qualified in order to compare the capabilities of each technology and assure the best reliability for deep space missions.

Idea Description:

Following selected semiconductor memory technologies will be validated for deep space missions:

- DICE (Dual Interlocked)
- HIT (Heavy Ion Tolerant)
- XR (eXtra Robustness) DRAM

The DUTs (Device Under Test) consist of single memory chips with Rad-Hard memory cells inside but also one memory chip will contain new Rad-Hard memory cells issued from the results of the qualification tests considering that one or more transistors may change the status as consequence of one single particle. Patents for the proposed technologies are available and the prototypes will be designed and manufactured with partners.

The prototypes will be tested first on the ground and after that on the DSG platform. Following radiation tests will be done:

- Total Ionizing Dose (TID)
- Single Event Effect (SEE) with particle accelerator and with a high power laser source

The test on the DSG platform allow a technology validation on the most extreme environment. Ones validated in space the best technology can be introduced for terrestrial applications as "indestructible" memory. The philosophy of the project is that Rad-Hard components will convert in the near future to COTS components.
The DUTs will be tested first on the ground in order to have a reference of the behaviour of the components in space. The test system will content ten samples from each memory and a software will write and read bit patterns to and from the memories. The telemetry system will evaluate the status of the components and collect the results of the memory tests. The most important electrical parameters of the components will be monitored. The test platform consists of robust validated electronic which guaranteed the accuracy of the collected data.
Also shielding and new protection techniques will be evaluated and analysed for the feasibility of implementation.
The main aim of this project is to find out the exact behaviour of the proposed technologies so that in future missions an accurate operating period for a mission can be clearly defined.
The measuring environment will be integrated in the test board and consists of well-known reliable electronics which was already used in similar activities. The experiments run automatically and telemetry data will be generated and send through the Deep Space Gateway (DSG) to the control center.
In order to simplify the design the experiment can follow the CubeSat standard and the PC/104. Power and data link will be expected from the DSG.
No special attitude conditions are necessary and no crew support is required.
The expected impact of this project is to learn more about new Rad-Hard technologies and COTS technologies introducing these in future deep space missions. This will increase the reliability of COTS components in such missions and Rad-Hard technologies will be introduced as COTS products, reducing mission costs. The reduction of costs for space electronics will boost the development of new space hardware and systems where SME companies can contribute a lot because the required investment will be low and no permissions will be needed for the use of such technologies.

Estimated experiment properties	Description
Mass of hardware	3 kg
Volume of hardware	20x20x20 cm
Accommodation (e.g. internal/external)	External
Power required	30W
Data generated	10MB daily
Pointing/viewing/line of sight needs	No
Communications needed	No direct
Duration of experiment	1 - 5 years
Crew tasks (if needed)	No needed
Access and servicing by crew (if needed)	No needed
Need for retrieval and return to Earth	No required
Specific orbit needs (if any)	No
Operations without crew (if any)	Operations from the ground. Activities will be planned.

ENERGY EFFICIENT NANOMEMBRANES FOR AIR AND WATER RECYCLING DURING EXTENDED SPACE MISSIONS

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Scientific Domain:
Physical Sciences, Materials, Nanotechnology, 2D Materials, Nanomembrane

Idea Description:
Manned space missions require stable, lightweight, highly selective and energy efficient filtration devices for the recycling of gases, liquids and most important, water. For this purpose, recently developed two-dimensional (2D) nanomembranes are suitable candidates. Their extreme "thinness" of a few nanometers leads to a low weight and allows an energy efficient filtration. The latter is achieved by a "ballistic molecular sieving" mechanism that requires much lower pressure differences and, hence, less energy than the solution-diffusion mechanisms used in conventional membranes, see Fig. 1.

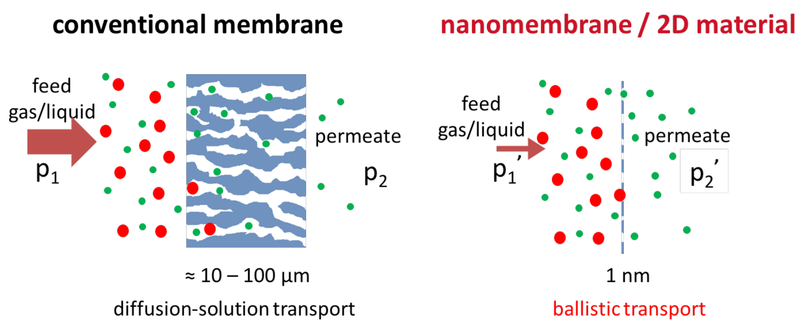

Fig. 1: Permeation through conventional membranes and nanomembranes. The ballistic transport needs smaller pressure differences than a diffusion-solution transport: $(p_1'-p_2') < (p_1-p_2)$.

Carbon Nanomembranes (CNMs)[1,2] are 2D materials with a thickness of ~1 nm that have demonstrated a high selectivity and permeance as gas[3] filters and showed a record-breaking

[1] A. Turchanin and A. Gölzhäuser: Carbon Nanomembranes, Advanced Materials 28, 6075 (2016).
[2] D. Emmrich, A. Beyer, A. Nadzeyka, S. Bauerdick, J. C. Meyer, J. Kotakoski and A. Gölzhäuser: Nanopore fabrication and characterization by helium ion microscopy, Applied Physics Letters 108, 16310 (2016).
[3] M. Ai, S. Shishatskiy, J. Wind, X. Zhang, C. T. Nottbohm, N. Mellech, A. Winter, H. Vieker, J. Qiu, K.-J. Dietz, A. Gölzhäuser, A. Beyer, Carbon Nanomembranes (CNMs) Supported by Polymer: Mechanics and Gas Permeation, Advanced Materials 26, 3421-3426 (2014).

permeance as water filters[4]. The use of CNMs as filtration membranes would allow the fabrication of lightweight and small volume water recycling devices. CNMs are made by the cross-linking of molecular monolayers and my group has ~10 years of experience in manufacturing and tailoring CNMs for It is the core idea of the proposal to explore the use of CNMs in manned space missions and therefore to test their performance as well as their stability in a spacecraft. We plan specific experiments to determine the permeances of CNMs in space and identify effects of gravity on water filtration with 2D materials, and the stability of CNMs after multiple cycles of use towards radiation.

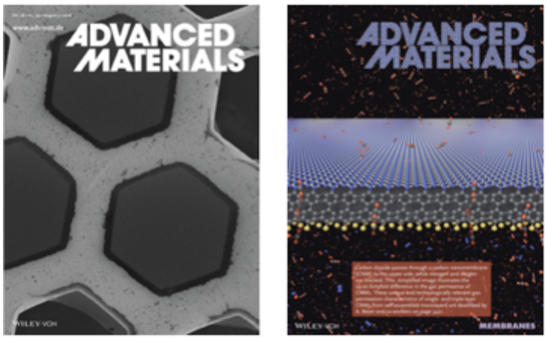

Fig. 2: Two journal covers that showing carbon nanomembranes (CNMs) from our group. Left: Helium Ion Micrograph of a CNM spanned over a hexagonal grid *(1)*. Right: Scheme of using CNMs to separate CO_2 from air *(3)*.

Akin to CNMs, perforated 2D materials such as porous graphene[5] can also provide mass transport pathways with posing certain ion selectivity mechanisms. If the ion selectivity is optimized, porous 2D materials could mark a great candidate for the very efficient air/water filtration. Besides, porous 2D materials can function as a flexible, porous mechanical support of CNM membranes without imposing internal concentration polarization in osmotic water filtration.

Finally, 2D nanomembranes have to be incorporated into membrane modules to become part of filtration devices. Hence, our consortium is looking for collaboration with researchers experienced with air/water filtration modules in manned spacecraft. We also can team up with manufacturers of spacecraft filtration and recycling modules.
In the Deep Space Gateway, we plan to test a small fully automatic membrane device that does not need to be permanent monitoring by the crew. High air/water permeance common in both nanomembrane materials will lead to a significantly small footprint requirement.

Expected impact: The proposed research could provide highly selective, energy efficient and lightweight membrane materials for long-time space applications.

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[4] Y. Yang, P. Dementyev, N. Biere, D. Emmrich, P. Stohmann, R. Korzetz, X. Zhang, A. Beyer, S. Koch, D. Anselmetti and A. Gölzhäuser: Carbon Nanomembranes (CNMs) Combine Record-Breaking Water Permeance with High Selectivity, submitted (2017).
[5] C. Celebi, J. Buchheim, W. M. Roman, A. Droudian, P. Gasser, I. Shorubalko, J.-I. Kye, C. Lee and H. G. Park: Ultimate Permeation Across Atomically Thin Porous Graphene, Sience 344, 289-292 (2014).

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	<100g
Volume of hardware	<10 cm3
Accommodation (e.g. internal/external)	internal
Power required	y
Data generated	Membrane performance
Pointing/viewing/line of sight needs	no
Communications needed	yes
Duration of experiment	months
Crew tasks (if needed)	
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	no
Specific orbit needs (if any)	no
Operations without crew (if any)	

REAL-TIME PENETRATING PARTICLE ANALYSER ON THE DSG

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Scientific Domain:
Solar System Sciences, Astrophysics and Space Travel

Idea Description:
Using a magnetic spectrometer with particle identification capability, it is possible to measure and monitor the flux, composition, direction and time variation of the highly penetrating energetic particles in deep space, to a precision that has never been achieved before. Deploying such a device on the Deep Space Gateway (DSG) will allow to make real-time monitoring and long term measurements over a full solar cycle (~11 years). These precise measurements will improve our understanding of the connection between the high energy particle environment in deep space and the solar activities, as well as bring new insight to the origin and the propagation of these particles. The real-time measurements are also crucial for future human deep space travel since these high energy particles are difficult to be shielded therefore needed to be constantly monitored.

The science objective of the research is to measure the composition and the flux of energetic particles, from 100 MeV/n to 10 GeV/n (an energy range where particles become minimum ionizing, thus "penetrating"), in deep space, over a period of a solar cycle. In the meantime, the instrument will provide real-time monitoring of the penetrating particle environment to the crew. The key instruments are: a permanent magnetic spectrometer (MS) for momentum measurement, a Time-of-Flight detector (TOF) to determine the flight direction of the particle and to provide a trigger, and a charge detector (CD) for particle charge measurement. The data processing of a magnetic spectrometer is straightforward, allowing for real-time calculation of particle fluxes as function of energy and species, which can be displayed and monitored by the crew on DSG. The crew can decide to point the instrument at a particular direction if the situation requires.

The magnetic spectrometer consists of a dipole permanent magnet system instrumented with silicon microstrip detector to measure the bending of the particle in the magnetic field, thus its rigidity. An NdFeB permanent magnet assembly of below 10 kg can provide a dipole magnetic field of ~0.2 Tesla in a cavity of 15 cm in diameter and 40 cm long (square cavity is also an option). The goal is to have a geometrical factor of about 10 cm^2sr. TOF detectors made from plastic scintillators with fast readout are placed from both ends of the spectrometer. The charge measurement can be done by a layer of dedicated detector attached to the TOF. The total length of the instrument is about 50 cm.

The instrument is symmetric thus can measure particles entering from both ends. The deployment of the instrument on the DSG allows an easy control of its orientation, making possible to run the instrument in automatic scanning mode, or controlled by the crew for instantaneous monitoring of the penetrating particle environment. The design of the instrument should also take into account of the possibility of changing faulty critical components by the crew, thus providing a safety margin for the instrument to operate for as long as required. The instrument should be mounted at an external site that allows for maximal sky coverage.

The instrument can be easily scaled down in mass, size and power, but keeping still the essential measurement capability. It affects only the rigidity resolution at high energy and the geometrical factor, which can be compensated by longer measurement time at each direction.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	~20 kg
Volume of hardware	~25 cm×25 cm×50 cm
Accommodation (e.g. internal/external)	External
Power required	<100 W
Data generated	~GB/day for storage on board for processing, down link to earth ~100kB/day
Pointing/viewing/line of sight needs	Survey mode and pointing mode. Unobstructed view for both end of the instrument.
Communications needed	
Duration of experiment	>1 solar cycle (11 years)
Crew tasks (if needed)	Crew can control the pointing of the instrument. Monitor the particle flux.
Access and servicing by crew (if needed)	Possibly exchange faulty components
Need for retrieval and return to Earth	Raw data
Specific orbit needs (if any)	No
Operations without crew (if any)	Yes

A Research Proposal Submitted to The European Space Agency

Proposed Research Idea

Manned Mission Space Exploration Utilizing a Universal Module

Peter Humphries and Fred Barez
Advanced Space Manufacturing Systems, Inc. (ASMS,Inc.)

The recent successful developments related to space exploration have created great opportunities. The proposed research is related to the development of a Universal Module to be used as Habitation or a Manufacturing environment in support of the Deep Space Gateway Project within the lunar vicinity to host crewed missions and operate with or without crew as need be. The Universal Module, in the form of a cylindrical vessel is equipped to accommodate the members of a manned mission spacecraft with the basic necessities while creating an environment for on-demand manufacturing of space structures and components to allow fabrication of parts in case of an emergency. One of the two modules would be used as a dedicated habitation unit while the second would be used as the 'Space Fab Workshop.'

The self-contained modular unit's designs are of the size to fit in the cargo bay of X-Type Space Vehicles utilizing available technologies. These modular units for space exploration applications are expected to provide a safe environment against the harsh conditions of the outer space.

The idea for the research proposed here consists of having two such Universal Modules connected through a docking mechanism to allow the crew to transfer between the two modules if needed. Parts could be manufactured using advanced robotic systems and to move raw materials from storage bins to the fabrication stations equipped with various manufacturing tools. The manufacturing operation is monitored using high definition cameras, and communication protocols to send command to various enabling manufacturing pieces of equipment not only from the second module, but also from Earth if needed. Specific research to be conducted here is to evaluate the fabrication of large structures such as 'truss' members to be connected to create a platform for the logistics of loading and unloading of cargo as well as to allow the crew to have the opportunity to exit the modules to perform a spacewalk.

These Modular Units are designed to provide a robotic manufacturing facility to allow fabrication of various components using laser cutting and welding, laser additive manufacturing, and robotic assembly of various components to form space structures for the purpose of repair of space vehicles. Multi-material additive manufacturing method using advanced imaging technology based on neutron radiography and tomography could provide extremely valuable components. The proposed research would include investigation of various materials and methods to fabricate truss components and alike.

These Universal Modules are designed with a configurable, slidable platform with rollers such that various ‘environments’ could be set up for different operations and applications. This provided a major benefit as these modules could also be placed on Moon or other planets as a permanent ‘habitation’ or ‘research lab’ including a possible ‘medical’ facility in support of long duration space exploration missions.

The Modular Units can be configured for various applications including health care, manufacturing of exotic materials, engineered plants and other biological research on Earth prior to launch.

The expected impact of this research will enable Deep Space Gateway platform the opportunity to have established not only a habitation environment, but also a manufacturing capability in support of exploration.

The specific benefit of this research would allow the European Space Agency and its Deep Space Gateway Platform to establish itself as an enabling community in support of long duration crewed mission utilizing a flexible habitation environment as well as a demonstrated manufacturing capability needed for any long exploration mission.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	16000kg Module +200kg manufacturing equipment + 500kg miscellaneous interior
Volume of hardware	4.6 m diameter x 7.6 m long for 126 cubic meters
Accommodation (e.g. internal/external)	Internal Habitation requirements and manufacturing hardware
Power required	10 kW
Data generated	Testing & evaluation of results
Pointing/viewing/line of sight needs	Hatch windows
Communications needed	Deep Space Communication Network
Duration of experiment	1st phase, 24 months.
Crew tasks (if needed)	Controlling the manufacturing while in the Astronaut unit. Gathering CAD/CAM data from engineers on Earth.
Access and servicing by crew (if needed)	Utilizing a hybrid docking mechanism
Need for retrieval and return to Earth	Not required, can stay in space for a long period
Specific orbit needs (if any)	Currently studied for LEO
Operations without crew (if any)	Yes, robot controlled manufacturing

TRANSPORT OF VOLATILES IN LUNAR SOIL SIMULANTS

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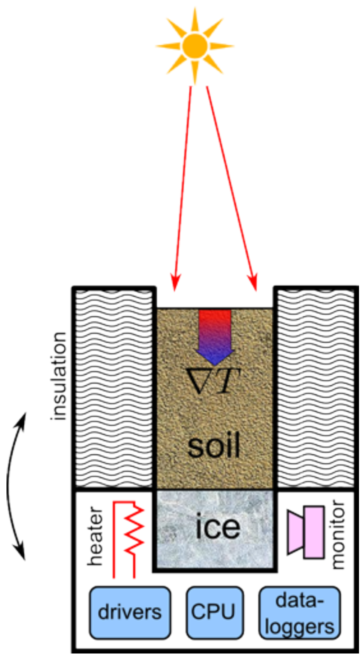
Scientific Domain:
Physical Sciences, Solar System Sciences.

Idea Description:

The recent space missions to distant areas of the Solar system had confirmed the existence of water beneath the surface of planets and their satellites. The water-ice beds on the lunar south pole were found in 2009 using the LCROSS NASA probe. The spacecraft hit the lunar surface with the aim to create a debris plume that could be analysed by spectrographic measurements for signs of water-ice. The signs of water had been seen in both infrared and ultraviolet spectroscopic measurements. The exact origin of water in the lunar interior is still a big question.

Water can be found in two aggregate states in Moon-surface conditions: solid and gas. According to the phase diagram, liquid water cannot persist on the sun-illuminated part of the Moon's surface. Some studies suggest the required conditions can be maintained in shadowed regions at the lunar poles, but these locations are difficult to access.



The growing evidence of an existence of water-ice on/under the Moon's surface puts forward the problems of the volatiles' survival and transport under lunar conditions. The proper mimicking of the lunar conditions includes not only a rarefaction of the lunar exosphere and similar temperature variations caused by solar radiation, but also an imitation of main features of lunar soil. Moreover, the same problems are specific for Mars, for comets and, possibly, for other bodies of the solar system.

To address this problem, we propose an investigation of the transport of a volatile through samples of soil simulants featuring different properties: by material, by layer thickness, by grain size, by porosity etc.

The test section of the set-up can be seen as an elongated cuvette (tube) filled with at least two layers of different materials: one layer of frozen water and a layer of porous material emulating the soil. The external surface of the soil simulant has to be oriented towards the Sun (as shown on the figure) and exposed to space vacuum. This exposure perfectly models the

conditions on the surface of Moon. The heat propagating through the soil's layer gradually heats up the frozen volatile and forces it to sublimate. The vapour molecules then diffuse through the porous layer (presumably via free molecular flow) and escape into vacuum. The escape rate can be monitored by different means: either optically, with transparent container for volatiles, or by acoustic probing of the ice bulk.
In case an intensified sublimation rate is needed, an additional heater can be foreseen.

The main practical outcome expected from this research is a predictive model for the survival depth of water beneath the lunar surface, at variable insolation conditions.

Equally important are some purely scientific questions, like the dependence of the volatile's total mass flux through the soil on properties of the porous medium (grain size, porosity).

Another intriguing problem is the effect of thermal stress on the soil layer. It is known that in a rarefied gas, within a geometry such as presented here, thermal stress facilitates vapour escape – the effect known as Knudsen pump. However, the question of what this effect becomes when the gas is rarefied down to a free molecular flow regime – is unanswered yet.

The experimental setup could comprise several test sections with different ratios of ice/soil or different types of volatiles and solid substances. If the scientific program of the mission allows a design with cartridge-like replacement of the test cells containing the soil simulant and the frozen volatile, the experiment could profit from the capability of multiple runs**.**

The soil simulants, prepared in advance, have to be uploaded from Earth; the cell-container with the volatile may be either prepared on the ground and uploaded in permanently frozen conditions, or could be prepared on-board, provided that water and a freezer are available there. In the latter case, crew time is obviously needed for preparation of the frozen volatile, final assembly of the test section, and delivery of the set-up to outside the station.
In case the design allows multiple experiments, the whole set-up has to be taken back into the station after finalisation of one experimental run, for replacement of the cartridges and downloading of the data acquired.

One particularly interesting option would be the possibility to use the present set-up to test the permeability of a sample of real lunar regolith delivered from the surface of Moon, before its exposure to atmospheric oxidation.

A specific advantage of this research idea is the possibility of comparative analysis, where the effects of deep space conditions, such as vacuum and temperature, can be reproduced and studied as separate factors on Earth in order to quantify their individual impact.

The research group from the University of Brussels has got extensive experience in space studies, having conducted various experiments onboard the International Space Station (ISS) [1,2] and during Parabolic Flights [3].

1. S.Mazzoni, V.Shevtsova, A.Mialdun, D.Melnikov, Yu.Gaponenko, T.Lyubimova, M.Z.Saghir, Vibrating liquids in space, (2010), **41(6)**, 14-16
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Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	30 kg
Volume of hardware	40 x 40 x 60 cm^3
Accommodation (e.g. internal/external)	External
Power required	75 W
Data generated	Max. 500MB per experiment
Pointing/viewing/line of sight needs	Pointing to Sun
Communications needed	-
Duration of experiment	Few hours – several days
Crew tasks (if needed)	Experiment assembling, mounting outside the station, drawing into the station, data download
Access and servicing by crew (if needed)	Access and manipulations are supposed to take place inside the station
Need for retrieval and return to Earth	Return to Earth is not needed
Specific orbit needs (if any)	-
Operations without crew (if any)	-

GAUGING SYSTEM SIMULATOR FOR ELECTRIC PROPULSION (GAUSS-PRO)

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Scientific Domain:
Physical Sciences, Technology Readiness Level (TRL), Fluid Mechanics, Electric Propulsion, On-board systems.

Idea Description:
The GAUSS-PRO is a multiple-purpose experiment based on the improvement of propellant gauging methods for Electric Propulsion (EP) systems. Its effective use is critical for the success of the Deep Space Gateway (DSG) mission in terms of: (i) planning attitude and orbital manoeuvres, which is essential in this mission with multiple orbits; and (ii) the possibility of extension and optimization of fuel resources, hardly and costly refilled. This optimization will result in an increase in the station lifetime and new orbital possibilities. Accuracy needs of classical gauging methods in EP systems has increased as consequence of propellant tanks growth, i.e. measuring at tanks 4 times bigger than before with the same accuracy. New modelling to address this pressing need is required if the propellant consumption in long-term missions from initial beginning-of-life propellant at supercritical state to final low pressure end-of-life state wants to be measured accurately enough.

With this experiment: (i) a double check and correction of DSG station's remaining propellant retrieval would be performed; and (ii) an experimental chamber for retrieval process perfection would be present in parallel, applying new algorithms to its mass retrieval by using the existing TRL-9 sensing technology of the experiment, similar to the one used at the station. In addition, (iii)) after the crew leave the station for a long period of time, the experiment could be placed outside and being operated remotely.

Earth gravity field leads the effect of convection phenomena within propellant tanks, which artificially modifies its temperature distributions and thus the density and mass retrieval. The special low gravity environment at the station would allow such research and improvement of mass gauging retrievals as gravity field is highly reduced and it would not induce these artificial internal convective forces that modifies the propellant mass measurements at every classical method on Earth, but the same found at the DSG station's tanks. This in turn would allow to investigate the impact of the strong temperature gradients originated at propellant tanks as consequence of lack of convection, taking into account that low Moon's gravity field would differently affect the retrieval in comparison to Earth's one experimented at the ISS.

The objectives of this platform, see Figure 1, would change depending on the DSG station mission's stage.

- Station with crew. The GAUSS-PRO's main research would be the perfection of new propellant gauging methods for EP propellant tanks making the most of the low gravity environment experimented at the station, which totally modifies the retrieval process of any known mass retrieval based on temperature measurements of tanks. Lack of gravity favours strong thermal gradients undetected in current retrievals that affect the measuring of density within the tanks and thus, the remaining propellant. Connection of telemetry data of pressure and temperature from station propellant tanks could additionally be corrected with the mass retrieval of this small scaled propellant tank. The crew would install the GAUSS-PRO at one of the internal walls of the station, and it could be operated remotely.

- Station without crew. The experiment could be remotely operated within the station once the crew leaves. It could be installed outside the station as well, if EVA operations were available or planned in future, so both DSG station's tanks and GAUSS-PRO would be operated within similar environment. The main research would here again focused in mass retrieval corrections from DSG propellant tanks telemetry data and the investigation of better and optimising mass gauge retrievals.

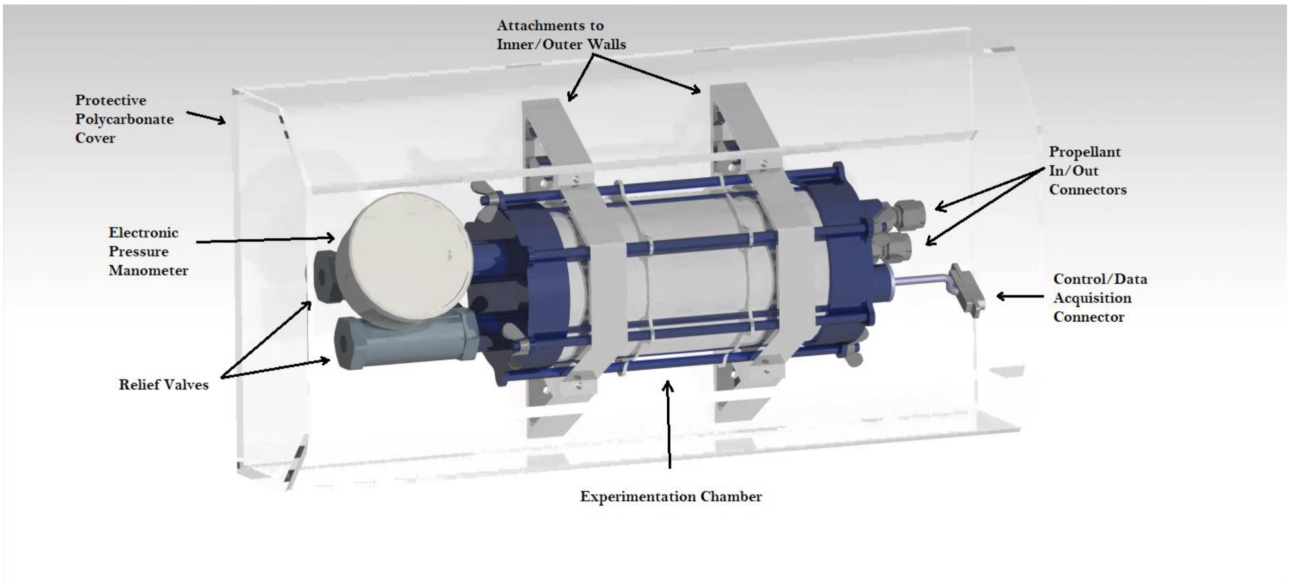

Figure 1. Schema of GAUSS-PRO chamber at Inner configuration. It would include two relief valves for a double failure tolerant approach, an electronic pressure manometer, strain gauge sensors at the walls, tri-axial accelerometers, and Pt 1000 temperature sensor at the skin and within the chamber at different radius. It would be connected to DSG station telemetry and remotely controlled.

The gravitational scenario presented in the planned orbits could provide results that would shed some light in new and better mass retrievals for EP systems, which in consequence could extend telecommunication satellites lifetime or the operations of the Deep Space Gateway station itself, making them safer at situations were fuel is scant by optimising its use. The research could help to develop new algorithms, or validate developing ones, with TRL-9 technology that could be immediately applied to the DSG station's mass retrieval with no structural modification. As a result, a better measuring process could be developed and validated with flight data in real conditions for every spacecraft using EP systems with pressure and temperature measurements at their propellant tanks.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	2.5 kg.
Volume of hardware	0.012 m^3 (400 mm x 200 mm x 150 mm).
Accommodation (e.g. internal/external)	Internal/External.
Power required	20 W.
Data generated	Pressure, temperature, deformation, acceleration measurements.
Pointing/viewing/line of sight needs	Internal: Aligned with axial direction of the station. External: Same alignment of the propellant tanks of the station.
Communications needed	Only if operated remotely.
Duration of experiment	Lifetime of the station.

Crew tasks (if needed)	Internal: Experimentation. Connection to station telemetry, fixation to a spot in one of the inner walls. Switch on. Autonomous system and remote control. External: Fixation at an external position and remote retrieval. Connection to station telemetry, fixation to a spot in one of the external walls. Switch on. Autonomous system and remote control.
Access and servicing by crew (if needed)	Passive experiment supervision.
Need for retrieval and return to Earth	If requested by the planned operations of the station.
Specific orbit needs (if any)	No.
Operations without crew (if any)	It could be remotely controlled and autonomous functioning.

PHOTOELECTROCATALYSIS:

SOLAR-ASSISTED HYDROGEN AND OXYGEN PRODUCTION IN REDUCED GRAVITY ENVIRONMENTS

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Scientific Domain:

Physical Sciences

Idea Description:

Artificial photosynthesis systems, which follow the energetic concept of the Z-scheme of natural photosynthesis, are presently being realized as catalyst-functionalized photovoltaic tandem devices for the photoelectrochemical oxidation of water and the simultaneous generation of hydrogen as a so-called "solar fuel" [1,2]. The successful implementation of an efficient photoelectrochemical (PEC) water splitting cell utilizing sunlight as an energy source is, however, not only a highly desirable approach to solving the energy challenge on earth: an effective air revitalization system generating a constant flux of O_2 while simultaneously recycling CO_2 and providing a sustainable fuel supply is also essential for long-term space missions, where a frequent resupply from Earth is not possible.

We recently investigated light-induced hydrogen production in catalyst-functionalized semiconductors half-cells in microgravity environment realized at the Bremen Drop Tower [3]. Our findings indicate that the surface topology of the photoelectrode plays a crucial role for the overall half-cell performance and the realization of light-assisted hydrogen production in reduced gravity environments. Changes in the electrocatalyst topography resulted in an efficiently hydrogen producing half-cell in microgravity environment.

A monolithic device capable of oxidizing water at the photoanode and producing hydrogen and/or reducing CO_2 at photocathode surface presents a compact and lighter alternative to the currently employed photoelectrolysis system, also avoiding significant fabrication and installation costs and efforts. The Deep Space Gateway provides an excellent opportunity to carry out long-term experiments on light-induced oxygen and hydrogen producing half-cells and fully integrated water-splitting devices to test their application in long-term space missions. Therefore, it can not only advance the development of currently existing extra-terrestrial life support systems, but it also allows studies for the further development and optimization of the device for terrestrial applications.

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Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	~ 50kg
Volume of hardware	$1m^3$
Accommodation (e.g. internal/external)	internal
Power required	min. 24V DC for short-term experiments (e.g., for BioLogic Potentiostat (SP-200), electronic light shutter)
Data generated	Videos and electrochemical data, amount depending on experiment duration
Pointing/viewing/line of sight needs	-
Communications needed	-
Duration of experiment	1h up to 1 month for long-term stability tests
Crew tasks (if needed)	Starting and terminating the experiment (programming of electrochemical software, exchanging samples in the cell set-up)
Access and servicing by crew (if needed)	-
Need for retrieval and return to Earth	Only the photoelectrode samples to analyse them spectroscopically and optically with respect to damage
Specific orbit needs (if any)	-
Operations without crew (if any)	-

HIGH-ENERGY MONITORING TELESCOPE AND LARGE AREA TIMING INSTRUMENT

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Scientific Domain:
Astronomy and Astrophysics

Idea Description:
The idea is to use the Deep Space Gateway as an enabling platform for a broadband X-ray telescope that monitors the X-ray sky to search for transient X-ray sources and for studying long-term variability of these sources.

Regarding the equipment, the monitoring telescope can be realised using coded mask Silicon Drift Detectors. As these detectors only provide accurate position information in one direction, pairs of two orthogonal cameras are needed to obtain precise two-dimensional source positions. The number of pairs of cameras needed depend on the field of view of the cameras and on the portion of the sky that should be covered. As silicon drift detectors cover energies between two and several tens of keV, adding a Lobster eye camera that covers the same field of view at energies between 0.1 and 3-5 keV, would allow extending the monitoring to lower energies, while adding a camera similar to the BAT instrument on board the Swift satellite would allow us to extend the monitoring to energies above 100 keV, enabling us to detect γ-ray bursts.

MAXI already showed that an X-ray all sky telescope operating on a space station can provide valuable scientific data. The coverage of the soft end of the energy range down to ~0.1 keV of the monitoring telescope will allow us to precisely locate the high-energy photon sources of gravitational wave and neutrino transients and transients located by the new generation of astronomical facilities. With the broadband coverage of energies between 0.1-100 keV the monitoring telescope will help us to reveal the physics underlying the variety in the population of gamma-ray bursts, including high-luminosity high-redshift bursts, low-luminosity bursts and short bursts. While the bursts will be detected at high energies, the soft band coverage allows studying the X-ray afterglow emission immediately. In addition, the monitoring telescope will allow us to discover new high-energy transient sources over the whole sky, including X-ray counterparts of optical novae, supernova shock breakouts, black hole tidal disruption events, magnetar flares, and to monitor the long-term evolution of known X-ray and γ-ray sources.

The second part of the idea is to combine the monitoring telescope with a large area high time resolution instrument to investigate sub-second variability of X-ray binaries during outburst.

To create such an instrument that combines high time and CCD-class spectral resolution with a significant increase in colleting area compared to telescope-based missions, we would need to cover a (significant) part of the hull of the Deep Space Gateway with panels of Silicon Drift Detectors. To achieve the scientific objectives laid out below an effective detector area of a few square meters would be needed. In order to address the observed variability to a certain source it will be necessary to reduce the field of view of the timing instrument to about 1 degree. This can be obtained by combining the drift detectors with a collimator using micro-channel plate technology. The constraining of the field of view will require that the instrument can be pointed to a source of interest detected by the monitoring instrument.

As the large detector area and the pointing ability will put sever limitations on the feasibility of the high timing instrument as part of the Deep Space Gateway, a more feasible idea will be to realise the timing instrument as an own small satellite and to use the Deep Space Gateway as a communication relay. The monitoring instrument on board the Deep Space Gateway will trigger the observations of the timing instrument and the communication and on board data processing can take place through the Deep Space Gateway, allowing to reduce the size, mass and payload of the timing satellite instrument.

The scientific objectives of the large area timing instrument will be to probe dense matter and strong gravity, areas of fundamental physical as well as astrophysical interest, by observations of neutron stars (NSs) and stellar-mass and supermassive black holes (BHs). The nature of matter at the extreme densities of neutron star interiors is one of the great open unknowns in physics, making neutron stars unique laboratories for nuclear physics and quantum chromodynamics. The fundamental diagnostic of dense matter interactions is the pressure-density-temperature relation of bulk matter, the equation of state (EoS), observationally encoded as the NS mass-radius relation. Since the larger effective area will allow detecting pulsations and vibrations of NSs at enormous signal to noise ratios, we will be able to perform precise measurements of mass and radius values for several NSs, by using different complementary methods (pulse profile modelling of 3 types of pulsations, the mass-shedding limit from the spin distribution, vibrational modes in magnetars). The timing instrument wills thus enabling us to overcome model systematics. This will result in the reconstruction of the EoS of zero-temperature supranuclear density matter.

The theory of General Relativity, verified to exquisite accuracies in the weak-field regime, predicts large effects on the motion of matter under the influence of strong-field gravity, such as Lense-Thirring precession of the accretion discs or the very existence of the ISCO (innermost stable circular orbit). CCD quality spectra, coupled with the large throughput of a pile-up free detector, will allow to characterize, by complementary measurements, the motions of accreting matter down to distances a few Schwarzschild radii from BHs and NSs in X-ray binaries and bright AGNs. Using relativistic spectral lines and their variations on relativistic time scales, the timing instrument will resolve the relativistic Fe lines simultaneously in time as well as energy at the enormous photon throughput required to directly witness the motions of matter near black hole event horizons. The timing instrument will measure the effect of relativistic frame dragging induced precession on the disk Fe K line profile in phase resolved spectroscopy of a low frequency quasi-periodic oscillation.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	
Volume of hardware	
Accommodation (e.g. internal/external)	External
Power required	
Data generated	
Pointing/viewing/line of sight needs	Monitoring (pointing)
Communications needed	Regular data transfer to earth (communication to satellite instrument)
Duration of experiment	2-5 years
Crew tasks (if needed)	No
Access and servicing by crew (if needed)	No
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	
Operations without crew (if any)	

GRB MONITOR

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Scientific Domain:
Astronomy and Astrophysics.

Idea Description:
Install a detector that will provide precise timing and spectrometry of Gamma ray bursts (GRB). The detector should be very wide filed of view (half or full sky) have a large effective area and have good spectroscopic performances.
Such a detector will be sensitive to at least half of all the GRB. The Moon location insures that the timing information will be each time useful to perform triangulation with any of the Near Earth orbit based detectors (providing typically a 1 second delay with a microsecond precision). The Moon orbit is also favorable for the cold thermal environment of the detector.
This detector will provide useful spectrum and GRB triangulation information typically every second day. It will provide counterpart measurement for half of the gravitational waves candidates.
It guaranties that this detector will be cited at least by 50% of all GRB detections and by 100% of all gravitational waves detections.
The detector could be a single Germanium detector passively cooled. The data is very limited due to the fact that there will be only about one GRB alert per day. The data will consist of energy and time of arrival of each photon falling on the detector. We need to download only two minutes of telemetry per day. We need one uplink telemetry session per day to indicate the specific time of interest for the day. The detector can also find the time of interest by itself if uplink telemetry is not available.
Existing TRL7 detectors of this type exists. Reasonable size for such a detector is 30X30X30 cm, weight of 30 kg, power of 30 W, daily data rate of 10 Mb 1 kb of uplink session per day. The detector work without interruption all the time. The proposer has experience with proven flight hardware of this type.
If the detector is mounted on an extensible boom, the field of view will cover 100% of the sky for most of the proposed moon orbits (NRHO, L2Halo, DRO). For every orbit, such a boom would improve the noise performances of the detector.
The Moon orbit will give this rather mundane detector a decisive advantage over all existing Earth orbit detectors.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	30 kg
Volume of hardware	30X30X30 cm
Accommodation (e.g. internal/external)	External
Power required	30 W
Data generated	10 Mb per day
Pointing/viewing/line of sight needs	Deep space view
Communications needed	1 kb upload per day
Duration of experiment	3 years or more
Crew tasks (if needed)	none
Access and servicing by crew (if needed)	no
Need for retrieval and return to Earth	no
Specific orbit needs (if any)	Any proposed orbit is fine
Operations without crew (if any)	Detector works all the time

OBSERVING THE EARTH AS AN EXOPLANET WITH LOUPE

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Scientific Domains

Astronomy and Astrophysics, Earth Sciences

Idea Description

After more than two decades of detecting planets around other stars, we now know that almost every star has a planet. The next step in exoplanet research is characterizing these planets and comparing their physical properties with those of the Solar System planets. Characterizing potentially habitable exoplanets and identifying biomarkers on them is of particularly high interest because would answer humankind's burning question "Are we alone?"

But what would we be looking for in observations of such Earth-like exoplanets? First, we need to have a benchmark: how does the spectrum of the Earth look like when seen from far away, when we see Earth as an exoplanet? We urgently need observations of the Earth as an exoplanet to build a database of benchmark spectra of the only known planet with life on it. We will use these data to validate computer algorithms for the prediction of exoplanet spectra and for the retrieval of biomarkers, such as ozone, oxygen, liquid water, and the red edge of vegetation [Stam, 2008]. As such, the data will be crucial for setting the requirements on future exoplanet characterization instruments and space missions and validate the data retrieval approaches.

LOUPE is a small spectropolarimeter [Hoeijmakers et al., 2016; Snik et al., 2009] that measures the total flux and degree and direction of linear polarization of sunlight that is reflected by the Earth across the spectral range from about 400 to 800 nm [Karalidi et al., 2012]. The polarization is a particularly useful tool to characterize the composition and structure of an exoplanet's atmosphere and to separate unpolarized starlight from polarized exoplanet light. From any of the Deep Space Gateway's orbits, LOUPE will be able to monitor the temporal, spatial and spectral variations of the Earth's signal due to changing weather patterns like clouds, due to rotation during an Earth's day, due to phase angle variations during a month, and due to seasonal variations during a year. These variations are similar to those we expect to detect when observing an Earth-like exoplanet orbiting its star. Because we know the properties of the Earth, LOUPE data will allow us to investigate what exoplanet properties could be retrieved.

Particularly interesting questions that LOUPE observations of the Earth-as-an-exoplanet will address are:

- What is the rotation period of the planet?

- What is the typical cloud coverage?
- What is the composition and phase of the cloud particles?
- Are there continents and oceans? How is their distribution?
- What is the surface coverage? Is there vegetation?
- Is the rotation axis inclined? Are there seasons?
- Is there ozone and/or oxygen? What are the mixing ratios of these gases?
- Are there other trace gases?

Despite the many Earth-observing satellites, LOUPE measurements will be unique because 1. there are no Earth-observing satellites with spectropolarimetric capabilities, and 2. the vantage point on the Deep Space Gateway offers a combination and range of illumination angles and viewing angles across the distant disk of the Earth that is not available from satellites and that *cannot be reproduced* from data from such satellites (the vantage point of a geostationary satellite comes close, except that it does not see the Earth's daily rotation).

In addition to the integrated measurements to study Earth as an exoplanet, LOUPE can provide limited spatial resolution across the Earth's disk depending on the distance to the Earth at the time of the observations. Spatially resolved spectropolarimetric data of the Earth can be used to improve specific parts of radiative transfer codes, and will be valuable for remote-sensing purposes, especially because high accuracy, spectropolarimetric data is unavailable otherwise. LOUPE data also allow for measuring and monitoring the Earth's reflectance and albedo, which are crucial parameters for understanding climate change. LOUPE is robust (without moving parts), small (<1 kg), and requires little power. On the Deep Space Gateway, the instrument should have the Earth in view (at least on a regular basis), and would not need any direct crew involvement.

Because LOUPE will image the Earth, the data will without doubt also be interesting for the general public, comparable to the famous Pale Blue Dot picture taken of the Earth by Voyager-1 from a distance of 6 billion kilometers, except with the variations in time included. Indeed, we plan to release the data on a regular basis, and to engage the public by also releasing free online tools that can be used to analyze LOUPE data.

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Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	~ 1 kg
Volume of hardware	~ 1 litre
Accommodation (e.g. internal/external)	External (with the Earth regularly in view).
Power required	~ 1 W
Data generated	T.B.D.
Pointing/viewing/line of sight needs	The Earth should be in view for the observations.
Communications needed	For uploading observational sequences (these would depend on the type of orbit) and data transfer.
Duration of experiment	Minimum: 1 month (all phase angle of the Earth), maximum: undetermined
Crew tasks (if needed)	None
Access and servicing by crew (if needed)	Not applicable
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	No
Operations without crew (if any)	The instrument can measure without crew involvement.

LOW FREQUENCY SCIENCE ON THE DEEP SPACE GATEWAY

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Scientific Domain:
Astronomy and Astrophysics, Solar System Sciences

Idea Description:
Over the last century, astronomy and space science have changed our understanding of the evolution of the universe beyond recognition. Nevertheless, our view is still incomplete in the lowest frequency range below 30 MHz (wavelengths longer than 10 m), which is one of the last unexplored frequency bands in radio astronomy. Below 30 MHz, the ionosphere severely hampers observations from Earth, and below ~10 MHz observations even become impossible due to the ionosphere's opacity. Another complication of observing with ground-based facilities in this frequency range is the presence of strong man-made radio interference. Deploying a radio instrument in space is therefore the only way to open up this unique observing window to the universe, making exciting new science possible.

A consortium consisting of astronomers and engineers from institutes, academia and industry worked on a roadmap to support developing and establishing a future large scale interferometric set of radio antennas in space, opening-up this last frequency range for science [1,2]. A first step towards this goal is deploying a wide bandwidth single antenna in space. In fact, this is currently being developed in the form of the Netherlands-China Low frequency Explorer (NCLE) payload, to be mounted on the Chinese Chang'e 4 relay satellite. This satellite is planned to be launched in mid-2018, and will be located near the Earth-Moon second Lagrange point. The next step is deploying a multiple element radio interferometer in space. The Deep Space Gateway can be used for this step as an enabling platform.

Our proposal is to place <u>four low frequency radio antennas</u> on the outside of the Deep Space Gateway in conjunction with receivers and a correlator computer inside the space craft. Together they can form 6 interferometer pairs on board the station. The signals from the receivers will be correlated in real time on-board the station and the resulting signals will be integrated over time and sent down to Earth for offline processing.

Science objectives:
The major science driver for a low frequency space-based radio interferometer is the study of the Cosmological Dark Ages and Cosmic Dawn. The Cosmic 'Dark Ages' is generally defined as the era in cosmic history between the recombination of protons and electrons about 400,000 years after the Big Bang, as seen through the Cosmic Microwave Background (CMB) photons (e.g. with Planck) and the formation of the first stars about 100 million years after the Big Bang (see Figure 1). It remains a truly unexplored part of our cosmic history, currently without any observable constraints, despite being a major treasure trove for understanding the fundamental nature and physics of our universe. The only conceivable tracer of matter currently known during that era is the red-shifted 21-cm line of neutral hydrogen, as seen in absorption or emission against the CMB. However, strong foreground radiation from the Milky Way and extragalactic radio sources are superimposed on this redshifted 21cm signal. To detect the signal from the Dark Ages, it is essential to subtract out this foreground radiation with very high precision. Please note that the averaged global signal of this early phases of the universe can in principle be detected with a single antenna, but imaging it would require the scaled-up interferometer.

LUNAR RADIOSCIENCE EXPERIMENT (LUREX)

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Scientific Domain:
Solar System Sciences, Deep Space Exploration.

Idea Description:

The end-to-end timing of the radioscience measurements for deep space exploration missions must be highly precise. The orbit of Gaia has to be determined to very high accuracy (to within 150m at 1.5 million km). Bepicolombo performs a radio science experiment which would coordinate a gravimetry experiment, a rotation experiment and a relativity experiment, by processing ultra-accurate range and range rate tracking data. Juice's Gravity & Geophysics of Jupiter and Galilean Moons (3GM) expirement uses a radio science package comprising a Ka transponder to study the gravity field - up to degree 10 - at Ganymede and the extent of internal oceans on the icy moons.

To this end, these deep space probes are carrying an atomic clock to time stamp the science data, which has to be matched by ultra-precise time stamping on ground at data reception. The traditional radiometric methods are supplemented by optical observations from ground-based telescopes, which take pictures of the spacecraft against the background stars, and Delta-DOR measurements in the commissioning phase (a method where multiple DSA stations are used to precisely determine the spacecraft position with respect to a Quasar).

The Delta-Differential Oneway Ranging (Delta-DOR) technique uses two widely separated antennas to simultaneously track the location of a transmitter in space in order to measure the time delay between signals arriving at the two stations. Theoretically, the delay depends only on the positions of the two antennas and the spacecraft. In reality, it is affected by several sources of error: for example, the radio waves travelling through the troposphere, ionosphere and solar plasma, and clock instabilities at the ground station. DDOR corrects partly these errors by 'tracking' a quasar in a direction close to the spacecraft for calibration.

The accuracy of the DDOR technique is thus driven by the baseline distance of two radio beacons and by the calibration accuracy. Extending the radioscience capabilities foreseeing the lunar environment with additional DSN stations such that:

1- The baseline distance increases with a factor 50 (compared to distances on Earth)
2- The tropospheric and ionoshpheric has not to be calibrate for;

3- The availability of DSN increases;
4- The communication link less sensible to the inherit Earth's rotation.

The smallest DSN antennas are 26 meters in diameter. Originally built to support the Apollo moon missions, these antennas are now used to track Earth-orbiting spacecraft. Other DSN antenna diameter range from 34 to 70m.

Therefore, LUREX would exist of two small lunar beacon (LB) receiver antennas (d<2m) placed on the lunar surface, where they receive the radioscience data from the DSG to provide a proof of concept. Therewith they shall attempt to raise the TRL for a Lunar Deep Space Network (LDSN) with the advantages stated above. In particular the experiment will show that no tropospheric and/or ionospheric calibration is required. In a next phase, a hybrid DDOR technique could be set up with an Earth DSN and a LDSN where the DSG position is accuracutely determined.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	100kg
Volume of hardware	50x50x50cm
Accommodation (e.g. internal/external)	External
Power required	TBD
Data generated	Radio science data
Pointing/viewing/line of sight needs	DSG Antenna towards the LBs
Communications needed	TBD
Duration of experiment	TBD
Crew tasks (if needed)	Deploying the antenna
Access and servicing by crew (if needed)	TBD
Need for retrieval and return to Earth	TBD
Specific orbit needs (if any)	No
Operations without crew (if any)	Possible

Assessing and imaging man-made radio interference far away from the Earth's ionosphere is the second goal of the experiment. Other possible science cases are galactic surveys, cosmic ray detections, planetary research and solar physics.

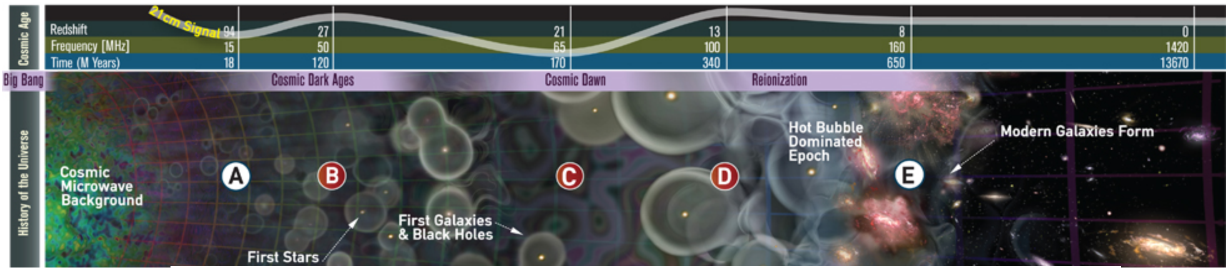

Figure 1: The history of our Universe. On the top the 21cm line is indicated.

Required equipment and facilities:

The idea is to place four low frequency radio receivers on the outside of the Deep Space Gateway in conjunction with receivers and a correlator computer inside the space craft, to investigate the signals below 50 MHz. Since the space craft is limited in size and the wavelength of the experiment is rather long (wavelength over aperture diameter ratio is of the order unity at 30 MHz), the correlated outputs will be used to tune the beam-shape of the four-antenna constellation. Antenna booms may be used to improve the self-generated radio interference situation, and also to extend the baseline lengths a bit. The receivers consist of a relative small (few meters) 3D antenna system and a low-noise amplifier to amplify the signals. Via coaxial cables (or RF over fiber) the signals are fed into the central part of the Deep Space Gateway, where after digitization, a computer system will correlate and integrate the signals, so that compressed datasets can be sent to Earth.

The required equipment on board of the Deep Space Gateway is a data downlink to Earth. The data will be captured by the antenna systems and processed on a dedicated computer. Another possible extension of the research is launching one or more CubeSats from the space craft. The CubeSats contain an antenna system as well and can therefore, increase the baseline of the experiment.

Role of the crew of the Deep Space Gateway:

The role of the crew is limited. In principle the roll-out of the antennas can be controlled by the crew, as well as starting and stopping the experiments. Data transfer to Earth might need the interaction of crew members. For the rest the experiment is self-supporting.

Impact of the research:

The impact of the research can be very high:

- Observations on the Deep Space Gateway might be the first interferometric observations at low frequencies in space. The antennas on the Deep Space Gateway can be used for Very Long Baseline Interferometry in Space (VLBI in Space) with the intended CubeSats.
- The RFI levels leaking through the Earth's ionosphere will be measured and better models can be made for this man-made interference.
- The signals from the Earth AKR (Auroral Kilometer Radiation) and Jupiter can be studied in more detail. This can lead to a better understanding for probing planets low frequency radiation (eventually for planets out of our solar system).
- A number of technical elements of the system can be brought to higher technology readiness levels, like the antenna systems, interferometer, and correlator.

References:

[1] R.T. Rajan et al., "Space-based Aperture Array For Ultra-Long Wavelength Radio Astronomy," in Experimental Astronomy, November 2015.
[2] "Breakthrough technologies for Interferometry from Space", NWO-PIPP proposal, September 2017.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	Approx. 4 x 0.5 kg for the antennas outside the space craft and approx. 5 kg for the receivers, correlator and post processing.
Volume of hardware	Antennas will be approx. 5 meters long (unfolded position), receiver system and (software) correlator the size of two regular laptop computers. If there is not an accurate clock signal available, a rubidium clock must be placed.
Accommodation (e.g. internal/external)	Antennas will be placed outside the space craft. The rest of the equipment will be internal.
Power required	Approx. 20 W for the whole system.
Data generated	If experiment is running, can add up to 10 Mbps.
Pointing/viewing/line of sight needs	No restrictions
Communications needed	Downlink. Depending on available data rates, the experiment can be tuned.
Duration of experiment	TBD
Crew tasks (if needed)	Monitoring and data transfer
Access and servicing by crew (if needed)	N.A.
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	No restrictions
Operations without crew (if any)	All operations can be done without crew.

THE HERMES SYSTEM: MULTIMESSENGER ASTROPHYSICS WITH A CLUSTER OF SATELLITES AROUND THE MOON

Authors: L. Burderi[1], T. Di Salvo[2], M. Feroci[3], F. Fiore[4]

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Scientific Domain:
Astronomy and Astrophysics

Idea Description:

The HERMES SYSTEM (High Energy Rapid Modular Ensemble of Satellites) envisages the development of a swarm of nano/micro satellites designed for the rapid and precise localization of electromagnetic counterparts of gravitational waves events (or other impulsive events in the hard X-ray/gamma-ray band) and for the study of the quantum nature of the space-time. These goals will be reached thanks to a sub-microsecond time resolution coupled with energy sensitivity in a wide, high-energy band.

At present time, we are pursuing a mission concept called HERMES PROJECT, based on a swarm of nano-satellites in low Earth orbit, hosting simple but fast scintillators to probe the X-ray emission of bright high-energy transients.
The main scientific objective of the HERMES PROJECT is the accurate and prompt localisation of bright hard X-rays/soft gamma-rays transients such as gamma-ray bursts (GRBs) and the electromagnetic counterparts of the gravitational wave events (GWE) recently discovered by Advanced LIGO/Virgo interferometers. Accurate positions are obtained from the delays of arrival time of the bursts to different detectors. The position accuracy scales with the inverse of the average baseline, and the inverse of the square root of the number of detectors. In low Earth orbits (LEO) baselines of the order tens of thousands km are achievable, which would produce position accuracies of the order of arc-minutes using a dozen detectors.
Moreover, several of the proposed models for space-time quantization predict an energy dependent speed for photons. Although the predicted discrepancies with the general speed of light are minuscule, it is possible to detect this intriguing signature of space-time granularity with a new concept of modular observatory with a large total effective area for photons in the energy band 4 keV – 30 MeV. The sub-microsecond time resolution and wide energy band of HERMES will allow to probe tiny energy dependent delays, expected to be the signature of the granular structure of space-time in several of the proposed theories of Quantum Gravity. Moreover, the capability of the HERMES PROJECT to determine the transient event position with accuracies of arcminutes, allow to determine, in most cases, the host galaxy and its distance through subsequent determination of its redshift. Delays induced by Quantum Gravity effects are expected to linearly correlate (to first order) with:
a) differences in energy bands
b) host galaxy distance.

This behavior is the unique signature of a genuine Quantum Gravity effect (note that an intrinsic photon emission mechanism in which, for instance, hard energy photons lag soft energy photons does not correlate with galaxy distance).

In summary, the three main scientific objectives of the HERMES PROJECT are:
1) the accurate and prompt localization of bright hard X-ray/soft γ-ray transients such as γ-ray bursts (GRBs). Fast high-energy transients are among the likely electromagnetic counterparts of the gravitational wave events (GWE) recently discovered by Advanced LIGO/Virgo, and of the Fast Radio Burst.
2) Open the window of timing down to a fraction of microseconds at X-ray energies, and thus investigate for the first time the microsecond structure of GRBs.
3) Test quantum space-time scenarios by measuring the delay time between GRB photons of different energy.

A pathfinder experiment, HERMES PATHFINDER, consisting in three units has been recently funded by the Italian MIUR (Ministry of University and Research). A proposal to study and realise a constellation of 10-12 units is being submitted to MIUR.

This experiment allows to perform temporal triangulation of high signal to noise impulsive events with positional accuracies of few arcseconds, making this observatory a promising hunter for the elusive electromagnetic counterparts of Gravitational Waves or other impulsive high-energetic events.

Increasing the baseline would greatly increase the position accuracy. We therefore propose here to extend the baseline of the HERMES PROJECT with the HERMES SYSTEM, i.e. placing part of the swarm on DSG, in orbit around the Moon (or even on its surface, in perspective, considering the lack of a Lunar atmosphere able to absorb X-ray/gamma-ray photons). Two/three simple nano-satellites on orbits close to that of the DSG, in addition to a detector hosted on the DSG and to the constellation on LEO) would produce sub-arcsec accuracies. These will be crucial to properly locate the transient in the right galaxy environment.
As an example, let us discuss a NS-NS merging event at a distance of 200 Mpc, that is the distance for this kind of events that will be reached by Advanced LIGO/Virgo in a few years. For this merging event the spatial-resolution/angular scale is 1 kpc/arcsec. A position accuracy of 1 arcsec would then unambiguously identify the transient host galaxy and roughly locate the transient within the galaxy structure (nucleus, bulge, disk, halo). A position accuracy of 0.1 arcsec would correspond to a spatial resolution of ~100 pc, which is the average distance between molecular clouds and HII regions in local spiral galaxies. Therefore, with such accuracy we would be able to identify with great precision the transient environment.

This proposal therefore consists in two parts:
1) a very simple X-ray detector (a scintillator with SiPM read out) to be placed on the DSG.
2) Two/three 6U cubesats to be deployed from the DSG and put in orbits close to the DSG. Several cubesats have been deployed from the ISS, so we assume a similar strategy may be implemented on the DSG.

The expected impact of the research proposed with the HERMES SYSTEM are mainly:
1) Locating the GRB prompt events with sub-arcsec accuracies, allowing a precise identification of the GRB host galaxy (and its distance through subsequent determination of the redshift). Identification of the GRB environment within the host galaxy.
2) Performing an accurate and robust experiment of Quantum Gravity in order to probe an energy dependent law for the speed of photons to first order in the ratio photon-energy/Planck-mass-energy.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	2kg per detector
Volume of hardware	1000cm^3 per detector
Accommodation (e.g. internal/external)	One detector external from the DSG. Two/three detector hosted in 6U cubesat to be deployed from the DSG
Power required	Few Watts
Data generated	100bytes/s most of the time. ~10 burst/yr ~10Mbyte data each.
Pointing/viewing/line of sight needs	Rough pointing accuracy, degrees. FoV a few steradians
Communications needed	Downlink data generated nearly realtime (minutes)
Duration of experiment	As long as possible. At least 1 year
Crew tasks (if needed)	No tasks
Access and servicing by crew (if needed)	No servicing
Need for retrieval and return to Earth	No need for retrieval and return to Earth
Specific orbit needs (if any)	Any orbit different from LEO
Operations without crew (if any)	No need for operations. Detectors can be operated from Earth

8U CUBESAT DEPLOYMENT FOR UV EXPLORATION

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Scientific Domain:
Physical Sciences, Solar System Sciences, Earth Sciences, Astronomy and Astrophysics.

Idea Description:

Summary: An 8U cubesat will be launched from ESA Gateway to determine the distribution of neutral gas in the Earth exosphere and its response to solar wind and magnetic activity, aiming at producing a large-scale 3D map of the Earth exosphere from outside by monitoring the Earth Lyman-α emission. Lunar surface observations in the UV range will be also carried out.

Objectives: A key question affecting the human race regards the possible presence of life outside of the Earth. In the last decades, more than three thousand planets have been discovered. UV observations of exoplanet atmospheres during transits allows understanding the physical processes driving the formation and evolution of planet exospheres and magnetospheres, giving access to important properties of the planets and their interaction with the parent star (Kulow et al. 2014). Detailed calculations have been carried out to evaluate the instrumentation needed to detect bio-tracers in Earth-like planets by the transit method (Gómez de Castro et al. 2006). Observations of the Earth as an exoplanet will obviously help in this area. This project aims at determining the distribution of neutral gas in the Earth exosphere and its response to the solar wind/activity. Solar Lyman-α (Lyα) photons are scattered by the Hydrogen (HI) atoms in the exosphere producing a Lyα halo around the Earth that extends further than 10 Earth radii. ***The goal is producing the first 3D map of the Earth exosphere from outside by monitoring the Earth Lyα emission***. The variation of the line source function across the exosphere will be obtained allowing the detailed evaluation of the Lyα flux. The spatial distribution of neutral Oxygen and Helium will also be measured.
During is duty cycle, the satellite will also survey ***systematically the heliosphere in Lyα***, ***investigating the distribution of diffuse matter within the heliosphere: cometary tails, planetary exospheres and dusty clouds***. First, it will detect and study the evaporation of comets; Lyα observations are an ideal way to search for comets since neutral Hydrogen is the main component of the coma. These observations will be used to derive the water production rate of the comet as a function of time (Maekinen et al. 2000). In addition, the far UV range is very sensitive to small dust columns, and surveys in the full [112-180 nm] range will detect dust clouds concentrations. Dust filaments and clouds will also be detected against the heliospheric ultraviolet background and Planet 9 could be detected if surrounded by a cloud of small bodies and dust from the outer Solar System.

A third objective is the ***monitoring of the water content and the space weather in the Moon poles***. Future Lunar settlements will be most likely sited on the Moon poles. It is thus crucial to determine the abundance of the water content. Observations of the Moon surface in UV range with a wide field of view will make feasible differential measurements of the Lyα emission variability and hence, of the variations of surface ice and frost in the polar regions. Also the presence of dust clouds and plumes will be detected and their interaction with solar radiation and particles. During the Apollo era, astronauts saw "horizon glow" and "streamers" in the moon's outmost atmosphere, or "exosphere." Since then many scientists have suggested that these phenomena were caused by sunlight scattered by dust grains in the exosphere. Questions about how lunar dust and dusty plasmas are charged, mobilized and transported remain at the center of dusty plasma studies.

Gateway suitability: All previous missions (Cluster, IMAGE, TWINS) with similar objectives have been orbiting the Earth and hence, located within the magnetospheric cavity. As a result, the interpretation of the data has been hampered by the difficulties to determine the Lyα emission within a complex geometry and to measure at the same time the Solar flux and the heliospheric background. ***From the vantage point of the gateway location, a cubesat with UV instrumentation on board may be easily launched and it will map the exosphere from outside measuring simultaneously the exospheric emission and the variable background obtaining the most accurate measurements of the Hydrogen distribution at large Earth radii*** because will allow to separate the contributions from solar radiation and other processes like excitation by high energy particles from the Sun or internal magnetospheric sources.
Gateway Needs: ***A cubesat deployment capability*** will perfectly match with the goals of the intended research. An 8U cubesat satellite will map the Earth, its exosphere and magnetosphere, the heliosphere and the Lunar poles with a wide field imager having a field of view of 200 × 300 with an angular resolution of 3 arcmin. The satellite will be orbiting the Moon at 500 km of the surface in a low eccentricity polar orbit and may use the ESA Gateway or a Lunar Orbiter as Data relay with Earth. A proposed optical design may be similar to the WALRUS design (Hallam et al. 1984), a three-element mirror system. This design provides a very wide field of view, for a reflective telescope, and a very important compact design, suitable as a 8U cubesat payload, including the MCP and the CMOS detector, and all remaining components conforming an obviously needed service module (star tracker, reaction wheels, on board computer, ...). The payload module is assumed to weight of 8 kg, consume 4 W and require a pointing accuracy of 14 arcseconds (3 sigma).

Impact and Benefits: These maps are fundamental for future missions to detect and study exo-Earths. These studies allow to gain deep understanding on the interplay between the solar activity and the Earth environment, with its profound consequences for the understanding of the Earth climate. Obviously, this project will help in improving existing exosphere models. Finally, future Lunar explorations programs will benefit of the observations of the lunar surface in the UV as described.

References: Kulow et al. 2014, ApJ, 786, Gómez de Castro et al. ApSS,303, Maekinen et al. 2000 Natur, 405 , K.L. Hallam et al, proc. SPIE. 0445, Instrumentation in Astronomy V, 295, 1984.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	As required by gateway cubesat deployment facilities (
Volume of hardware	8U
Accommodation (e.g. internal/external)	External, but the satellite may be stowed inside the gateway before deployment.
Power required	As required by gateway cubesat deployment facilities
Data generated	0.1-1 GB/day. Data will be pre-processed on board. Final budget associated with the feasibility to use the ESA Gateway as data relay.
Pointing/viewing/line of sight needs	Pointing 1 arcmin. FoV: 22^{o}x20^{o}
Communications needed	N/A, unless ESA Gateway is used as data relay.
Duration of experiment	2 years
Crew tasks (if needed)	As required by gateway cubesat deployment facilities
Access and servicing by crew (if needed)	As required by gateway cubesat deployment facilities
Need for retrieval and return to Earth	N/A
Specific orbit needs (if any)	No for the main science case. Lunar polar orbit would be required to observe the Lunar poles.
Operations without crew (if any)	As needed

SEARCH FOR EVIDENCE OF DARK MATTER

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Scientific Domain:
Astronomy and Astrophysics

Idea Description:

The characterization of antimatter in cosmic rays is a key topic in astrophysics and essential for the understanding of the early universe. The direct detection of primordial antimatter, i.e. antimatter that was created at the beginning of our universe, would significantly affect our understanding of the formation of the universe and the creation of all matter around us. Although small numbers of antimatter particles have been observed in the cosmic radiation background, these are believed to be of secondary origin, created in interactions of high-energy cosmic rays with molecules of interstellar gas or planetary atmospheres. Despite many decades of unsuccessful searches, no primordial antimatter has ever been detected.

In the absence of primordial antimatter, the observation of such particles could be a strong signal for dark matter. We currently believe that the universe is made up of about 4.5% matter—the stuff that stars, planets, and life are made of. The rest is about 23% dark matter and 72% dark energy, of which we know almost nothing. Many theories trying to explain the nature of dark matter predict that antimatter particles are created when its particles decay or annihilate. The detection of low-energy antiprotons, antideuterons, or even antihelium could be a nearly background-free indicator for the presence of dark matter in the universe.

Current experiments using space-based detectors, such as AMS-02 and PAMELA, have revealed a deviation of the predicted fluxes of antimatter created in collisions of high-energy cosmic rays with gas molecules to the measured fluxes. More data in a wider energy range is needed to understand this deviation. Also, current experiments are situated rather close to our planet at LEO altitudes. This places them well within the realms of residual atmosphere and deep within Earth's magnetosphere, limiting their ability to measure at very low particle energies. But exactly this region is most interesting, since high-energy cosmic rays never produce antimatter particles with such low energies. Any observation of certain antimatter particles in this energy region would thus be an unambiguous sign of the existence of dark matter.

The DSG will be far outside Earth's atmosphere and in the outer regions of its magnetosphere. A suitable particle detector externally mounted to the DSG would thus be situated in an ideal location to perform the above-described measurements far better than any current experiment can. It would also extend the measurement range significantly, potentially delivering the very first evidence of the existence of dark matter.

The instrument would need to be a particle detector that is specially designed to identify antimatter particles over a wide range of energies. A collaboration of U.S. and European researches is currently building a balloon-borne experiment that could serve as a precursor to the instrument on the DSG. The experience gained during this stratospheric experiment and experiment performed on the ISS could be used to construct a much a lighter and more powerful instrument for the DSG.

The experiment would need no other facilities than the instrument itself. After installation, it would run autonomously and would not require any interaction with the crew.

The proposed instrument could deliver data for ground-breaking discoveries. Antimatter particles at the right energies would be a first evidence for the existence of dark matter—and thus show that our current theories of the creation and composition the universe are mostly correct. But even if no particles were found, the scientific return of the experiment would be no less meaningful, because it would mean that we still have no idea how to explain the composition of the universe.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	100 – 200 kg
Volume of hardware	NA
Accommodation (e.g. internal/external)	external
Power required	100 – 300 W
Data generated	NA
Pointing/viewing/line of sight needs	away from moon surface (not a strict requirement)
Communications needed	data downlink, some housekeeping & commanding
Duration of experiment	as long as possible, minimum 2 years
Crew tasks (if needed)	
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	no
Specific orbit needs (if any)	
Operations without crew (if any)	

large solid angle. This information can be used to assess the shielding in different station sections, particularly where astronauts spend significant time—for example, the sleeping quarters.

In cooperation with the Center for the Advancement of Science in Space (CASIS) and NASA, we are currently preparing the deployment of a first demonstrator instrument to the ISS. A launch is currently targeted for late 2018 or early 2019. Once verified against existing instruments on the ISS, the instrument will be ready for use on other spacecraft.

We propose to install two of our instruments on the DSG—one internally and one externally. Together, they could deliver data that is crucial to the operation of the DSG and for the planning of missions that venture further into deep space. High-precision data of cosmic ray fluxes outside of Earth's atmosphere will help to significantly advance our understanding of the deep-space radiation environment. Only with this knowledge can we begin to send humans to destinations beyond the moon.

The experiment would need no other facilities than the instruments themselves. After installation, it would run autonomously and would not require any interaction with the crew.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	< 10 kg
Volume of hardware	0.004 m^3
Accommodation (e.g. internal/external)	external and internal
Power required	< 60 W
Data generated	NA
Pointing/viewing/line of sight needs	NA
Communications needed	data downlink, some housekeeping & commanding
Duration of experiment	while DSG is operational
Crew tasks (if needed)	
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	no
Specific orbit needs (if any)	
Operations without crew (if any)	

A SUPER-SHARP SPACE TELESCOPE AT THE DEEP SPACE GATEWAY

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Scientific Domain:
Astronomy and Astrophysics, Solar System Sciences

Idea Description:
We propose the deployment and/or crew servicing of one or more 1.2m (3U CubeSat), 6.4m (Deep Space Gateway Airlock-Max), or 25m (Ariane 6-Max) aperture SUPER-SHARP space telescopes at the Deep Space Gateway.

SUPER-SHARP (Self-aligning Unfolding Primary for Earth-observation/astronomy Research via Space-based High Angular Resolution Photography) is a high performance space telescope optics platform to support multiple research applications in astronomy, astrophysics, earth-observation, exoplanet research, solar system science and more.

A sparse self-deploying self-aligning primary mirror is packaged into a free flying astronaut serviceable and upgradable modular spacecraft design. 1.2m or 6.4m variants could be deployed from the Deep Space Gateway, or a 25m version could be launched on an Ariane 6 to rendezvous with the gateway.

These platforms would be launched with initial instrumentation to support specific scientific roles or missions. For example, the Ariane 6-Max variant could identify how many Earth-like exoplanets in the habitable zone show the O_2 A-band bio-signature in their spectra. The Airlock-Max variant could potentially characterise exoplanets via reflected light, and the CubeSat be a pathfinder for servicing operations and obtaining 30cm or better imagery at the moon, Mars and beyond. The intention would be that these spacecraft have lifetimes similar to or exceeding the Hubble Space Telescope thanks to subsystems and instrumentation that would be serviceable by astronauts on the Deep Space Gateway.

For the 1.2m and 6.4m variants intended for deployment from the Deep Space Gateway or its service vehicles, a suitable mechanism or science airlock protocol would be required to ensure safe crew initiated deployment of the space telescope into an orbit similar enough to the Deep Space Gateway's that they could be serviced by spacewalk or robot arm (if available). For the larger variant, a method for astronauts to safely rendezvous with SUPER-SHARP would be required. As the science goals of the telescope(s) evolve, consumables are expended, or instrumentation advances render initial instrumentation obsolete, crew would replace modules with upgrades sent on resupply flights.

The impact of having one or more serviceable/upgradable Hubble resolution or better long-life space telescopes available to the global research community would be significant. The potential to have access to a 25m aperture space telescope would be game changing for many research areas, particularly exoplanet research.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	<5kg (3U CubeSat), <60kg (DSG Airlock-Max)
Volume of hardware	0.003 m^3 / 0.033m^3
Accommodation (e.g. internal/external)	Internal Storage, CubeSat/Airlock deployment protocol
Power required	Not applicable (self-powered)
Data generated	Not applicable (data returned direct to earth)
Pointing/viewing/line of sight needs	Deployment along safe vector from Deep Space Gateway required
Communications needed	Not applicable (data returned direct to earth)
Duration of experiment	At least one year
Crew tasks (if needed)	Initially deployment only for 3U / Airlock-Max variants
Access and servicing by crew (if needed)	Retrieval and/or servicing by robot arm or spacewalk to upgrade instrumentation / replace consumables
Need for retrieval and return to Earth	Not applicable
Specific orbit needs (if any)	None
Operations without crew (if any)	Operation primarily from the ground except during deployment and servicing

LOCATION-BASED PHYSICAL CHARACTERISATION OF LUNAR SOIL FOR FUTURE BUILDING MATERIALS

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Scientific Domain:
Physical Sciences, Other.

Idea Description:
The idea to use indigenous materials for the construction of a human base on the Moon is not new and has been developed since the first human missions in the 1970s. The lunar soil, whose primary constituent is called regolith, has already been extensively investigated (e.g., in terms of physical and mechanical properties) thanks to the large amount of samples returned to the Earth.
However, the samples were collected only in some specific locations, i.e., the landing sites of the respective missions. Therefore, a complete map of the characteristics of the lunar soil and their relation with the geographical location is still missing. As observed on the Earth, in fact, the properties of soil, and in general of natural materials, can change depending on latitude, intensity of the magnetic fields, temperature, etc.
On the other side, the granulometry of powders is of extreme importance in the realization of building materials or for their use in additive manufacturing (e.g., 3D printing) technologies.

The Deep Space Gateway will provide a unique opportunity to study the physical properties of the lunar soil at different locations. By collecting soil samples at specified times and coordinates, the purpose of the present research is to extract two basic physical properties of the material: granulometric composition and bulk density. In this way, it will be possible to assemble a detailed map of lunar soil characteristics, which will be important for the future development of building materials.

The idea here presented is applicable depending on the availability of a sample collection and return system, e.g. a probe able to reach the lunar surface and return on the Deep Space Gateway. In addition to this, other equipment needed will be a granulometer and a precision balance to be installed on board, for a total power consumption lower than 1 kW and an occupied volume of about 0.1 m^3.
The crew of the Deep Space Gateway will be asked to carry out the research by performing the following tasks:
- collection and storage of the soil samples;

- operation of the on board equipment (i.e., the granulometer and the precision balance) according to the corresponding user's manuals;
- data analysis and preparation for post-processing or communication.

The duration of the experiment will be the minimum for mapping the whole surface of the Moon, or selected parts of it. Thus, according to the specifications of the proposed orbits, for instance the Near Rectilinear Halo Orbit (NRHO), the suggested duration is between 9 and 12 months.

The long-term impact of the proposed research is to extract fundamental information for the preparation of building materials on the Moon, thus providing useful insights for the optimal location of future human activities.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	< 10 kg
Volume of hardware	0.1 m^3
Accommodation (e.g. internal/external)	Internal
Power required	< 1 kW
Data generated	
Pointing/viewing/line of sight needs	None
Communications needed	None
Duration of experiment	9-12 months
Crew tasks (if needed)	- Collection of soil samples - Sample analysis with the on board instrumentation - Data analysis and post-processing
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	NRHO (suggested)
Operations without crew (if any)	Collection of soil samples and return to the Deep Space Gateway

NANO PLANET FINDER (NPF)

Authors: Jaime Estela. Author[1]

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Scientific Domain:
The missions TPF (Terrestrial Planet Finder) from the NASA and the Darwin Mission from the ESA hat the aim to find exoplanets using new interferometry techniques. Unfortunately both missions were cancelled. This project idea proposes the use of a small instrument to validate a **Nuller interferometer** for the search of exoplanets, by testing the potential of the nanosatellite technology based mainly on commercial products for deep space missions.

Idea Description:
Exoplanets belongs to a new research field of the Astronomy with technical limitations in the acquisition of data. Satellite missions were already launched to find and catalogue exoplanets in the near vicinity. For future research missions new techniques and innovative instruments will be needed for the gathering of more information. The Nuller interferometer offers a promising technique to gain more valuable information from exoplanets. The missions mentioned above planned the use of such instrument. The proposed project idea will revive the interest in such instruments that can revolutionize the Astronomy.
The installation of a **Nuller interferometer** experiment will allow the validation of such instrumentation in a real space mission. The privileged position in space of the DSG supports the generation of high-quality data.
The experiment consists in two telescopes Maksutov-Cassegrain in order to get the best possible focal distance. Both telescopes gather the same image and combine it. With the **Nuller interferometer** the image of the main star will disappear. A new In-House solution will be also tested, where the entering light can be precisely manipulated. For the image acquisition high resolution cameras will be installed and the data will be stored in a SSD drive (capacity of 4 TB). The electronics and the optical parts will comply performance and environmental tests, especially radiation tests. Furthermore the use of commercial components (COTS) and materials will preferred in order to reduce costs keeping a good instrument performance.

The objectives of this project is the acquisition of much more information from exoplanets validating innovative instruments and techniques in space. The use and validation of commercial products will intensify in the near future the manufacture of more space hardware. It will support the growth of research activities in space with lower budget. SME companies will be able to support future space projects, because less investment will be required by the use of commercial products.

This project will require from the DSG power supply and a data link. It would be favourable to have the possibility to store part of the science data in the DSG.

The experiment works autonomous and no extra external equipment or facilities are needed. Also crew support is not necessary because the experiments work automatically and can be controlled from the ground.

The concrete impact of the Nano Planet Finder is the gathering of more valuable and unique information from exoplanets. The validation of new instruments generation based mainly on commercial parts facilitate the realization of future missions thanks to cost reductions.

Estimated experiment properties	Description
Mass of hardware	8kg
Volume of hardware	50x60x60 cm
Accommodation (e.g. internal/external)	External.
Power required	60W
Data generated	20 GB generated daily. Only selected image areas will be sent to the ground. 175 MB to be downlink daily is planned. This amount of information can be reduced in case the data transfer to the Earth is limited. Much information can be stored on the SSD drive.
Pointing/viewing/line of sight needs	Pointing accuracy 0,5 arcsec or better. The telescope should point to the outer space.
Communications needed	Direct communication to the ground through the DSG data link.
Duration of experiment	At least 1 year.
Crew tasks (if needed)	No needed.
Access and servicing by crew (if needed)	No needed.
Need for retrieval and return to Earth	No necessary.
Specific orbit needs (if any)	No.
Operations without crew (if any)	The experiment activities will run automatically and will be commanded from the ground.

OPTICAL TELECOMMUNICATIONS RESEARCH PLATFORM

Authors: G.T.S. Kirby[1]

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Scientific Domain:
Physical Sciences, Other.

Idea Description:
As we venture further afield and unmanned missions continue, bandwidth requirements escalate. We generate more data than ever before and deep space missions are constrained with a data bottleneck. I propose an optical communications research platform with the goal of enhancing our understanding of Earth-Space direct optical communications. Optical communications are a key focus for deep space research community and indeed the planned NASA Psyche mission (2022 launch) will employ a communications laser transceiver. NASA also demonstrated optical communications during the recent Lunar Atmosphere and Dust Environment Explorer (LADEE) mission (2013-2014). This experiment, named Lunar Laser Communications Demonstration (LLCD), demonstrated downlink data rates of 622 Mbps [1].

As well as both investigating and utilising an optical communications technology, A serviceable long-distance experiment, such as this, gives the research community unprecedented abilities to test and refine new concepts. I myself would love to determine the feasibility of using a modulating retro-reflector for ultra-low power probes. A modulating retro-reflector would reflect a terrestrial laser signal back to earth and modulate information onto the earth-bound reflection. This is not a new technology, but it is certainly a new application.

Specific equipment is still to be determined but will likely include a reconfigurable external optical array, an RF transponder beacon (to assist with target acquisition) and appropriate hardware to facilitate optical communications such as a computer (for encoding), laser diodes, amplifiers etc.

Refinement of this technology will assist us in preparing for deep space exploration. The benefits of higher bandwidth data communication need no further justification. Additional benefits of optical communications (over radio) are a potential 50% mass saving and a 65% saving in power [2].

A reconfigurable optical platform in Lunar vicinity gives the research community a robust and realistic test-bed for the next-generation of deep space optical communications.

[1] Robinson, B.S., Boroson, D.M., Burianek, D.A. and Murphy, D.V., 2011, February. Overview of the lunar laser communications demonstration. In Proc. SPIE (Vol. 7923, p. 792302).
[2] "Benefits of Optical Communications" https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_opticalcomm_benefits.html 7th May 2014 (Accessed 29th September 2017).

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	<100Kg
Volume of hardware	<1m^3
Accommodation (e.g. internal/external)	External with provisions for internal hardware.
Power required	Dependant on research type.
Data generated	Understanding leading to publications/IP in long-range optical communications. This equipment could also supplement the native transceiver array to communicate more data.
Pointing/viewing/line of sight needs	Pointing towards Earth. Continuous line-of-sight not required.
Communications needed	Set-up may require the exchange or targeting and timing information.
Duration of experiment	Ongoing.
Crew tasks (if needed)	Not needed.
Access and servicing by crew (if needed)	Changing/upgrading optical modules.
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	None
Operations without crew (if any)	None

TECHNOLOGY

INFLATE : INFlate Landing Apparatus TEchnology

Authors: Dr. Vsevolod V. Koryanov[1] and Victoria Da-Poian[2]

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Scientific Domains:
Life Sciences, Solar system Sciences, Surface landing operations

Idea Description:

INFLATE : INFlatable Landing Apparatus Technology

« The objectives of the LM landing planning strategy are to anticipate the lunar environmental problems and to plan the landing approach so that the combined spacecraft systems, including the crew, will most effectively improve the probability of attaining a safe landing. »

(From *Cheatham 1966*)

1) Overview

Space exploration missions are very complex scientific projects. One of the greatest challenges during such missions is the spacecraft's landing on the surface of the targeted planetary body. The vehicle has to be decelerated in a very short period of time from its orbital entry velocity to a complete rest on the surface. This mission phase is hardly fault tolerant. Moreover narrow targets for the vehicles position, velocity and attitude have to be met for a controlled landing within the vehicle's functional capabilities. Furthermore, each mission is highly constrained by the planetary environment, such as the gravity field, the atmosphere, the illumination conditions and also the surface properties. For instance, Viking (NASA ,1975) and Luna (Soviet Union, 1973) landings on the Moon relied on luck not to strike a large boulder or to be stuck into a large crater.

According to Adler et al (2012), "Entry, Descent and Landing (EDL) is defined to encompass the components, systems, qualification and operation to safely and usefully bring a vehicle from approach conditions to contact with the surface of a solar system body". Safely and Usefully are the main keywords of this definition. The scientific goals characterize not only the design of the spacecraft, but also the landing site in order to land in an area where the science objectives will be met. The site has to be « useful » to make the mission successful, and the landing must be « safe » to avoid fatal consequence in case of failure of such costly missions. The mission design deals with a high degree of uncertainty in the apriori knowledge of the environment.

2) Objectives

Our project, named INFLATE (INFlatable Landing Apparatus TEchnology) aims at reducing space landing risks and constraints and so optimizing space missions (reducing cost, mass and risk and in the same time improving performance). Inflatable braking systems are now the subjects of many researchers, but what about an inflatable landing system?

As the future space exploration projects are focusing on the installation of a Moon Village and then on an exploration of Mars, landing operations must be safe. In order to land on a celestial body surface, the lander's kinetic energy must be entirely safely removed, while traveling before the entry phase at high speeds (about 4 to 7 km/s). Re-entry friction with atmosphere is used to slow down from orbital speed (aerodynamic braking operations). For instance, with Earth's thick atmosphere, the only use of parachutes provides a gentle decent. The martian atmosphere is so thin that it cannot provide enough resistance to slow a spacecraft to a safe landing speed only thanks to a heat shield and parachutes. And on the Moon, as there is no atmosphere, only rockets are used all the way down to ensure a soft landing. Nevertheless, all these landings have ont thing in common: the touchdown which is also a very critical phase.

Mars exploration proved that it is not the fall that kills the mission but the landing. Remember the landing crashes of Mars Polar Lander, (NASA, 1999), Mars Express, (ESA, 2003, with Beagle 2 technology), and more recently ExoMars Schiaparelli lander, (ESA, 2017)
Nevertheless, in the last 50 years, landing technology has evolved and each generation of landing technology has attempted to resolve the challenges posed by the previous generation. For instance, some landing devices were:

- Legged landing system was the first system used (Viking mission in 1976) and was also used for Apollo programs in the 1960's. This solution is simple but limits the regions of landing (rocks, craters, sloped terrains) and can be very risky (Mars 98 crashed).

- Air bag landing systems were developed to reduce cost and mass and to avoid the problem of orientation and stability during landing. Nevertheless it arises a new challenge: the horizontal velocity control.

3) Equipment, facilities required

Our INFLATE lander vehicle would be designed with inflatable lander system to avoid many of the previous landers uncertainty.

The INFLATE lander will be composed both by an inflatable landing structure and by a penetrator system based on the landing devices, it will be like an inflatable mattress with a reliable and safe anchorage system to avoid rebounds on the surface. As one of the main goals of Deep Space Gateway (DSG) missions will be to build a safe and livable moon base, this considerable construction will need a great lander composed of inflatable braking device (IBD), system of inflation, shock absorption system, payloads, on-board equipment...

This lander that will be sent from DSG, will have the advantage to be composed of inflatable braking system with special thermal protection material that will absorb the heat flux during landing (Moon vicinity or for future missions to Mars atmosphere). The advantage of this selected concept is that the lander physical size and the overall mass of the lander are much smaller than in case of the traditional landers with rigid heat shield and rigid landing system.

Moreover this innovative lander would also be equipped of various payload assuring science on the target surface (Mars, Moon, other celestial bodies...). This lander will :

- take panoramic pictures,
- perform observations of pressure, temperature, humidity, magnetism, wind speed and direction
- for bodies with atmosphere: atmospheric dynamics, interactions between the surface and the atmosphere, as well as atmospheric optical depth.
- analyze the surface (dust raising mechanisms, seismology seismometer)
- cycles of CO_2, H_2O...

The main advantages of using this inflatable lander concept in the DSG missions are the compact size and mass compared to the conventional rigid heat shield landers, are even more significant when pursuing landing on other celestial body or planets (The Moon, Mars, Titan...).

4) Future steps

To make this project a reality, we listed some specific points that will have to be treated:

- the accuracy of the landing: it depends mostly on the entry angle, but some other parameters (air, pressure, temperature, wind, dust) are also involved. The system requires a controlled way of braking and adjusting the entry angle and velocity.

- amount of the available payload mass for DSG missions: lander size, landing type (soil), heat shield durability, additional landing devices and scientifique payloads

- study of the deformation of inflatable devices that leads to the change of aerodynamic coefficients of the forces and moments, as well as to the occurrence of additional small asymmetries like products of inertia, and form asymmetry.

- study of the materials properties that would meet almost all the criteria

- mathematical and physical models to ensure the feasability of this INFLATE project, and development of reduced scale mock-up testings

To conclude, INFLATE project aims to developing the safest landing system, using inflatable devices and anchorage system. Not only this project is a low cost and low mass project but also this is a simple construction that will revolutionize landing operations.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	400 – 2000 kg (Middle 2 project)
Volume of hardware	TBD
Accommodation (e.g. internal/external)	External (for landing and for surface exploration)
Power required	TBD
Data generated	From sensors (temperature, pressure, dust rate…)
Pointing/viewing/line of sight needs	TBD
Communications needed	With the Earth control centre, with the DSG control
Duration of experiment	Active experiment (some minutes for landing) , passive experiment (during all the mission on the surface)
Crew tasks (if needed)	Deploy the inflatable lander when needed if manual mode
Access and servicing by crew (if needed)	None
Need for retrieval and return to Earth	TBD
Specific orbit needs (if any)	None
Operations without crew (if any)	Passive work (sensors datas)

ACTIVE PHASED ARRAY ANTENNA ON DEEP SPACE GATEWAY PLATFORM TO MONITOR AND CATALOGUE HIGH ALTITUDE SPACE DEBRIS

Authors: S. Konatham[1], A. Bhardwaj[1], J. Martín-Torres[1,2,3], M.-P. Zorzano[1,4], D. Fernandez-Remolar[1], J. Ramirez-Luque[1], R. Fonseca[1], T. Mathanlal[1], A. Soria-Salinas[1], M. I. Nazarious[1], A. Vakkada[1] and J. Rosenqvist[1]

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Scientific Domain:
Space debris tracking, Technology, Observation platform

Idea Description:

We propose active phased array radar to track and catalogue space debris at high altitudes on DSG platform. Present estimates of debris in orbit, by statistical models indicate:
29 000 objects of size > 10cm
750 000 objects of size 1cm - 10cm
166 million objects of size 1mm - 1cm
And the numbers are ever increasing due to the increased frequency of satellite launches. This poses a threat of loss of instruments and satellites in orbit, and operations, for example.

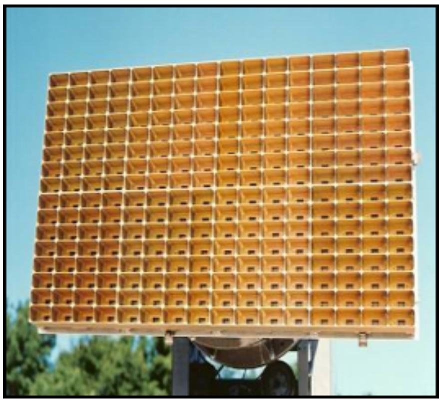

Figure 1: (a) space debris around earth, credits @ESA; (b) Phased array antenna (defense applications)

Space debris tracking with radar stations on ground can track debris of size up to 10 cm in LEO and the efficiency decreases to 0.3m in GEO. The performance of these ground based radar stations used to track debris is although efficient for the LEO, for GEO we still largely depend on the ground based telescopes which give the best estimates only for the debris over

10 cm in size. However, these telescopes face the challenge of atmospheric distortion. Installing a radar based sensor on DSG platform will solve 2 issues for monitoring GEO and beyond:
(1) it will decrease the detection resolution limit up to mm.
(2) it will not be affected by the atmospheric distortion.

The DSG platform provides unique field of view from orbits around the moon, facilitating increased area of coverage and opportunity to view and track significantly more debris, from high ground as compared to that of ground based stations.

Objectives, instrument requirements and role of the crew:

Through this instrument, we intend to catalogue more space debris located at altitudes ranging from GEO and beyond, around the lunar vicinity. Debris tracking was not done ever before for altitudes higher than GEO, which will be accomplished with this instrument on-board DSG station. The antenna operates in microwave frequency, preferably L band/S band for detection and tracking of debris. This system can provide improved alerts of debris impact to satellites and space stations while essentially ruling out atmospheric distortions and with zero mechanical moving parts, phased array radar facilitates robust electronical beam steering with high directivity. The instrument requires proper mechanical structure to hold the instrument based on the size, which can be modified based on requirements, due to the modular nature of the phased array radars in contrast to parabolic antennas.

The radar system requires to be installed on the exterior of the DSG station, requiring multiple EVAs by the crew during installation and for servicing of the radar in case of repairs/malfunction/upgradation of instrument.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	
Volume of hardware	Configuration of array elements determine volume (circular, rectangular configuration)
Accommodation (e.g. internal/external)	External
Power required	Depends on number of array elements and efficiency of power amplifiers
Data generated	Space debris detection and tracking data
Pointing/viewing/line of sight needs	Pointing towards Earth
Communications needed	Downlink of data.
Duration of experiment	Continuous scan of space around Earth
Crew tasks (if needed)	EVAs for installation

Access and servicing by crew (if needed)	EVAs required for servicing in the event of system malfunction
Need for retrieval and return to Earth	Not required
Specific orbit needs (if any)	No specific requirements, as all orbits of DSG provide constant earth visibility
Operations without crew (if any)	None

ADDITIVE MANUFACTURING PRINTING LUNAR EXPERIMENT (AMLE)

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Scientific Domain:

- Physical Sciences, Solar System Sciences.
- Collecting and returning planetary material.

Idea Description:

The 3D Additive Manufacturing Printing Lunar Experiment (AMLE) serves as a proof-of-concept test of the properties of additive manufacturing (AM) in the low gravity environment of the Deep Space Gateway. The lessons learned from this technology demonstration can be applied in the future developments of advanced in-space AM facilities located at the Moon or Small Solar System Bodies (SSSBs). This includes any future additive manufacturing technologies ESA may plan to use raw materials from in-situ ore extraction (e.g. steels or FeNi). Future manufacturing chains in a lunar/asteroid environment will anticipate a collection and processing process, which not only foresees 3D-printing of dust but also metallic alloys gained from the soil. Therefore this experiment has a direct application with a direct real future application scenario.

AMLE would be the first step towards realizing extraterrestrial (on-demand) in orbit services, a critical enabling component of any Deep Space Mission. The intent of this project is to design a testbed confirm with a lander (not in the scope of AMLE) and a 3D printing facility as a payload to be driven inside the DSG where successful a 3D-printing demonstration in a low gravity environment (<1/6g) is the goal. If the gravity would be the driver, a quasi-zero g environment could be provided by a slow rotation of the testbed.
The technology readiness level (TRL) of the system is to be risen to TRL6, preparing for a future experiment, AMLE 2, where a lander will be released from the DSG. In addition, the lessons learned are infused into the industry with the robust design of a small lander and the 3D AM payload.

This AMLE project enables:

- The first demonstration of additive manufacturing at the lunar vicinity.
- Benchmarking the AM in the lunar gravity environment with AM technology on Earth.
- Correlating the AM results with NASA Zero-G Technology Demonstration.
- Advance the TRL of AM processes to a level for a testbed with small lander and AM tool to be released from DSG to the lunar surface. A prepared metallic powder or wire sample will be foreseen. In this way, with the anticipated collect & processing

unit, this demo has a direct real future application scenario. Focus will be on the printing capabilities in a low-g environment (<1/6g).

- The gateway to fabricating parts on-demand in space, thus reducing the need for spare parts on the mission manifest.
- The first step towards evolving AM for use in space, and on Deep Space Missions.

The numbers below are based on a first scaling exercise and need further investigation.

Table: AMLE Experimental needs

Estimated experiment properties	Description
Mass of hardware	150kg
Volume of hardware	55x40x100cm
Accommodation (e.g. internal/external)	Internal
Power required	<500W (laser and cooler)
Data generated	AM samples
Pointing/viewing/line of sight needs	No
Communications needed	No
Duration of experiment	24h
Crew tasks (if needed)	Preparation of AM tool (~1-2 hours)
Access and servicing by crew (if needed)	Yes
Need for retrieval and return to Earth	AM sample, quality should be checked with microscopes (if not available on DSG)
Specific orbit needs (if any)	No
Operations without crew (if any)	No

A SUSTAINABLE BRIDGE WITH THE DEEP SPACE GATEWAY: THE LUNAR SPACE TUG

Authors: M. Mammarella[1], N. Viola[2]

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Scientific Domain:
Other – Support to Deep Space Gateway – DSG refurbishment and crew resupply.

Idea Description:

The gateway could move to support robotic or partner missions to the surface of the Moon, or to a high lunar orbit to support missions departing from the gateway to other destinations in the solar system. Because the DSG would be uninhabited for long period, at least at the begin of its operational life, the gateway requires high level of reliability, controllability and robotic capabilities to operate autonomously. On the other hand, when the crew is at the station, the DSG would require refurbishment missions to provide life support items such as food, water, and oxygen. The Orion MPCV is designed to support long-duration deep space missions, with up to 21 days active crew time plus six months quiescent, during which the crew life support should be demanded to space habitat modules, in this case the DSG. Hence, to support the crew for the whole mission duration, cargo ships are required to transport and delivery refurbishment and resupply to the station. Thus far, several alternatives have been considered, mainly based on the evolution of existing resupply systems, as the SpaceX Dragon spacecraft, i.e., cargo spacecraft adopting rocket engines as primary propulsion. On the other hand, a sustainable alternative is here proposed, a high-power electric propulsion spacecraft to enable high- Δv missions with heavy payloads, thanks to its higher propellant efficiency than other in-space propulsion technologies. The Lunar Space Tug (LST) is designed to rendezvous with the target resupply module, make an assessment of its current position, attitude and operational status, capture the target and then move it to the DSG. Injected into GTO, the LST will rendezvous the cargo module and then, they will move to the DSG through a low-thrust spiral trajectory for a total of about 3 km/s of Δv. Once the LST reaches the DSG orbit, the automated rendezvous final approach to the station is performed adopting chemical propulsion.

As anticipated before, the LST represents one of the elements of the DSG scenario and its operability is strictly linked to the other mission elements. Hence, the LST traffic plane should be coordinated with the Orion MPCV and the launch schedule, establishing a common traffic model defined in terms of cargo loading and unloading priorities (type of cargo for each platform), scheduling rules (launch windows, time between flights, number of vehicle), and performance characteristics (mainly cargo and propellant mass and volume resupply/return capabilities).

Completely automated, the LST requires high-level of reliability and autonomy during all its mission profile, especially for critical maneuvers, e.g. rendezvous with the DSG. Nonetheless, it has been conceived to be reusable, in compliance with the current trend, to reduce the mission cost. Hence, the required crew time is limited to cargo loading/unloading operations, whereas the station shall provide power, data, and mechanical support when the LST is docked to the DSG.

In addition to refurbishment and replenishment functionalities, the LST could also be used to transfer to Earth proximity planetary samples, experiments, and other sensitive equipment.

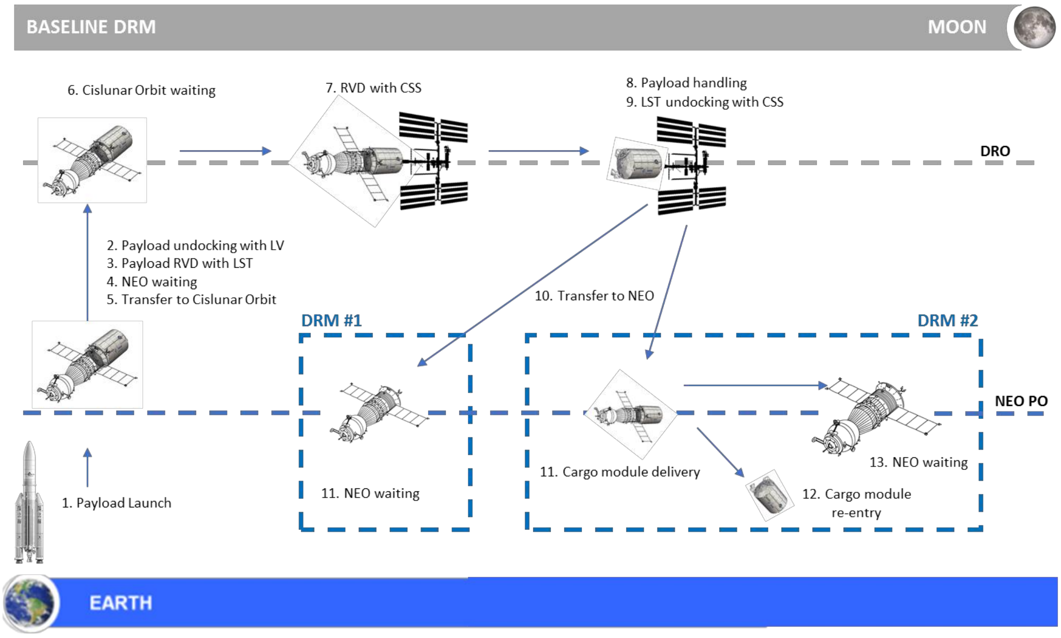

Figure 1 - Lunar Space Tug Design Reference Mission

In Figure 1, the LST operational scenarioe can be represented through a baseline Design reference Mission (DRM) and differentiated final phases (dashed-line squares). Considering the LST nominally operative i.e. excluding the LST launch, release, and transfer to the GTO Parking Orbit phases, the baseline DRM starts with the payload launch phase and the following release in a GTO. The LST approaches the payload with a rendezvous (RDV) maneuver, starting from LST parking orbit (TBD), and grasps the cargo (eventually using a Canadarm-like berthing device). After that, the LST brings the payload up to the DSG orbit, from where the RDV phase with the DSG starts, ending with the final docking/berthing with the station. Once all the activities related to the cargo are completed, the LST undocks from the DSG and starts the transfer phase back to the TBD orbit. In the DRM#1, the LST reaches its parking orbit, where it will remain until the next transfer. On the other hand, in the DRM#2, a new cargo module must be transfer from the DSG back to Earth proximity using the LST. Hence, once the LST has delivered the payload into the re-entry trajectory, it returns to its parking orbit, waiting for the following delivery.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	8000 kg (4000 kg LST + 4000 kg Cargo Module)
Volume of hardware	340 m^3
Accommodation (e.g. internal/external)	External (robotic arm and docking port required)
Power required	TBD
Data generated	TBD
Pointing/viewing/line of sight needs	none
Communications needed	TBD
Duration of experiment	Deep Space Gateway lifetime
Crew tasks (if needed)	Cargo unloading operations
Access and servicing by crew (if needed)	Cargo unloading operations
Need for retrieval and return to Earth	Cargo loading operations (possibly)
Specific orbit needs (if any)	DRO/NRHO - TBD according to the DSG needs
Operations without crew (if any)	None - Automated mating and undocking maneuvers

UNDERSTANDING AND DEVELOPING THE FULL RANGE OF SPACE ROBOTIC ASSISTANCE MODALITIES

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Scientific Domain:
Space Robotics and Technologies, Space Robotic Assistance.

Idea Description:

Premise

Robots are becoming increasingly indispensable in a wide array of applications. They are particularly useful to serve in locations and environment difficult to reach by humans as a result of distance or harsh conditions. In the space domain, robots can partner with mission crews through different command modalities to effectively carry out large, complex tasks, which may be difficult to impossible to complete by a human crew alone.

In a lunar surface scenario, a team of robots can serve as the first responders to any new site for reconnaissance and exploration. They can also extend the range and area of coverage each crew member can handle. New sensing, manipulation, and navigation technologies, as well as continuously improving robot intelligence, will make the robotic assets on the lunar or other planetary surfaces increasingly useful assistants for the human crew. On the other hand, on-orbit robotic assistants may reside on an orbiting station such as the Deep Space Gateway. In this scenario, the robotic assets can be utilized for station service tasks as well as scientific work intra- or extra-station.

Depending on the available conditions, such as lunar surface task complexity, communication time delays, capabilities of the robotic assets on ground, and the user interface modalities, the human user in orbit may wish to use a more immersive mode of commanding the robot. One possibility is with real-time force reflection command, such that the user may "feel" the environment the robot is working in. Such haptic feedback robotic teleoperation studies have begun with the on-going DLR/Roscosmos Kontur-2, and ESA's METERON Interact space teleoperation experiments. In these experiments, using force-reflection joysticks on board the ISS, the crew can command the robot on earth to perform different haptic manipulation tasks.

The immersiveness of haptic feedback teleoperation, or telepresence, gives the crew in orbit the most involvement in the task at hand. This enables the user to inject human intelligence into the work in progress, which is most suited for physical tasks of the unknown nature. However, this mode of telerobotic assistance also places a high cognitive and physical workload on the human user as the astronaut takes over full manual control of the robot in the remote environment. Telepresence also requires highly dependable communication network with low latencies, which may not be available under all space operation conditions.

The supervised autonomy mode of teleoperation, can address this problem. As studied in the DLR/ESA METERON SUPVIS Justin experiment, the robot assistants on the lunar or planetary surface function as co-workers for the crew members in orbit. Through the use of a user interface device such as a tablet PC, abstract, tasks level commands and replies are exchanged between the human user and the robots. The crew member takes the role of the supervisor to the robotic co-worker, commanding task packages for the robot to carryout. This mode of robot assistance relies on the robot's intelligence to reason and plan task executions. The local intelligence of the robots can also ensure that they remain the safety for the robot and its environment throughout operation without the need for user input. As such, orbit-to-surface communication blackouts or variable communication delays can be safely handled. In addition, this mode of teleoperation greatly reduces the workload for the human crew members in charge, which enables them to work with large teams of robot assistance to perform larger tasks over longer durations or perform the commanding of the robots as a side task during other scientific work.

In missions with more communication blackouts and/or increased communication delays, robotic operations must tend toward full autonomy. Such concepts have been studied and deployed on rovers such as NASA's Pathfinder and Curiosity, as well as ESA's ExoMars, for Mars exploration missions. In this modality, the communication time delays are significantly higher than with supervised autonomy or telepresence. The rover/robotic task packages must be designed to be planned and executable by the robot without human intervention over a long period of time of up to hours or days.

With the experience we gained from the aforementioned space robot assistance experiments, our goal is to further study the use of these different modalities of space robot assistance in terms of usability for the crew, robot assistance functionality, and human-robot team performance. With these findings, we aim to elucidate and develop an effective holistic approach to space robot assistance design to effectively, and seamlessly employ all modalities.

The case for the Deep Space Gateway

The Deep Space Gateway provides a unique use-case condition in which we can study all the desired modalities of space robotic assistance. With its position at the at the L2 Earth-Moon Lagrangian point, an estimated <0.5 second communication time-delay between the Deep Space Gateway the lunar surface can be expected. This enables the real-time closed-loop control necessary for force feedback telepresence. The Deep Space Gateway gives the possibility for us to understand effects of extended time (<10 minutes continuous) in micro-gravity, combined with the limited space, while using all different modalities of robot assistance. Equally important is the possibility to operate robotic assets on the lunar surface to help study and validate our proposed concepts in a true orbit-to-lunar surface setting.

Expected outcome

With this proposal, we aim to extend the capability and usability of the aforementioned robotic assistance modalities, to be manifested in new user interface designs, from telepresence and supervised autonomy formats, to quasi-full autonomy. It is also envisioned, that through these studies, new space robotic assistance technologies shall emerge to enable human-robot tasks of larger scales and higher complexities. In the early stages of the propose studies, the focus shall be placed on the user interface side of the space assistance concepts, where we can pair virtual robots set in a virtual lunar environment. As future assets become available on the lunar surface and/or on-orbit, the full space robotic assistance concept can be realized for to enable the holistic study. Finally, a methodology/guideline for the full-modal of robotic assistance deployment can be proposed.

Figure: Full range of space robotic assistance modalities. From telepresence (left), supervised autonomy (center), to quasi-autonomous operation, robotic assets on the lunar or planetary surface (right) can be utilized effectively through the use of a holistic, cohesive set of space robotic assistance modalities.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	<10kg
Volume of hardware	<20 liters
Accommodation (e.g. internal/external)	Internal; for crew use
Power required	(All estimates) Graphic user interface device: <50 Watts peak Haptic input device: <80 Watts peak Communication gateway: <50 Watts peak
Data generated	On-board user interface input usage data On-surface robot performance data
Pointing/viewing/line of sight needs	View of astronaut performing experiment desired
Communications needed	Voice communication; DSG-ground real-time/quasi real-time data communication (e.g. analog to S-Band, Ka-band, Ku-band/MPCC)
Duration of experiment	Under investigation
Crew tasks (if needed)	Telecommand of virtual and real robotic assets on surface or on-orbit
Access and servicing by crew (if needed)	Telecommand of robotic assets
Need for retrieval and return to Earth	Experimental data retrieval required; upmassed assets retrieval optional
Specific orbit needs (if any)	Under investigation
Operations without crew (if any)	Under investigation

AUTOMATIC PASSIVE WASTE DISPOSAL VEHICLE FROM THE DEEP SPACE GATEWAY

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Scientific Domain:
Technology demonstrator of a passive waste disposal vehicle from the DSG.

Idea Description:
As exploration is moving towards the Deep Space, logistics is becoming a key element to support longer, more sustainable and more autonomous operations. In addition to large orbital vehicles to transfer crew and materials, future exploration missions will also need cheaper vehicles for waste disposal from Space Stations to a planet atmosphere. This need will be particularly relevant in a scenario of long-duration human missions far from Earth (for example, on the Moon and subsequently also on Mars). In such a scenario, especially when the DSG or even a Moon base will be established, a waste disposal vehicle will be needed to de-orbit trash materials towards the Earth atmosphere.

The Deep Space Gateway would present the opportunity to investigate and demonstrate the feasibility of an innovative waste disposal vehicle. The objective is to demonstrate the feasibility of a simple, cheap and passive vehicle that does not require a propulsion system for de-orbiting. Such solution can be independent on the availability of a traditional launcher capsule. In this way, only one habitable capsule (such as the Orion) will be used to transfer humans towards and from the DSG, while other vehicles will be in charge of the waste disposal operations.

The envisaged concept consists of a cargo transfer vehicle that relies on a solar sail to progressively modify its orbit to move from the DSG orbit towards the Earth atmosphere. In particular, the concept would be more convenient if a solar sail made of flexible solar cells (see NASA's ROSA experiment, for example) is used. In this way, the solar sail would be used not only to control the spacecraft's attitude and orbital motion, but also to produce the required electrical power. Furthermore, the waste container of the cargo transfer vehicle could be made of an inflatable structure, so that it would occupy a small volume inside the DSG. Finally, it could be inflated right before filling with trash materials and subsequent disposal.

In the initial technology demonstration mission, depicted in Figure 1, a small CubeSat, representing the cargo vehicle and containing a folded solar sail, could be delivered from the DSG. The on-board crew would then be in charge of the deployment of the cargo vehicle using the CubeSat deployment system or the robotic arm. If possible, the crew could take pictures during the cargo vehicle and sail deployment. For safety reasons, a propulsion system should be included in this first demonstrator to provide a redundant de-orbiting solution, in case the solar sail fails.

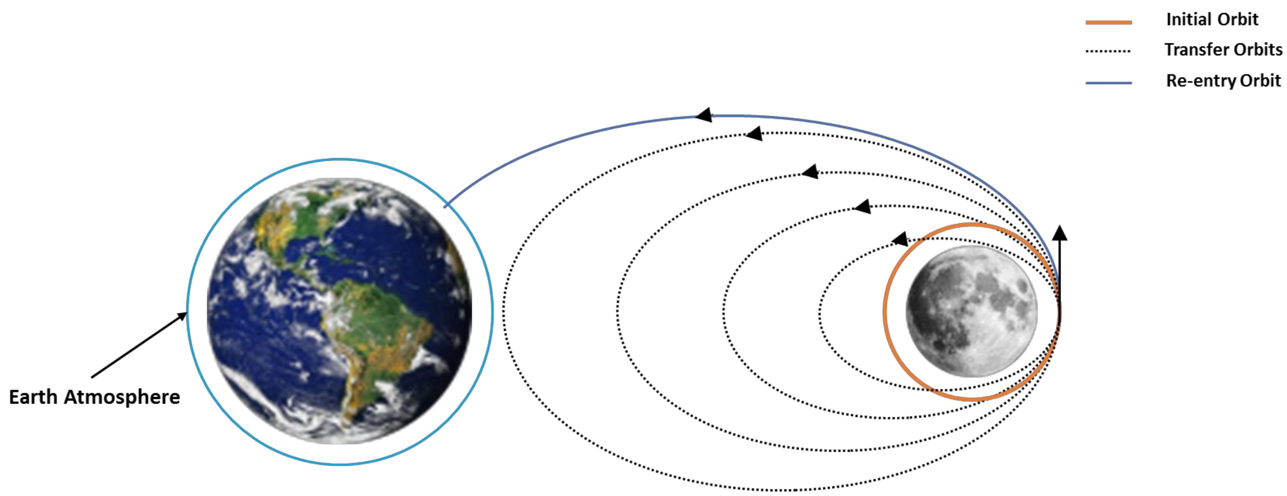

Figure 1: Passive Waste Disposal Demonstration Mission Concept

Table 1: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	<15 kg.
Volume of hardware	20 cm x 10 cm x 30 cm
Accommodation (e.g. internal/external)	Internal. To be deployed by means of the CubeSat deployment system or robotic arm.
Power required	
Data generated	
Pointing/viewing/line of sight needs	
Communications needed	Yes, DSG relay (TBC)
Duration of experiment	Crew time required only for deployment and taking a few pictures.
Crew tasks (if needed)	Payload preparation and subsequent release. Shooting pictures.
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	
Specific orbit needs (if any)	
Operations without crew (if any)	

AUTONOMOUS SPACE DRONES FOR CREW SUPPORT AND DSG INSPECTION

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Scientific Domain:
Life Sciences, Physical Sciences.

Idea Description:

A multi-purpose small free-flyer in the Deep Space Gateway environment would provide valuable support to flight crew as an effective tool to inspect the external DSG ecosystem providing real-time feed on-board, potentially avoiding relying on complex robotics and extravehicular activities.

A number of free-flyers shall be considered as standard asset of the DSG crew, whose tasks execution can be facilitated and/or supported by nanosatellite-platform-based semi-autonomous drones flying in proximity of the station. Crew shall be able to release and retrieve drones as necessary during nominal and off-nominal operations (e.g. routine medium-distance surveillance, radiation sensing/monitoring and alert, on-demand close-distance inspection in visible & infrared spectra, stereoscopic and/or LIDAR snapshots for micro-meteoroids strikes observations and image reconstruction).

Rendez-vous and docking capabilities, in addition to intrinsic modularity of nanosatellite platforms will offer unprecedented opportunities for science experiments deployment and retrieval, as well as multi-mission re-usability of drone's platforms themselves. Recharging/refuelling capability (e.g. standard electrical ports, N2 interfaces) would be nice-to-have DSG resources in favour of this concept.

The research is aimed at providing a set of requirements and the conceptual design of a DSG-environment free-flyer. The activity objectives are:

- To identify a reference concept of operations for a small free-flyer orbiting around the DSG, by involving the ISS and DSG community extracting high-level needs and the mission requirement
- To investigate the feasibility of the mission through a Preliminary Conceptual Design aimed at
    - Identifying the flight rules for the small free-flyers around the DSG
    - Identifying the technology readiness level of on-board equipment and the available/potential DSG resources.
    - Define a concept of operations and related external resources need (ground communications, scheduled operations, communications assets available)
    - Preliminary Design of the DSG Drone

Tyvak International led a Phase A/B1 Mission concept and preliminary design study for ESA in 2016-2017, under the contract "4000116866 - Multipurpose CubeSat at ISS", with the participation of Politecnico di Torino and OHB Bremen, which applies to the present research proposal, and is eager to investigate opportunities for future collaborations with the Agency in favour of the development of similar concept in the framework pf the DSG design, implementation and successful operations.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	10-20 kg (single satellite + orbital deployment system)
Volume of hardware	Equivalent of CubeSat 6U
Accommodation (e.g. internal/external)	Primarly external (docked configuration, recharging) Internal if platform used to swap different payloads or refuelling
Power required	n/a
Data generated	Images/videos for inspection,
Pointing/viewing/line of sight needs	n/a
Communications needed	UHF/S-band with DSG for proximity ops (ranging), S-X-band for image/video stream
Duration of experiment	Precursor flight can endure weeks. Goal: permanent asset for DSG operations support
Crew tasks (if needed)	Image/video streaming review, collision avoidance man. execution
Access and servicing by crew (if needed)	Full access to drone control
Need for retrieval and return to Earth	Retrieval necessary if intended as re-usable asset. Docking foreseen
Specific orbit needs (if any)	n/a

PLATFORM FOR CONDUCTING EXPERIMENTS TO STUDY THE LONG-TERM EXPOUSRE EFFECTS OF SPACECRAFT COATING, MATERIALS AND COMPONENTS IN DEEP-SPACE ENVIRONMENT

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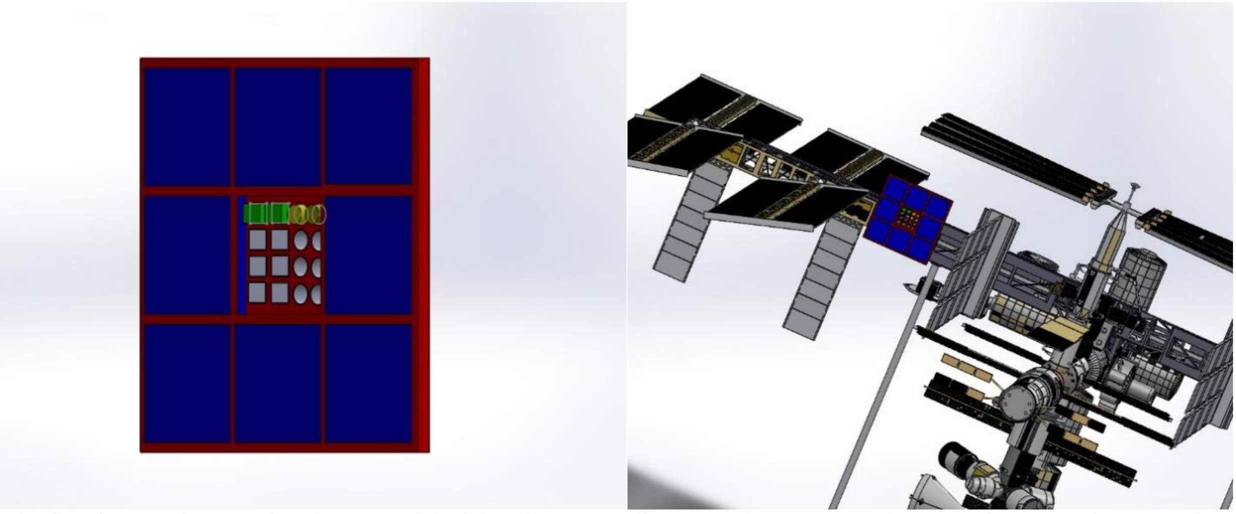
Scientific Domain:
Physical Sciences, Materials, Coating, Technical Readiness Level (TRL), Aging.

Idea Description:
The idea of this experiment is to provide a platform for testing various kinds of coating, paint, materials, components etc. to determine that the experiment being tested is suitable/viable to be applied on future spacecraft/space stations used for deep-space travel. The platform can also be used to test anything designed to be placed on the outside of a spacecraft, for example solar panels, protective alloys and many other currently existing, and upcoming concepts.

The rapid growth in research and development of spacecraft capable of deep-space travel results in an increasing demand for technology capable of enduring the conditions that come with this kind of long-term exposure. Space travel to potential destinations like Moon, Mars and others involve demanding technological challenges to overcome long term exposure to bombarding space radiation, huge temperature fluxes, possible attack of micro-meteorites etc. that degrades the health of spacecraft in several ways. This calls for technology and materials capable of sustaining human activity for long periods at a time. Therefore, improved designs on existing concepts will be required for materials that can endure this type of environment. This calls for a simple, reliable, versatile and adaptable method for testing these new technologies being brought forward to meet these challenges.

The platform would be designed as a $1m^2$ plate (plate size is subject of change), which has a grid-shape designed placement to fit in 8 smaller plates, which could be made from the same material as the space stations outer hull, or any other material that is of interest in testing in a deep-space environment. The centre of the central plate would leave room for attachment of sensors, which can be interchanged based on what is of interest to measure. This plate would be attached to the outside of the space station. The smaller plates would be attached via a detachable method to the main plate. The smaller plates would have different kinds of coating applied, to be tested over a long-term period. Most of the coatings that would be tested might already have a TRL of 9, but what hasn't been possible before is long term monitoring of these coatings, as well as possible sample return for closer examination. Other components can be tested on the same central plate, having been modified to fit to the central plates' attachment mechanism. Several sensors will be mounted to the central plate to check important variables such as radiation, temperature gradients, light-levels etc, but there will also be room to add other sensors that are relevant for a specific experiment, and these, too, can be interchanged. A monitoring camera would be attached next to the central plate, and connected to a live network which can be accessed and checked by on-board crew as well as researchers on ground.

The camera would be able to monitor micro-meteorite impacts on the experiments, and provide a visual result of this event.



The first image shows a simple 3D model of the plate, as well as a good camera-angle to monitor experiments. The second image shows an example of the placement of the plate on a space station (not to scale).

A few examples of experiments that could be performed on this platform would be to test a new type of MLI (Multi-Layer Insulation) material designed to be used in spacesuits with a current TRL of 6 and associated sensors of relevance, experiments that could lead to further development in spacecraft coating for deep-space travel, testing protective alloys to protect from different elements, such as micro-impacts. Many components/materials of existing and upcoming concepts would allow for possible increase in TRL and development of better versions more suited to the long-term exposure, as well as improving the sustainability and protection of human passengers on board a spacecraft located in deep space. The long term-exposure effects could be quantified and new improvements for existing spacecraft can be formulated from this, resulting in less degradation over time.

This testing platform offers the possibility of raising the TRL of many upcoming concepts with a simple, inexpensive testing method, opening access for more companies, research groups etc. to improve the TRL for their concept ideas, that involves deep-space exposure. There will likely be interest from research groups, companies, agencies etc. to bring back the experiments to Earth for closer examination of the long-term exposure test. This will be easily achieved, as the experiments would be of a fairly small size to fit on the main plate, which allows for easy and lightweight transport on a spacecraft heading back to earth.

On-board crew would have to be available to attach the main plate to the exterior hull of the space station. They would also have to be available to detach experiments and attach new ones on to the main plate. A simple attachment mechanism would allow for experiments and sensors to be easily interchanged by the crew. Ability to survey the experiments from the station would be recommended, possibly through a window, or a live-feed from the monitoring camera connected to a monitor inside the station.

Estimated experiment properties	Description
Mass of hardware	Depends on material mass.
Volume of hardware	1 m^2. (plate size is subject of change)
Accommodation (e.g. internal/external)	Outer attachment on the space stations hull. Availability to connect power and data-transfer cables to the platform. Availability to attach a monitoring camera close to the platform.
Power required	Power required to operate sensors and camera.
Data generated	Images from the monitoring camera. Data from sensors in case any sensors were tested.
Pointing/viewing/line of sight needs	Clear view of the platform and the experiments attached.
Communications needed	Data transfer back to earth.
Duration of experiment	Various.
Crew tasks (if needed)	Visual monitoring of experiments.
Access and servicing by crew (if needed)	Interchangement of experiments on the central plate.
Need for retrieval and return to Earth	Yes, if requested by experiment owner.
Specific orbit needs (if any)	None.
Operations without crew (if any)	Video monitoring of experiments, and data-transfer to earth.

SPACECRAFT-ON-DEMAND AT THE DEEP SPACE GATEWAY

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Scientific Domain:
Solar System Sciences, Astronomy and Astrophysics, Other.

Idea Description:
We propose installing a Spacecraft-on-Demand spacecraft printer at the Deep Space Gateway to permit the frequent manufacture and deployment of ad-hoc spacecraft for science and technology missions in deep space.

The current system is designed to operate at CubeSat scale and permit the manufacture, deployment and operation of individual or swarms of mg to g scale spacecraft in deep space. Such spacecraft can include avionics, communications, propulsion systems and instruments designed and optimised on Earth by a principal investigator or team. The spacecraft design is uploaded to a Spacecraft-on-Demand printer located at a convenient place of deployment such as the Deep Space Gateway, where they are automatically manufactured and deployed to perform their mission.

The initial objective would be to demonstrate the feasibility of the approach, which once proven, would be applicable to almost any space science field. These might include radio astronomy (e.g. manufacture and deployment of swarms of spacecraft implementing radio telescopes), space weather applications (e.g. deployment and replacement of space weather buoys), or planetary science, for example, orbiters or probes printed and deployed from the Deep Space Gateway which make their own way to the body of interest.

A minimal implementation would be the installation or deployment of a CubeSat scale spacecraft printer on or from the Deep Space Gateway, to implement a limited number of proof-of-concept missions. The preferred implementation would be similar to a CubeSat dispenser, a permanent or semi-permanent facility of the Deep Space Gateway which would permit continuous ongoing deployment of missions of all types from the station. If deployed as a CubeSat, then only the standard support facilities required by any CubeSat would be required. If implemented as a permanent facility, then the facilities and crew interaction required would be similar to those to support a CubeSat dispenser.

We expect the impact of the research to be a dramatic increase in the number and cadence of robotic deep space missions of all types. Once on orbit, the Spacecraft-on-Demand system eliminates many of the bottlenecks of a traditional spacecraft mission process such as launch availability and delays. It also makes the process of designing and operating missions more accessible, whether professional scientist, educator or student.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	At least 5 kg (the greater the mass available, the greater the capacity of the materials cartridges and hence number of spacecraft that can be printed)
Volume of hardware	At least $0.003m^3$
Accommodation (e.g. internal/external)	External
Power required	<100W peak for <1 hour duration of each spacecraft print and deployment. <1W standby.
Data generated	<1MB day telemetry, video nice to have if available
Pointing/viewing/line of sight needs	Needs to pointed such that free flying spacecraft can be deployed from it
Communications needed	Upload of spacecraft designs to printer via suitable interface (<100MB per spacecraft typical). Deployed spacecraft communications expected to be direct to Earth via U/V/S/X band.
Duration of experiment	At least one month, but if materials cartridges can be replaced or can be very large, then potentially permanent
Crew tasks (if needed)	Replacement of materials cartridges if permitted
Access and servicing by crew (if needed)	Replacement of materials cartridges if permitted
Need for retrieval and return to Earth	Not required
Specific orbit needs (if any)	None
Operations without crew (if any)	Upload of spacecraft designs, scheduling of deployments, status monitoring

TECHNOLOGY AND OPERATIONS RESEARCH ON A FUTURE DEEP SPACE GATEWAY

Authors: D. Sabath[1] , T. Müller[2], and G. Söllner[3]

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Scientific Domain:
Other: Technology and Operations Research

Idea Description:
The currently discussed Deep Space Gateway in an orbit around or nearby the Moon offers new and exciting possibilities for investigations on future spaceflight. The Deep Space Gateway offers the following new environmental conditions, opportunities and location compared to space stations in low Earth orbit:

- First manned station not close to Earth, i.e. in the vicinity of the Moon
- Comparable radiation conditions to a later Mars mission
- No permanent contact to Ground Control (dependent on chosen trajectory/orbit)
- Longer turnaround time for crew and spare parts as well as (small) communication delays

These special conditions offer new challenges, not only for development and manufacturing of the modules of the Deep Space Gateway, to the astronauts and their training, but also to the operation of such a manned station. Hence, the new planned station should not only be used as a new base for scientific research, e.g. Moon observation and investigation, but also for testing new approaches of manned space operations, which could be of great interest for future exploration mission beyond Earth orbit.
DLR/GSOC has longstanding experience in manned space flight operations starting with FSLM (First Spacelab Mission) in 1983, D1, D2, Euromir, Astrolab and since 2008 Columbus. DLR/GSOC would contribute its vast experience in this field gained over the last decades. Moreover, new tools and processes developed recently at DLR/GSOC could offer new ways to operate a future human base or interplanetary spacecraft under the special conditions of deep space given by the relevant mission.
The Deep Space Gateway offers a unique opportunity to implement some of these new operation approaches in an environment

- close enough to Earth to ensure a safe return in case of any contingency
- far enough away from Earth to offer more challenging conditions compared to ISS

There are two areas of research DLR/GSOC wants to contribute to the Deep Space Gateway collection of ideas:

- Implementation and testing of new tools for deep space operations
  - New tools on ground supporting flight controller in analysing on-board systems on signatures of potential failures
    - DLR is currently developing and testing a software tool (ATHMoS) to detect such signatures using data mining procedures
  - New on-board tools to improve the reliability of the spacecraft reducing the need of permanent monitoring and human intervention
  - KI like algorithms reacting more flexible on on-board flaws and misconfiguration
  - Pre-configured but flexible, automated on-board command system assisting the astronauts in re-configuration and switching on/off on-board subsystems and experiments (cp. improved Master Timeline of Columbus)
  - Observation of radiation hardened equipment with special tools on board and on ground to judge in near-real time the status an fitness of the on-board equipment
  - Implement, use and analyse delay tolerant networks and tools which allow communications between space and ground with minimum communication breaks
  - Implementation and operation of an enhanced user gateway/infrastructure for remote usage as well a multi-partner network including HD/4K video distribution

- Implementation and testing the following new processes for deep space operations:
  - Test of new approaches for deep space operations, e.g. how to work together with astronauts on long distances including communication delays
  - Implementation and test of new communication tools and approaches to cope with environmental conditions in deep space, like solar flares or interruptions of communications (e.g. if the station is behind the Moon), e.g. including optical communication additionally to Ku/Ka/S/X Band to offer two physically different means of communication with different dropout conditions
  - Implementation of remotely controlled robotic operations
    As the Deep Space Gateway won`t be crewed all the time, remotely controlled robotic operations would become increasingly important to maintain scientific research activities on-board even during times when Astronauts are absent. DLR/GSOC has already gained experiences in providing the necessary infrastructure and communications capabilities for this kind of operations together with DLR`s robotics institute DLR/GSOC can therefore contribute its expertise in this area in order to help design the Deep Space Gateway for maximum scientific output.

DLR/GSOC will present more details on the possible applications in the workshop in December in ESTEC and is looking forward to develop new tools and strategies with ESA to make the next step in human space exploration.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	Not known but expected to be included in mandatory subsystems
Volume of hardware	Not known but expected to be included in mandatory subsystems
Accommodation (e.g. internal/external)	internal
Power required	Unknown but only marginally higher than standard equipment
Data generated	1 – 2 Kbyte per sec (on top of normal TM/TC data)
Pointing/viewing/line of sight needs	For best testing condition communication outages, i.e. some flight phases with no line of sights from earth are recommended
Communications needed	New communication equipment due to study results, e.g. DTN, Laser and Ka Band communication means
Duration of experiment	At least 1 year / full lifetime of station
Crew tasks (if needed)	Crew training and feedback on new types of interaction
Access and servicing by crew (if needed)	Normal work
Need for retrieval and return to Earth	none
Specific orbit needs (if any)	None / For best testing condition communication outages, i.e. some flight phases with no line of sights from earth are recommended
Operations without crew (if any)	Normal operations

MICROWAVE SINTERING TEST ON THE MOON SURFACE

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Scientific Domain:
Physical Sciences, Solar System Sciences.

Idea Description:

Overview and the objectives of the research

We would like to observe the microwave sintering phenomenon of lunar dust/regolith under the lunar surface environment in order to determine if microwave sintering could be an appropriate fabrication method of 3D printing technique for lunar construction, i.e. establishing a Lunar Village. We are currently designing a bespoke microwave heating equipment, which includes a vacuum chamber to mimic lunar surface environment (see Fig. 1). Although the equipment would provide some valuable outputs, it would not be capable to observe the effects of microgravity and dust reaction during the sintering process. The Deep Space Gateway is, therefore, an excellent platform to conduct an invaluable onsite experiment which will overcome the limitation described above.

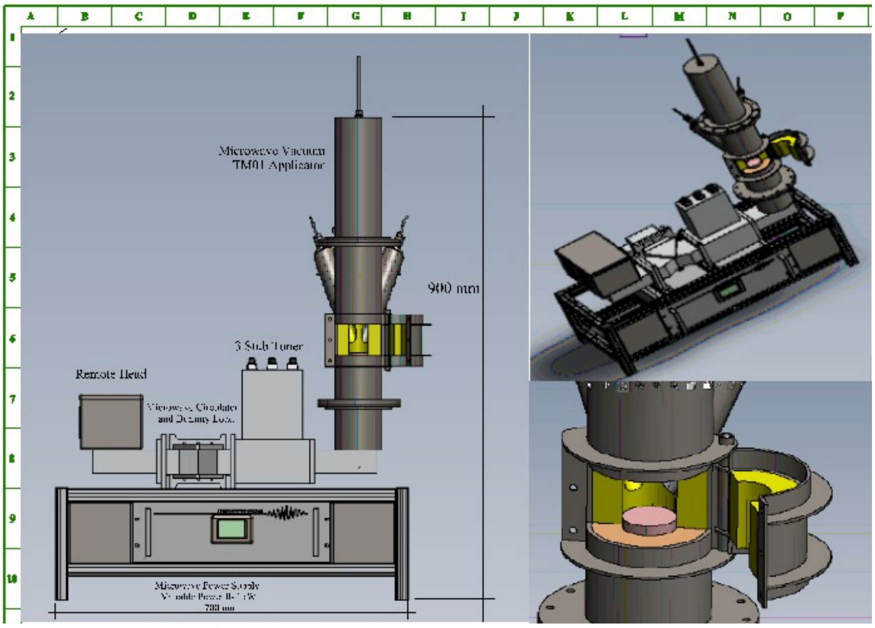

Fig. 1: A concept drawing of a bespoke microwave sintering equipment with a vacuum capability

Required equipment and anticipated functions

In order to conduct the proposed research on site, we would re-design the microwave sintering equipment to be deployed on the lunar surface prior to the Deep Space Gateway mission. The anticipated functions of the equipment for the research are:

- Compaction of lunar dust/regolith in the sintering chamber
- Periodic (once per 24 Earth hours) or continual (if we can set it as an automatic) measurement of the surface temperature of the sintered specimens
- Collection of the sintered and analysed specimens to return it to the Earth

Required role the crew of the Deep Space Gateway

The crew would need to control and monitor the equipment remotely to make sure the equipment does the job as planned. Note that the periodic temperature measurement can be automated without the crew's intervention.

Expected impact of the research

Since the Apollo 11 touched down the lunar surface, many researchers have been tried to develop an appropriate fabrication method and materials to be used for building various lunar construction components, including a protection cover of micrometeoroids/cosmic radiation and surface pavement, etc. Initially, conventional casting and wet-mix based 3D printing techniques have been tested. Nowadays, however, sintering techniques using raw local resources, e.g. lunar dust/regolith, are considered as a more appropriate method for a lunar construction, and microwave sintering is particularly considered as a potential method compare with solar and laser sintering methods [1]. The proposed experiment would, therefore, directly impact on the development of extra-terrestrial construction process, particularly on the Moon and Mars by verifying previous and ongoing experiments on the Earth.

Expected benefits from the research

The proposed research through the Deep Space Gateway platform would provide invaluable benefits to the governmental space agencies, academics and industry working on the subject as follows.

- Opportunity to measure real microwave sintering phenomenon under the real lunar surface environment using real lunar dust/regolith: There is no valid data of microwave sintering using lunar regolith under the real lunar environment yet, i.e. vacuum, electrostatic dust and microgravity.
- Opportunity to sinter meaningful volume/mass of real lunar dust/regolith: Returning a number of meaningful volume of specimens would allow us to conduct conventional and destructive measurement of the mechanical properties of sintered specimens.
- Opportunity to observe potential system malfunction caused by dust penetration and other risks: The results of the research would allow us to develop appropriate mitigation methods.

Reference:

[1] **Lim, S.,** Levin Prabhu, V., Anand, M., Taylor, L., (2017), "Extra-terrestrial construction processes - advancements, opportunities and challenges", Advances in Space Research Journal, Vol 60, Issue 7, pp. 1413-1429. https://doi.org/10.1016/j.asr.2017.06.038

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	TBD
Volume of hardware	TBD (less than 1000 (H) x 700 (L) x 400 (D) cm)
Accommodation (e.g. internal/external)	N.A. (The equipment should be placed on the lunar surface.)
Power required	Minimum 1kW (for the sintering device on the surface)
Data generated	Sintered specimens (dimension & the numbers: TBD)
Pointing/viewing/line of sight needs	N.A.
Communications needed	Yes (remote control of the device)
Duration of experiment	Total 14-days (or longer if possible) • 1^{st} day: sintering • 1^{st} – 14^{th} day: measure the surface temperature of the sintered specimens on each day • 14^{th} day: verify if the specimens are hardened enough to be collected (if not, repeat the measurement another 7 days) • 14^{th} day (or 21 days): collect the specimens
Crew tasks (if needed)	• Remotely control and monitor the equipment to sinter the lunar surface material dust / regolith. • Measure the mechanical properties of the sintered specimens on the lunar surface. (*optional as it could be automated*) • Collect the sintered specimens to the Earth
Access and servicing by crew (if needed)	N.A.
Need for retrieval and return to the Earth	Specimens of sintered dust/regolith will be returned to the Earth.
Specific orbit needs (if any)	N.A.
Operations without crew (if any)	Temperature measurement of the sintered spicemens (if the process can be autonomous)

Human-Robot Interaction Methods for Lunar Surface Science Using Tele-Presence

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Up to now tele-operation can be used for the control of robot by experienced robot operators only. This is especially true for the control of an exploration rover and its arm too. But for an effective scientific research on the lunar surface the conduction of investigations like selecting and taking probe or positioning of instruments should be controlled by a scientist directly. Such kind of operations includes several tasks, e.g.:

- Visual inspection of the terrain
- Visual inspection of a stone including taking it and turning it to inspect it from several sides
- Grasping of probes

For all these operations a good immersion and visualization of the surface and the investigated objects would be advantageous. The scientist must be able to inspect an object from several sides, to turn the camera around to look for other objects, to inspect objects from different distances. With the current state of the art of communications, animation techniques and control interfaces cannot be performed in the necessary quality and with the adequate time response due to communication time delay, restricted FoV of the cameras and the limited number of cameras on the rover. Especially the communication time delay would not allow a direct visualization and control of the scientific investigations in real-time.

The main idea of the proposed project is the de-coupling of the image acquisition by rover cameras and the visualization on-ground.

This can be implemented with three different control loops (see figure). In a first loop, the acquisition loop, images of the environment are acquired by the arm and mast camera of the rover. A control computer on-board the DSG controls this activity with the goal, to get a mostly complete image of the environment in course of time, using all cameras of the rover in a dedicated and harmonized way. The acquisition strategy must be determined autonomously taking into account the movement of the rover, operator actions, like turning the head, and open areas to be explored. Furthermore, differences between the current model and new image data are computed.

In a second loop, the model update loop, these model difference data are transmitted to the on-ground station and it will be used to update the overall model.

This overall model is the basis for the visualization of the surrounding of the rover for a human operator in a third loop, taking into account the current illumination conditions and the current pose of the operator. Thus, a human operator works in a modelled and animated environment in real-time, whereas the model of the environment will be generated step by step by automated camera movements mostly independent of the operator commands and taking account communication constraints.

With such an approach a quasi-real-time response to the operator activities can be achieved even in the case of limited communication possibilities. Such a de-coupling is possible, because the surface of the moon is static. Also robotic interactions can be reflected by updating the on-ground model.

For the implementation of such method several scientific investigations are necessary. These include:

- Generation of an environment model suited for operator control
- Update of the model reflecting changing illumination conditions (sun)
- Update of the model due to robot activities
- Generation of the model using the various rover cameras (on arm, on mast) in a coordinated way

- Control of the camera trying to establish a complete model of the surrounding as fast as possible taking into account the last activities of the operator (e.g. turning the head in a direction)
- Prediction of the operator movements and understanding its intention to control the cameras accordingly.

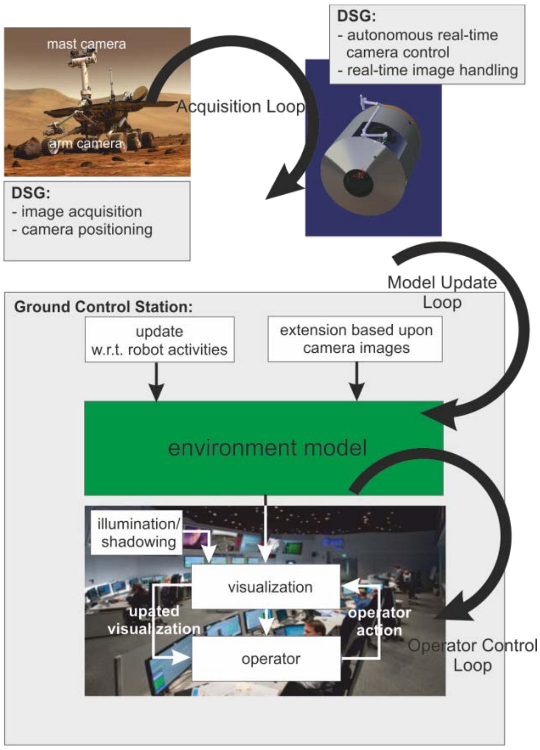

Table: Expected equipment and operational needs

Estimated experiment properties		Description
Mass of H/W	1kg	The basic idea is to use available rover cameras and communication lines. Additional DSG-on-board l computer is required for the autonomous camera movement control and model difference computation
Volume of H/W	200x200x20 mm^3	See above
Accommodation	internal	
Power	20W	See above
Data		Downlink: Model difference data, 5Mbit/s (TBC) Uplink: control commands, some Byte/s
Pointing needs		Camera control
Communication	No extra needs	Model update if data are available
Duration	n/a	
Crew tasks	none	
Access by crew	none	
Retrieval	no	
orbits	n/a	
Operations w/o crew	yes	On-ground operations only

THE 'WORKSHOP': IN SITU REPAIRS/CALIBRATIONS OF RESEARCH/SCIENTIFIC EQUIPMENT ON THE DEEP SPACE GATEWAY USING ANALOGUES FROM THE ESA²C

Authors: S-J. Gill[1], M.S. Rumsey[1], K. Manick[1], H. Schroeven-Deceuninck[2], L. Duvet[2] and C. L. Smith[1]

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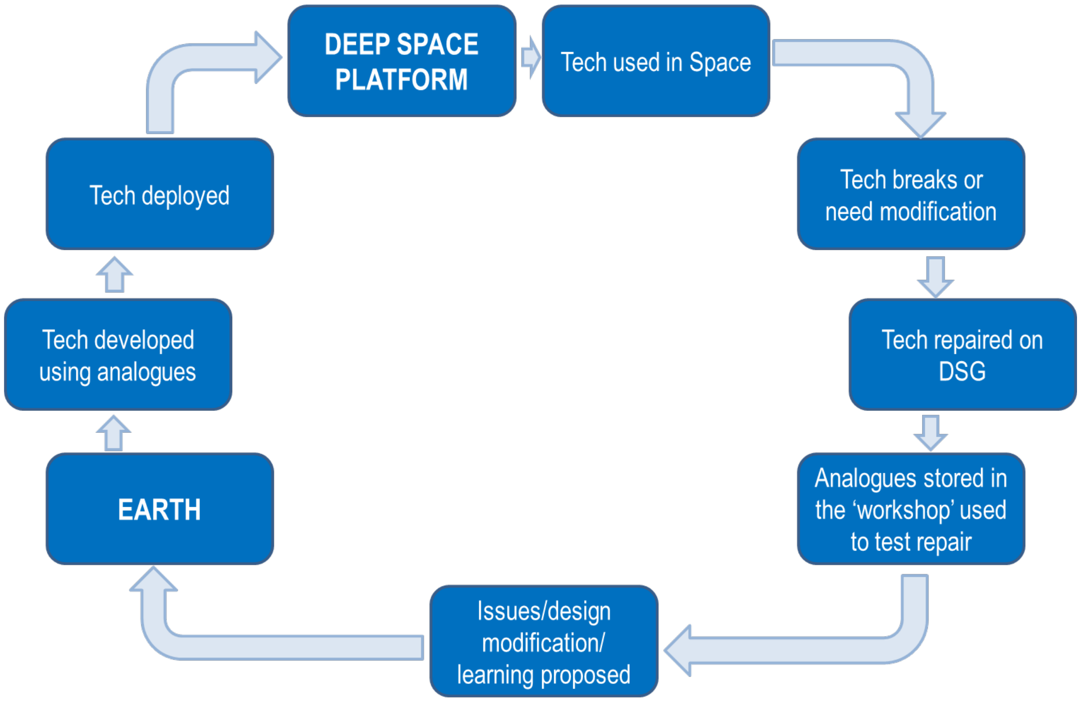
Scientific Domain:
Physical Sciences, Solar System Sciences, Earth Sciences.

Idea Description:
Since 2014, the Natural History Museum (NHM) has been the primary contractor to the European Space Agency (ESA) for defining and initiating the development of a Sample Analogue Collection and Curation Facility in support of exploration programmes. The ESA Sample Analogue Collection (ESA²C) has been designed to support the ongoing or future technology development activities that are required for human and robotic exploration of Mars, Phobos, Deimos, C-Type Asteroids and the Moon. The long-term goal of this work is to produce a useful and useable resource for engineers and scientists developing technologies for ESA missions. But what happens when these technologies ('tech') leave the Earth? What happens when they are damaged, malfunction or require recalibration? Sending the tech back to Earth will likely be prohibitive in terms of cost and time so we propose that the Deep Space Gateway (DSG) is used to carry out these repairs/modification/recalibrations. Deep space exploration will be an iterative process; as more information is gathered, tech may need to be modified or adapted. We believe that having some capacity on the DSG to carry out these changes and effect repairs/calibrations will be vital to the success of this endeavour, to achieve this we propose including a 'workshop' on the platform. In addition to supporting tech requirements/repairs, we propose that the workshop include a store of analogues to test whether the modifications or repairs have been successful. This will ensure that all the scientific and research activities being carried out on the DSG will be supported in situ.

The crew would be expected to carry out diagnostics on any tech as required, under guidance from the technology lead on Earth. The choice of analogues, equipment and expertise required to service the tech will depend strongly on the final activities to be carried out on the DSG, but could be tailored accordingly.

The benefits and impact of having a workshop and carrying out test work using the ESA²C analogues is summarised in the flowchart below, starting with the Earth.



At present specimens from the ESA²C are being used by engineers and scientists in the United Kingdom, Hungary and the United States to support planetary research and related technology developments and testing activities for a variety of missions and mission architectures. Having analogues from the ESA²C on-board the DSG would allow for:

- Testing the tech calibrations or repairs
- Avoidance of using high value planetary materials
- Creation of recipes for (new) planetary analogues which can be refined as data becomes available from deep space exploration activities
- Learning from DSG could be fed back to Earth to generate new analogues which simulate the target body with increased accuracy
- Cost saving – no need to return equipment to Earth, utilise existing 'resources' already being used in technology developments. Extra-terrestrial sample returns to the DSG can be used exclusively for scientific and research objectives
- Payload – the analogues need not be present in large quantities as material can be reused in multiple testing scenarios without loss of volume/scientific value.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	Unknown
Volume of hardware	Unknown
Accommodation (e.g.	Internal

internal/external)	
Power required	Unknown
Data generated	
Pointing/viewing/line of sight needs	No
Communications needed	Yes, for crew to contact the tech leads for repair/calibration advice if needed
Duration of experiment	Life-span of the DSG
Crew tasks (if needed)	Repairs/calibrations/modifications
Access and servicing by crew (if needed)	Yes
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	None
Operations without crew (if any)	Unknown

OPTICAL LUNAR NAVIGATION VIA IMPLEMENTATION OF DEEP LEARNING NEURAL NETWORKS

Authors: Newman, Clark P.[1]

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Scientific Domain:
Astrophysics, Other: Aerospace Engineering, Artificial Intelligence, Technology Demonstration

Idea Description:
Optical Navigation is the use of camera images to return spacecraft position for navigation. It is crucial for robotic operations where the round-trip light time exceeds task timeliness so a robot must function autonomously using on-board measuring and actuation. For human spaceflight it is used as an auxiliary to ground-based direct tracking using communications antennae.

Currently, the NASA/ESA EM-1 mission is slated to have a technical demonstration optical navigation system on-board. This camera requires the limbs of the Moon and Sun to be in view, and the measurement is an angle between the Moon and Sun as viewed from the Spacecraft. This limits the operational geometry, and the resulting angle measurement has high uncertainty.

Through the use of Machine and Deep Learning, an existing or cheap camera can be trained using a supervised model training set to return a Moon-centered position based on an image or partial image of the Moon only. A model of the Moon will generate a supervised training set from which a Neural Network or other machine learning algorithm can return your position relative to the Moon based on a single or partial photograph.

The objective would be to improve current optical navigation performance and reduce the geometry required for successful operation. The ultimate goal would be to reduce out the need for ground-based observation for Lunar proximity operations. Secondary to this would be the exploration of the lowest-quality image which still has positive value for optical navigation. It is technically feasible to perform this navigation with a low resolution partial image of the Moon, or the Moon cut out of an existing photograph taken for other purposes.

The Deep Space Gateway (DSG) is in a unique and advantageous position to perform this testing as a test bed for Low-Lunar orbit and Lunar surface operations. Its novel near-rectilinear halo orbit will capture images of the Moon from a variety of orientations, and its tracking from ground-based antennae will serve as a baseline to test optical navigation results against.

The impact to personnel on-board the DSG would be transparent or minimal. The capture of images of the Moon can be commanded via schedule or from the ground, and the subsequent downlink of images will be commanded from the ground. The use of existing exterior cameras would further reduce impact to crew operations.

From there, the test images will be processed through one or more algorithms who have been trained on a Moon model supervised training set. The resulting position estimates will be compared against the ground-tracking baseline, and the process/algorithm can be refined to support different lighting, geometry, and quality of image. This iterative refinement will be executed across different regimes of the DSG orbit, and can be the inspiration for Low Lunar Orbit optical navigation and eventually Lunar surface operations.

In summation, the effort aims to leverage existing or cheap camera hardware in conjunction with advanced machine learning image processing on the ground to improve cis-lunar optical navigation performance and/or efficiency.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	<1 kg, or use existing hardware
Volume of hardware	<0.1 m^3, or use existing hardware
Accommodation (e.g. internal/external)	Existing external camera or window-mounted handheld camera
Power required	Negligible
Data generated	<1 MB per photo. No long-term storage necessary (will be stored on ground)
Pointing/viewing/line of sight needs	1. View of the Moon from various geometries and lighting 2. Downlinked images to Earth on existing comm
Communications needed	Semi-regular downlinking of Moon images
Duration of experiment	Ongoing, flexible
Crew tasks (if needed)	Install and activate the camera if handheld camera is used.
Access and servicing by crew (if needed)	None
Need for retrieval and return to Earth	Data downlink. No physical recovery required.
Specific orbit needs (if any)	DSG near-rectilinear halo orbit desired for maximum change in distance, angle, and lighting. Other orbits will work.
Operations without crew (if any)	Downlink images to Earth where research team trains optical navigation, produces position estimates, compares against ground-based tracking.

CRAFT : Collaborative Rover and Astronauts Future Technology

Authors: Dr. Vsevolod V. Koryanov[1] and Victoria Da-Poian[2]

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Scientific Domain:
Life Sciences, teleoperation development and human factors

Idea Description:

CRAFT : Collaborative Rover and Astronauts Future Technology

1) Overview

As the ISS will be de-orbited in the next few years, we need to think beyond. The future step in the space exploration are missions to the Moon or to Mars, astronauts and engineers have to be ready for it. To accomplish these new missions, telerobotics are essential. Robots have already demonstrated their potential for the space exploration and they are likely to play an important role alongside Humans for future extra-terrestrial missions. Therefore, improving the Human/Robot collaboration is a challenging field of work that is complicated by the special environment in which astronauts have to progress through. A special effort has to be made in order to make interfaces as intuitive as possible. In the context of space exploration, space agencies and companies are currently researching and developing projects on Human-Machine Interfaces (HMI). This is the way humans and machines interact and work together to accomplish different tasks. This is vital as machines perform better and better, and men will need to interact with them and often rely on them during future space exploration missions.

The space exploration has become a reality for several decades and is now looking forward extra-terrestrial colonization. Our closer neighbours, the Moon and Mars are at the centre of attention. The European Space Agency (ESA) is developing its "Moon village" concept that aims to establish the first manned base on the Moon. To achieve this goal, robots will be firstly sent to begin the constructions, before the arrival of the first lunar inhabitants. Moreover, the private sector also wishes to take part into space exploration: Elon Musk, SpaceX founder and CEO, wants to send humans on Mars by 2024. These projects reflect the new approach of space exploration activities.

2) Objectives

In all these new projects, it appears undeniable that robots will play a major role alongside Humans. Astronauts will constantly have to deal with high workloads, high-risk, technology-dominated environment, and the effects of the environmental condition. Even simple tasks, as carrying tools, walking, are very constraining. Using robots will save time and ensure the astronauts a greater safety.

Our project, CRAFT, is focusing on the relationship between astronauts and rovers to best work together during surface explorations. The exploration of planetary surfaces (Mars, Moon…) will require not only astronauts but also robots to achieve some tasks during their mission. Robots will help and assist astronauts, and will also carry out tasks outdoors autonomously. In order to simulate this type of missions, and to give the astronauts the best preparation, our project is to develop a rover doing all these tasks.

A robot system brings a lot of challenges such as weight and size constraints, sensors and actuators suitable for extraterrestrial environnement conditions, communication delay. In this work we present the CRAFT rover that we designed for the challenges of Human Machine Interface (HMI) exploration missions.

3) Equipment, facilities required

Our CRAFT rover will not only be an autonomous rover but also the astronauts partner. CRAFT will be able to navigate in rough terrain and explore areas to work on relevant sites.

The delay between a ground station on Earth and a rover on Moon is limited to 100 Mbit/s and delayed by two seconds in each way. Nevertheless during exploration missions, monitoring and intervention on robot's task execution is primordial. Sevevre delays and periods of blackouts between the Earth and the Moon during high level tasks, will be partly solved by using the METERON technology developed by ESA. The rover could be monitored from different control centres : Earth control centre, Deep Space Gateway (DSG) orbital centre, Moon base control room.

Locomotion system: It will be equipped by a high maneuverable locomotion system (using individually steered wheels), stereo cameras, inertial measurement unit, GPS, self-localization system, environment mapping, robotic arm, and also by human linked systems.

EVA operations system:

- On autonomous mode, during EVAs, the rover will be able to dig and take sample thanks to his six degree-of-freedom robotic arm (while recording each location and time of sampling tasks). His perception of the environment will be purely vision-based thanks to stereo-cameras.

- The rover will also be able to send astronauts datas (hearth rate, temperature,) to the control centres (Earth control centre, DSG control centre and Moon Surface control base). In case of any malaise, the rover will be extended in a medical stretcher and will go automatically to the moon base.

We designed this CRAFT rover to operate both in autonomous mode and in monitoring mode in order to assist the astronaut and to rescue him if necessary. This is essential to conduct efficient and safe exploration space missions.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	50-100 kg
Volume of hardware	TBD
Accommodation (e.g. internal/external)	External rover for lunar exploration
Power required	TBD
Data generated	Sensors for lunar exploration, sensors for astronaut state, robotic arm for lunar sampling
Pointing/viewing/line of sight needs	TBD
Communications needed	METERON technology (ground control centre, DSG centre, Moon base centre)
Duration of experiment	TBD
Crew tasks (if needed)	Collaborative work between astronauts and rover
Access and servicing by crew (if needed)	Yes, the rover could be used both in autonomous mode and in monitoring mode
Need for retrieval and return to Earth	TBD
Specific orbit needs (if any)	none
Operations without crew (if any)	Yes, during autonomous mode or when driven by the DSG or Earth control centres

ROBOTIC MANIPULATION OF EXTRA TERRESTRIAL SAMPLES FOR BIO-EXAMINATION AND STERILIZATION

Authors: M. I. Nazarious[1], A. Vakkada[1], T. Mathanlal[1], M.-P. Zorzano[1,2], J. Martín-Torres[1,3], A. Bhardwaj[1], D. Fernández-Remolar[1], R. Fonseca[1], J. Ramirez-Luque[1], A. Soriá-Salinas[1], S. Konatham[1] and J. Rosenqvist[1]

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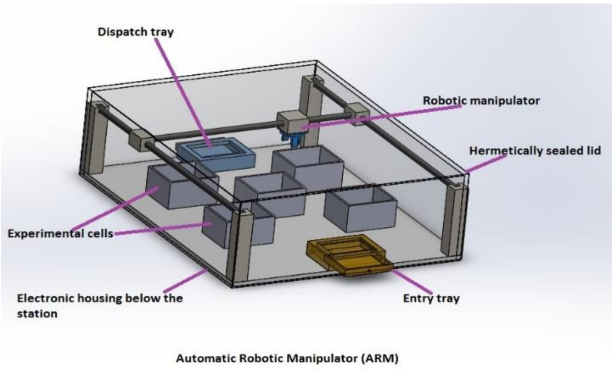
Scientific Domain:
Planetary Exploration, Exobiology, Sample Return, Clean Room, Life Detection, Planetary Protection, Life Sciences, Physical Sciences, Robotics.

Idea Description:

The idea of this proposal is to use the Deep Space Gateway (DSG) spacecraft as a platform to house an autonomous robotic manipulation (ARM) enabled bio-examination and protection station (Fig. 1) to perform biological activity examination on extra-terrestrial samples obtained from different celestial bodies and sterilize samples before returning to Earth for further analysis. Exhaustive study of samples from celestial bodies is the need of the era to deeply investigate the evolution of the Universe, and several sample return space missions are in course (Hayabusa 2 (2020) and OSIRIS-REx (2023)) or proposed. Performing such studies of samples on Earth is not straightforward due to the risk of contamination of Earth's biosphere, if alien microbial life should be present. To mitigate this probable hazard, we propose to have a station aboard the DSG spacecraft that shall serve as a checkpoint to investigate the sample from the Planetary Protection (PP) point of view and render it non-hazardous before transport to Earth. The robotic manipulation of the sample ensures the safety of the crew on-board the DSG spacecraft. The robotic manipulation also considers the effect of micro-gravity in handling the samples. This technological demonstration shall not require any modification to the spacecraft itself as the station shall maintain the ambient pressure, temperature and local atmosphere required for performing the analysis. The station shall be hermetically sealed such that the contents from within shall not contaminate the environment of the DSG spacecraft.



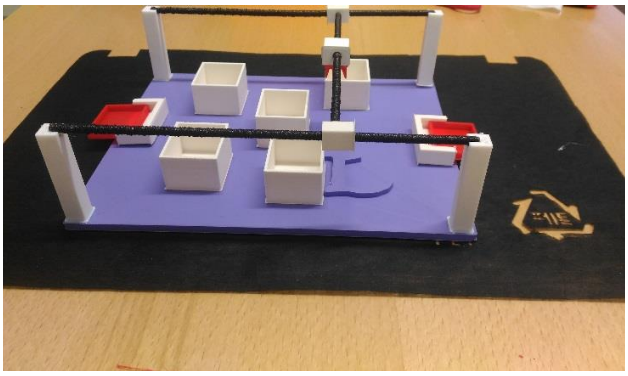


Figure 1: Left: Proposed CAD Model of ARM station. Right: Scaled 3D printed Model of ARM Station developed at LTU.

Objectives:

The proposed ARM enabled bio-examination and protection station on the DSG spacecraft shall perform:

1. biological examination of planetary samples with focus on presence of biological life, and
2. planetary protection protocols on return samples

with the use of autonomous robotic manipulation for handling samples. The station has a receiving point where the return sample is fed in 'x' pieces and has 'y' cells with each cell performing a unique experiment on the sample as described below.

Biological examination of planetary samples:
Bio-examination of planetary samples are classified into search for presence of organics in the tested sample that undergoes a series of destructive catalytic metabolic tests including dry heat, addition of water, addition of stereo-specific organics, etc. To distinguish between chemical and biological activity of the samples, some tests are planned to search for the presence of inorganic oxidants in the samples.

Measuring techniques to examine the biological activity of the samples are to detect the gas release upon reaction of samples to the additives and to monitor the redox state of samples both in its dry form and the locally created atmosphere upon reaction. The suite of gas sensors shall include detection of O_2, CO_2, H_2, N_2, CH_4 and other compound gases. Redox state of samples is analysed by monitoring the degradation of redox sensitive organic coated plates that are in contact with the samples with an electrical system with respect to a reference plate that is either inert or placed outside the test environment. Similar experiment has been carried out at LTU facility to study the redox state and gas concentration in soil during bacterial metabolism (Fig. 2).

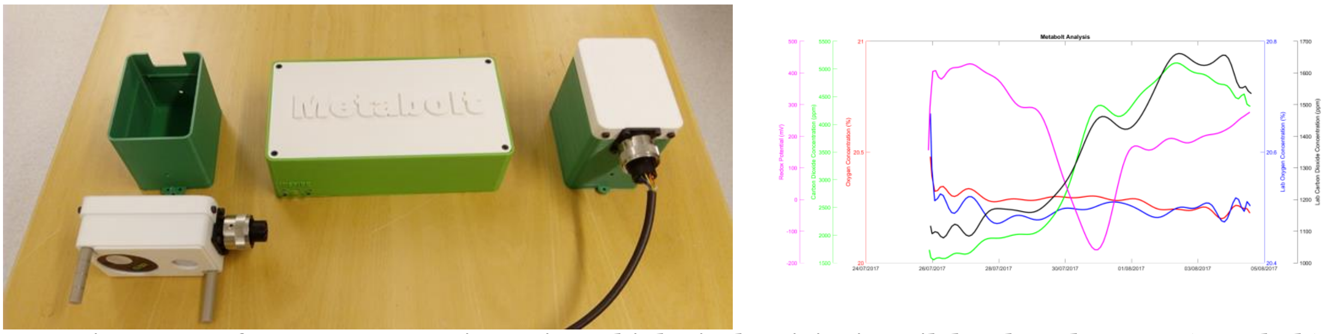


Figure 2: Left: Instrument to investigate biological activity in soil developed at LTU (Metabolt). Right: Monitoring redox state, O_2 and CO_2 concentrations of soil and lab environment.

The station shall perform simultaneous examination on samples (enlisted in Table 1) within the contained cells each dedicated for an individual experiment. Each cell is equipped with its gas and redox sensors for measurements and inlet and exhaust lines for introducing and expelling liquid or gaseous additives required for the experiment.

Table 1: List of planned experiments on planetary samples in the proposed station

Cell	Name of the Experiment	Purpose of the Experiment	Expected Outcome (if positive)
1	Dry heating (60 – 70 °C)	To test the presence of C and N isotopes	Volatilized C and N compounds
2	H_2O addition	To test the presence of inorganic oxidants	Water oxidation with O_2 release
3	Organics addition (stereo-specific chiral compounds)	To test the presence of microbes	Organics consumption with CO_2 release
4	H_2 local atmosphere	To test the presence of H_2-oxidizing microorganisms	H_2 consumption and increased biomass
5	N_2 local atmosphere	To test the presence of microbes	N_2 cycle
6	Fertilizer (CNOPSH molecules) addition	To test the presence of microbes	Organics consumption and mineralization to inorganics

Planetary Protection protocol:

The ARM station can be used to perform the classified test for planetary protection. Cells are designated for sterilization and cleaning technique. The robotic manipulator will be used to move the samples from one cell to other. The cell used for sterilization will have its own heating plate to rise the temperature of that cell for the stated time. Once the protocol is completed the sample is picked by the manipulator and placed in the dispatch tray where the crew members can now safely handle and transport back to Earth. The ARM station as such shall be sterilized after completion of all the tests to make sure that there is no contamination inside and the station is ready to process the next sample.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	Robotic Manipulator 2 kg. Cell unit 0.5 kg each. Electronics 1 kg. Pressurized gas cylinders: depends on cell units.
Volume of hardware	0.5m x 0.5m x 0.5m
Accommodation (e.g. internal/external)	It can be placed inside the gateway mounted on a stationary table
Power required	Unknown yet
Data generated	Scientific Data and Control log
Pointing/viewing/line of sight needs	Not required
Communications needed	Downlink of data and service configuration when needed
Duration of experiment	One batch of sample analysis takes 1 day to 2 weeks depending upon the experiment
Crew tasks (if needed)	Loading and unloading the sample
Access and servicing by crew (if needed)	At the beginning and end of the experiments and for service if needed.
Need for retrieval and return to Earth	Retrieval and return to Earth of tested samples is mandatory for detailed analysis.
Specific orbit needs (if any)	None
Operations without crew (if any)	None

LIFE SCIENCES

SENSING AND MONITORING OF ASTRONAUTS' BIO-ACTIVITIES FOR BIG DATA GENERATION AND ANALYSIS

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Scientific Domain:
Life Sciences, Physical Sciences, Data Sciences.

Idea Description:
Monitoring and sensing parameters monitoring physiological/pathological conditions and biological processes in crew members is of outmost importance for long duration missions both on-board spacecraft and on planet-based installations. In an ideal scenario, astronauts should be equipped with sensors allowing them and the earth-based Control Centres to monitor their physiological/pathological conditions and biological response, not only during the different activities inside the spacecraft but also against the external environment conditions during EVA. Also, those sensors should be able to deliver data that are easily transmissible and readable as well as ready to be analysed for early warning danger detection. The main objective of the proposed research is to provide astronauts with a series of wearable sensors (as developed in the frame of

Sensor placement		Sensors type	Key technical features	TRL	Clinical focus
Chest, torso		▪ ECG/PPG (CardioMem®,[14, 15]) ▪ Glucose (Dexcom®) ▪ Adenosine triphosphate [16] ▪ Accelerometer [17] ▪ Galvanic skin response (GSR) [15] ▪ Temperature [18]	▪ Electrodes on conductive fabric/flexible "heart sock". ▪ Glucose needle patch. ▪ Tested on mouse model with air pouch. ▪ Flexible system with middleware. ▪ "Smart Vest" with multi-parameter monitoring. ▪ Temperature patch.	▪ 9 (CardioMem®), 6 [14, 15] ▪ 9 ▪ 9 ▪ 6 ▪ 6 ▪ 6	▪ Cardiac arrhythmia [14, 15] ▪ Diabetes. (Dexcom®) ▪ Inflammation [16] ▪ Rehabilitation [17] ▪ Obesity [15] ▪ Infection [18]
Head	*Eye*	▪ Intraocular pressure (IOP) [19] ▪ Glucose (Google® contact lens)	▪ IOP by change in corneal curvature. ▪ RFID readout.	▪ 6 ▪ 5	▪ Glaucoma [19] ▪ Diabetes (Google®)
	Brain	▪ Impact force (Checklight™) ▪ Glucose/lactate (Pinnacle™) ▪ EEG (NeuroPro™)	▪ Impact logging. ▪ Rat head capsule with multichannel potentiostat. ▪ 8 channel EEG.	▪ 9 ▪ 9 ▪ 7	▪ Concussion (Checklight™) ▪ Trauma/haemorrhage (Pinnacle™) ▪ Epilepsy (NeuroPro™)
	Ear	▪ Acceleration [8, 20] ▪ Audio [21]	▪ Three axis accelerometer behind the ear. ▪ Binaural hearing aid.	▪ 8 ▪ 6	▪ Clinical gait analysis [8, 20] ▪ Hearing loss [21]
	Tooth	▪ Bacteria [22]	▪ Anti-microbial peptide coated grapheme as bacterial sensor. Read out with battery-less wireless interrogation.	▪ 6	▪ Infection [22]
Musculoskeletal	*Wrist/arm*	▪ Activity levels/energy expenditure (Nike®) ▪ Skin conductance [23] ▪ Accelerometer [24, 25] ▪ Gyroscope and magnetometer[26] ▪ EMG and EEG [25]	▪ Custom metric for energy expenditure. ▪ Soft wrist band for electrodermal activity. ▪ Accelerometer network on limbs. ▪ Wrist/elbow mounted motion tracker. ▪ Multi-modal flexible/conformal patch.	▪ 9 ▪ 6 ▪ 6 ▪ 6 ▪ 6	▪ Obesity (Nike®) ▪ Emotional stress [23] ▪ Parkinson's disease [24, 25] ▪ Stroke rehabilitation [26] ▪ Neo-natal ICU [25]
	Feet	▪ Accelerometer [24, 27] ▪ Gyroscopes force, bend and pressure, electric field height, air pressure [28]	▪ Posture/activity from heel acceleration and planar pressure. ▪ Gait shoe monitors in-shoe air pressure for ground contact force.	▪ 6 ▪ 6	▪ Obesity [24, 27] ▪ Clinical gait analysis [28]
	Hand/fingers	▪ Blood pressure, SpO_2 (iHealth®) ▪ Accelerometer [29, 30] ▪ Bend/force [30]	▪ Wireless finger cap and pressure cuff. ▪ Sensor network on glove for hand gesture analysis. ▪ Pressure sensor network glove measuring range of motion.	▪ 9 ▪ 6 ▪ 6	▪ Hypertension (iHealth®) ▪ Surgical training [29, 30] ▪ Arthritis [30]
Hip		▪ Vibration [31]	▪ Hip prosthesis tested with artificial thigh.	▪ 6	▪ Hip prosthesis [31]
Implantable/Ingestible wireless sensors/stimulators		▪ pH [32] ▪ Temperature, HR/respiration (VitalSense®) ▪ Heart rhythm (Evera™) ▪ Auditory nerve (Cochlear®) ▪ Visible light (SecondSight®) ▪ Brain stimulator (Soletra®) ▪ Medicine ingestion (Proteus®) ▪ Force sensor [33] ▪ Pressure sensor (Carmat™)	▪ pH capsule attached to oesophageal wall. ▪ Ingestible capsule for wireless core temperature. ▪ Implantable defibrillator. ▪ Auditory nerve stimulation with wireless powering. ▪ Retinal ganglion cells (RGC) stimulation. ▪ Single lead implantable neurostimulator. ▪ Ingestible pill with wireless interrogation for ingestion signatures. ▪ Battery-less piezoelectric energy harvester knee implant. ▪ Complete artificial heart.	▪ 9 ▪ 9 ▪ 9 ▪ 9 ▪ 9 ▪ 9 ▪ 8 ▪ 6 ▪ 6	▪ GERD [32] ▪ Infection (VitalSense®) ▪ Cardiac arrhythmia (Evera™) ▪ Deafness (Cochlear®) ▪ Blindness (SecondSight®) ▪ PD, Tremor (Soletra®) ▪ Tablet ingestion management (Proteus®) ▪ Knee replacement surgery [33] ▪ Heart replacement (Carmat™)
Wearable for ambient environment		▪ Ozone Chlorine, Methane, Carbon monoxide, humidity, temperature (Sensordrone®)	▪ Environmental sensing link with smartphones.	▪ 9	▪ Poisoning (Sensordrone®)

Figure 1 Sensors that can be used for Big Data acquisition

the Topical Team "Tissue Healing and monitoring in Space) in order to monitor and record series of biological/environmental data for creating predictive models, developing biodata classifiers, and generating a set of analytical tools to enhance life support in future Space missions. Big data from a special environment such as Spacecraft will impact also the full understanding of biological processes/cycles on-earth both in the e-health sector and IoE one.

The crew of the Deep Space Gateway will be involved mainly in the setting phase of the experiment, while the experiment in itself will take advantage of the monitoring of normal activities of the astronauts. It is important to stress that the sensing platform will be non-invasive. The crew activities will be not affected by the installation of the monitoring systems due to wireless connections between the sensors and the analysers.

Sensors planned to be tested will monitor three types of signals:

- crew member activities ,
- parameters monitoring physiological/pathological conditions and biological response
- parameters monitoring environmental conditions

Different approaches will be considered for generating the data of biomedical interest, depending on the design and requirements of the Deep Space Gateway: i) wearable sensors; ii) textile-based wearable sensors iii) skin-adhering wearable sensors iv) vision-based system v) Implantable/digestible sensors.
The data that we plan to generate will concern: i) potentially dangerous chemicals' releases ii) body and skin temperature iii) electro-dermal activity iv) arterial oxygen saturation v) muscle activity vi) eyes movements vii) water content, sweat of skin

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	200gr for sensing + 1Kg for controlling/recording
Volume of hardware	Sensing= ~3cm³; controller:=~2dm³
Accommodation (e.g. internal/external)	Internal
Power required	~50W
Data generated	Depending on the operational mode (continuous and/or sampling)
Pointing/viewing/line of sight needs	No
Communications needed	Between the sensing and the receiver
Duration of experiment	42d

Crew tasks (if needed)	Yes limited to switch on/off
Access and servicing by crew (if needed)	No
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	No
Operations without crew (if any)	

RADIATION STUDIES, COMMUNICATIONS RELAY, AND SAMPLE RETURN AT THE DEEP SPACE GATEWAY

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Scientific Domain:
Life Sciences, Solar System Sciences

Radiation Studies

Lockheed Martin is the prime contractor for the Orion deep space exploration vehicle, and is also working with NASA in studying Deep Space Gateway concepts. Understanding, characterizing, and accurately modeling the radiation environment of space outside of the Earth's magnetic field is critical to long term human deep space exploration. In low earth orbit, the International Space Station (ISS) is partially protected by the Earth's magnetic field. While some deep space radiation environments have been measured at the Moon and Mars by the Lunar Reconnaissance Orbiter and the Mars Science Laboratory, further study is needed on the long term deep space radiation environment internal to manned spacecraft and its biomedical effects. Only the 24 Apollo astronauts were exposed to deep space radiation for a short period of time. Humans in deep space will be exposed to both solar radiation and galactic cosmic rays which can damage cells and DNA and create dangerous secondary radiation upon interaction with the spacecraft structure. The Deep Space Gateway in cislunar space allows for continuous monitoring of the radiation environment inside a human spacecraft as well as testing materials for radiation shielding. These tests can occur when the Gateway is inhabited by astronauts or in an uncrewed configuration. As an example, the Matroshka AstroRad Radiation Experiment (MARE) payload on the upcoming Exploration Mission 1 (EM-1) mission could be modified to fly on the Deep Space Gateway. MARE is comprised of two radiation therapy phantoms (referred to as Matroshkas) which combine natural bone and a material to simulate human tissue in the shape of a human head and torso. The tissue-equivalent radiation phantoms also have densities representative of the specific organ sites. Up to thousands of passive and active radiation sensors at key organ sites and on the skin [1] will characterize the radiation environment. One Matroshka will wear an AstroRad vest, personal protective equipment developed in cooperation with StemRad, Ltd. in Israel which functions as a radiation shield for astronauts [2]. The detectors will measure how effectively AstroRad shields astronauts from deep space radiation. Consistent with ISS MATROSHKA heritage and the Orion MARE forward path, radiation detectors could be provided by the larger space radiation measurements community as part of the first long term deep space dosimetry comparison geared toward crew radiation protection.

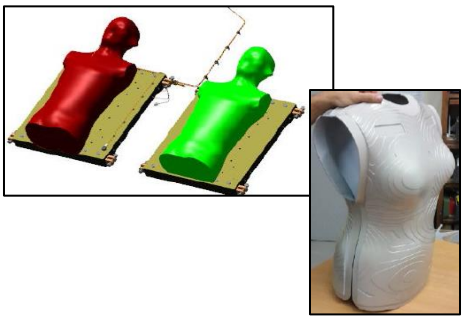

Figure 1 – The MARE Experiment Matroshka Torsos and AstroRad Vest

Communications Relay

The lunar farside is of scientific interest but has never been explored because no communications relay infrastructure exists to support scientific missions. The Deep Space Gateway can act as a communications relay to surface or orbital missions, including international missions, and can transmit the data back to scientists on Earth via either the high gain radio frequency antenna or the optical communication terminal. The science and video data relayed by the Gateway is most efficiently downlinked to Earth using an optical communication system. Optical communication enables a significant increase to downlink bandwidth capability compared to traditional radio frequency communication. For example, NASA's Lunar Laser Communication Demonstration demonstrated a record-breaking Moon to Earth download rate of 622 Mbps.

Telerobotics is the synergistic intersection of human perception, planning and intellect with the safe, predictable operations of robotics. In a telerobotic operation, the human operator acts as the supervisor, communicating commands through a computer-driven interface that is then able to provide feedback in human-friendly terms of proximity information such as a local command responses, environmental changes, and current hardware and software states. Studies have shown that depending on the agility requirements of the task, two-way latency becomes problematic with delays of 0.5 to 2 seconds [3]. The 2.6 second two-way latency between the Earth and the Moon, while being manageable for gross navigational tasks, would be limiting when short response times are required. Scientist-astronauts teleoperating vehicles from the Gateway in orbit will provide the most value in tasks that are complex and require quick decisions. Some example tasks include drilling, driving, and sample collection.

The lunar farside has long been recognized as a unique astronomical platform for conducting radio astronomy at frequencies below 10-30 MHz [4]. Several low-cost experiments on lunar orbiting spacecraft have been proposed to carry out these observations from the Moon [5]. With the Gateway already in orbit around the lunar farside, low frequency receivers can instead be placed directly on the surface for continuous radio measurements instead of in lunar orbiting spacecraft. Burns et al. have also developed a novel concept for telerobotically deploying such an antenna array directly to the lunar farside [6]. The Gateway would then act as a communications relay to process and transmit data collected by the low frequency radio instruments to Earth. Furthermore, the crew on board the Deep Space Gateway can assist in remotely deploying instruments to their ideal locations, as well as visually confirming successful installation.

Sample Return

The Moon is key to understanding the early history of planet formation within the inner Solar System. Historically, all lunar surface missions have taken place on the Moon's Earth-facing side and the majority of what is known about the Moon is confined to the samples collected from this area. To date there have not been any surface missions on the lunar farside, making it an obvious target of scientific interest. On the lunar farside lies the South Pole-Aitken Basin, the oldest impact basin on the Moon and potentially the largest in the Solar System. A sample return mission has been identified as a priority in the past two planetary science decadal surveys by the National Research Council and the Lunar Exploration Analysis Group [7].

While a sample return mission can be operated autonomously from Earth, the Deep Space Gateway presence would allow humans to remotely operate assets from orbit with shorter delays, effectively enhancing and accelerating the exploration process. During a sample return mission, trained geologists in the Gateway could take advantage of the near real-time operating conditions to focus their expertise on identifying the best samples possible and making course adjustments. In doing so, more valuable samples could be collected in a shorter period of time such as to fit within a single lunar day. After these samples are robotically placed into lunar orbit, they can be retrieved by the Gateway through the robotic arm and airlock elements. By using Orion as the Earth return vehicle, a large quantity of samples can be returned to Earth without developing a new robotic re-entry vehicle with a large capacity. This capability would be most useful for lunar polar volatile samples. Through a future mission kit, Orion can fly a freezer similar to GLACIER to return frozen samples to Earth in a pristine condition to be analyzed by scientists. The crew could receive and process samples for safe transport on Orion. As a versatile scientific platform, the Gateway is also capable of hosting scientific instrumentation which could allow astronauts to analyze samples in orbit. By providing extended crew presence, scientific workspace, and communication relay capabilities, the Gateway and Orion greatly enhance the scientific yield of a telerobotic sample return mission to the lunar farside. Human assisted sample return using Orion and in-space sample analysis would also be a demonstration of future Mars exploration capabilities, such as described in Lockheed Martin's Mars Base Camp concepts [7].

References: [1] Matroshka Fact Sheet (ESA-HSO-019 Rev 2.0), European Space Agency, [2] G. Waterman, et al IAC 2016 (IAC-16,A1,4,7,x3509), [3] J.B. Hopkins, et al 2012 GLEX 2012 (GLEX-2012.02.3.2x12595), [4] S. Jester, et al New Astronomy Reviews, 53, (2009) 1-26, [5] J.O. Burns, et al DARE 2011, Advances in Space Research, [6] J.O. Burns, et al Advances in Space Research. 26 (2012) 3–9, [7] T. Cichan et al IAC 2017 (IAC-17,A5,2,7,x40817)

Estimated experiment properties	Description
Mass of hardware	Matroshka torso: 35 kg each + ancillary hardware AstroRad vest: 26 kg Lunar surface communication system: 20 kg Optical communication system: 50 kg
Volume of hardware	TBD
Accommodation (e.g. internal/external)	Matroshka torso: internal AstroRad vest: internal Lunar surface communication system: external Optical communication system: external Sample container: internal
Power required	Matroshka torso: TBD (internal battery or vehicle) AstroRad vest: none Lunar surface communication system: 75-150 W Optical communication system: TBD Sample container: none
Data generated	Matroshka torso: internal recorder (TBR)
Pointing/viewing/line of sight needs	Lunar surface communication system: view of surface, may be a gimbaled antenna Optical communication system: view of Earth, may be a gimbaled platform
Communications needed	No additional
Duration of experiment	Matroshka torso and AstroRad vest: 1 year
Crew tasks (if needed)	Matroshka torso and AstroRad vest: option for crew to wear vest for periods of time Telerobotics: operation of robotic assets Sample return: sample capture operation
Access and servicing by crew (if needed)	None
Need for retrieval and return to Earth	Matroshka torso: yes AstroRad vest: no Lunar surface communication system: no Optical communication system: no Sample container: yes
Specific orbit needs (if any)	None
Operations without crew (if any)	Matroshka torso and AstroRad vest passive during uncrewed period Communication relay continues with ground control during uncrewed period

CHRONIC RADIATION ON PLANTS (CROP)

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Scientific Domain:
Life Sciences

Idea Description:
The proposed idea is within the context of using higher plants as elements in Closed Ecological Life Support Systems (CELSS) to support long-term exploratory-class manned missions. The realization of such missions is based on the regeneration of resources (e.g. air, water and food) needed by the crew. One of the main constraints for the establishment of extra-terrestrial outposts is the presence of high levels of ionizing radiation which affect organisms' growth, thus plant survival and efficiency as regenerators of resources. Therefore, one of the main challenges is ensuring the survival and productivity of edible plants in CELSS even in such harsh conditions. However, plants are much more resistant than animals to ionizing radiation: doses that are detrimental for animals can be ineffective or induce positive responses in plants.
Most of the studies on the effect of ionizing radiation on plants have been performed by exposing the plants, especially dry seeds, to acute doses of specific radiation types, either Low-LET (Linear Energy Transfer) (e.g. X-rays and gamma rays) or High-LET (e.g. protons, HZE particles). Simulating the cosmic radiation is impossible on Earth because of technical constraints. Low-LET ionizing radiation is generally easily available in many Universities and research centres, while facilities to produce High-LET ionizing radiation are available at a few centres such as APSS (Italy), GSI (Germany), GANIL (France), NARILIS (Belgium), LNS-INFN (Italy), PSI (Switzerland) and HIMAC and CNAO (Japan). However, in such structures, only one type of radiation can be handed out at each irradiation treatment, which hardly simulates the complex spectrum of cosmic radiation occurring in Space. Moreover, the reduced volume and beam-time available is not always appropriate for experiments on higher plants.
The Deep Space Gateway (DSG) would give the opportunity to expose seeds, and possibly plants at early stages of development (e.g. seedlings), to chronic doses of cosmic radiation to evaluate their effects on survival, growth and productivity.
Different facilities shall be used to expose seeds/plants at increasing levels of cosmic radiation. A possible experimental design would consider the exposure of seeds/plants at different levels of ionizing radiation, by combining multiple factors such as: the orbital position of the DSG, accommodation of the seeds/plants in both internal and external payloads in the presence/absence of different shielding materials, duration of exposure, etc.
The possibility to expose seeds to the chronic radiation is considered an easy and low-risk configuration of the experiment which requires very simple hardware support (likely only temperature and humidity control). In such a configuration, after the exposure, the seeds shall be retrieved. Part of the seeds shall be subjected to molecular analyses to detect possible induction of

genetic aberrations. Part of the seeds will be germinated and plants cultivated to evaluate growth performance and productivity.
The possibility to expose seedlings to the chronic radiation is also considered, but requiring a more complex hardware development to support plant growth in the presence of altered gravity, more resources for plant growth cycle and plant health monitoring, and crew support. In such a case, plant fixation on board needs to be considered and laboratory analyses should be performed after retrieval.
The proposed idea has both biological, agronomical and technological objectives. The main biological objective aims at analyzing plant's sensitivity to chronic doses of ionizing radiation in crop/model species (including leafy vegetables and horticultural crops). Plants grown from seeds exposed to different levels of ionizing radiation (consequent to the modulation of the above-reported multiple factors) will be cultivated and analysed in terms of molecular indicators (e.g. genetic aberrations), morpho-anatomical traits (i.e. anatomical signs for early stress signalling and photo-protective mechanisms, biomass production), eco-physiological and biochemical aspects (photosynthetic performance, nutritional quality of edible parts) to detect plants' reaction to radiation and to build dose-response curves. Plants cultivated on board, once downloaded to the ground laboratories, will be used for similar analyses. It is worth to underline that valuable information is expected from the data and images (HD, fluorescent images) collected during the onboard plant growth cycle to detect early signs of stress.
Special emphasis will be addressed to those parameters affecting the ratio between edible/waste biomass (e.g. biomass partitioning) and nutritional quality of edible organs (e.g. the content of compounds such as antioxidants which have an important role in rising physiological defense mechanisms of astronauts). The hereditability of possibly-induced mutations can be analyzed in the successive generation.
The main agronomical objective will be to act on the cultivar choice and the modulation of the cultivation factors in order to improve the plants' tolerance to abiotic stresses to achieve a sort of RAD-HARD plant suitable for cultivation in Space outposts.
As far as the technological task is concerned, several fields have to be considered:

- The evaluation of the shielding properties of materials also available *in situ* (e.g. Lunar or Martian regolith) through specific irradiation tests (e.g. proton beam tests) to measure structural properties and to compare the shielding effects.
- The proper choice of active and passive dosimetry for monitoring the doses.
- The identification of proper plant health monitoring methodologies (e.g. HD and/or fluorescent imaging, VOC's data acquisition and analysis, etc.)
- The definition of tools and process for telescience operations and interaction with crew

The implementation of this idea on the DSG would provide information and data about plant's sensitivity to chronic doses of ionizing radiation that are useful for the evaluation of threshold doses still allowing plant survival and productivity. The definition of the different plant shielding requirements as well as the realization of a RAD-HARD plant has valuable technical and economical consequences since it affects the design of space greenhouses, shielding strategies and related costs.
It is worth to underline that this idea has already been submitted as SHIELD proposal (Call for New Science Ideas in ESA's Science Programme, 2016). The SHIELD proposal was based on a step by step approach including ground preliminary activities using the INFN facility followed by a space experiment phase intended through a satellite to be developed out of the terrestrial magnetic field. The DSG platform would be an ideal platform to pursue the proposed scientific objectives.
This idea may interest many Universities, Research centers and Industries both within and outside the ESA Member States involved in the field of plant cultivation, space system management and radiation applications. The following private companies are potentially interested in this proposal: Telespazio, TAS-I, Technosystem, Kayser Italia, AIRBUS, etc.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	
Volume of hardware	
Accommodation (e.g. internal/external)	Both internal and external
Power required	None in the case of seeds. Yes in case of seedlings
Data generated	Dosimetry, molecular, traits of plant growth and crop productivity
Pointing/viewing/line of sight needs	
Communications needed	None in the case of seeds. Yes for telescience operations and plant growth monitoring
Duration of experiment	3-6-9-12 months
Crew tasks (if needed)	None in the case of seeds. Yes for seedling harvesting and fixation procedure
Access and servicing by crew (if needed)	None in the case of seeds
Need for retrieval and return to Earth	Yes
Specific orbit needs (if any)	
Operations without crew (if any)	None in the case of seeds

INTEGRATIVE COUNTERMEASURE DEVICE FOR DEEP SPACE HUMAN EXPLORATION

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Scientific Domain:
Life Sciences; Integrative Countermeasure.

Idea Description:
Because all parts of human physiology are affected by microgravity, an integrative countermeasure strategy is needed. Loss of muscle and bone mass along with deconditioning of the cardiovascular system are long known effects of microgravity and more recently the Spaceflight-Associated Neuro-ocular Syndrome (SANS) has been identified and classified as a major risk factor for deep space exploration class missions. Although the full pathophysiology behind spaceflight-induced deconditioning has yet to be described, the combined effects of mechanical unloading and cephalic fluid shift are predominating factors. For SANS the lack of diurnal cephalad pressure and volume variability is likely a major part of the pathophysiology[1]. Taken together, countermeasures that can simulate the effects of gravitational stress, including caudal fluid shift, are warranted.

Previous ground-based studies have demonstrated the efficacy of combined exercise and caudal fluid displacement by lower body negative pressure (LBNP) to preserve musculoskeletal strength along with aerobic capacity. More recently, we have demonstrated the ability of LBNP of 20 mmHg to lower intracranial pressure without impairing arterial blood pressure and cerebral perfusion in healthy awake subjects[2]. Furthermore, during a recent 3-day bedrest trial, application of low-level LBNP for 8 hrs every day reduced the time dependent engorgement of posterior ocular structures, which is likely a precursor of SANS (unpublished data).

The aim of this project is therefore to develop a wearable integrative countermeasure device, comfortable and mobile enough to use for 8-10 hours every day without interfering with the daily activity or restrictive exercise scheme in the confined space of a cislunar space station or Martian-capsule (Orin). This countermeasure will reintroduce diurnal cycles of “gravitational stress” to normalize intracranial pressure and volume regulation, maintain the cardiovascular health, and provide mechanical loads to maintain bone and postural muscle strength.

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[1] Lawley JS, Petersen LG, Howden EJ, Sarma S, Cornwell WK, Zhang R, Whitworth LA, Williams MA, Levine BD. Effect of gravity and microgravity on intracranial pressure. *J Physiol.* 15: 2115-2127, 2017

[2] Petersen LG, Petersen JCG, Andresen M, Secher NH, Juhler M. Postural influence on intracranial and cerebral perfusion pressure in ambulatory neurosurgical patients. *Am J Physiol Regul Integr Comp Physiol.* 310:100-104, 2016

Requirements and outcome:

Recent and current work (including the “Fluid Shift” trials using the Russian “Chibis” combined with ground-based studies involving direct measurement of intracranial pressure during LBNP) has focused on physiological effects of fluid displacement and exercise as a countermeasure to obtain proof-of-concept data. Future efforts should involve further development of the specific hardware and technology of a countermeasure suit comprised of LBNP-trousers and attached vest for use in space.

Preliminary data from a mobile and fully operational prototype of such intravehicular pressure-suit has demonstrated that application of 20 mmHg in supine healthy humans increased ground reaction force at the bottom of the feet from 0% to 57% bodyweight while the vest insured comfortable distribution of the mechanical load along the entire body axis. Leaving arterial blood pressure unaffected, use of the suit reduced internal jugular vein cross sectional area by 39% (from 0.66 cm^2 to 0.40 cm^2). In 6° head-down tilt position, this reduction was augmented to 45% (from 1.52 cm^2 to 0.84 cm^2) while at the same time relieving the subjective feeling of congestion in the head. To further insure high compliance from the astronauts to wear the suit for extended periods of time, the environment inside is tightly regulated by adjustment of the vacuum pump incorporated in the waist belt and increasing or decreasing a controlled leak through valves at the feet to ensure constant temperature and humidity both during rest and varying levels of activity.

Future work will finalize the prototype by optimizing materials, vacuum system and power-supply. Additionally, comfort, gait and range of motion will be mapped out and optimized using both short-duration microgravity (e.g. by parabolic or suborbital flights) and long duration application (the Deep Space Gateway). Physiological outcome measures both from cerebral, ocular, cardiovascular and musculoskeletal system will be closely monitored and compared to effects of current countermeasure strategies.

Crew involvement is required as combined operator, evaluator, and subject.

Overall outcome and benefits of the proposed hardware and technology development along with physiological validation include: an integrative countermeasure suit to simulate effects of gravitational stress by displacing blood and tissue fluids to the lower body while at the same time inducing a ground reaction force at the bottom of the feet and a mechanical load along the entire body axis. As an overall long-term aim, use of the suit will 1) re-introduce the diurnal variability of intracranial pressure and volume to help prevent development of SANS; 2) stimulate the cardiovascular system to maintain cardiac muscle mass and vascular compliance; 3) counteract loss of postural muscle mass and bone density; 4) finally, the axial loading will preserve curvature of the spine, paraspinal muscle and disc morphology to both ameliorate in-flight back pain, and reduce risk of post-flight disc herniation.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	
Volume of hardware	
Accommodation (e.g. internal/external)	Internal
Power required	Operated by re-chartable batteries
Data generated	Physiological data: pre- and post-flight; ocular-, cerebral-, cardiovascular-parameters; exercise capacity; muscular volume/function/strength; bone density. In-flight: non-invasive estimation of intracranial and intraocular pressure (funduscopy, tonometry) and ocular and vascular evaluation along with of fluid distribution and structural remodelling by sonography. Classification of fluid distribution and compartmentalisation. Device specific data: Ground reaction forces and mechanical loads. Intra-device temperature, humidity, and volume flow rate. Comfort, gait, and range of motion.
Pointing/viewing/line of sight needs	NA
Communications needed	NA
Duration of experiment	Duration of flight of each astronaut
Crew tasks (if needed)	Subjects / object of the proposed countermeasure intervention
Access and servicing by crew (if needed)	Wearable pressurised suit to simulate gravitational stress by mechanical axial load and fluid shift towards the feet
Need for retrieval and return to Earth	
Specific orbit needs (if any)	
Operations without crew (if any)	None

MICROBIAL SPACE BIOTECHNOLOGY SUPPORTING FUTURE HUMAN AND ROBITIC SPACE EXPLORATION

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Scientific Domain:
Life Sciences, Biotechnology, Space Microbiology, Earth Sciences

Idea Description:
A major step for the development of a spacefaring society will be the shift from our dependence on Earth-bound materials to the use of renewable, e.g. microbial-based resources. Here, provision of food, food supplements, preservatives and drugs derived from microbial fermentation (e.g., organic acids, vitamins, antibiotics, etc.) and microbial removal of waste products (e.g., urine) represent a straightforward and sustainable approach for future life support, whether constituting a human habitat or a cell culture bioreactor. However, the adaptation of microorganisms (e.g., selection for most spaceflight-adapted) and new technical constraints (e.g., efficiency, diversity, etc.) define the challenges to be met. These can be addressed by applying already established state-of-the-art tools for systems biology, synthetic biology and fermentation, to spaceflight conditions.

The ISS is, beside the six crew members, also inhabited with billions of microorganisms. These belong to the natural human microbiota or are tough spacecraft colonizers, resisting pre-flight sterilization techniques and in-flight long-term exposure to radiation and microgravity. As microorganisms evolve extremely fast, they adapt to space conditions easily, by changing their genetic constitution, metabolism, and consequently, their behaviour. The idea presented here is thus focused on exploiting microorganisms under spaceflight conditions for human welfare and to enter a new era in space: space biotechnology. We propose to study the effectiveness of already well-established biotechnological processes with microbial cell factories under spaceflight conditions; and to search for new biological processes and production opportunities for novel compounds of interest. We propose two main areas of activities:

1. Characterizing the efficiency of microbial antibiotics production and assessing if new and more effective antibiotics can be produced under spaceflight conditions is one prerequisite to guarantee successful long-term space exploration. This opens research opportunities at different levels ranging from microbial systems biology, synthetic biology, metabolic engineering to bioprocess optimization.

2. Biomining became an essential process in the mining industry (biohydrometallurgy) as many microorganisms are able to leach metallic ions (e.g., iron, gold, uranium, silicon) from different soil, rock or regolith material. By retrieving lunar soil samples from different geographic areas of interest, several biomining experiments can be set. The most suitable microorganisms for leaching the soil composition or the mineral of interest can be identified thus paving the way for the most effective leaching process under spaceflight conditions.

The set-up for testing the microbial production portfolio and their capacities is flexible, being mostly dependent on the amount required of the desired product for the crew. Experiments can thus be done in mL to L scales and can be adjusted to the dimensions of potential spaceflight bioreactors. Here, microorganisms as payload represent a sustainable, reasonable and efficient option, as they can be frozen and revived when needed.

Expected impact of the research: Space biotechnology as a new life science effort of humanity to i) sustain medicine and human health both on Earth, in space and in new solar system habitats; and ii) initiate a lunar asteroid and Martian biomining process.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	depending on setting (bioreactor arrangements)
Volume of hardware	different bioreactors (from mL to L scale)
Accommodation (e.g. internal/external)	internal
Power required	yes (depending on setting)
Data generated	information on produced organic or inorganic substance
Pointing/viewing/line of sight needs	N/A (tbc)
Communications needed	depending on setting (can be remote controlled)
Duration of experiment	depending on setting (days to year(s))
Crew tasks (if needed)	operation of bioreactors (can be remote controlled)
Access and servicing by crew (if needed)	depending on setting (depending of the complexity/simplicity during the operation of bioreactors)
Need for retrieval and return to Earth	yes (depending on setting)
Specific orbit needs (if any)	none
Operations without crew (if any)	N/A depending on setting

DEEPRAD (DEEP SPACE RADIATION MEASUREMENTS)

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Scientific Domain:
- Life Sciences, Physical Sciences

Background:

Cosmic radiation is generally considered the main health hazard for manned exploration and the colonization of the Solar system. The main biological effects associated to exposure to cosmic radiation are carcinogenesis, late degenerative tissue effects, hereditary effects and acute effects after high dose exposure. Cancer currently dominates risk estimates, but non-cancer effects, especially central nervous system (CNS) and cardiovascular risks are becoming an increasing source of concern.

The radiation field in space is the most complex natural radiation environment consisting of the contributions from Galactic Cosmic Rays (GCR), sporadic contributions from Solar Particle Events (SPE) and secondary particles from the interaction of these two primary components with either a spacecraft or a surface (Lunar surface).

Since the early times of human spaceflight space radiation and especially the heavy ion component of the galactic cosmic radiation has been recognized as a main health concern for human space missions. The monitoring of the radiation exposure received by humans already started in the 1960´s with the Mercury and Gemini missions and the Apollo missions to the Moon [1]. The experiment suite applied at these times already consisted of passive (integrating) and time resolving active (battery or otherwise powered) detectors. Nevertheless in the last decades only two data sets have been generated for radiation measurements in the vicinity of the Moon. The data available is limited to the ones from the US CRATER experiment [2] and from the Indian Chandrayaan-1 mission to the Moon [3]. Compared to the Moon we currently even know more from the radiation environment on the flight to Mars [4] and on its surface [5].

The **ESA Radiation Roadmap** [6] clearly states the objectives of ESA´s space radiation goals in the fields of the *Biological Effects* and the relevant *Radiation Physics* to investigate (Research topics: B1: Radiation environment / B2: Personal dosimetry / B3: Transport codes / B4: Forecast / B5: Shielding). The necessity of the monitoring of the radiation environment for exploration missions is as well reflected in the **Global Exploration Roadmap** in the area of *"space radiation protection"*.

Idea and concept:

The Deep Space Gateway should be used as an enabling platform to provide the possibility to mount relevant radiation detectors at (a) the outside and (b) inside the Deep Space Gateway to fulfil the following **objectives**:

- Determine relevant radiation field quantities as the absorbed dose, the Linear Energy Transfer Spectra and the dose equivalent in the vicinity of the Moon.
- Determine these quantities for a relevant outside exposure and an inside exposure to quantify the effects of shielding on the radiation field parameters.
- Determine possible contributions from Solar Particle Events to the radiation quantities.

To fulfil the objectives the instrument of choice would be an active radiation detector system [**DEEPRAD**] which enables time resolved measurement data and measures in autonomous mode. This system can be based on heritage as for example currently flight hardware for the DLR Eu:CROPIS mission [RAMIS detector see [8]].

NOTE: In addition it could be envisaged to also use passive radiation detectors at certain positions inside the Deep Space Gateway for area monitoring purposes, but these would have to be returned to Earth for data evaluation, as is currently done for the DOSIS 3D project on board the ISS [9].

The impact of the research can be summarized in the following points:

- Provision of radiation data for the vicinity of the Moon in support of exploration missions.
- Provision of radiation data for benchmarking relevant radiation transport codes and investigations in shielding effects of the Deep Space Gateway.
- Provision of radiation data in support of possible foreseen biological and astrobiological experiments performed using the Deep Space Gateway (as for example the **BIOMER** and the **DeepCytoLab** proposal by DLR).

It has to be emphasized, that all relevant research in terms of radiation protection, dosimetry and radiation research in the view of human exploration - the Deep Space Gateway is the next logical step - has to be performed within an international collaboration and has to be seen as joint effort of the space faring nations to understand and to mitigate the effects of radiation on humans.

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Table: DEEPRAD – Deep Space Radiation Measurements (all data heritage from experiments currently either in preparation or already built for space missions).

Estimated experiment properties	Description
Mass of hardware	Max. 300 g
Volume of hardware	9 x 9 x 9 cm
Accommodation (e.g. internal/external)	To be accommodated on an external platform (DEEPRAD-O) and also inside the Deep Space Gateway (DEEPRAD-I)
Power required	Input voltage 9 – 36V / Power consumption 2.5W
Data generated	Max. 10 Mbyte/day (uncompressed) per instrument
Pointing/viewing/line of sight needs	Both instruments shall point in the same direction (for example NADIR)
Communications needed	Data transmission of science data at least once a week
Duration of experiment	At least for 12 months
Crew tasks (if needed)	Depending on the experiment setup – crew would have to install the DEEPRAD-O outside the Deep Space Gateway and the DEEPRAD-I inside the Deep Space Gateway
Access and servicing by crew (if needed)	Systems should (after connection to data and power interface) work fully autonomous
Need for retrieval and return to Earth	Currently not foreseen, but could be implemented
Specific orbit needs (if any)	-
Operations without crew (if any)	System shall be able to accept uplink commands from Earth

THE DEEP SPACE PETRI-POD (DSPP): A GENERAL PURPOSE BIOLOGICAL PLATFORM FOR THE DEEP SPACE ENVIRONMENT

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Scientific Domain:

Life Sciences, Physical Sciences, Solar System Sciences & Astrobiology

Idea Description:

With the additional launch cost of lifting experiments beyond LEO, the Deep Space Gateway will necessitate the use of novel low mass and volume efficient solutions for its scientific hardware. Already funded by the UK Space Agency NSTP programme (2016/17), the Deep Space Petri-Pod (DSPP) is a new "matchbox" sized, TRL 4, general purpose, micro-fluidic platform for conducting a wide range of parallel biological experiments within the unique 'laboratory environment' of deep space. To take advantage of that environment Fig 1a shows a user configurable, common interface DSPP "cassette" that will use a generic Base Unit designed to be compatible with typical spacecraft interfaces (in this case, the Deep Space Gateway). The "cassette" is a layered FDA approved (important for US customers) acrylic (PMMA) assembly comprised of up to 56 discrete wells, referred to as Bio-Pods and not dissimilar to a Microtiter plate; this is where wet biological experiments are performed. Construction exploits diffusion molecular bonding that eliminates the need for adhesives or cements that can be a source of contamination in biology. The Bio-Pods are separated by a PTFE gas permeable membrane into wet and dry sections and serviced by 3D micro-fluidics within the acrylic manifolds with the top sealed by a miniature flange (optional). At the base of the "cassette" a printed circuit board (PCB) substrate, incorporates individually addressable embedded heaters, with surface mounted sensors, protected from the chemistry by a 15 micron parylene coating, within each Bio-Pod (see Fig 1b Cross Section). For example, the TRL 4 prototype shown in Fig 1a adopts a configuration with additional top layer PCB's and LED's that enable multi-wavelength optical density measurements of the Bio-Pod column via a photodiode on the base. Current testing uses *Caenorhabditis elegans* (*C. elegans*) as an established *in vivo* model organism of human health and disease (see Fig 1c).

A key design feature of the DSPP is configuration flexibility of the "cassette" to meet many user applications within the community. For example, the volume of the Bio-Pods can be changed to accommodate single or multi-cellular organisms with different sensor technologies incorporated on the substrate, depending on the scientific objectives. While a basic version includes temperature, pH ISFETS's, RADFET and photodiode sensors, we believe a future device might incorporate powerful analytical capability by including NanoPore technology on the substrate. Furthermore, the use of diffusion molecular bonding during manufacture of the manifolds allows for internal 3 dimensional micro-fluidics, which increases technical density of the system within its small envelope (see example of a Carville Plastics device in Fig1d).

The international spaceflight community has recognised in the 'Global Exploration Roadmap' [1] that characterising the biological consequences of deep space is an essential pre-requisite to mitigating the dangers of future human missions. DSPP is a facilitating platform that is designed to address this strategic aim. Moreover, the Global Exploration Roadmap promotes the use of lower organisms to expedite knowledge advances towards ultimately sending humans to Mars and other planetary bodies. Our DSPP prototype when used to culture *C. elegans* and other organisms like *Panagrolaimus superbus* or tardigrades, represents a realistic and, importantly, cost-effective and mass saving solution that circumvents many of the challenges associated with present flight capabilities.
The platform is led by the University of Leicester with four high impact PI led science experiments being proposed for initial flight opportunities.

1) **Human Physiology** using *C.elegans* as a space physiology model (PI: Dr Tim Etheridge, University of Exeter)
2) **Synthetic Biology & ISRU** demonstrated in deep space (Prof Lynn Rothschild, NASA Ames)
3) **Increased Pathogenicity & Virulence of Organisms** (Prof Lewis Dartnell, University of Westminster)
4) **Mammalian Cell Cultures** in deep space (Prof Dave Cullen, Cranfield University)

In terms of impact, DSPP is a tool to address two knowledge gaps in relation to human exploration of deep space, which also forms our primary science goals for this technology. <u>**Firstly;**</u> it facilitates long term, multi-generation investigations (to provide good statistical data) of the systemic effects on an organism, cellular and DNA damage caused by the combined space radiation environment and other physiological stressors resulting from space travel. For example, increased pathogenicity and virulence of organisms is a concern for long duration human space flight and DSPP could be used to investigate this effect. DSPP also enables testing within the same platform of engineering countermeasures (eg. shielding materials to inform future spacecraft design), pharmacological prophylaxis / repair therapies and the development of novel techniques like induced metabolic reduction to limit radiation damage. Such investigations will inform the mission design of human exploration of the Moon and Mars. <u>**Secondly;**</u> a key technology for extended duration human exploration is Synthetic Biology, which can be demonstrated inside the DSPP Bio-Pods. Synthetic biology proposes using modified organisms to augment the production of *in situ* resource utilisation (ISRU) for fuel, and other energy commodities, bio-composites and plastics to be used as feed stock in 3D printing or provide materials for spacecraft repair, engineered food recycled from human excrement, and drugs on demand. In collaboration with NASA Ames, demonstrating the application of synthetic biology outside of LEO would be a major step change in preparing for deep space exploration [2, 3].

As an example of potential future applications, ESA's Advanced Concepts Group have convened a Topical Team to identify enabling technologies in the field of human topor and hibernation (a state of hypo-metabolism). This has the advantage of reducing extended space travel resources (eg. food, water and energy for heating) and reduces the cellular damage caused by radiation. DSPP is a cost effective technology and could be used to test these concepts and analyse the type of damage to a cells structure, organelle and its DNA. This data is then correlated with measurements from active and passive radiation sensors within DSPP to help understand the mechanism of damage and whether, for example, it is systemic or localized in nature. (See URL: http://www.esa.int/gsp/ACT/bio/projects/Hibernation.html)

In the same way that the ISS has a standard rack interface, it is proposed that a DSPP Base Unit is included inside the Deep Space Gateway and on the outside (similar to EXPOSE). Pre-prepared "cassettes" are deployed and recovered at crew rotation with one or multiple pre-loaded DSPP "cassettes" interfaced to the Base Unit for science operations. Additionally, as more demanding science objectives are proposed, the base unit could be upgraded if necessary to meet evolving requirements of the "cassette".

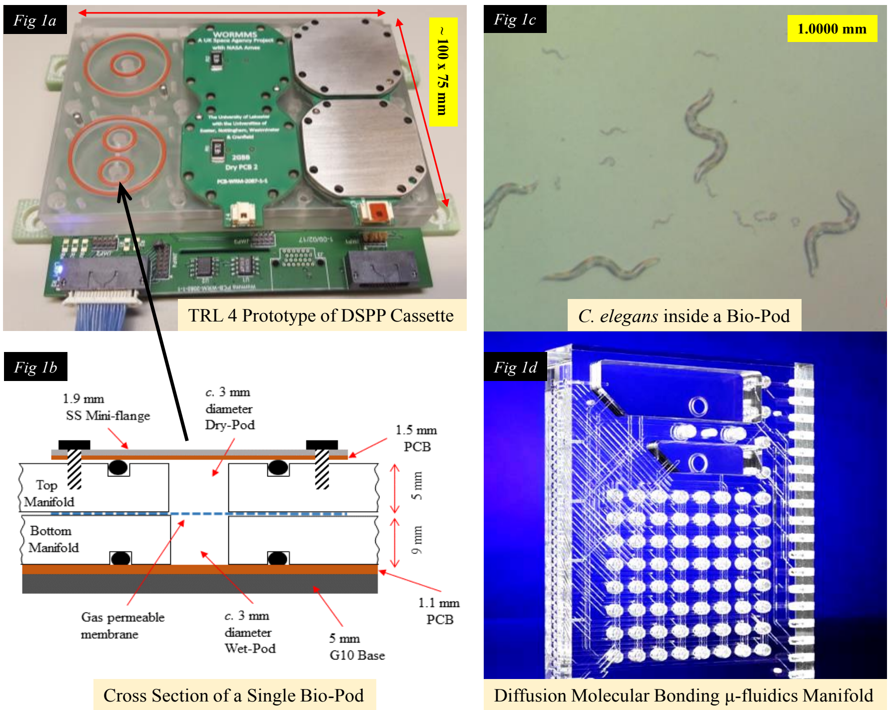

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Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	Cassette ≈ 300g +/- 10%; Base unit ≈ 1000g +/- 25%
Volume of hardware	Cassette 100 mm x 75 mm x 25 mm (188 cm^3) Base unit is TBD; however, estimated 800 cm^3
Accommodation (e.g. internal/external)	DSPP is adaptable and may be used by an astronaut inside or placed outside for exposure experiments.
Power required	Estimated 3W (external operations with heaters TBC)
Data generated	Raw data = CSV <1 MB Data products = TBD
Pointing/viewing/line of sight needs	N/A
Communications needed	Wireless (Base Unit to laptop) Wired (FPGA based electronics with programmable IF)
Duration of experiment	Few days to 6 months for an exposure experiment
Crew tasks (if needed)	Yes, DSPP is designed to be used by an astronaut and activities may include: ✓ Changing a cassette ✓ Experiment start/stop via software ✓ Adding fluids (from a syringe) ✓ Monitoring growth activities via software
Access and servicing by crew (if needed)	DSPP experiments may be optimised for automatic operation (requiring an astronaut to place the cassette in the Base Unit and initiate ‘start’ in software) with control from the ground or designed for basic *in situ* operator intervention. External exposure will require placement on an EXPOSE type facility.
Need for retrieval and return to Earth	Ideally yes. However, because of the way the cassettes are designed they may be disposed of or potentially reused by the crew for subsequent experiments.
Specific orbit needs (if any)	N/A
Operations without crew (if any)	If DSPP is configured for an active exposure experiment it will be placed outside the spacecraft and the electronics used to monitor biological growth/development.

ELECTROACTIVE BIOFILMS IN SPACE

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Scientific Domain:

Life sciences, life support systems, waste treatment, microbial surface interaction, extracellular electron transfer, biofilm

Idea Description:

Over the last decade, Extracellular Electron Transfer (EET) has gained a lot of scientific interest, as this unconventional way of microbial metabolism seems to be much more widespread than initially presumed. EET is a process in which microorganisms develop strategies to contact a solid electron donor or acceptor outside their cells to establish microbial respiration. Two main types of EET have been described:

- Direct electron transfer, which involves membrane bound or associated enzyme complexes, and may involve conductive pili or pilus like structures. The latter are also referred to as nanowires (Figure 1).

- Indirect electron transfer, where an organic or inorganic, soluble compound is reduced or oxidized at the cell and subsequently diffuses towards the insoluble electron acceptor/donor. Examples of organic shuttles are pyocyanin and humic acids. Examples of inorganic shuttles are sulfur compounds and hydrogen. These shuttles can be produced by the microorganism itself or added externally

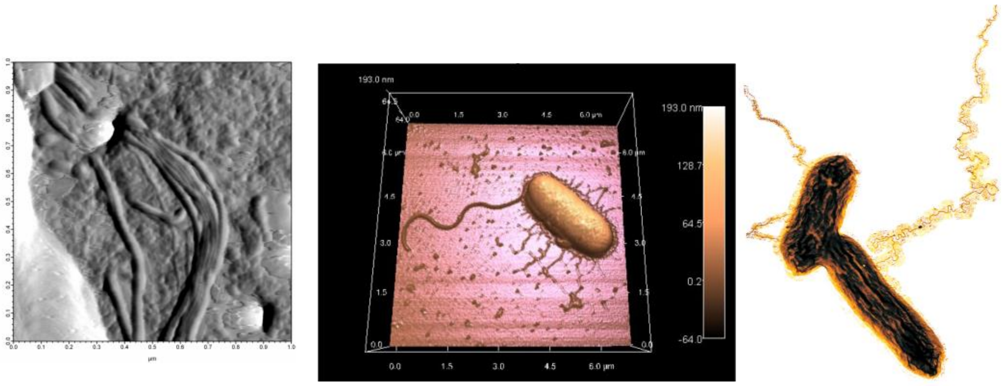

Figure 1. Images of microbial nanowires (left and middle after Rabaey *et al.* 2007 [1], right after www.geobacter.org)

When microorganisms use a solid surface as an electron acceptor, the solid surface with the associated biofilm is called a bioanode, whereas if the solid surface acts as the electron donor, the term biocathode is used. These processes turn out to be important natural microbial respiration processes in anaerobic zones where bacteria are capable of oxidizing or reducing metals and humic acids but are also important when describing microbially induced corrosion processes. These recent insights in EET have resulted in a variety of possible applications, such as electricity, hydrogen or methane production from wastewater, biosensors, bioremediation and the production of valuable organic compounds through biocathodical catalysis.

Extracellular Electron Transfer is typically a biofilm based process which strongly depends on the diffusion and convection of reagents and products and generally not on differences in density. As a result, it is expected that EET based conversion processes, e.g. for waste treatment, are compatible with Space applications as they are most likely gravity independent. However, EET has not been tested in microgravity conditions yet according to the authors' knowledge.

So a first driver for EET research in Space is related to fundamental scientific questions on whether microbial activity relying on EET is possible in Space, if the biofilm structures develop differently and whether similar or different EET mechanism will be expressed in Space. Such insights will be very important for elucidating microbially induced corrosion processes on board and possible terraforming processes on other planets with different gravity forces than on earth.

Secondly, a process based on bioanodic EET has been proposed for MELiSSA, ESA's Life Support System. In the first compartment of the MELiSSA loop, organic waste is converted into a mixture of volatile fatty acids. The further oxidation of these volatile fatty acids has been considered as a bottleneck but could now be resolved with bioanodic oxidation, relying on EET. For the success of the MELiSSA loop in future Space mission, the validation of bioanodic EET is essential. Recently, also direct bioanodic oxidation of urine has been demonstrated on earth, which might be helpful for the treatment of urine on board of future space missions.

Finally, also biocathodic processes can be applied to convert nitrate (e.g. from urine) into dinitrogen gas (N_2)[2]. The production of N2 from urine has been proposed earlier as a way to help pressurize a Space capsule

The Center for Microbial Ecology and Technology (CMET) has in the last 17 years build up a considerable experience in the analysis of electroactive ecosystems, both for bioanodic and biocathodic EET. Based on our in-house experience with electroactive microorganisms and the technology deduced from it, we envision the feasibility of developing electroactive bioanodes and biocathodes on board of a Space module.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	1 kg
Volume of hardware	2L or smaller
Accommodation (e.g. internal/external)	internal
Power required	yes
Data generated	Yes, automatically analysed using software, with a possibility to steer microbial management
Pointing/viewing/line of sight needs	
Communications needed	Not necessarily
Duration of experiment	Days, weeks
Crew tasks (if needed)	Starting and stopping experiments
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	Not necessarily
Specific orbit needs (if any)	
Operations without crew (if any)	

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ORGANIC EXPOSURE FACILITY FOR ASTROBIOLOGY AND ASTROCHEMISTRY

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Scientific Domain:
Life Sciences, Solar System Sciences, Astronomy and Astrophysics.

Idea Description:
Organic matter is thought to be one of the key ingredients involved in the origin of life, on Earth, and potentially beyond. Solar UV photons, Solar Particles and Galactic Cosmic Rays drive its evolution, either through complexification or degradation, in the Solar System. They can initiate an exceptionally complex chemistry as seen in Titan's atmosphere that turns the lightest gaseous organic compounds such as methane, into heavy and solid organic aerosols[1], be at the origin of complex macromolecular structures found in primitive meteorites and in comets[2-4] or alternatively could have erased the traces of past life at the surface of planets, such as Mars[5,6] or Europa, or destroy organic molecules present on meteorites and in cometary ices[7], hindering their delivery to planets. The balance between formation and degradation processes is rather complex to estimate: it requires proper kinetics assessment of the processes involved. Henceforth there is a need for realistic simulation of the conditions to which such materials are exposed in their natural environment.

The influence of UV photons on some key compounds (e.g. amino acids, nucleobases, polycyclic aromatic hydrocarbons (PAHs), Titan's atmosphere mixtures) has already been studied in space, outside the MIR station, FOTON capsules, and the International Space Station in the ESA Expose facilities[8]. Although these experiments benefit from an extremely valuable return of the samples on Earth, they could be substantially improved (1) if the samples evolution could be monitored in real time during exposure with an appropriate analytical tool, (2) if the samples were placed in an environment where energetic particles (Solar and galactic) are not be filtered by the Earth magnetosphere as is the case in Low Earth Orbit, and (3) if the temperature of the samples could be controlled to allow the exposure of ice samples. Such a complex space environment cannot be fully simulated in the laboratory, especially regarding the combination of entire UV photons and energetic particles spectra.

In 2010, a NASA Cubesat experiment, O/OREOS, flew on a polar orbit equipped with an on-board UV spectrometer, demonstrating the capabilities to adapt compact instrumentation to suit the scientific requirements for in situ measurements[9]. By 2020 ESA is planning to implement a new European Exposure Facility on the ISS with active experiments and in-situ spectroscopy. This includes development of compact instrumentation not only in the UV-Vis-NIR but also in the mid-infrared range, which is considered as a valuable complement to UV to monitor the evolution of organic molecules. Moreover, implementation of icy samples in such exposure programs is currently under investigation, and broadens those experiments to the icy worlds such as the satellites of the giant planets, and cometary ices.
A further step toward realistic simulation would be to implement exposure experiments where the Solar and galactic particles would not be filtered, which would allow to follow the effect of a realistic combined UV/particles flux on selected organic samples (or organic mixed with minerals & biosignatures), with data sent to Earth by telemetry, and, ideally, samples shipped back to Earth after exposure.

The Deep Space Gateway would provide an unprecedented step forward in Exposure experiments in Astrobiology and Astrochemistry. It would meet of the recommendations issued by the ESA Astrobiology Topical Team[8] and the independent ESF review for active experiments beyond the International Space Station. This new project would benefit from the long-term heritage held by ESA and NASA in Exposure programs, and the support of a large and well-structured community.

The proposed program could be implemented under various forms in the Deep Space Gateway (DSG) context:

- As an external exposure platform outside the Deep Space Gateway with active UV & IR spectrometers, and data sent to Earth by telemetry. Samples would be recovered after a few thousands hours of Solar exposure by the crew, and returned to Earth. The experiments could be conducted also during the cruise phase from Earth of the DSG, or outside various service modules to or from the DSG. The exposure platform could be conceived on a cubesat basis to facilitate technology transfer between on-going and future cubesat projects.
- The exposure platform could also be located at the surface of the moon, pending telemetry to DSG and sample return.
- The samples could also be accommodated on cubesats deployed from Deep Space Gateway (sample return could then be not possible, but on board instrumentation would provide valuable information).

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ANNEX: some examples of samples that could be exposed outside the Deep Space Gateway

- Simple organic compounds to study stability and assess exogenous deliveries or stability at or near the surface of planets and small bodies: amino acids, di- or tripeptides, nucleobases, nucleoside+P, nucleotides, carboxylic acids, quinones, PAHs…
- Simple gaseous mixture to study complexification towards larger molecular structures (Titan atmosphere, primitive earth atmosphere, exoplanet atmosphere simulations): CH_4/N_2, CH_4/NH_3, $CO_2/N_2/H_2$…
- Simple ice mixture to study formation of macromolecular material such as insoluble organic matter (interstellar, protostellar chemistry): CH4/NH3/H2O…*
- Complex refractory material (IOM or IOM analog) to asses evolution (molecular and isotopical)
- Molecular « Biosignatures » and fossils: pigments, lipids, porphyrins, , hopanes et hopanoides, carotenoides).
- Interaction of these samples with minerals, catalytic surfaces, dust particles…

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	If based on cubesats, typically 1 kg per U. Multiple of basic units possible: e.g. 2U (2-3kg), 3U (3-6kg), 6U (6-12kg)
Volume of hardware	6 to 12 U cubesat 1 U = 10cm x 10cm x 10cm
Accommodation (e.g. internal/external)	Outside or deployed on a cubesat
Power required	via solar panels or power provided through mothership (typical range: <2W to 10W per 1U)
Data generated	Payload Interface Control Memory storage: typically 50-200MB on-board, more storage capacity typically available via mothership
Pointing/viewing/line of sight needs	Significant exposure time toward Sun
Communications needed	Spectra transferred to Earth on a regular basis (e.g. 1/week)
Duration of experiment	> 1 yr
Crew tasks (if needed)	
Access and servicing by crew (if needed)	Installation and recovering of samples during EVA.
Need for retrieval and return to Earth	Preferred
Specific orbit needs (if any)	Foreseen orbits for DSG are appropriated
Operations without crew (if any)	Measurements of spectra

Deep Sapce Gateway Workshop Abstract

BIOMER-Biological Response to Moon Environment and Radiation

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An important part of the recommendations of the ESA Astrobiology Topical Team (Cottin et al., 2017), the European Astrobiology Roadmap (AstroMap, Horneck et al., 2016) and the ESA Roadmap is astrobiology and radiation research in space complementing ground research in simulation facilities. Previous ground based studies and experiments in low Earth orbit, particularly using the EXPOSE facility, have investigated the response of dormant organisms to the LEO environment including extra-terrestrial solar UV radiation (with direct relevance for the biosphere in times of a changing ozone layer), cosmic radiation and vacuum. However, for the future, further investigations on metabolically active biological systems in space with automated *in situ* analysis methods were recommended to assess the response of active life to the space environment, in particular to radiation under microgravity, as well as to environments of solar system bodies that are potentially habitable (supporting the development of planetary protection measures for icy moons).
With respect to cosmic radiation, the Moon orbits are of special interest. The combination of active astrobiological experiments focussing on the biological effects of cosmic radiation in microgravity complemented by active radiation measurements performed in parallel inside the spacecraft and outside on exposure platforms with consequently lower shielding by the spacecraft itself will provide essential data for the radiation risk assessment for future manned missions to Moon and Mars, encompassing also EVAs.

The experiment proposal BIOMER – BIOlogical response to Moon Environment and Radiation, based on the radiation induced DNA damage dependent luminescence of genetically modified microorganisms (GMO) developed by the Astrobiology Group of the Institute of Aerospace Medicine at DLR in Cologne will be presented.

Cottin, H. et al., (2017). Space as a Tool for Astrobiology: Review and Recommendations for Experimentations in Earth Orbit and Beyond. *Space Science Reviews* 2017.

Horneck, G. et al., (2016) AstRoMap European Astrobiology Roadmap. *Astrobiology* 16 (3), 201-243

AUTONOMOUS MONITORING OF RADIATION ENVIRONMENT (AMORE)

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Scientific Domain:
Life Sciences, Physical Sciences

Idea Description
Background
Proper mitigation of radiation risks below acceptable thresholds is a must to enable deep space exploration. Relevant primary radiation is constituted by Galactic Cosmic Rays and by Solar Particle Events (SPEs). In this proposal we focus on the SPEs. These would require, for example, a combination of i) solar physics based forecasting in addition with now-casting provided by real time analysis of the SPE precursors, to issue proper "warnings", as well as ii) mitigation procedures to be activated following the warning. Understanding the risk level of an SPE from the combination of fore- and now-casting is needed to optimize the SPE mitigation procedure. DSG would be the best platform to experimentally study this issue, providing also grounds for model validations. A combination of external radiation monitoring (for precursors), area & personal monitoring would be needed for the warnings generation and for studying the correlation between warnings and actual SPE risk as measured by the area and personal internal monitors.

Objectives
This proposal addresses the above points. Its objectives respond to the call identified area "Understanding the Effects of Deep Space Radiation".

The proposed project is aimed at understanding the relationship between SPE precursors (as measured outside a space vessel) and SPE risk level (as measured inside the vessel), also validating existent models. Furthermore, the project will use such understanding to provide best countermeasures suggestions to the crew, with a real time, autonomous intelligent system. This strategy will be implemented in flight for a demonstration test.

Even if focused on SPEs, parts of this proposal may be applied to the GCR mitigation as well.

In detail
1) Study, for the first time in a human habitat in deep space, the detailed relationship between externally measured SPE precursors and the related internally measured radiation field and consequent risk increase. SPE forecasting, from Solar physics results (see for example Anastasiadis et al. Sol Phys (2017) 292: 134. https://doi.org/10.1007/s11207-017-1163-7), and a preliminary study on SPEs databases will permit the selection of the best precursor(s) to be measured suggesting also risk prediction matrices (see, for example, Posner, Space Weather, 5, S05001, doi:10.1029/2006SW000268,2007). The project will provide data to validate these strategies and estimate the accuracy of SPE nowcasting. The same data could allow for detailed studies and validations of transport codes through the habitat hull.
2) Intelligent tools will be provided to use at best the information coming from the "nowcasting" in (1) to mitigate SPE impact on the crew, also using the detailed knowledge of the shielding capabilities of the vessel, with no intervention of Mission Control, and minimal intervention of the crew. The amount of

residual radiation health risks increase, due to a fast and connected SPE (with too short warning times), will be also estimated using models and simulations and the related dose/dose rates excess validated during the project.

In order to optimally manage the available shielding of the spacecraft for best SPE protection (attitude variations, internal disposition of the items, shelter preparation etc.) an ad hoc smart system will be developed. This would require the precise knowledge of position and shielding efficiency of all massive items in the vessel, including the movable ones: proper wireless tagging sensors will therefore be developed. The time between the SPE precursors and the arrival of the dangerous part of the SPE may be shorter than the time needed to perform the countermeasure procedures. Starting from the acquired data, the project will estimate the residual health risks the crew will face in these conditions through ad hoc designed simulations and models.

During an emergency (such as following an SPE warning), the above procedures will have to be performed in quasi-real time, and eventually (when in interplanetary missions) with no support from Mission Control due to the large comm – delay. DSG is the best platform to master these procedures in view of these voyages. This project will provide a first set of intelligent systems to collect all the sensor and needed knowledge information, and provide real time suggestions to the crew.

The system will be mostly automatic, and data will be directly downlinked on Earth whenever possible. Crew activity would be restricted to the mounting, set up and eventually the rearrangement of items, and would be minimal.

Equipment to be developed

The project will need:

i) a set (minimum of 2: one external, one internal) of small light novel and performing radiation detectors wirelessly linked to an operating virtual platform – smart system to provide supporting outputs to the crew;

ii) a novel tagging system for the movable items of relevant dimensions associated with the knowledge of the shielding distribution of each item (such as a detailed CAD).

More in detail a minimal set of equipment would be:

a) 1 external detector for SPE precursors (probably: X gamma and e-. Nice to have: ions, for an internal-external validation of transport codes);
b) 1 area detector;
c) 1 personal detector (nice to have);
d) 1 operating platform – smart system (wirelessly collecting all the outputs of the detectors). This operating platform could also be implemented on existing systems such as tablets or smartphones;
e) 2 tagging sensors linked to a system calculating in real time the shielding contribution of the items to which are connected. This information will be available to the smart system;
f) models and simulation to estimate the residual risk due to the fastest SPEs, that will not allow for full exploitation of the countermeasures in due time.

Expected impacts

The research described here will provide several important advances aimed at enabling human space exploration:

a) the study and test of the procedures to nowcast incoming SPEs from the precursors that can be measured outside the vessel will i) provide an estimate of the possible minima for warning times, ii) support the minimization of the SPEs radiation risks using the items available in the space vessel, and iii) permit to estimate the residual risk through ad hoc developed models.

b) it will provide a first seed toward a fully automatized radiation managing system, testing also the ability of migrating the radiation-related decision processes from Mission Control to space. This "smart system" would be open to collect, correlate and analyse inputs from all the radiation and environmental detectors, toward an integrated smart system for the autonomous managing of all operations linked to environmental conditions.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	< 1 Kg (including 2 detectors, tagging system and hardware)
Volume of hardware	< 2 lit
Accommodation (e.g. internal/external)	1 detector external 1 detector, tagging elements, hardware internal
Power required	< 10 W (possibly partly battery powered)
Data generated	< 1 GB / day
Pointing/viewing/line of sight needs	Yes for the external detector.
Communications needed	Nice to have
Duration of experiment	Long (looking for SPEs)
Crew tasks (if needed)	Minimal: mounting, set up, eventually rearrangements of items
Access and servicing by crew (if needed)	TBD
Need for retrieval and return to Earth	Nice to have
Specific orbit needs (if any)	None
Operations without crew (if any)	Most of the time

LOGOS (LUNAR ORGANISMS, GEOMICROBIOLOGY AND ORGANIC COMPOUND SPACE EXPERIMENT).

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Scientific Domain:
Astrobiology, Life Sciences, Solar System Sciences, Earth Sciences

Idea Description:
The Deep Space Gateway opportunity will be used in our proposal for supporting future astrobiological manned and unmanned exploration missions to Mars and the icy moons. The idea is to use a LOGOS-exposure platform for simple exposure experiments on a lunar based module as complement to an orbital module. The samples to be exposed will be organisms, (lunar-, Icy Moon-, Mars-analogous) salts, rocks, minerals, fossils and biomolecules to study their resistance to space environments, their detectability by spectroscopic analysis in space and in case of the microorganisms their suitability to be used for further studies within life supporting systems.

The main objectives of the research would be:

- In situ measurements by spectroscopy methods to analyse the stability of biosignatures (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 the 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

The facilities, which are needed, are one to two exposure platforms (one placed in orbit outside the orbiter module and one on the surface of the moon). These platforms are divided into two compartments. One is for in situ monitoring of changings of biomolecules during the exposure time by spectroscopic measurements and one is to test microorganisms in a micro-habitat with access to solar radiation on their metabolic or photosynthetic activity by fluorescence measurements. The crew has to bring these mobile facilities outside the orbiter module to be attached on the module and on the surface of the Moon. During these operations they could make pictures of the installation. After installation the operations can be run automatically with data transfer to Earth but could also from time to time be controlled and observed by the crew.

This research has a significant impact for Planetary Research and in particular for life detection operations on Mars and the icy moons in the outer solar system. Another important outcome of LOGOS will be relevant for the Life Sciences. By first in situ tests of microorganisms in a micro-habitat located in orbit of the Moon and/or on the surface of the Moon the resistance and the metabolic/photosynthetic activity using solar radiation in addition to provided gas and humidity inside the habitat compartment can be investigated. Results obtained by these experiments might give insights if some of these organisms are suitable to be used in future life supporting devices as oxygen producers, nitrogen fixators or even lunar soil consumers.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	5 to in max. 8 kg
Volume of hardware	tbd (but not more than a cube of 50 cm x 50 cm x 50 cm)
Accommodation (e.g. internal/external)	external (on orbiter + on the surface of the Moon)
Power required	< 100 W (all hardware instruments)
Data generated	Data download needed: 1Mbps per sample (approximatively 256 samples → has to be confirmed)
Pointing/viewing/line of sight needs	Spectra monitoring, environmental measurements (rH (%), T(°C), p (bar),...), photos, limited video monitoring
Communications needed	yes
Duration of experiment	Minimum: 2 months / Maximum: 2 years
Crew tasks (if needed)	Placement outside orbiter module, on the Moon, photographs/videos of operations – potentially observation (observations not mandatory, because planned to be automatically controlled from Earth).
Access and servicing by crew (if needed)	Placement of proposed facilities outside the orbiter module/ surface of the moon (camera / video actions)
Need for retrieval and return to Earth	Retrieval of samples for further analysis on Earth needed
Specific orbit needs (if any)	No specific limits
Operations without crew (if any)	Spectroscopic measurements / environmental monitoring of external and internal environment of the compartments

EFFECTS OF COSMIC RADIATION ON HUMAN PSYCHOEMOTIONAL PERFORMANCE AND NEUROLOGICAL STATUS

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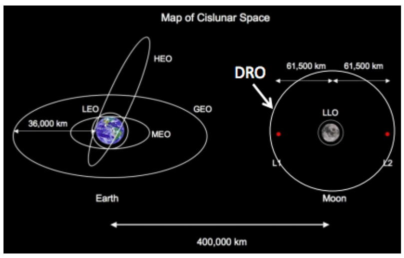
Scientific Domain:
Life Sciences.

Idea Description:

As a group, astronauts and cosmonauts are selected to work in a highly dangerous environment and to perform at their peak level. This level of focus for a long period of time can initially mask some neurological and psychological problems but they can become crucial later in the mission. To this date not much is known on the effects of radiation on astronauts although research has been done in animal models. Both, crews and ground personnel need to be aware of the potential damage that these problems may produce in these missions. They must learn to recognize signs of neurological and psychosocial dysfunction among other signs, have tools to detect them and neutralize or treat these issues.

We know that microgravity and also radiation may have a potential hazardous effect on the brain, especially the latest. Galactic cosmic rays include heavy, high-energy *ions* of elements that have had all their electrons stripped away as they journeyed through the galaxy at nearly the speed of light. Cosmic rays, which can cause the ionization of atoms as they pass through matter, can pass practically unimpeded through a typical spacecraft or the skin of an astronaut. Galactic cosmic rays are the dominant source of radiation that must be dealt with aboard the International Space Station, as well as on future space missions within our solar system. Because these particles are affected by the Sun's magnetic field, their average intensity is highest during the period of minimum sunspots when the Sun's magnetic field is weakest and less able to deflect them. Also, because cosmic rays are difficult to shield against and occur on each space mission, they are often more hazardous than occasional solar particle events. They are, however, easier to predict than solar particle events. Research on the effects of radiation on the brain is very important in order to prepare future human exploration of the solar system. This Deep Space Gateway ESA initiative represents the first serious opportunity we have to test these effects on humans beyond LEO and serve as a real testing platform for future successful planning of manned Mars, Moon or asteroids missions.



We propose an experiment consisting in testing cognitive, emotional and neurophysiological status of crew of Deep Space Gateway in its different orbit configuration but especially in the DRO configuration. DRO supposes the best experimental situation for this kind of experimentation. Experiment would consist on using NASA standardized tests (WinSCAT) (currently available at ISS), Psychomotor Vigilance Test (PVT) and other Psychological tests previously tested in space analogs by NASA and ESA. All these tests can be available in portable tablets or laptops and they would be password protected for confidentiality of data. Data could be send periodically to Earth for analysis.

Together with these psychological measures, a pupil examination for presence of possible neurological and brain general tone status will be used. This can be achieved with very portable and small handheld

pupilometers. Pupillometric methods are used to measure variations in the diameter of the pupillary aperture of the eye in response to psychophysical and/or diverse psychological stimuli. In the past, changes in pupillary motility have been noted and employed as indicators of both emotional arousal as well as signs of medical state. Activation of the sympathetic system stimulates the radial dilator muscles of the pupil, causing enlargement of the pupil, or decrease in diameter as sympathetic activation decreases. When the parasympathetic system is stimulated, with the efferent pathway originating in the oculomotor nucleus, the sphincter muscles of the iris aligned in a band formation, produce active constriction of the pupil, as seen in the reflex reaction to light. Inhibition of the parasympathetic system can also result in significant dilation. Very important factors of Human Spaceflight phenomena, such as hypoxia, fatigue, motion sickness, cognitive workload, and operational stress, are known to be under autonomic control. Specific components of the light reflex waveform are differentially related to subjective feelings of alertness and anxiety. Different components of pupillary responses can also be linked to different neurological and psychological processes and conditions such as cognitive effort, fatigue, etc. Thus, pupillometry may represent a useful, affordable and easy method to detect and monitor these problems in Spaceflight and other extreme environment conditions. Finally some brief neurological exam adapted to space environment consisting in reflexes and exercises can be performed to track neurological status. Crew could provide heart rate, blood pressure and oxygen saturation data by wristband devices or wearables such as Polar exercise bands (table 1).

Finally we plan to test Allais effect measuring Shapiro delay in light responses on pupils during eclipse configuration if performed by mission. This has been never measured in humans and only in physics before.

Orbit	**Psychological Tests**			**Physiological Tests**		
LLO	WINSCAT, PVT, questionnaires			Pupil Exam, Oxygen Saturation, Heart Rate and Blood pressure Tests. Brief Neurological Space Exam		
DRO	WINSCAT, PVT, questionnaires			Pupil Exam, Oxygen Saturation, Heart Rate and Blood pressure Tests. Brief Neurological Space Exam		
NRHO	WINSCAT, PVT, questionnaires			Pupil Exam, Oxygen Saturation, Heart Rate and Blood pressure Tests. Brief Neurological Space Exam		
HALO	WINSCAT, PVT, questionnaires			Pupil Exam, Oxygen Saturation, Heart Rate and Blood pressure Tests. Brief Neurological Space Exam		
Periodicity	1 month Before on Earth	Once a month	First 1-2 days after orbit change	1 month Before on Earth	Once a month	First 1-2 days after orbit change

Table 1. Summary of experiment for every crew member if present in these orbits.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	2Kgs.
Volume of hardware	Computer laptop, Handheld Pupilometer and wirst band
Accommodation (e.g. internal/external)	None
Power required	None
Data generated	Human/ Psychological/ Physiological
Pointing/viewing/line of sight needs	None
Communications needed	None
Duration of experiment	Full crew mission duration.
Crew tasks (if needed)	Simple Psychological and neurological Tests by computer laptop or tablet. Simple Pupil exam by pupilometer handheld.
Access and servicing by crew (if needed)	None
Need for retrieval and return to Earth	DATA
Specific orbit needs (if any)	None but Eclipse orbit is of interest
Operations without crew (if any)	None

DEEP SPACE GATEWAY BIOLOGY TWIN BOX (DEEPCYTOLAB)

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Scientific Domain:
Life Sciences, Radiation Biology, Gravitational Biology

Idea Description:
We suggest a reusable multipurpose cell and organ culture lab in the Deep Space Gateway in order to address scientific questions in radiation protection and gravitational biology for long duration human missions in deep space. Such long cruise phases will have serious consequences on the astronauts' health mainly because of direct action of space radiation and microgravity conditions, and of their possibly combined interactions. For risk considerations and development of countermeasures, the profound knowledge of the effects of space radiation and microgravity on cells of the human body is urgently required. Cellular experiments are needed, which elucidate the connection between cellular DNA damage detection, different signalling pathways and induced stress response, as essential parameters for cell survival and maintenance of genome stability.
On Earth, gravity is permanent and constant stimulus for all living organisms. The loss of this stimulus results in alterations of signaling pathways and of the cytoskeleton and in functional changes in single cells. It is concluded so far, that these effects might result in dysfunctions in the human body, e.g. in the immune system or in wound healing. This relationship can be directly investigated in the proposed reusable lab by analyzing specific biomarkers in cells or body fluids from astronauts in order to determine the immune and general health status of the crew.
Furthermore, biomonitoring of radiation damage is recommended for individualized risk assessment of astronauts' space radiation exposure. Such biomonitoring can be based on radiation-induced DNA damage, such as DNA double strand breaks (phosphorylated H2Ax, γH2AX) and oxidative DNA damage (8-hydroxydeoxyguanosine, 8-OH-dG) in human samples. A minimally invasive method to retrieve cell samples is using cytology brushes or a mouthwash for buccal epithelial cells from the mouth. A more invasive method is blood sampling and isolation of lymphocytes. γH2AX and 8-OH-dG are detected by immunofluorescence staining and quantified by image analysis.
Therefore, we suggest a two-step approach with a biomonitoring box called "**Deep Space Health Box**" for the initial gateway and a possible upgrade with a cell culture box ("**Deep Space Cell Box**") for the gateway evolution (Figure 1). The biomonitoring box enables e.g. immunofluorescence staining of buccal epithelial cells, hair follicle cells or white blood

cells that are sampled in regular intervals by the astronauts. It will contain a miniaturized microscope or flow cell in order to detect the immunofluorescence signal. Analysis of the DNA damage markers is planned to be performed on board of the gateway. The DNA damage in astronauts' samples will reflect the sum of all damaging factors during spaceflight. The biomonitoring will provide valuable information on the individual space radiation exposure and will thereby improve individual risk assessment. For correlation with the radiation dose, personal dosimetry for astronauts based on passive or active dosimeters is required. The radiation damage biomonitoring will be complemented by immune and health status monitoring.

During gateway evolution, the second box, allowing automated cell and organ culture, can be added. Here, mechanistic research and the single and combined effects of spaceflight environmental factors can be performed using cell or small organ cultures. Also, astronauts' cell samples can be incubated in order to follow e.g. DNA repair processes. A radiation dosimeter will provide necessary space radiation exposure data (e.g. the proposed DEEPRAD-I). The biomonitoring box can be used for analysis, or samples can be fixed and downloaded to Earth for further analysis. Alternatively, additional analysis boxes might be added, e.g. an "omics" analysis box. The cell culture experiments will require upload of frozen or growing cells or sampling of easily accessible cells from astronauts, download of data and possibly also of fixed samples. This will be the first cell culture lab outside the Earth's magnetic field, offering the unique possibility to study cellular and organ responses under these conditions (cosmic radiation, microgravity, no magnetic field) which are not available on ground.

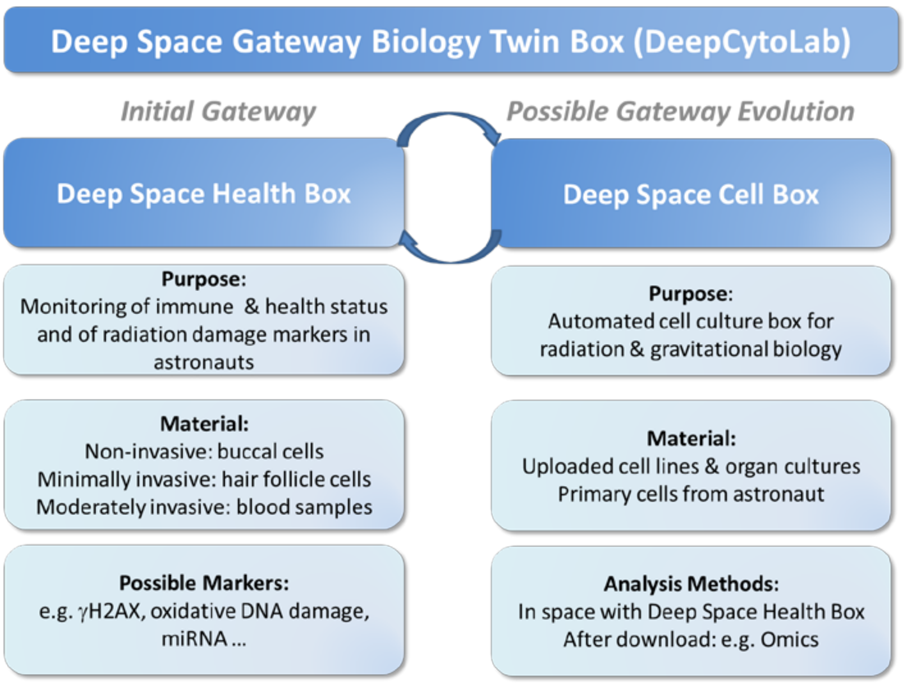

Figure 1 In the initial phase of the Deep Space Gateway, the "Deep Space Health Box" can be used for monitoring of immune and health status and of space radiation damage in astronauts. After upgrade of the station, the cell culture box called "Deep Space Cell Box" can be added for biological experiments on the station.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	Deep Space Health Box: ~ 500 g Deep Space Cell Box: ~ 1 kg (depending on design)
Volume of hardware	Deep Space Health Box: ~ 20 cm x 30 cm x 30 cm Deep Space Cell Box: ~ 40 cm x 30 cm x 30 cm (for both: estimation, miniaturisation might be possible)
Accommodation (e.g. internal/external)	Internal
Power required	Yes
Data generated	Fluorescence intensities / fluorescence microscopy images
Pointing/viewing/line of sight needs	None
Communications needed	Depending on setting (can be remote controlled)
Duration of experiment	Hours, can be repeated
Crew tasks (if needed)	Taking of buccal epithelial samples Blood sampling Collection of hair follicles Integration of cell culture experiments / download
Access and servicing by crew (if needed)	Yes
Need for retrieval and return to Earth	No (astronaut samples) Yes (depending on experiment type)
Specific orbit needs (if any)	None
Operations without crew (if any)	None

HEALTH EFFECTS AND PHYSICO- CHEMICAL PROPERTIES OF LUNAR REGOLITH

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Scientific Domain: Life Sciences

Idea Description - While Mars expeditions are being planned, the moon is considered the natural gate for future interplanetary missions. The Deep Space Gateway could be the first platform from which human exploration of the Solar System can set forth. Moreover it could allow the crew to access and explore the moon surface in order to increase our knowledge about environmental conditions on the Earth satellite and evaluate the feasibility of infrastructures on it.
Based on reports of astronauts of Apollo missions and studies performed so far also using Lunar Dust Simulant (LDS), lunar dust can cause inflammation and irritation, leading to ocular, respiratory and skin diseases [Lam et al., 2002; Latch et al., 2008; Loftus et al., 2010, Linnarsson et al 2012]. Therefore, in view of exploration activities of astronauts on the moon surface, the study of lunar dust properties and its possible toxicity is mandatory.
Lunar dust has very peculiar properties: it is fine-grained, adhesive, pervasive, abrasive, rich in iron particles which give magnetic properties. As far as toxicity is concerned, our previous in vitro studies, carried out using LDS, demonstrated that the dust particles are internalized by human airway epithelial cells and skin fibroblasts, where the particles accumulate and induce morphological changes and cell membrane damage [Sundaresan et al., 2016; Sundaresan et al., 2011]. Moreover, we found that LDS induces significant alterations in fibroblast functions involved in wound healing processes, where fibroblasts play a key role. In further studies, carried out on an in vitro model of wound healing (scratch test) we observed a significant decrease in the functional ability to heal a scratch by fibroblasts exposed to LDS [Monici et al.; 2012]. These results agree with other reports in attributing to lunar dust a significant toxicity towards respiratory system and skin and suggest that, in case of wounds, burns, abrasions, lunar dust could affect the healing process by interfering with all the cellular components of the interested tissue.

Aim of the study – 1) Get more information on physical-chemical properties of lunar dust and its toxicity. The knowledge of physical-chemical properties allow to better understand the interaction between lunar dust particles and cells. 2) Get more information on the effects of dust particles on different cells (airway epithelial cells, fibroblasts, endothelial cells, keratinocytes, keratocytes), also evaluating effects due to accumulation within cells and the extracellular matrix.

Proposed activity - Lunar dust samples collected during exploration activities on the moon surface in Deep Space Gateway missions will be analyzed in order to:

1. Characterize the most relevant physical-chemical properties of dust particles.
   - The hydrophobicity (or hydrophilicity) of the regolith particles, as well as the modification rate of this property under atmospheric oxidation, will be firstly examined. Dust exposure and inhalation could have a range of toxic effects on human lunar explorers. Dust particles penetrate the body through different routes (e.g., skin, systemic circulation, mucous coats). Once the surface of a particle is in contact with body fluids, cells or tissues, the rate of penetration/repelling depends on the characteristics of the particle surface, in particular the wettability of the particle with respect to the physiological milieu.
   - When smallest particles enter a physiological liquid (blood or mucous coats) they diffuse and/or move in the fluid stream. This movement is governed by several main transport phenomena: in the case of a thermal non-uniformity within the liquid, the process of thermodiffusion occurs; while in presence of an electromagnetic non-uniformity, the phenomenon of electrophoresis takes place. Further, the dust particles interact with large molecules, such as DNA, which are in their turn moved in temperature gradients. Hence, the other essential characteristics to study are the transport properties of dust particles in simulants of human body fluids, mainly the coefficients of diffusion and thermodiffusion (plus potentially electrophoresis).The results may suggest safe particle removal from the

human organism, applying thermodiffusion (electrophoresis) to extract dust particles from affected body parts in a controlled way.

2. Evaluate toxicity towards the respiratory system, cardiovascular system, eyes and skin using human lung epithelial cells, endothelial cells, skin fibroblasts, keratinocytes, keratocytes, immune cells and in vitro models of wound healing. On these different cellular models dust toxicity and effects on cell morphology/function will be evaluated.
Inflammation models will be used to evaluate the effect of particles on physiopathological conditions accompanying acute events as wounds and infections. For example, since endothelial cells come in contact with absorbed material circulating in blood, the effects of dust on cultured endothelial cells will be monitored per se and in the presence of inflammatory stimuli to mimic a physiopathological condition of tissue damage. We will investigate inflammation specific functions, including cellular stress such as oxidative stress caused by different dust concentrations. Allergenic responses will be addressed via immune dysfunction and cardiovascular damage assessment (HERO) via oxidative stress, DNA damage and cardio biomarker ELISAs. Silica will be used as a positive reference material and Titanium dioxide will be used as a negative reference material. Specifically, we will assess the cellular DNA damage causing ability of Titanium dioxide, Lunar dust or LDS, and Silica quartz on specific viral shedding immune cells and normal immune cells. DNA damage, will be determined utilizing F.L.A.R.E. (comet) Assay Kits with DNA repair enzymes (h OGG1 , and formamidopyrimidine-DNA glycosylase(FPG)) to assess the type of damage. We will also assess (by ELISA) inflammatory biomarkers such as VEGF and PlGf- induced to spill into supernatant when perturbed by lunar dust. Cell morphology, cytoskeletal and extracellular matrix proteins will be evaluated by immune-fluorescence microscopy. Cocultures of endothelial cells and fibroblasts will be used to study wound healing (scratch assay, pseudocapillary organization) and release of an response to inflammatory and angiogenic proteins as VEGF.

Group Expertise – The study is based on the collaboration between researchers from the physical- and life science fields. The research group from the University of Brussels has got extensive experience in space studies, having conducted experiments measuring diffusion and thermodiffusion on board the International Space Station (ISS). In particular, the forthcoming experiment DCMIX4 on the ISS will measure thermodiffusion in the liquid with nanoparticles**.** Dr. Monici has expertise in the role of physical factors (gravity, light, mechanical stress, etc…) on biological processes. The laboratory of Dr. Sundaresan has expertise on the assessment of inflammatory biomarkers in microgravity and high altitude environments. Dr. Morbidelli expertise is grounded on endothelial and stromal cell activity during wound healing and angiogenesis. In addition she has experience on synthetic nano and micro-particle bioavailability for tissue healing and drug delivery. Drs. Sundaresan and Monici have collaborated over the past 6 years. Together they will gather inflammatory and immune oriented functional data in ground based studies on the LDS, silica quartz and titanium dioxide in lung airway cells, immune cells and fibroblasts. Since 2005, Drs. Morbidelli and Monici collaboration is ongoing on the characterization of simulated gravity conditions on both endothelial and fibroblast behavior.

Impact – This research is expected to provide relevant information concerning toxic effects of lunar dust on human organism and the connection to its physical-chemical properties. The findings will be useful to better understand the risk associated with exposure to lunar dust. Moreover, the results will help to validate toxicity markers. The information, methods and techniques deriving from the study can be applied to the risk assessment of different types of dust (mars dust, fine dust on Earth, etc…).

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Estimated experiment properties	Description
Mass of hardware	
Volume of hardware	
Accommodation (e.g. internal/external)	
Power required	
Data generated	
Pointing/viewing/line of sight needs	
Communications needed	
Duration of experiment	
Crew tasks (if needed)	The collaboration of the crew is required to collect and storage lunar dust samples
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	
Specific orbit needs (if any)	
Operations without crew (if any)	

MANIPULATION AND IRRIGATION OF SELF-SUSTAINED GREENHOUSES

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Scientific Domain:

Planetary Exploration, Life Support, ISRU, Life Sciences, Physical Sciences, Greenhouse, Robotics.

Idea Description:

We suggest to use the Deep Space Gateway (DSG) spacecraft as an enabling platform to demonstrate long time functionality under different gravitational environments of a self-sustained greenhouse and to solve the problem of providing critical resources such as water, oxygen and food to humans in space, where harsh climatic conditions impede farming and easy access and where water supply, temperature and radiation are a challenge. We focus the proposal on research studies that demonstrate the technologies which are critical for self-sustained greenhouses in a representative gravitational, thermal and space radiation environment where solar panels can be used to provide power for temperature compensation and illumination of plants. Special attention should be payed to investigating in-situ the performance of soils, and the bacteria that live within, which are critical for the growth of more complex, healthy plants. Its location in the lunar vicinity, and outside of the Earth's deep gravity well and magnetic field allow it to be used as a representative staging post for exploration missions to the lunar surface and eventually to other deep space destinations including Mars.

Objectives, instrument requirements and role of the crew: Our greenhouse proposal is based on solid opaque partially pressurized greenhouses that can screen the harmful space radiation. This system shall be able to work both at ambient pressure and in de-pressurized conditions (research has shown that plants can grow optimally also under hypobaric conditions between 20 and 100 kPa). Ideally greenhouses should be scalable and self-sustained. Operating a greenhouse in space, the Moon or Mars, at low internal pressure reduces the pressure differential across the structure, saves structural mass and reduces leakage and complexity but impedes the access of humans to it without aided systems. Alternatively, at an initial stage the greenhouse prototypes could be at ambient pressure and within the Gateway.

Illumination for photosynthesis can be easily provided with lamps fed by solar panels (or the Gateway). Energy is also required to feed the **thermal control** and the **pressurization** of the environment. Because water availability is scarce, irrigation should be done in a self-sustained, efficient manner that minimizes losses, if possible, obtaining water from local resources (ISRU on Mars, as in HABIT, see Figure 1). On Earth this is done using **capillarity** and irrigating the plants from below as needed with nutrients which can be added if needed. The activity of the soils and the atmosphere of greenhouse should be monitored with a set of sensors, **including RH%, ORP, O_2 and CO_2 emissions, temperature, radiation, gravity, pressure and electrical conductivity** (to quantify the wetting level of soils) and the evolution of the crops should be monitored with **cameras** and supported by the **robotic aid**, to allow for remote operation, see Figure 1. The robotic hand shall be operated, for instance with a glove, by an operator that is located away from the greenhouse. The crew would occasionally verify functioning of the critical systems and collect the harvest whose slow self-sustained evolution has been monitored by the robotic hand, the cameras and the sensors. The crew would also participate on tests of operation of the robotic hand on orbit, or for teleoperation on the moon.

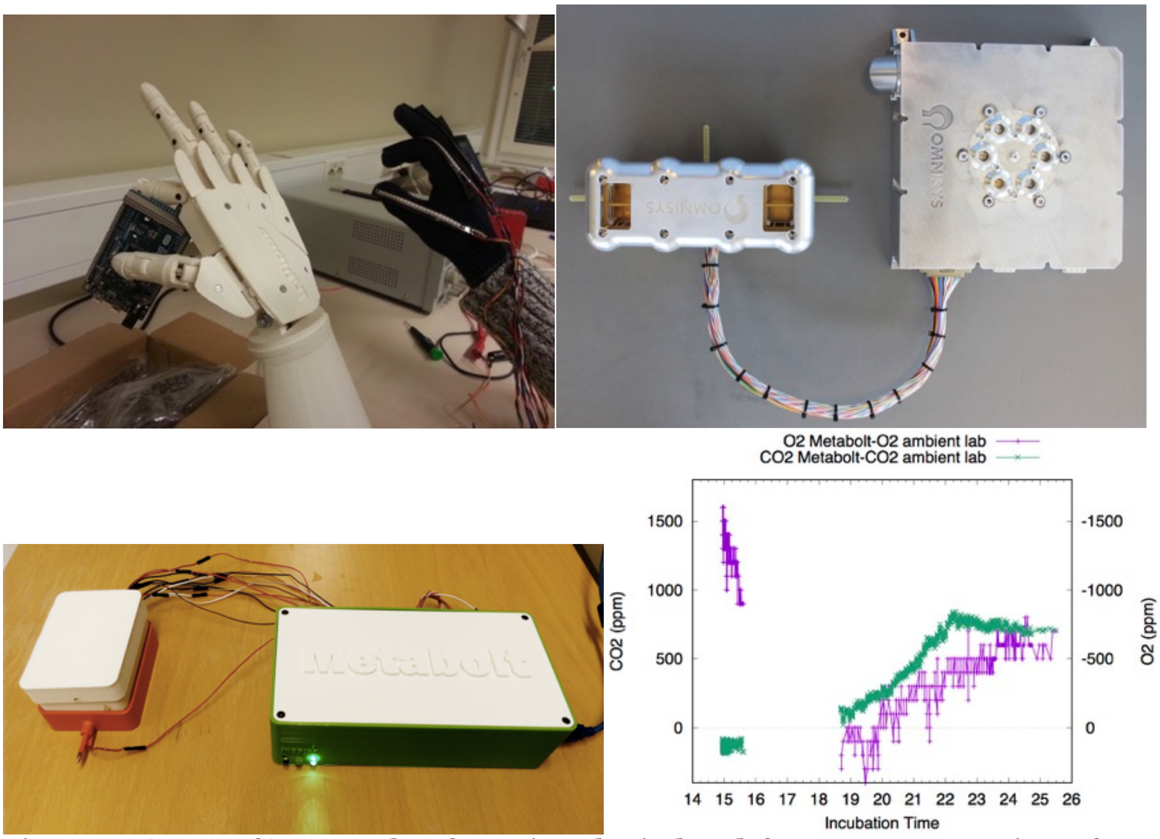

Figure 1: (Top-Left) Example of LTU´s robotic hand for remote operation of greenhouses. (Top-Right) Engineering model of the water-farming instrument HABIT, of the ExoMars project for Mars (photo credit Omnisys/LTU). (Bottom-Left) Example of the LTU´s small-size greenhouse prototype (Metabolt) where soil activity and atmospheric changes are monitored by sensors. (Bottom-right) Example of LTU´s real time monitoring of CO2-O2 changes caused by bacterial soil respiration (Metabolt data).

Benefits: Sustaining a greenhouse will allow to produce O2, for crew respiration in addition to food products. In particular, green plants need healthy soils. Monitoring the cycle of fixation of nutrients, release of metabolites, oxidation-reduction reactions in the soils caused by bacteria under low-g environments and the role of water diffusivity and capillarity on this activity will be critical. Once these infrastructures have been investigated aboard they can be later on operated remotely from Earth, extended for Moon-surface teleoperation and be used as a demonstrator for self-sustained greenhouses for the Moon, Mars or other outer Earth environments. Demonstrating the correct remote operation of robotic hands with low-risk, but continuous, actions will allow to improve our understanding of the operability of an anthropomorphic robotic hand by humans under different g (for servomotors), the longevity of mechanical parts, and the role of human perception of the transferred movements under perturbed gravitational forces and time delays caused by the transmission.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	Robotic hand 1 kg. Metabolt controlling unit 1 kg. Soil mass 1 kg. Pressurized chamber weight: depends on configuration (outside or inside the gateway). If power is supplied by the DSG then no need for solar panels.
Volume of hardware	At a minimum a chamber of about 0.5 m x 0.5 m x 0.5 m should be used.
Accommodation (e.g. internal/external)	It can be placed outside the gateway in connection with a pressure system and thermal control, or inside the Gateway (but then there is no exposure to space radiation).
Power required	Unknown yet, but it shall be minimized to make the greenhouse efficient and sustainable by solar panels.
Data generated	Both scientific and health-system data.
Pointing/viewing/line of sight needs	If power is self-supplied by solar panels, transient view of Sun.
Communications needed	Downlink of images and data. Uplink of instructions for the robotic hand.
Duration of experiment	Two weeks at a minimum, for bacterial soil respiration monitoring, to one harvest-year for plants. Longer duration experiments may be more representative of long-time operability of greenhouses, the nutrient cycle, life-form mutations and sterilization by space radiation caused by more possibility of exposure to high-radiation events.
Crew tasks (if needed)	Not needed for the baseline operation. Can provide support testing the operation of the robotic hand. Can take the harvest when the experiment is finished and replenish nutrients in the soil and water to the external irrigating bottle if finished.
Access and servicing by crew (if needed)	At the beginning and end of the experiments.
Need for retrieval and return to Earth	Not needed. But it would be very interesting if the soil, bacteria in the regolith and harvest are investigated on Earth after the growth on orbit and compared with controlled experiments on Earth.
Specific orbit needs (if any)	none
Operations without crew (if any)	Remote operation (camera and robotic hand operation)

LUNAR REGOLITH FOR PLANT-BASED LIFE SUPPORT

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Scientific Domain:
Life Sciences

Idea Description:
Human beings are uniquely qualified to undertake key scientific investigations in the space environment, ranging from life and physical sciences research in microgravity, to geological and biological fieldwork on planetary surfaces (Crawford & Cockell, 2005). Human-based exploration of the Moon and Mars will greatly accelerate the pace of scientific discovery relative to what can be achieved robotically (Crawford & Cockell, 2005).

For human mission durations that extend beyond one or two years, resupply of large volumes and masses of food, water, and atmospheric gases becomes unrealistic (Barta & Henninger, 1994). Therefore, long-duration future habitation of space involving great distances from Earth and/or large crew sizes (for example a lunar outpost or a Mars base) will require a controlled ecological life-support system to simultaneously revitalize atmosphere (liberate oxygen and fix carbon dioxide), purify water (via transpiration), and generate human food (in the form of cereals, legumes and oilseeds) (Mitchell, 1994).

Photosynthetic higher plants are able to provide key roles in several of these essential processes, including atmosphere regeneration, wastewater recycling and food production. For larger and longer-term habitats on the Moon or Mars, additional benefits from plants include construction materials, fabrics, medicines, dyes, lubricants, biofuels, well-being and aesthetics. A first attempt to design and research larger-scale life support systems was made in Arizona in 1991. For two years, the Earth-based closed ecological system Biosphere 2 supported over 3000 documented species of plants and animals in a number of ecosystems patterned after natural biomes (e.g. rainforest, savanna, desert, fresh-water and salt-water marsh and coral reef oceanic systems) as well as an intensive agriculture system and a human habitat (Poynter & Bearden, 1997; Allen *et al.*, 2003).

Since plants will play several key roles in long-term life support systems on other planetary surfaces, it is crucial to know how they should be grown in such systems. The use of *in situ* regolith as a seed germination and plant growth substrate may have several advantages over hydroponic systems, such as the immediate bioavailability of plant essential ions, low-tech mechanical support for plants, and easy access to *in situ* materials once on the surface (Ming & Henninger, 1989; Schuerger *et al.*, 2002). However, the growth of certain plant species may be reduced by phytotoxic substances present in the regolith, such as high levels of soluble magnesium sulphate minerals found in various locations on Mars (Visscher *et al.*, 2010).

Although no sample return missions have ever taken place for Mars to date, approximately 380 kg of lunar material was collected and returned to Earth during the

Apollo spacecraft era. A review of the subsequent experiments performed with some of this material shows that none of the studies accomplished so far have used pure lunar substrates for seed germination and plant growth analyses (Ferl & Paul, 2010). In all tests, seeds and plants were grown "in contact with" rather than "in" lunar samples (Ferl and Paul, 2010). Based on these findings we can conclude that future research addressing the use of *in situ* regolith for plant growth on the Moon is dependent on access to sufficient amounts of planetary material.

By using the Deep Space Gateway as an enabling platform, we propose to investigate the plant growth potential of pure lunar regolith samples that will be collected and returned to Earth from several locations on the Moon differing in geochemical composition. In addition, we aim to assess potential differences in responses to lunar regolith between plant species by selecting a range of species representing wide taxonomic diversity, climatic zones, habitats, life forms, seed characteristics (including internal nutritive tissues) and plant uses.

In order to achieve our objectives, we would require several collection missions to the lunar surface using the Deep Space Gateway. Following each collection of surface materials, the lunar regolith is proposed to be stored inside the Deep Space Gateway until the arrival of the next available return vehicle from Earth (e.g. Orion). The possible involvement of the crew depends on whether, and to what extent, the tasks outlined above could be done robotically and remotely controlled from Earth.

Once the returned lunar regolith arrives in our laboratories, we will be able to generate unique and comprehensive data sets by drawing on our scientific expertise in comparative seed and plant biology, in combination with access to >30,000 species available as seed through Kew's Millennium Seed Bank Partnership. The expected results will lead to conclusions regarding the suitability of lunar regolith as a substrate for seed germination and plant growth in biodiverse life support systems on the moon.

Information of this kind is essential to the design and technical requirements of long-term moon bases, as it may impact the decision to include *in situ* resources such as lunar regolith, and, if so, for what processes (seed germination and/or plant growth) and what plant species (in case species vary in their performance). In addition, it may influence the location of a potential moon base (depending on differences found between regolith samples of varying geochemical composition).

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Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	Mass of collected planetary material: as high as possible.
Volume of hardware	Volume of collected planetary material: as large as possible.
Accommodation (e.g. internal/external)	Internal
Power required	N/A
Data generated	N/A
Pointing/viewing/line of sight needs	N/A
Communications needed	N/A
Duration of experiment	Multiple collections of planetary material: from at least three different lunar sites if possible.
Crew tasks (if needed)	Collecting and returning of planetary material (unless this is done without crew; see below).
Access and servicing by crew (if needed)	N/A
Need for retrieval and return to Earth	Yes: retrieval and return to Earth of collected planetary material.
Specific orbit needs (if any)	Suitable for access to the lunar surface to enable collection of planetary material.
Operations without crew (if any)	Collecting and returning of planetary material (unless this is done by the crew; see above).

PERSONAL SYSTEMS FOR CREW ENHANCED SPE PROTECTION (PSYCHE)

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Scientific Domain:
Life Sciences, Physical Sciences

Idea Description
Background

Space radiation is a key limiting factor for human missions in deep space. Besides the risk of long-term detrimental health effects due to galactic cosmic rays (GCRs), the crew needs to be protected from solar particle events (SPEs) - huge fluxes of particles, mainly protons up to 100's of MeV. Exposure to such events can lead to mission impairment and immediately endanger astronauts' life. Differently from high energy galactic cosmic rays, solar particles are easier to be shielded passively: the most promising solutions are those based on the optimal usage of resources available on board, and on a selective shielding strategy, designed to provide a varying degree of shielding to different body areas, focusing on the most radiosensitive organs (such as blood forming organs - BFO). Multifunctional and personal radiation protection systems are in development and proposed, at different stages, for Deep Space Habitats, entailing:

- Crew quarters with "storm shelter" capability, shielded via water and wastewater storage walls;
- Wearable flexible jackets, fillable with water and allowing astronauts to perform emergency operations outside a radiation shelter during the SPE, such as in the PERSEO demo project;
- Sleeping bags similarly conceived, providing additional protection also in nominal conditions during astronauts' sleep period.

For effective mitigation of SPE-related risks and for supporting crew operations, personal protection systems should be associated with SPE monitoring and forecast / now-cast / warning systems, such as AMORE, which become fundamental when missions are carried out in deep-space, far away from Earth based monitoring systems.

DSG would be the best platform to experimentally study these systems, providing ground for testing their shielding efficacy, practicality and ease to use, and for radiation transport models validations.

Objectives

The PSYCHE idea, regarding the area identified in the call as "Understanding the Effects of Deep Space Radiation", has the following objectives:

*Deepen our **understanding of the effectiveness** and actual ease of use of **innovative personal SPE protection systems** for humans in deep space, via the realization of actual **flight demonstrators** of such systems, associated with appropriate **radiation detectors**, and radiation **transport modelling**, for correlation and validation of such models and determination of residual risk.*

*The achieved understanding will enable optimal crew protected operations in case of SPEs, in **combination with warning systems**.*

In more detail

We want to study, for the first time in a human habitat in deep space, innovative personal and flexible SPE protection systems, based on the use of available water, thus limiting at most the launch mass; we want to test the actual health risk reduction effectiveness of different versions of such systems, measuring dose rates and dose equivalent rates with a set of radiation detectors positioned in different areas of interest, both unprotected and protected (i.e. inside and outside the protection systems).
The study will entail the following activities.

1) Realize actual flight demonstrators of innovative personal SPE protection systems:
   a) Simple geometry (rectangular, tubular) water flexible bags, multifunctional in their own nature of fluid storage for crew life support, and SPE shielding;
   b) Next generation flexible and inflatable jacket and sleeping bag. PERSEO, funded by ESA (Ariadna initiative) and ASI (Bando Volo Umano Spaziale), led to the development of a prototype of radiation protection garment for use in pressurized space habitats: the garment can be filled with on-board water at need, allowing for low launch masses, and thus shielding astronauts' most radiosensitive organs during SPEs. Water can be recycled after use, thus optimizing the use of available resources. The prototype will be tested by the ESA astronaut Paolo Nespoli on the ISS, during the VITA mission. The lessons learned from this demo will allow us proceeding towards a next-generation ergonomic jacket and a sleeping bag, in collaboration with other non-space industrial partners, with the goal of testing it on the DSG.
   c) The personal protection system may embed a set of miniaturised active detectors for real time studies of shielding effectiveness and of the effects to, and due to, the astronaut's body.
2) Provide a first evaluation in a space habitat of the detailed shielding capabilities of personal protection systems possibly using appropriate phantoms (such as Matroshka) and novel, low power, newly developed active detectors to be used also in conjunction of these phantoms. These detectors should be able to perform broad range nuclear discrimination and LET spectra. Collaboration with other European groups to maximize efforts and results would be envisaged in this case.
3) Perform radiation transport modelling with Monte Carlo codes, for comparison with dosimetry measurements and validation of the shielding strategy, so that residual doses, dose rates and their biological weight can be determined, and possible related health effects assessed. This would also allow the validation of transport codes through the habitat structures and PSYCHE systems.
4) Devise optimal crew protected operations in case of SPEs, in combination with warning systems, such as the AMORE system (Note: Amore, or Cupid, and Psyche were meant to be joint, as originally conceived by Lucius Apuleius and beautifully represented by A. Canova. In our contest, AMORE is another idea proposed for this call). Emergency procedures following a SPE warning will have to be performed in quasi-real time and, when in interplanetary missions, with no support from Mission Control due to the large communication delay. DSG is the best platform to master these procedures in view of these voyages.

Equipment to be developed or adapted:

1) set of simple geometry (rectangular, tubular) water bags, fillable on the DSG, allowing easy positioning on detectors for dosimetric measurements;
2) ergonomic jacket and sleeping bag, fillable with water on the DSG, for measurements on detectors and phantom, and for crew testing;
3) novel miniaturised, low power, modular, active detectors to be placed in such a way to provide a mapping of doses and achieved dose reductions, with the possibility of being embedded in the newly developed protections systems;
4) simulation tools for validation of doses and assessment of related residual SPE health risk.

Role of the DSG crew in performing the research

- Filling, emptying, and positioning the water bags in different locations, on phantom and detectors;
- Testing the comfort of the provided personal protection systems and the easiness of filling/draining procedures.

Expected impacts

The research will provide several important advances aimed at **understanding and mitigating radiation risks for enabling human space exploration**:

- support the minimization of SPEs radiation risks using resources available in the space habitat;
- permit to estimate the residual doses and dose rates after shielding and assess related health risk;
- contribute to an automated radiation protection management system, testing the ability of employing autonomously the most effective countermeasure at the right time.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	< 10 Kg
Volume of hardware	< 40 l
Accommodation (e.g. internal/external)	internal
Power required	< 10 W for detectors (using batteries)
Data generated	Detectors measurements
Pointing/viewing/line of sight needs	No
Communications needed	Nice to have for crew demos and detectors data
Duration of experiment	Long (addressing SPEs), part of it during solar max conditions
Crew tasks (if needed)	Set up (on detectors), filling and testing of wearable systems
Access and servicing by crew (if needed)	Access to the H/W (internal), no servicing
Need for retrieval and return to Earth	Nice to have
Specific orbit needs (if any)	No
Operations without crew (if any)	No

INFLAMMATION MARKERS IN SUBJECTS EXPOSED TO DEEP SPACE ENVIRONMENT

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Scientific Domain: Life Sciences

Idea Description

Progressively accumulated molecular and epidemiological evidence suggests inflammation to be not only a well-known reaction to any viral or bacterial attack, but also an accompanying feature of a broad range of non-infectious diseases. In fact autoimmune disorders (e.g. rheumatoid arthritis), cancer, diabetes, cardiovascular diseases (e.g. atherosclerosis, dyslipidemia, high blood pressure), and neurodegenerative diseases~~)~~ may all be related to low grade chronic inflammation. The latter has been also shown to lead to a feedback cycle involving increased visceral adipose tissue release of inflammatory cytokines (e.g. interleukin-1β(IL-1β), IL-6, tumor necrosis factor alpha, γ-interferon) and decreased production of the anti-inflammatory peptide adiponectin (Ouchi et al., 2011;~~;~~ Catalán et al., 2013; Paragh et al., 2014; Martyniak and Masternak, 2017; Ruscica et al., 2017). On the other hand, acutely occurring inflammation plays an important role in physiological processes, as wound healing, tissue repair, regeneration and remodeling. In greater detail, inflammation *per se* prompts the healing mechanism and strongly regulates its subsequent phases. Therefore, the smooth progression of any inflammatory reaction is a key factor in the complex process leading to successful healing, which is typically represented by the regeneration of a fully functional tissue. In the absence of that, pathologic changes are expected to occur, ranging from chronic ulcers to fibrosis. During long term missions astronauts experience problems related to isolation-confinement, cosmic radiation and gravity unloading. With reference to the latter, several undesirable consequences have been described since the very beginning of the space era, including bone loss, muscle atrophy, immune response impairment, nervous system functional derangement, cardiovascular deconditioning, metabolic dysregulation, etc… (Lane and Smith, 1999; Strollo, 1999). All of them represent models of a series of chronic diseases commonly observed on Earth and typically sharing the same pathophysiological mechanisms, namely vascular dysfunction, oxidative stress and chronic inflammation (Mancuso 2016; Nishida and Otsu, 2017). Our data on endothelial and stromal cells cultured in modeled microgravity (RPM and RCCS) document impaired endothelial functioning and survival (Morbidelli et al., 2005) and fibroblast dysfunction, inducing the release of several inflammatory markers, including products of the cyclooxygenase pathway, like prostanoids, and white cell adhesion proteins (Cialdai et al., 2016). Studies performed by our group on human volunteers kept in isolation during the MARS-105 mission showed glucose metabolism alterations and suggested environmental stress to have a strong impact upon metabolic and stress response (Strollo et al., 2014).

Aim of the study and proposed activity

The future manned missions on the Deep Space Gateway represent an unique opportunity to evaluate inflammatory and oxidative stress markers in biological samples from human subjects undergoing long-duration missions and exposed to deep space radiation and fractional gravity. Blood, salivary and urinary samples will be collected at 0, 10 and 30 days in microgravity, immediately after the mission and 30 days after returning to Earth, to evaluate eventually occurring inflammation marker changes during the flight as well as the time course of their recovery, if any. To detect and follow-up any signs of low grade inflammation, we propose to analyze cellular biomarkers (leukocyte and platelet counts and granulocyte/lymphocyte ratio) along with plasma levels of circulating inflammatory peptides like C-reactive protein, all the above mentioned cytokines and CD44, a transmembrane adhesion molecule strongly linked to phlogosis. Moreover, in order to determine the role of lipid derived pro-inflammatory and anti-inflammatory mediators and their role in the inflammatory process during space flight, lipidomics analysis will be studied on plasma of crew members. In fact it is well known that omega-3 poly unsaturated fatty acids (PUFA) displays potent anti-inflammatory properties, by inhibiting leukocyte chemotaxis, adhesion molecule expression and leukocyte–endothelial adhesive interactions, production of eicosanoids like prostaglandins and leukotrienes from arachidonic acid, production of inflammatory cytokines, and

T-helper 1 lymphocyte reactivity. In addition, PUFA give rise to eicosanoids that have different biological potency and might generate a plethora of mediators with anti-inflammatory and inflammation resolving activity. Metabolic markers including adiponectin, leptin, irisin, glucose and insulin will also be measured in blood at the same time-points and compared with pre/post-flight whole body bioimpedance assessed fat free mass changes. Similarly, the total antioxidant capacity (TAC) and total oxidant status (TOS) will be evaluated in sera. To assess their tissue availability, we will also test salivary concentrations of the same markers expected to enter saliva independent of any active transport mechanisms: if logistically feasible, due to its easy sampling and handling, saliva could be collected at the same time points as blood as well as at shorter intervals for optimal process evaluation and follow-up. Urine will be also collected on blood sampling days to allow 8-isoprostane (8-iso) and F2-isoprostanes (F2-IsoPs), 8-hydroxy-2'-deoxyguanosine (8-OHdG) to be measured as reliable biomarkers of oxidative stress and lipid / DNA damage.

Impact

This research is expected to provide patho-physiologically and therapeutically relevant information concerning:

- wound healing and the biological response to injury and infections in deep space environment;
- possible relationship with inflammation and insulin resistance.

The information obtained can help to develop models on the evolution of inflammation in deep space conditions and can have a strong impact in planning medical care procedures, life support systems and therapeutic strategies for future interplanetary missions.

Moreover, the research findings will help to validate inflammatory and redox markers in biological fluids in different chronic pathologies mainly affecting old and/or sedentary people, to be correlated with disease degree and efficacy of treatments.

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Estimated experiment properties	Description
Mass of hardware	
Volume of hardware	
Accommodation (e.g. internal/external)	
Power required	
Data generated	
Pointing/viewing/line of sight needs	
Communications needed	
Duration of experiment	
Crew tasks (if needed)	The collaboration of the crew is required in terms of: • Consent to collection and use of their biological fluids for research purpose. • Consent to the withdrawals (*). • Involvement in proper sampling and proper handling and storage of samples.
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	
Specific orbit needs (if any)	
Operations without crew (if any)	

(*) The number and timing of the withdrawals proposed in the text can be modified depending on duration of missions and astronaut's activities

DEVELOPMENT OF A SYSTEM FOR LASER THERAPY IN SPACE

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Scientific Domain: Life Sciences

Idea Description

The Space Agencies know that the planning of future space exploration missions requires the concomitant planning of new concepts for medical care in space. Stay in the deep space for months, without the possibility of returning to Earth quickly and with limited possibility to have a direct reply when asking for the advice of a physician, requires on board the presence of technologies, therapeutic strategies and procedures to manage emergencies and all the various health problems, serious or minor, which may occur. Of course, great efforts are focused on serious problems, as trauma care and surgical emergencies, because they threaten the survival of the crew members. However, also mild health problems deserve attention, because they will be quite frequent (of course, much more frequent than the serious ones) and may compromise psycho-physical well-being and performance of the crew members.

In missions performed so far, the 75% of astronauts had minor health problems during missions and used drugs. About the 60% of the problems was due to Space Adaptation Syndrome and sense organs. But, among all the other problems, over the 30% was connected with minor trauma and musculo-skeletal system (for example, low back pain). On Earth, we can choose among many different therapies to counteract these problems. Often, drugs are associated with physical therapies to fasten the healing. Sometimes, with the opinion of the physician, drugs are replaced by physical therapies to avoid drug side effects. In order to provide medical care close to the terrestrial standards in the future space exploration missions, the development of new technologies and therapeutic strategies is needed. On the basis of the expertise of team members on laser therapy, astronauts' health problems and Kayser Italia experience in the development and qualification of instruments and payloads for space applications we propose the development of a laser system that could be applied on space vehicles and space bases.

The literature on laser therapies and underlying action mechanisms is extremely wide. Sometimes data and results appear controversial and difficult to interpret. It is mainly due to the very different experimental conditions (in particular the type of laser source and treatment parameters) which are used in the studies. However, laser therapy has been used for many years in various fields of medicine and has demonstrated its effectiveness in treating many different diseases [Enwemeka et al., 2004; Chow et al., 2011; Bjordalet al., 2003; Jang andLee, 2012].

The laser system we propose will be based on specific high power laser sources emitting in the Near Infrared (NIR) region of the electromagnetic spectrum. The action mechanisms underlying the therapeutic effects of these laser emissions have been studied in depth in our laboratories. On Earth, laser systems based on these sources are effectively applied to treat musculo-skeletal diseases, including those derived from trauma, some skin and mucosa diseases (for example *candida* infections), lesions and wounds (to fasten healing and avoid fibrotic scars).

The possibility to apply laser therapy in so many different pathological conditions depends on the effects that these NIR wavelengths have on some important biological processes such as inflammation, pain perception, cell energy metabolism, extracellular matrix turnover, etc… Studying the proteomic profile of myoblasts exposer to laser radiation, we observed that the treatment induced the increase of NLRP10, an anti-inflammation protein that inhibits the production of interleukin 1β, one of the most known pro-inflammatory factors [Monici et al., 2013a]. Inflammation is present in many different patho-physiological conditions, from musculoskeletal and traumatic problems to wound healing and infectious diseases. The powerful anti-inflammatory action contributes to decrease pain symptomatology and restore the endothelial function and microcirculation in the diseased tissues, thus favoring edema resorption. The anti-pain effect is also due to other mechanisms acting on production of anti-pain substances (endorphins), peripheral nerve conduction and transmission of nociceptive stimuli, as demonstrated by the very fast analgesic effect evoked by laser radiation in animal models of persistent pain [Micheli et al., 2017]. Moreover, NIR laser radiation can improve cell energy metabolism through the increase of ATP, ATP-binding proteins and Protein Phosphatase 1 (PP1) [Monici et al., 2013a]. In an *in vitro* model of myoblasts, we demonstrated that NIR laser radiation was effective in counteracting, via increase in phosphatase activity, the impairment in cell energy metabolism induced in the cells by exposure to microgravity, modeled by Random Positioning Machine (RPM) [Monici et al., 2013b]. Moreover, NIR radation emitted by the above sources can affect the ECM turnover [Monici et al., 2011] and inhibits the growth of some microrganisms, such as *candida* [Clemente et al., 2015].

In order to apply laser therapy in space vehicles and bases, laser systems currently used on Earth will be re-designed and developed in order to comply with the interface requirements of the Deep Space Gateway, the operative constraints and the safety requirements for opto-electronic devices to be used by the crew.

The availability of such a technology in space could offer to the crew a physical therapy that, alone or associated with drugs, is effective in many different non-emergency, but quite frequent diseases. Moreover it is easy to use, after appropriate training, no painful, non-invasive and safe, when properly used. The use of laser therapy can prevent or reduce the use of drugs and their side effects.

Outcomes

Support to space exploration missions through implementation of new therapeutic strategies and improvement of psycho-physical well-being and performance of the crew.

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Estimated experiment properties	Description
Mass of hardware	
Volume of hardware	
Accommodation (e.g. internal/external)	
Power required	
Data generated	
Pointing/viewing/line of sight needs	
Communications needed	
Duration of experiment	
Crew tasks (if needed)	In case this idea is selected and the proposed laser system is implemented, the collaboration of the crew is required as follows: Each time a crew member uses the devices should fill a questionnaires (pain scales and functional scales) to assess the effectivenes of the treatment.
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	
Specific orbit needs (if any)	
Operations without crew (if any)	

USE OF PORTABLE ALGORITHM BASED SOFTWARE IN MEDICAL EMERGENCIES DURING DEEP SPACE MISSIONS

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Scientific Domain:
Life Sciences and Medicine.

Idea Description:
Current standard operating procedures and checklists in use for the management of medical problems on the ISS have scope for significant improvement in terms of user friendliness, speed of access and portability. To date, most medical issues have been managed satisfactorily with existing systems, in conjunction with communication with ground-based medical support staff.

Future long duration exploration missions to the Moon or Mars will render communications with Earth-based teams much more limited, and make crew evacuation more problematic, meaning that a greater degree of medical autonomy must be planned for to maximise the chances of mission success and crew survival. Longer, more distant missions will also increase the chances of a medical or surgical emergency arising, making the challenge of increasing medical autonomy more pertinent.

Terrestrial health care providers are increasingly relying on instant access to information in emergency situations in the form of algorithms, decision aid tools and best practice guidelines. These are now commonly designed in easy to use, graphical, app-based formats, available on handheld electronic devices such as mobile phones and tablets. This improves availability and speed of access to information in medical emergencies in both hospital and pre-hospital fields. Even in common medical scenarios where clinicians may be expected to know specific management from memory, the use of easily available algorithms can be very useful as an aid to memory when stress levels are elevated. To date these systems are regularly used by both authors in the care of acutely unwell patients.

We propose to develop a similar, easy to use "app-style" interface that would allow astronauts to easily access a wide range of medical protocols and other medical information via a small, portable, smart phone sized screen. To reflect the many adverse environments in which a medical problem may arise during a mission, we envisage that this system should be designed to be used anywhere on board a station or during an EVA by being integrated into EVA suit, in order to access data quickly. Within the app, the astronaut could quickly navigate to the required algorithm and access information such as diagrams and drug doses, in order to deal with a given scenario. The app interface could also allow for recording of data relating to the care of an unwell or injured astronaut.

To test efficacy, we would utilise simulation scenarios, comparing the efficiency of current medical algorithm systems to the new system. Ideally, testing would simulate scenarios occurring in different environments such as an orbital station or Lunar/planetary surface.

Our objectives would be to provide faster and more convenient access to information, reduce the time to treatment of an injured or unwell astronaut and increase the confidence of the healthcare provider. Through this proposal, we also aim to increase the medical autonomy of crew during future long duration missions.

Expected equipment and operational needs:

Estimated experiment properties	Description
Mass of hardware	<1kg
Volume of hardware	c.100mls – handheld “touch pad” size
Accommodation (e.g. internal/external)	Portable device. Attachment to EVA suit considered.
Power required	Rechargeable battery
Data generated	Medical
Pointing/viewing/line of sight needs	N/A
Communications needed	TBC
Duration of experiment	6 hours simulation time
Crew tasks (if needed)	Comparing new and existing systems
Access and servicing by crew (if needed)	Accessed on astronaut personal handheld device
Need for retrieval and return to Earth	N/A
Specific orbit needs (if any)	N/A
Operations without crew (if any)	N/A

USE OF HANDHELD DIAGNOSTIC ULTRASOUND DEVICES DURING DEEP SPACE MISSIONS

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Scientific Domain:
Life Sciences and Medicine.

Idea Description:
Ultrasound has found widespread and varied uses in modern medical practice, including diagnostic applications and identification of anatomical structures during procedures. In a critically unwell patient, ultrasound is often utilised to identify signs of life threatening trauma or obtain information about cardiovascular function. Until recently, ultrasound scanning has relied on bulky, large devices that provide limited image quality. More recently, image quality and the portability of scanners have advanced. Ultrasound probes are now becoming available which have compatibility with common hand held display devices including smart phones and tablets.

Both authors have concerns regarding the increased likelihood of trauma in longer duration deep space missions and the associated risks posed to astronaut health and mission success. Astronauts have particular physiological disadvantages should they sustain traumatic injury, in view of the known decrements in bone structure, muscle strength, circulating blood volume, red cell mass and cardiac output experienced through prolonged exposure to microgravity. Furthermore, there are numerous challenges to adequately assessing an injured astronaut, including access constraints presented by EVA suits.

Deep space, long duration mission astronauts will require more robust training in the concepts and use of ultrasound imaging for a wide range of conditions, particularly in view of the impractically long delays in communication with ground-based medical staff. We propose that the new generation of portable, handheld medical ultrasound systems may lend themselves well to deep space mission applications, and offer advantages over existing systems. The new ultrasound probes could be used in conjunction with existing small electronic devices such as tablets and smartphones, posing advantages in terms of the power, mass and volume constraints of mission design. Both authors have recommended the use of these devices for another application, also submitted to ESA.

We envisage that performance assessments would utilise simulated scenarios, looking at:

1. Comparison with current ultrasound equipment

2. Ability to hasten medical decision making
3. Range of potential diagnostic applications
4. Ease of data sharing and communication with ground staff

Our objective would be to evaluate the application of new handheld ultrasound technology as an adjunct to autonomous medical decision making during deep space missions, thereby contributing to minimisation of risks to astronaut health and mission success.

Expected equipment and operational needs:

Estimated experiment properties	Description
Mass of hardware	<1kg
Volume of hardware	<1L
Accommodation (e.g. internal/external)	Internal
Power required	Via attachment to smartphone/tablet
Data generated	Yes
Pointing/viewing/line of sight needs	N/A
Communications needed	Yes – transfer of images
Duration of experiment	TBC
Crew tasks (if needed)	Using of ultrasound equipment on human subjects
Access and servicing by crew (if needed)	Storage with existing medical kit
Need for retrieval and return to Earth	N/A
Specific orbit needs (if any)	N/A
Operations without crew (if any)	N/A

USE OF SPLINTING DEVICES IN THE MANAGEMENT OF TRAUMA DURING DEEP SPACE MISSIONS

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Scientific Domain:
Life Sciences and Medicine.

Idea Description:
Trauma is a leading cause of death in younger adults on Earth. Long duration deep space missions are likely to expose astronauts to an increased risk of sustaining traumatic injury. This risk is compounded by an increased risk of large bone fracture, due to the known musculoskeletal changes which occur through long term exposure to a reduced gravity environment. Future deep space missions will mandate provision for a high degree of autonomous capability in the assessment and management of the traumatically injured astronaut.

In trauma, large blood volumes can be quickly lost from fractures of the pelvis and long bones. The early splinting of such fractures with pelvic binders and long bone splints is vital in the initial management phase, both from the point of view of haemorrhage control and pain management. Furthermore, splinting of such fractures allows for safer transport of an injured patient from a pre-hospital to definitive care environment, reducing the risk of further bone or muscle injury. Current modern splinting devices used by terrestrial per-hospital teams are low in mass and volume, and are generally easy to apply with minimal training.

Numerous factors make the application of splinting devices to the traumatically injured astronaut more challenging. These include: application of splinting devices in a reduced gravity environment and, effective application of splinting devices to an astronaut wearing an EVA suit.

We propose that certain designs of modern, lightweight and compact bone splinting devices may lend themselves well to deep space mission applications, and that further study is required to investigate the application of these devices in various deep space mission scenarios, including EVA. The overall objective of this research would be to improve the chances of astronaut survival following traumatic injury during deep space missions.

Particular areas of interest would include:

1. Suitability of existing terrestrial designs and any design modifications required
2. Ease of use with limited training
3. Consideration of use in different surroundings, gravitational environments and in scenarios with EVA suits

Expected equipment and operational needs:

Estimated experiment properties	Description
Mass of hardware	<5kg
Volume of hardware	<1L
Accommodation (e.g. internal/external)	Internal
Power required	N/A
Data generated	N/A
Pointing/viewing/line of sight needs	N/A
Communications needed	N/A
Duration of experiment	Estimated 1 – 2 hours
Crew tasks (if needed)	Application of splinting devices to simulated casualties
Access and servicing by crew (if needed)	Storage with existing medical kit
Need for retrieval and return to Earth	N/A
Specific orbit needs (if any)	N/A
Operations without crew (if any)	N/A

ELECTRO-MECHANICAL BRAIN PLASTICITY IN LUNAR PROXIMITY: A COMPUTATIONAL STUDY

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Scientific Domain: Life Sciences.

Idea Description:

Aim: Identify brain countermeasures.

Objectives:

1. Electrophysiological and structural changes of the brain within and outside Earth's magnetic field.
2. Identify the reciprocal impact of changes in neural activity on brain structure, including fluid-shift and radiation.

Equipment/ facilities:

With the purpose of collecting bio-signals and no-invasive measurements relative to the brain adaptation (i) with and without gravity and (ii) within and outside Earth's (electro-)magnetic field (EMF):

1. Brain Imaging (Ultrasound [1], MRI (pre and post-flight) [2], Near Infrared Spectroscopy [3], Low resolution brain electromagnetic tomography [4] and EEG).
2. Computational modelling and 3D finite element modelling [5];
3. Smart intravehicular-activity helmet collecting no-invasive signals such as head-temperature, heart rate, venous pressure, breathing and nose blood perfusion.

Impact:

Brain adaptation to different gravitation level has been widely investigated [4]. Recently, published studies reports studies about human brain structure and brain plasticity, in correlation to vision problems, intracranial pressure and sensorimotor adaptation [1], [2], [6]. However, further investigations are needed to link structural changes to space radiation and EMF [7].

Additionally, numerous mechanical events have been experimentally observed in neuronal membrane excitability and are thought to play an important role in regulating neuronal activity [5]. Nowadays, the mechanical features of the neural signalling are thought to be an electrically driven phenomena [8], [9]. Thus, further studies about brain structure must consider electro-mechanical changes at macro and micro scale. Studies, including electro-mechanical features of the brain [5] could be fundamental in advancing the understanding of space radiation on neurological performance and plasticity [7], thanks to the close interaction of high energy particles on osmotic gradient at the cellular level.

Thus, it is urgent to study (i) the electro-mechanical changes of the brain induced by structural alterations at altered-gravity levels, (ii) the corresponding changes of plasticity, (iii) the impact of EMF and (iv) radiations on neural activity and plasticity, (v) investigation of altered perception, (vi) establishing valid countermeasures to preserve neural activity and plasticity, and (vii) identify potential markers of psycho-social alteration of crew members and crew interconnections and performance.

Countermeasure of human performance failure are critical for the success of most aerospace activities. Safety can be improved thanks to a better understanding of neural networking by using computational modelling [5]. Modelling provides timely information to contribute to mission architecture and operation decisions in area where clinical data are lacking and/or the use of medical technology undergoes to restrictions (as in space [4]). Modelling has been successfully applied to address, predict, characterize and mitigate potential risks to health and performance. Benefits from this study arise both for crew safety and mission design/structure. Furthermore, a completed investigation of neurocognitive processes and functionalities might lead to findings about brain damage valuable to Earth's applications (as in the case of traumatic brain injury [10]).

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	Less than 15 kg
Volume of hardware	
Accommodation (e.g. internal/external)	Internal
Power required	Standard
Data generated	
Pointing/viewing/line of sight needs	
Communications needed	With Mission Support
Duration of experiment	All the mission
Crew tasks (if needed)	Acquisition of no-invasive data
Access and servicing by crew (if needed)	Acquisition of no-invasive data
Need for retrieval and return to Earth	Only data are needed
Specific orbit needs (if any)	
Operations without crew (if any)	

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EFFECT OF REDUCED GRAVITY AND MAGNETIC FIELD ON FRUIT VEGETABLE GROWTH AND GERMINATION

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Scientific Domain:
Life Sciences.

Idea Description:
Research on plant growth in microgravity conditions was already carried out successfully on the International Space Station (ISS), within the Plant Research Unit.
Starting from the outcomes of the previous project, the objective of the present research proposal is to investigate more deeply the plant growth and germination of selected species of vegetables. The Deep Space Gateway, in fact, provides a unique opportunity to study the effect of a reduced gravity and magnetic field on biological processes, with conditions much different from those experienced on the ISS.

We propose to monitor the growth and germination of three selected species of fruit vegetables, chosen for their importance in the human nutrition: *Cucumis sativus*, *Solanum melongena* and *Cucurbita*. The main novelty of the idea proposed here is the selection of plants producing fruits with particular (e.g., elongated) shapes. The investigation to be carried out on the Deep Space Gateway will be aimed at:
- studying the effect of zero gravity (or particular gravitational condition) on the fruit growth and geometry;
- monitoring the potential effect of a reduced magnetic field, which is well known to be able to affect plants;
- studying the effect of environmental conditions (temperature, gravity, magnetic field, light exposure) on the growth duration and germination times.

The equipment needed for this research is analogous to that used on the ISS: a modular horticulture unit with LED lighting. The crew of the Deep Space Gateway will be asked to perform the following tasks:
- management and collection of seeds;
- measurement of fruit growth (dimensions and weight as function of time);
- residual waste disposal;
- data analysis and post-processing.

We believe the present research could be of interest for providing useful guidelines for the future horticulture activities on the Moon and on the Deep Space Gateway, where also standard species of fruit vegetables could be grown. Therefore, the biological studies on human nutrition in space can be integrated with important information on fruit vegetable availability.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	< 50 kg
Volume of hardware	< 0.1 m^3
Accommodation (e.g. internal/external)	Internal
Power required	< 2 kW
Data generated	
Pointing/viewing/line of sight needs	None
Communications needed	None
Duration of experiment	6 months
Crew tasks (if needed)	- Management and collection of seeds - Measurement of fruit growth (dimensions and weight as function of time) - Residual waste disposal - Data analysis and post-processing
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	None
Operations without crew (if any)	None

SOLAR SYSTEM AND EARTH SCIENCES

EARTH RADIATION BUDGET EXPERIMENT ON THE MOON

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Scientific Domain:
Earth Sciences, Solar System Sciences

Idea Description:

Overview
We propose Earth Radiation Budget Experiment on the Moon (ERBEM) as a payload of the Deep Space Gateway. The idea is to use the Deep Space Gateway as a vehicle for the delivery and deployment of a pair of identical multispectral radiometers to the surface of the Moon for measuring the radiative fluxes and detecting changes in the radiation budget of the planetary Earth for climate change analysis. The ERBEM spectral radiometers will be similar to the latest version of the CERES (Clouds and the Earth's Radiant Energy System) instrument with a shortwave (0.3 to 5 microns) channel, a longwave (5 to 35 microns) channel, and a total (0.3 to 200 microns) channel to measure the reflected solar radiation, the infrared thermal emission, and the total outgoing radiation from the Earth, respectively. However, as opposed to high resolution and small instantaneous spatial coverage of the CERES instruments, the Moon-based ERBEM instruments will have an instantaneous field of view of the whole terrestrial disk to allow for a better quantification of the radiation fluxes on the planetary scale which is of critical importance to our understanding of the working of the global climate system. The redundancy of the instrumentation is to allow for internal verification to ensure high data qualities. The obtained Moon-based measurements will be compared to satellite-borne measurements for cross verification and calibration. The results from the ERBEM will lay the foundation for the development of a permanent Lunar International Observation Network of Earth System (LIONES).

Rationales
The Earth's climate system receives energy from the Sun via solar radiation and releases energy to deep space via thermal emission. Changes of the state (*e.g.,* temperature, precipitation) of the Earth climate system are fueled by the energy retained within the system. Detection of variation in this energy budget at the top of atmosphere (TOA) is essential to our understanding of global climate change [*Trenberth et al.*, 2015]. Because of the atmospheric barrier, accurate observations of radiations incoming to and outgoing from the Earth rely heavily on the advance of space technology. Several satellite missions have been launched for the very purpose of studying this energy budget since 1978 when the high precision and self-calibrating solar probes were loaded aboard NOAA Nimbus-7 satellite. Satellite data have greatly enhanced our understanding of the

dynamics of climate change. However, the results from satellite measurements are not without pitfalls. A man-made satellite is small in size with a drifting orbit, has a short lifespan, and can only provide a snapshot of a limited area of the Earth at a time.

In contrast to an artificial satellite platform, the nearside of the Moon is a permanent and stable platform of enormous capacity for Earth observation [*Guo et al.*, 2016; *Huang et al.*, 2016]. An analysis of the accidentally acquired lunar surface temperature time series from the Apollo-15 Heat Flow Experiment shows that terrestrial radiative fluxes can be practically measured from the lunar near-side [*Huang*, 2008]. Moreover, the existing techniques developed for the instrument for a man-made satellite platform for Earth observation can be adopted for the ERBEM and LIONES. Of particular relevance to this proposal is the long duration and still on-going Clouds and the Earth's Radiant Energy System (CERES) Experiment [*Wielicki et al.*, 1996].

The instrument of the CERES, a key component of NASA's Earth Observing System (EOS), is a three-channel multispectral radiometer designed to measure reflected and emitted radiative energy from the surface of the Earth and the atmosphere. NASA's EOS satellites Terra and Aqua are currently each carrying a pair of CERES instruments in orbit. CERES instruments were lofted abroad TRMM and will be lofted abroad JPSS-1 into orbit. The CERES experiments are intended to provide precise and continuous measurements to increase the accuracy of estimates of radiative fluxes at the TOA for a more reliable assessment of Earth system radiation budget. A comparative analysis of the perspective ERBEM/LIONES data with the existing and upcoming CERES data would allow for a cross-verification and calibration. The technology readiness level (TRL) of ERBEM/LIONES is very high because it would be based on the state of art CERES technologies.

Moreover, ERBEM/LIONES will be superior to CERES in planetary Earth energy budget measurements and detection. Although their measurements are of high accuracy and high spatial resolution (up to 20 km for CERES on Terra and Aqua satellites), the instantaneous field of view of CERES instruments is very limited. Synthesizing a globally representative long-term global time series from CERES data sets has been a challenging task. The whole disk terrestrial radiative fluxes data from a permanent lunar observatory will be complementary to those obtained from satellite-borne sensors and ground-based stations. From a viewpoint on the Moon, such an observatory is poised to uncover hidden climate change patterns, to reveal new mechanism of the earth system energy balancing, and to foster the development of new theory and models. We urge international efforts to make the Moon a new platform for terrestrial climate change study.

This feasibility study is supported by the National Natural Science Foundation of China through Award 41590855.

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Table: Expected equipment and operational needs (*Based on CERES*).

Estimated experiment properties	Description
Mass of hardware	2×45 kg
Volume of hardware	2×(60cm × 60cm ×58cm)
Accommodation (e.g. internal/external)	Either way
Power required	47 W (average) per radiometer, 104 W (peak) both radiometers
Data generated	2×10.5 kbps on average
Pointing/viewing/line of sight needs	Sub-lunar point of the earth, instantaneous field of view of whole terrestrial disk
Communications needed	SpaceWire
Duration of experiment	>7 years
Crew tasks (if needed)	Optional
Access and servicing by crew (if needed)	Deployment via a lunar module robotic or crewed
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	
Operations without crew (if any)	

MULTISPECTRAL VISIBLE-IR POLARIMETRIC MAPPING OF THE LUNAR SURFACE

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Scientific Domain:
Solar System Sciences, Astronomy and Astrophysics.

Idea Description:
The polarimetry of Solar System bodies at visible and IR wavelengths reveals valuable information on the properties of the bodies' surface materials, with imaging polarimetry revealing how these parameters vary across a bodies' surface. The polarimetry of the surface reveals constraints on regolith material such the size distribution of soil grains, their structure and shapes. As the polarimetric responses of surface materials are also a function of wavelength, and albedo, multispectral observations combined with polarimetric studies further maximizes the scientific value of such observations.

If placed in a lunar orbit or Near-Rectilinear Halo Orbit, the Deep Space Gateway will provide an excellent platform for multispectral polarimetric mapping of the moon's surface. All such studies to date have been performed from Earth or its near vicinity. The advantages of performing such mapping from the DSG are clear, allowing high spatial resolution imaging for the whole lunar surface, and extending our knowledge of lunar surface polarimetry to the farside.

Multiple passes over the lunar surface by the DSG will allow many observations of the same surface regions over a wide range of solar illumination and phase/scattering angles, extending the range of parameters over which the surface has been characterized.

The instrument concept we have in mind combines polarimetry with multispectral filtering in a pushbroom camera. Standard operation would involve the pointing of the instrument towards the nadir direction at the periapsis phases of the lunar mission. Pointing control of the instrument would greatly increase its versatility, ensuring that the pushbroom CCD array is oriented perpendicular to the groundpath direction, and also allowing oblique viewing of the surface to maximize the phase angle coverage of the instrument. Spatial resolution will naturally vary depending on the DSG-moon distance, but a camera with modest capabilities is expected to far outperform observations with more powerful instruments at Earth, with the additional clear advantage of near-global lunar surface coverage as well as almost complete phase angle characterization.

The camera is also expected to have complementary science capabilities, such as polarimetric observations of near-Earth asteroids, as well as multispectral polarimetric imaging of spatially-resolved comets, including near-Sun objects, and the solar corona if the Sun itself is suitably occulted by the lunar surface.

To summarize, the objectives of the research would be to produce a near-global polarimetric map of the lunar surface at several visible and possibly near-IR wavelengths. This will reveal valuable information on the lunar regolith's properties, such as grain size, which will complement data on the lunar surface obtained by other instruments and missions. The observations would contribute to our ever-improving knowledge of the lunar surface, helping maximize our understanding of variations in lunar surface properties.

The equipment required on the DSG would be the camera itself, ideally mounted on a pointing platform on the exterior of the DSG, and an interface for data transfer to Earth. Rather than commanding the pointing of the camera from Earth, the DSG crew could take on this role, to maximize the scientific return of this instrument. This approach, subject to review, could greatly reduce costs and complexity of the instrument.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	0.5-5 kg, depending on instrument design and platform.
Volume of hardware	TBD
Accommodation (e.g. internal/external)	External.
Power required	TBD.
Data generated	Flexible.
Pointing/viewing/line of sight needs	Ideally nadir-pointing at lunar periapsis.
Communications needed	TBD, but data transfer to Earth for near real-time decision
Duration of experiment	One crew rotation or ideally longer
Crew tasks (if needed)	Pointing of camera, subject to further study.
Access and servicing by crew (if needed)	None once mounted.
Need for retrieval and return to Earth	None.
Specific orbit needs (if any)	NRHO or LLO (L2 Halo of more limited lunar science return)
Operations without crew (if any)	Yes – mapping of lunar surface during each periapsis pass under changing solar illumination conditions.

LUNAR ACTIVE EXPERIMENT (LAX) FOR LUNAR WATER INVESTIGATIONS

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Scientific Domain:
Solar System Sciences

Idea Description:

Abstract
The lunar environment is characterized by complex interactions among several domains. Due to the lack of the atmosphere, the lunar surface, exosphere, space plasma, and dust are a closely coupled system. It is entirely different from that at Earth, while similar environments can be found elsewhere in the Solar System. The proposed experiment, LAX, Lunar Active Experiment, aims to investigate these couplings by actively disturbing the system and monitoring its responses through remote sensing in various wavelengths and particles. LAX is an equipment installed onto the Deep Space Gateway with two main modules: the Lunar Impacting Module (LIM), injecting a projectile with sizes of 0.1–10 kg depending on the experiment and the Remote Sensing Module (RSM), monitoring the response. LIM can be re-charged by the crew allowing various impact experiments.

Science background
The complex environment of the Moon is characterized by couplings of the surface, exosphere, dust, and the plasma. In particular, several independent measurements claim the existence of water at the lunar surface and the cold traps, but its dynamics, including the source, transport, loss mechanisms are not fully characterized. We at IRF lead a proposal to the ESA's M5 mission call, named SELMA (Surface, Environment, and Lunar Magnetic Anomalies), which also aims to study such interactions. Two missions, if realized, would increase the science return using simultaneous (while independent) experiments.

An area of particular scientific interest where the Deep Space Gateway can contribute is the study of the water (or hydroxyl) at the top-most layer of the lunar surface, and its coupling to the environment, including the exosphere, magnetic anomalies, and dust. Top-surface lunar water was first observed by infrared spectroscopy (e.g., Pieters et al., 2009), and it exhibits a diurnal variation (e.g., McCord et al, 2011; Li and Milliken, 2017). Recently, Wöhler et al. (2017) reported a reduction of surface water signatures in the South Pole Aitken, where a local magnetic field can shield the proton flux precipitating onto the surface (Vorburger et al., 2014). These measurements indicate that the solar wind proton precipitation is a strong candidate for surface water production. Transport (or loss) of such water is yet unknown, in particular the transport to cold traps at the lunar poles is not solved. The Lunar South Pole has several permanently shadowed regions where water molecules are thought to be stored in a form of ice. An impact experiment by L-CROSS mission (Colaprete et al., 2014) concluded that up to 6% of the surface materials in the Cabeus crater is water (likely ice). However, how much water exists is still controversial, mainly because different measurements led to different conclusions on the water content distributions. Most likely, states of the ice (e.g. embedded depth of the ice cube) are the reason for the contradicting observations.

Equipment and Deep Space Gateway

LAX is composed of two permanent units. Lunar Impacting Module (LIM) and Remote Sensing Module (RSM). LIM is a module to inject an impactor with a volume of up to 1 liter and a mass of 0.1–10 kg from the Deep Space Gateway. RSM will monitor the signatures of the lunar surface. RSM is equipped with four remote-sensing sensors and a dust monitor. RSM remote sensing sensors are an infrared spectrometer, with a wavelength coverage of 1.5–3.6 µm, a UV spectrometer, with a wavelength covering 115–315 nm, a visible camera and an energetic neutral atom (ENA) sensor. These wavelength ranges are optimized for water absorption bands, but by extending the IR wavelength to 3.6 µm we can mitigate the ambiguity of thermal background, which has been a problem of existing IR measurements (e.g. Pieters et al., 2009). The UV wavelength range is also capable of exospheric gas composition measurements. The ENA spectrometer can detect the solar wind flux and the speed at the lunar surface, which we can directly correlate with the surface water signatures. RSM also includes dust monitor. Impact experiment (as well as natural meteoroids) can produce dust, which may potentially reach to DSG. The mass flux and the speed characterize the response of lunar regolith to the impact experiment (and bombardment of natural meteoroids). Dust monitoring also mitigates the potential hazard for the crew during DSG activities.

The unique idea of using the Deep Space Gateway and its crews is that the projectiles can be prepared right before the ejection. For example, we may even suggest to launch a water ice cube to emulate a comet nucleus. Such preparation and curation of projectiles and LIM recharging are only possible with manned missions.

Ideas for projectiles and the science

- Copper ball (or equivalent) with 10 cm diameter, impacting at cold traps to make a dust and water plume
- Water ice cube impacting to the surface to make artificial "pond" of surface water to simulate a cometary nucleus impact
- Copper ball (or cubesat) to impact a magnetic anomaly in order to monitor the volatile motion and its difference to other un-magnetized areas.

Expected impact

The active experiment conducted by LAX provides multiple opportunities of projectiles. Such repeatable controlled impacts provide a statistical view of the water contents inside the cold traps, as well as insights on the transport of the water molecules.

Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	RSM: 4.0 kg (IR), 4.0 kg (VIS), 12 kg (UV), 4.5 kg (ENA), 4.5 kg (Dust) / LIM 10 kg / Impactor 0.1-10 kg, depending on the experiment
Volume of hardware	RMS: 250 x 250 x 500 mm (IR), 130x140x220 mm (VIS), 350x390x160 (UV), 270x230x150 (ENA), 250x200x400 (Dust) / LIM: 800 x 200 x 200 mm / Impactor 100 x 100 x 100 mm (max)
Accommodation (e.g. internal/external)	External
Power required	RSM (on operation, continuous) 20W (IR), 5W (VIS), 20W(UV), 15W(ENA), 7W (Dust) / LIM 30 W (instantaneous, TBD)
Data generated	RSM 1 Mbps (max)
Pointing/viewing/line of sight needs	RSM: Moon surface (nadir pointing)
Communications needed	No
Duration of experiment	2 hours (for a single experiment)
Crew tasks (if needed)	Preparation and curation of projectiles. Recharge of LIM.
Access and servicing by crew (if needed)	Preparation and curation of projectiles. Recharge of LIM.
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	No
Operations without crew (if any)	RMS

SPACE ENVIRONMENT EFFECTS ON RELEASE OF VOLATILES FROM MATERIALS

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Scientific Domain:
Solar System Sciences, Physical Sciences.

Idea Description:

The behaviour of volatile substances within celestial bodies – whether comets, lunar soil, or other planets – is a topic of acute interest and with potentially ground-breaking consequences. While investigations in this domain keep progressing, as of today, the subject leaves more questions than answers. The following experiment is proposed with the aim to increase our understanding of the storage, migration, and behaviour of volatile media within porous solids in deep space conditions. It focuses on the phenomenon of sublimation, which is the relevant phenomenon of substance behaviour in deep space.

The Experimental Setup. A spherically shaped porous body is impregnated with a substance capable of sublimation in deep space conditions. The impregnated sphere is pre-frozen, in order to start with a solid state of matter and allow for sublimation. It is then placed into outer space overboard the space station. The sphere must be positioned in such a way that it is affected by direct sunlight, so that pure solar energy is used to achieve sublimation.

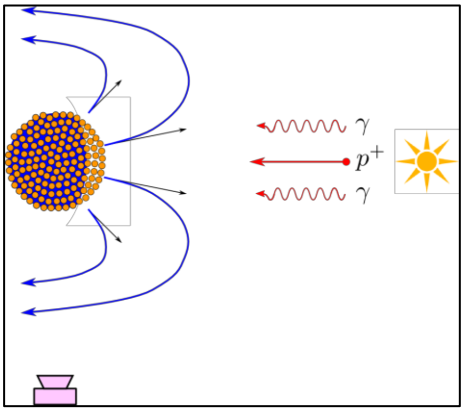
The purpose of the experiment can be divided into two main objectives. The first one is a qualitative description of the effect of deep space conditions on the sublimation from a porous body. The second objective is a quantitative description of sublimation in deep space, achieved by a thorough study of the system's heat-and-mass transfer. The technicalities of these objectives are detailed at the end of the section.

A key point in the proposed experiment is the adequate selection of the substance mimicking cometary/planetary volatiles. It should have a relatively high molecular weight, resulting in a moderate escape speed and localised tail-trace, and has to be visualised easily. A suitable choice is hence an organic molecule capable of fluorescence in the solar UV rays – the substance coumarin can serve as a good practical example.

The applied diagnostic methods for the initial tests can be relatively simple, in the form of a visual observation & filming from inside/outside the station.

Once the feasibility study has demonstrated the vitality of the proposed idea, the investigation can be expanded in many different ways. For example, the porous body emulating the nucleus might be either a rigid structure prepared by sintering with the volatile emulator filling up its pores, or be a volatile matrix filled by disjoint solid particles. The latter geometry can allow the formation and studying of both gas and dust tails.

The body itself can be placed in the outer space with or without rotation around own axis; in the former case, the sun radiation heating will be rather uniform, while in the latter case the body will experience a one-side heating. In case of promising preliminary results, the external observation can be supplemented by a local instrumentated platform bearing the body as a payload and allowing a closer look at the processes happening on the surface and in its vicinity.



The advantages offered by the proposed system are considerable:

- It does not require any specific and restrictive conditions for functioning; instead, it makes use of the natural features of the open-space surroundings.
- It allows to study essential transport phenomena in a very direct way, through a system of relatively low complexity, with a minimum of fragile and moving parts.
- It allows a close and controlled observation of a phenomenon which is otherwise difficult to harness.

The expected outputs are also significant.

The characteristic time of sublimation, the intensity, the shape and the size of the volatile substance's cloud shall be observed and recorded. This will allow to estimate the influence of various factors, such as solar wind and the Earth's magnetic field, on different phenomena like comet tail formation. Further, these results can lead to evaluate the possibility of using the proposed system as a sensor or probe for these factors.

The heat-and-mass transfer study, on the other hand, will provide quantitative data on the characteristic values of sublimation in deep-space, listed above. They can lead to a better understanding of how vital elements such as water and ice behave on planetary bodies, e.g. what conditions facilitate their escape from the planetary bodies, and what settings increase the probability for the volatile substance to not leave the porous body completely.

The research group from the University of Brussels has got extensive experience in space studies, having conducted various experiments onboard the International Space Station (ISS) [1,2] and during Parabolic Flights [3].

1. V. Shevtsova, Y. A. Gaponenko, V. Sechenyh, D. E. Melnikov, T. Lyubimova and A. Mialdun, J. Fluid Mech. (2015), **767**, 290-322.
2. A. Mialdun and V. Shevtsova J. Chem. Phys. (2015) **143**, 224902
3. V. Shevtsova, Y. Gaponenko, V. Yasnou, A. Mialdun, A. Nepomnyashchy, Langmuir Letter (2015) **31**, 5550-5553

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	10
Volume of hardware	0.2m x 0.2m x 0.2m
Accommodation (e.g. internal/external)	Accommodation external
Power required	TBD
Data generated	Optical & digital : 1-3 Gb
Pointing/viewing/line of sight needs	Exposure to direct sunlight.
Communications needed	
Duration of experiment	TBD
Crew tasks (if needed)	Minimal to none
Access and servicing by crew (if needed)	None
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	No
Operations without crew (if any)	Yes

USING THE DEEP SPACE GATEWAY SCIENCE AS A PLATFORM FOR XRF OBSERVATIONS OF THE MOON AND SUN

Authors: K.H. Joy[1], E.J. Bunce[2], D.A. Rothery[3], A. Martindale[2], J.C. Bridges[2], I. A. Crawford[4] and M. Anand[3].

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Scientific Domain:
Physical Sciences, Solar System Sciences

Idea Description:
We provide a concept for how, by its proximity to the Moon, the Deep Space Gateway can be an enabling platform for opportunistic scientific research. We propose a science payload package of an optimized X-ray fluorescence spectrometer (XRF) instrument and solar X-ray monitor to enable lunar surface and solar science. Planetary XRF spectroscopy is a methodology used to measure the elemental abundance of airless planetary surfaces. The elemental composition of the lunar surface regolith is representative of the types of underlying geological materials. Emitted X-rays are characteristic of elements present at the surface and therefore can be used to constrain the nature of local geochemical and geological variation. Normal levels of solar intensity result in the excitation of low atomic number elements, including several elements common in lunar rock-forming minerals such as Mg, Al and Si. During solar flares, intense levels of solar X-rays are emitted and the excitement of heavier elements such as S, K, Ca, Ti, Cr, Mn, Fe, and Ni occurs and can be observed if they are present at levels above instrument detection limits.

XRF instrument packages have been flown previously on crewed missions (Apollo 15 and 16 service modules). European heritage in planetary XRF instrumentation comes from development of the D-CIXS instrument on the SMART-1 misson, the C1XS instrument on Chandrayaan-1 to the Moon (Crawford was science lead, Joy and Anand Co-Is), and the MIXS instrument on BepiColombo to Mercury which Bunce leads and Martindale is the instrument scientist. Our team would be organised to capitalise on the experience in existing missions and ultimately perform new science at the Moon.

<u>Objectives of the research</u>
Lunar surface composition: Elemental mapping using XRF spectroscopy in the 0.5-20 KeV energy range will provide spatially resolved information on the global composition of the lunar crust, helping to investigate key lunar science topics including: the extent of crust formation from a lunar magma ocean (what caused the key chemical differences between the near and farside highland crust); the variability of mare basalts as probes of deep mantle partial melting and mantle heterogeneity; the extent of Mg-rich magmatism and through this the Moon's thermal history; determination of the composition of the lower

crust and perhaps even mantle through exposures found in impact crater central peaks and in the walls of the giant South Pole Aitken basin. Chemical maps may also provide information about the budgets and distribution of potentially useful elements that could be utilised by future *in situ* resource utilisation exploration activities.

Lunar exosphere and magnetotail charged particle evolution: Night time observations will enable studies of lunar exosphere evolution via Particle Induced X-ray Emission (PIXE) from the continuous flux of protons and electrons in the eV to GeV range from galactic cosmic rays, solar cosmic rays and terrestrial magnetic tail particles bombarding the Moon. The Deep Space Habitat and Moon will pass through the Earth's geotail once a month, allowing for long term observations of the charged particle environment.

Solar X-ray emission: Simultaneous monitoring of the solar X-ray spectrum through an energy range of 0.5-20 KeV is essential for obtaining calibration spectra for the lunar surface X-ray fluorescence measurements and for inflight calibration using astronomical targets. The instrument(s) will undertake solar science in their own right making X-ray spectral observations of coronal emissions throughout one or more 11 year solar cycles. Such results will be useful for understanding the evolution of flares through solar maxima and nanoflares during coronal quiescence, and monitoring of the Sun in X-rays as a star to baseline it against other stellar objects.

Deep Space Gateway as a platform

The Deep Space Gateway provides a stable, long term platform to undertake XRF observations of the Moon and Sun through one or more 11 year solar cycles. Different orbit options have been proposed ranging from low lunar orbit, distant retrograde orbits and a Earth-Moon L2 Halo Orbit. The range of options implies a potential wide range of surface geochemical footprint sizes (dependent on observational height above surface) and an opportunity to chemically map different regions of the Moon. Studies of localised variations in lunar geology on the scale of km to a few tens of km will be enabled by instrument collimation and high spatial resolution mapping – such mapping efforts would notably be facilitated from a Deep Space Gateway in low lunar orbit and long-term observations throughout the solar maxima interval.

Equipment required

An XRF instrument with appropriate radiation shielding and calibration devices would be required on the lunar surface pointing platform. The degree of radiation shielding and understanding limitations to radiation damage would need to be studied as part of a technical design review. One or two X-ray solar monitors would also be required mounted on different pointing surfaces.

Role the Deep Space Gateway crew

Crew role would be limited in the operaton activities instrument operation beyond monitoring that the instrument is working within operational parameters (thermal control for example). However, they could be employed in deployment and servicing missions could facilitate replacement of limited lifetime X-ray source calibration devices, and replace / upgrade the instruments to ensure long-term monitoring.

Impact and benefits of the research

Beneficiaries include lunar scientists interested in understanding the geological evolution of the Moon. Observations of and surrounding lunar surface geological sampling sites will provide geological context for returned samples, helping to place them within a global geological framework. More widely data will benefit solar terrestrial physicists interested in observations of the magnetosphere and its interaction with the Moon and X-ray astronomers interested in understanding our Sun as a stellar object. Societal impacts will include public enhancement of space science through STEM education programmes built around the project.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	6– 10 kg for XRF instrument, < 1 kg solar monitors
Volume of hardware	Apx. 50 x 50 x 50 cm for XRF instrument, 10 x 10 x 10 cm for solar monitors
Accommodation (e.g. internal/external)	External to habitat
Power required	<25W (more during detector annealing)
Data generated	X-ray spectra, ancillary housekeeping data
Pointing/viewing/line of sight needs	View to Moon – could be static or movable depending on orbit. SIXS requires line of sight to the Sun.
Communications needed	~5-400 kbps depending on solar conditions.
Duration of experiment	11-22 years (through one or two complete solar cycles)
Crew tasks (if needed)	Not key. Possible deployment and replacement of instrument as required.
Access and servicing by crew (if needed)	Necessity to be assessed and minimised.
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	Ideally low lunar orbit to facilitate lunar science mapping goals, but other orbit options are useful for solar and magnetotail science
Operations without crew (if any)	Routine operation to be commanded from Earth.

CONNECTING REMOTE SENSING AND SURFACE SCIENCE FOR THE MOON AND EARTH– CLOSING THE GAP

Authors: N. E. Bowles[1], K. L. Donaldson Hanna[1] , T. Warren[1], C. M. Pieters[2], B. T. Greenhagen[3], C. Snodgrass[4]

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Scientific Domain:
Solar System Sciences, Earth Sciences, Astronomy and Astrophysics.

Idea Description:
Remote sensing, using observations across the electromagnetic spectrum, provide the most efficient method of providing a global overview of a planetary body. However, to maximise the scientific return of any remote sensing data set requires access to accurate analogue laboratory measurements, accurate theoretical modelling and direct connection "ground truth" measurements. The unique location of the Deep Space Gateway (Gateway) provides an opportunity to combine remote sensing and *in-situ* measurements of the Moon and Earth at multiple scales using a set of common experimental hardware based around an integrated multiband hyperspectral imaging system.

Remote sensing observations: The Moon as an airless body
Multi-spectral and hyperspectral remote sensing observations (e.g. [1], [2]) can be used to map surface compositions and thermophysical properties across the surfaces of airless bodies. However, the lack of an atmosphere, presence of fine particulates resulting from the continued bombardment of the surface and low thermal conductivity make interpreting remote observations particularly challenging. Comparisons between terrestrial laboratory spectra of Apollo soils in the visible, near and thermal infrared (IR) differ from remote sensing observations from orbit [3], [4] most likely due to the difficulty of replicating the porosity and surface textures resulting from the low gravity environment and possibly electrostatic lofting of fine particles in the laboratory on Earth. In particular porosity and surface textures can have a significant effect on the contrast in spectral features ([5], [6]), and this is before effects such as overturning and exposure to the space environment are considered [7]. A coordinated observation campaign using the Gateway as a hub with orbital (e.g. sub-satellite/cubesat) and surface (e.g. telecommanded rover/astronaut) assets allow measurements to be made from orbit and the surface of undisturbed and disturbed regolith that can then be compared to laboratory measurements of returned samples, on the Gateway and back on Earth. This is achieved using the following remote sensing instruments and experiments, each with a common set of spectral bands:

- **Mounted on the Gateway:** A very broadband high resolution (<1 m spatial resolution) hyperspectral imaging system, possibly using a common telescope to allow targeted observations of the lunar surface from different points in the Gateway's orbit. Ideally this instrument would provide spatially resolved spectral maps (i.e. image cubes) from near-UV (~308 nm for OH limb detection), visible and near-IR (composition, OH and H_2O detection, 0.5 – 5 μm), thermal-IR (composition, surface texture, rock abundance, 6-200 μm) and sub-mm (for microwave sounding of the sub-surface temperature e.g. 20- 3 GHz).
- **Sub-satellites or "hoppers",** possibly deployed by the Gateway, which contain a miniature version of the UV and IR focal planes of the main telescope. These will be sent to measure both the surface visible from the Gateway and latitudes that are not accessible, depending on the Gateway's orbit. A typical configuration for the sub-satellite is a 6/12U cubesat with an orbit that is guided gradually towards the lunar surface, increasing the spatial resolution.
- **Surface operations, either via telecommanded rover or astronaut.** This would be a version of the instrument, again based on a common focal plane for close up imaging of the surface, both before and after disruption due to the presence of the rover/astronaut. This would provide a hyperspectral dataset similar to the stereo imaging of the regolith carried out by Apollo 16 [8]. Controlled mechanical experiments over varying areas can then be hyperspectrally imaged on the surface, from low-orbit sub-

satellite and finally the Gateway, with returned samples from the imaged areas providing ground-truth. This can include evaluating trench or drill cuttings to investigate texturing, mineralogy and weathering at depth, combined with in-situ microscope imaging for analysis at grain scales.

- **Experimental support from the crewed Gateway**. The crew on the Gateway provide operational support and telecommanding for the sub-satellites and any surface rover operations, as well as measurements of returned samples in different gravitational conditions using e.g. a small centrifuge in the microgravity of the station.

This sequence of observations and experiments will transform our understanding of remote sensing observations of airless bodies, especially in low and microgravity environments. They will contribute to wider exploration goals by improving analysis of remote sensing data for resource prospecting on airless bodies such as asteroids and the moons of Mars. The Gateway instrument will also have the capability for wide field of view hyperspectral imaging of other Solar System targets including Near Earth and Main Belt objects

Earth Observation

Depending on the final orbit (NRHO or L2 halo) the Gateway can offer unique observation geometries for long term, broad spectral band coverage of the Earth. Long term (~multiyear to decadal) monitoring of the Earth's radiation budget using the top of the atmosphere (TOA) fluxes at shortwave (input) and longwave (output) can provide a sensitive test of radiative transfer models of the planet's atmosphere. Spatially resolved long term monitoring of the TOA flux also provides a powerful validation tool for global circulation and climate models.

Typically the Earth's radiation budget is monitored via instrumentation from geostationary orbit (e.g. GERB [ref], Meteosat Second Generation) or from low Earth orbit (LEO; e.g. the EarthCARE Broadband radiometer). However, these have limited viewing geometry; geostationary orbit cannot provide estimates for TOA fluxes near the poles and an instrument in LEO is restricted to relatively high spatial resolution but local-time restricted observations (e.g. EarthCARE is expected to be placed in a Sun synchronous 1400 hr orbit). Observations from the Gateway as part of the wider Earth Observation data system can fill this important gap.

A test of this observation concept is already underway. Since 2009 the Diviner Lunar Radiometer (Diviner) on NASA's Lunar Reconnaissance Orbiter has been viewing the Earth at low spatial resolution from lunar orbit as a target of opportunity (the EarthScan observation campaign, Bowles et al 2011, Figure 1). This data set includes albedo and calibrated radiances from 0.3 to > 200 μm (Paige et al. 2010). Diviner was optimized for lunar surface observations; measurements from the Gateway can be made at higher spatial resolution (~10 km) so will be more broadly compatible with climatologies derived from existing Earth observation spacecraft.

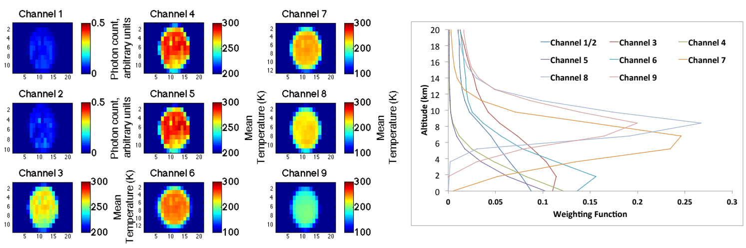

Figure 1. (Left) Example Earth scan data from a sequence of observations made on July 13, 2010 at 14:10 UTC. (Right) Approximate weighting functions for the Diviner channels when viewing Earth. Channel 1, 2: albedo, channel 3: 7.8 μm, 4: 8.25 μm, 5: 8.55 μm, 6: 13-23 μm, 7: 25 -41 μm, 8: 50 -100 μm, 9: 100 – 400 μm.

Conclusion

The Deep Space Gateway provides a unique opportunity for the long-term study of the Moon and Earth. The high resolution, multiband hyperspectral imaging system mounted on the outside of the station can provide continuous monitoring and mapping of the lunar surface. This can be complemented by measurements from sub-satellites deployed for higher resolution hyperspectral imaging from lunar orbit and finally ground truth from rovers, crew operations and returned samples. Experiments on the samples in the Gateway under microgravity will then allow comparisons between remote sensing observations of both the Moon and asteroids and complete our investigations of the theory of thermal transfer in airless body regoliths. Observations of the Earth will provide the unique viewing geometries offered by the Gateway and better our understanding of the Earth's radiation budget.

Table 1: Expected requirements for remote sensing camera on the Gateway, sub-satellite and surface elements.

Estimated experiment properties	Description
Mass of hardware	TBD
Volume of hardware	TBD
Accommodation (e.g. internal/external)	External
Power required	TBD
Data generated	TBD
Pointing/viewing/line of sight needs	Line of sight to Moon, observation of Earth
Communications needed	Telecommanding of sub-satellites deployed from hub, surface rover element.
Duration of experiment	Earth observation, throughout mission. Lunar: mapping throughout mission
Crew tasks (if needed)	Rover telecommanding and sub-satellite deployment operations
Access and servicing by crew (if needed)	N/A
Need for retrieval and return to Earth	Samples from ground truth locations
Specific orbit needs (if any)	
Operations without crew (if any)	Autonomous/remote operations of Gateway hyperspectral imaging system

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[7] Pieters, C. M., and S. K. Noble (2016), Space weathering on airless bodies, J. Geophys. Res., 121, 1865-1884, doi: 10.1002/2016JE005128.
[8] Helfenstein, P, Shepard, M. K., 1999. Submillimeter-Scale Topography of the Lunar Regolith. *Icarus*, **141**, p. 107 - 131.

INVESTIGATION OF LUNAR SWIRLS FROM THE SURFACE AND THE ORBIT

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Scientific Domain:
Solar System Sciences

Idea Description:

Space weathering is a prominent and continuous process that affects the chemical, physical and optical properties of the surface of airless bodies. This highly affects the study of mineralogy of surface materials from orbital spectroscopy. Among various space weathering agents such as solar winds, micrometeorites, cosmic rays, impact and thermal weathering the lunar surface has been effectively weathered by irradiation, implantation, and sputtering from solar wind particles, and bombardment by micrometeorites. There is a long-standing debate in their relative contribution to the weathering of the upper layer of the lunar regolith.

Lunar swirls are enigmatic high albedo and complex sinuous shape features distributed across the lunar surface. The Moon has no intrinsic magnetic field but these swirls are associated with locally high magnetic field strength. These mini-magnetospheres around the swirls deflect the impacting solar wind ions due to the shielding magnetic field. This reduces the effects of space weathering due to ion implantation and sputtering; however, the magnetic field cover cannot screen out micrometeorites. These swirls have been studied over decades by Apollo sub-satellite magnetometers, Lunar Prospector (1998–1999), Kaguya (2007–2009), Chandrayaan-1 (2008–2009), and Nozomi (1998) spacecraft. However, the origin and nature of swirls still remain a mystery.

This makes lunar swirls a natural laboratory that would help us to investigate the importance of micrometeorite bombardment vs. solar wind sputtering/implantation processes in the optical weathering of lunar regolith. In-situ exploration of two major swirls on geologically distinct lunar terrains, 1. Mare filled nearside (Reiner Gamma; 7.5°N, 302.5°E) and 2. Highland crust on lunar farside (Firsov; 10.5°S, 16.5°E) will help us to bridge the gap between lunar geology, planetary magnetism, space weathering and remote sensing. The results from the investigation can therefore be extended to space weathering processes in other airless rocky bodies such as Mercury and Vesta.

The proposed Lander-Rover-Modules (LRMs) deployed from the Deep Space Gateway (DSG) to both of the selected swirls from the NRHO/HALO orbit and therefore perform simultaneous investigation of these swirls on both lunar nearside and farside. Each LRM will have a lander and a rover, which will be launched separately from DSG satellite deployment ports/robotic arms to overcome the total mass (dry mass+fuel mass) constraints. The existing Canadarm in the ISS has capabilities to handle payloads up to 3000 kg. With this legacy, small LRMs can be easily launched from one of the robotic arms. As an alternative, assuming the existing technology of cubesat deployment from "NanoRacks Cubesat Deployer" in ISS is evolvable, the LRMs can also be considered launching from the DSG through such ports. Each Lander in LRM will carry a surface magnetometer (will constrain the depth and thickness of magnetic anomaly source region), solar wind spectrometer (will measure the solar wind flux reaching the surface), and seismometer (will record lunar seismicity on nearside and farside) and each rover in LRM will carry the UV-visible-NIR hyperspectral imagers (will detect the mineralogy, volatiles and constrain optical maturity spectral index wrt $npFe^{0}$), IR Radiometer (will measure thermo-physical properties of upper lunar regolith) microscopic imager (will detect the particle size distribution), and Mössbauer spectrometer (will measure $npFe^{0}$). The highlight of this proposal is that the simultaneous in-situ investigation of lunar nearside and farside swirls, lunar crust, magnetism, and seismicity has never been attempted before.

LRMs are of semi-automatic type and can be assumed to be of cylindrical shaped with body mounted solar panels. The casing of the LRM shall be made of lightweight composite material (such as Carbon Fiber Reinforced Plastic). Each lander shall have a maximum dry mass of 10 kg and the rover shall have a maximum dry mass of 15 kg with capability of traversing few hundred meters within the lunar swirls. Along with the primary instruments mentioned above, a deployable antenna for communication shall be included for tele-operation of rover, and for data transmission between the LRM and the DSG. LRMs shall be fitted with small packets of solid boosters externally, which are used for de-orbiting into Low Lunar Orbits, controlling the attitude and for propulsive landing on the swirls, with at least two thrusters operating at a time. As the lunar swirls are wide in nature (30 to 100 km), the LRMs shall land anywhere within the swirls and the rover shall be moved around. This eases the requirement for precision landings.

The primary reason to go for DSG based deployment and tele-operations is to perform in-situ study on the lunar swirls that are spread widely in nature using tiny LRMs. The control of the LRMs instruments operation, sample selection and testing and precise motion control of rovers is only possible through tele-presence. Also, DSG based operations will enable the technology demonstration of deployment of 'tiny' LRMs from small satellite launching ports/Robotic arms. More than just cubesat deployment, DSG should also have capabilities to launch LRMs, at least for applications those does not require precision landing as in the case of Lunar swirls study. The entire duration of the mission shall be last for at least one lunar day/night cycle. The sample return concept is avoided here mainly because of the complexity of the ascent vehicle and higher fuel consumption required.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	-Total mass of 1 Lander (approx): 130 kg (Dry mass of 10 kg, fuel mass of 120 kg) -Total mass of 1 rover (approx): 165 kg (dry mass of 15 kg, fuel mass of 140 kg)
Volume of hardware	TBD. Volume shall accommodate small satellite deployment port of DSG
Accommodation (e.g. internal/external)	Volume for instruments. TBD
Power required	Instruments for Lander: 60-100 W (approx) Instruments for Rover: TBD
Data generated	TBD
Pointing/viewing/line of sight needs	Pointing of antennas towards DSG or Low lunar orbiting satellites for tele-operations/data transfer
Communications needed	TBD. As required for tele-operations
Duration of experiment	At least one day/night cycle
Crew tasks (if needed)	1.Deployment of Landers and Rovers (2 sets for 1st mission) 2. Control of Lander instruments/rovers
Access and servicing by crew (if needed)	Same as above
Need for retrieval and return to Earth	No, Data alone is essential
Specific orbit needs (if any)	NRHO, or anything similar for deployment purposes and tele-operations. Lagrangian orbits will increase Delta V slightly
Operations without crew (if any)	TBC

LUVMI – A LOW-COST, LIGHT-WEIGHT, MOBILE SURFACE SCIENCE UNIT

Authors: J. Biswas[1], J. Gancet[2], J.E. Rushton[3], S. Sheridan[4], C. Pitcher[4] and L. Richter[5]

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Scientific Domain:
Solar System Sciences/Lunar Surface Exploration/Lunar Volatiles

Idea Description:

The Lunar Volatiles Mobile Instrumentation (LUVMI), is a light-weight, low-cost rover and instrument package, designed to investigate possible deposits of volatiles, such as those discovered by the LCROSS mission inside the permanently shadowed Cabeus Crater [1]. With a total mass of less than 40 kg, LUVMI is able to fulfil 4.5 out of 5 priority targets, defined by the Volatiles Specific Action Team of the ISECG.

LUVMI can be used as mobile platform for the Herakles mission, as a scout prior to the Herakles mission or as a standalone surface exploration mission that profits from the Deep Space Gateway as a data relay or through teleoperation by astronauts.

Figure 1: Left: Render image of LUVMI on the lunar surface. Right: CAD Model of the Volatiles Sampler/Volatiles Analyser instrument package

LUVMI provides a smart, low mass, innovative, modular mobile payload comprising of surface and sub-surface sensing with an in situ sampling technology capable of depth-

[1]: A. Colaprete, P. S. (2010). Detection of Water in the LCROSS Ejecta Plume. *Science*, 463-468.

resolved extraction of volatiles, combined with the volatile analyser, a mass spectrometer capable of identifying the chemical composition of the most important volatiles. This will allow LUVMI to:

- obtain subsurface samples up to a depth of 20 cm,
- extract water and other loosely bound volatiles,
- identify the chemical species extracted,
- sample volatiles in and around permanently shadowed regions (PSR).

1.1 Mobile Platform

The rover platform developed in LUVMI is designed to accommodate volatiles sampler and analyser instruments, and to allow their deployment in relevant locations on the South Pole of the Moon. The rover locomotion as well as the thermal and communication concepts make provision for operations in extremely harsh conditions, including permanently shadowed regions (PSR). The dimensions (1m x 1m x 0.5m stowed) and mass (below 40kg) of the overall LUVMI rover including instruments makes it possible to envisage low cost options to fly it to the Moon (private company service or piggybacking as part of a regular national space agency mission).
The imaging system on LUVMI will consist of two novel light-field cameras. The navigational camera will provide 3D images of the rover's environment for teleoperation or autonomous navigation. A surface camera will be used to provide close-up images of the lunar regolith and allow depth measurement of the rover tracks. The cameras will also acquire high quality imagery of mission equipment and of Earth.

1.2 Volatiles Sampler/ Volatiles Analyser

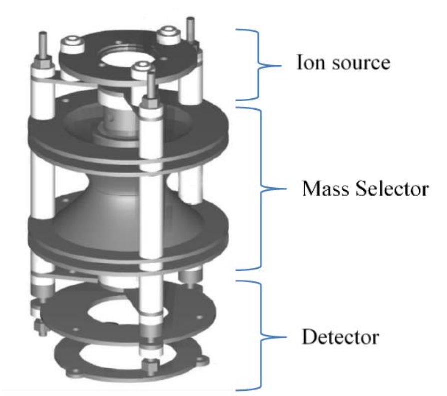

Figure 2: Volatiles Analyser miniature mass spectrometer

The Volatiles Sampler (see Figure 1) is a novel instrument that combines drill, sample handling and preparation, gas extraction and gas analysis in a small and compact unit. Its drill can penetrate up to 20 cm into the soil. After insertion into the ground, a heating rod inside the drill will heat up the enclosed regolith to release the bound volatiles. On top of the Volatiles Sampler, the Volatiles Analyser is mounted. This miniature mass spectrometer, based on the flight proven Ptolemy instrument of the Rosetta Lander, is capable of rapidly detecting chemical compounds with masses in the range of m/z 10 to 150, even at extremely low pressures with a power consumption of less than 5W.

LUVMI is currently being developed under the Horizon 2020 program by the European Union. It involves the development of high fidelity prototypes of the rover and instruments, and will conclude next year (2018) with a mission demonstration campaign.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	< 40 kg
Volume of hardware (stowed)	1m x 1m x 0.5m
Accommodation (e.g. internal/external)	Inside Heracles Lander or with its own lander
Power required	Self sustained
Data generated	Instrument Data, Video Stream,…
Pointing/viewing/line of sight needs	-
Communications needed	Data Relay from surface to earth
Duration of experiment	14 days
Crew tasks (if needed)	Possible teleoperation tasks
Access and servicing by crew (if needed)	None
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	Visibility from Lunar Poles (latitude >80°)
Operations without crew (if any)	Teleoperation from Earth/Partial Autonomy

L-DART: LUNAR DIRECT ANALYSIS OF RESOURCE TRAPS; AND L-DART-LITE

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Scientific Domain:

Physical Sciences, Solar System Sciences, Earth Sciences, Lunar Volatiles; ISRU

Summary

Lunar science and exploration is currently enjoying a spectacular renaissance, driven by the scientific interest in lunar polar volatiles (especially water ice) and consequent implications for exploration. After the lull that followed the Apollo and Luna era – in which the seminal work that is The Lunar Sourcebook (Heiken et al. 1991) categorised the Moon as an 'essentially waterless planet', many spacefaring nations are preparing new lunar missions. Many of these missions target the lunar poles, which have been shown to be very different to the largely equatorial areas studied in detail via Apollo and its returned samples. Orbital missions have revealed an extraordinary near-polar thermal environment: the Moon's low angle of tilt dictates that topography dominates illumination conditions and temperatures in Permanently Shadowed Regions (PSRs) are among the lowest in the solar system. These areas act as cold traps where a range of volatiles are thermally stable on geological timescales (Paige et al. 2010) potentially harbouring a scientific treasure trove of time-integrated volatile inventory. Together with raised areas nearby that offer near-constant illumination for solar power generation (e.g. Noda 2008), these volatiles are regarded as key enablers for sustained exploration and even extended human presence in a "Moon Village".

Although a variety of instruments on orbiters have indicated the presence of hydrogen or water at or near the surface, there isn't consensus on the interpretation of orbital data. For instance, hydrogen concentrations from neutron spectrometers (Feldman et al. 1998, 2001; Mitrofanov et al. 2010) do not correlate with thermal maps (e.g. Paige et al. 2010) which could signify instrumental technique variability or could result from broader factors such as a past change in the spin axis of the Moon ('true polar wander' – see for example Siegler 2016). Moreover there is an absence of sub-surface temperature data leaving thermal models insufficiently bounded. The most direct evidence for lunar polar volatiles comes from the Lunar Reconnaissance Orbiter (LRO) Lunar Crater Observation and Sensing Satellite (LCROSS) (Colaprete et al. 2012). This culminated in the impact of the spacecraft's spent upper rocket stage into the permanently shadowed Cabeus crater near the lunar south pole. The impact was observed by a suite of instruments on the shepherding LCROSS, leading to deduction that the concentration of water ice at the impact site was 5.6 ± 2.9% by mass (Colaprete et al. 2010). In addition to water, a number of other volatile species were detected by instruments on both the shepherding spacecraft and LRO (including near-infrared, visible and ultraviolet spectrometers; Colaprete et al. 2010; Gladstone et al. 2010). Many of these were consistent with calculations on thermal stability (Zhang and Paige 2009; 2010).

But LCROSS still leaves key questions unanswered. The derived concentrations of volatiles in the regolith are influenced by uncertainties in regolith strength and excavation volume; the remote measurements are susceptible to chemical reactions in the plume altering the nature of the parent volatiles; and the sub-surface thermal environment was not measured directly. These uncertainties are of fundamental scientific importance, and also are strategic knowledge gaps for the design of future lander, rover, sample return and human missions.

The Lunar Direct Analysis of Resource Traps concept (L-DART) concept was conceived by OU/QQ/ADS /MSSL to answer many unknowns remaining after LCROSS and to provide ground truth data to calibrate the existing remote datasets. It builds on UK expertise in the ~500 gram mass spectrometer of the Rosetta Ptolemy (Morse et al. 2015, Wright et al. 2015) and PROSPECT (Barber et al. 2017) packages, deploying it directly into a lunar PSR, inaccessible to traditional soft landers and rovers. The penetrator itself serves as the sampling tool and the

mass spectrometer analyses in situ the volatiles released both in the impact and in the subsequent thermal soak from lander to surrounding regolith. A pair of 3-axis accelerometers measure regolith structure during the landing event and constrain penetrator final location. Temperature sensors constrain regolith thermal properties. Within hours or even minutes after landing, science is complete meaning battery mass is minimised, and data are transmitted to a satellite for relay to Earth. The possible landing sites include an obvious candidate in Cabeus crater. Discussions have already been held with Dr Anthony Colaprete (PI of LCROSS mission) in this regard – who described the planned L-DART in-situ measurements as "hugely complementary to the LCROSS data which were all remote". Other candidates might include Shoemaker crater which exhibits excess hydrogen or areas indicated by LRO to exhibit putative surface frost. Alternatively, L-DART could target the hypothesised ancient (paleo) south pole (Siegler 2016) and hence potentially ancient volatiles.

L-DART Status

L-DART builds on many years of development under UK and ESA funding. Currently UKSA is funding a study by OU and QinetiQ on the attenuation of the communication signal by overlying regolith after landing. The all-up system mass is to be updated soon to reflect optimisation in payload mass and accommodation.

Role of the DSG

We are convinced that a mission such as L-DART will be implemented in the coming years. The DSG could release instrumented penetrators which de-orbit and land into a range of landing sites including PSRs. The DSG may or may not be the best way to deploy these penetrators due to delta-v and safety considerations relating to the propulsion system. However the penetrators could be a 'payload of opportunity' on a mission facilitated by the DSG e.g. HERACLES, whereby the penetrators would never be inside the station and the majority of the landing could be performed by the host spacecraft. We are of course very keen to discuss such possibilities with the Agency. There is, additionally, a potentially uniquely symbiotic way to combine the opportunities afforded by L-DART and the DSG, through a concept named 'L-DART-LITE', as set out below.

L-DART-LITE

L-DART-LITE combines the shock-hard miniature instrumentation of L-DART with the precision deployment capability afforded by a landed mission such as HERACLES, to emplace a series of miniature darts or microprobes in scientifically valuable locations inaccessible to conventional landers or rovers.

The DSG offers access to the lunar surface, but landing site selection will trade off scientific/exploration merit against technical risk and mission safety (with heavy emphasis on the latter aspects for human missions). This means that the DSG is not likely, at least in early missions, to enable astronauts to directly access sites such as PSRs that are of highest value from the perspective of ISRU. However, those astronauts can use the unique skills afforded by human surface presence, possibly with guidance from the DSG crew, to deploy a series of L-DART-LITE microprobes into high value sites at ranges from 10s to 100s of metres (or more: range is determined by lunar surface-based delivery system; see below).

Advantages of the surface-deployed L-DART-LITE over its delivered-from-orbit counterpart (L-DART penetrators) thus include this reusability of deployment system with concomitantly much higher payload-to-delivery-system mass ratio; precision targeting enabled by human interaction and close-range delivery; and that scientific results can be placed in a rich geologic context through observations of the deployment area. Downsides include potentially limited lateral range (TBD), and limited penetration depth on landing.

The design parameter space is wide enabling a rich variety of surface mission concepts (e.g. Rogoyski et al. 2006). Payloads can be tailored for the targeted landing site and scientific investigation, and could include sensors for regolith geotechnical properties (accelerometers, cameras, thermal sensors) and for volatiles detection (mass spectrometers and electrically or chemically induced heating/volatilisation devices). Various deployment methods are feasible, but common feature is that the microprobes should be ballistic (i.e. free-falling), with a reusable delivery system to increase system efficiency. Probes could be dart-shaped which enables high shock tolerance in the axial direction but places requirements on delivery system performance, or could be spherical which relaxes launcher requirements at expense of requirement for shock tolerance in all axes. An alternative would be to capitalise on the proliferation of CubeSat hardware, which could be packed with some shock-absorbing protection depending upon launch method employed. Sub-surface measurements could be made through deployment of instrumented moles/augers/drills/push-tubes, in some cases with the aft body serving as antenna. The mass of L-DART-LITE microprobes depends on payload and other functionality, but could start from ~100 gram per unit (Rogoyski 2006).

Table: L-DART-LITE

Estimated experiment properties	Description: L-DART-LITE
Mass of hardware	Varies according to science objective/payload. Typically 1-10 kg
Volume of hardware	See above
Accommodation (e.g. internal/external)	Deployed on lunar surface
Power required	Self-contained
Data generated	Typically 10s of MB (driven by imager data)
Pointing/viewing/line of sight needs	N/A
Communications needed	Requires relay form lunar surface to DSG (TBC)
Duration of experiment	Typically hours to days (operates autonomously)
Crew tasks (if needed)	Deployment on surface
Access and servicing by crew (if needed)	N/A
Need for retrieval and return to Earth	N/A
Specific orbit needs (if any)	N/A
Operations without crew (if any)	Operates autonomously after deployment

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SAMPLING LUNAR PALAEOREGOLITH DEPOSITS

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Scientific Domain:
Solar System Sciences

Idea Description:

The Deep Space Gateway (DSG) has the potential to assist in sample collection and return from the lunar surface. In particular, tele-robotic operation of landers, rovers and other equipment has the potential to enable more complex surface operations than would be possible using purely automated space vehicles. Moreover, by providing the opportunity for samples collected on the surface to be cached at the DSG and then returned to Earth in an Orion spacecraft, this mode of operation will greatly increase the mass and diversity of samples returned to Earth for analysis over and above what could be obtained using a robotic ascent vehicle to transfer samples to Earth directly. Moreover, depending on the chosen orbit of the DSG, it will be possible to return samples from widely separated geographical locations. Many aspects of lunar science will benefit from this capability, but here we address its application to the return of lunar palaeoregolith samples.

The lunar regolith is a unique witness to over 4 billion years (Gyr) of Solar System history, and records changes in solar activity (via the implantation of solar wind ions), the population of small bodies in the Solar System (via the retention of meteorites, micrometeorites, and interplanetary dust particles), and the passage of the Solar System through the Galaxy (via cosmogenic nuclei produced by galactic cosmic rays (GCRs) and accretion of supernova ejecta). Collectively, these lunar geological records will provide a window into the early evolution of the Sun and Earth, and of the changing galactic environment of the Solar System, and are likely to be of wide interest to the astrobiology, planetary science, solar physics, and astrophysics communities.

Studies of Apollo samples have confirmed that such records are preserved in the lunar regolith, but the surficial layers from which these samples were collected have been subject to ‘gardening’ by meteorite impacts for the last 3-4 Gyr, with the result that the records they contain have been averaged over this time. From the point of view of obtaining ancient records of the Solar System’s cosmic environment, we require access to materials that have been exposed to the space environment at known times and for known durations throughout Solar System history. Fortunately, the Moon has hosted a range of geological processes which can provide just such a temporally calibrated record by covering over, and thereby preserving, previously exposed surfaces. A key concept is that of a 'palaeoregolith': a once surficial regolith layer that has been buried by later geological processes. Such palaeoregoliths will preserve a record of everything that impinged upon them (including the solar wind, GCRs, and other aspects of the space environment) dating from their time on the surface. Moreover, the strata underlying and overlying a palaeoregolith layer can be independently dated using standard radiometric dating techniques, thereby assigning a precise age and duration for the record retained in the intervening palaeoregolith. This is essential for understanding the temporal evolution of the astronomical processes recorded when the palaeoregolith was on the surface and exposed to the space environment.

Because palaeoregoliths will be preserved below the present surface of the Moon, and because the elucidation of records that they contain will require analysis in laboratories on Earth, any space mission designed to study them will have to consist of the following elements:

• Precision landing of a spacecraft at a location where sub-surface palaeoregoliths are suspected to exist based on earlier remote-sensing measurements;

• Drilling into the sub-surface to extract samples of palaeoregolith and the immediately under- and over-lying strata. Drilling depths will vary depending on location, but are likely to be in the 10s of metres.

• Extraction and examination of the resulting drill core, and transfer of parts of it to an Earth-return vehicle;

• Return of samples to Earth for curation and analysis.

We note that ESA is already making investments relevant to the first two bullet points (i.e. the PILOT precision landing system, and the ExoMars and PROSPECT drilling technologies. Use of the DSG will greatly aid in addressing the remaining two requirements: extraterrestrial drilling (to estimated depths of tens of metres) is likely to be a complex operation that would benefit from real-time tele-robotic operations, while transferring samples to the DSG will enable a greater mass to be returned to Earth and some initial triaging of the samples. Operation from the DSG would also allow access to multiple geographical localities, which is important given the wide spatial distribution of likely palaeoregolith deposits on the lunar surface.

A science case for a similar project was submitted in response to ESA's 'Call for New Scientific Ideas' in 2016 (see http://www.star.ucl.ac.uk/~iac/New_Scientific_Ideas.pdf). ESA's evaluation of that concept noted the complexity of the drilling requirement and explicitly recommended that "tele-robotics is suggested as a potential need due to complexity of the [sample] selection process". The review also highlighted the low TRL of ESA's sample return capability. Incorporating the DSG into the proposal would mitigate these concerns by enabling tele-robotic operation on the lunar surface and leveraging NASA's Earth-return capabilities with the Orion spacecraft. We also note that if tele-robotic operation from the DSG proves to be impractical this aspect might instead be implemented from Earth, while still making use of the human assisted sample return capability of the DSG/Orion combination.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	Mass will be required on the DSG to permit for telerobotic surface operations. This will be similar to what will be required for other proposals wishing to use the DSG for telerobotic operations. However, tele-robotic operation from the DSG is not absolutely essential as it may be possible to implement this from Earth. TBD.
Volume of hardware	Ditto
Accommodation (e.g. internal/external)	Storage space for sample caching. Volume TBD
Power required	
Data generated	
Pointing/viewing/line of sight needs	Telerobotic operations may require line-of-sight communications with the surface lander.
Communications needed	Whatever is required for tele-robotic operations
Duration of experiment	
Crew tasks (if needed)	Collection of samples from an ascent vehicle and transfer to Orion for Earth return.
Access and servicing by crew (if needed)	See above.
Need for retrieval and return to Earth	Yes, Earth return of samples to appropriate curation facilities will be essential.
Specific orbit needs (if any)	Telerobotic operation of surface assets may be desirable, but not essential to the concept.
Operations without crew (if any)	

NEW SOLAR SYSTEM SCIENCE AND EXPLORATION ENABLED BY DEEP SPACE GATEWAY AROUND THE MOON

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Scientific Domain:
Solar System Sciences, Resource Utilisation of Planetary Materials; Applied Science.

Idea Description: All ideas below require either robotic or human-assisted sampling on the lunar surface followed by human-operated geochemical laboratory on the DSG platform.

- Geochemical analysis of volatile(+organic)-bearing lunar samples in near-ambient lunar environment.
    - Payloads (e.g., ProSPA) already in development for deployment on a lander could easily be re-purposed for this, maximising science outputs while minimising the risk of 'returning no data'; for example, in case the lander doesn't land as expected. Besides, analysis of volatiles (and potentially organic compounds) bearing lunar soil could be analysed in this DSG lab avoiding or minimising any non-lunar contamination. This would be particularly relevant for samples that may be meta-stable once removed from their ambient lunar environment (e.g., water-ice, clathrates). Analysis on a DSG lab would minimise the time and complexity required to perform cryogenic sampling of such material and return them to Earth without compromising their original physical or chemical characteristics. Additional benefits would include knowledge gain in understanding the performance of complex instrumentation in reduced gravity for optimising future instruments for deployment on the surfaces of asteroids or Mars.
    - As well as ProSPA-type hardware being used on the DSG itself, elements of it (and related hardware) could be used by astronauts on the surface to find and select which samples are the best ones to bring up to the DSG for detailed analysis there (and ultimately on Earth). Such techniques could include remote sensing for identifying rocks which are typical for their location (or indeed atypical, meaning that they could be non-lunar e.g. scientifically valuable Earth rocks), and close-up imagers and spectrometers to identify and verify target rock types.
- Performing experiments on lunar soils in DSG labs to evaluate the feasibility of resource extraction (e.g., production of oxygen)
    - This could expedite the progress for exploring the Moon and the wider Solar System for valuable resources by yielding results that would be of significant interest in the established commercial sector (e.g., mining industry) or new private enterprises (e.g., Deep Space Industries).
- Experiments involving lunar soils to test technologies for 3D printing of components for potential lunar habitats/infrastructure
    - DSG would be an ideal platform to conduct feasibility experiments under more 'controlled' conditions, than would be possible at the lunar surface, using real lunar soils to 3D print components and objects that would be required for sustained surface exploration of the Moon and/or for building infrastructure for extended human presence on the Moon.
- Monitoring of lunar environment for meteoroid impacts and, if possible, collecting these meteorites shortly afterwards and analysing them in DSG labs.
    - This would allow a better understanding of the nature of impactors and their present-day flux to the Earth-Moon system. Besides, being scientific targets in their own right, the chemical makeup of these impactors would inform prospecting missions to asteroids.
- Intermediate step involving geochemical analysis of samples returned from asteroids and Mars before returning them to Earth
    - DSG could also be used as a receiving laboratory for Mars sample return, especially in the context of Planetary Protection. This would require microbiology laboratories, which could

    - be added to the DSG in an incremental manner after DSG has been utilised for Solar System science studies, facilitated by the near-term lunar and asteroid surface exploration.
- Using DSG to promote public engagement with "Exploration Science".
    - By virtually creating a "Museum in Space", where rare and unique planetary samples will not only be curated for long term but also be used as facilitators for performing applied science experiments devised by the members of the public.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	Variable: indicative example is ProSPA
Volume of hardware	Variable: indicative example is ProSPA
Accommodation (e.g. internal/external)	Internal
Power required	Typically, up to few 10s W
Data generated	Typically, of order of MB or 10s MB for multiple images
Pointing/viewing/line of sight needs	No
Communications needed	
Duration of experiment	Variable, from seconds to ~hour depending upon analysis type
Crew tasks (if needed)	Collection of material on the Moon. Analysis in DSG lab(s)
Access and servicing by crew (if needed)	Routine maintenance?
Need for retrieval and return to Earth	Yes, of material deemed worthy of more detailed analysis using Earth-based lab infrastructure.
Specific orbit needs (if any)	As close to the Moon as possible to reduce Moon-DSG transit time (in case of analysis of delicate samples)
Operations without crew (if any)	Continuous monitoring of lunar exosphere for meteoroid impacts

INTERDISCIPLINARY LUNAR SCIENCE USING SURFACE PENETRATORS

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Scientific Domain:
Solar System Sciences

Idea Description:
High speed penetrators are instrumented projectiles specifically designed to withstand impacts onto solid surfaces at high speed, e.g. several hundred metres per second. The viability of penetrators as an efficient delivery platform for the emplacement of rugged instruments in planetary near-subsurfaces has been proven independently in ground tests by several teams. These include in the past decade the UK Penetrator Consortium, which carried out several tests in support of the then-proposed MoonLITE lunar penetrator mission. Several penetrator missions have been proposed, and two launched, though unsuccessfully, and more recently have been put forward as viable platforms to operate in low temperature environments for extended periods, e.g. the Akon penetrator proposed for delivery to Jupiter's moon Europa. The latter would carry several geophysical experiments as well as sensors to help ascertain the viability of Europa as a habitable environment.

If operating in a Near-Rectilinear Halo Orbit or Low Lunar orbit, the Deep Space Gateway (DSG) will provide a platform from which penetrators could be delivered to the moon's surface. Delivery of the penetrators would involve the release from the DSG of each penetrator and its delivery module. The latter would primarily comprise a rocket and AOCS system dedicated to completely arrest the sub-penetrator ground motion, providing enough delta-V to cancel lateral motion. This will allow a penetrator impact orthogonal to the lunar surface. The DSG could also act as a telecommunications relay through which data from the penetrators can be received from the penetrators and transferred to Earth. Depending on the penetrators' design, operations could continue for extended periods, spanning at least a full Near-Rectilinear Halo Orbit of the DSG.

It can be argued that the DSG may not be the ideal platform from which to deliver penetrators compared to a dedicated unmanned mission. It is noted for example that periapsis speeds of the DSG would be high compared to a platform in low lunar orbit. However, as the US space shuttle programme demonstrated the viability and indeed value of launch of satellite and interplanetary probes from a crewed spacecraft in low Earth orbit, the DSG may also allow flexibility in the delivery of penetrators and their deorbit modules. The Apollo 15 and 16 lunar subsatellites are another example of successful unmanned platforms released from crewed spacecraft. Crew safety will without question be paramount; use of solid propellant only in the penetrator delivery system, as well as delivery and handling of the penetrators only taking place outside the DSG could minimize any inherent risks to the crew. Indeed, the penetrators' mounting on the Orion spacecraft, minimizing the need for any handling by astronauts for transfer to the docked DSG, should also be considered.

The scientific return from lunar penetrators could be extremely high, with the platform potentially addressing the scientific areas of lunar soil volatile content (see Barber et al., this meeting) and lunar seismology (see McClean & Pike, this meeting). Other potential experiments include a subsurface heatflow monitor, magnetometer, radiation environment monitor, and a descent imager to allow impact site characterisation and context pre-landing. The latter camera could make multispectral polarimetric observations of the lunar landing site at very high spatial resolutions pre-impact, using a low-mass miniaturized design related to a camera also suggested for the DSG (Jones & Brydon, this meeting).

The equipment required on the DSG would be the penetrators and their delivery systems, temporarily mounted on the exterior of the DSG until release, radio receivers for the gathering of data from the penetrators, and an interface for data transfer to Earth. A single penetrator would be of significant scientific value, but a network of several operating concurrently would collectively return a much more valuable dataset than the sum of several devices operating at different times. A minimum number of four penetrators is thus suggested, for redundancy.

Estimated experiment properties	Description
Mass of hardware	Up to 50kg per penetrator, depending on instrument complement and penetrator design. DSG orbit will determine exact delta-V requirements.
Volume of hardware	TBD
Accommodation (e.g. internal/external)	External.
Power required	Minimal on DSG except for radio receiver; penetrators operating on internal batteries.
Data generated	Flexible, dependent on experiment complement.
Pointing/viewing/line of sight needs	Release with penetrator aligned with DSG lunar ground-track.
Communications needed	Radio receiver on DSG for data transfer to Earth.
Duration of experiment	Dependent on design. Several days possible if employing conventional batteries. Alternative technologies could extend lifetime considerably.
Crew tasks (if needed)	Possible release and visual monitoring of penetrators.
Access and servicing by crew (if needed)	None once mounted for release.
Need for retrieval and return to Earth	None.
Specific orbit needs (if any)	NRHO or LLO.
Operations without crew (if any)	Possible.

Traversing the Schrödinger Basin from a Pyroclastic Vent to The Basin Centre for a Human-assisted Robotic Sample Return Mission

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Scientific Domain:
Physical Sciences, Earth Sciences.

Idea Description:

Introduction: Situated on the lunar farside and approximately 500 km from the south pole, the Schrödinger peak-ring basin is the second youngest and one of the best preserved impact basins on the Moon. With a diverse geology and potential for *in-situ* resource utilization (ISRU), Schrödinger is a prime target location for a long duration sample return mission [1-5]. With no current infrastructure at the lunar surface to support humans, a human-assisted robotic sample return mission is proposed and two long duration rover traverses have been constrained. The traverses were designed to collect samples that can address most of the 31 remaining lunar scientific and exploration objectives defined in the 2007 report by the National Research Council (NRC) [6] and agreed upon by the international lunar science community [e.g. 7].

HERACLES: The traverses have been planned in parallel with the ESA-led HERACLES multi-mission concept architecture that utilizes NASA's Orion Spacecraft and Deep Space Gateway. The Deep Space Gateway may be situated at the Earth-Moon L2 Lagrange point or other lunar vicinity enabling a communication relay between the lunar farside and the Earth to aid tele-operation of a rover. A reusable landing/ascending vehicle is envisioned that deploys the rover at the lunar surface with successive meetings with the rover then occurring at 3 consecutive landing locations along the traverse. Each meeting involves collected samples being sealed in a sample transfer container and transported by the landing/ascending vehicle from the surface to the Deep Space Gateway for subsequent return to Earth.

Method: Both traverses build upon the ~14 day (1 lunar day) traverse of Potts et al. [8], expanding for 3 years duration. LOLA derived slope maps, an interpreted geologic map [4], M^3 spectral data and an FeO map derived from Clementine multispectral data [4] were overlain onto LROC-WAC (100 m/pixel) and NAC imagery (0.5 m/pixel). Detailed analysis of these enabled identification of scientifically interesting target sites (for which a notional rover payload was designed to carry out *in-situ* analysis that can support interpretation of the returned samples), specific sample collection points and landing locations for the reusable landing/ascending vehicle. Presented here is a 207 km traverse with a longer being presented in a companion abstract [9].

Traversing The Basin Center: The rover traverse encounters 6 lithologies within the central peak ring (fig. 1) and is separated into 3 sections defined by 3 landing locations (yellow closed circles). 50 sites of interest (red circles) are identified of which 18 are prioritized as sample collection points (closed red circles). A sample mass of at least 30 kg (3 collections of at least 10 kg per section) is to be collected and returned; samples masses of at least double those values are reasonable.

Sampling capabilities. A minimum science return can be accommodated from 30 kg sample return [8,10], but increased productivity would benefit from greater ascent mass. A study of volume to mass ratios for a spherical sample transfer container of varying internal diameter was conducted, in conjunction with an engineering study that determines if the Moon escape velocity can be exceeded with increased landing/ascending vehicle payload. The results suggest a total sample return mass greater than 30 kg may reasonably be accommodated (subject to the payload of the Deep Space Gateway and Orion Spacecraft).

Traverse Section 1: A 35 km loop returns peak ring samples, pyroclastic material and inter-peak ring impact melt breccias to the first landing site. This loop is the shortest section of the traverse designed to address the most science objectives within a small area [8], minimizing risk of no sample return. The pyroclastic unit (associated with the vent) is targeted first, inferred to be volcanic glasses with volatile-rich coatings (based on the presumably analogous Apollo 15 and 17 picritic glass beads). Analysis of this unit is most important for assessing ISRU potential [11].

The peak ring (~2 km high) comprises of uplifted crust and has 3 mineralogically distinct units determined from M^3 spectra (anorthositic, olivine-bearing and orthopyroxene-bearing) [4,12]. Boulders accessible to the rover have identifiable tracks tracing back to outcrops of the peak ring, providing access to the first in-context samples of lunar mid- and lower-crust. Combined *in-situ* and lab analysis can provide insight into peak ring formation mechanisms, and test the lunar magma ocean hypothesis including processes of planetary differentiation and 'flotation' crust formation.

Traverse Section 2: A 112 km section en route to the second landing site traverses both the pyroclastic unit and mare basalts. Determining the ages and chemical compositions of these first in-context farside volcanic units can provide information on their different mantle sources and mechanisms of delivery to the surface. Potential chemical stratification of the mantle can also be sought, along with an overall more complete understanding of the thermal and magmatic evolution of the Moon (and other small rocky planetary bodies).

Section 2 also crosses smooth inner-peak ring melt sheet. Sampling from several locations across the basin addresses the optically different types of melt present, and assesses melt sheet homogeneity/heterogeneity. The top of the melt sheet has a dominantly noritic composition (inferred from M^3 spectra) [4] and may represent a quenched surface layer. Dating this layer constrains Schrödinger's formation age and hence the end of the basin forming epoch. This in turn can be applied to models testing the cataclysm hypothesis (a proposed spike in the inner solar system impact flux at 3.9 Ga). Further *in-situ* and lab analysis of the melt sheet, its surface layer and excavated melt breccias can determine the average composition of the pre-impact target material and to what extent differentiation may have occurred.

Traverse Section 3: The final ~59 km section provides outcrop mare samples from the wall of a ~4 m deep sinuous rille, of which *in-situ* analyses can also address how it was formed. Asymmetrical secondary craters formed by ejecta from the Antoniadi crater forming event are estimated to have retained up to 18% of extra-basinal material (using a

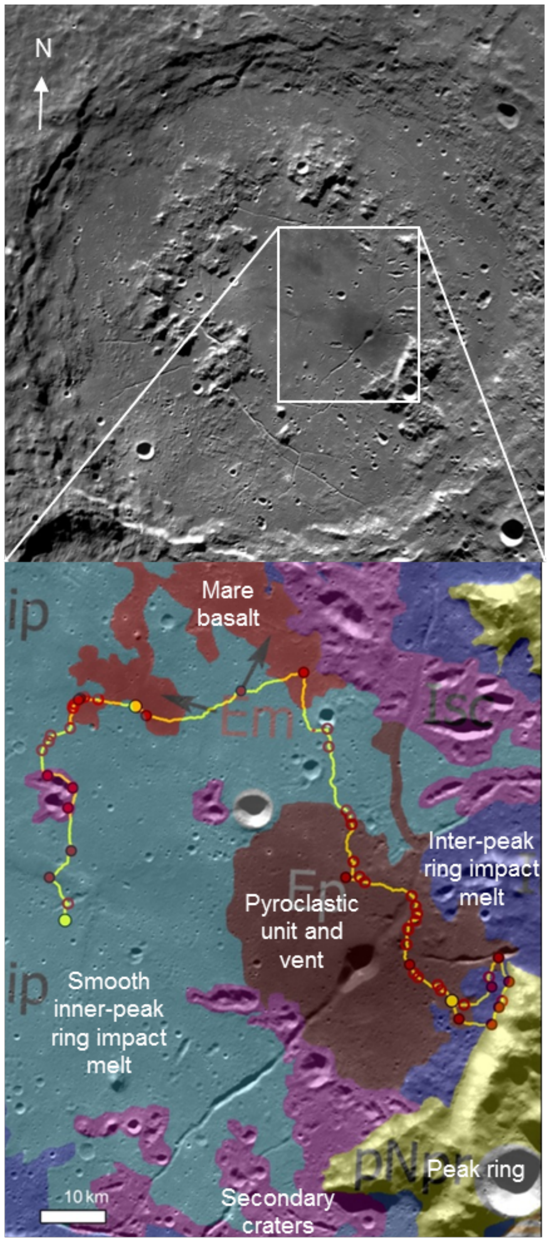

Figure 1: WAC imagery of the Schrödinger basin (diameter ~320 km) with overlain geologic map [4] and basin center traverse route (using ArcGIS 10.1™).

ballistic model calculation [13]). Therefore, sampling of the secondary crater ejecta blankets may possibly return additional material distal to the Schrödinger basin.

An intriguing iron-rich ridge is targeted as the final site of interest. It is suspected to be associated with the volcanism but may be attributable to some tectonic activity. Finally, intermittent regolith sampling along the traverse also addresses impact cratering and regolith gardening processes.

Conclusions: A long duration human-assisted robotic mission to the central region of the Schrödinger basin should return a minimum of 30 kg of sample. Such material includes the first samples of lunar farside volcanic units, unaltered basin melt sheet and in-context crustal lithologies. Subsequent analysis would address 20 of the 31 remaining lunar science goals, including 5 of the top 10 prioritized goals [7]. The potential for ISRU also provides an important step toward using the Moon as a platform for onward space exploration.

Acknowledgements: Thanks for the support and funding from USRA-LPI, NASA SSERVI and CLSE.

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Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	To be defined
Volume of hardware	To be defined
Accommodation (e.g. internal/external)	Internal accommodation required at Deep Space Gateway.
Power required	Yes, for communication and habitability purposes.
Data generated	~0.1 to 8000 kbps
Pointing/viewing/line of sight needs	Line of sight between Gateway and rover
Communications needed	Yes – X-band radio communication
Duration of experiment	3 years (with abundant margin)
Crew tasks (if needed)	Teleoperate rover from Deep Space Gateway. Collect lunar samples from reusable landing/launch vehicle.
Access and servicing by crew (if needed)	Access to Deep Space Gateway required for crew to collect lunar samples and teleoperate rover.
Need for retrieval and return to Earth	Yes – rock and regolith samples, at least 30 kg total (at least 10 kg per ascent from surface).
Specific orbit needs (if any)	Prefer halo Orbit around Earth-Moon L2 Lagrange Point.
Operations without crew (if any)	Yes – telerobotics via communications relay on Deep Space Gateway.

THE DEEP SPACE GATEWAY AS A PLATFORM FOR THE DEPLOYMENT OF A LUNAR SEISMIC NETWORK

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Scientific Domain:

Solar System Sciences / Planetary Science

Idea Description:

For decades, planetary scientists have proposed seismic networks on Solar System bodies such as the Moon and Mars. Seismic networks, made up of several seismic stations spaced apart on the planetary scale, address important research objectives in planetary science. These include improving our understanding of planet formation, present-day seismic activity, and the rate of external seismic activity from impacts.

To date, seismic stations have been deployed only at one or several closely-spaced locations on the surface, and all have been deployed on stationary landers. Closely-spaced seismic stations limit the extent to which the above research questions can be addressed, and deploying a planetary-scale seismic network using a series of individual landers is not compatible with any planetary science budget.

This problem can be addressed by deploying each seismic station using penetrators instead of landers. Penetrators are typically contained within a descent module released from an orbiting spacecraft and, following a de-orbiting manoeuvre, follow an almost ballistic trajectory to the surface. On impact, the penetrator separates into two sections: a subsurface section, which contains the science instruments, and a surface section, which relays science data back to Earth either directly or via the orbiter. However, even with the penetrator method of deployment, the need for an expensive orbiter remains.

The Deep Space Gateway (DSG) solves the separate orbiter problem, but more importantly offers advantages for both exploration and planetary science.

For exploration, the main advantage is that penetrators are by their nature easily integrated as a 'piggy-back' payload: they do not require any interface (e.g. power), and only minimal crew interaction (monitoring deployment, if the DSG is crewed at the time of release). Mass and volume are modest and are reducing, largely driven by the miniaturisation of seismometer technology for the InSight Short Period (SP) seismometer. The hardware is at a medium technology readiness level, having been demonstrated on Earth. The main payload accommodation on the DSG would be an external lock and release mechanism. Deployment of penetrators from the DSG would be a technology demonstration for the successful targeted deployment of other exploration surface assets, and instrumentation that specifically addresses exploration objectives (for example sampling of water ice deposits which are important for potential in-situ resource utilisation) can be included within the penetrator payload.

For planetary science, the main advantage is that the DSG offers a platform well-suited for the first lunar-scale seismic network deployment, because of the high inclination of its near rectilinear halo orbit. Other planetary science objectives, besides those relating to seismometry, can be addressed, for example in the areas of geochemistry and lunar heat flow.

In summary, the DSG can function not just as an orbiting platform, but as a deployment platform for lunar surface assets. Penetrators, especially those containing seismic instrumentation, offer a uniquely-suited type of spacecraft that can address both exploration and planetary science objectives.

Estimated experiment properties	Description (LunarEX/MoonLITE heritage)
Mass of hardware	40 kg
Volume of hardware	20 l
Accommodation (e.g. internal/external)	External, lock/release mechanism
Power required	60 mW (penetrator internal power)
Data generated	30 kb/day
Pointing/viewing/line of sight needs	If using DSG as a relay, line of sight required between deployed seismic stations
Communications needed	Possible use of DSG as telecommunications relay from seismic stations to Earth
Duration of experiment	Zero on DSG (deployment platform only), ~1 year once on lunar surface
Crew tasks (if needed)	If penetrators released when DSG crewed, crew monitor deployment, otherwise none
Access and servicing by crew (if needed)	No
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	High inclination to allow for widely-spaced impacts
Operations without crew (if any)	Release of descent modules at appropriate times

All values are estimates, and are per descent module unless otherwise stated. Each descent module contains one penetrator. Four seismic stations are typically proposed.

Values taken from: Smith, A., Crawford, I.A., Gowen, R.A. et al. *Exp. Astron.* (2009) 23: 711. https://doi.org/10.1007/s10686-008-9109-6

DEEP SPACE GATEWAY – MICROPARTICLE ENVIRONMENT SAMPLING SUITE (MESS)

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Scientific Domain:

Solar System Sciences, Interplanetary meteoroids, Lunar dust environment, Hypervelocity Impacts

Idea Description:

This is a proposal for an instrument suite to utilize the external surface of the Deep Space Gateway as microparticle impact detector. By applying impact sensitive, acoustic and electromagnetic detectors, unprecedented multidisciplinary recording of microparticle impact events in space can be performed.

The objectives of the research would be:

- Real-time measurement of the interplanetary micrometeoroid flux
- Real-time measurement of the lunar dust flux
- Correlation of multidisciplinary observables to identify microparticle population properties as e.g. mass, density, porosity, velocity vector and possibly material composition

Equipment and/or facilitates required:

- Surface monitors to detect location, energy, directionality and velocity of impacts
- Acoustic sensors to detect impact location where no surface monitors are placed and derive impact momentum with attitude control data and spacecraft design
- Optical sensors to record impact flashes and identify impactor properties
- Radio sensors to record plasma waves generated in the impact
- Sample collector to retrieve microparticle samples for detailed studies on shape, density, porosity and material composition
- Ground facilities as dust accelerators to support development and complementary research

The role the crew of the Deep Space Gateway would play in performing the research:

- Observation of the real-time microparticle data
- Installation and maintenance of the monitoring hardware
- Handling and analysis of sample collection experiments

The research results and technology developed would prepare future interplanetary missions e.g. to Mars, where the knowledge on the microparticle environment and thus the respective risk for spacecraft, lander and habitats is limited.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	50 kg
Volume of hardware	2 m^3
Accommodation (e.g. internal/external)	Mainly external
Power required	30 W
Data generated	
Pointing/viewing/line of sight needs	
Communications needed	
Duration of experiment	Continuous over DSG lifetime
Crew tasks (if needed)	Installation and maintenance of the hardware, sample collection and possibly analysis
Access and servicing by crew (if needed)	Data observation, maintenance tasks
Need for retrieval and return to Earth	Micrometeoroid samples collected with potential analysis capabilities on-board
Specific orbit needs (if any)	
Operations without crew (if any)	Continuous sampling of micrometeoroid environment

OBSERVATIONS OF TRANSIENT LUMINESCENT PHENOMENA ON THE LUNAR SURFACE FROM A DEEP SPACE PLATFORM

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Scientific Domain: Solar System Sciences, Space Environment

METEOROID ENVIRONMENT MONITOR (MEM)

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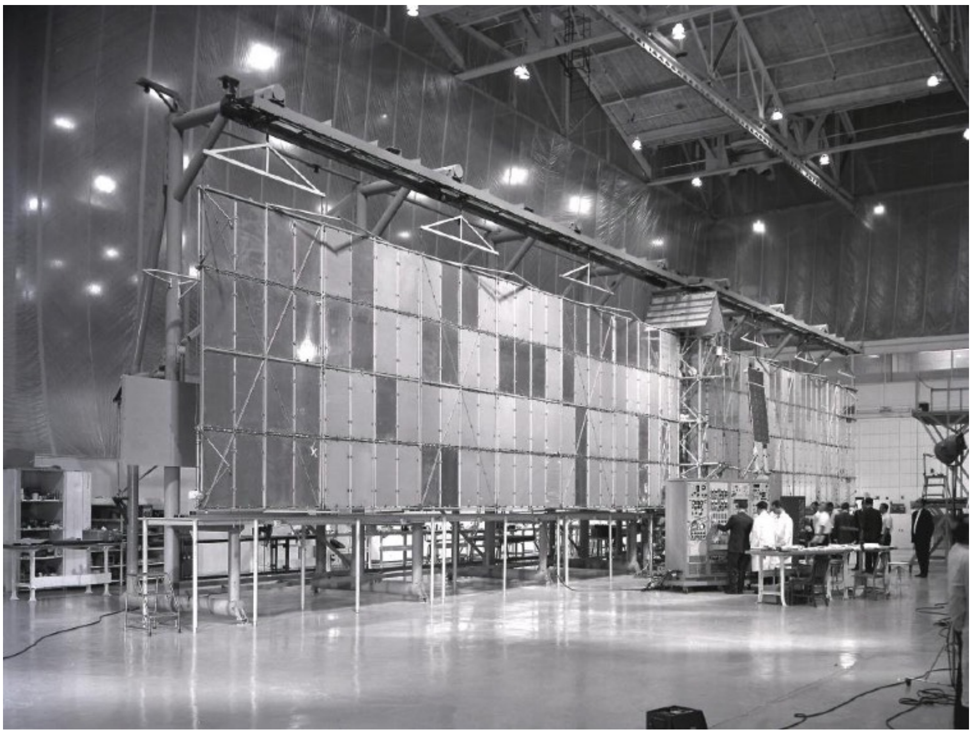
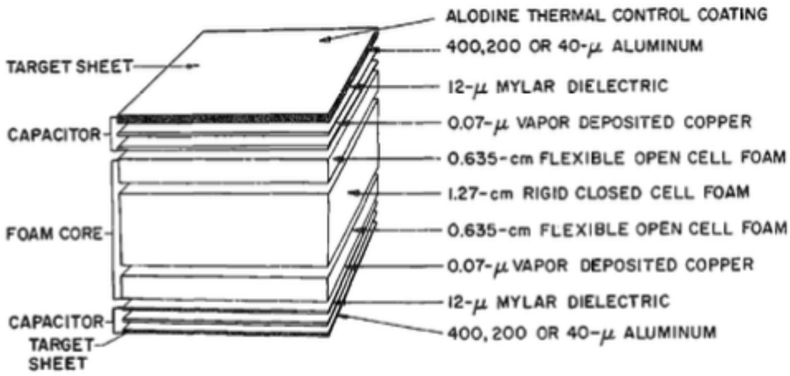
Scientific Domain: Solar System Science, Earth Science, Astronomy and Astrophysics, Space Weather, Environment Monitor, Hazard Monitoring

Idea Description: The Deep Space Gateway is used as a station to **characterize the meteoroid environment** from micron to mm sized particles. The goal is to fly a 100 m^2 area detection system in combination with a high-fidelity more sensitive but smaller in-situ detector package for cross-calibration and complementary compositional measurements.

For the latter detector a Dust Telescope (LAMA, SUDA, DDA) and an active dust collector are suited. The Dust Telescopes will provide compositional information of interplanetary and interstellar dust particles. The active dust collector will provide particle mass, trajectory and flux. The collector allows sample-return functionality for a detailed laboratory analysis (particle mass, directionality, composition).



PEGASUS spacecraft with deployed meteoroid sensor panels. The panels carried 208 segments with a size of 50 cm x 100 cm giving a total sensitive area of 194 m^2 (front and back side).



Concept of the PEGASUS I and II meteoroid large area dust detector. The outer aluminium layer of the capacitor determines the mass threshold for penetrating particles.

For the Large Area Sensor an improved version of the PEGASUS detector (lower mass, mass threshold, trajectory) is taken. A 200 m² class detector was flown on the PEGASUS I and II spacecrafts in 1965 (R. J. Naumann, 1966). The detectors had a solar-panel like structure and used segments of capacitive solid state sensors with various mass thresholds. It provided particle flux and particle mass information with low resolution. The detectors provided reliable data.

The PEGASUS detector had a mass of 1450 kg for an area of 208 m² (two-sided). Today, a much more light-weight version can be developed. The development might be taken in one or two steps, the sensor can be replaced by crew members. As a start, a 1 to 10 m² detector is flown. A later upgrade will replace the detector by a 100 m² (or larger) version. The sensor mass shall be reduced by at least a factor of 10 with respect to the PEGASUS system. PEGASUS was used to prepare for the Apollo program - now, we need to prepare for the human lunar and Mars programs. The objectives are:

- Characterize the upper end of the meteoroid mass distribution (100 μm and larger) in particle mass, speed and directionality. This provides a long-time monitoring opportunity and better hazard estimates for deep space travel and lunar exploration.
- Test and develop new large area and light-weight meteoroid sensor techniques, e.g. for Mars dust ring detection or future debris sensors.
- The in-situ package covers topics of interplanetary and interstellar dust research. What is the composition of interstellar dust in Earth vicinity? What are the differences in asteroidal and cometary dust populations? What kind of organics are found in extraterrestrial material?
- Identify challenges for meteoroid compositional analysis on a space station-like platform (cleanness).
- The platform enables the means of large area detection technologies (high volume and mass).
- Compare meteoroid measurements with existing dust environment models for model improvements. Calibrate Earth-based meteor stream data.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	Large Area Sensor : 2 kg/m2 (tbc), Dust Telescope 20 kg, Active Dust Collector : 10 kg
Volume of hardware	The sensors are scalable: Large Area Sensor: 0.3 m * 1 m * 1 m (deployable) Dust Telescope 25 cm diameter * 30 cm (small), 60 cm diameter * 85 cm (big), Active Dust Collector: 20 cm * 20 cm *25 cm (small), 40 cm * 40 cm * 35 cm (big)
Accommodation (e.g. internal/ external)	external
Power required	10 - 20 W for each sub-system
Data generated	10-100 MB / day
Pointing/viewing/line of sight needs	variable, "dust RAM", interstellar
Communications needed	no real-time, planning weeks ahead, 10 commands/ day
Duration of experiment	At least 12 months
Crew tasks (if needed)	Large area sensor : deploy (can occur automatically) Dust Telescope : none Active Dust Collector : Replace collector target for sample return
Access and servicing by crew (if needed)	None
Need for retrieval and return to Earth	only for Active Dust Collector target stage
Specific orbit needs (if any)	none
Operations without crew (if any)	N/A

DUST CHARACTERISATION WITH DEEP SPACE GATEWAY

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Scientific Domain: Solar System Sciences.

Idea Description: We propose the installation of an experiment on the Deep Space Gateway to investigate and monitor levels of dust in the Earth-Moon-Mars transfer environment.

Dust is continually generated by Solar System bodies, but also by the break down of spacecraft components in the harsh environment of space. We anticipate that the dust inventory in the vicinity of the Moon will initially be dominated by naturally occurring particles originating from dust-producing bodies such as asteroids and comets, as well as particles liberated from the surface of the Moon itself by impacts. Over the lifetime of the Deep Space Gateway mission, however, the relative abundances of natural cosmic dust vs. man-made space debris particles will change as the near-lunar environment becomes populated by spacecraft. Monitoring and investigating these two populations is vital to not only understand and mitigate against the hazards they pose to our spacecraft, but also to understand the inventory, formation and evolution of the Solar System bodies from which the naturally occurring dust population originates. Consequently, our primary objectives will be to:

1. Determine the initial abundances of natural cosmic dust (cometary, asteroidal, lunar) and anthropogenic space debris in the vicinity of the Moon and Deep Space Gateway.
2. Monitor anthropogenic space debris levels as traffic in the lunar vicinity increases.
3. Learn about the dust producing bodies of our Solar System.

To address these objectives, we propose the installation of two independent but complementary dust collection sub-systems. Several of each will be exposed over the lifetime of the mission. We describe these collectors here for deployment once in orbit, however, both could also be used to measure dust in transit.

Collector 1: Passive Foil Collector

Collector 1 is composed of foils that will be exposed to space and impact by dust particles before being returned to Earth for analysis. A wide range of passive surfaces exposed on spacecraft in low Earth orbit (e.g. the Long Duration Exposure Facility, the European Retrievable Carrier, the International Space Station) have been found to capture dust particles as they impact, preserving them as residues that line the craters or penetration holes that they create (Fig. 1). It is possible to identify natural cosmic dust vs. space debris for individual craters/penetrations based on the disparate chemical signatures of these residues [e.g. 1,2]. The science of residue analyses has been driven recently by the return of NASA's Stardust mission, which captured cometary particles from comet 81P/Wild2 via impact [3]. A significant number of laboratory impacts have been performed to determine how impacting particle mineralogy can be interpreted from their residues [e.g. 4-12]. Consequently, we are now able to not only differentiate between a residue of natural or man-made origin, but also uncover details of their parent bodies. Passive foil collectors are therefore a simple, yet extremely effective means of investigating dust in space.

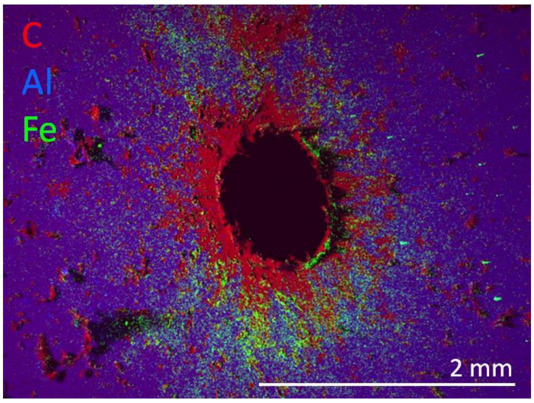

Fig. 1: Residue around penetration hole made by 1mm steel particle impacting Al-coated Kapton foil

Our passive foil collector will be based upon the multi-layer polymer experiment (MULPEX) described in [13], consisting of multiple thin Kapton foils, held apart by PTFE frames. The ability of such foils to capture and retain substantial quantities of residue that are easily identifiable has been demonstrated in previous studies of LEO exposed multilayer insulation [e.g. 14,15], and in laboratory experiments with millimetre-scale impactors (e.g. Fig. 1). Dimensions of the impacting particle may also be estimated from the crater/penetration hole on the surface foil. The foil surfaces exposed to space will be coated in a protective layer of Pd (a coating whose composition will not hinder identification of cosmic dust and space debris). The collector will have a total deployed surface area of ~1m^2, composed of multiple smaller 'cells' to facilitate handling and analysis.

Collector 2: Real-time particle impact sensor

Our real-time particle impact sensor design is similar to NASA's Space Debris Sensor (SDS) experiment scheduled for deployment on the International Space Station in Nov. 2017 [16,17]. This large area impact sensor is composed of two resistive grid thin film layers above a solid back plate (Fig. 2). Impacting particles are detected by acoustic sensors fitted to all layers. This design enables the in-situ measurement of an individual particle's impact direction and speed, and an estimate of it's diameter, mass and density. The data collected may therefore be used to obtain an estimate of total particle flux throughout the mission. The use of multiple sensors on each film enables the location of each impact event to be triangulated, thus, if returned to the laboratory, these samples can also be analysed for residue to learn more about their composition and distinguish between the natural and man-made populations. Together this would enable a real time analysis of dust flux as well as allow for the complete characterization of impacting particles. The detecting area of the collector will be 0.5m^2.

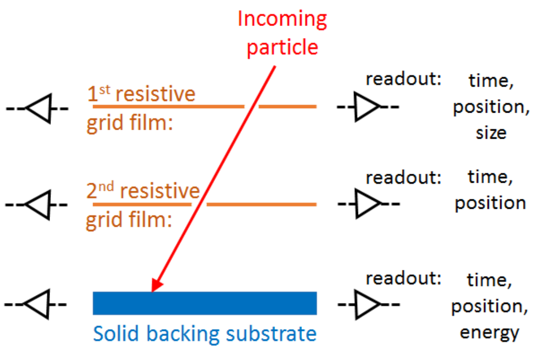

Fig. 2: Schematic of real time sensor design with data readouts

Implementation Requirements: Both collectors would require one space walk to expose and one to retrieve. Each will be exposed for a period of >12 months to ensure the collection of sufficient particles to determine confident flux data. Fresh collectors can be deployed upon the retrieval of previous collectors. We request they be located on the spacecraft exterior in the ram-facing direction. Collector 2 would also require a small amount of power and a computer to collect and perform weekly transmissions of sensor data.

Proposer Expertise: Our group has expertise in the study of extraterrestrial materials (meteorites, cosmic dust, lunar and Martian samples) and impact cratering and residues gained through years of experience working on surfaces from low Earth orbit, NASA's Stardust collector and laboratory impact experiments. A number of our group were involved in the design and development of NASA's SDS experiment. We therefore have the pedigree to design and construct a successful collector and perform sample analyses and interpretation of data to maximise the scientific return.

Research Outcomes and Impact: Throughout the lifetime of the mission, data from Collector 2 would be used to measure real-time dust flux (Objectives 1 and 2). Post-flight, SEM-EDX analyses would be performed on Collector 1 to confirm results from Collector 2 and determine relative abundances of cosmic dust vs. space debris (Objective 1 and 2). Complete characterisation of impact features on Collector 1 and 2 using a combination of analytical techniques including SEM-EDX, transmission electron microscopy, synchrotron and nano-SIMS will then enable us to address Objective 3.

By measuring the flux of particles, we will be able to directly monitor the impact of our activities in the near lunar environment. This data is vital to the design of future spacecraft and effective shielding as well as to choice of operational protocols (e.g. how to deal with waste). The collection of residues for further analysis on Earth will provide details of the conditions and processes occurring on, and variability amongst, dust producing Solar System bodies. Such returned surfaces also provide an opportunity for Citizen Science, with survey images being made available to the public to identify features of interest for further study.

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Table 1: Expected equipment and operational needs.

Estimated experiment properties	Description	
	Collector 1: Passive foil collector	Collector 2: Real time impact sensor
Mass of hardware	~A few kg	~3.5 kg if using an Aluminium backing plate ~8.5 kg if using an absorbing backing plate (preferred)
Volume of hardware	1m² surface, ~20cm deep (composed of multiple smaller cells)	0.56 × 0.56 (0.5m² detecting surface), and up to 37cm deep
Accommodation (e.g. internal/external)	External	External
Power required	None	~0.5W continuous power required for sensor
Data generated	Analytical data upon return	Real time sensor data plus analytical data of returned samples
Pointing/viewing/line of sight needs	Ram-facing	Ram-facing
Communications needed	None	Data collection and transmission About 20MB of data generated per impact – can be compressed by a factor of 10 with additional processing (not included in mass and power budget) before transmitting
Duration of experiment	>12 month exposure	>12 month exposure
Crew tasks (if needed)	Space walk to expose and collect	Space walk to expose and collect Confirm data transfer
Access and servicing by crew (if needed)	Deployment/retrieval	Deployment/retrieval
Need for retrieval and return to Earth	Yes	Not necessary to obtain some data (total flux) but preferred in order to address all objectives completely
Specific orbit needs (if any)	None	None
Operations without crew (if any)	None	Data collection

FAR-INFRARED AND MICROWAVE REMOTE SENSOR SUITE FOR EARTH AND MOON OBSERVATION

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Scientific Domain:
Physical Science, Solar System Sciences, Earth Sciences, Astronomical observations, Energy Balance, Lunar mineralogy, Cloud coverage, Observation post, Mineralogy, Resources

Idea Description:
A thorough scientific understanding of the spectral distribution of the infrared energy emitted by the Earth system is of the utmost importance, being fundamentally linked to the Earth's Radiation Budget (ERB), and implicitly containing signatures of many of the components responsible for driving, and responding to, climate change. In the global mean, approximately half of the Earth's outgoing longwave radiation (OLR) to space is located at wavelengths greater than 15 mm, within the so-called far infrared (FIR). This wavelength region is highly sensitive to upper tropospheric water vapour and to cirrus cloud, both of which critically influence the ERB and climate sensitivity. Moreover, **the FIR has a more important role than previously recognised in determining the pace of change in our fragile polar regions. Nevertheless, despite its importance, the FIR has never been measured spectrally, in its entirety, from space, due primarily to the technical difficulties associated with achieving the necessary instrument signal to noise across the region.** The situation has now changed thanks to recent advances that have been made in both detector and optical technology.

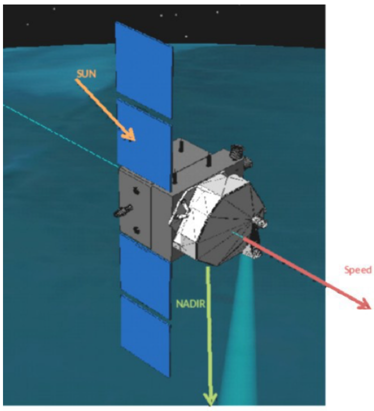
On the other hand, with the recent announcement of widespread abundance of water in the lunar surface using observations in the near-infrared spectrum, it will be a wise thing **to employ radar capabilities for mapping the possibilities of subsurface lunar water using microwave wavelengths**. From astrobiological and mineralogical perspectives, such onboard instruments and following experiments can provide exceptional data about the lunar regolith and substratum. The recent decade has witnessed unprecedented advancements in the sensor capabilities and compact payload designs. There is a need to revisit the lunar subsurface by deploying a wideband low-frequency nadir-looking pulse limited radar sounder operating at 15-25 MHz frequency band in order to get the desired high depth resolution for first tens to thousands of meters. Several past missions have tried to characterize lunar terrain and subsurface using radar frequencies. The japanese Selenological and Engineering Explorer (SELENE), launched in September 2007, was equipped with first such sounder called Lunar Radar Sounder (LRS) which carried surface penetration up to several kilometers. However, the mission lasted for less than 2 years and the sounding observations could be made only for a small fraction of total lunar surface. Chinese Chang'E-1/2 satellites carried passive microwave sensors and were primarily focused on a rough estimation of the thickness of lunar regolith and assessment of the content of helium 3. India's Chandrayaan-1 was equipped with a mini SAR operating in S-band frequency and the planned Chandrayaan-2 will have additional L-band operability. However, for kilometer scale penetration with a good resolution, such frequencies are not sufficient. Thus, **there is an imminent need for deploying a long-lasting lunar microwave mission for exploring lunar subsurface, caves, and water**.

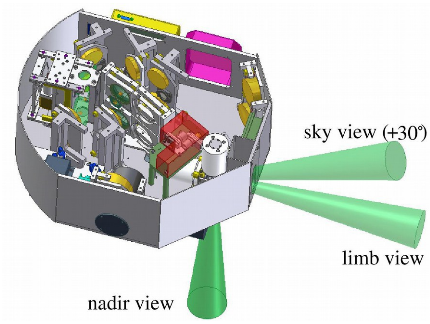
The proposed mission will fill the long-standing gap in FIR spectral observations of the Earth. These observations could be extended to the surface of the Moon. FIR and MW observations will provide unprecedented information of the mineralogy and subsurface water availability.

By closing this gap, this mission will deliver an improved understanding of the climate system, informing climate policy decisions by supplying, for the first time, a complete characterisation of the Earth's OLR spectrum. This goal will be achieved by performing a spectral measurement that: (i) covers the Earth's top-of-atmosphere (TOA) emission spectrum from 100 to 1600 cm-1 (100-6.25 mm) with a nominal resolution of 0.3 cm-1; (ii) fills the observational gap across the so-called far-infrared (from 100 to 667 cm-1), never before sounded in its entirety from space; (iii) complements, by flying in tandem with the Meteorological Operational Satellite – Second Generation (Metop-SG), mid-infrared spectral measurements performed in the 645-2760 cm-1 range by the Infrared Atmospheric Sounding Instrument Next Generation (IASI-NG); (iv) provides a multi-year dataset benchmarked against international standards with an absolute accuracy of at least 0.1 K in TOA brightness temperature. On the other hand, radar measurements will provide: (v) mapping of the possibilities of subsurface lunar water, and lunar mineralogy.

To meet these objectives, we propose a remote sensing suite composed by 3 main units: (i) a Fourier Transform Spectrometer (FTS); (ii) a Radar system; and (iii) the electronic unit controlling (i) and (ii).

The observing mode should be nadir-viewing to Earth and Moon. The proposed mission lifetime is 3 years in order to perform Earth´s measurements covering different seasons and capture inter-annual variability in a sun-synchronous orbit. The fixed overpass time precludes studies of diurnal variability, but provides a consistent set of observations for climatological assessments. A Fourier transform spectrometer (FTS) operated with uncooled detectors is sufficient to meet these requirements and can be built. This electronics includes: the detectors; the front-end electronics which perform analog-to-digital conversion for all data channels (FFTS, laser receiver, FEI, radar data); electronics for mirror drive mechanisms; the laser source with its driver; the black-body temperature control and the housekeeping sensors. The IEU includes the power supplies and the instrument control unit. The data rate of the instrument and the onboard memory, which are also managed by the IEU, allow the use of only one ground station for a limited time. All the data processing is performed off-line on the ground.





Figs 1 and 2: Schematic representation of the proposed remote sensor (credits: Luca Palchetti, IFAC, Italy).

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	85 kg
Volume of hardware	1200 mm x 1100 mm x 500 mm
Accommodation (e.g. internal/external)	External
Power required	70 W
Data generated	3 GByte/day
Pointing/viewing/line of sight needs	Nadir/Limb views, Cold space view
Communications needed	yes
Duration of experiment	3 Earth years
Crew tasks (if needed)	Accommodation in platform
Access and servicing by crew (if needed)	None
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	TBD
Operations without crew (if any)	Ground-based pointing commands

DEEP SPACE GATEWAY RADIATION RESEARCH FACILITY

Authors:

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Scientific Domain:

Life Sciences, Physical Sciences, Solar System Sciences, Astronomy and Astrophysics

Idea Description:

Under this proposed development, a comprehensive and dedicated Radiation Research Facility would be designed for the Deep Space Gateway. This would build upon the long-term experience gained from the ISS, but address it in a more coherent form and expand to the interplanetary space, where the radiation environment is substantially different and more severe than at LEO.

The objectives of the research would be:

- Providing means for continued and real-time measurement of the interplanetary radiation environment at the Deep Space Gateway orbit or location, including sources from Solar events, Galactic Cosmic Rays and lunar albedo neutrons
- Real-time local observation of the Sun for solar events, in those parts of the Deep Space gateway orbit or location that are not eclipsed
- Measurement of the transported radiation fluxes inside the crewed area
- Provision of onboard capabilities for radiobiological research and real-time effects in the interplanetary environment e.g. for biochips, DNA samples and future electronics
- Development of a real-time simulation capability for the local radiation environment and its effects both for biological matter and electronics

Equipment and/or facilitates required:

- External and internal radiation monitors capable of measuring the local proton, heavy ion, electron and neutron environments
- Solar X-ray imaging instrumentation
- Test-bed type structures for radiation effects evaluation on biological samples and Deep Space Gateway electronics
- Dedicated computing infrastructure for radiation transport and effects simulation
- For comparison to ground data, complementary research from accelerator facilities such as GSI/FAIR

The role the crew of the Deep Space Gateway would play in performing the research:

- Observation of the real-time interplanetary and Deep Space Gateway internal radiation data
- Installation and maintenance of the monitoring hardware
- Setting up and analysing biological effects experiments

The research would complement and significantly expand the radiation research being conducted at the ISS, most notably regarding the interplanetary radiation environment which is substantially more severe than that encountered at ISS altitudes.

The research results and capabilities developed would point the way for handling future missions e.g. to Mars, where the problems related to the radiation environment and its effects on both humans and hardware become even more pronounced.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	50 kg
Volume of hardware	1 m^3
Accommodation (e.g. internal/external)	Both internal and external
Power required	50 W
Data generated	
Pointing/viewing/line of sight needs	Line of sight to the Sun for X-rays, pointing to 3 axis for external radiation monitors
Communications needed	
Duration of experiment	5 years
Crew tasks (if needed)	Installation and maintenance of the hardware
Access and servicing by crew (if needed)	Observation of the radiation data, maintenance tasks
Need for retrieval and return to Earth	Biological samples yes, although local analysis capabilities should be explored
Specific orbit needs (if any)	
Operations without crew (if any)	Continuous radiation environment and solar X-ray monitoring

ION AND NEUTRAL ESCAPE FROM MOON AND EARTH

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Scientific Domain:
Solar System Sciences

Idea Description:
Moon orbit is a good platform to study the atmospheric escape, both from the Moon surface-bounded exosphere and from the Earth, when the Moon gets into the Earth's magnetotail. We propose to measure the different ions/neutrals with dedicated measurements in order to quantify the ion escape rate and to identify the different escape mechanisms from Earth and moon and their variability due to different solar activity. Such knowledge is important to understand the long-term (billion years scale) evolution of the atmosphere and essential to the history of the moon and Earth as well as their interaction processes with the early Sun. We propose to install dedicated instruments: plasma, magnetic field measurements, energetic neutral imager, and neutral particle detectors outside the spaceship to continuously monitor the environment plasma/particles. These are all passive measurements and do not require any extra operation except for health check of the instruments.

(1) Measurement of potassium and escape of other surface elements from the Moon

It would be interesting to identify and classify the efficiency of various surface release processes (thermal release, photon stimulated desorption, micrometeoroid evaporation and sputtering) from elements with a key focus on Potassium (K) and finally the accurate estimation of the global total ion and neutral escape rate as a function of solar activity. Besides other elements the focus will lie on K which is released from the surface by the above mentioned processes so that a fraction can escape from the Moon.

This is important for reproducing the K/U ratio during the Moons history as a function of solar activity. Understanding the K/U fraction will help to constrain the solar activity evolution of the young Sun, thermal history of the Moon during the first 100 Myrs after its origin and clues on the age of the Moon forming impact.

(2) Heavy ion escape from Earth

A second interesting science case would be the observation of heavy ions (i.e. O^+, N^+, etc.) which originate at Earth and could be transported into Earth's tail. If it is possible to measure heavy ions that originate from the Earth could shed some light in Earth's present day ion escape processes from the exosphere via polar wind escape (many ions that outflow over the cusps will be directed back to Earth but at the Moon's orbit, ions would be lost). Moreover, identifying terrestrial ions and noble gases that reach the Lunar surface and separating them from Moon's interior, and impacts will also give us a better understanding on the escape of ions from Earth today and also during Earth's history.

INSTRUMENTATIONS

We propose an instrument package which consists of (1) MCP Ion mass spectrometer (MIMS), (2) magnetometer (MAG) (3) (low) energetic neutral atom imager (LENA/ENA), (4) Neutral mass spectrometer ?

Estimated experiment properties	Description
Mass of hardware	MIMS: 9 kg , MAG: sensors 3kg + boom: 1kg/m LENA/ENA: 3kg/6kg
Volume of hardware	MAG: Sensor: 15 x 15 x 8 cm LENA/ENA: 27 x 23x 16cm /20 x 19 x 12 cm
Accommodation (e.g. internal/external)	MIMS: external on boom MAG: 2 Sensors external on a boom DPU (external/internal?)
Power required	MIMS: 8 W, MAG: 5 W, LENA/ENA: 10 W
Data generated	MIMS: Distributions of ions, i ~5 eV/q to 40 keV/q MAG: magnetic field vector LENA/ENA: 10 eV–3 keV/3-200 keV
Pointing/viewing/line of sight needs	MIMS: FOV 360° x 5° LENA/ENA: 60° x 10°/90° x 10°
Communications needed	Data to be saved in recorder or to be sent to ground Change of the instrument operation mode to be commanded
Duration of experiment	Continuous measurements during the entire mission
Crew tasks (if needed)	n/a
Access and servicing by crew (if needed)	n/a
Need for retrieval and return to Earth	n/a
Specific orbit needs (if any)	n/a
Operations without crew (if any)	Yes

Magnetic Field Experiment

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K-H. Fornaçon[2] R. Nakamura[3]

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Scientific Domain:
Solar System Sciences

Idea Description:
Since the Apollo era, only three missions carrying magnetometers have been placed in orbit around the Moon, all of them in the last two decades: NASA Lunar Prospector (LP) (Binder, 1998), JAXA Kaguya (Kato et al., 2010), and NASA ARTEMIS (Angelopoulos, 2010). The spatial domain investigated by these missions is very different from the regions explored by the DSG. LP and Kaguya measured the magnetic field on low Lunar orbits in the immediate vicinity of the Moon, mostly below 100 km from the surface and were able to map in detail the crustal magnetic field. ARTEMIS on the other hand follows elongated equatorial orbits, taking measurements from tens of km from the surface up to more than $10\,\mathrm{R_M}$ away. DSG will reach four times this distance to the Moon and, more importantly, due to the 90° inclination of its orbit, will measure the distant magnetic field out of the Moon's orbital plane.

Placing a three-axial Flux Gate Magnetometer (FGM) onboard the Deep Space Gateway (DSG) will allow detailed measurements of the magnetic field in several key regions of the Lunar and Terrestrial plasma environment: **1.** Circumlunar plasma, from near-surface to many Lunar radii (inside and outside the Lunar wake); **2.** Distant Earth magnetotail (magnetosheath, tail lobes and plasmasheet); **3.** Upstream Earth Solar wind and distant foreshock. The magnetic field of these regions have not been systematically investigated yet at the locations offered by the future DSG orbits.

To achive the required accuracy, the FGM should be placed on an extended boom and combined with the recently developed ESA SOSMAG to aid the removal of spacecraft generated magnetic fields from the measurements. Also, to enable three-dimensional measurements in the same manner as the ESA Cluster mission (Escoubet et al., 1997), a fleet of minimum 4 autonomous cubesats carrying magnetometers should be launched by the crew at appropriate times. When not taking measurements, the cubesats would rest in a docking station installed on the DSG exterior. The docking station would serve also for charging the cubesats batteries and for downloading the data gathered during the formation flight.

As the Moon orbits the Earth, DSG will sample the key regions mentioned above and will provide the necessary data to clarify many open questions related to this regions:

1. Circumlunar plasma: Incident particles are reflected by the local magnetic anomalies or by surface electrostatic fields, are accelerated by the wake electric fields, or just scattered by the surface material. These particles travel upstream along the magnetic field, are picked up by the solar wind and some of them even reach the deep wake on the night side. They excite plasma waves from the surface up to many thousands of kilometres away from the Moon. These waves and particles form interaction regions reminiscent of the Earth's foreshock. The morphology of these interaction regions extending upstream of the Moon and of the Moon's wake is still largely unknown, as it is their dependence on the solar wind conditions and on the position of the Moon relative to the Earth's magnetosphere.

2. Distant Earth Magnetotail: During magnetic substorms, reconnection takes place in the Earth's magnetotail, propelling plasma both toward the Earth and down the tail. ARTEMIS data show clear reconnection signatures in the distant magnetotail. Magnetic field measurements made on DSG orbit can determine e.g. the dependence of the reconnection site position on the solar wind properties. Even more, as the DSG is expected to operate for a long time, the influence of the solar cycle on reconnection characteristics such as position along tail, energy released, occurrence rate, etc can be statistically determined. When a space weather event is expected to reach the DSG location, the crew will deploy the cubesat fleet to take detailed 3D measurements.

3. Upstream Solar wind: ACE (Stone et al., 1998) monitors the upstream Solar wind at Sun-Earth L_1, providing advanced warnings of geomagnetic storms. Depending on the chosen DSG orbit and on the phase of the Moon, DSG can monitor the magnetic field at intermediate distances (Earth-Moon L_2 distance from Earth is about one third of the ACE distance). By comparing the DSG magnetic field measurements with the ACE data, one can improve the short time predictions. The Moon's orbit adds a new dimmension to the interplanetary magnetic field measurements, enabling e.g. simlutaneous observations of a CME arrival to ACE or space weather spacecraft in the Earth vicinity and to DSG one Lunar distance away from the Sun-Earth line when the Moon is in the first or last quarter.

The objectives of the magnetic field experiment on-board DSG are: **1.** Investigate the Solar wind – Moon interaction regions from the Moon's close vicinity up to $40\,\mathrm{R_M}$ and determine their boundaries, properties and dependence on the Solar wind parameters, Moon's position with respect to the Earth's magnetosphere, and Solar activity; **2.** Investigate the magnetic reconnection in the Earth's magnetotail and estimate the reconnection site position, released energy, occurence rate and the dependence on the solar wind properties and on the Solar cycle; **3.** Monitor the IMF at Lunar distances and provide data to be used in conjunction with ACE and closer to Earth measurements to improve space weather predictions and to investigate large scale Solar wind structures; **4.** Improve ESA SOSMAG technology; **5.** Test technological solutions for autonomous formation flying using cubesats.

The benefits derived from a magnetic field experiment on-board DSG are manyfold: **1.** Will help advance our knowledge on the circumlunar environment at scales never investigated before (from 1 to $40\,\mathrm{R_M}$); **2.** Will help us gain further insights into the physical mechanism of geomagnetic storms by providing essential data from the Earth distant magnetotail; **3.** Will improve the accuracy of space weather warnings by providing an independent measurement of the IMF; **4.** In conjunction with data from other spacecraft, will help the understanding of large scale structures in the Solar wind; **5.** Will serve as a technology test bed for improving magnetic field measurements in a noisy environment (variations of SOSMAG sensors placement and number can be done with the help of the crew); **6.** Will build capacity for autonomous formation flying spacecraft.

Table: Expected equipment and operational needs.

Estimated experiment properties	Description
Mass of hardware	TBD
Volume of hardware	TBD
Accommodation (e.g. internal/external)	external + internal
Power required	TBD
Data generated	TBD
Pointing/viewing/line of sight needs	no
Communications needed	TBD
Duration of experiment	DSG lifetime
Crew tasks (if needed)	manipulate SOSMAG sensors, launch cubesats
Access and servicing by crew (if needed)	internal
Need for retrieval and return to Earth	no
Specific orbit needs (if any)	NRHO
Operations without crew (if any)	yes

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EXPLORING GEOSPACE THROUGH SOLAR WIND CHARGE EXCHANGE X-RAYS

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Scientific Domain:
Solar System Sciences, Earth Sciences

Idea Description:

As our world becomes ever more dependent on complex technology, both in space and on the ground, it becomes more exposed to the vagaries of space weather, i.e. the conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of technological systems and endanger human life and health. Fundamental research into the Earth's plasma and magnetic field environment, and its response to solar activity, directly leads to the validation of models, and to strategies for predicting and mitigating the effects of space weather. This is the area of research that our idea is focused on.

Plasma and magnetic field environments can be studied in two ways – by in situ measurement, which provides precise information about plasma behaviour, instabilities and dynamics on a local scale, or by remote sensing, which offers the global view necessary to understand the overall behaviour and evolution of the plasma. The vast majority of our knowledge of the Earth's magnetospheric boundaries response to solar activity comes from very localised in situ measurements which inform us on the microscale. However, piecing the individual parts together to make a coherent overall picture, capable of explaining and predicting the dynamics of the magnetosphere at the system level, proves to be extremely difficult.

A novel and global way to explore solar-terrestrial relationships by soft X-ray imaging is offered by the SMILE (Solar wind Magnetosphere Ionosphere Link Explorer) mission, currently being developed jointly by the European Space Agency and the Chinese Academy of Sciences and due for launch at the end of 2021 (Raab et al. 2016, SPIE, 9905, id. 990502). Remote sensing of the magnetosheath and the cusps with X-ray imaging is now possible thanks to the relatively recent discovery of solar wind charge exchange (SWCX) X-ray emission, first observed at comets, and subsequently found to occur in the vicinity of the Earth's magnetosphere (Walsh et al. 2016, JGR, 121, 3353-3361). SWCX occurs when highly charged ions of the solar wind interact with exospheric neutrals, acquire an electron, are left in an excited state and then decay emitting soft X-ray lines of wavelengths characteristic of the de-exciting ion.

SMILE's soft X-ray imaging of the Earth's magnetopause and magnetospheric cusps will establish this novel technique as a powerful diagnostic tool of the conditions of geospace under the vagaries of the solar wind; SMILE will break new ground, but as a small class mission will have limited spatial, temporal and sensitivity reach over the whole of geospace.

The Deep Space Gateway (DSG) allows observing from a distance of 50 – 70 R_E (Earth-Moon L1 or L2) from Earth depending on orbit, hence offers the opportunity of expanding very substantially the coverage of geospace available at any one time to an X-ray imager compared to SMILE: for example a 10° x 10° FOV provides a good compromise for encompassing continuously a large part of the primary region of scientific interest (7 – 10 R_E centred on the nose of the magnetopause depending on L1 or L2) whilst excluding the bright Earth, and covering both magnetospheric cusps together (which SMILE cannot do most of the time from its Earth polar orbit).

Impact of the research and specific benefits

Observations with the DSG X-ray imager will extend those of SMILE to the level of having long term, semi-continuous monitoring of the response and evolution of geospace conditions under the buffeting of the solar wind. This will provide direct scientific input to the studies of space weather and to the validation of global models of solar wind-magnetosphere interactions, leading to the mitigation of the possibly disastrous effects of space weather on Earth's technological infrastructure and human life and health.

Instrumentation

For the DSG X-ray imager we are considering adopting as a baseline the Japanese concept instrument GEO-X which has been proposed for magnetosheath imaging from the Earth-Moon L1 point. It is therefore well-matched to adoption for the DSG. GEO-X employs novel ultra-light-weight X-ray telescope units (see Figure 1) with large aperture (Φ100 mm ~ 5°), short focal length (250 mm) and good spatial resolution (<10 arcmin). The Wolter-type optic is a low cost in-house fabrication constructed from metal coated Si wafers (Ezoe et al. 2010, Microsys. Tech., 16, 1633). To realise the combined 10° x 10° FOV required for the DSG X-ray imager four GEO-X telescope units are required. Radiation hard DepFET devices operating at -70° C, ideal for deep space missions, are under consideration for the detector.

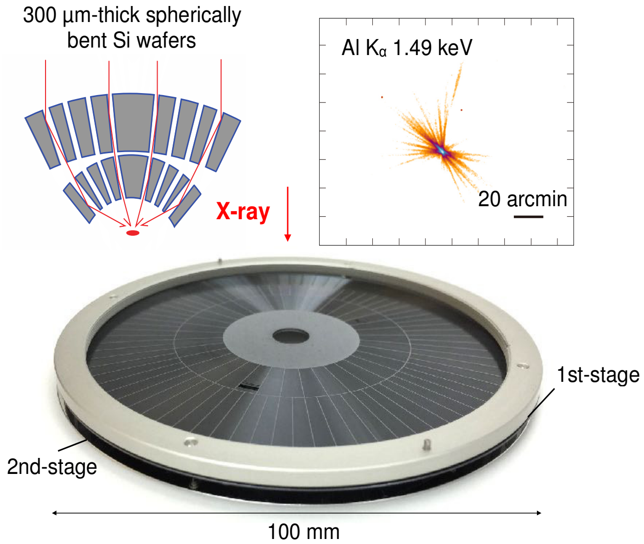

Figure 1: Ultra-light-weight X-ray telescope.

The X-ray imager would operate autonomously and would not require intervention by the crew of the DSG. Preliminary estimates of the resources required for the X-ray imager are shown in Table 1. It is worth noting that for a small increase in required resources (~4 kg, 5W, not included in Table 1) the addition of an in situ package (comprising a light ion analyser and a magnetometer) would add very significant benefit to the research by self-sufficiently providing measurements of the solar wind conditions, so as to set the X-ray observations into context.

Table 1: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	15 kg x 4 units
Volume of hardware	20 cm x 20 cm x 30 cm x 4 units
Accommodation (e.g. internal/external)	External
Power required	15 W x 4 units
Data generated	TBD
Pointing/viewing/line of sight needs	Towards the nose of the Earth's magnetopause (excluding the bright Earth), 3-axis stabilised, pointing accuracy 0.02 deg
Communications needed	Telemetry downlink and commanding needed
Duration of experiment	As long as feasible
Crew tasks (if needed)	N/A
Access and servicing by crew (if needed)	N/A
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	N/A
Operations without crew (if any)	Commanding from Earth

ACTIVE TRACER EXPERIMENTS FOR THE MAGNETOSPHERIC SYSTEM, MOON AND SOLAR WIND

Authors: R. A. Bamford[1], R. Bingham[1], and B. Kellett[1]

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Scientific Domain:
Physical Sciences, Space Plasmas.

Idea Description:

The proposal is to conduct a series of deliberate gas canister releases, either near to, or ejected from, the Deep Space Gateway spaceship. The ~1-2kg of gas released by the spacecraft would create an expanding cloud of ***tracer*** element atoms, rapidly ionized by solar UV through photoionization. The time for which the release would need to be sustained would be determined by the choice of release gas and type of experiment that is wished to be performed. Remote, in-situ and ground based optical, electromagnetic and particle observations can be made of the resulting distributions of ions and neutrals, under a variety of conditions, determined by a pre-planned gas release programme.

The properties and dynamics of the solar wind, the magnetosphere and the lunar environment may be studied by analogy, by observing the motion and evolution of these tracer particles. Knowing the precise time and location of a tracer element ion would allow laboratory-like controlled experiments to be conducted in space. It would allow theoretical and computer simulations of the above plasma environments to be validated, thus eliminating many of the current uncertainties over event timing and origin.

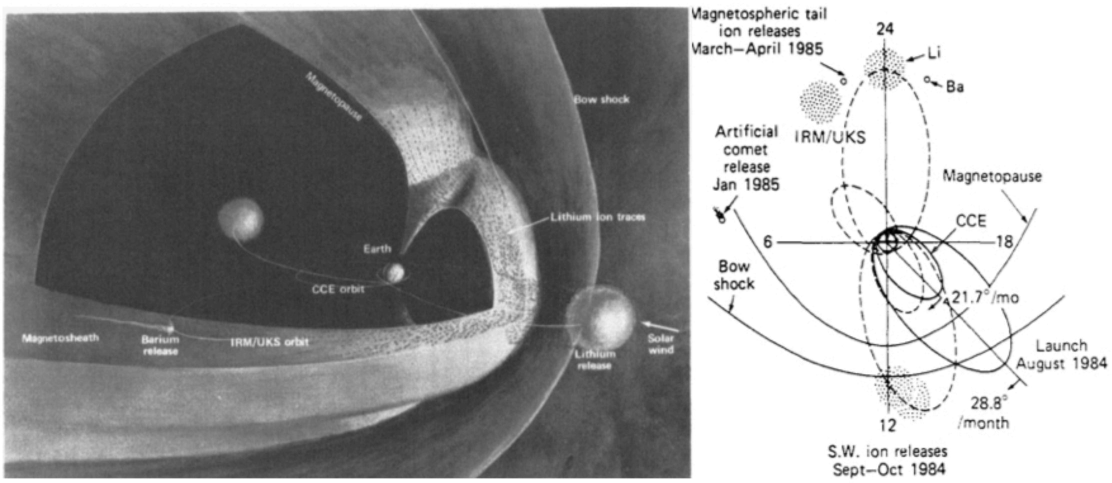

Figure 1. The Active Magnetospheric Particle Tracer Explorers (AMPTE) programme consisted of three spacecraft launched in 1984 that injected tracer ions (lithium and barium) inside and outside the earth's magnetosphere. The release ions were to be detected and monitored by the other two spacecraft. Shown are 3 experiments: (1) the Li release in the solar wind on the sunward side of the earth, (2) a Ba release generating an artificial comet in the dawn magnetosheath, and (3) a lithium tracer release in the deep magnetospheric tail. The cloud resulting from the ionization process of the release into the solar wind was similar to the case of gases produced by a real comet. In fact, the cloud resembled real comets, in that a head and tail were clearly visible even from the ground. (From Jones et al. 1984.)

The only mission of this type ever conducted was in the 1980s (See Figure 1). One of the main experiments of the Active Magnetospheric Particle Tracer Explorers (AMPTE) satellite mission was the release of neutral atoms in the solar wind, creating for the first time two man-made artificial "comets", the observations of which provided an invaluable data set to test both the theoretical and computational models of collisionless plasmas. All the experiments produced surprises and stimulated discoveries, many of which are summarised in a dedicated Nature issue (Vol. 320 in 1986).

The proposal takes advantage of the simplicity of the required payload (a remote triggered release canister of material) and the relative ease with which it could be carried on a manned (or large unmanned) vehicle. The payload would work with any other programme of suggested in-situ instrumentation.

Compared to the 1980s, the number of spacecraft currently in and around the Earth-Moon system is considerably higher and the computational capabilities availablr (particularly for modelling kinetic scale processes using particle-in-cell PIC codes) are far more advanced.

The range of observational platforms is also far more extensive than was available for the short AMPTE mission. The instruments available can be either on board the Gateway craft or on other operational missions. They could include, for example, ARTEMIS, Lunar Reconnaissance Orbiter, MMS, Cluster, SWARM, Alfven, Hubble, James Webb space telescopes depending upon operational status. Campaigns coordinated using ground based instruments like EISCAT, auroral cameras, LoFAR and other wavelength telescopes can be done. Joining with Gateway tracer experiments can add a fresh perspective to established long-term programmes.

Science

The experiments are particularly important in trying to understand the collisionless coupling processes occurring in the interactions of plasma interfaces and will provide valuable insights into momentum and energy coupling processes between the solar wind and the plasma of real comets.

When released, the migrating ions trace out the distant magnetic and electric fields and provide direct evidence of the topology of the fields. Controlled artificial release allows for definite knowledge of time and location of the origin of the particles. These can then be set to be released at different sites to suit different areas of scientific interest. These can include solar wind, magnetotail, cusp, auroral regions, radiation belts, magnetopause, lunar wake, Earth or lunar terminator passage, or release during particular events such as within a sub-storm, Coronal Mass Ejection, coronal hole fast stream etc.

The size of the released cloud after expansion (~100s of km), would still be smaller than the ion gyroradius of a solar wind ion or the release ions provides an opportunity of studying small scale effects where finite Larmor radius effects dominate, such effects are sometimes not always observable in planetary magnetospheres or comets. The use of tracer experiments is like conducting a laboratory experiment in space. Recent work in this way has successfully shown the kinetic plasma processes occurring by taking advantage of the fixed footprint of the sub-Larmor orbit crustal lunar magnetic fields that produce miniature collisionless shocks and mini-magnetospheres [Bamford et al 2012, 2016].

Recording important effects such as the generation of a diamagnetic cavity within the volume enclosed by the expanding cloud and also the generation of a shock like region at the interface of the solar wind and the cometary plasma boundary. Intense bursts of electrostatic and the magnetic wave activity together with energization of electrons are also observed on the upstream side of the ion clouds with the electrostatic wave signature similar to observations at the Earth’s bow shock.

Natural and artificial cometary comas like Hailey, 67P and AMPTE are known for making diamagnetic cavities that exclude the interplanetary magnetic field and slow down the ions of the solar wind. Diamagnetic cavity effectiveness for higher energy particles has not been studied in-situ. Theoretically there is a finite scattering even at highest energies. Examination of this topic would provide potential for establishing the feasibility of optimising an artificial plasmasphere for emergency storm shelter for astronauts from the radiation shielding in longer duration missions.

Table:

Estimated experiment properties	Description
Mass of hardware	Variable. A typical individual AMPTE Barium canister was 2kg
Volume of hardware	Variable
Accommodation (e.g. internal/external)	To be ejected
Power required	None
Data generated	None for payload data will be from other instruments and spacecraft and ground based.
Pointing/viewing/line of sight needs	Intermittent separate ejections timed with conjunctions with other in-situ spacecraft or instruments and/or ground based instruments. The location in inside/outside magnetosphere boundary, in magnetotail, in solar wind, in proximity of the Moon etc. It is adaptable to any orbit choice.
Communications needed	Triggering
Duration of experiment	Several hours
Crew tasks (if needed)	Ejection and triggering
Access and servicing by crew (if needed)	None
Need for retrieval and return to Earth	None
Specific orbit needs (if any)	No
Operations without crew (if any)	Yes

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NEUTRAL AND ION MASS AND ENERGY IMAGING SPECTROMETER (NIMEIS)

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Scientific Domain:
Solar System Sciences (Planetary Science)

Idea Description:
Context

The Moon exosphere is formed from particles ejected by various processes from its surface and from solar wind and magnetospheric particles reflected and neutralized when interacting with the Moon surface. The Moon exosphere is therefore a tracer of:

- the Moon erosion and aging. Any surface analysis needs to understand how the Moon surface is being permanently modified by the particle precipitation (sputtering, radiolysis…) and eroded.

- the Moon interaction with the solar wind and magnetospheric plasma. Several recent orbiter missions around the Moon have highlighted the unexpected albedo of the solar wind particles with more than 10% of the particles being reflected as neutral (Rodriguez et al. 2012 from IBEX; Vorburger et al. 2013 from Chandrayaan-1). These observations were completed by several observations of reflected protons from the surface as well (Saito et al. 2008).

Scientific Objectives.

Measurements of the energy and mass of the neutral species in the Moon exosphere:

1. composition and density of the neutral species in the Moon exosphere.
2. energy distribution of the reflected particles from the Moon surface.

Objective 1 has been partially covered by NMS on LADEE. NMS got its first results (Benna et al. 2014) showing to be able to measure down to 10^{-2} (counts/s)/(particle/cm^3), that is, typically to be able to measure 100 particle/cm^3. However, it is using a close source for the ionization of the neutral particles (before entering in the quadrupole analyzer), limiting its capacity of detection to species non-reactive with the walls of the ionization source chamber (that is essentially noble gases). NMS has therefore a second aperture using an open ionization source but which is less sensitive. Moreover, one of the issue is the own local spacecraft atmosphere which should increase the background noise (see as an example, the measurement done on ROSETTA; Schlappi et al. 2010). Our instrument NIMEIS is being designed to improve the sensitivity by using an original technology for an open ionization source (using carbon nano-tubes as emitted, Becker et al. 2013) and an electrostatic optic specifically designed to reduce as much as possible the measurement duty cycle. Moreover, NIMEIS is also imaging the energy distribution of the particles entering the instrument. In this way, NIMEIS is also able to significantly reduce (by one to two orders of magnitude) the background associated with the spacecraft atmosphere.

Objective 2 has been achieved also by several previous experiments. However, these experiments covered energy range above 10 eV because they are using surface ionizing surface to ionize the ENA coming from the surface. IBEX-Lo is able to measure energy down to 14 eV whereas CENA was used down to 250 eV. However, it is predicted that a large part of the reemitted hydrogen should have very low energy (Hodges 2011). Therefore, the real albedo of a regolith surface might be much larger. Moreover, the shape of the energy distribution of the reflected particle provides information on the physics leading to this reflection (Hodges 2011). At the end, not only hydrogen should be reflected from the surface but also helium particles. NIMEIS will have the capacity to make an energy measurement of these particles from ~ 100 eV down to 0.5 eV (this limit being set by the local S/C atmosphere) with emphasis put on the low energy particles below about ~ 20 eV and should therefore cover an energy range never observed so far.

Measurement techniques.

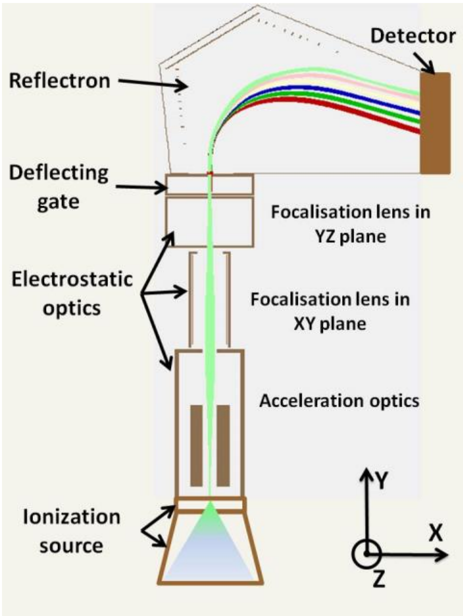

Figure 1: *Schematic view of NIMEIS. Colors are for energy difference of 1 eV).*

The gas enters NIMEIS through **an ion source** in which it is ionized by electron bombardment. Ions are then extracted towards **an electrostatic optic of acceleration followed by two lenses**. The source optics and these three elements were designed to focalize the ion beam at the entrance of a **reflectron**. The reflectron will focalize in time particles with same mass over charge ratio and will disperse in energy the ions along one direction (Y axis). The measurement of the mass of the particles is provided by the measurement of the time of flight of particles at a given energy. The “Start” time is either provided by gating the ion beam at the entrance of the reflectron (high mass resolution mode), or determined using a deflector with a variable electric field (low mass and energy mass resolution mode). The impact position of the ion on the detector along the deflecting direction (Z axis) is related to the time the ion passed through the deflector, that is, the “Start” time of the ion. NIMEIS will therefore simultaneously measure energy and mass. A 90% duty cycle will be obtained by dividing a deflection cycle into two sequences on two independent detectors, each composed of two MCPs and one collector.

We built a prototype of this instrument (Figure 2). First tests were realized in 2013 and led to several improvements of the prototype that are being implemented.

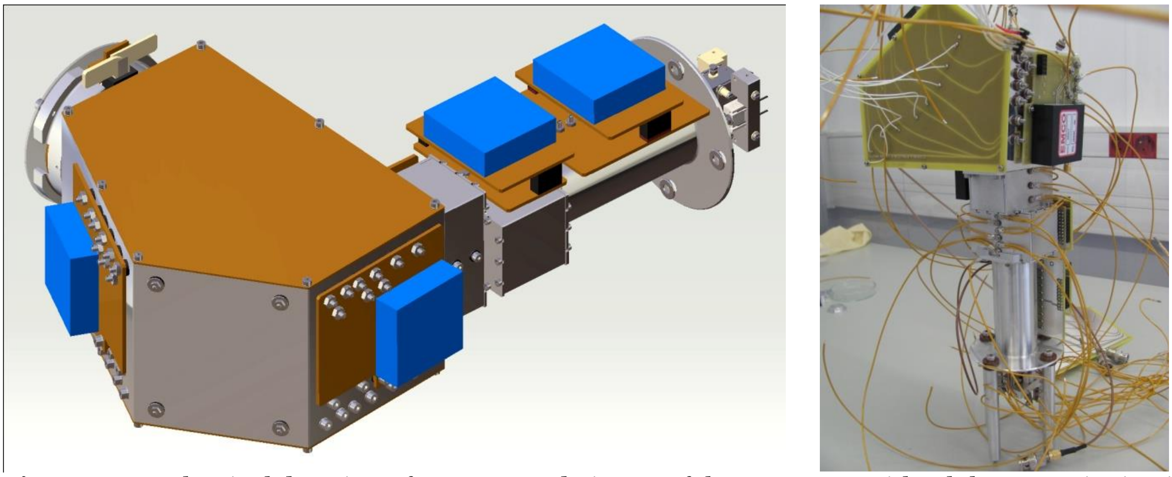

Figure 2: Mechanical drawing of NIMEIS and picture of the prototype with a laboratory ionization source.

The ionization source is being tested apart from the optic of this instrument. It is using carbon nano-tubes as emitters and this innovative electron source is developed in the frame of a collaborative effort with Ajou University (Pr. Soonil Lee). Figure 3 displays pictures of one of the device tested in our laboratory. This new approach to ionize neutral particle should allow us a much lower power consumption (less than 0.1 W) for a much better efficiency of ionization and no heating issue with the background as with classical technique of ionization in space exploration (filament emitter as an example).

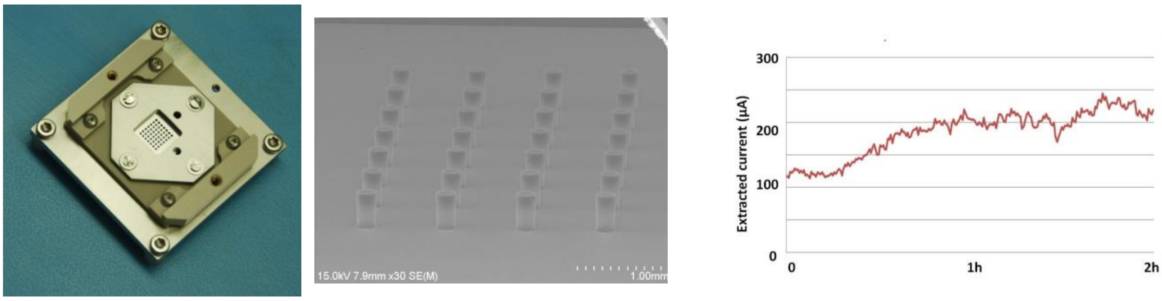

Figure 3: Left panel: picture of the extraction device developed for the first set of tests. Panel in the middle: networks of CNT on their substrate. Right panel: example of electron currents extracted using this device during 2 hours. A typical current of 200 µA/cm² is produced by this device.

A preliminary assessment of the NIMEIS resources is summarized in the following tables. Since no strong efforts were performed up to now to reduce the mass of the current lab mock-up of the instrument, we expect that the ultimate weight may be reduced to less than ~ 3 kg

NIMEIS subs-system	Weight (g)	Margin (30%)
Ionization source	145	43
Electrostatic Optics	983	295
Detector	420	126
Harness, DC/DC and FPGA	1766	530
Structure	200	60
Total	3514	1054
Total with 30% margin (g)	4568	

NIMEIS subsystem	Power (W)	Margin (30%)
Ionization source	0.5	0.1
Electrostatic Optics	0.2	0.06
Detector	0.5	0.15
Electronics and FPGA	4	1.2
Total	5.2	1.4
Total with 30% margin (W)	6.6	

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Vorburger, A., P. Wurz, S. Barabash, M. Wieser, Y. Futaana, C. Lue, M. Holmström, A. Bhardwaj, M. B. Dhanya, and K. Asamura (2013), Energetic neutral atom imaging of the lunar surface, *J. Geophys. Res. Space Physics*, *118*, 3937–3945, doi:10.1002/jgra.50337.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	4;5 kg (30% margin included)
Volume of hardware	Height: 390mm Depth: 110mm Width: 200mm
Accommodation (e.g. internal/external)	Internal with an external access
Power required	6.6 W (30% margin included)
Data generated	1167 bits/s (30% margin included + compression)
Pointing/viewing/line of sight needs	Ram direction
Communications needed	Data transmission
Duration of experiment	As long as possible
Crew tasks (if needed)	None
Access and servicing by crew (if needed)	None
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	Low altitude orbits
Operations without crew (if any)	Operation of the device

LUNAR ENVIRONMENT PACKAGE

Authors:

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NB: The package proposed is composed of on a number of instruments developed in various studies run by TEC-EPS which can benefit the Deep Space Gateway

Scientific Domain:
Solar System Sciences, Space Physics, Planetary Science, Astronomy and Astrophysics

Idea Description:

The Deep Space Gateaway platform offers an excellent vantage point for Lunar and Geo space environments monitoring in preparation of future lunar outposts and provide Europe with critical knowledge on environment parameters. A suite of instruments including plasma and energetic neutral atoms spectrometers, a magnetometer, as well as a wave instrument would allow depending on the selected orbit, to measure and correlate the environment parameters with the Moon location and Solar Activity.

Objectives of the research:

- To determine the Earth Magnetosphere and Solar Wind environment parameters (densities, temperatures, magnetic field) variability at the lunar orbit, including the poorly characterized Lunar wake
- To determine the lunar exosphere composition, in relation with surface composition and volatiles content
- To monitor the Geospace environment through radio waves (e.g. active regions such as radiation belts as response to solar activity)
- To detect hypervelocity impacts signatures on the Deep Space Gateway platform

Equipment and/or facilitates required:

- Plasma (electrons and ions) spectrometers (eV to 30keV range)
- A fluxgate magnetometer
- An Energetic Neutral Atom analyser (assuming preferably Low Lunar Orbit or cubesat deployed spectrometer) – see NIMEIS proposal
- A wave instrument DC-100MHz allowing monitoring of the Geospace environment (possibly cubesat based)
- A hypervelocity impacts sensor

Role of the crew:

- Installation and maintenance of the monitoring hardware

While each sensor is valuable in itself, the combination allows to correlate environment parameters, including the response of magnetospheric regions through waves generation, to observables of interest (e.g. plasma input to the lunar surface / exosphere density and composition) and to Solar activity especially during extreme events (CMEs, SEPs).

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	25kg
Volume of hardware	$1m^3$
Accommodation (e.g. internal/external)	external
Power required	25W
Data generated	
Pointing/viewing/line of sight needs	Lunar surface for NIMEIS, Earth for wave instrument, on orbit dependent for plasma spectrometers
Communications needed	
Duration of experiment	5 years
Crew tasks (if needed)	Maintenance of the hardware
Access and servicing by crew (if needed)	Real time data observation during specific events
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	LLO would be needed for exospheric composition
Operations without crew (if any)	

OTHER ABSTRACTS

Title:Harvesting of Solar Wind

Authors: Vincent Armstrong and Pamela Armstrong

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Scientific Domain:
– Physical Science

Idea Description:
Objective:To capture and store charged particles (electrons, protons and alpha particles) from the Solar Wind and convert the energy from the particles to provide electricity to be used on the Deep Space Gateway or Lunar/other Planetary habitats

Specific Benefit: The electricity generated would be an alternative or supplementary source of power to Solar Array power, so that smaller arrays could be used in future, especially for habitats further away from the Sun.

This is our idea as Lay people and so would not be able to present at a workshop, hope the experts could pursue the idea.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	
Volume of hardware	
Accommodation (e.g. internal/external)	External
Power required	
Data generated	
Pointing/viewing/line of sight needs	
Communications needed	
Duration of experiment	
Crew tasks (if needed)	Monitor particles being captured
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	None
Specific orbit needs (if any)	
Operations without crew (if any)	

MAKING OUTER SPACE HABITABLE: THE DEEP SPACE GATEWAY AS A SOCIOLOGICAL STAGING POST (WRITTEN SUBMISSION)

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Scientific Domain

Social sciences.

Idea Description

1. <u>Research question</u>

Making the human species "multiplanetary" is not only a matter of engine development and technical issues: once such difficulties are overwhelmed, new questions and concerns emerge regarding travelling further and for a longer time than what we are currently used to. Any long-term sustainable programme regarding an extended human presence in outer space would lead, at some point or another, to question the latter's social impacts. Because the Deep Space Gateway aims to be a staging post for missions to the lunar environment (and beyond), the station would also be a strategic platform where social, cultural and psychological challenges of long duration space missions can be addressed.

Thus, the Deep Space Gateway should serve as a strategic platform for future exploration missions and be a step further towards the understanding of social processes structuring any society such as the crafting and the reproduction of habits or customs, the deployment of cultural values and the social normalization in specific leaving conditions out of the Earth: promiscuity, isolation, restricted assistance and required autonomy, family separation, hard-working conditions, physiological adaptation, and so on. Indeed, manned infrastructures which will be developed in outer space in the upcoming years will not only serve as research platforms in science and technology or as a laboratory of international cooperation (the ISS demonstrates every day that such utilizations are starting to be well-proven), but should also allow to working on enhancing the quality of life in outer space and settle in to build sustainable and durable frames of living off the Earth.

The DSG marks a transition from the experimentation to the installation of what would eventually be the future of the human life into the Solar System, from the Moon to Mars passing by asteroids and Mars satellites; where leaving and working in outer space will be decreasingly extraordinary – but always challenging. Moreover, while the Moon and its orbit remain "the right place to be" as humans expand economic activities beyond LEO and elaborate physiological countermeasures as well as technical support to human space activities, the DSG could play an important role in the democratization of space flights, allowing space tourists to experience stays under microgravity conditions, which would force to think about how to support non-professional flyers and would progressively lead to an extended utilization of the outer space.

2. <u>Objectives and structuring of the research</u>

In the aftermaths of the International Space Station, the Deep Space Gateway would launch the start of a new area in manned space flights, where it is no longer only about learning of reactions of the microgravity on leaving bodies, fluids and so on, but where it will also be about building social frames of daily and routinized life. Hence, this contribution proposes to think about social and cultural consequences of what is at stake in human space flights while the DSG is starting to enter in a development phase, as well as about the outputs of an anthropological survey defining some prerequisites to make life off the Earth a socially speaking realistic programme. Two phases would organize the inquiry, each being related to a specific methodological protocol:

> *Phase 1. – Investigating sociotechnical interactions among crew and ground support in control centres through communication networks*: this phase would aim to provide an understanding of the modalities, conditions and consequences of a decreasing contact with the ground support, in order to prepare future long-duration spaceflights where an autonomy of the crew will be requested (such as during flights to Mars or its satellites).
>
> *Phase 2. – Building frames of social order and rethinking political frames*: the Deep Space Gateway invites to make a point on what habits and social rules to reproduce (or not) in the rebuilding of a social order off our current home-planet. As introduced here-above, the DSG then presents an astounding opportunity to draw up a state of the art of the social, cultural and organisational challenges addressed by the future of the human expansion in outer space. Coupled with the interviews performed as part of P1, the realization of a feature-length documentary mixing video recordings of interviews and footages of astronauts' flights aboard the DSG infrastructures would constitute the base of a collection of accounts and recommendation from crews' experiences turned towards social capacity-building and reflections on cultural patterns and political systems.

3. <u>Methods</u>

Such a project does not have any impact on the Deep Space Gateway design. Nevertheless, it would lay on the following inquiry protocol:

- A documentary realized according to methods of ethnographic films about the life aboard the DSG, mixing recorded and live video feed from the station and extracts of filmed interviews with crews (P1).
- Equipment and crew time: non-prescriptive interviews before and after the flight; no crew time required during flights (P1 and P2).
- A parallel inquiry about the life aboard the International Space Station as part of a PhD research (based on interviews with astronauts and cosmonauts, on ethnographical work in European and Russian control centres, and on archives of European and Soviet human space programmes) would allow drawing a comparative analysis of the DSG and the ISS, in order to highlight enrich the empirical data used in the analyse.

4. <u>Expected impact and benefits</u>

> *4.1. Contributing to collective memory of a new space era*: recorded interviews and ethnographic videos would constitute a material for feeding what will later be needed as sources of space historiography. In the same vein than ESA history project reconstituted an oral history of the European space endeavour in the past years in collaboration with the historical archives of the European Union – cf. http://archives.eui.eu/en/oral_history/#ESA –, this project would contribute to pursuing the storing of the European manned space programme *in statu nascendi*, while it enters in a new operational and cultural age. Gathered material would then be let at ESA history office disposal after data processing.
>
> *4.2. Crafting an explanatory sociological survey* about switching between space exploration to settlement and routinization of human occupation of the solar-system beyond the LEO (e.g. about a process of civilization of social behaviours): this project would lead to outline a roadmap regarding

social, cultural and political consequences of the current re-arrangement of manned space exploration (including in sight of the democratization of human space flights).

4.3. Outreach: the documentary based on interviews and footages from the DSG – especially the social and political reflections it would highlight in a period of transition in the space sector – would aim to open up a dialogue with the civil society and, in the long run, to serve as part of an international colloquium gathering scholars, policy-makers and space operational staffs.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	None.
Volume of hardware	None.
Accommodation (e.g. internal/external)	Not applicable.
Power required	Not applicable.
Data generated	Documentary and interviews with crews.
Pointing/viewing/line of sight needs	None.
Communications needed	Video feed broadcasted on the station depending on the space-to-ground video communication which will be installed.
Duration of experiment	To specify according the number of interviews with crews (desired ratio: N=20).
Crew tasks (if needed)	None during the flights; interviews before and after depending of the project section investigated.
Access and servicing by crew (if needed)	None.
Need for retrieval and return to Earth	Not applicable.
Specific orbit needs (if any)	Not applicable.
Operations without crew (if any)	Not applicable.

LOCATION-BASED PHYSICAL CHARACTERISATION OF LUNAR SOIL FOR FUTURE BUILDING MATERIALS

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Scientific Domain:
Physical Sciences, Other.

Idea Description:
The idea to use indigenous materials for the construction of a human base on the Moon is not new and has been developed since the first human missions in the 1970s. The lunar soil, whose primary constituent is called regolith, has already been extensively investigated (e.g., in terms of physical and mechanical properties) thanks to the large amount of samples returned to the Earth.
However, the samples were collected only in some specific locations, i.e., the landing sites of the respective missions. Therefore, a complete map of the characteristics of the lunar soil and their relation with the geographical location is still missing. As observed on the Earth, in fact, the properties of soil, and in general of natural materials, can change depending on latitude, intensity of the magnetic fields, temperature, etc.
On the other side, the granulometry of powders is of extreme importance in the realization of building materials or for their use in additive manufacturing (e.g., 3D printing) technologies.

The Deep Space Gateway will provide a unique opportunity to study the physical properties of the lunar soil at different locations. By collecting soil samples at specified times and coordinates, the purpose of the present research is to extract two basic physical properties of the material: granulometric composition and bulk density. In this way, it will be possible to assemble a detailed map of lunar soil characteristics, which will be important for the future development of building materials.

The idea here presented is applicable depending on the availability of a sample collection and return system, e.g. a probe able to reach the lunar surface and return on the Deep Space Gateway. In addition to this, other equipment needed will be a granulometer and a precision balance to be installed on board, for a total power consumption lower than 1 kW and an occupied volume of about 0.1 m^3.
The crew of the Deep Space Gateway will be asked to carry out the research by performing the following tasks:
- collection and storage of the soil samples;

- operation of the on board equipment (i.e., the granulometer and the precision balance) according to the corresponding user's manuals;
- data analysis and preparation for post-processing or communication.

The duration of the experiment will be the minimum for mapping the whole surface of the Moon, or selected parts of it. Thus, according to the specifications of the proposed orbits, for instance the Near Rectilinear Halo Orbit (NRHO), the suggested duration is between 9 and 12 months.

The long-term impact of the proposed research is to extract fundamental information for the preparation of building materials on the Moon, thus providing useful insights for the optimal location of future human activities.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	< 10 kg
Volume of hardware	0.1 m^3
Accommodation (e.g. internal/external)	Internal
Power required	< 1 kW
Data generated	
Pointing/viewing/line of sight needs	None
Communications needed	None
Duration of experiment	9-12 months
Crew tasks (if needed)	- Collection of soil samples - Sample analysis with the on board instrumentation - Data analysis and post-processing
Access and servicing by crew (if needed)	
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	NRHO (suggested)
Operations without crew (if any)	Collection of soil samples and return to the Deep Space Gateway

ARTIFICAL GRAVITY FOR CIS-LUNAR DEEP-SPACE-GATEWAY

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Scientific Domain:
Life Sciences, Life Support System, Crew Health

Idea Description:
Our proposal is to equip the Deep-Space-Gateway with a large rotating structure by which the crew will be exposed to artificial gravity (AG) during long duration missions. For years AG has been neglected as one of the necessary contributions to a healthy life support system. The crew is kept in a comfortable temperature-controlled surrounding with

sufficient oxygen and, especially nowadays, reasonable levels of CO_2. They are fed *ad libitum* and their social needs regarding family and friends are met via direct voice and video communications. The one factor that has been missing since the onset of human space flight is providing gravity. Humans have been totally deprived from this force, while, as numerous studies show, microgravity, and most likely also Moon gravity, is really unhealthy for human beings. Over the years various in-flight countermeasures have been developed and have to some extent been successful but not completely. The only comprehensive solution seems to be to provide gravity to the crew. This should mimic Earth gravity as closely as possible. This implies using long-arm / large-radius rotation, where there is a small body-gradient while providing a sufficient stimulus for the vestibular system.
Such a structure might be classified as 'research' but may also be regarded as part of the life support and general infrastructure of a future Gateway.

All research and operation regarding crew health will relate to such an AG infrastructure. We can start to understand how *e.g.* intermittent or chronic AG impact human health and performance and how this can be applied for later missions to *e.g.* Mars.

The results of such an infrastructure are totally new, will provide scientific breakthroughs, are of high impact and are world leading, but most of all it is humane for crew members on long duration missions. In Europe we have a long-standing history of using centrifuges for in-flight related research. Europe could be leader toward this accomplishment, and with such a contribution to the Deep-Space-Gateway, in collaboration with international partners, can continue to be the leading party in this field.

Discussions on AG platforms have been around for decades, actually since Tsiolkovsky. This ambitious project has reached a very good level of maturity. Implementation has always have been hampered by technology issues that we can circumvent nowadays but also by budget or policy issues. A serious and innovative Deep-Space-Gateway program would include such an infrastructure and finally implements the requirement for gravity for human health. It might even be regarded as unethical to deprive human beings from proper gravitational loading!

References:

- 2014 International Workshop on Research and Operational Considerations for Artificial Gravity Countermeasures. NASA/TM-2014-217394.
- Van Loon, J. J. W. A. et al. A large human centrifuge for exploration and exploitation research. Ann. Kinesiol. 3, 107- 121, 2012. UDC: 001.891:612:629.78.

Table: Expected equipment and operational needs. Please complete this table where you can but feel free to leave blank where you are unable or unsure of how to complete it.

Estimated experiment properties	Description
Mass of hardware	Tons
Volume of hardware	Numerous cubic meters
Accommodation (e.g. internal/external)	Part of spacecraft infrastructure
Power required	>>
Data generated	Human physiology / psychology related but life support as well as animal and plant research
Pointing/viewing/line of sight needs	TBD
Communications needed	Part of spacecraft infrastructure
Duration of experiment	Years
Crew tasks (if needed)	No specific tasks required. They will be relieved from their daily, time consuming, exercise regimes.
Access and servicing by crew (if needed)	Crew will live in this structure
Need for retrieval and return to Earth	No
Specific orbit needs (if any)	No
Operations without crew (if any)	No