L-DEPP Definition Study for Lunar Lander

EXECUTIVE SUMMARY

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1 Introduction

The primary objective of the ESA contract No. 4000103352/11/NL/AF was to conduct the initial design study phase of the Lunar dust, plasma, waves, and fields package for lunar exploration (L-DEPP) as a potential payload of the Lunar Lander mission.

The Lunar lander mission is managed by the ESA's Human Spaceflight Directorate as the first step for ESA future human lunar exploration. It is meant to be a precursor mission for future human explorers and as such it shall provide (*i*) technology for precision lunar landing and (*ii*) lunar environmental exploration and monitoring. These activities shall provide support for future moon exploration projects in the means of environmental data and characterization of possible effects on human life and habitation.

The Lunar Lander mission was initially planned to be launched in 2018 with a target landing location near the lunar south pole. The landing site has been chosen in order to maximize continual periods of illumination by the solar radiation which in turn shall maximize the expected scientific return of the mission (providing sufficient power for required operations). However, the proposed landing site also represents many new technological and scientific challenges since this area of the moon has not yet been explored by any in-situ observations. The knowledge of the near-surface lunar environment properties, such as plasma and dust behavior, are crucial for future mission planning and mission design concerning the scientific exploration as well as human habitability and hazard evaluation. The ESA Lunar Lander thus represents in that respect a pioneering mission which could provide first direct observations of the complex environment.

The L-DEPP package, being the primary objective of the present study, shall explore in particular the mobilization and transport of lunar charged dust, analyse properties and behaviour of near-surface plasma sheath on background electromagnetic fields and provide an environmental survey measurements for potential future lunar low-frequency radio-astronomy arrays. The measurements performed by the L-DEPP instruments shall thus provide:

- Charges, velocities and sizes of levitating lunar dust particles
- Temperature and density of the local plasma populations
- Electric surface potentials and the induced electric fields
- The radio spectrum associated with the local dust-plasma environment and transient events

2 Scientific background

The current state of art in the knowledge of the lunar surface environment with focus on expected conditions in the polar regions were assessed in the initial project technical note, namely the Requirements Specification and Concept Recommendation report, leading to a detail list of scientific objectives and relevant instrument requirements.

The mission target environment represents a home of a unique dusty or dust polluted plasma populations on a background of complex electromagnetic fields and various external stimuli. The Moon as a whole is not shielded by any dense atmosphere nor magnetosphere, and its surface is constantly exposed to many variable external drivers. The bombardment of the lunar surface by solar radiation, micrometeorites, and energetic plasma particles act to charge the surface and create a photoelectron sheath resulting in significant localized electric fields (up to few thousands of Volts) and possible mobilization of lunar charged dust particles. In the orbit at about sixty Earth's radii the Moon is placed in direct contact with the solar wind for about three weeks per month and spend the rest of the orbit crossing the different regions of the terrestrial magnetosphere represented by completely different ambient plasma populations and background magnetic fields. Evermore, small local crustal magnetic anomalies with magnetic field strengths up to a few hundreds of nT, i.e. sufficiently strong to create “mini-magnetosphere” phenomena that cause strong perturbation to ambient plasma impacts, may be potentially present in the target landing site and are therefore of interest of the pioneering exploration of the Lunar Lander mission.

All the external drivers thus create a dynamic and ever-changing environment at the surface, which has to-date only been explored with limited instrumentation only at a few locations in low equatorial latitudes (Luna, Surveyor, and Apollo missions). However, the south pole region chosen as the target of the ESA Lunar Lander may prove a very different environment from the already visited landing sites namely due to much smaller incident angles of impacting radiation and particles and temporal scales of light to dark transitions.

In is not only the dust and plasma measurements that have a high priority for the pilot south pole surface observations. The absence of any significant ionosphere and or charged exosphere and the unique shielding against disturbing interference from Sun and Earth all make the lunar surface accessible for even very low-frequency radio emissions that is not the case for terrestrial ground-base telescopes which experience the ionospheric cut-off already between 10-50 MHz. The lunar surface is thus believed as a promising platform for future low-frequency radio experiments. However, also lunar surface may represent non-negligible constraints on radio observations including the photoelectron sheath, the charged dust environment or possible effects on wave reflection by subsurface discontinuities in the electrical properties of the lunar regolith which have to be first described before any construction of large dipole arrays on the lunar surface may take place. Therefore an initial site survey of radio observations needs to be acquired which shall be accessible for the Lunar Lander mission including the L-DEPP package.

3 Instrumentation

The derived scientific objectives led to a natural selection of available diagnostic techniques and corresponding instrumentation required to fulfill priority goals and maximize the scientific return of the L-DEPP experiment. The instrument down-selection was summarized in the final part of the initial project technical note (Requirements Specification and Concept Recommendation Report). There are five measurement principals identified as the optimized set for the L-DEPP package to measure the dust, plasma, electric field, magnetic field, and radio emissions.

The dust analyzer will utilize the charge carried by the dust particles for their detection. The measurement principle is to sense the particle as it passes through the instrument by an array of wire electrodes, with each electrode connected to a separate charge sensitive amplifier. The wire electrodes are typically parallel and arranged in two planes. As the particles pass through the electrode array, the image charge induced in the wires is detected. The shape, amplitude and timing of induced signals allow the measurements of the particle charge and velocity vector. When completed with a trajectory deflection field region, such technique is capable to even estimate the particle mass from measured deviation between the initial and modified particle velocity.

For basic plasma diagnostic Langmuir probes are very often believed to be a must for any exploration mission of unknown environments. In its simplest form, a Langmuir or electrostatic probe consists of a conducting electrode immersed into the plasma with a bias voltage applied to it. As a result of the charge collection from the plasma, a current between the charged electrode and the ground can be measured. The basic principle of the Langmuir probe measurement technique then consists in varying the bias voltage on the electrode over a predefined potential range and measuring the resulting current, i.e., one acquires the current-voltage (I-V) characteristic of the probe. The shape of such characteristic is a function of the basic local plasma parameters. Langmuir probes are also frequently operated in fixed bias or freely floating regime and only the temporal evolution of the resulting potential/current is used for further analysis. This mode does not provide the full set of plasma parameters but gives the probe to spacecraft potential which may serve as a good proxy of the relative plasma density fluctuations. With multiple spatially separated Langmuir probes at fixed bias, the technique can serve as an effective diagnostic tool for the local DC electrical fields measurements representing one of high priority objectives of the L-DEPP package.

The Langmuir probe technique is reliable to provide the bulk plasma properties. However, for distinction of various energetic populations expected to be present at the lunar surface, an instrument based on retarding potential has to be employed in addition. For a full energy distribution function measurement, directional electrostatic analyzers must be used. Usually such instruments consist of sensor head in which variable applied voltages are used to select the energy range of particles entering the instrument. A sensitive micro channel plate, target of the impacting particles, is divided into sectors in order to gain directional information. Electrostatic analyzers are capable of acquiring almost full 3D distribution functions. Current advances in the electrostatic plasma analyzer techniques also enable to analyze both negative electron and positive ions with even one common sensor.

For in-situ diagnostic of the magnetic field vector in space applications, different type of magnetometers are used. As the most reliable techniques with required sensitivity and observable range were proven the so called fluxgate magnetometer sensors. The principle of fluxgate magnetometers is based on measuring the induced field of a soft magnetic core which is excited by a periodic magnetic field. Like a transformer the core is surrounded by a primary and a secondary coil. The primary coil is used to excite the core, and a secondary one measures the response. Passive search coil magnetometers as well as AC driven transformers work within the linear regime. By contrast, the core of the fluxgate magnetometer needs to be saturated by a sufficient large alternating field. Oscillations of odd multiples of the excitation frequencies (odd harmonics) compose the signal induced in the secondary coil due to the non-linear characteristics of the core material. If an ambient field is added to the excitation field, the symmetry of excited magnetic flux is disturbed. This causes a non-symmetrical signal in the secondary coil corresponding to the even harmonics of the excitation frequency. These even harmonics are proportional to the ambient field. Using a secondary coil which is wrapped around two core elements with opposite excited flux, odd harmonics of the induced voltage vanish and the field dependent even harmonics remain.

For radio-astronomy observations on-board S/Cs various radio frequency spectral analyzers are employed. However the main principal is common for all. The induced voltage across a monopole, dipole, or even full tripole antenna configuration is measured by a sensitive (differential or direct) pre-amplifiers. This signal then undergoes spectral analysis in a digital flight-programmable gate array to produce the observed wave spectra of detected radio emission in selected frequency range. The sensitivity of such radio receivers is typically mostly constrained by the effective lengths of the applied monopoles and mainly by disturbing electromagnetic emissions produced by the present S/C body. In case of Lunar Lander mission significant interference of the landing module are to be expected, however, the radio site survey observations shall still to be accessible with an appropriate instrumentation.

4 Technology requirements

The driving technology and mission related requirements for L-DEPP, which are constraining the system design in terms of function, performance, available resources, interfaces to both L-DEPP subsystems and Lunar Lander and overall configuration constraints were assessed in the second project technical note, namely the Instrument Technology Assessment Report. The challenging drivers in case of the lunar missions were represented namely by limited mass budget and power available for the survivability in the dramatic lunar thermal environment.

The Lunar Lander is primarily a technological mission and the mass available for the L-DEPP payload is limited. The L-DEPP mass requirement of 7.7 kg places a significant challenge and it is the most important driver for instrument subsystems selection and performance. Also the availability of electrical power from the Lunar Lander platform during the lunar night drives the operational concept to incorporate low-power modes and challenges the thermal design together with component selection and qualification.

The objective of Lunar Lander is to land on lunar south pole where L-DEPP can experience, depending on local topography, temperature variations from as low as 100K up to 300K. The illumination on various landing spots varies, with possibility of experiencing dark periods several days long (estimated to around 55h according to mission specifications). The thermal and power concept of the L-DEPP system should allow the longest operation possible, with nominal operational lifetime of at least 4-5 months. The ability to measure during the day-night transient period and during the lunar night will significantly increase the scientific output of the L-DEPP operation but will be strongly limited.

Estimated Total Ionizing Dose (TID) for Lunar Lander mission extrapolated to L-DEPP with assumed aluminum box wall thickness of 3 mm is approximately 7 to 10 krad(Si). With considering 100% margin our electronic design concept shall be able to withstand up to 20 krad(Si). This dose is quite favorable and should be achieved with Rad-Tolerant microelectronic components at a suitable low cost. COTS components or any rad-sensitive components with TID below this value are not assumed to be used. Moreover the electronics will be stacked and placed onboard the Lander body providing additional shielding.

The mechanical alignment and placement on the Lunar Lander platform must confirm to the scientific objectives with respect to requirements on field-of-view, EMC, while accepting the available volumes on the dedicated Lunar Lander top platform, free space for boom deployment, mass constraints, and maximize the electrostatic and electromagnetic cleanliness.

The Earth communication on the proposed landing site will be available on a cyclic basis for approximately 14 days per month. L-DEPP operations during Earth eclipse thus shall be autonomous and predefined by previous Earth communication. Also the limited mass storage capacity of the Lunar Lander system needs to be taken into account while planning the out of contact L-DEPP operations.

5 Design concept

The final L-DEPP design concept of the whole package derived from both the scientific and technology requirements was provided in two technical notes for the system part (System Design Report) and the instrument subsystems respectively (Instrument Design Report). All relevant details were described in the delivered Payload Interface Document.

To achieve the scientific objectives the L-DEPP experiment consists of 5 kinds of diagnostic sensors. Namely the L-DEPP package includes one charged dust trajectory sensor called the Electrostatic Lunar Dust Analyser (ELDA), two flux-gate magnetometers and two spherical Langmuir probes integrated into two combined Lunar Plasma Monitor (LPM) sensors, two electric field antennas forming a dipole sensor of the Lunar Radio Unit (LRU), and finally a miniaturized energy plasma detector of the Lunar Electron and Ion Analyser (LEIA).

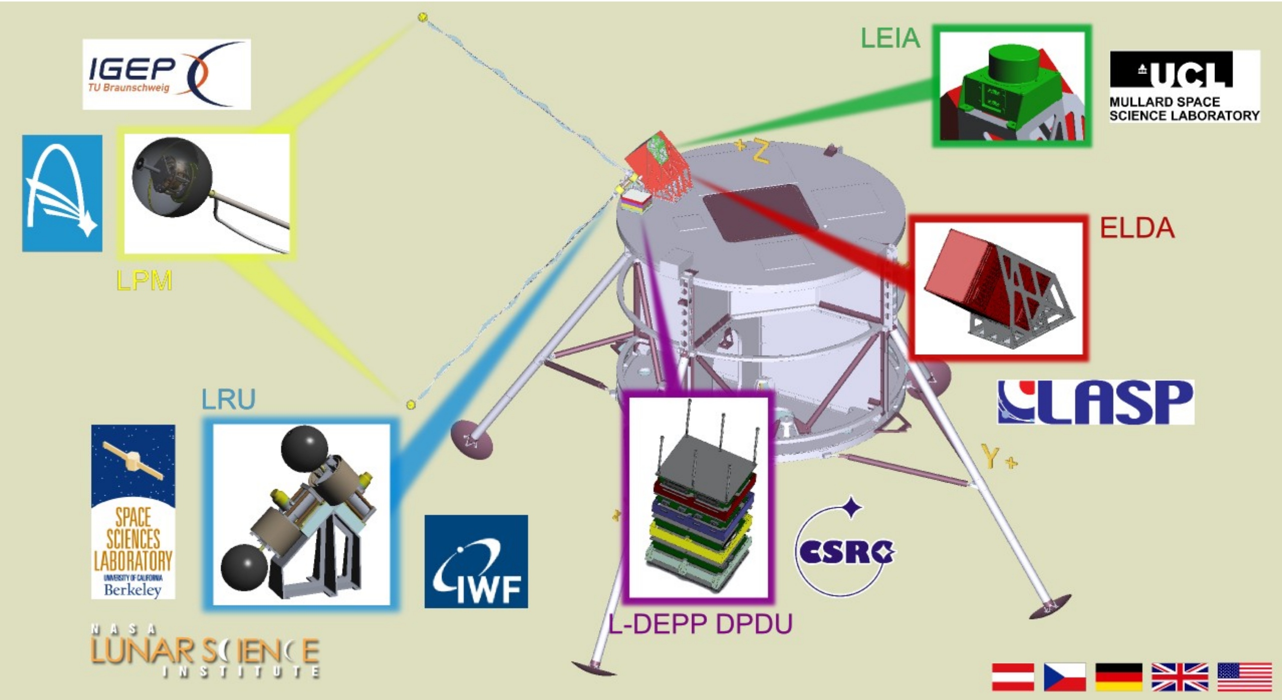

Figure 1: The overall picture of the L-DEPP instrumentation including the related responsibilities of individual consortium members for the H/W development.

Mechanically the L-DEPP package is integrated into three mechanical entities all mounted on the edge of the top Lunar Lander platform as shown in figure 1. The whole L-DEPP system is built up around a Main Electronics Box (MEB), which houses the core electronics boards including the Power and Data Distribution Unit (DPDU) providing a common data and power interface of all L-DEPP sensors with the main Lunar Lander system and complete experiment thermal control. The two other mechanical L-DEPP entities interfacing the MEB are the mechanical supports, one integrating the ELDA and LEIA sensors and part of their electronics and the other providing mechanical interface for the two LPM sensors deployed on the radio stacer antennas. The present L-DEPP system approach greatly minimizes the required interfaces and consequently tends to optimizes the demand on very limited Lunar Lander system resources.

The Electrostatic Lunar Dust Analyser (ELDA), representing the largest mass and volume part of the package, is proposed for the L-DEPP payload as a sensitive and sophisticated dust detector, which will provide the full characterization of the mobilized dust population by measuring the charge, mass and vertical and one horizontal component of the velocity vector of individual grains. The optimal field-of-view is achieved by edge placement and 45 degrees tilt from the horizon.

The Lunar Plasma Monitor (LPM) represent a novel combined plasma instrument composed of two different sensors. Its two identical units implement one spherical Langmuir Probe and one fluxgate magnetometer into single sensor providing bulk electron plasma properties and as well as vector magnetic field measurements. The two LPM sensors are vertically separated on two deployable booms further enabling the measurement of vertical electric field component responsible for the mobilization and levitation of the charged dust particles. The deployment on 2.5 meters long booms shall also guaranties required separation from the lunar module and thus minimize the potential interference of LPM measurements.

The LEIA instrument is an electrostatic particle analyzer that will provide diagnostic of the near-surface plasma population. The combined sensor, namely the particle electrostatic deflector operating in both positive and negative potentials, is able detect both electron and ions through the common aperture giving a considerable benefit to the overall scientific performance of the L-DEPP package. The LEIA architecture is based on miniaturized sensor (wrt. standard top-hat-type detectors) being currently under development for demonstration on the TechDemoSat mission. The LEIA field-of-view at the top of ELDA box provides full 360 degrees in azimuth with 60 degrees of elevation above and below the horizontal plane.

The lunar radio unit (LRU) is proposed as a software digital radio receiver that has been under development for the last 4 years. The system merges high heritage components into one fast-sampling system. The LRU experiment will provide first survey diagnostic of lunar surface environment with respect to radio-astronomy measurements via measurements of induced voltage across the L-DEPP stacer booms serving as a V-shape dipole antenna. Signals will be measured by a sensitive RF coupled differential pre-amplifier and further undergo sampling in high dynamic range 14-bits ADCs to produce spectral analysis in the FPGA FFT softcore.

6 The consortium

The project was conducted under a scientific-technology consortium which gathers both European and non-European (USA only) institutes/companies from 5 different countries. The consortium lead and the primary contractor of the corresponding ESA contract was the Astronomical Institute of the Academy of Sciences of the Czech Republic with Petr Hellinger as Principal Investigator and Štěpán Štverák as the project manager. In order to facilitate the management and communication between the European and non-European members the US activities were coordinated by the Co-PI Pavel Trávníček from Space Science Laboratory of University Berkeley.

Here we list the complete set of consortium members with involved personnel and indicated responsibilities in the L-DEPP project.

Czech Republic

Astronomical Institute, Academy of Sciences of the Czech Republic (ASI), *consortium lead*
Fričova 298, 251 61 Ondřejov, Czech Republic
Principal Invesigator: Petr Hellinger
Project Manager: Stepan Stverak
Technical lead: Jaroslav Laifr
Team members: Petr Hellinger, David Hercik, Ondrej Sebek, Roman Pavelka, Martin Jilek
Responsibilities: LPM

Czech Space Research Centre (CSRC)
Jánská 12, 60200 Brno, Czech Republic

Technical lead: Petr Váňa (Co-I)
Team members: Jan Brinek, Zdenek Kozacek, Lukas Kozacek, Jan Mares
Responsibilities: L-DEPP System

Austria

Österreichische Akademie der Wissenschaften, Institut für Weltraumforschung (IWF)
Schmiedlstraße 6, 8042 Graz, Austria
Scientific/Technical lead: Helmut Rucker (Co-I)
Team members: Manfred Sampl, Georg Fischer, Thomas Oswald
Responsibilities: LRU

Germany

Institut für Geophysik und Extraterrestrische Physik, Technische Univeritat Braunschweing (TU-BS)
Mendelssohn str. 3, D-38106 Braunschweig, Germany
Scientific/Technical lead: Uli Auster (Co-I)
Team members: Karl-Heinz Glassmeier, David Herčík
Responsibilities: LPM

U.K.

Mullard Space Science Laboratory, University College London (MSSL)
Holmbury St. Mary, Dorking, Surrey, RH5 6NT, U.K.
Scientific lead: Christopher J. Owen
Technical lead: Dhiren Kataria (Co-I)
Team members: Geraint Jones
Responsibilities: LEIA

USA

NASA Lunar Science Institute, Goddard Space Flight Center (NLSI)
Mail Code 695, Greenbelt, MD 20771, U.S.A.
Technical lead: William M. Farrell (Co-I)
Scientific lead: Robert J. MacDowall
Responsibilities: LRU

Laboratory for Atmospheric and Space Physics, University of Colorado (LASP)
1234 Innovation Dr., Boulder, CO 80303-0392, U.S.A.
Scientific lead: Mihaly Horanyi
Technical lead: Zoltan Sternovsky (Co-I)
Responsibilities: ELDA

Space Sciences Laboratory, University California Berkeley (SSL UCB)
7 Gauss Way, Berkeley, CA 94720-7450, U.S.A.
Scientific lead: Pavel Trávníček, (Co-PI)
Technical lead: Paul Turin
Team members: Gregory T. Delory, Jasper Halekas, Stuart Bale, Davin Larson
Responsibilities: L-DEPP deploy-able booms/antennas

7 Summary Tables

L-DEPP Scientific Performance	
Measured characteristic	**Description**
AC magnetic field	resolution of 1nT
Charge of dust particles	0.2 to 100fC
Mass of dust particles	10^{-15} to 10^{-11} kg
Vertical component of particles velocity	1 m/s to 300 m/s
One horizontal component of particles velocity	1 m/s to 300 m/s
Vertical component of the near-surface electric field	+/- 15 V/m
Bulk plasma density	10^{1}-10^{4} cm^{-3} 10^{-1}-10^{2} cm^{-3} – dark periods
Bulk plasma temperature	< 10 eV / 1-100 eV
3D electron velocity distribution function	~ 1eV to 30 keV angular resolution 22.5°x3-7° 87% of full solig angle
3D ion velocity distribution function	~ 1eV to 30 keV angular resolution 5.6°x3-7° 87% of full solig angle
DC magnetic field measurement	10 nT accuracy
Probe to Lunar Lander potential	+/-100 V +/-5 kV (dark periods)
Background radio emissions	10kHz-30MHz

L-DEPP dimensions summary		
Part	**Dimensions [mm]**	**Comment**
Main Electronics Box	160 x 200 x 120	Width x length x height
ELDA sensor	270 x 270 x 340	
LPM sensor	80	sphere diameter
LEIA unit	34 x 71	cylinder (height x diameter)
LRU stacer	2500 x 14-10	length x diameter (base - tip)
LRU preamplifier box	100 x 50 x 15	Two preamplifiers for two stacers

L-DEPP Mass Budget			
Structure	**Part**	**Mass [g]**	**Applied mass margin [%]**
Stacers	Stacer support structure	*350*	*20*
	Upper Stacer + preamp	*465*	10
	Lower Stacer + preamp	*465*	10
	2 LPM sensors	*285*	10
	Stacers total	*1565*	
ELDA structure	ELDA sensor + CSA	*2865*	20
	ELDA support structure	*2420*	20
	ELDA total	*5285*	
LEIA Box	LEIA support structure	*270*	20
	LEIA sensor	*575*	20
	LEIA total	*845*	
Main Electronics Box	MEB structure (4 frames)	*1530*	20
	DPDU PCB	*350*	20
	LPM PCB	*350*	20
	LRU PCB	*400*	20
	ELDA PCB (- box estimate)	*500*	20
	MEB total	*3130*	
Harnesses	LEIA to MEB	*70*	20
	ELDA to MEB	*150*	20
	Stacers to MEB (LRU)	*40*	20
	Stacers to MEB (LPM)	*70*	20
	Harnesses total	*330*	
Total (including margin)		**11055g**	

L-DEPP Power Budget		
Unit	**Power [W]**	**Power + 20% margin [W]**
ELDA	7	8.4
LPM	4.5	5.4
LEIA	1	1.2
LRU	5	6
DPDU	3	3.6
Total	**20.5**	**24.6**