NASA L'SPACE PDR - Preliminary Design Review

The DORA Explorer Mission

Team 28

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List of Acronyms

MHP	Marius Hills Pit
BOOTS	Base Operational Observation Terrain Surveyor
DORA	Deep Operation Reconnaissance Agent
MAHLI	Mars Hand Lens Instrument
APXS	Alpha Particle X-Ray Spectrometer
GEF-LiDAR	GoldenEye 3D Flash LiDAR
RAD	Radiation Assessment Detector
CCT	Cernox® Cryogenic Thermometer
LET	Linear Energy Transfer
MGPR	Miniature Ground Penetrating Radar
NASA	National Aeronautics and Space Administration
DEM	Digital Elevation Model
TL	Team Lead
PM	Project Manager
PDR	Preliminary Design Report
MDR	Mission Definition Review
LE	Lead Engineer
CAD	Computer-aided design
DPMR	Deputy Project Manager of Resources
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
SMA	Shape Memory Alloys
LaRC	Langley Research Center
AMPB	Advanced Materials and Processing Branch
MLI	Multilayer Insulation Blankets
TRL	Technology Readiness Level
MLI	United States Nanomaterial Research Inc
ISO	International Organization for Standardization
DoD	Department of Defense
IBM	International Business Machines Corporation
MCCET	Mission Concept Cost Estimate Tool
MSSS	Malin Space Science Systems
SwRI	Southwest Research Institute
CLPS	Commercial Lunar Payload Services
CCD	Charge-Coupled Device
NICM	NASA Instrument Cost Model
ASC	Advanced Scientific Concepts Inc.
FMEA	Failure Mode and Effect Analysis
PDR	Preliminary Design Report
LS	Landing Site
RIDM	Risk-Informed Decision Making
CRM	Critical Risk Management
LOTO	Lockout/Tagout
PPE	personal protective equipment
GSA	General Services Administration
CADRe	Cost Analysis Data Requirement
CER	Cost Estimating Relationship
PDU	Power Distribution Unit
BCR	Battery Charge Regulator
BDR	Battery Discharge Regulator
SOC	System On Chip
GNC	Guidance, Navigation, and Control
RFA	Request for Action
ADV	Advisories
CRF	Change Request Form

CCB	Change Control Board
CCL	Change Control Log

1 Mission Overview

1.1 Mission Statement

The DORA Explorer Mission presents a comprehensive plan to assess the suitability of the Marius Hills Pit (MHP) for long-term human habitation and advance understanding of the Moon's volcanic past and evolution. The mission will provide valuable data that will inform future manned missions to the Marius Hills by investigating the physical structure and integrity, thermal stability, radiation shielding capabilities, and the available in-situ resources of the MHP and potential lava tube structure beneath the pit. The DORA Explorer Mission will study MHP's exposed regolith flood basalt layersto obtain key insights into the Moon's volcanic history and surface processes, advancing understanding of lunar geology and the evolution of rocky bodies. Finally, the mission will explore along the edge of a nearby sinuous rille all the way to the rille source 25km away. It will analyze the morphology of the rille and image nearby sites of interest include craters and lava domes with the purpose of characterizing available surface science for future astronauts and studying lunar rilles.

The DORA Explorer Mission consists of two robotic probes: the rover BOOTS (Base Operational Observation Terrain Surveyor) and the pit explorer DORA (Deep Operation Reconnaissance Agent). BOOTS is the parent rover, whose task is to traverse the lunar surface to arrive at the pit, supply power and communication to DORA, and eventually survey the surface surroundings of the pit. The child craft, DORA, will descend into the pit cave to collect data on the internal structure of the pit and lava tube, measure radiation levels and temperatures, and identify in-situ resources within the lava tube. It will also measure and characterize exposed flood basalt and regolith layers on the side of the pit opening. Aboard DORA are the the Mars Hand Lens Instrument (MAHLI), the Alpha Particle X-Ray Spectrometer (APXS), GoldenEye 3D Flash LiDAR (GEF-LiDAR), Radiation Assessment Detector (RAD), and Cernox® Cryogenic Thermometer (CCT). BOOTS has two scientific instruments: Miniature Ground Penetrating Radar (MGPR) and MastCam-Z.

The DORA explorer mission is critical not only for determining the viability of future human habitation in lunar pit caves but also for expanding scientific knowledge of the Moon's geology and evolution to provide further context and background for the future scientific activities of lunar astronauts.

1.2 Science Traceability Matrix

Tables 32a and 32b, the Science Traceability Matrix, outlines the science goals, objectives, and measurements of this mission. The science goals of this mission stem from two customer-provided goals. The first goal, a goal of the Lunar Exploration Analysis Group, is to "provide safe and enduring habitation systems to protect individuals, equipment, and associated infrastructure" on the Moon.[1] The lunar environment poses numerous challenges to sustained human habitation, including stark temperature variations, high levels of radiation, and micrometeorites. Lunar pit caves could be ideal shelters for astronauts and act as long-term bases of operations.[2] The first goal of this mission is to characterize a pit cave's merit to provide safe and enduring habitation systems. Two objectives are derived from this goal. The first is to characterize the depth, terrain variation, ease of access, structural integrity, temperature, and radiation levels within lunar pits/caves to determine the viability of human habitation. Each of these parameters will be measured as indicators of merit for habitation. The second objective derived from the goal of providing enduring habitation systems is to characterize in-situ resources and materials inside selected lunar caves. In-situ resources are critical for NASA's plans of continuous lunar habitation, as using these resources eliminates dependence on Earth for resupplies. As part of this objective, the mission will analyze regolith composition and volatile distribution in the pit and on the surface to constrain where astronauts could obtain fuel and oxygen.

The second top-level goal of this mission, a goal from Origins, Worlds, and Life: A Decadal Strategy for Planetary Science, is to "develop precursor lunar robotic missions and define those scientific activities that astronauts will conduct on the Moon."[3]

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[1] "The Lunar Exploration Analysis Group (LEAG)," Lunar Exploration Analysis Group (LEAG) (2024), https://www.lpi.usra.edu/leag/roadmap/.

[2] Tyler Hovarth, Paul O Hayne, and David A Paige, "Thermal and Illumination Environments of Lunar Pits and Caves: Models and Observations from the Diviner Lunar Radiometer Experiment," Geophysical Research Letters 49, no. 14 (2022), https://doi.org/10.1029/2022gl099710.

[3] National Academies of Sciences, Engineering, and Medicine, "Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032," Washington, DC: The National Academies Press, (2023): 18,

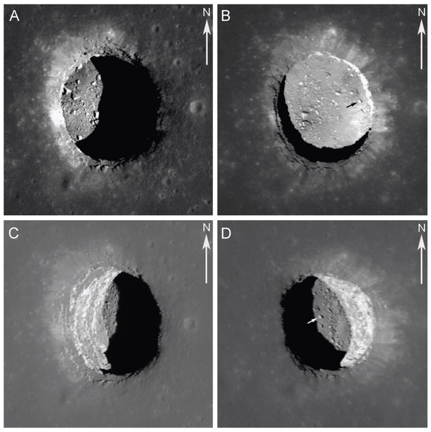

Figure 1: Images of Marius Hills Pit from different angles from Robinson et al. (2012)

In accordance with this goal, the mission aims to learn more about the history and features of the lunar mare in order to provide more geologic context and information to better plan future human scientific activities. The first objective derived from this goal is thus to constrain the flood history, effusion rates, and composition of basaltic lava flows lunar mare. This objective aligns with the fifth priority science question of the Decadal Survey: "Q5. Solid-body interiors and surfaces. How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?"[4] Understanding the history of basaltic lava flows in lunar mare advances understanding of the transition from primary crust to secondary crust, which is crucial for understanding how solid bodies and their surfaces evolve.[5] The Moon's basaltic flow history is an ideal case study for investigations of secondary crust formation because of the Moon's lack of plate tectonics and relative geologic simplicity.

The timing and effusion rates of flood basalts on rocky bodies are still poorly understood. Understanding these factors is critical for interpreting volcanic features and constraining the secondary crust formation process. Additionally, flood basalt events are linked with large-scale climate deviations, so understanding how they work is of great importance on Earth.[6] The exposed layers of flood basalt on the side of the favored mission destination, the Marius Hills Pit, provide an accessible way to study historical basaltic flows without having to drill far below the surface. The mission will sample these layers, seen in the lower two images of Figure 1,[7] and collect data on chemical composition, mineralogy, and morphology in order to constrain flow regime, flow velocity, and average composition, the latter of which is critical for gaining a holistic view of the magma's origin.[8] These data will advance understanding of the history and characteristics of flood basalts on the moon, thus providing information about the Moon's early and late volcanic history and how volcanism shapes rocky bodies.

The second science objective derived from the second science goal is to investigate the surroundings of the pit to determine ideal human scientific activities. This goal will be accomplished by exploring the Marius Hills area by following the path a nearby sinuous rille. The surroundings of the Marius Hills Pit contain a plethora of volcanic features of unknown origin, making it an ideal site for human scientific activities.[9] This mission will study the rille and neighboring features including a crater and a lava dome. Preliminary examinations of these features using multi-spectral stereoscopic imaging will further characterize the volcanic geology of Marius Hills and identify further sites of intrigue for future scientific investigations.

The third and final science objective stemming from the second goal is identifying the characteristics and formation of regolith in lunar mare to better understand the significance and effects of regolith on terrestrial planetary bodies. When bedrock is altered into regolith through micrometeorite impacts and other weathering factors, the regolith obscures geologic features on the Moon's surface.

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https://doi.org/10.17226/26522.

[4] Ibid, 97.

[5] James W. Head, Lionel Wilson, "Lunar mare volcanism: Stratigraphy, eruption conditions, and the evolution of secondary crusts.," Geochimica et Cosmochimica Acta 56, no. 6 (1992): 2155. https://doi.org/10.1016/0016-7037(92)90183-J.

[6] I. A. Nesnas, et al,"Moon Diver: A Discovery Mission Concept for Understanding the History of Secondary Crusts through the Exploration of a Lunar Mare Pit," IEEE Aerospace Conference, Big Sky, MT, USA (2019): 5, https://doi.org/10.1109/AERO.2019.8741788.

[7] M.S. Robinson, J.W. Ashley, A.K. Boyd, R.V. Wagner, E.J. Speyerer, B. Ray Hawke, H. Hiesinger, C.H. van der Bogert, "Confirmation of sublunarean voids and thin layering in mare deposits," Planetary and Space Science 69, no. 1 (2012): 23, https://doi.org/10.1016/j.pss.2012.05.008.

[8] Grant Heiken, David Vaniman, and Bevan M. French, eds, "Lunar sourcebook: A user's guide to the Moon," no. 1259, Cup Archive (1991): 186.

[9] Robinson, 21.

Understanding the properties of regolith is critical for better interpreting images taken from space and how representative they are of actual surface features, which will, in turn, make site studies more accurate in preparation for human activities on the Moon.[10] Due to its fine particle size, regolith is also one of the primary surface hazards on the Moon, so seeking to understand its formation and physical properties is critical in preparing for long-term lunar habitation. This mission will gather data on the transition between bedrock and regolith by looking at the layers in the sides of the pit and measuring grain size, chemical composition, and lithology.

In support of science objectives, seven instruments have been chosen and distributed between the DORA and BOOTS rover systems. All subsurface measurements, taken during descent and upon arrival at the base of the Marius Hills Pit will be performed by the instruments on DORA. DORA will host five of the seven instruments planned for the DORA Explorer mission. The DORA rover instrument payload contains an alpha particle x-ray spectrometer, a stereoscopic multipurpose imager, sensors for temperature and radiation, and a LiDAR. While DORA traverses the interior of the MHP, BOOTS will probe the surface and subsurface structure of the area surrounding the pit. The BOOTS rover system will deploy two scientific instruments of the seven selected for the mission, a ground penetrating radar for mapping of structural characteristics and a stereoscopic camera for quantifying topographic features.

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[10] Nesnas, 5.