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First simultaneous detection of terrestrial ionospheric molecular ions in the Earth's inner magnetosphere and at the Moon

I. Dandouras (1), A. R. Poppe (2,3), M. O. Fillingim (2), L. M. Kistler (4), C. G. Mouikis (4) and H. Rème (1)

(1) Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse/CNRS, Toulouse, France, (2) Space Sciences Laboratory, University of California, Berkeley, California, USA, (3) Solar System Exploration Research Virtual Institute, NASA Ames Research Center, Moffett Field, California, USA, (4) Department of Physics and Space Science Center, University of New Hampshire, Durham, New Hampshire, USA

(Iannis.Dandouras@irap.omp.eu)

Abstract

Heavy molecular ions escaping from a planetary atmosphere can contribute to the long-term evolution of its composition. The ARTEMIS (Acceleration, Reconnection, Turbulence, and Electrodynamics of the Moon's Interaction with the Sun) spacecraft has recently observed outflowing molecular ions at lunar distances in the terrestrial magnetotail [1]. Backward particle tracing indicated that these ions should originate from the terrestrial inner magnetosphere. Here we have examined Cluster data acquired by the CIS-CODIF (Cluster Ion Spectrometry-Composition Distribution Function) ion mass spectrometer, obtained in the terrestrial magnetosphere. Events were selected for which the orbital conditions were favourable and the Cluster spacecraft were in the high-latitude inner magnetosphere a few hours before the ARTEMIS molecular ion detection, a time compatible with the transfer to lunar distances. Analysis shows that the CIS-CODIF instrument detected, in upwelling ion beams and in the ring current, a series of energetic ion species including not only O^+ but also a group of molecular ions around ~30 amu. Given the 5-7 m/Δm mass resolution of the instrument, these could include N_2^+, NO^+, or O_2^+. The events were during active periods, with CME arrivals followed by a northward rotation of the IMF. Although energetic heavy molecular ions have been detected in the storm time terrestrial magnetosphere in the past (e.g. [2], [3]), these events constitute the first coordinated observation in the Earth's inner magnetosphere and at the Moon. They show that molecular ion escape, during active periods, is an additional escape mechanism (with respect to the atomic ion escape). Quantifying these mechanisms is important in order to understand the long-term (billion years scale) evolution of the atmospheric composition, and in particular the evolution of the N/O ratio, which is essential for habitability. Terrestrial heavy ions, transported to the Moon, suggest also that the Earth's atmosphere of billions of years ago may be preserved on the present-day lunar regolith [4]. Future missions, as the proposed ESCAPE mission, should investigate in detail the mechanisms of atomic and molecular ion acceleration and escape, their link to the solar and magnetospheric activity, and their role in the magnetospheric dynamics and in the long-term evolution of the atmospheric composition.

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SELMA: a mission to study lunar environment and surface interaction

S. Barabash, Y. Futaana and the SELMA Team
Swedish Institute of Space Physics, Kiruna, Sweden (stas@irf.se / Fax: +46-98079050)

Abstract

SELMA (Surface, Environment, and Lunar Magnetic Anomalies) is an interdisciplinary mission to study how the Moon environment and surface interact. SELMA investigates the complex interplay between the surface, lunar exosphere, plasma in the near-Moon space, dust and meteoroids, and surface magnetizations (magnetic anomalies). SELMA was proposed to ESA as a M5-class mission candidate in October 2016.

1. Introduction

SELMA (Surface, Environment, and Lunar Magnetic Anomalies) is a mission to study how the Moon environment and surface interact. SELMA addresses four overarching science questions:

- What is the origin of water on the Moon?
- How do the "volatile cycles" on the Moon work?
- How do the lunar mini-magnetospheres work?
- What is the influence of dust on the lunar environment and surface?

SELMA uses a unique combination of remote sensing via UV, IR, and energetic neutral atoms (ENA) and local measurements of plasma, exospheric gasses, and dust. It will also conduct an impact experiment to investigate volatile content in the soil of the permanently shadowed area of the Shekleton crater. SELMA carries an impact probe to sound the Reiner-Gamma mini-magnetosphere and its interaction with the lunar regolith from the SELMA orbit down to the surface.

2. Objectives and instruments

The four science questions are broken down into science objectives as given in Table 1. The objectives associated with each science question are highlighted by the same background color. The SELMA scientific instruments are shown in Table 2.

3. SELMA mission

SELMA is a flexible and short (15 months) mission including the following elements (Fig. 1) SELMA orbiter, SELMA Impact Probe for Magnetic Anomalies (SIP-MA), passive Impactor, and Relaying 6U CubeSat (RCS).

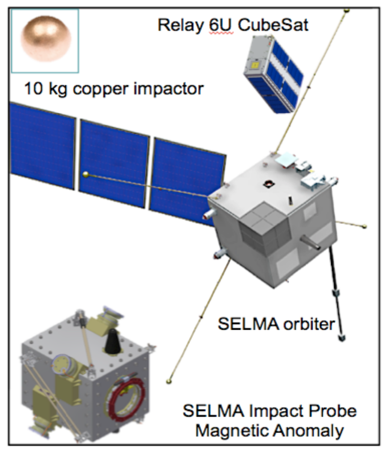

Figure 1: SELMA elements.

It launches on January 1, 2029 (flexible) by Souyz-Fregat launcher and perform direct transfer to the Moon. After 5 days it reaches it nominal quasi-frozen polar working orbit 30 km x 200 km with the pericenter over the South Pole. Approximately 9 months after the launch SELMA releases SIP-MA to sound the Reiner-Gamma magnetic anomaly with very high time resolution <0.5 s to investigate small-scale structure of the respective mini-magnetosphere. At the end of the mission the passive impactor impacts the permanently shadowed region of the Shekleton crater >10 sec before SELMA and SELMA orbiter flies through the resulted plume to perform high resolution mass spectroscopy of the released volatiles. The data are downlinked to ground and RCS. RCS stays on orbit for 2 more hours to downlink the complete data set.

SELMA uses a common 3-x stabilized nadir pointing platform of 627 kg dry-mass, carrying 106 kg payload, SIP-MA, passive impactor, and RCS with 20%m margin. The total mass at launch 1302 kg. SIP-MA is 42 kg 3-x stabilized free-flyer carrying 7.6 kg payload. SIP-MA powered by batteries operates only for about 30 min before the impact. SIP-MA communicates with SELMA via one-way 1 Mbps link. RCS is a 6U CubeSat equipped with a S-band communication package and a simple camera to monitor the SELMA impact.

Table 1: SELMA science objectives

SELMA science objectives	**SELMA measurements**
What is the origin of water on the Moon?	
Establish the role of the solar wind and exosphere in the formation of the water bearing materials	IR and UV spectroscopy, solar wind monitoring, proton flux at the surface via scattered hydrogen, exospheric gasses composition and density
Investigate the process of the solar wind surface interaction	Measurements of scattered H^0, H^+, H^-; secondary ions
Determine the water content in the regolith of the permanently shadowed region and its isotope composition	Mass spectroscopy measurements of the plume created by an impactor.
How do the "volatile cycles" on the Moon work?	
Establish variability, sources and sinks of the lunar exosphere Investigate how the lunar exosphere content is related to impact events	Exosphere gasses densities and composition with simultaneous monitoring of the solar wind, meteor impact, particle releases processes from the surface
How do the lunar mini-magnetospheres work?	
Investigate a mini-magnetosphere interaction with the solar wind Establish structure and topology of the magnetic field at the surface	Ions and electrons, waves and field with a time resoluiton <0.5 sec corresponding to the electron gyro-radius from 10s down to the surface
Investigate the long-term effects of mini-magnetospheres on the local surface	IR and UV spectroscopy, plasma and fields, proton flux at the surface via backscattered scattered hydrogen
What is the influence of dust on the lunar environment and surface?	
Investigate how the impact events affect the lunar dust environments	Dust and meteor impact monitoring
Investigate how the plasma effects result in lofting the lunar dust	Dust, plasma, field and wave measurements

Table 2**:** SELMA scientific instruments

Remote sensing instruments	**In-situ instruments**
Infrared and visible spectrometer: *Spectral range 400 – 3600 nm*	Lunar ion spectrometer : *M/ΔM > 80*
Wide angle and transient phenomena camera: *Visible, FoV 120 °x60 °; Meteoroid impact (>100 g)*	Lunar scattered proton and negative ion experiment: *Energy: 10 eV – 10 keV*
Moon UV imaging spectrometer: *Spectral range 115 - 315 nm*	Lunar electron spectrometer
ENA telescope: *Energy range 10 eV – 3 keV; Ang. resolution < 10 °*	Moon magnetometer
SELMA Impact Probe for Magnetic Anomaly sounding (SIP-MA)	Lunar exospheric mass spectrometer: *M/ΔM > 1000*
Waves and electric field instrument	Plasma wave instrument
Impact probe ions and electrons spectrometer: *Time res. < 0.5 s/3D*	Lunar dust detector: $M>10^{-15}$ kg
Impact probe magnetometer	**Passive 10 kg copper impactor**
Context camera	

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Investigation on layer-wise powder deposition and sintering of regolith

A. Cowley (1), M. Fateri (2), J. Reguette (2), M. Sperl (2) and S. Cristoforetti (1)
(1) ESA- European Astronaut Centre (EAC), 51147 Köln, Germany
(2) DLR- Deutsche Zentrum für Luft- und Raumfahrt, Institut für Materialphysik im Weltraum, 51147 Köln, Germany, (Miranda.Fateri@dlr.de)

Abstract

Constructing an extraterrestrial outpost remains as one of the most challenging steps for human colonization in space [1]. Several space agencies are planning to develop a lunar habitat capable to master Additive Manufacturing (AM) for construction purposes. Based on this, In-Situ Resources Utilization (ISRU), reduces the involved cost of launching material from the Earth, approximately 5,000-10,000 €/kg [2]. Furthermore, manufacturing in a lunar gravity environment would not only affect the manufacturing process parameters, but also change the mechanical integrity of the constructions in which the structural dead loads will be reduced by 5/6 compared to the one on Earth [2-4]. Towards this issue, increased knowledge about the powder deposition in a layer-wise manner will potentially improve the efficiency of the powder based AM final products. With respect to this, layer lamination quality, layer's packing density following with layer-wise sintering of regolith simulant are investigated in this study.

Objectives

This study targets powder deposition analysis for AM applications under lunar gravity condition. The aim is to develop a multi-setting prototype capable of layer-wise compaction of the powder and to measure the saturation point regarding the powder bed density for variety of particle sizes and distributions. JSC-2A has been applied as the test lunar simulant in this study. An illustration of the developed prototype is shown in Figure 1. the setup consists a rotating arm with an integrated weight container. Powder is then deposited in a circular path atop of the building platforms which would be subsequently exposed to heat radiation.

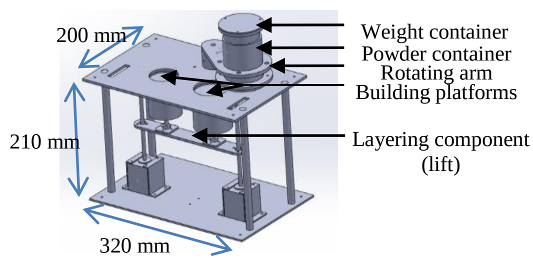

Figure 1: Isometric view of the prototype assembly for layer-wise deposition study.

Furthermore, the lamination quality of the powder using different coating speeds, temperatures, layer thickness as well as the grain size distribution have been investigated in this study. This was followed by layer-wise sintering of the power using the investigated optimum process parameters. Fabricated samples were studied regarding their morphology, thermal and mechanical properties. Different components of the developed layer deposition setup are shown in Figure 2.

Figure 2: Layer-wise sintering of the JSC-2A

Outlook

The layer-wise powder deposition will be conducted under lunar gravity during a parabolic flight and the results will be compared to the obtained one on earth. The setup process parameters will consequently be adjusted in order to duplicate the lunar gravitational fabrication results.

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Human Exploration Initiatives at EAC: Spaceship EAC and the Development of Large-Volume Lunar Regolith Simulant for LUNA

V. Nash (1), A. Cowley (1), M. Fateri (2), Sander Coene (1), Stefan Siarov (1) and S. Cristoforetti (1)
(1) European Astronaut Centre EAC, European Space Agency, 51170 Köln, Germany
(2) Deutsches Zentrum für Luft- und Raumfahrt, Institut für Materialphysik im Weltraum, Linder Höhe, 51147 Köln, Germany (Victoria.Nash@esa.int)

Abstract

In order to address analogue capability gaps previously identified by ESA studies [1], EAC has embarked on a number of exploration enabling initiatives at the centre in Cologne, Germany. Herein, preliminary results of two of these projects are presented; the Spaceship EAC initiative and EAC-1, a large-volume lunar regolith simulant for the LUNA facility.

1. Introduction

The operational capabilities of the European Astronaut Centre (EAC) in terms of training and support for human spaceflight operations on the ISS are well known. With increasing attention now being given to post-ISS human spaceflight and exploration scenarios, teams at EAC and the broader ESA are collaborating on projects that would leverage the capabilities and experience available from EAC to further these exploration objectives.

1.1 LUNA and EAC-1

EAC is currently constructing a 900 m^2 surface operations testbed facility. This facility, called LUNA, will provide the capability to run high-level integrated simulations on site by combining a habitat, FlexHab, the lunar terrain testbed, changeable lighting conditions, an operational crane, storage and temporary office spaces, with access to power, data and communication networks. The location of the facility in Cologne will allow for ease of access to ESA personnel, but the facility is also envisaged to be readily accessible to external researchers and stakeholders without any cost-barriers.

The structure consists of a 34 m diameter inflatable dome housing the testbed area, with an experiment preparation area and a ~600 m^2 lunar regolith testbed. This has identified the need for an accessible and cost-effective lunar regolith simulant. Herein, the physical and chemical data for the chosen lunar regolith simulant material "EAC-1" are described and discussed with comparisons to other commercially available regolith simulant materials.

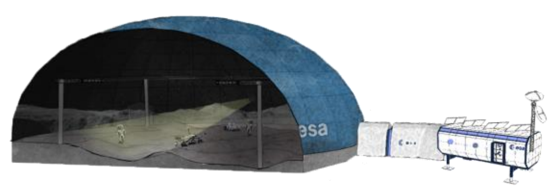

Figure 1: The LUNA facility with the habitation module, FlexHab attached. Image: O. Punch, Spaceship EAC.

The depth of the lunar regolith simulant testbed is foreseen to be about 60 cm, which requires almost 700 tonnes of material. As there are currently no available commercial providers of lunar regolith simulant material in such volumes, efforts have been made to develop a suitable material in-house. The Eifel volcanic region, situated approximately 40 km away from EAC, was selected as a potential source due to its proximity. A basaltic material has been identified and is currently under investigation. The results of these studies are presented herein.

Figure 2: The EAC-1 lunar regolith simulant.

1.2 Spaceship EAC

In addition to LUNA, another effort to foster human lunar exploration at EAC is the Spaceship EAC initiative, started in 2012. This transversal initiative aims to utilize the spaceflight experience of EAC and other involved agencies to investigate and validate low Technology Readiness Level (TRL) ideas and operational concepts for human lunar exploration scenarios. The initiative further helps prepare the centre for exploration activities envisioned in the future.

Some of the topics that are covered are:

- Virtual Reality for training
- Sintering studies of regolith
- Radiation Shielding
- Additive Manufacturing
- Energy Production and Storage
- Robotics and Human Factors

Herein, the current plans and projects of Spaceship EAC are outlined and discussed.

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Flowability of Lunar Regolith Simulant

M. Fateri (1), A. Cowley (2), C. Bernillon (1), M. Sperl (1), S. Cristoforetti (2)
(1) DLR - Deutsches Zentrum für Luft- und Raumfahrt, Institut für Materialphysik im Weltraum, 51170 Köln, Germany, (2) ESA – European Astronaut Center (EAC), 51147 Köln, Germany, (Miranda.Fateri@dlr.de)

Abstract

Further exploration of the Moon and destinations beyond requires a deeper understanding of the granulate matter and rheology.

Flow behaviour of the lunar regolith plays an important role in producing a fundamental database in order to find a safe landing site; predict the regolith deposition on the rovers and; minimize the Moon walk challenges for future manned missions. Moreover, understanding the flow behaviour of the regolith will improve the construction quality for on-site manufacturing using in-situ resources.

Currently, the flowability of various lunar simulants is experimentally studied on Earth as well as on board of parabolic flights in order to investigate the effect of reduced gravity on the static and dynamic angle of repose under ambient and vacuum conditions [1-4]. However, the impact of temperature variation under reduced gravity and vacuum condition on the regolith flow behavior has not been studied yet.

Based on this, flow behavior of the lunar regolith simulant under different pressures and temperatures is investigated in this study.

Objectives

In this study, static angle of repose [5] of JSC-2A is initially studied within the temperature range of -150 ºC to 150 ºC, representing of the lunar surface temperatures. Based on this, JSC-2A powder was dried at 250 ºC for 48 hours and then subsequently exposed to liquid nitrogen while its temperature was constantly recorded. Results regarding the static angle of repose measurements of JSC-2A under ambient conditions showed an average maximum angle of repose of 42.8º at -100 ºC, while the average minimum angle of repose was measured to be 33.7 º at 50 ºC. As the static angle of repose was shown to be significantly influenced by the temperature, dynamic angle of repose studies under vacuum conditions were investigated further. Based on this, a rotating drum setup capable of measuring the dynamic angle of repose at different temperatures under vacuum conditions was developed. Both sides of the rotating drum were sealed with transparent observation glass windows. Different back scattered light source colours and intensities enabled the recording of the powders' dynamic angle of repose (avalanche angle) on-site. The developed setup for the dynamic angle of repose measurements is shown in Figure 1.

Figure 1: Rotating drum setup for dynamic angle of repose measurements

Outlook

Dynamic angle of repose will be analyzed by varying the rotating drum's pressure, temperature and speed for variety of the lunar simulants' particle sizes and distributions. Furthermore, relations of the indicated parameters under reduced gravity will be studied. Consequently, different rheological flow regimes will be classified for different applications such as Additive Manufacturing (AM) on the Moon.

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Solar Sintering for Additive Manufacturing on the Moon

M. Fateri[1], A. Meurisse[1], M. Sperl[1], and the RegoLight Consortium[2]
[1]Institute of Materials Physics in Space, German Aerospace Center DLR, 51170 Cologne, Germany[1]
[2]Space Applications Services, Comex, Bollinger + Grohmann, Liquifer Systems Group, (Miranda.Fateri@dlr.de)

Abstract

Recently, various concepts have been investigated in the context of building Moon village using ISRU. Regarding this, laser sintering, microwave sintering, Contour Crafting (CC) and Powder Binder Bond Printing (D-shape 3DP) are among the most investigated Additive Manufacturing (AM) techniques so far [1-3]. However, unlimited solar energy source on the Moon combined with absence of the atmospheric fluctuations, make the solar sintering a competent candidate for the On-site manufacturing.

In this context, the project RegoLight investigates sintering of lunar regolith using solar light. RegoLight has been funded through the European program (Horizon 2020) under the lead of German aerospace center (DLR), Space Applications Services (SAS), COMEX and LIQUIFER Systems Group and Bollinger + Grohmann Ingenieure from Austria.

Objectives:

In this project, AM concept capable of manufacturing building elements under ambient and vacuum conditions is developed and followed by manufacturing 3D printed test geometries. 3D printed test geometries such as bricks and interlocking elements are studied due to their geometrical accuracy as well as their mechanical properties. Subsequently, properties of additive manufactured parts are used in structural engineering to optimize both building elements and full constructions for a lunar environment. In this project, JSC2-A lunar simulant is used as the raw material while studying its sintering feasibility using actual and artificial sun light energy source. Moreover, layering concepts using a translation table and a mobile printing head are investigated. Additive manufactured building block structure out of JSC2-A is shown in Figure 1.

Figure 1: Additive Manufactured building element using solar sintering of lunar regolith simulant.

Scenarios:

Scenario aims at building a stable structure assembled out of single interlocking elements. The structure targets shielding the pressurized and unpressurized modules from radiation, lunar thermal cycles and micro-meteorites impact. The dome-shape structure concept design is shown in Figure 2.

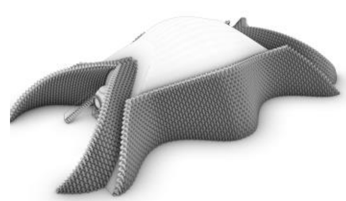

Figure 2: Dome-shape structure designed out of interlocking building elements with an internally integrated inflatable dome structure.

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SOLVE: a small spacecraft for near lunar environment exploration

B. Ritter (1,2), Ö. Karatekin (1), N. Gerbal (1), B. Van Hove (1), J. Carrasco (3), S. Ranvier (4), J. De Keyser (4)
(1) Royal Observatory of Belgium, Brussels, Belgium (birgit.ritter@observatory.be), (2) Université de Liège, Belgium, (3) Embedded Instruments and Systems S.L., Spain, (4) Royal Belgian Institute for Space Aeronomy, Brussels, Belgium

Abstract

SOLVE (Small spacecraft fOr near Lunar enViroment Exploration) is a novel mission proposal to employ a 12U CubeSat which will be deployed by a lunar orbiter providing transportation and data relay services. SOLVE will characterize the Lunar environment by studying the complex set of interactions between radiation, illumination, plasma, magnetic field and dust in dependence of altitude. It will decrease its orbit gradually from 500 km altitude in a controlled way until it finally reaches the surface with an attempt to land softly. Besides the above-mentioned geophysical variables, the radiation environment relevant to humans will be measured along the trajectory by detecting highly penetrating ionizing particles (GCRs and SEPs). SOLVE will provide a unique opportunity for demonstration of new and innovative technologies. It will have propulsion systems enabling high Delta-V maneuvers and state-of-art attitude determination and Control System (ADCS) of relevance to future CubeSat missions. Demonstration of small landers for the Moon would open new science opportunities and exploration possibilities that may lead to future geophysical network stations on the Moon as well as other solar system bodies.

1. Introduction

The Moon is key to understand the early history and evolution of the Solar System, in particular it is a fundamental source of information on the origin and evolution of rocky planets and on the Earth–Moon system. The lunar surface is directly exposed to the harsh space environment, including a continuous bombardment by interplanetary large and small impactors, high energy radiation, UV/X-rays, and solar wind plasma. The remnant magnetic fields might allow an accumulation of solar wind plasma near the lunar surface.

The tight coupling between magnetic field, electric field, plasma, radiation and dust makes the understanding of lunar near surface environment and exosphere challenging. By exploring these couplings relative to the altitude SOLVE will shed light onto fundamental processes relevant to space weathering processes, dust transport, origin, migration and preservation of volatiles, and will help to identify the effects and hazards of the dusty plasma environment on future robotic and human exploration.

2. Science investigations

The SOLVE mission has three primary (S#1 – S#3, outlined in detail below) and three secondary (S#4 – S#6) science objectives:

S#1	Ionosphere investigation (and dust in orbit)
S#2	Crustal magnetic anomalies
S#3	Radiation environment relevant for humans
S#4	Surface dust
S#5	Thermal environment
S#6	Dynamical state

2.1 Ionosphere investigation

Today, there is no general consensus on the electron density and altitude ranges of the lunar ionosphere, on the physicals mechanism for producing the high electron concentrations observed in the lunar environment, and if the ionosphere is gas or dust dominated. Two different and independent methods for determining the electron content will be used: the first is radio occultation, in order to obtain the total electron content along the line of sight (TEC), the second is Langmuir probe measurements for an in-situ measurement of the electron density and temperature. By sweeping the Langmuir probe potential in the ion saturation region (negative potential with respect to the plasma potential) the mass-to-charge ratio of the positive ions - or dust grains - can be estimated [1].

2.2 Crustal magnetic anomalies

In-situ measurements of lunar crustal magnetic anomalies are required to fully understand the nature of anomalies and the various processes such as solar wind interaction with crustal anomalies, origin of the lunar “swirls”, space weathering history of the core dynamo, paleomagnetic pole positions, etc. Especially close to the surface is a lack of such measurements. A network of small magnetometers distributed within the spacecraft and on short booms will be used and their signals combined in order to separate ambient field from spacecraft-generated magnetic perturbations.

2.3 Radiation environment relevant to humans

The radiation exposure is considered to be one of the main health detriments for humans in space and poses a limiting factor for long duration space flights. While on the Moon the solar wind can be shielded with a reasonable amount of mass, galactic cosmic rays (GCRs) and solar energetic particles (SEPs) are highly penetrating up to several meters within the lunar surface. But no surface measurements have been performed since the Apollo missions. With a two element silicon detector telescope [2], which can measure minimal ionizing protons up to GCR iron ions, the linear energy transfer (LET) spectra, the absorbed dose and dose rates can be derived, which will give a good estimate of the dose equivalent.

3. Mission scenario

The mission consists of several phases, including the orbit injection into a 500 km circular orbit; measurements from a stable orbit around Moon; a descent phase, in which the measurement parameters are obtained as a function of altitude down to the lunar surface; after a soft landing (if achievable), operation continues on the surface. Different scenarios are under investigation. One of the possible scenarios considers a stepwise descent down to the surface, using a total Delta-V of about 100 m/s. Additionally a large Delta-V maneuver will be required in order to land softly on the lunar surface. A soft landing requires a total Delta-V of about 1.8 km/s. Preliminary analysis shows promising results, however, even if the soft landing fails, primary science objectives will be fulfilled during the previous mission phases.

4. CubeSat and instrumentation

SOLVE is a 3-axes stabilized 12U CubeSat based on the XCube platform [3]. Due to the large Delta-V requirement, the propulsion and ADCS system are the main design drivers for the spacecraft. The second is the harsh thermal environment on the lunar surface.

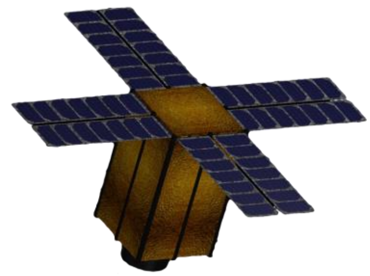

Figure 1: XCube platform.

The spacecraft and instruments are partly based on ESA’s SIMBA and PICASSO CubeSats [4] and on the Asteroid Geophysical Explorer (AGEX) [5], which was part of ESA’s CubeSat Opportunity Payload Intersatellite Network Sensors (COPINS). The payload consists of a radio transponder (S- or X-band), a Langmuir probe, UV sensors, several small magnetometers, a two-element particle detector telescope, surface charge probes, thermal sensors and retro-reflectors.

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TOMOX: an x-ray tomographer for lunar and planetary exploration

L. Marinangeli[1], L. Pompilio[1], A. Baliva[1], M. Alvaro[2], G. Bonanno[3], M.C. Domeneghetti[2], F. Frau[5], V. La Salvia[1], M.T. Melis[5], O. Menozzi[1], A.C. Tangari[1], M.C. Rapisarda[3] , P. Petrinca[5] , S. Pirrotta[6] and Angela Volpe[6]

[1]DiSPUTer, Università D'Annunzio, Chieti, Italy; [2]Università di Pavia, Italy; [3]INAF, Osservatorio, Astrofisico Catania, Italy; [4]Università di Cagliari, Italy; [5]OMICA srl, Roma; [6]Agenzia Spaziale Italiana, Roma (lucia.marinangeli@unich.it, ph. +3908713555333)

Abstract

The TOMOX instrument has recently been founded under the ASI DC-EOS-2014-309 call. The TOMOX objective is to acquire both X-ray fluorescence and diffraction measurements from a sample in order to:

a. perform a no destructive, in situ analysis of chemical and mineralogical composition of rocks and soils based on in X-ray fluorescence (XRF) and diffraction (XRD) mode

b. reconstruct a 3D mapping of the sample exposed surface combining chemical and mineralogical information by tomographic approach

c. give hints regarding the rock age by comparing the total contents of Rb and Sr elements and the supposed isotopes which are commonly used for geochronology.

Nevertheless, this technique has applicability in several disciplines other than planetary geology, especially archaeology. The proposed instrument is based on the MARS-XRD heritage, an ultra miniaturised XRD and XRF instrument developed for the ESA ExoMars mission [1-3].

1.Concept design and objectives

The word ‘tomography’ is nowadays used for many 3D imaging methods, not just for those based on radiographic projections, but also for a wider range of techniques that yield 3D images. Fluorescence tomography is based on the signal produced on an energy-sensitive detector, generally placed in the horizontal plane at some angle with respect to the incident beam caused by photons coming from fluorescence emission. So far, a number of setups have been designed in order to acquire X-rays fluorescence tomograms of several different sample types.

The general idea of TOMOX is to distribute both sources and detectors along a moving hemispherical support around the target sample (Figure 1). As a result, both sources move integrally with the detectors while the sample is observed from a fixed position, thus preserving the geometry of observation. In that way, the whole sample surface is imagined and XRD and XRF measurements are acquired continuously.

We plan to irradiate the target sample with X-rays emitted from ^{55}Fe and ^{109}Cd radioactive sources. ^{55}Fe and ^{109}Cd radioisotopes are commonly used as X-ray sources for analysis of metals in soils and rocks. The excitation energies of ^{55}Fe and ^{109}Cd are 5.9 keV, and 22.1 and 87.9 keV, respectively. Therefore, the elemental analysis ranges are Al to Mn with K lines excited with ^{55}Fe; Ca to Rh, with K lines excited with ^{109}Cd. ^{55}Fe will be primarily dedicated to XRD measurements, as it has been already tested for the MARS-XRD development. ^{109}Cd will be used to reinforce the efficiency of ^{55}Fe source in the production of fluorescent X-rays generated in the sample as a consequence of irradiation and to extend the analytical range of elements.

Two different detectors has been used in order to increase the total amount of events collected and allow the spatial distribution of events to be recorded as well. The detectors are a SDD (Silicon Drift Detector) and a stand-alone CCD (Coupled Charge Detector). The SDD has higher count rate and stability and has been successfully used for XRF applications. On the other hand, the CCD is able to record the spatial position of each event of X-ray emission, together with its energy. Therefore, we plan to dedicate this detector to XRD measurements, where the spatial position of the event is directly correlated to the type of crystal through the Bragg's law.

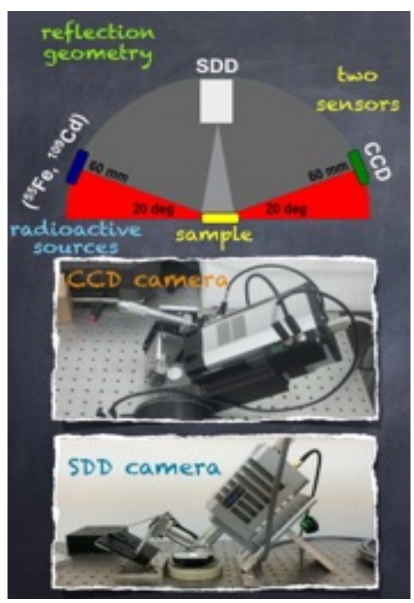

Figure 1: Schematic drawing and photos of the preliminary prototype setup.

TOMOX will be able to measure the total content of Rb and Sr but not the isotopic ratio as commonly used for geochronology purposes. However, we’ll try to estimate possible rock or soil age by make a comparison with rocks of known isotopic ratios for Rb/Sr in terrestrial rocks or meteorites. We know that the the isotopic ratio varies with the different igneous rock formation process on Earth, differences which are also recorded in the rocks petrography. Thus, we plan to build a database of isotopic Sr and Rb ratio of terrestrial and extraterrestrial materials to compare the total Rb and Sr contents as preliminary information on the rock age.

2.Future development

We are currently performing experimental tests for the sensors characterisation and signal calibration using different types of rock samples. Afterward , we will focus on the merging of XRD and XRF measurements to obtain the 3D tomographic modelling.

An appropriate mechanical design will be also developed to mount sources and sensors with movements to acquire in tomography mode.

As final evaluation of the TOMOX performance we will make measurement of artefact (mostly ceramics) for archeaometry application. This part of the experimental work will be realised with the archeologists involved in the team.

Acknowledgements

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Concept of Lunar Production and Research Base Creation

O. Kashanov, O. Kushnar'ov, G. Osinoviy

Yuzhnoye Design Office, 3, Krivorozhskaya St., Dnipro, 49008, Ukraine

The Ukraine space scientific and technical potential and experience in development and building of launch vehicles and spacecraft as well as high practical interest by the Ukraine scientific organizations and institutes enabled to develop the constructive concept of lunar scientific and production base creation. It is suggested to create such a base on the Moon in five phases:

First - preparatory: establishment of international cooperation for the Moon exploration, lunar exploration using unmanned vehicles, creation of space transportation systems.

Second – minimum-configuration base: delivery of the first base modules and construction of take-off and landing area.

Third – base extension: equipping of the scientific and production base, the lunar surface exploration.

Fourth – change-over to production: creation of self-contained life support system, production base and observatory.

Fifth – stationary base: support for human continuous presence and human life support on the Moon.

The options are suggested for creation of the lunar space transportation system "Earth-Moon-Earth", which is of great importance in creation of the lunar base.

Much attention is paid to creation of the lunar base infrastructure components, such as accommodations and production rooms modules, lunar transportation vehicles and power-plants complex.

The following issues were estimated in creation of the minimum-configuration base: delivery of the first base modules, the lunar base assembly, systems checkout and testing as well as construction of take-off and landing area.

In the base extension phase the following estimations are made: creation of the protective shell of moon soil as well as the territory selection and preparation for deployment of the production base and lunar observatory.

When the base is transferred to industrial production, the need is determined for creation of self-contained life support system and the following production complexes:

- rocket propellant;
- necessary resources for crew life support;
- building and construction materials;
- rare-earth mining (including supplies to the Earth).

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Observations of Lunar Exospheric Helium with LAMP UV Spectrograph onboard the Lunar Reconnaissance Orbiter

C. Grava (1), D. M. Hurley (2), K. D. Retherford (1), G. R. Gladstone (1), P. D. Feldman (3), W. R. Pryor (4), T. K. Greathouse (1), and K. E. Mandt (1).
(1) Southwest Research Institute, San Antonio, TX, USA. (2) Johns Hopkins University – Applied Physics Laboratory, Laurel, MD, USA. (3) Johns Hopkins University, Department of Physics and Astronomy, Baltimore, MD, USA. (4) Central Arizona College, Coolidge, AZ, USA.

Abstract

We present results from a dedicated campaign of the Lyman Alpha Mapping Project (LAMP) UV imaging spectrograph onboard the Lunar Reconnaissance Orbiter (LRO) to detect the 58.4 nm emission line of helium (^{4}He) atoms resonantly scattering sunlight. We compare LAMP line-of-sight column densities to: 1) those predicted by an exospheric model, to highlight regions of discrepancy; 2) solar wind alpha particles' flux measured by ARTEMIS, to constrain the source rate of lunar endogenic helium (i.e. coming from the interior of the Moon); 3) helium density measured in situ by LADEE's Neutral Mass Spectrometer (NMS), when possible, to map the latitudinal distribution of helium. Such campaign therefore yields a comprehensive picture of the extension of the lunar helium exosphere (in altitude, latitude, local time, and longitude).

1. Introduction

Helium is one of the main constituents of the lunar exosphere, with densities of ~10^4 cm^{-3} measured at the surface by the mass spectrometer LACE (Lunar Atmosphere Composition Experiment) deployed during the Apollo 17 mission. The lunar He density correlates with the solar wind [1,24], meaning that the source of lunar helium as the solar wind alpha particles, which get neutralized upon impact on the lunar surface and become part of the lunar helium exosphere. Whenever the Moon is in the Earth's magnetotail (± 2 days from full moon), the solar wind is turned off, and the helium population decreases due to gravitational escape, with a decay time constant of 4.5 days [2]. Interestingly, a recent campaign by LAMP itself provided evidence of enhancements of lunar exospheric helium uncorrelated with meteoroid streams or solar wind [3]. This supports the hypothesis that part of the lunar helium comes from the interior of the Moon. This ^{4}He population is produced by radioactive decay of ^{232}Th and ^{238}U, is trapped in micropores and cracks, and then released into the exosphere following shallow moonquakes (and hence opening of such voids), a mechanism which has been proposed for argon too [4]. One of the motivations behind the current paper is to constrain the endogenic source rate of helium, which currently ranges between 15% [2] and 30-40 % [5,6] of the solar wind, and to identify the regions where such outgassing occurs.

2. Observations

The spacecraft was pitched along the direction of motion. This allowed LAMP to look through a longer illumined column of gas, compared to the usual nadir-looking mode, and therefore enhancing the brightness of the 58.4 nm emission line. The lines of sight of the observations spanned a variety of local times, latitudes, longitudes, and altitudes.

3. Data-model comparison

To interpret the data, we use a Monte Carlo code of the lunar exosphere [5], scaled to the variation of the ARTEMIS solar wind alpha particles flux with respect to its median value during the period of interest (2013-2016). In this way we take into account the variability in the solar wind (and hence of the helium source rate). For each point along the LOS we computed the column density predicted by the model and we compare it to LAMP brightness, converted in column density. In Figure 1 we plot the model/LAMP ratio vs latitude of the shadow point, i.e. the point where the LOS encounters the shadow (LAMP is pointing at the night side surface). In this case, the model is predicting less helium than what is being observed by LAMP at lower latitudes, which also correspond to lower altitudes since LRO has its periapsis at the lunar south pole. In Figure 2 we report the 3D geometry of the same maneuver.

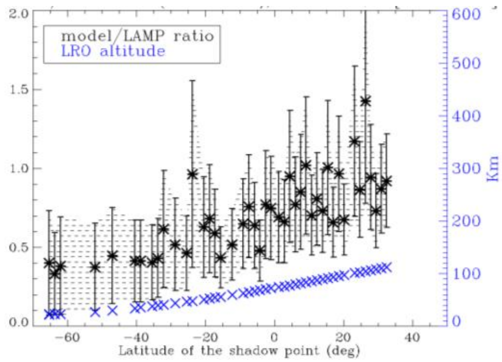

Figure 1: model/data ratio (black) and altitude of the spacecraft (blue).

The Moon is depicted (with a LOLA topography map) as viewed from Earth's northern hemisphere, with darker hemisphere illustrating night side. This observation was performed at post-dusk, and the model/data ratio progressively decreases towards the lunar south pole. Finally, Figure 3 shows the 3D geometry of two maneuvers taken at different days, at very similar local times (around 6:30 pm) but at different longitudes.

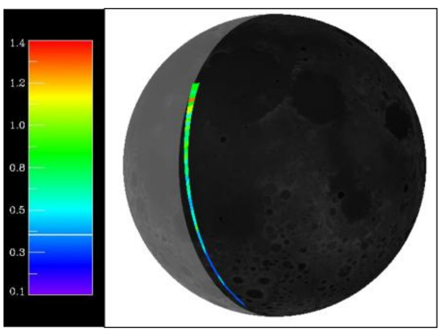

Figure 2: The model/data ratio in the LAMP LOS is colored according to the model/data ratio (see color bar on the left).

4. Discussion

These plots allow us to identify regions of discrepancy between the observations and the model both in local time and in longitude. The discrepancy highlighted in Figure 2 might be related to the scale height (which measures how rapidly an exosphere decreases its density by a factor of *e*) used in the model. The fact that we might need to revise it could mean that we need to revise our understanding of the interaction between the solar wind and the Moon. Alternatively, the discrepancy could be due to deviations from a steady state exosphere which come from time variability of the source, as well as variability in the spatial distribution of the source. Moreover, by comparing observations taken at the same local time but at different longitudes, like those in Figure 3, we can identify regions of possible outgassing of ^{4}He. In this case, there seems to be an excess of helium compared to the model above the Western Maria, close to where LADEE's NMS detected an enhancement in exospheric argon-40 [2]. However, the above-mentioned discrepancy must be fixed, to constrain the source rate of endogenic helium.

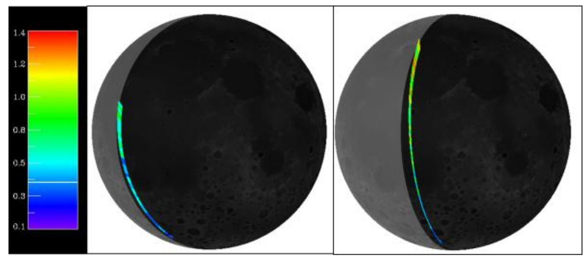

Figure 3: model/data ratio in 3D on two different observations with similar coverage in local time but different coverage in longitude.

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Iron abundances in lunar impact basin melt sheets from magnetic field data

J. S. Oliveira (1,2) and M. A. Wieczorek (3)
(1) Institut de Physique du Globe de Paris, Université Paris Diderot, Paris, France, (2) CITEUC, Geophysical and Astronomical Observatory, University of Coimbra, Coimbra, Portugal, (3) Observatoire de la Côte d'Azur, Laboratoire Lagrange, Nice, France. (joansofi@gmail.com)

Abstract

Some lunar impact basins possess weak magnetic anomalies in their interiors where the basin impact melt sheet is expected to be found. Metallic iron is the likely magnetic carrier, and this iron was most probably derived from the projectile that formed the basin. We estimate the abundance of iron in the impact melt sheet by inverting for the magnetization in lunar impact basins. The abundance of iron is then derived from a relationship that depends on the magnetizing field strength. We find abundances of metallic iron ranging from 0.5 to 2 wt.%, which is consistent with the range of values found in both lunar and terrestrial impact melts.

1. Introduction

Magnetic field data acquired from orbit shows that the Moon possesses many strong magnetic anomalies [1]. Though many of these are not associated with known geologic structures, some anomalies are found within large impact basins such Serenitatis, Nectaris, Crisium, Mendel-Rydberg, and Humboldtianum. The associated magnetic anomalies are generally in the center of the basin, within the interior peak ring [2].

The primary magnetic carrier in lunar rocks is metallic iron. However, most of indigenous crustal rocks have very low abundances of iron, which are incapable of accounting for the magnitudes of the observed magnetic anomalies [3]. In contrast, lunar impact melts derived from the largest basins often contain elevated abundances of metallic iron (1-2 wt.%), and this iron is believed to be derived from the projectile that formed the basin [e.g., 4]. Terrestrial impact melt rocks often contain traces of the projectile as well, with projectile abundances in the melt sheet ranging from less than a wt.% to up to several wt. % [5, 6]. Not all impact basins possess clear magnetic anomalies, but when they do, they are in general located within the interior portion of the basin where impact melt should be prevalent. The thickest portion of the impact melt sheet is predicted to be found within the peak ring [e.g., 7].

In this study, we use orbital magnetic field data to invert for the magnetization within large impact basins. Since the magnetization in lunar rocks is related to both the strength of the magnetic field at the time the rock cooled and the abundance of iron in the rock, basin magnetization can be used to constrain the composition of the projectile, the impact process, and the time evolution of the lunar dynamo.

2. Impact basin magnetization

We invert for crustal magnetization by making use of a method developed by Parker for studying seamount magnetism on Earth [8], and which was recently applied to lunar crustal magnetism by [9]. The only assumption that this method makes is that the magnetization within the crust is unidirectional, which is what one would expect if the material cooled below the Curie temperatures in the presence of a steady main field. As shown by Parker, a unidirectional distribution of dipoles within the crust is equivalent to unidirectional dipoles placed on the surface. The main strength of this method is that no assumptions about the intensity of magnetized sources, source geometry, or statistical distributions are made.

As described in [9], many dipoles are placed within a circle of specified radius over a region that encompasses an isolated anomaly. For an assumed direction of magnetization, we solve for the magnetic moments of the dipoles and determine the misfit between the model and observations using a non-negative least squares inversions approach [10]. To avoid unwanted edge effects, the misfit between the observations and model is calculated within a circle of a slightly larger radius. Since we make use of a global magnetic field model, only one component of the magnetic field is modeled (the other two are redundant), for which we chose the radial component. The surface dipoles were placed within a circle with a diameter just smaller than the main rim, and we note that the number of dipoles with non-zero moments must be less than the number of observations. The inversion naturally finds those dipoles that are non-zero, as well as their intensities.

For our inversions we use the global gridded magnetic field maps of [11] at 30 km altitude with a resolution of 0.5° that are based on Lunar Prospector and Kaguya magnetometer observations. We consider the central magnetic anomalies on five large basins: Serenitatis, Nectaris, Crisium, Mendel-Rydberg, and Humboldtianum.

The rms misfits at 30 km altitude obtained for all basins range between 0.16 nT and 0.33 nT, which is low in comparison to their respective central anomaly strengths. The dipoles with the strongest moments are found to be located almost exclusively within the inner depression of the basins. In some cases, there are few dipoles with strong magnetic moments between the peak ring and inner depression, or near the dipoles grid edge.

The strongest magnetizations are located within the inner depression, precisely where one would expect to find the thickest portion of the impact melt sheet. Using the dipole moment intensities, and assuming that the melt sheet is 1 km thick [e.g., 7], we estimate the average magnetization of the melt sheets ranging between 0.09 and 0.36 A/m.

3. Impact melt sheet iron abundances

Our analysis of the magnetic field provides an estimate of the average magnetization of impact melt sheets. The magnetization is related to both the strength of the magnetic field when the melt sheet cooled below the Curie temperature of iron, and the abundance of iron in the melt sheet. To estimate the abundance of metallic iron, we make use of a scaling relationship that is based on laboratory thermal remanent magnetism acquisition experiments, combined with the magnetic properties of lunar rocks [12]:

$$c = 1.1 \times 10^{-6} \frac{M_{tr}}{B_0}$$

In this equation, c is the volume fraction of metallic iron, M_{tr} is the thermal remanent magnetization of the rock, and B_0 is the strength of the magnetic field when the rock cooled below the Curie temperature. Using the obtained average magnetization, M_{tr} and assuming a representative surface field strength of 50 μT when the basin formed [13], the volumetric concentrations of iron obtained range between 0.18 and 0.8%.

Taking into account the difference in density between iron and silicates, the weight percentage of iron within the inner depression for the five large basins range between 0.5 and 2 wt.%. These values agree not only with the range of values from less than 1 wt. % to several wt. % of projectile contamination in terrestrial impact melts [5, 6], but also with the abundances of metallic iron found in Apollo impact melt rocks that range from 0.1 to 1.7 wt.% [4]. Given that both the thickness of the melt sheets and surface magnetic field strength are uncertain, our estimate of metallic iron abundances is probably uncertain by a factor of about 5.

4. Conclusions

The five studied large impact basins have central magnetic anomalies that are confined to the basin's peak-ring. Inversions of the magnetic field data show that the magnetic sources are in fact confined to the smaller inner depression that corresponds to the thickest portion of the impact melt sheet. By assuming the melt sheets thickness, as well as the surface magnetic field strength when the basins formed, the abundance of iron in the melt sheets was calculated to be just under 2 %. In analogy to lunar and terrestrial impact melts, we infer that the iron in the melt sheets was derived from the impactor. Investigations of impact basin magnetic anomalies will allow us to place constraints on both the magnetic field at the time the basins formed and the amount of projectile materials that are entrained in the impact melt sheets.

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Prelude to MoonVillage: Science and Innovation

B.H. Foing (1,2) (1) ESA ESTEC ; (2) ILEWG (Bernard.Foing@esa.int)

Abstract

We shall discuss the science goals, innovation, status of upcoming missions in the context of elaborating the concept of a Moon Village with the goal of a sustainable human presence and activity on the lunar surface [1-3] as an ensemble where multiple users can carry out multiple activities.

Previous MoonVillage projects

The Moon represents a prime choice for political, programmatic, technical, scientific, operational, economical and inspirational reasons. COSPAR and its ILEWG International Lunar Exploration Working Group (created 20 years ago) have been supporting opportunities of collaboration between lunar missions and exchange on future projects [4-8]. A flotilla of lunar orbiters has been deployed for science and reconnaissance in the last international lunar decade (SMART-1, Kaguya, Chang'E1&2, Chandrayaan-1, LCROSS, LRO, GRAIL, LADEE).

De facto, collaborative opportunities and elements of a Robotic Village on the Moon exist, as China landed in 2013 the Chang'E3 and its Yutu rover, and from 2017 other landers are planned (GLXP, Chang'E 4&5, SLIM, Luna 25-27, LRP, etc..). A number of human missions with Orion & ESA service module to lunar orbit, as well as private missions for humans and cargo are also planned.

Current missions for MoonVillage

We shall discuss roadmaps and technical studies held in international groups [4- 15] such as COSPAR, ILEWG, ISECG, IAF, IAA or national and regional groups (eg LEAG). We shall discuss the upcoming international and private lunar robotic and human missions and how they can address science, innovation and infrastructures to enable the vision and implementation of a Moon Village.

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