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Helios-Lune Tranquillitas: Artemis III Exploration Mission with Retrieval of Solar Activity Records

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Abstract

Helios-Lune Tranquillitas (HLT) is a proposal for a commercial-government partnership Artemis III lunar exploration mission to the Mare Tranquillitatis pit crater. HLT has a primary mission objective of obtaining samples to be returned to Earth for analysis from two locations within the crater: the sunlit wall and talus pile. The samples will be collected using a tailored, mission specific version of the Axel Rover (Axel) [1], developed to rappel into a lunar pit. Axel is controlled by Artemis lll crew using real-time telerobotic systems from the cabin of the HLT's pressurized electric rover (ROPE). The unique mission location and sampling strategy allows for solar activity record (SolAR) data to be analyzed from the sample layers upon return to Earth. SolARs imprinted on the long dormant Moon can provide critical data about solar behavior over geological time that is vital to building a reliable Climate Change model for Earth [2]. HLT's secondary objective is observation and scientific exploration of the lunar pit crater, through utilization of the rover's onboard scientific payloads. The mission overview is as follows: the HLT lunar lander touches down on the moon's surface at a safe distance from the Tranquillitatis pit. Once landed, ROPE is deployed and is driven by the crew from the landing site to a set location near the rim of the pit crater. On arrival, Axel is readied by being tethered to ROPE and thereafter begins to rappel into the crater, clearing debris on its downward descent. Once descent is complete, observation and experimentation through use of Axel's scientific payloads, including sampling of the talus pile commence. When this stage is complete, Axel ascends on the debris-cleared path towards the lunar surface, pausing at specified intervals to collect the remaining pit wall samples by drilling. The mission is designed to align with the Artemis program's objectives as the Tranquillitatis pit is a prime location for initial study aimed at revealing ancient SolAR data as well as lava studies that provide insight into past lunar planetary processes. HLT is a Commercial Human Space Exploration (CHASE) and government partnership mission. Thus, all stages of mission development can be open to company applications through worldwide tender, promoting international scientific collaboration and cooperation. Once obtained, data from the mission and results from sample analysis can be sold to public and private space sector companies, educational institutions, and other interested parties.

Keywords: Artemis, CHASE, Climate Change, Human Spaceflight, Lunar Exploration, Mare Tranquillitatis, NASA, Solar Activity Records, Space Exploration

Acronym	**Expansion**
3D	Three – Dimensional
CHASE	Commercial Human Space Exploration
ECLSS	Environmental Control and Life Support System
GPR	Ground Penetrating Radar
HLT	Helios-Lune Tranquillitas
ISS	International Space Station
LIDAR	Laser Imaging, Detection, and Ranging
JPL	Jet Propulsion Laboratory
LRO	Lunar Reconnaissance Orbiter
NASA	National Aeronautics and Space Administration
OPAL	Obscurant Penetrating Asynchronous LiDAR
ROPE	Pressurized Electric Rover
SolAR	Solar Activity Record
TBD	To Be Determined

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1. Introduction

From 1961, human spaceflight has been a catalyst for ingenuity and innovation across the globe, allowing civilization to rethink boundaries of science and technology as well as reshape discovery and understanding.

Today, the National Aeronautics and Space Administration's (NASA) Artemis missions (Fig. 1) are described as "the first step in the next era of human exploration" [3], where we are returning to the lunar surface with intentions outside of visiting for the first time in history: "We are going to the moon, to stay" [3] and to learn how to live sustainably on another celestial body in the solar system long-term.

The Artemis missions are founded on three governing principles: scientific discovery, economic opportunity and inspiration for the next generation [3]. Helios-Lune Tranquillitas (HLT), as a proposed commercial-government partnership Artemis III lunar exploration mission to the Mare Tranquillitatis pit crater, has mission goals that align with these three governing principles.

Fig.1. The next era of human exploration: NASA Artemis [4]

1.1 Scientific Discovery

Artemis III will be the first manned mission to the lunar surface in the 21st Century [5]. As the first touchdown mission, Artemis III provides an unparalleled opportunity for on-ground human led scientific discovery. The research focus areas for this scientific discovery are detailed by NASA in the Artemis III Science Definition Report [5]. The report outlines objectives identified by the Science Mission Directorate in the Artemis Science Plan, which considers the full range of exploration goals specified in Guiding Documents and NASA white papers [5]. These guiding documents allow mission planners to "weigh operational constraints to develop a science implementation plan for the mission, including the collection of samples, deployment of instruments, and key in situ observations by the crew" [5]. HLT focuses on Objectives 4 and 1 of the Artemis Science Plan: "Revealing the Records of the Ancient Sun and Our Astronomical Environment" and "Understanding Planetary Processes" respectively. The aforementioned Artemis III objectives aim to be achieved through HLT's mission objectives below:

- HLT Primary Mission Objective:

Sample collection for Earth return and analysis

Samples are obtained from two locations within the Mare Tranquillitatis pit crater: the Sunlit Wall and Talus Pile (Fig.2).

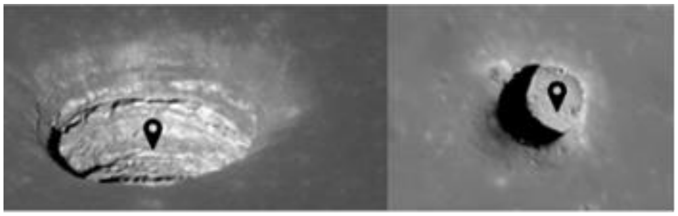

Fig. 2. Mare Tranquillitatis pit crater sample locations. Sunlit Wall (Left) and Talus Pile (Right) [6]

Fig. 3. The Mare Tranquillitatis pit crater is situated in the southeast middle of Mare Tranquillitatis. It is approximately 100 x 88 m wide and 105 m deep, with an overhang of around 20 m [7,8].

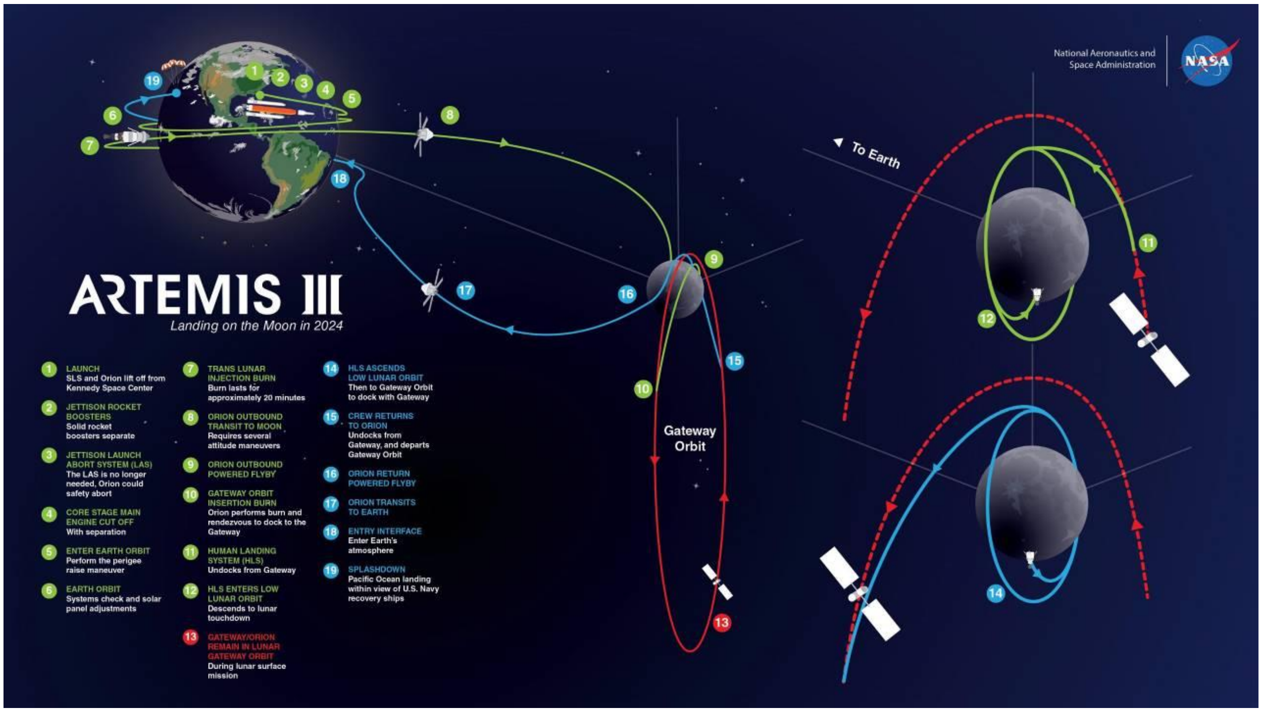

Fig.4. Artemis III Overview [9]

- HLT Secondary Mission Objective:

Observation and scientific exploration of the lunar pit crater

Data is obtained through utilization of the rover's onboard scientific payloads including wide and narrow lens cameras, a spectrometer, light weight ground penetrating radar (GPR), and three -dimensional (3D) laser scanning capabilities (Section 2.6).

Fig. 5. Astronaut observation and scientific exploration on the lunar surface [9]

1.1.1 *The Mare Tranquillitatis Location*

Mare Tranquillitatis has additional unique advantages as a location:

1- Free return trajectory

A free return trajectory is available and can be utilized if a mission abort is required. Artemis I and II provide key experience, as their orbital trajectory is over the lunar equatorial region.

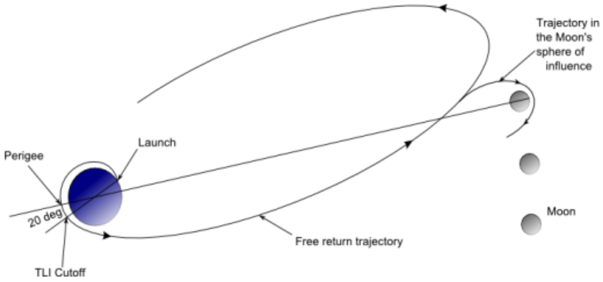

Fig. 6. Free Return Trajectory [10]

2- Apollo 11: Inspiration and Exploration

The Apollo 11 site is accessible from the Mare Tranquillitatis pit crater. HLT's mission objectives could potentially expand to include visiting the site. This would not only provide a thread from history, creating a platform to inspire and educate the public worldwide [11], but additionally provide the opportunity to test HLT's lunar rover over a greater distance and explore the weathering of Apollo hardware over half a century of exposure to the space environment.

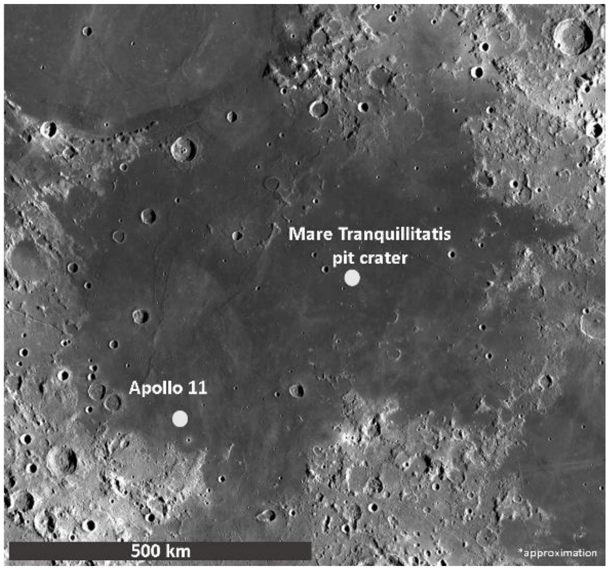

Fig. 7. Relative locations of the Apollo 11 site and Mare Tranquillitatis pit crater [12]

1.1.2 Solar Activity Record (SolAR) and Climate Change

HLT meets Objective 4 of the Artemis Science Plan, "Revealing the Records of the Ancient Sun and Our Astronomical Environment", by obtaining SolAR data from the lunar surface. As the lunar surface has been exposed to the space environment for billions of years, SolARs have accumulated in regolith and preserved paleoregolith over this timeframe [2]. As described by Crawford et al. [2], "records will be preserved in sub-surface layers, such as buried palaeoregoliths or lava flows, that were once exposed at the lunar surface". During the HLT mission, Artemis III crew obtain samples of sub-surface layers, which could provide an undisturbed solar record that greatly surpasses the record we can obtain on Earth. The Mare Tranquillitatis pit crater is a prime location for accessing these records as there are multiple exposed lava layers on the Sunlit Wall (Fig. 8)

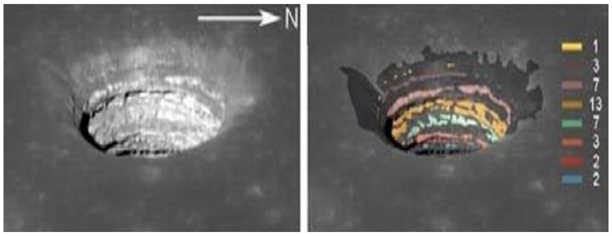

Fig. 8. Mare Tranquillitatis pit crater layering. Approximation of outcropping bedrock layer thickness meters, ± 1 meter (Right) [6]

Moreover, SolARs imprinted on the long dormant Moon can provide critical data about solar behavior over geological time that is vital to building a reliable Climate Change model for Earth [2]. Obtaining accurate data from SolARs will allow Climate Change models to become more precise, due to acquiring comparative historical data. Additionally, SolARs provide further research evidence on how solar variability impacts Earth's climate [13] and provide context as to how solar flux and composition have varied over time [2].

Through sample analysis and scientific observation of SolARs, HLT aims to meet the following Artemis III goals [5]:

- Understand the history of the Sun, including the composition and flux of the solar wind
- Understand the record of solar energetic particles, cosmic rays, gamma-ray bursts, and supernova
- Understand changing compositions of impactors with time, and the nature of the early Earth
- Understand the long-term variability in the solar constant

1.1.3 Lunar Planetary Processes

HLT meets Objective 1 of the Artemis Science Plan, "Understanding Planetary Processes", through sample analysis and return.

According to Kerber et al [8], Mare Tranquillitatis is of particular interest for the following reasons:

- Morphology

The flood basalts around Mare Tranquillitatis are generally representative of most flood basalts on the moon as they are "flat plains without clear flow boundaries or unusual morphologies"

- Lateral Regolith Mixing

The Mare Tranquillitatis pit crater is at prime location to test theories on lateral regolith mixing as it is situated away from the highlands and near a boundary between two lava types

- Comparison Data

The predicted exposed types of lava within the Mare Tranquillitatis pit crater have been spectrally linked to Apollo 11 basalt fragments, thereby allowing direct comparison of HLT's samples with existing returned samples

Additionally, through examining multiple layers from deposits on top regolith through to exposed in-situ bedrock layers, key questions such as "how regolith is generated from the original rocky surface, how mare lavas were emplaced (the true thickness of individual lava flow units and indications of their instantaneous flow velocities) and the effects of flow and in-situ fractionation on the compositions and petrologic origins of the mare basalts" [8] can be addressed.

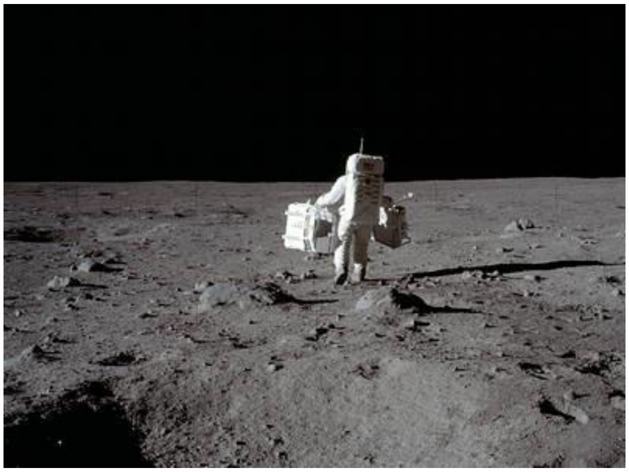

Fig. 9. Buzz Aldrin at the Tranquillity Base (Apollo 11) [14]

Through scientific observation of the Mare Tranquillitatis pit crater, HLT follows the following Artemis III goals and investigations [5]:

- Understand volcanism: partial melting, eruptions, flow sequence and compositions
- Determine physical properties of regolith at diverse locations of expected human activity

1.2 Economic Opportunity

The Artemis III missions are aligned to foster economic opportunities internationally. HLT is designed to align with US Space Policy goals to advance progress through a "robust, innovative and commercial space sector" [15] as well as "extending human economic activity in deep space" [15] by facilitating science-driven exploration on the moon.

As a commercial-government partnership mission, HLT can benefit from expanding economic opportunity from both perspectives. Through HLT's commercial partnerships, stages of mission development can be open to company applications through worldwide tender, promoting international scientific collaboration and cooperation. Opening mission stages to worldwide tender increases opportunities for international competition. Further, commercial opportunities create new pathways for generating economic growth, such as through selling mission data and results from sample analysis to public and private space sector companies, educational institutions, and other interested parties. Additionally, research proposals for sample data analysis and experimentation can be submitted by academic institutions and commercial space companies. From a government perspective, HLT will contribute to financing small businesses through established budgeting channels. Janet Petro, deputy director of the John F. Kennedy Space Center, states that two-thirds of the suppliers for the Artemis I rocket are small businesses and that through these suppliers, NASA provides approximately $2.8 billion a year directly to small businesses [16].

1.3 Inspiration for the next generation

Artemis has outreach programmes aimed at inspiring the next generation (Generation Artemis) to sustain future scientific advancement. The HLT mission joins with current NASA Artemis outreach programmes, such as 'Next Generation STEM' [17], which provides opportunities for children and young people (K-12) to engage with space science from grassroots levels. To illustrate the potential impact of space programs, according to a 2009 Nature survey [18] over 50% of researchers published within three years from the survey start cited inspiration from the Apollo space programme to join their field.

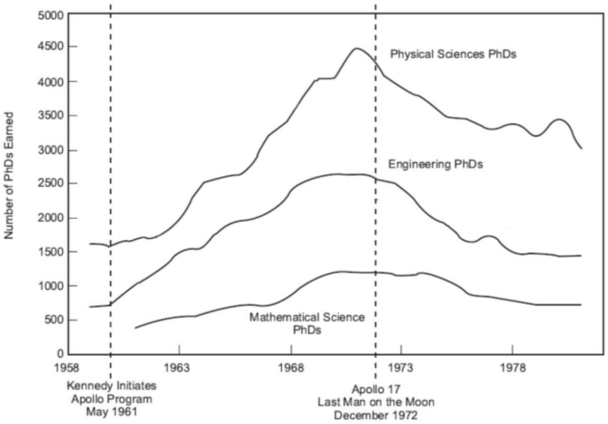

Fig. 10. PhDs earned vs. Apollo program years [19]

2. HLT Mission

The HLT mission is described by eight mission stages. The eight stages outline the overall procedure and activities performed by the crew from lunar landing to lunar lift-off. HLT mission stages are outlined below:

2.1 Stage 1: Lunar Lander Touchdown

The HLT lunar surface mission commences upon touchdown of the lunar lander. The landing occurs during the lunar day and the location was chosen with two main considerations: safety and accessibility.

2.1.1 Landing Site

The safety and accessibility requirements for the touchdown location include having the landing site at safe distance from the pit edge, on smooth terrain without detrimental landing obstructions, such as rockpiles (the smooth terrain of Mare Tranquillitatis is ideally suited as a heavy lander test site) and criteria discussed by Mitrofanov et al [20], such as maintaining an acceptable slope for lunar module re-launch and the area illumination levels being over 40% during the day.

Analysis of the landing site for obstructions and slope may be conducted utilizing Lunar Reconnaissance Orbiter (LRO) images of the pit crater (Fig. 11) and topographical mapping, such as mapping shown by Jawin et al (Fig. 12) [21] to measure vehicle tilt angle and ensure the maximum take-off angle is below structural limitations.

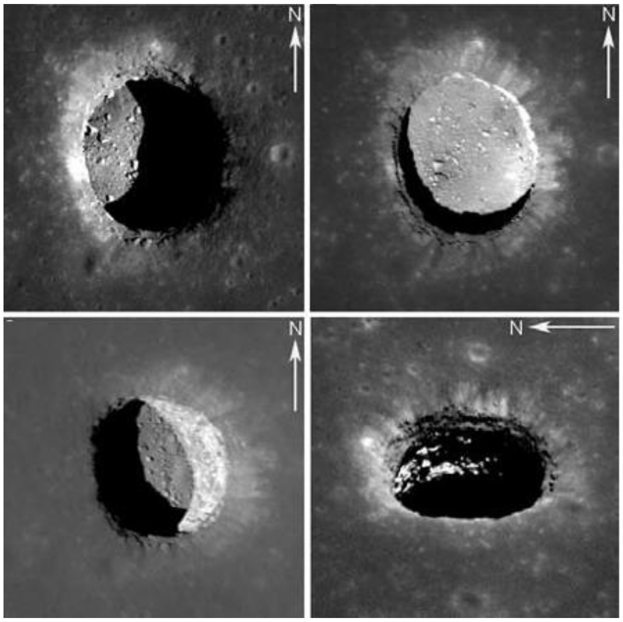

Fig. 11. Mare Tranquillitatis pit crater [12]

Furthermore, the touchdown location requires careful review to accommodate heavy landers. Consideration of the debris field associated with heavy landers to ensure that debris does not affect samples taken from the pit crater is critical. To illustrate the difference in mass between previous Apollo missions and today's proposed heavy landers, the Apollo 11 lunar lander weighed approximately 14 metric tonnes [22], while the current proposal for Starship is in excess of 100 metric tonnes [23].

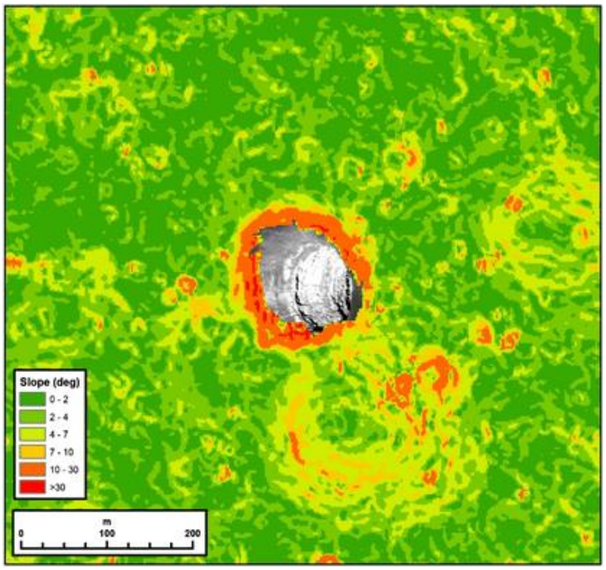

Fig. 12. Mare Tranquillitatis pit crater topographical mapping [21]

The landing location further accounts for travel time to the rim of the Mare Tranquillitatis pit crater, assuring that the time of travel aligns with HLT's overall mission timeline (Fig 13, p.8)

Landing locations are recommended within a 5-mile radius from the pit crater (TBD).

2.2 Stage 2: Pressurized Rover Deployment

Once lunar lander touchdown has been confirmed, a pressurized electric rover (ROPE) is deployed from the lunar lander and is driven by the crew from the landing site to a set location near the rim of the pit crater.

Fig. 14. Pressurised rover model showing relative astronaut size and smaller deployable roaming vehicles [Credit J.McDowell 26]

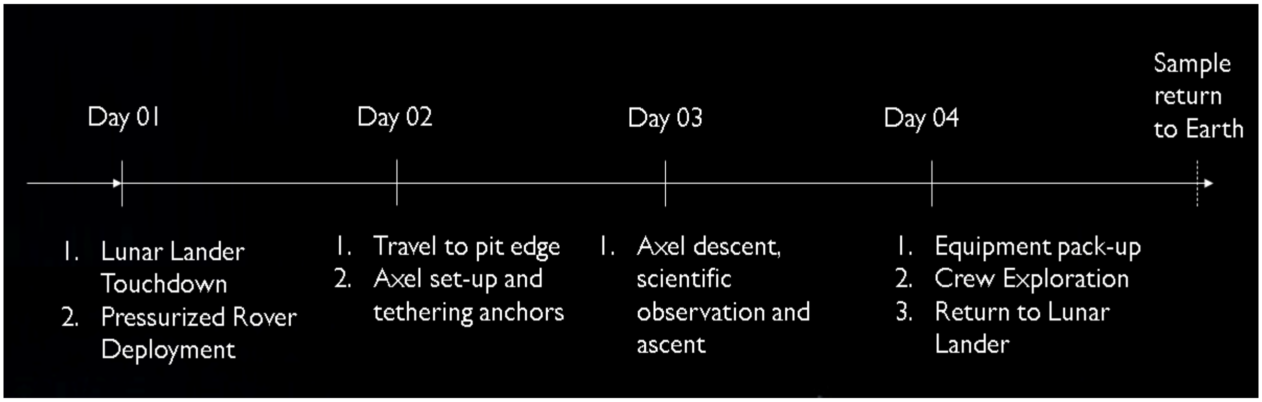

Fig 13. HLT Mission Timeline

The storage and deployment of ROPE potentially follows Clekner et al's [24] auto-deployable rover design, which outlines methods of collapse and expansion of ridged structures from packed to expanded configurations. This would allow ROPE to have a compact surface area during the transport phase to the lunar surface. ROPE could be used by future Artemis missions with an established base camp, in line with current perceived use cases for NASA's habitable mobility platform [25], or for longer duration surface missions to the Apollo 11 landing site (Section 1.1.1).

Fig. 15. Pressurised rover model showing deployment of smaller roaming vehicles [Credit J.McDowell 26]

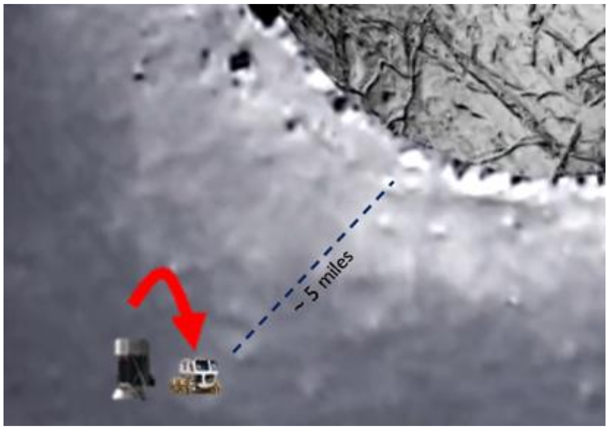

Fig. 16. ROPE deployment from lunar lander

ROPE is designed to be a mobile habitat equipped for astronauts to live on the lunar surface. It will contain all necessary provisions to allow astronauts to survive on the lunar surface for the mission duration, including atmospheric control, nutrition, water and sleeping facilities. The interior atmospheric constituents and water may be controlled by an Environmental Control and Life Support System (ECLSS), with the atmosphere inside the habitable area regulated to the International Space Station (ISS) standards of ambient pressure at 14.7 psi and partial pressure of oxygen held between 2.82 - 3.44 psi (TBD). Additionally, ROPE carries a portable solar storm shelter to protect astronauts from significant solar particle events.

Following Toyota's overview design an electric pressurized moon cruiser (Fig 17) [30], Hydrogen Fuel Cells can be considered as a potential electric power source for ROPE. The most suitable power option is to be chosen upon creation of detailed mission requirements.

Fig. 17. Toyota Electric Pressurized Cruiser [30]

2.3 Stage 3: Axel Rover Deployment

Once the crew arrives at the pre-designated zone near the rim of the Mare Tranquillitatis pit crater, Axel is deployed. Axel is a mission specific version of NASA's Jet Propulsion Laboratory (JPL) Moon Diver Axel Rover concept [1] tailored to automatically gather samples from the talus pile and sunlit wall by rappelling into the pit crater as well as perform scientific observations utilizing onboard payloads. Axel is controlled by the crew using real-time telerobotic systems, allowing them to make any adjustments to Axel's progress and perform initial data analysis throughout the time Axel is being used.

Fig. 18. Axel deployment from ROPE

2.4 Stage 4: Axel Rover Rappel

After Axel has been deployed and initial functionality tests have been completed, the rappel stage can commence. Axel is tethered to ROPE via two tether anchor points (for redundancy). The rappel into the crater is a controlled slow decent to ensure that debris on the path is cleared. Throughout the decent, the wide and narrow lens camera send live imaging feed to the crew aboard ROPE.

2.4.1 Axel's Tether

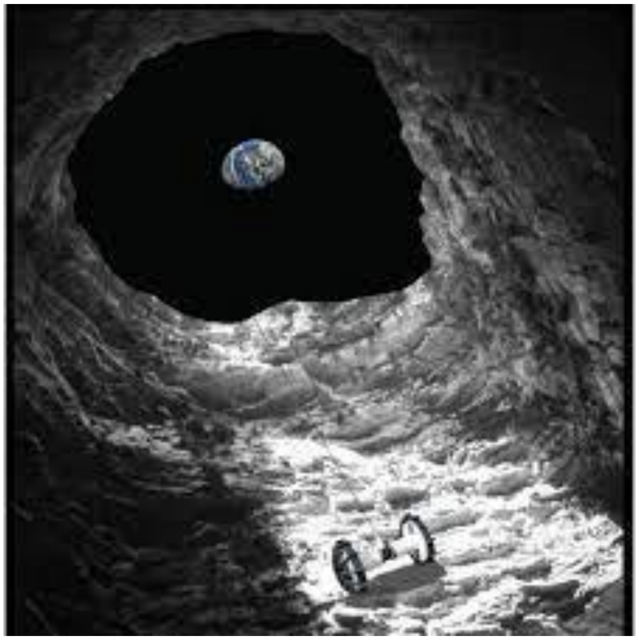

Fig.19. Axel Rover [1]

Axel's tether is a dual function power and communications cable. Analysis completed by McGarey et al [28] provides proposed materials for Axel's tether (Fig. 20), including Tefzel. Proposed materials provide low weight with high tensile strength. It will be necessary to consider tether material further once Axel's power and communication requirements are outlined.

Fig. 20. Field testing Axel's tether abrasion jacket [28]

2.5 Stage 5: Talus Pile Sampling

Confirmation of touchdown on the talus pile is sent from Axel to the crew on ROPE. This confirmation signals the beginning of sample acquisition. Two samples of the talus pile are acquired automatically by Axel. The acquisition process (TBD) aims to obtain samples without disrupting layers and with a method to obtain the maximum yield for SolAR data.

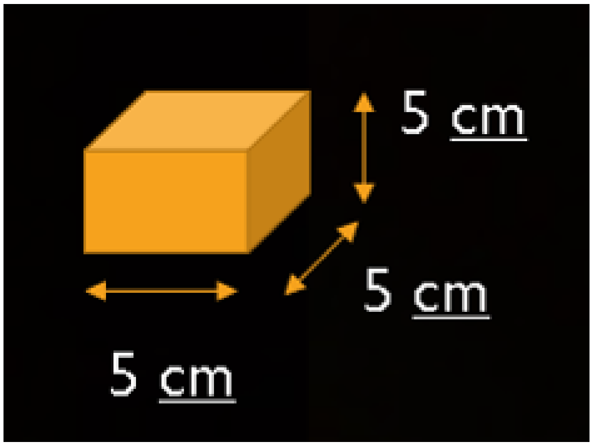

Fig. 21. Unperturbed Sample dimensions (TBD)

2.6 Stage 6: Scientific Observation

Once sampling is complete, observation and experimentation through use of Axel's scientific payloads commence.

2.6.1 Spectrometer

The spectrometer (Fig. 22) is used to provide in-situ spectral analysis of the talus pile samples. The amount and type of chemical elements in the sample's top layer is recorded.

Fig. 22. Axel's deployed spectrometer [1]

2.6.2 Light-weight ground penetrating radar (GPR)

The light-weight ground penetrating radar (Fig. 23) provides a method to visualize any underground structures and formations. This is specifically important for further studies relating to lava tube habitability (Section 2.6.4). Imaging can be used for modelling lunar planetary processes leading to the formation of any underground structures.

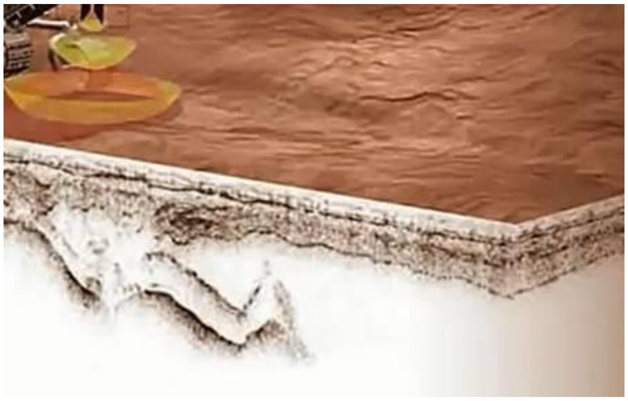

Fig. 23. GPR to map underground features [29]

2.6.3 3D laser scanning capabilities

Obscurant Penetrating Asynchronous LiDAR (OPAL) (Fig. 24) provides a method to visualize and map lava tubes (Section 2.6.4). Scanning capabilities provide preliminary data on lava tubes as a sustained lunar human habitat. OPAL has been selected as it is optimized for use in dusty environments.

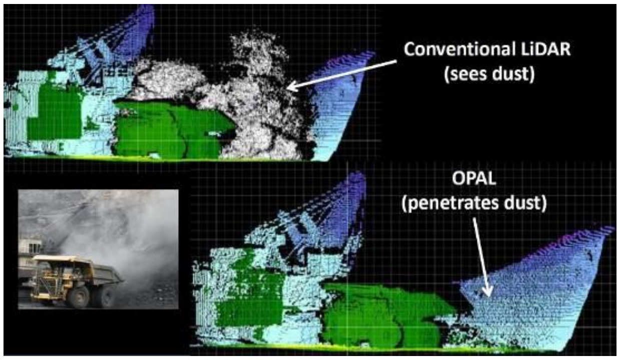

Fig. 24. Obscurant Penetrating Asynchronous LiDAR (OPAL) and dust penetration [30]

2.6.4 Lava Tubes

Creating a sustainable human presence outside of Earth is a necessity for protecting our species survival and HLT provides a gateway to understanding how to live outside of the planet through studying lava tubes (Fig. 25). The lunar surface provides a plethora of challenges for human survival; however, lava tubes provide additional benefits that may aid in solving some of the challenges associated with long-term human habitability on the lunar surface.

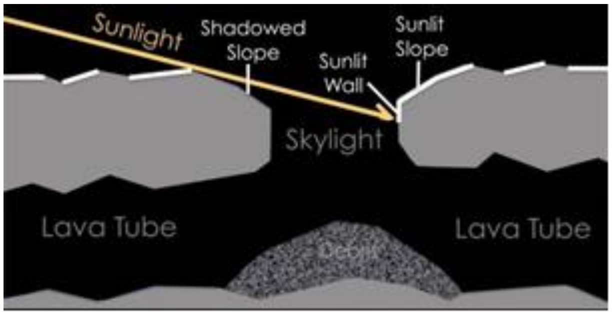

Fig. 25 Schematic section through lava tube [31]

Lava tubes are compelling exploration for studies in human habitability and sustained habitats on the lunar surface. For instance, they provide protection from the harsh space environment, including protection from solar radiation, cosmic rays, and micrometeorites [32]. This natural protection provides an advantage over manmade surface habitats from an engineering design and cost perspective [31]. Further, lunar pit craters are thermally stable relative to outside temperatures and provide protection from thermal extremes, such as variances on parts of the lunar surface from 127 to – 173 degrees Celsius. In a study conducted by Horvath et al [32], it was found that the Mare Tranquillitatis pit crater has a stable thermal environment, with temperatures varying minimally around 17 degrees Celsius in areas outside of direct sunlight [37] (Fig. 26). The aforementioned temperature measurements [37] require further verification.

Furthermore, from an exploration standpoint, lava tubes provide an unprecedented opportunity to detect sub-surface molecular water. In 2020, China’s Chang’e 5 rover identified molecular water on-site for the first time [33] (Fig. 27). HLT provides a platform to collect preliminary data on whether lava tubes contain repositories of ice, which can have major impacts on in-situ resource utilization for future lava tube habitats as well as in disciplines such as astrobiology.

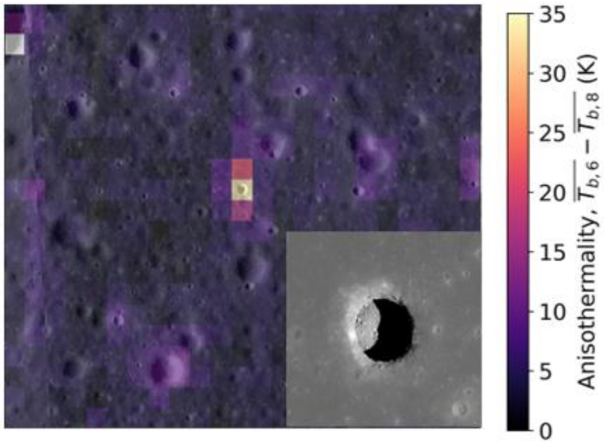

Fig. 26. Mare Tranquillitatis pit crater anisothermality (the variability of temperatures within a single bin over 9 AM to 4 PM LST) [32]

Fig. 27. Chang’e 5 on-site molecular water identification [33]

OPAL and GPR on Axel can be used in tandem to map any existing networks of lava tubes [31].

2.7 Stage 7: Axel Ascent

Axel sends confirmation of completion of scientific analysis to the crew on ROPE. The crew initiates the Axel’s ascent stage. To prevent potential dislodging of loose rocks, Axel follows the path cleared of debris from the descent to the talus pile. As Axel ascends, wall samples are obtained at intervals of ~5m (TBD) from multiple lava layers by drilling. This spacing interval is chosen to ensure that samples are obtained from the different lava layers (Fig. 8). The rappel and ascent of Axel can be used to provide data to establish a proven means of access to and egress from a lava tube skylight for use in future missions [31].

2.8 Stage 8: Return to Lunar Lander

Axel and the samples are packed into ROPE. Thereafter, the crew and samples return in ROPE from the pit crater to the lunar lander for take-off to Earth. ROPE and Axel remain on the moon for future mission utilization.

3. Future Research and Project Expansion

3.1 Future Research

Future research topics may include:

- Sample retrieval without disrupting layers
- Maximum yield SolAR retrieval method
- Reduction in avalanche risk upon Axel's rappel
- Axel's rappel in a moon gravity environment
- Drilling equipment for below lava layer access and Axel integration
- Lava tube exploration for human habitability
- Landing location for heavy landers and the associated debris field
- Tether material selection
- Additional HLT sampling methods and locations
- Apollo 11 hardware weathering analysis

The HLT mission concept is an ongoing project and is a work in progress.

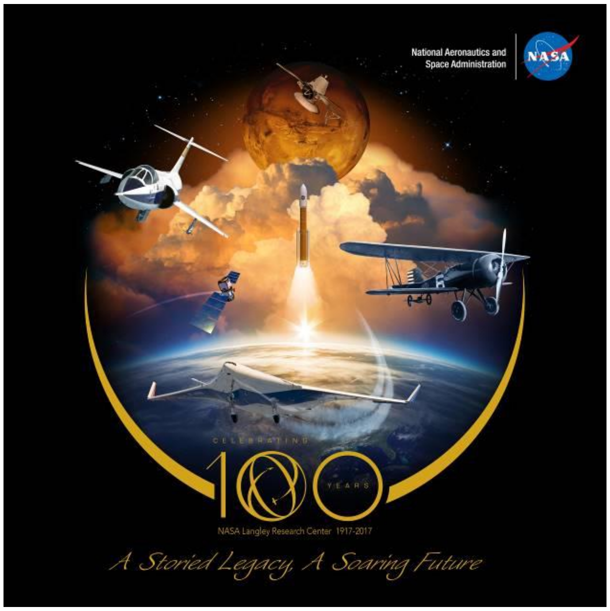

Fig. 28. A Storied Legacy. A Soaring Future. NASA [34]

3.2 Project Expansion

This paper describes a high-level mission overview of HLT. Expansion topics may include:

- Inbound and outbound spaceflight
- Mission Concept of Operations development
- Commercial market analysis

4. Conclusion

In summary, this paper has outlined the HLT Artemis III mission including HLT mission rationale and need, mission stages, scientific exploration and key implications of research, such as obtaining vital data for Climate Change modelling over geological timescales for Earth applications.

HLT is a dramatic and safety conscious lunar exploration mission involving human-robotic hybrid systems and utilizing state of the art technology.

"We are Going"
"The next era of human exploration"
-NASA Artemis Team

Fig. 29. NASA Artemis and CHASE [35]

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Helios-Lune Tranquillitas (HLT) was created in University of Southern California's Graduate Space Concept Studio (ASTE 527). Scan the QR code for further information and project slides [Fall 2021, CHASE #14]

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