UF | Herbert Wertheim
College of Engineering
UNIVERSITY *of* FLORIDA

COSMIC: Final Briefing

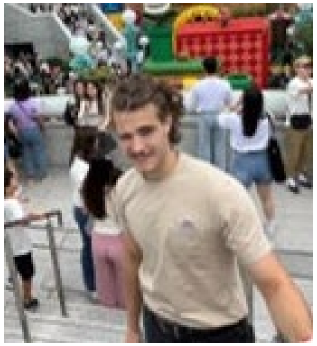
Orbital Gators – Advanced Underground Resource ObseRvAtion (AURORA-H3)

Andrew Dishchuk, Max Caldwell, Om Parbadia, Aidan Rowell, Grayson Neander, Santiago Daza, Bryce Kroehnfeldt, Paige DeMino, Jack Xu, Christian Szczeniak, Riley Cullingford, Benjamin Hamilton, George Rushevich, Nilson Bretas, and Arin Churi

Mentors: Christopher Petersen "Chrispy", Michael Generale, Bryan Zetlen, Kevin DiMarzio
April 15th, 2026

Our Team

Project Manager



Andrew Dishchuk

Chief Engineer

Max Caldwell

Computing Lead

Om Parbadia

Principal Investigator

Aidan Rowell

Systems Lead

Grayson Neander

Design Lead

Paige DeMino

Manufacturing Lead

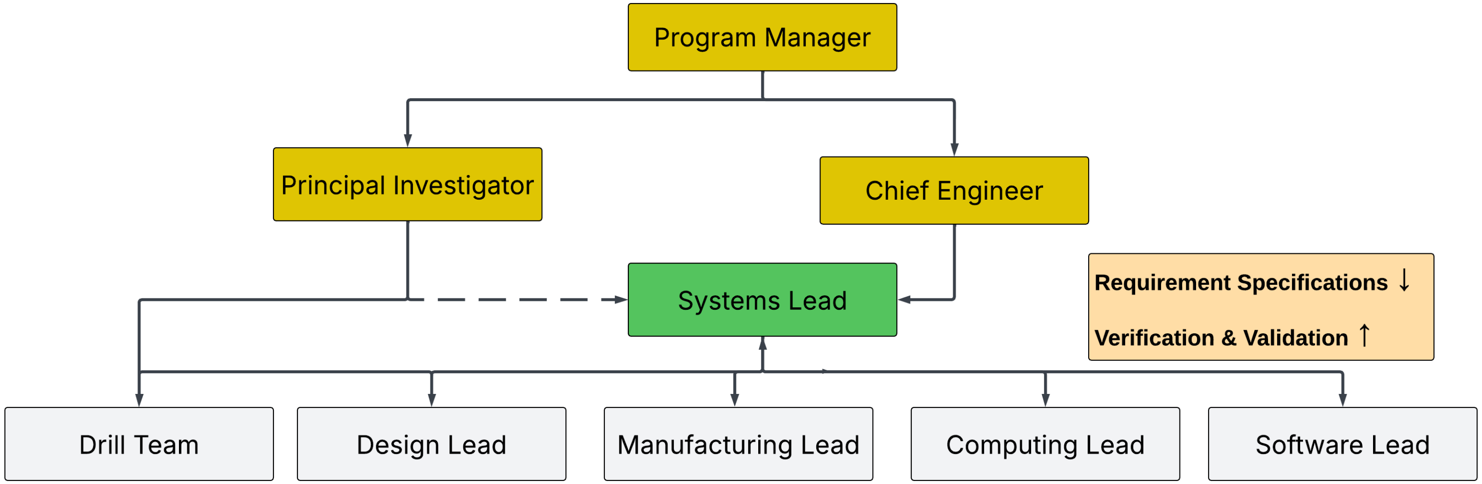
Riley Cullingford

Drill System Lead

Bryce Krohnfeldt

Program Overview

The Orbital Gators Lunar team used the following management structure to support the success of their capstone project:



Dashed - - Advisory, Solid – direct reporting*

Program Manager: Leads project deadlines, milestones, and budget.

Chief Engineer: Ensures engineering timelines are met within requirements.

Systems Lead: Ensures prototype will function, risk/failure analysis.

Sub teams: Test & integration in accordance with system requirements.

Mission

The **Advanced Underground Resource Observation** (Aurora) surveyor is a lunar resource-mapping tool-kit, capable of estimating Water and Helium 3 (He-3) across the lunar surface.

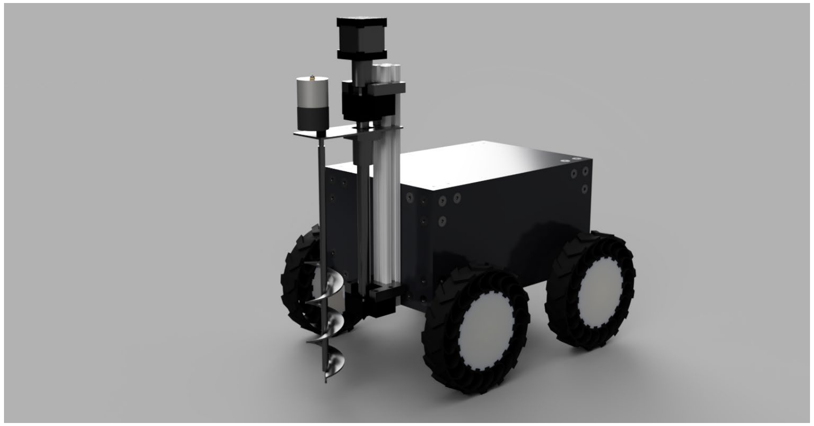


Figure 1. Aurora prototype concept.

AURORA's goal is to generate a proven reserve model (PRM) that guides future lunar In-Space Resource Utilization (ISRU), and site selection, for early infrastructure development of Moon-to-Mars architecture.

Program Overview

- AURORA aims to characterize the location of:
  - Helium-3
  - Subsurface water ice

Why?

- Produce a Probable Resource Model (PRM).

- How much of a resource is accessible, and how feasible?

- How much water?
- How much Helium-3

Program Overview

Why continued?

- Water ice — critical for ISRU-derived propellant and life support

- Helium-3 (He-3) — a solar wind-implanted volatile trapped in ilmenite-rich regolith, valued at ~$22M/kg

Missions such as the **Artemis** missions, and **Interlune's** excavator [2] would benefit from resource models developed by **AURORA** on the lunar surface.

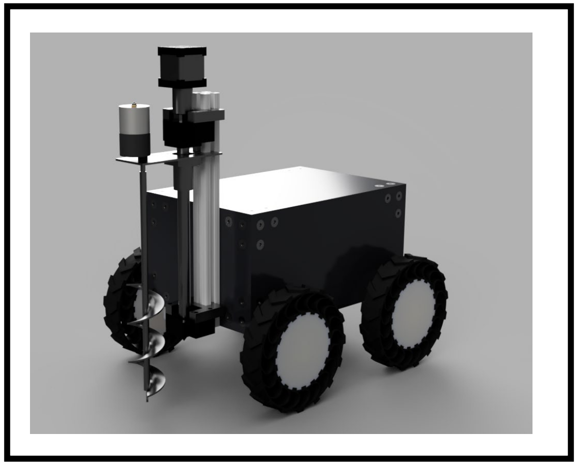


Figure 2. NASA Moonbase, NBC News

Program Overview

How?

- Look at surface dielectric contrast, or spectral imaging.

- Ilmenite captures and stores He-3 [1].

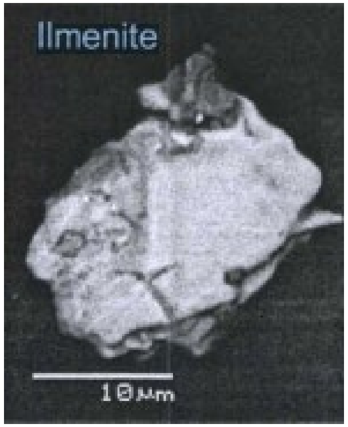


Figure 3. Ilmenite grains within lunar regolith.
Source: Noble (2009), NASA Lunar Regolith Report.

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The Final Briefing will cover:

- 1. Conceptual Design
  - 1.1. Project Impact
  - 1.2. Feasibility
  - 1.3. Innovation
- 2. Program Overview
  - 2.1. CONOPS
  - 2.2. Mission Modes
  - 2.3. Milestones
- 3. Systems Overview
  - 3.1. Systems (5 elements *From C3 Packet)
  - 3.2. Assumptions
  - 3.3. Risk Analysis
  - 3.4. System Requirements
  - 3.5. Command and Data Handling (C&DH) *Mentioned in C3 packet
- 4. Lessons Learned
  - 4.1. Innovative Ideas
  - 4.2. 3 technologies most important to develop.
  - 4.3. Design Challenges
- 5. Prototype
  - 5.1. Scope
  - 5.2. Results
  - 5.3. Technology Readiness Level
  - 5.4. Prototype Summary

1. Conceptual Design

The Conceptual Design portion of the briefing covers the mission’s place in the current space industry.

- Philosophy
- Project Impact
- Feasibility
- Site Selection
- Advancing High Valued Missions

1.1. Philosophy

AURORA’s Governing Philosophy:

- Build a modular, reusable platform that directly measures resource characteristics, while remaining extensible enough to expand coverage area.

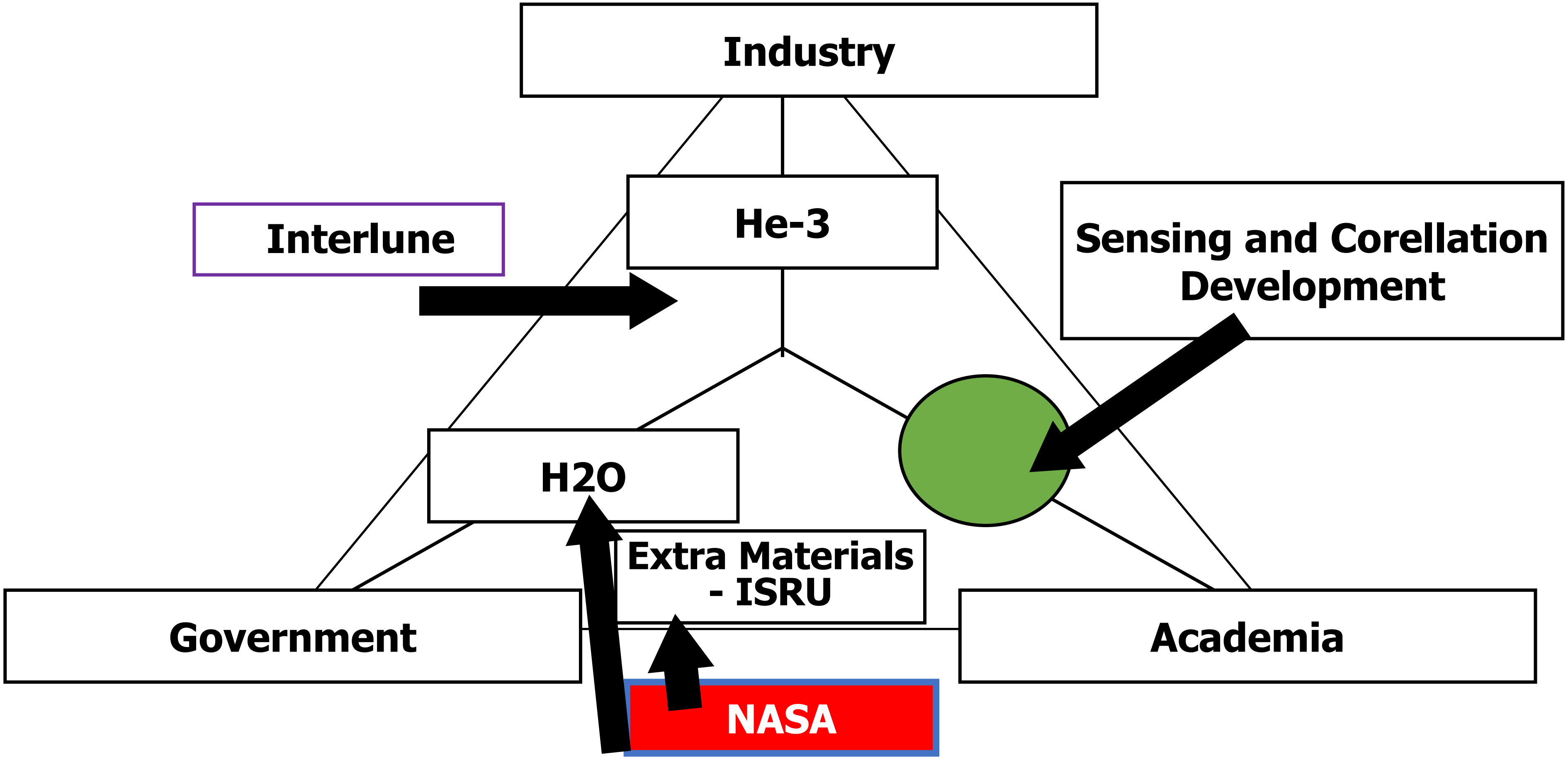
- Modular
- Resilient
- Capable

1.1. Project Impact

Securing the Lunar Energy Economy

- **90% Confidence Resource Mapping:** Reduces the high risk of "blind" lunar mining.
- **Economic Catalyst**,
  - H2O – Used for propellant, and human life support.
  - He-3 – Essential for the future of clean nuclear fusion medical & nuclear imaging, quantum cooling.
- **Foundation for ISRU:** Provides the primary prospecting data required for **In-Situ Resource Utilization (ISRU)**, allowing future missions to "live off the land" by producing fuel and life support from local water ice.
- **Sustainability:** Directly supports NASA's Artemis and commercial goals by identifying the most resource-dense sites for permanent lunar infrastructure.

1.2. What Does the Project Impact



Industry

Interlune

He-3

Sensing and Corellation Development

H2O

Extra Materials - ISRU

Government

Academia

NASA

Finding the Right Prospect

- **Helium-3 Concentration:**
  - High wt% of Ilmenite
  - With a long surface residence time
  - Fine Grained Regolith
- **Surface Ilmenite Scoping**:
  - Most concentrated in the equatorial Mare Tranquillitatis and Oceanus Procellarum
  - Measured via UV/Vis/NIR spectroscopy
- **Prospecting at Depth**:
  - He-3 implanted by solar wind
  - No constant stratigraphic distribution
  - Surface residence time via nanophase iron measured by magnetometer
  - Grain size via ground penetrating radar

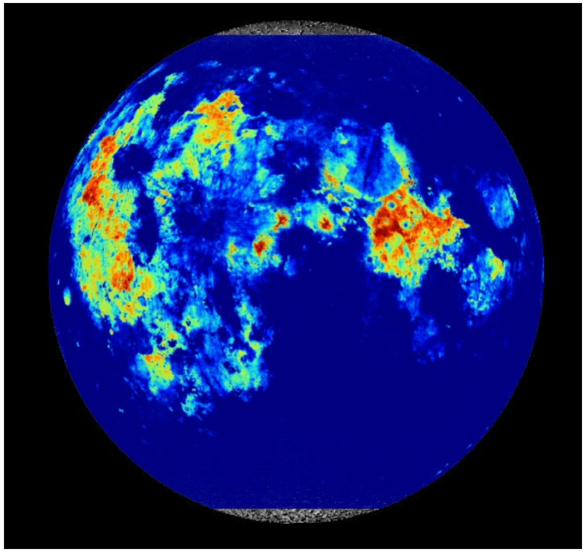


Figure 4. TiO2 wt% on Lunar Surface [2].

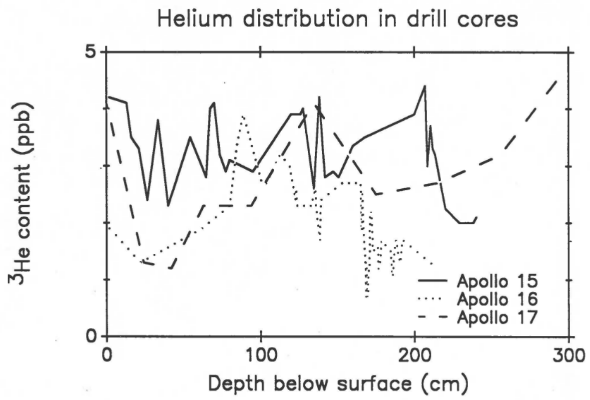


Figure 5. Apollo Core Samples He-3 Measurements [3].

Finding the Right Prospect

- **H_2O Concentration & Data Ambiguity**
  - OH & H2O signatures overlap @ 3μm band
- **GPR & Ground Truth**
  - GPR scans for dielectric constant determining if water is present
- **Strategic Presence:**
  - Target: Subsurface ice in mid-latitudes
  - **Stability:** Thermal conditions prevent ice sublimation.
  - **Impact:** Enables **Refueling Hubs**; cuts Earth-to-Moon launch mass by 60%.

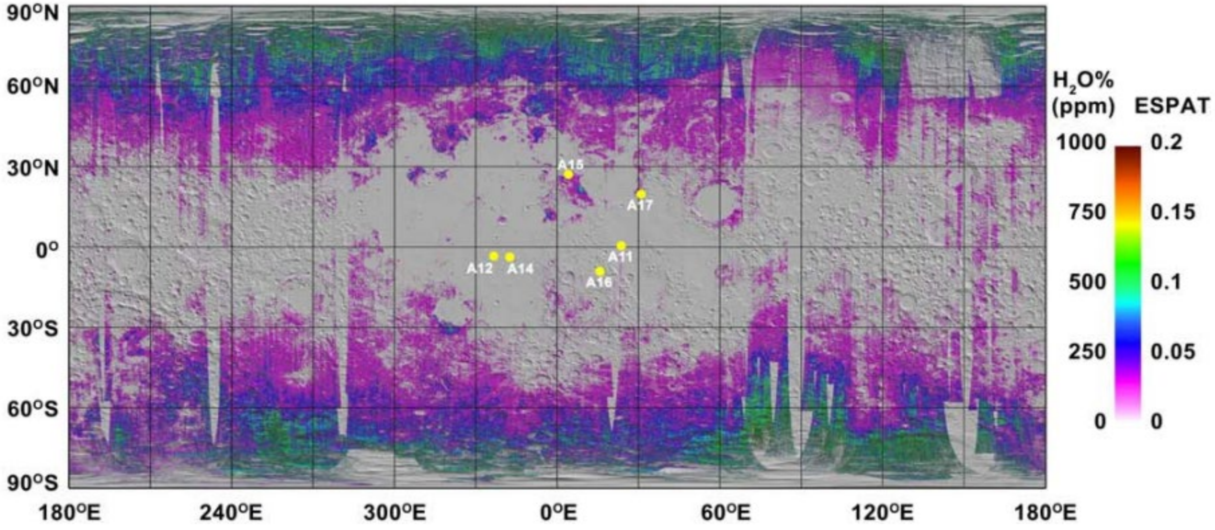


Figure 6. H2O ppm on Lunar Surface [3].

1.2. Feasibility

Could this Mission be Designed and Funded in 5 Years?

- **Standard Rover Platform:**
  - Our design utilizes Astrobotic's Polaris rover platform
  - Saves time and cost on design and testing for large parts of the system
- **Sensing Via Heritage Methods:**
  - UV/Vis/NIR
  - Ground penetrating radar
  - Magnetometry
- **Drilling System:**
  - Simple auger design only focused on creating a bore hole
  - Directly can measure Helium 3

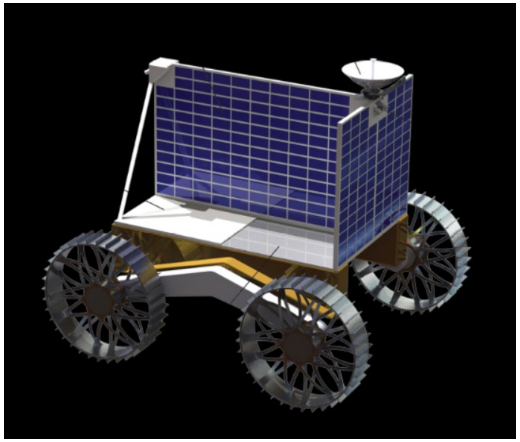


Figure 7. Astrobotic Polaris Rover Platform.

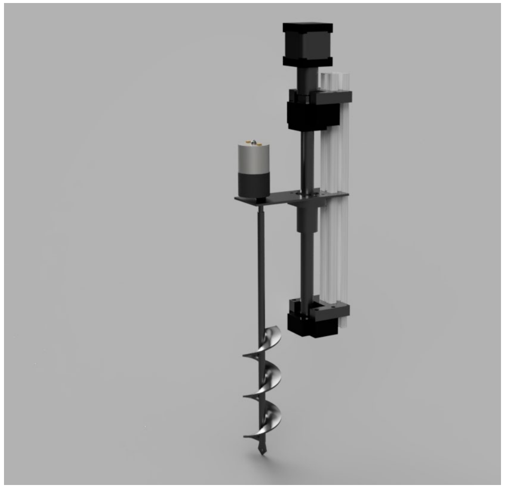


Figure 8. Drilling Mechanism.

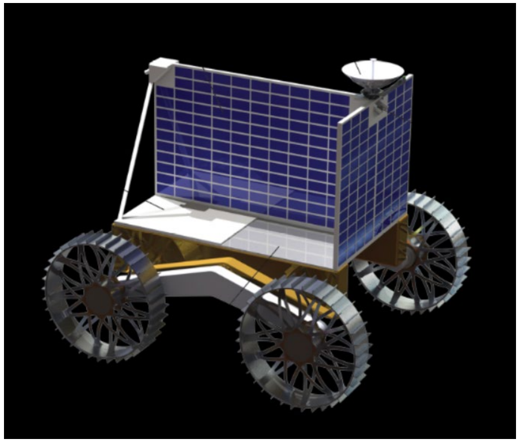
1.2. Feasibility

Could this Mission be Designed and Funded in 5 Years?

- 1. Accessible integration path using heritage methods, and simplified mission to develop.

- 2. Directly measure water using GPR, which correlates with helium-3 measurements, as well.

It can!



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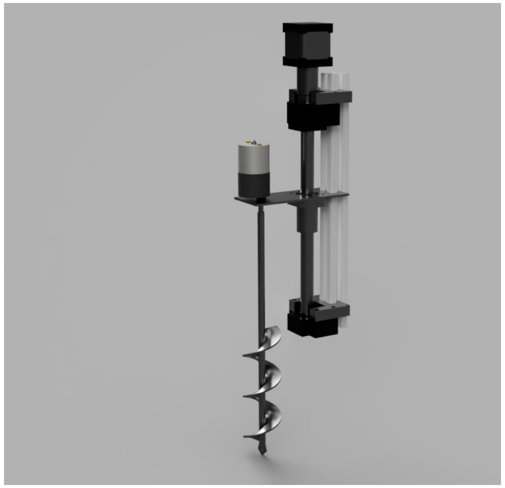

Figure 8. Drilling Mechanism.

1.4. Advancing High Valued Missions

Paving the Way for Lunar Industrialization

- **De-risking Commercial Mining:** Provides the data-driven "prospector's map" needed by commercial partners (e.g. Interlune) to justify the multi-billion dollar investment in extraction hardware.
- **Strategic Refueling Hub:** By characterizing H2O reserves, this mission enables the development of **Lunar-derived propellants**, turning the Moon into a refueling hub for the solar system.
- **Fusion Fuel Readiness:** Directly advances the roadmap for **clean energy on Earth** by locating the specific Ilmenite-rich basalt flows where He-3 is most abundant.
- **Technological Standardization:** Establishes a modular toolchain (Spectroscopy + Drilling + Thermal Analysis) that can be integrated into future lunar rovers.

2.1. Conops - AURORA

Aurora Surveying Tool

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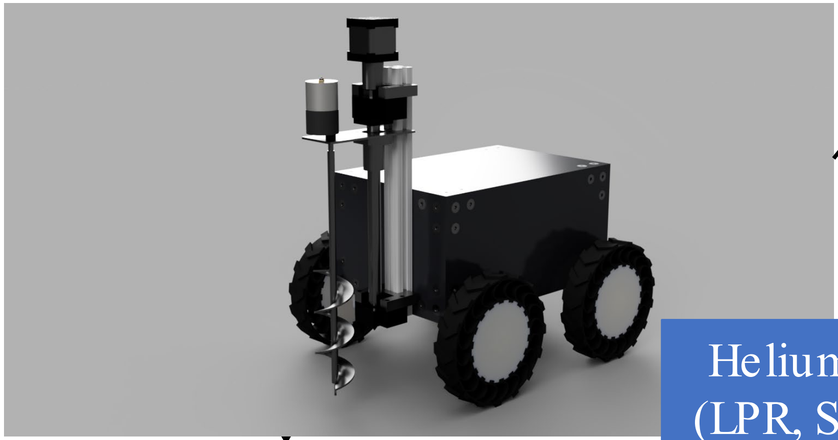
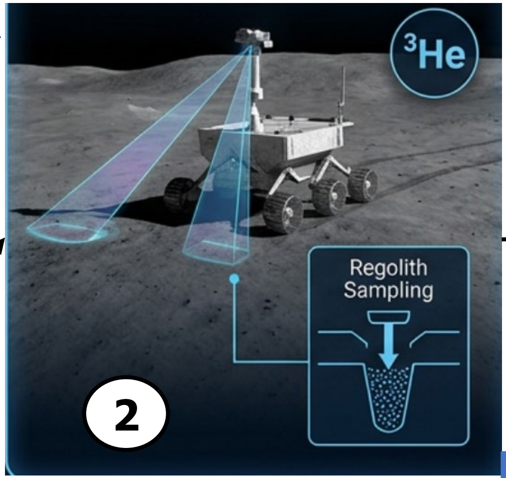
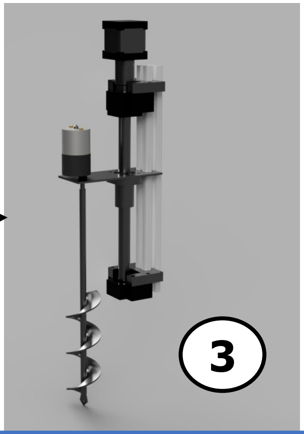


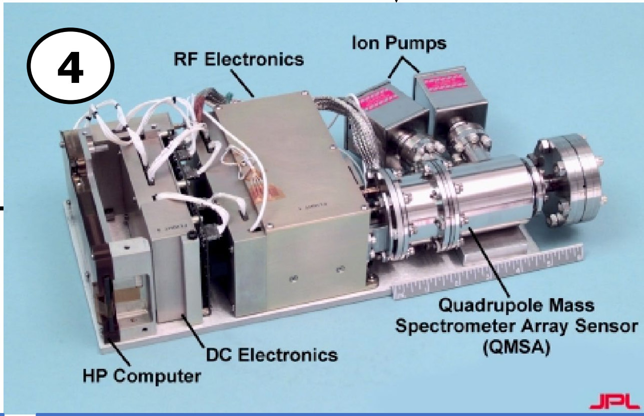


Helium-3 Sampling (LPR, Spectrometry)

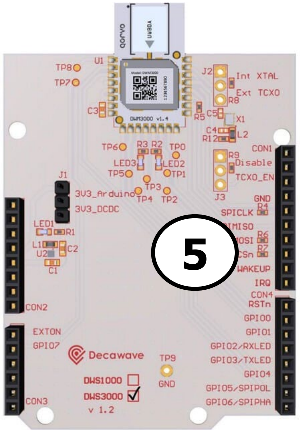


Helium-3 Sampling Aurora Drill Probe

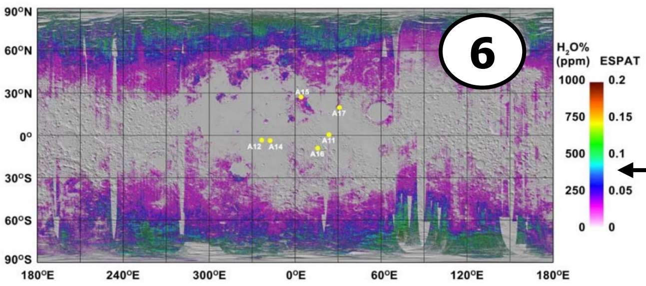
Communications System



Mass Spectrometry Quadrupole MS



Downlink (To Griffin-1 Lander)



Map development (Figure

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APXS ≤6 W
Surface TiO₂ & elemental composition

ESA ≤8 W
Solar wind flux measurement

MSI Camera ≤6 W
Wide-area TiO₂ mapping & traverse imagery

NPD ≤8 W
Neutral gas & volatile detection

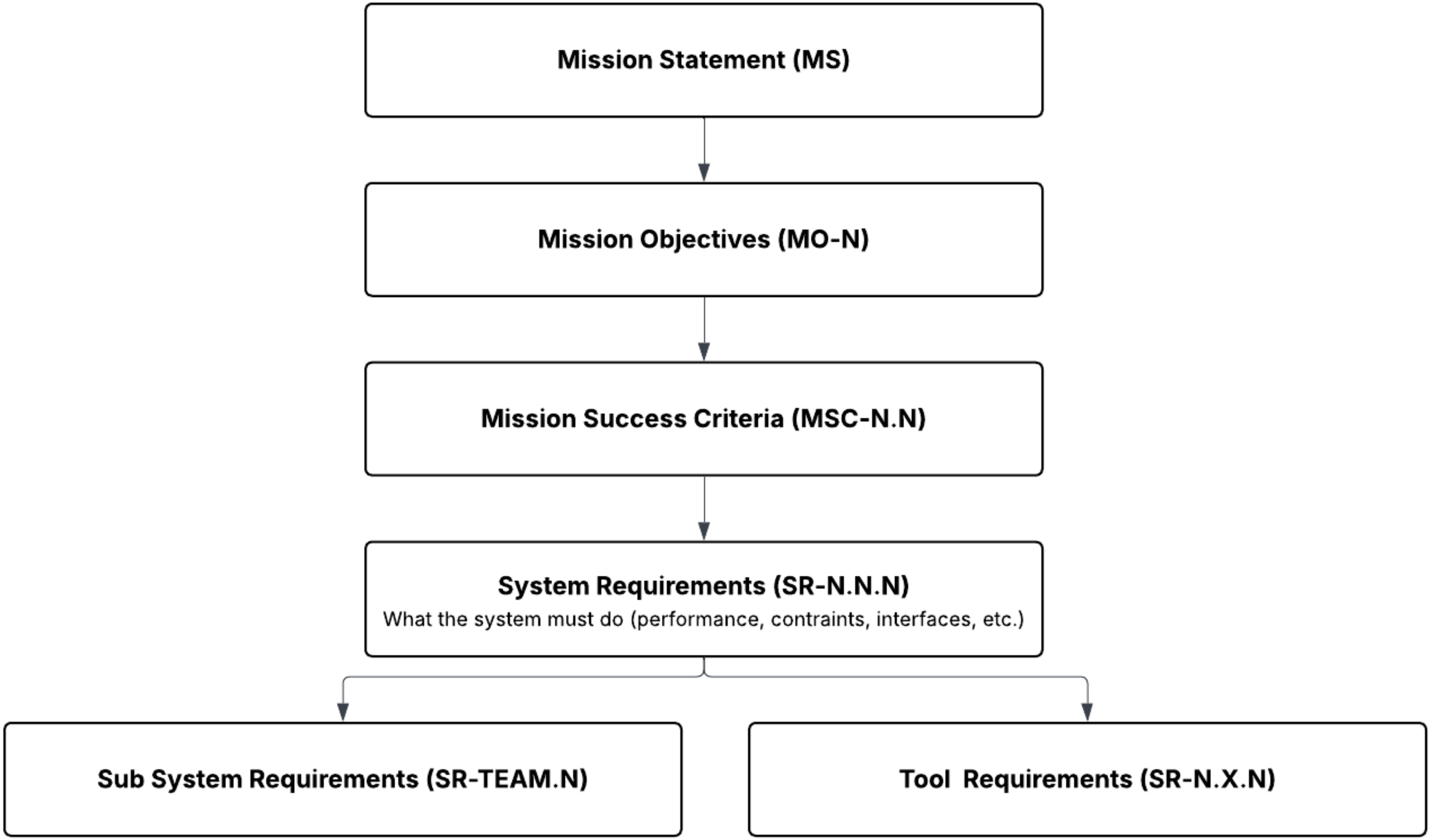
FMAG ≤3 W
Nanophase iron & regolith maturity via borehole

AGA ≤5 W
Regolith grain size distribution

LPR ≤8 W
Subsurface structure & water ice detection

Aurora Drilling Probe (ADP) + QMS Coupling
Direct He-3 mass spectrometric detection via borehole extraction – highest-confidence PRM data input

System Requirements Definition Structure



Mission Statement (MS)

Mission Objectives (MO-N)

Mission Success Criteria (MSC-N.N)

System Requirements (SR-N.N.N)
What the system must do (performance, contraints, interfaces, etc.)

Sub System Requirements (SR-TEAM.N)

Tool Requirements (SR-N.X.N)

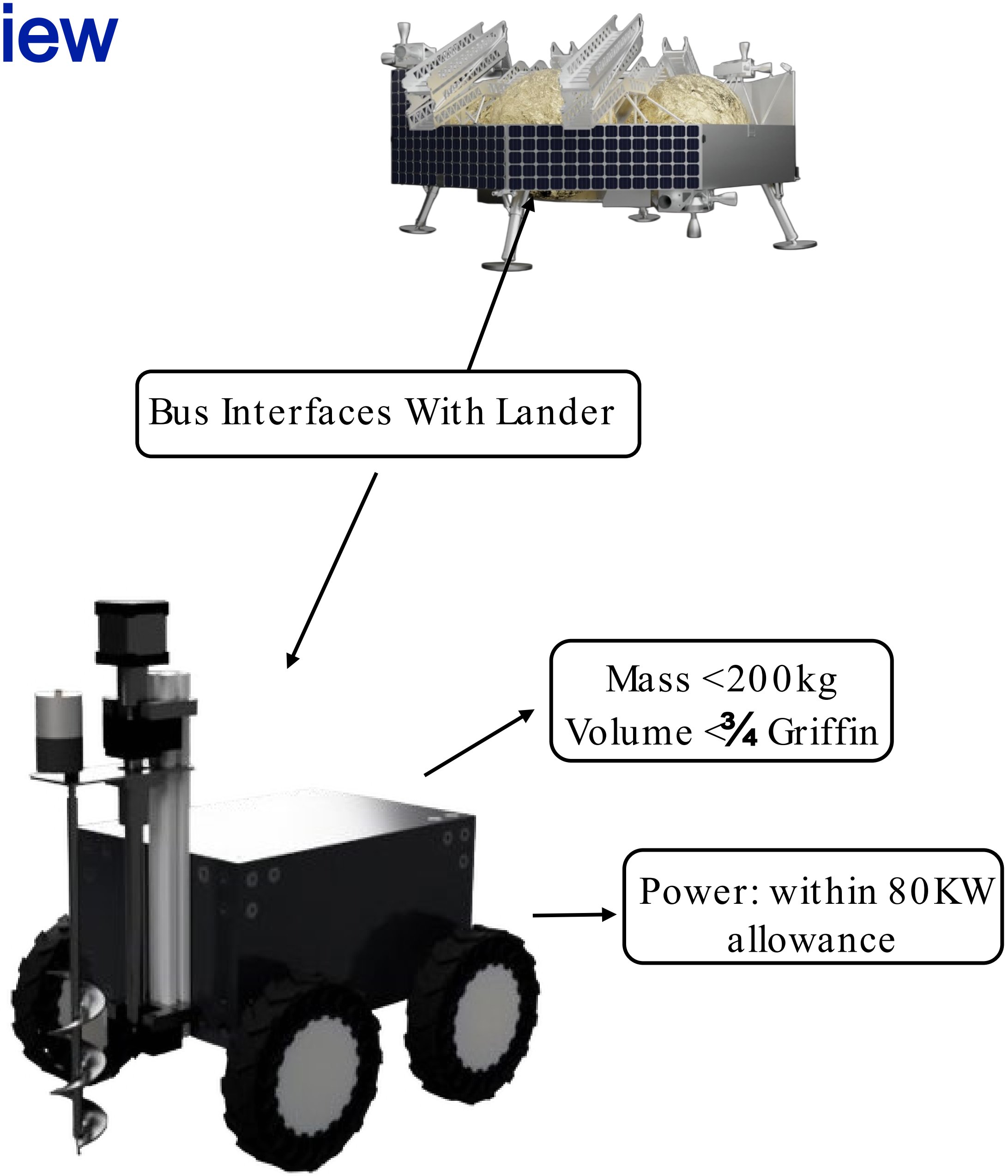
3.1. Systems Overview

- ✓ Mass & Volume
- ✓ Power Allocation
- ✓ Bus Compatibility
- ✓ Launch / Descent Environment

  (Design reflects thermal, mechanical and Vibration expected)
- ✓ Capability Demonstration

  (Feasible path to He-3 surveying)
- ✓ Analysis Completed

  (Mass, Volume, Power, and dust tolerance Analysis Done)

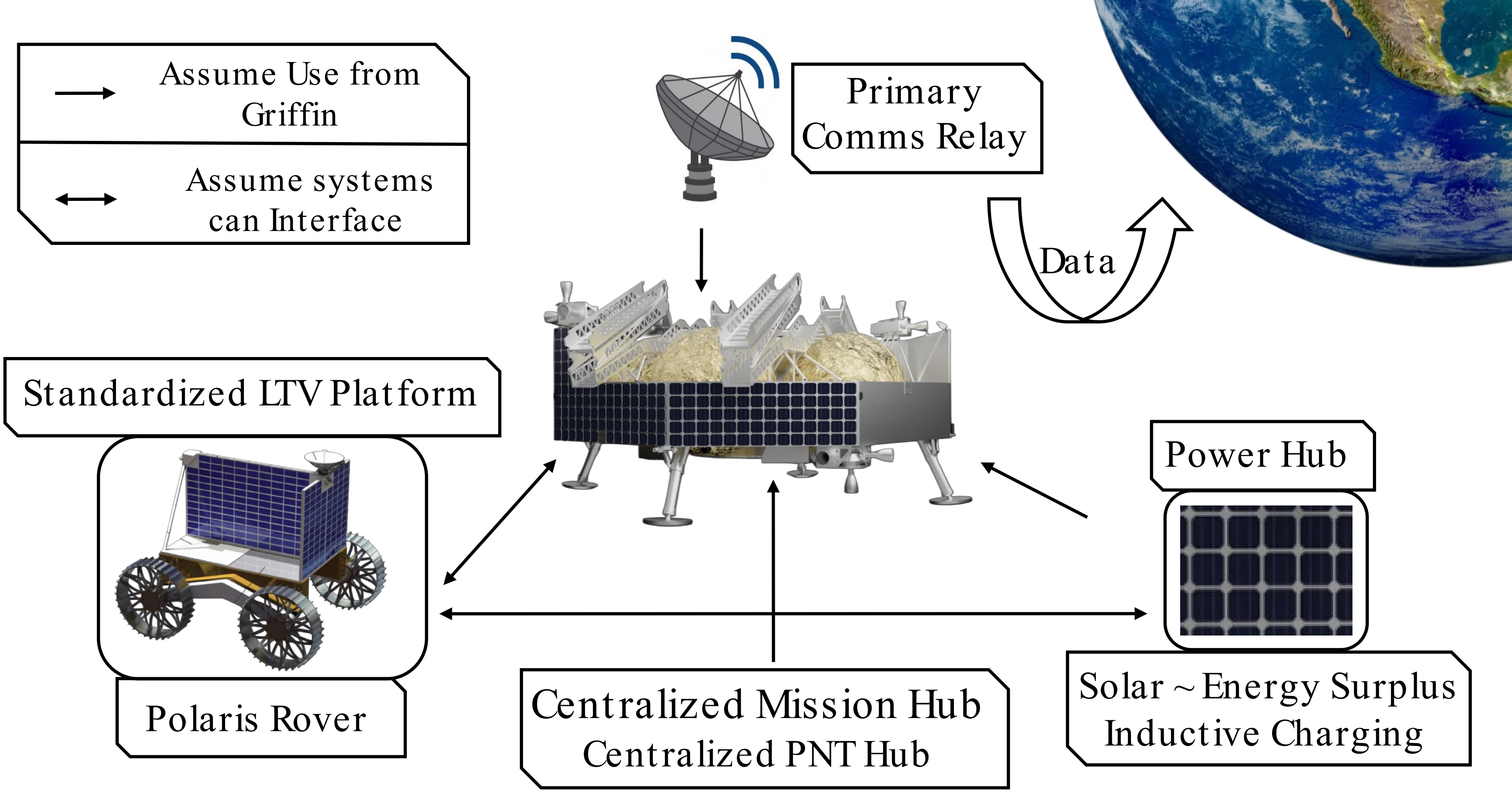


Bus Interfaces With Lander

Mass <200kg
Volume <¾ Griffin

Power: within 80KW allowance

3.2. Assumed Infrastructure



→ Assume Use from Griffin

↔ Assume systems can Interface

Primary Comms Relay

Data

Standardized LTV Platform

Power Hub

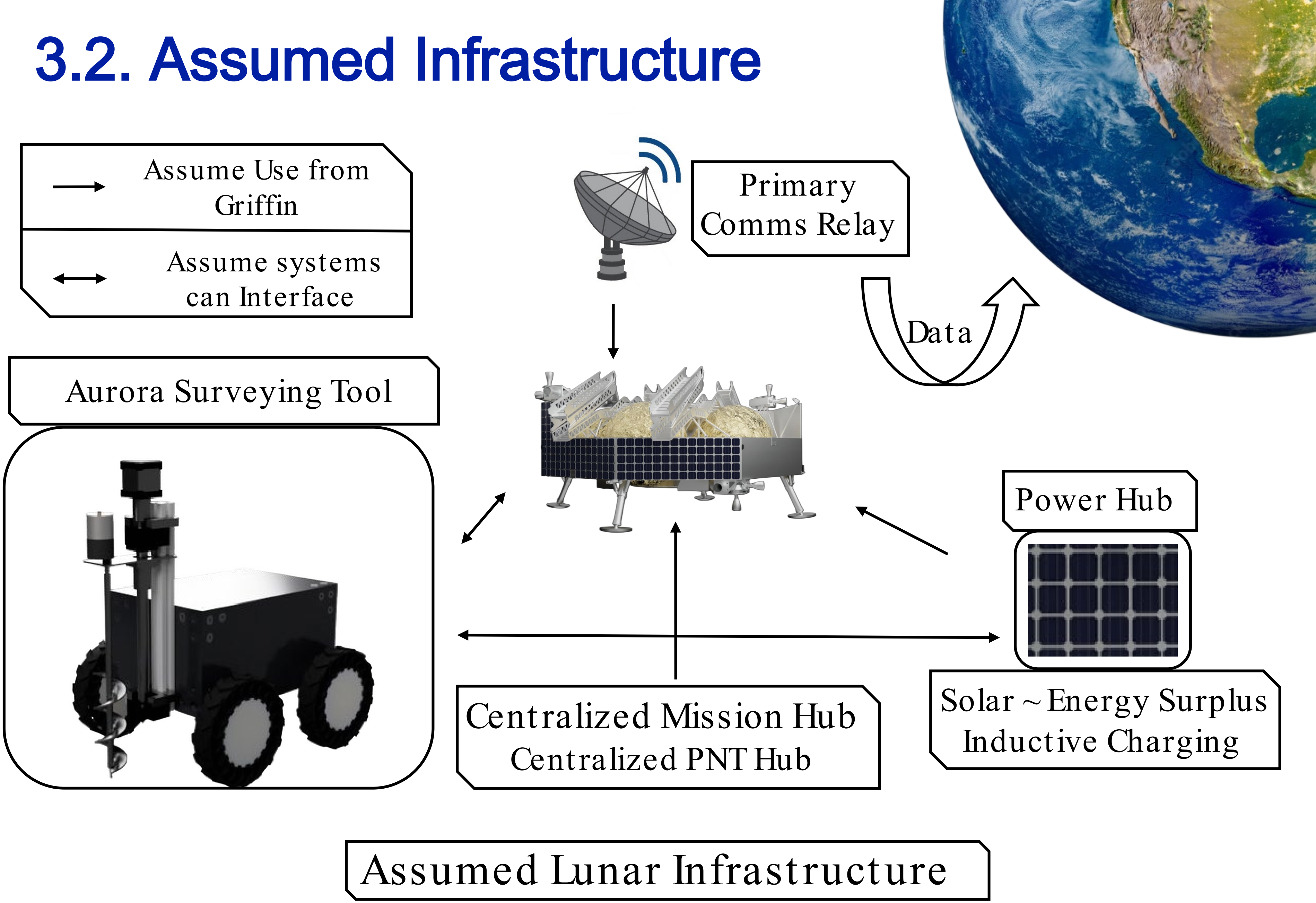
Polaris Rover

Centralized Mission Hub
Centralized PNT Hub

Solar ~ Energy Surplus
Inductive Charging

Assumed Lunar Infrastructure

3.2. Assumed Infrastructure



→ Assume Use from Griffin

↔ Assume systems can Interface

Primary Comms Relay

Data

Aurora Surveying Tool

Power Hub

Centralized Mission Hub
Centralized PNT Hub

Solar ~ Energy Surplus
Inductive Charging

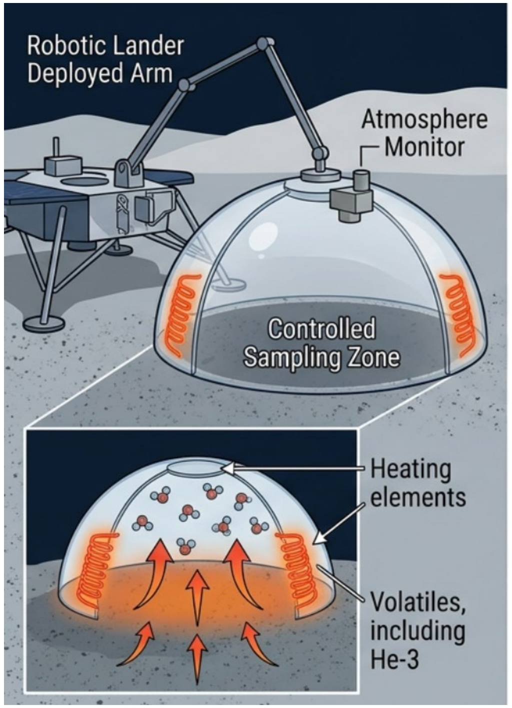
Assumed Lunar Infrastructure

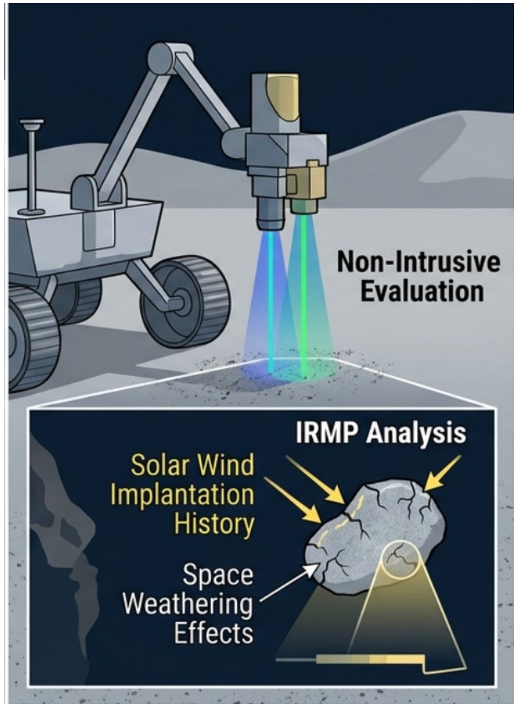
4.1. Innovative Ideas

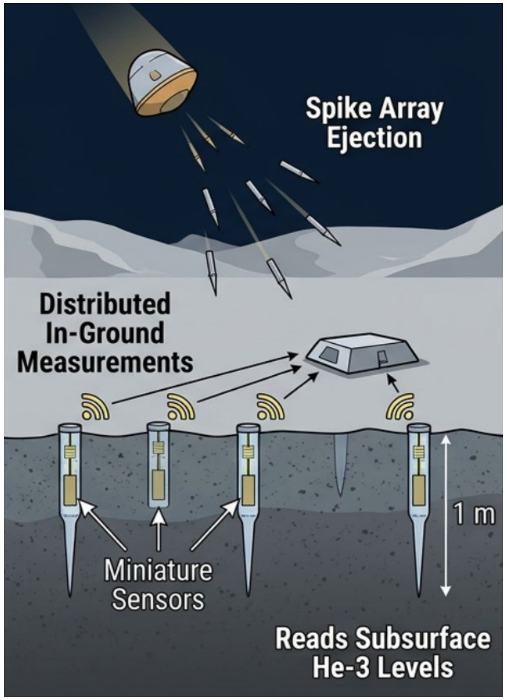
1. Bowl Cut Dome Design for He-3 detection

2. Integrated regolith maturity package

3. Descent Deployed Penetrating Spike Array



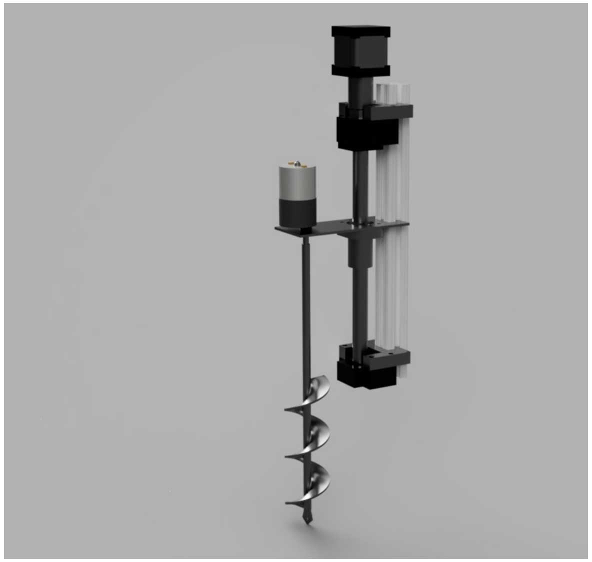




4.2. Technology Development

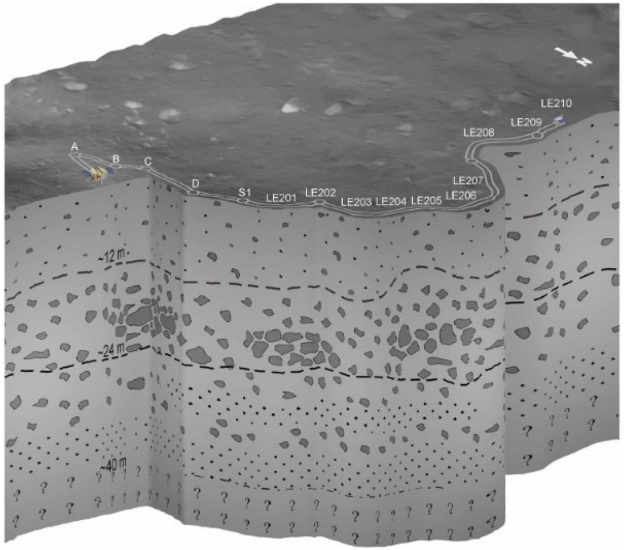
Three Most Important Technologies to Implement and Develop

Aurora Drill Plunge (ADP)



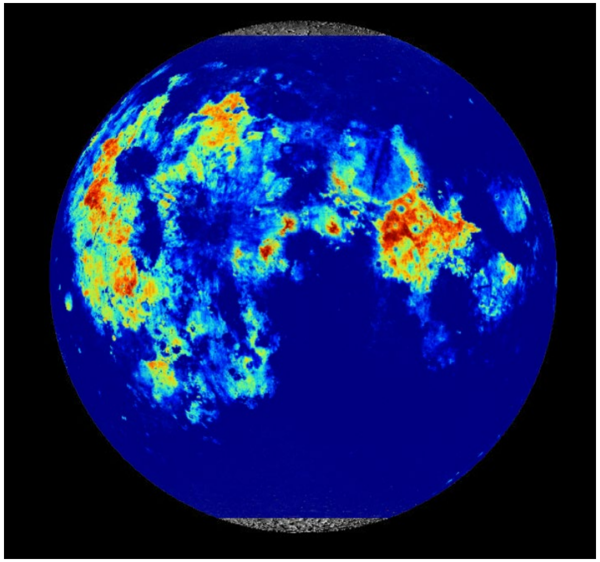
- Stratigraphically measures nanophase iron to determine regolith layer surface residence time

Ground Penetrating Radar



- Vertically measures regolith grain size to indicate regolith helium-3 density

UV/Vis/NIR Spectroscopy



- Measures surface TiO_2 to determine local regions with higher TiO_2 concentrations

4.3. Design Challenges

Determination of He-3 detection methods:

There are many methods of finding He-3 like scanning the lunar surface or taking regolith samples. Establishing a He-3 detection method for our design proved to be difficult as we first looked at the problem space.

Onboard sensor selection:

Instrument choice also played a significant role in our design process. Some instruments were infeasible due to cost or the power needed for steady operation. Certain sensors also force geometry or design constraints.

Scope creep:

Our preliminary designs featured components or mechanical features that were out of scope and added unnecessary complexity to the system.

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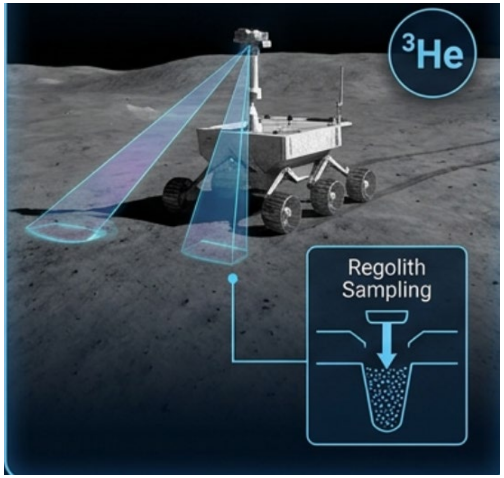
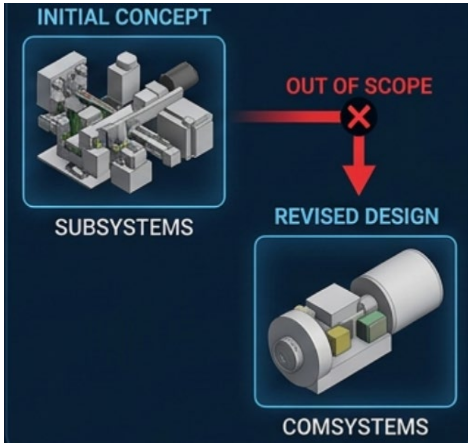
Determination of He-3 Detection Methods



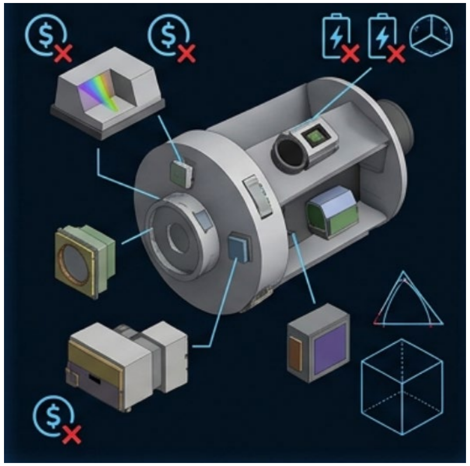
Many methods of He-3 detection, so picking on for design was first challenge

Scope Creep



Initial Designs out of scope and added unnecessary complexity

Onboard Sensor Selection



Instrument choice for design was difficult due to cost, power, and other design constraints

5. Prototype

This Prototype section covers:

- The Prototype
- Prototype scope
- Results of the prototype
- Final Technology Readiness Level (TRL)

Fig. 9: Orbital Gators Lunar team, and AURORA Prototype.

5. Scope

The prototype validates our mechanical, electrical, and computer architecture, as well as developing the TRL level of the ADP:

- Retractable auger for drilling.
- Jetson Orin Nano for data handling
- Bus housing for tools
- Internal component communication

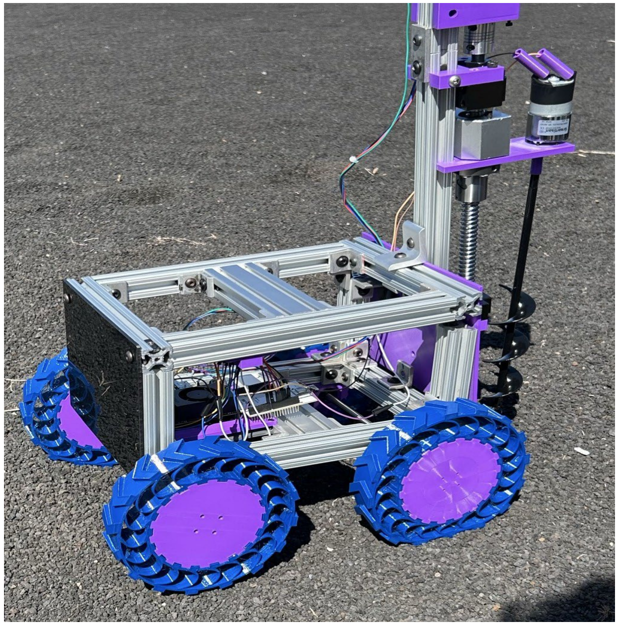


Fig. 10: Prototype at Marshal Space Flight Center Test Bed

How This Prototype Advances the Mission:

- **Mass & Volume Simulator** — The physical bus housing and drivetrain assembly can be used as a mass/volume mockup for Griffin lander integration testing.
- **Algorithm Validation Platform** — The Jetson Orin Nano running NASA cFS provides a live testbed.
- **Drilling Interface Baseline** — The retractable auger mechanism establishes the mechanical interface standard for the flight drill system.
- **Communications Architecture Test Bed** — Once internal component communication is integrated, the prototype becomes a full end-to-end test of the C&DH pipeline from sensor to downlink.

5. Results

<u>Prototype Testing at Marshal Space Flight Center:</u>

What Was Demonstrated:
Mobility — Rover successfully traversed test terrain, validating the wheel and drivetrain design for lunar surface operations.
Drilling — Auger drilled into a simulated surface, confirming the retractable bore mechanism function, but redesign for auger performance required.
Computing — Jetson Orin Nano successfully handled onboard data processing, validating the C&DH architecture.
What Was Not Demonstrated:
Internal component communication between subsystems was not fully integrated in this prototype phase.

Full sensor payload (LPR, APXS, ESA, MSI Camera, NPD, QMS) not included in prototype scope — consistent with TRL 3–4 target.

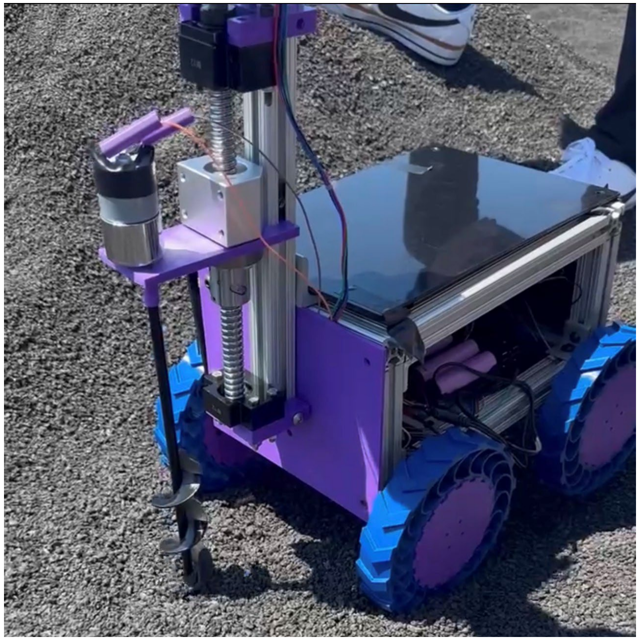


Fig. 11: Auger testing under progress on Marshal Space Flight Centers Lunar Test Bed.

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Comms and CDH Chart overviewing the power, power requirements, and data flow through the AURORA prototype.

Unregulated Power

Regulated Power

MIPI

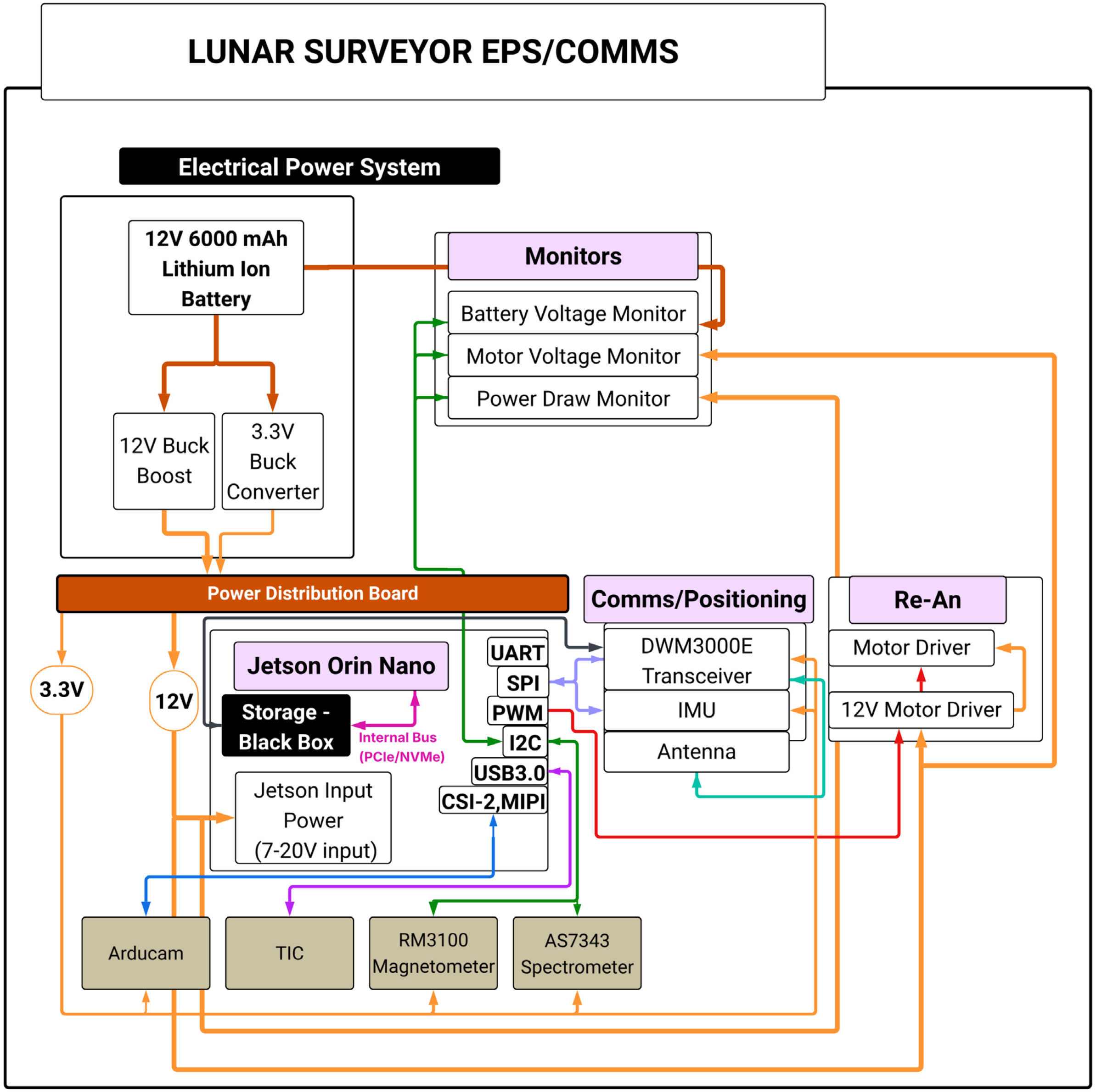
USB3.0

I2C

SPI

PWM

RF



5.3. Technology Readiness Level

- TRL 1: Lunar Resource Mapping
- TRL 2: "Ride Along" Rover Payload Concept with Auger and Magnetometer
- TRL 3: Auger and Magnetometer Validated Independently
- TRL 4: Integration of Electronics and Mechanical Systems Into Bus Payload
- TRL 5: Successful Testing of AURORA in NASA MSFC Lunar Testbed Environment

5.3. Technology Readiness Level

System Element	Current TRL	Status	Next Milestone
Aurora Prototype Rover	3-4	Physical prototype built and tested	MSFC testbed validation
Aurora Drilling Probe (ADP)	4	Auger tested at MSFC — borehole stability under investigation	Fine-grain simulant testing
DWM3000EVB PNT/Comms	3	Validated in prototype	Griffin relay simulation
Jetson Orin Nano C&DH	3-4	Processing and downlink validated	Multi-sensor data pipeline
Full Mission Instrument Suite	1	Conceptual — under trade study	Instrument selection at PDR
ADP-QMS Coupling	2	Conceptual — primary tech development challenge	Benchtop feasibility study
Multimodal Data Fusion Methodology	2	Research ongoing	Algorithm definition

5.4. Prototype Summary

The prototype included the following:

Built & Validated — Retractable auger, Jetson Orin Nano C&DH, and rover mobility demonstrated at TRL 3–4, confirming core mechanical and computing infrastructure.

Mission-Connected — Prototype directly validates the Sampling and Downlink phases of AURORA's CONOPS, proving the platform can physically access the lunar subsurface and process collected data.

Next Steps — Full sensor suite integration (LPR, magnetometer) and internal component communication targeted for TRL 5 testing in NASA MSFC Lunar Testbed Environment.

Fig. 10: Prototype development in progress.

Risk Identification

Risk Identification includes a stop-light chart that analyzes the failure of the AURORA system, derived from system requirements.

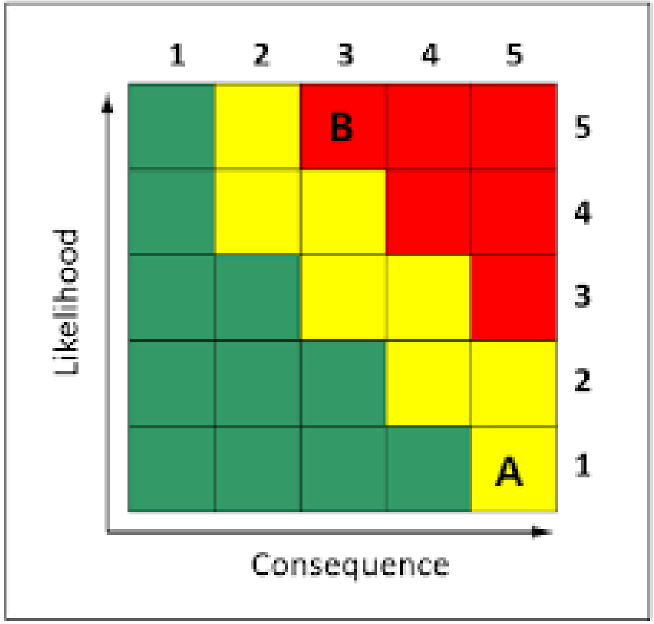


Fig. 10: Stop light chart, displaying correlation between likelihood, severity, and type of risk.

High Risk, High Severity, will cause end of mission/ life.

Mission critical, but either lower risk or consequence.

Not critical, may cause delays, but not necessarily end of mission.

Red-zone risks received full mitigation planning. Yellow risks were analyzed and monitored. Green risks were logged but deprioritized to preserve mission focus.

Risk Identification

Risk Matrix	Negligible	Minor	Moderate	Significant	Severe
Most Likely	🟩	🟨	🟥	🟥	🟥
Likely	🟩	🟨	🟨 R-7	🟥	🟥
Possible	🟩	🟩 R-13	🟨	🟨 R-2, R-5	🟥 R-1
Unlikely	🟩	🟩 R-8	🟩	🟨 R-6, R-9, R-11	🟨 R-3, R-4
Least Likely	🟩	🟩	🟩	🟩 R-12	🟨 R-10

Risk ID and Descriptions (R -1 – R-6):

R-1 Inadequate spatial resolution or measurement uncertainty prevents PRM -quality resource estimation

R-2 Insufficient power margin during peak science operations

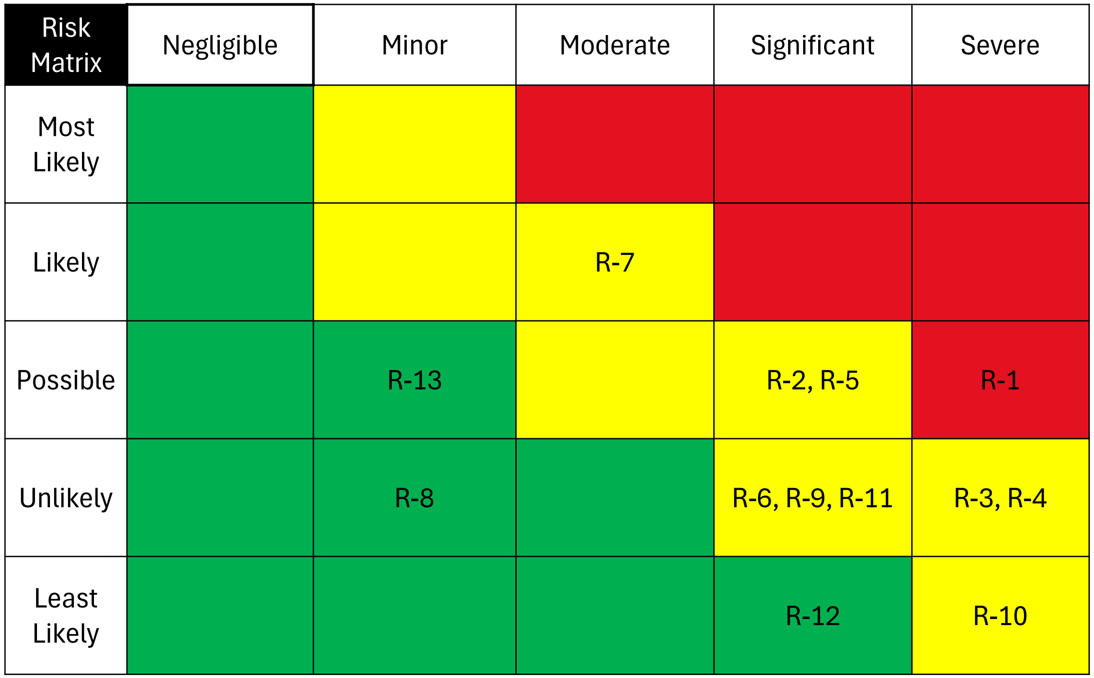
R-3: Data loss during comm outages or radiation events

R-4: Griffin lander interface incompatibility delays or prevents integration

R-5 Thermal excursions during lunar night degrade instrument performance

R-6 Radiation-induced data corruption impacts PRM outputs

Risk Identification



Risk Matrix	Negligible	Minor	Moderate	Significant	Severe
Most Likely	🟩	🟨	🟥	🟥	🟥
Likely	🟩	🟨	🟨 R-7	🟥	🟥
Possible	🟩	🟩 R-13	🟨	🟨 R-2, R-5	🟥 R-1
Unlikely	🟩	🟩 R-8	🟩	🟨 R-6, R-9, R-11	🟨 R-3, R-4
Least Likely	🟩	🟩	🟩	🟩 R-12	🟨 R-10

Risk ID and Descriptions (R-7 – R-12)

R-7	Excessive TBD/TBR values delay requirement closure
R-8	GNC accuracy insufficient for required geolocation fidelity
R-9	Data processing architecture insufficient for multi-sensor fusion
R-10	Launch vehicle failure
R-11	Structural failure of the lunar surveyor
R-12	Physical Failure of Sensing Instruments (Chronic)
R-13	Physical Failure of Sensing Instruments (Momentary)

Future Steps:

A Gantt chart displaying future steps for the Orbital Gators AURORA development Team are shown below

AURORA-H3 · Project Gantt Chart · Orbital Gators – University of Florida

🟦 Complete 🟦 In Progress ▨ Upcoming 🟥 Milestone

Task / Milestone	Status
Conceptual Design Finalized	✓ Done
Prototype Build	✓ Done
Prototype Testing & Results	✓ Done
► *C3 COSMIC Final Briefing*	✓ Done
PHASE 2 – Preliminary Design (PDR)	
Sensor Suite Trade Studies	► Active
Technology Freeze	○ Planned
Subsystem PDR Packages	○ Planned
Internal Component Comms Integration	○ Planned
TRL 5 Test Planning	○ Planned
► *Preliminary Design Review (PDR)*	○ Planned
PHASE 3 – Detailed Design	
Hardware Interface Design	○ Planned
Calibration Strategy Development	○ Planned
Data Fusion Pipeline Design	○ Planned
NASA MSFC Lunar Testbed Testing (TRL 5)	○ Planned
► *Critical Design Review (CDR)*	○ Planned
PHASE 4 – Manufacturing	
Component Fabrication	○ Planned
Full System Integration	○ Planned
► *Manufacturing Readiness Review*	○ Planned
PHASE 5 – Testing & Verification	
Environmental Testing (Thermal/Vibe)	○ Planned
End-to-End CONOPS Simulation	○ Planned
► *Flight Readiness Review (FRR)*	○ Planned
PHASE 6 – Payload Integration & Launch	
Griffin Lander Payload Integration	○ Planned
Launch Preparation	○ Planned
► *LAUNCH*	○ Planned

Future Steps:

A Gantt chart displaying future steps for the Orbital Gators AURORA development Team are shown below

Phases Mapped:

- Phase 1 — Conceptual Design & Prototype (Sep 2025 → Apr 2026, marked complete)
- Phase 2 — Preliminary Design / PDR (Apr → Dec 2026, currently active)
- Phase 3 — Detailed Design (2027–2028)
- Phase 4 — Manufacturing (2028–2029)
- Phase 5 — Testing & Verification (2029–2030)
- Phase 6 — Payload Integration & Launch (2031)

Conclusion

AURORA

Building the foundation for the future lunar economy.

So Far:

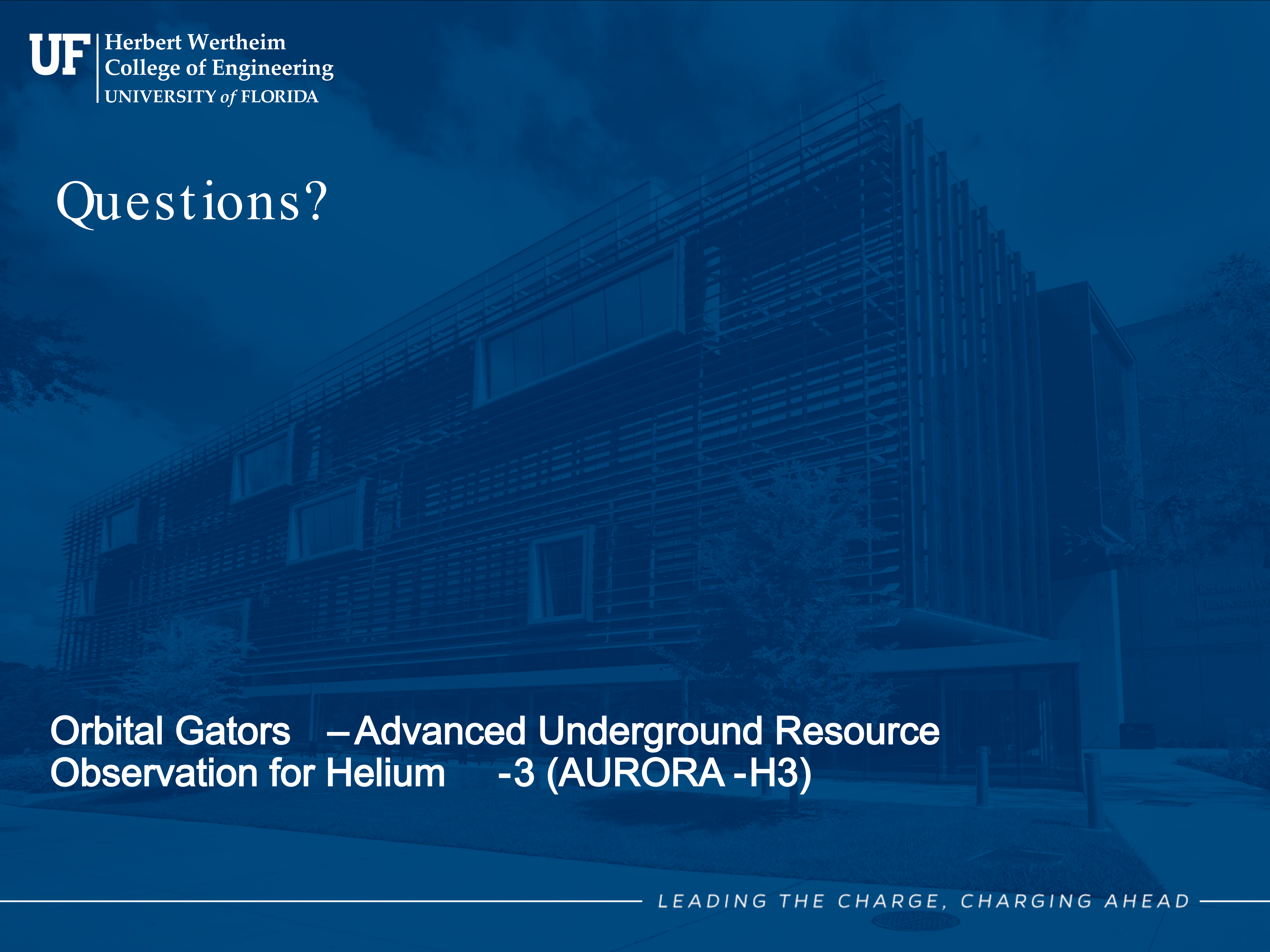
- Concept of modular, reusable sensor payload with sensor suite,
- Functioning TRL 3-4 Prototype

What AURORA Delivers:

- A 90% confidence Proven Resource Model for He-3 and H2O on the lunar surface.
- Direct Measurements, enabling confident site selection for future ISRU missions.

Path Forward:

- Full sensor suite integration and internal communications at TRL 5
- Further Lunar Testbed testing to validate in simulated lunar conditions
- Target launch: 2031 aboard Astrobotic Griffin lander



Questions?

Orbital Gators – Advanced Underground Resource Observation for Helium-3 (AURORA-H3)

References

[1] H. Song, J. Zhang, Y. Sun, Y. Li, X. Zhang, D. Ma and J. Kou, “Theoretical study on thermal release of helium-3 in lunar ilmenite,” *Minerals*, vol. 11, no. 3, art. 319, Mar. 2021, doi:10.3390/min11030319.

[2] Interlune, “$20 MILLION/KG…,” Accessed: Feb. 6, 2025. [Online]. Available: https://www.interlune.space/

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[4] M. Lemelin, C.-E. Morisset, M. Germain, V. Hipkin, K. Goïta, and P. G. Lucey, “Ilmenite mapping of the lunar regolith over Mare Australe and Mare Ingenii regions: An optimized multisource approach based on Hapke radiative transfer theory,” Journal of Geophysical Research: Planets, vol. 118, no. 12, pp. 2582–2593, Dec. 2013, doi: https://doi.org/10.1002/2013je004392.

[5] W. Fa and Y.-Q. Jin, “Quantitative estimation of helium-3 spatial distribution in the lunar regolith layer,” *Icarus*, vol. 190, no. 1, pp. 15–23, 2007, doi: 10.1016/j.icarus.2007.03.014.

EXTRA SLIDES:

Orbital Gators – Advanced Underground Resource Observation for Helium-3 (AURORA-H3)

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Technology Readiness Level – Describes the state of the technology in its stage of development. 1, lowest (unicorn)

- Scanning – Scanning the surface.

TRL	③ Magnetometer	② LPR	②

- Sampling –Aurora Drill Probe ④
    - Quadropole Mass Spectrometer ②
- Downlink – Downlink data stored in computer black box. ⑤
- Corellation Development – After scanning the data ⑥ process it at mission control, using developed algorithms.

System Requirements Definition Structure

Requirement Language and Intent:

- **Mission Statement (MS):** Describes overall mission purpose and scope. (1)
- **Mission Objectives (MO):** Express mission intent and capability goals. They are qualitative. (7)
- **Mission Success Criteria (MSC):** Introduce measurable outcomes that define mission success. (7)
- **System Requirements (SR):** Define what the system *shall* do to satisfy MSCs, including performance, interfaces, constraints, and behaviors and are written to be testable, analyzable, inspectable, or demonstrable.
- **Sub-System and Tooling Requirements:** Derived from system requirements to further specify and verify tooling criteria.

Technical Reasoning

Past Modeling Implementations:

Ilmenite and H2O research models already exist. Our objectives differ from those models because we aim to provide direct measurements for ilmenite and H2O reserves [4].

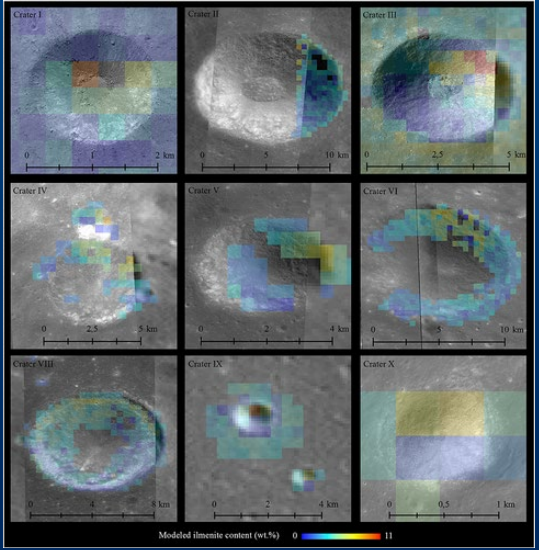

Figure 4. Ilmenite abundance (0–11 wt%) across Mare Australe craters, derived from spectral mapping.
Data from Lemelin & Morisset (2013).

Other resource distribution maps use prior correlations to suggest resource quantities across lunar regions [5].

- Increased Optical Maturity (OMAT) displays less TiO2 content.
- Greater solar wind flux displays greater TiO2 content.
- Thinner regolith layers display increased TiO2 content.
- Decreasing regolith grain size displays increased TiO2 content.

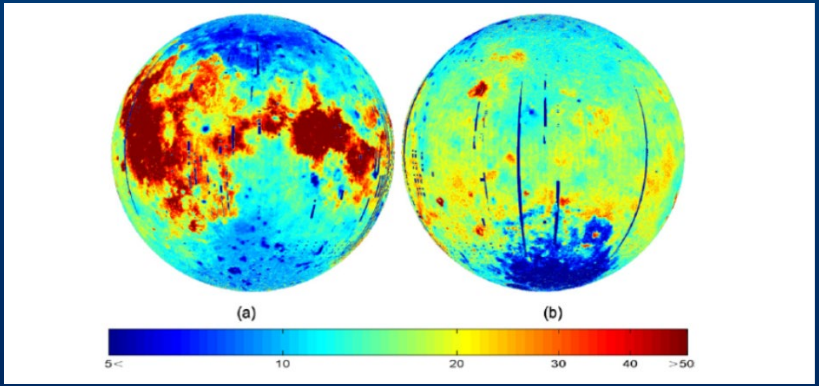

Figure 5. Modeled He-3 abundance (ppb) across the lunar surface, derived from Apollo soil data and Clementine multispectral reflectance. *After Fa & Jin (2007).*

Mission Objective & Design Drivers

We aim to:

- Produce a quantitative resource model for potential water and Helium-3 extraction
- Characterize lunar surface and subsurface composition
- Provide a data-driven platform, which will pave the way for future exploration

Figure 2. Full-scale prototype of the Interlune helium-3 excavator, developed in partnership with Vermeer. *Source: Interlune 2025*

Roadmap

Current Status (2025):
- Completing final revisions of System Requirements.
- Finalizing the Conceptual Design.

Mid-Term Plan (First quarter 2026):
- Complete Preliminary Design
- Technology Freeze.
- Develop list of prototypes and intent.
- Purchase parts for first prototype.
- Begin initial prototyping.

Second quarter 2026:
- Complete initial prototype.
- Develop plans for additional prototypes.
- Summarize success and plausibility of concept implementation.
- Present for the C3 Final showcase

Long-Term Roadmap:
- Progress into future detailed design process in 2027–2028, refining hardware interfaces, calibration strategies, and data-fusion pipelines.
- Manufacturing (2028–2029) of components for full-system integration.
- Testing and Verification (2029–2030) to ensure mission reliability.
- Payload Integration (2031) followed by Launch in 2031.


Conceptional Design 2025-2026`
Prototype Built 2026
Preliminary Design Technology Freeze 2026
Detailed Design 2027-2028
Manufacturing 2028-2029
Testing 2029-2030
Payload Integration 2031
Launch 2031

Closing Statement

Our mission moves beyond mapping the Moon, we are building the foundation for future lunar industry. By validating He-3 and H_2O resource models with a high-confidence architecture, we enable safer planning, lower risk, and more sustainable surface operations.

As we finalize system requirements and advance toward prototype development, our intent is clear: deliver a practical, data-driven toolchain that accelerates humanity's permanent presence on the lunar surface.

Figure 7. Interlune natural resource acquisition prototype. *Source: Interlune 2025*

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3.1. Systems (5 elements *From C3 Packet)
3.2. Assumptions
3.3. Risk Analysis
3.4. System Requirements
3.5. Command and Data Handling (C&DH) *Mentioned in C3 packet

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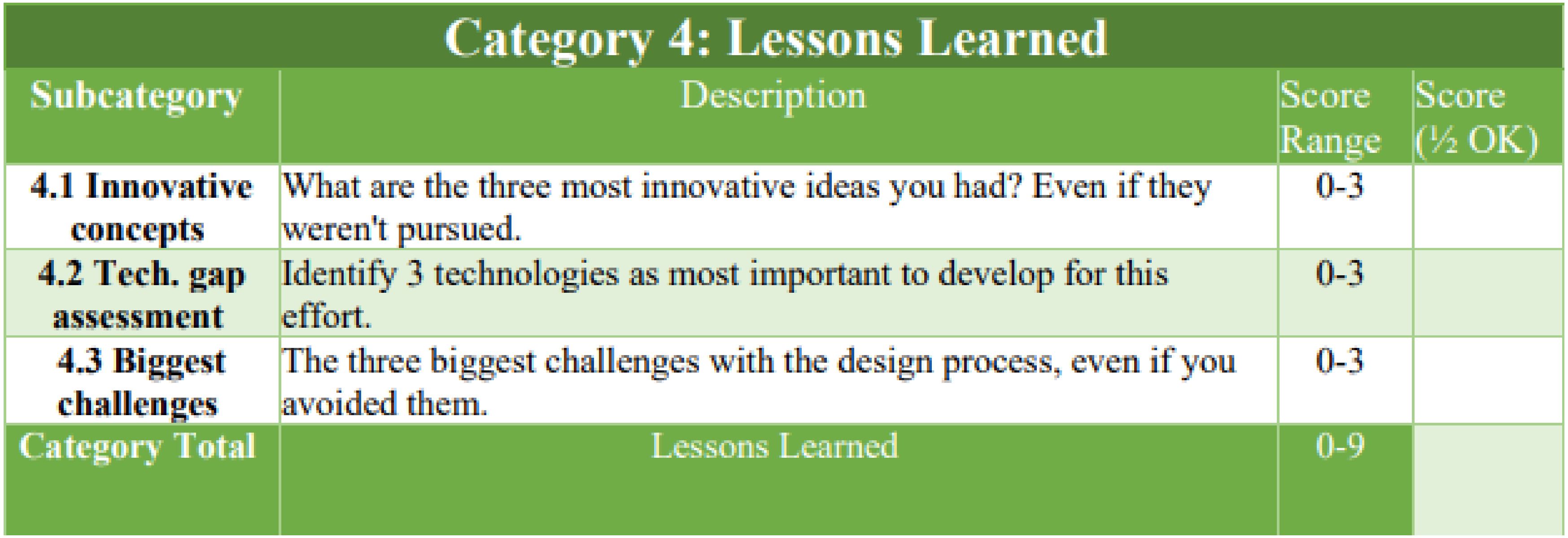

Category 4: Lessons Learned			
Subcategory	**Description**	**Score Range**	**Score (½ OK)**
4.1 Innovative concepts	What are the three most innovative ideas you had? Even if they weren't pursued.	0-3	
4.2 Tech. gap assessment	Identify 3 technologies as most important to develop for this effort.	0-3	
4.3 Biggest challenges	The three biggest challenges with the design process, even if you avoided them.	0-3	
Category Total	Lessons Learned	0-9	

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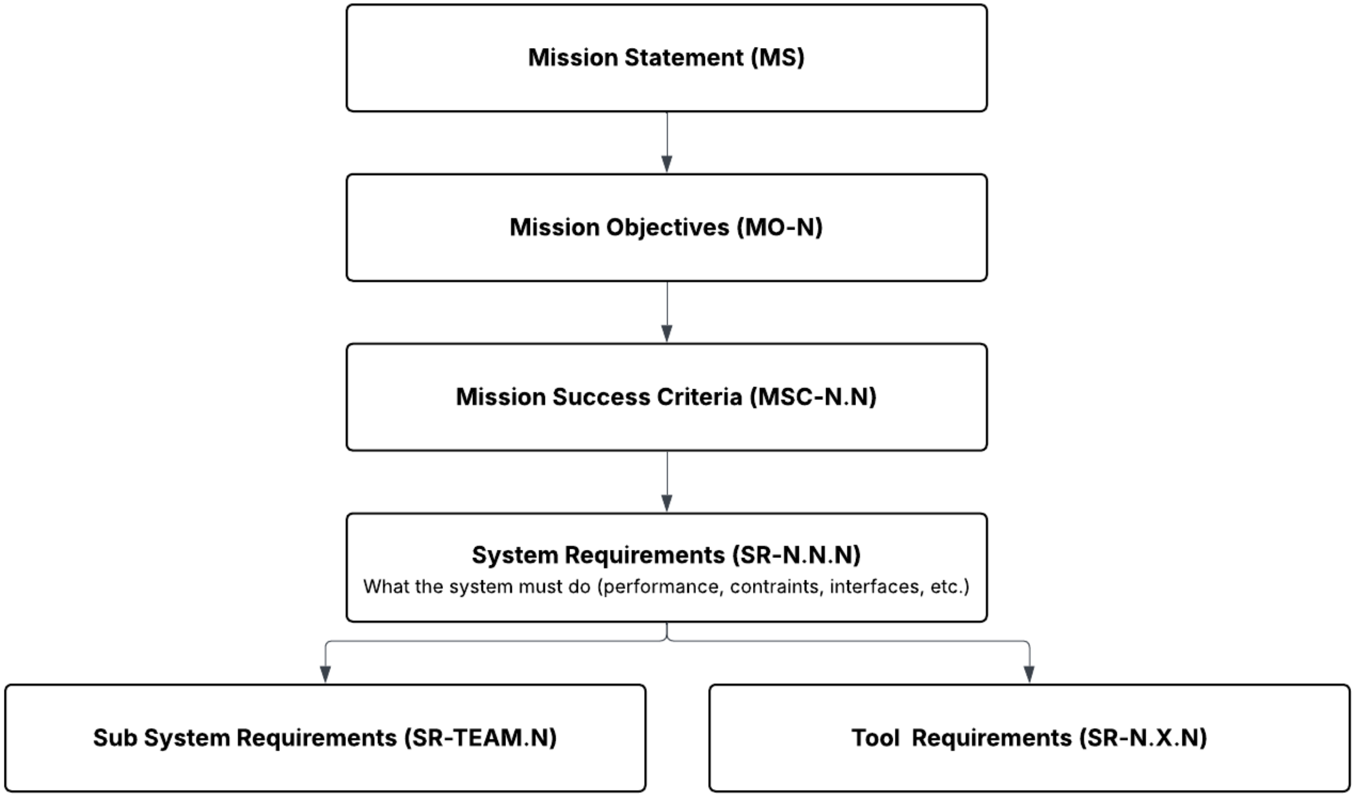

Mission Statement (MS)

Mission Objectives (MO-N)

Mission Success Criteria (MSC-N.N)

System Requirements (SR-N.N.N)
What the system must do (performance, contraints, interfaces, etc.)

Sub System Requirements (SR-TEAM.N)

Tool Requirements (SR-N.X.N)

This hierarchy ensures that all subsystem requirements are traceable to system requirements, which are derived from mission success criteria and mission objectives, preventing unverified or unnecessary design features.

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Mission Objective	Mission Success Criterion	System Requirement	Subsystem
MO-1	MSC-1.1	SR-1.1.1	Payload
MO-1	MSC-1.2	SR-1.2.1	EPS
MO-2	MSC-2.1	SR-2.1.1	Comms
MO-3	MSC-3.1	SR-3.1.1	Mobility

- Traceability:
- Each MSC traces to ⩾1 MO
- Each SR traces to ≥1 MSC
- Each Subsystem, and Tool Requirement traces to ≥1 SR

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SRR Composition:

- The System Requirements Review (SRR) creates requirements at multiple levels of, progressing from mission intent to system behavior.
- Requirement wording is intentionally structured to distinguish between objectives, success criteria, and enforceable system requirements.
- Only requirements at the System Requirement (SR) level and below are written as “shall” statements, indicating mandatory, verifiable behavior.

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Requirement Language and Intent:

- **Mission Statement (MS):** Describes overall mission purpose and scope.
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MS-1:

Shall generate a map of lunar surface characteristics using tooling such as spectroscopy, and ground-penetrating radar, to create a model of resource distribution of H2O, & He3 at a 50% confidence level

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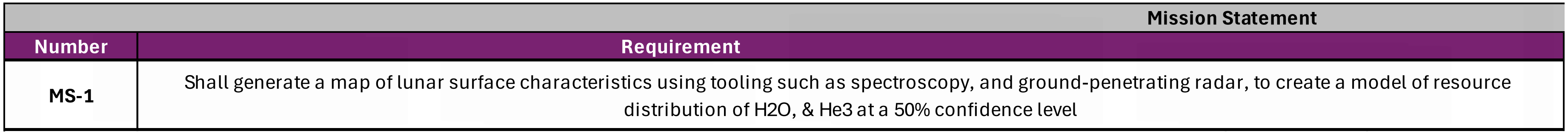
MS-1:

Shall generate a map of lunar surface characteristics using tooling such as spectroscopy, and ground-penetrating radar, to create a model of resource distribution of H2O, & He3 at a 50% confidence level



	Mission Statement
Number	**Requirement**
MS-1	Shall generate a map of lunar surface characteristics using tooling such as spectroscopy, and ground-penetrating radar, to create a model of resource distribution of H2O, & He3 at a 50% confidence level

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C3 Cosmic derives requirements for students to build an architecture for a Capstone project.

The requirements given are listed, and used as the foundation of the system requirements detailed in MO -7, MSC-7.N, and SR-7.N.

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The following assumptions are those given by the C3 COSMIC Capstone Challenge.

ID	Assumption / Constraint	**Status**	**Plan**	Rationale
AC-1	The Griffin lander provides a maximum of 200 kg payload mass to the C3 mission.	Closed	Verified via DR-7.1.3	Allocated from total Griffin payload capacity
AC-2	The C3 payload volume shall not exceed ¾ of the available Griffin payload volume.	Partially Closed	Envelope defined in Mechanical ICD	Lander integration constraint
AC-3	Griffin provides up to 5 kWe solar power generation during surface operations.	Assumption	Sensitivity trades in EPS	Enables base-station architecture
AC-4	Griffin provides energy storage sufficient for ~100 hr lunar night survival.	Assumption	CONOPS clarification	Supports continuous operations
AC-5	Griffin provides a surface communications relay (≈60 Mbps) and Earth relay capability.	Closed	COMM/COMP SRs	Enables data downlink
AC-6	Griffin base-station systems consume approximately 400 kg of total lander mass.	Closed	Program allocation	Remaining mass allocated to payloads

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MO-1:

Enable detection and quantification of indicators correlated with Helium-3 presence in lunar regolith.

MO-2:

Enable detection and characterization of H_2O and/or hydration indicators in the lunar environment.

MO-3:

Characterize key lunar surface and subsurface properties relevant to resource assessment and site selection.

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MO-4:

Provide a reusable and cost-balanced system architecture enabling repeated lunar surface characterization missions.

MO-5:

Provide coordinated position, navigation, and timing capability with the Lunar Lander to support geolocated data collection.

MO-6:

Generate georeferenced maps and data products of lunar resources and surface characteristics over the mission area of interest.

MO-7:

Interface with the Astrobotic Griffin lander to support lunar surface resource surveying operations.

System Requirement	Header Purpose
SR-1	Sensing & Measurement
SR-2	Resource Characterization
SR-3	Site Characterization & Suitability
SR-4	Reuse, Modularity & Lifecycle
SR-5	Position, Navigation, Timing
SR-6	Data Products & Delivery
SR-7	Griffin Lander Interfacing

Ensuring Implementable and Verifiable Requirements:

- System Requirements are written to be testable, analyzable, inspectable, or demonstrable, ensuring each requirement can be objectively verified.
- Subsystem and tool requirements are derived from system requirements, rather than directly from mission objectives, to preserve verification ability.
- This hierarchical structure prevents the introduction of unverified or unnecessary design features and ensures all implemented capabilities are traceable to mission intent.

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MSC Group	Associated Mission Objective	Scope of Success Criteria
MSC-1	MO-1	Helium-3 proxy detection and quantification performance
MSC-2	MO-2	H_2O / hydration indicator detection and characterization
MSC-3	MO-3	Surface and subsurface property characterization for resource assessment
MSC-4	MO-4	Reusable, modular, and cost-balanced system architecture
MSC-5	MO-5	Coordinated position, navigation, and timing with the Lunar Lander
MSC-6	MO-6	Generation of georeferenced maps and mission data products
MSC-7	MO-7	Compatibility and integration with the Astrobotic Griffin lander

Each Mission Success Criterion group defines objective-level success and serves as the direct parent for system requirements.

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System Requirement	Header

SR-1	Sensing and Measurement
SR-1.1	Sensing and Measurement Requirements
SR-1.2	Spatial Coverage and Resolution
SR-1.3	Data Processing & Modeling
SR-1.4	Uncertainty & Confidence
SR-1.5	Data Products & Archiving

SR-1.1.1	Helium-3 Abundance Tooling
SR-1.1.1.A	Alpha Particle X-Ray Spectrometer (APXS) Requirements
SR-1.1.1.B	Multispectral Imaging (MSI) Camera Tool Requirements
SR-1.1.1.C	Flux Magnetometer (FMAG) Tool Requirements
SR-1.1.1.D	Electrostatic Analyzer (ESA) Tool Requirements
SR-1.1.1.E	Neutral Particle Detector (NPD) Tool Requirements
SR-1.1.1.F	Automated Grain Analyzer (AGA) Tool Requirements

SR-1.1.2	H2O Abundance Tooling
SR-1.1.2.A	Lunar Penetrating Radar Requirements

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AURORA Tooling Property Data:

Helium -3:

Subsurface Density:

Lunar Penetrating Radar (LPR)

Grain Size:

Automated Grain Size Analyzer

Multispectral Imaging Camera

Water :

Dielectric contrast:

Lunar Penetrating Radar (LPR)

TiO2 Content :

Alpha Particle X-Ray Spectrometer (APXS)

Magnetic Anomalies (Negative Correlation)

Fluxgate Magnetometer

Solar Wind Flux

Electrostatic Analyzer (ESA)

Neutral Gas Flux

Neutral Particle Detector (NPD)

[illegible]

Subsystem	Primary Responsibility	Owned Requirement Domains
Instrumentation / Payload	Science sensing and measurement tools	SR-1 (Sensing & Measurement), SR-2 (Resource Characterization), tool-level SR-1.1.x
Subsurface Scanning	Subsurface structure and volatile indicator detection	SR-1.1.2, SR-2.1, SR-2.2 (LPR-driven requirements)
Structures	Mechanical integrity, mounting, and modular interfaces	SR-4 (Reuse & Modularity), SR-7 (Griffin mechanical integration)
Thermal	Thermal control and survivability across lunar environments	SR-4.4 (Environmental survivability), SR-7.4 (Griffin thermal constraints)
Electrical Power System (EPS)	Power generation, storage, and distribution	SR-4 (Reuse impacts), SR-7.2 (Griffin power interface), EPS-allocated SRs

[illegible]

Subsystem	Primary Responsibility	Owned Requirement Domains
Computer / Avionics (COMP)	Data processing, fusion, storage, and control	SR-1.3, SR-1.4, SR-1.5, SR-6 (Data Products & Archiving)
Communications (COMM)	Data transfer, lander relay, and interfaces	SR-5.5 (PNT data exchange), SR-7.3 (Griffin comms interface)
Guidance, Navigation & Control (GNC)	Position, navigation, timing, and frame alignment	SR-5 (PNT & Lander Coordination)
Radiation	Radiation environment assessment and survivability	SR-4.4.2 (Cumulative radiation exposure)
Griffin / Lander Interface	External system integration and constraint management	SR-7 (Interface requirements), Assumptions & Constraints (AC-1 to AC-6)

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- Mitigation approach for each top risk
  - Ensuring System requirements are met will mitigate the risk factors
  - R-7: Explicit TBD/TBR closure plan; sensitivity-based prioritization; phased resolution
  - R-13: Patching gaps in data where momentary data-loss occurs due to failure with numerical estimation and filtering. Ensuring robust communications to mitigate error.
- What reduces likelihood vs consequence

Risk Area	Likelihood Reduction	Consequence Reduction
Griffin power	Conservative EPS sizing, duty cycles	Reduced science rate
Mass growth	Mass margins, early estimates	Descoping non-critical payloads
Data downlink	Bounded data products	Onboard storage, delayed downlink
Thermal survival	Passive thermal design	Reduced operational timeline
Interface mismatch	Early ICDs	Manual operational constraints

- What remains after mitigation
  - Re-scan data if data-loss is critical, could take away from available mission time.

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- Top Driving Requirements:
  - Communications of data between lander and systems on Earth, implementing error detection systems to mitigate corrupt data. **(SR-COMM.1, SR-COMM.9)**
  - Instrumentation/sensors **(SR-1.1, SR-1.1.3.1, SR-1.3, SR-1.4)**
  - Power allocation and consumption **(PWR-03, PWR-06)**
  - Auto/Semi-Autonomous Control of Lunar Lander Vehicle **(SR-GNC.1, SR-5.1.1, SR-5.3)**
  - Mesh metrics together to create a probable reserve model **(SR-6)**
  - Data Validation– Making sure the Data sent is not corrupted **(SR-5.6)**
  - The system shall incorporate lifecycle cost considerations into the design to support economically viable reuse and refurbishment. **(SR-4.2)**

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- **1. Framework Selection: NASA cFS**
- **Action:** Adopted **NASA Core Flight System (cFS)** as the flight software architecture.
- **Why:** Provides flight-proven fault protection (Health & Safety app) and modularity (SR-4.3) out of the box, reducing development risk compared to a custom solution.
- **2. Data Standardization (PDS4 & PRM)**
- **Action:** Defined a strict **Master File Naming Convention** and a **Universal Binary Header** mapped to PDS4 standards.
- **Why:** Ensures all science data is legally admissible for the **Proven Reserve Model (PRM)** by guaranteeing traceability (MSC-6.4) and enables automated generation of archival labels.
- **3. Hardware Architecture Selection**
- **Action:** Conducted trade study comparing Heritage (RAD750) vs. Modern (VIPER/Ingenuity) architectures.
- **Decision:** Selected a **COTS Architecture** (ARM v8 + 2 TB NVMe) for the prototype phase.
- **Justification:** The Lunar Penetrating Radar (LPR) generates ~170 GB/day of raw data. We prioritized high-speed buffering (NVMe) to validate algorithms now, with a path to a **Split-Architecture** (Rad-Hard Supervisor + Rad-Tolerant Compute) for the final flight unit.
- **4. Data Lifecycle Strategy**
- **Action:** Defined a Store-and-Forward state machine using the **cFS CFDP** application.
- **Why:** Manages the downlink bottleneck by prioritizing map products over raw data, while guaranteeing data integrity (CRC32) and automated retransmission during comms outages (DR-7.3.4).

Metric	Heritage (Perseverance)	NASA VIPER (Modern Lunar)	Our Prototype (Target)
CPU Speed	200 MHz	Split: Rad-hard + FPGA	1.5 GHz (ARM)
RAM	256 MB	1 GB	8 GB LPDDR4
Storage	16 GB Flash	~ 1 TB	2 TB NVMe
Cost	$200,000+	High (Class C)	< $500
Primary Optimization	Radiation Survival	Hardware Acceleration	Algorithm Validation

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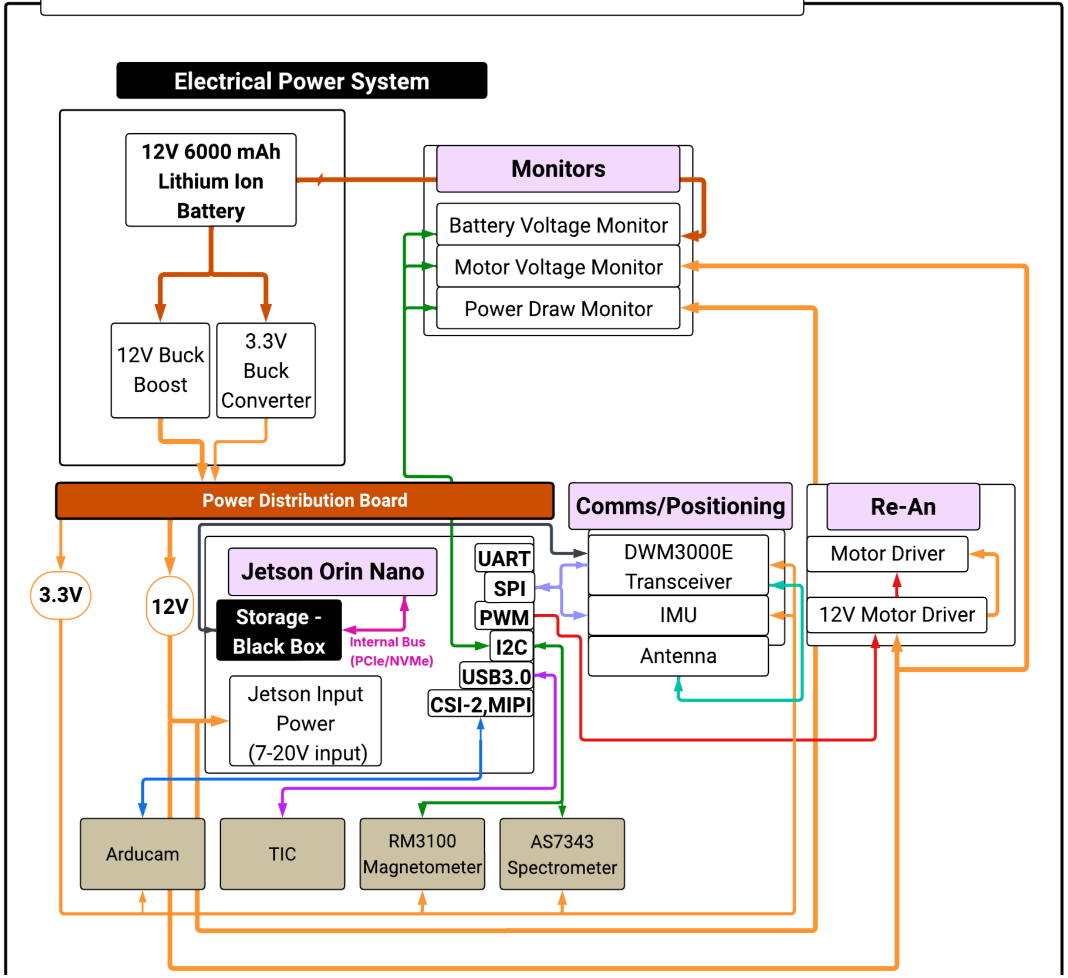
Abbreviations:

TIC - Thermal Imaging Camera
Re-An - Regolith Analyzer Instrument
RF - Radio Frequency
IMU - Inertial Measurement Unit
MIPI - Mobile Industry Processor Interface
CSI2 - Camera Serial Interface 2
I2C - Inter-Integrated Circuit Protocol
SPI - Serial Peripheral Interface Protocol
PWM - Pulse Width Modulation
V - Volts
A - Amps

LUNAR SURVEYOR EPS/COMMS



System Requirements Definition Structure

Requirement Language and Intent:

- **Mission Statement (MS):** Describes overall mission purpose and scope. (1)
- **Mission Objectives (MO):** Express mission intent and capability goals. They are qualitative. (7)
- **Mission Success Criteria (MSC):** Introduce measurable outcomes that define mission success. (7)
- **System Requirements (SR):** Define what the system *shall* do to satisfy MSCs, including performance, interfaces, constraints, and behaviors and are written to be testable, analyzable, inspectable, or demonstrable.
- **Sub-System and Tooling Requirements:** Derived from system requirements to further specify and verify tooling criteria.

Technical Reasoning

Past Modeling Implementations:

Ilmenite and H2O research models already exist. Our objectives differ from those models because we aim to provide direct measurements for ilmenite and H2O reserves [4].

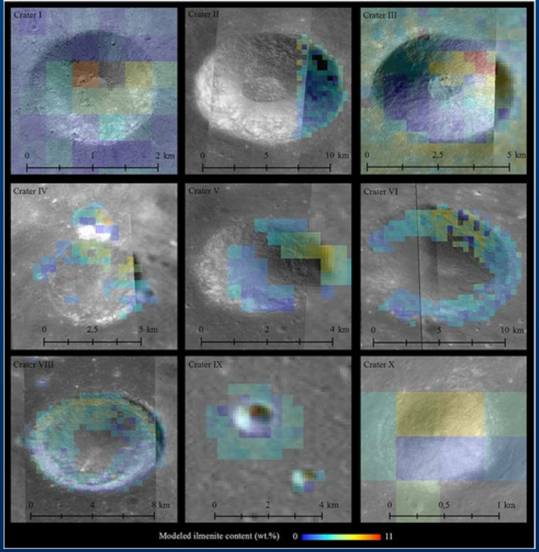


Figure 4. Ilmenite abundance (0–11 wt%) across Mare Australe craters, derived from spectral mapping.
Data from Lemelin & Morisset (2013).

Other resource distribution maps use prior correlations to suggest resource quantities across lunar regions [5].

- Increased Optical Maturity (OMAT) displays less TiO2 content.
- Greater solar wind flux displays greater TiO2 content.
- Thinner regolith layers display increased TiO2 content.
- Decreasing regolith grain size displays increased TiO2 content.

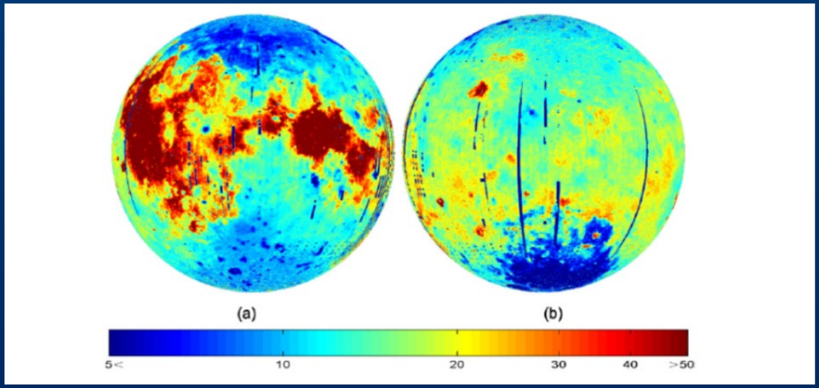


Figure 5. Modeled He-3 abundance (ppb) across the lunar surface, derived from Apollo soil data and Clementine multispectral reflectance. *After Fa & Jin (2007).*

Mission Objective & Design Drivers

We aim to:

- Produce a quantitative resource model for potential water and Helium-3 extraction
- Characterize lunar surface and subsurface composition
- Provide a data-driven platform, which will pave the way for future exploration

Figure 2. Full-scale prototype of the Interlune helium-3 excavator, developed in partnership with Vermeer. *Source: Interlune 2025*

Roadmap

Current Status (2025):

- Completing final revisions of System Requirements.
- Finalizing the Conceptual Design.

Mid-Term Plan (First quarter 2026):

- Complete Preliminary Design
- Technology Freeze.
- Develop list of prototypes and intent.
- Purchase parts for first prototype.
- Begin initial prototyping.

Second quarter 2026:

- Complete initial prototype.
- Develop plans for additional prototypes.
- Summarize success and plausibility of concept implementation.
- Present for the C3 Final showcase

Long-Term Roadmap:

- Progress into future detailed design process in 2027–2028, refining hardware interfaces, calibration strategies, and data-fusion pipelines.
- Manufacturing (2028–2029) of components for full-system integration.
- Testing and Verification (2029–2030) to ensure mission reliability.
- Payload Integration (2031) followed by Launch in 2031.

Conceptional Design 2025-2026`

Prototype Built
2026

Preliminary Design
Technology Freeze
2026

Detailed Design 2027-2028

Manufacturing
2028-2029

Testing
2029-
2030

Payload
Integration
2031

Launch
2031

Closing Statement

Our mission moves beyond mapping the Moon, we are building the foundation for future lunar industry. By validating He-3 and H_2O resource models with a high-confidence architecture, we enable safer planning, lower risk, and more sustainable surface operations.

As we finalize system requirements and advance toward prototype development, our intent is clear: deliver a practical, data-driven toolchain that accelerates humanity's permanent presence on the lunar surface.

Figure 7. Interlune natural resource acquisition prototype. *Source: Interlune 2025*

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3.1. Systems (5 elements *From C3 Packet)
3.2. Assumptions
3.3. Risk Analysis
3.4. System Requirements
3.5. Command and Data Handling (C&DH) *Mentioned in C3 packet

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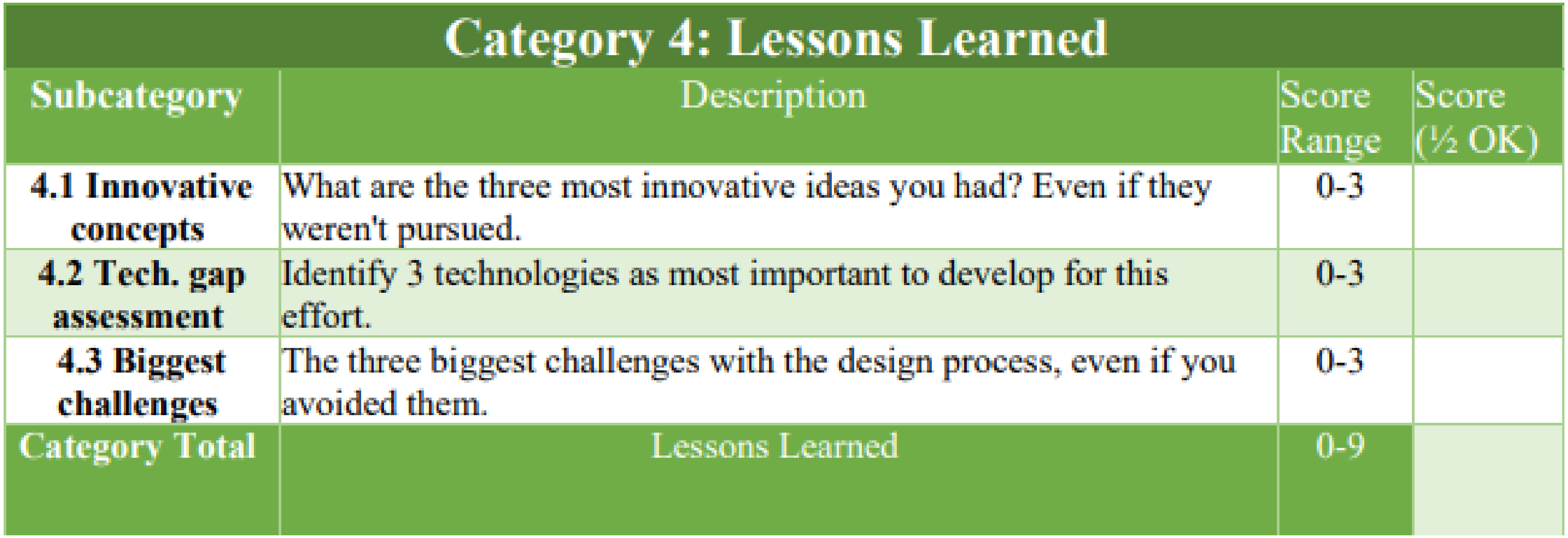

Category 4: Lessons Learned			
Subcategory	**Description**	**Score Range**	**Score (½ OK)**
4.1 Innovative concepts	What are the three most innovative ideas you had? Even if they weren't pursued.	0-3	
4.2 Tech. gap assessment	Identify 3 technologies as most important to develop for this effort.	0-3	
4.3 Biggest challenges	The three biggest challenges with the design process, even if you avoided them.	0-3	
Category Total	Lessons Learned	0-9	

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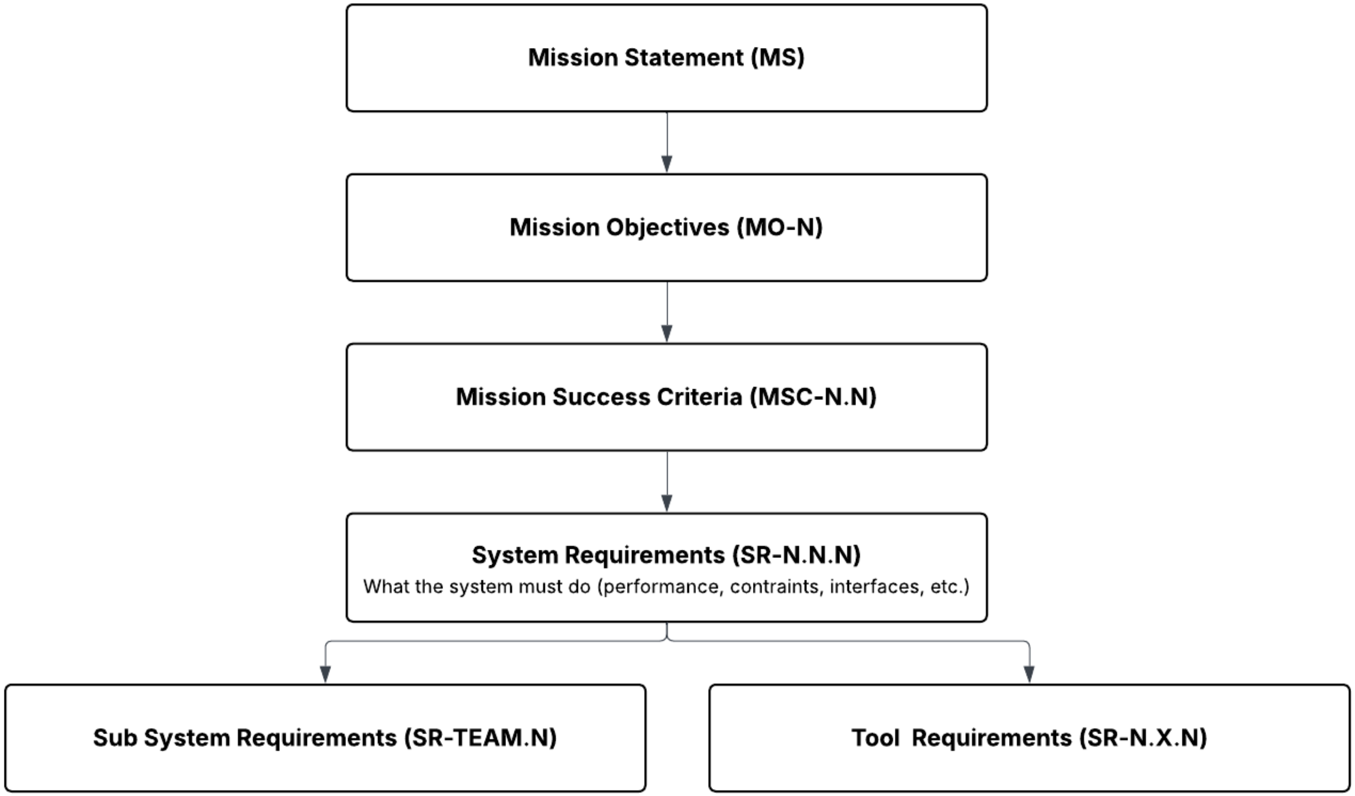

This hierarchy ensures that all subsystem requirements are traceable to system requirements, which are derived from mission success criteria and mission objectives, preventing unverified or unnecessary design features.

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Mission Objective	Mission Success Criterion	System Requirement	Subsystem
MO-1	MSC-1.1	SR-1.1.1	Payload
MO-1	MSC-1.2	SR-1.2.1	EPS
MO-2	MSC-2.1	SR-2.1.1	Comms
MO-3	MSC-3.1	SR-3.1.1	Mobility

- Traceability:
- Each MSC traces to ⩾1 MO
- Each SR traces to ≥1 MSC
- Each Subsystem, and Tool Requirement traces to ≥1 SR

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SRR Composition:

- The System Requirements Review (SRR) creates requirements at multiple levels of, progressing from mission intent to system behavior.
- Requirement wording is intentionally structured to distinguish between objectives, success criteria, and enforceable system requirements.
- Only requirements at the System Requirement (SR) level and below are written as "shall" statements, indicating mandatory, verifiable behavior.

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Requirement Language and Intent:

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MS-1:

Shall generate a map of lunar surface characteristics using tooling such as spectroscopy, and ground-penetrating radar, to create a model of resource distribution of H2O, & He3 at a 50% confidence level

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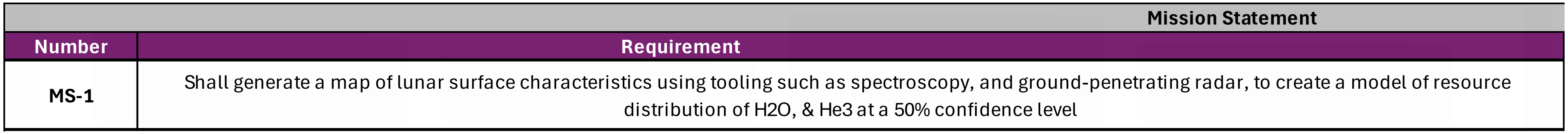

Mission Statement	
Number	**Requirement**
MS-1	Shall generate a map of lunar surface characteristics using tooling such as spectroscopy, and ground-penetrating radar, to create a model of resource distribution of H2O, & He3 at a 50% confidence level

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C3 Cosmic derives requirements for students to build an architecture for a Capstone project.

The requirements given are listed, and used as the foundation of the system requirements detailed in MO -7, MSC-7.N, and SR-7.N.

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The following assumptions are those given by the C3 COSMIC Capstone Challenge.

ID	Assumption / Constraint	**Status**	**Plan**	Rationale
AC-1	The Griffin lander provides a maximum of 200 kg payload mass to the C3 mission.	Closed	Verified via DR-7.1.3	Allocated from total Griffin payload capacity
AC-2	The C3 payload volume shall not exceed ¾ of the available Griffin payload volume.	Partially Closed	Envelope defined in Mechanical ICD	Lander integration constraint
AC-3	Griffin provides up to 5 kWe solar power generation during surface operations.	Assumption	Sensitivity trades in EPS	Enables base-station architecture
AC-4	Griffin provides energy storage sufficient for ~100 hr lunar night survival.	Assumption	CONOPS clarification	Supports continuous operations
AC-5	Griffin provides a surface communications relay (≈60 Mbps) and Earth relay capability.	Closed	COMM/COMP SRs	Enables data downlink
AC-6	Griffin base-station systems consume approximately 400 kg of total lander mass.	Closed	Program allocation	Remaining mass allocated to payloads

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MO-1:

Enable detection and quantification of indicators correlated with Helium-3 presence in lunar regolith.

MO-2:

Enable detection and characterization of H_2O and/or hydration indicators in the lunar environment.

MO-3:

Characterize key lunar surface and subsurface properties relevant to resource assessment and site selection.

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MO-4:

Provide a reusable and cost-balanced system architecture enabling repeated lunar surface characterization missions.

MO-5:

Provide coordinated position, navigation, and timing capability with the Lunar Lander to support geolocated data collection.

MO-6:

Generate georeferenced maps and data products of lunar resources and surface characteristics over the mission area of interest.

MO-7:

Interface with the Astrobotic Griffin lander to support lunar surface resource surveying operations.

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System Requirement	Header Purpose
SR-1	Sensing & Measurement
SR-2	Resource Characterization
SR-3	Site Characterization & Suitability
SR-4	Reuse, Modularity & Lifecycle
SR-5	Position, Navigation, Timing
SR-6	Data Products & Delivery
SR-7	Griffin Lander Interfacing

Ensuring Implementable and Verifiable Requirements:

- System Requirements are written to be testable, analyzable, inspectable, or demonstrable, ensuring each requirement can be objectively verified.
- Subsystem and tool requirements are derived from system requirements, rather than directly from mission objectives, to preserve verification ability.
- This hierarchical structure prevents the introduction of unverified or unnecessary design features and ensures all implemented capabilities are traceable to mission intent.

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MSC Group	Associated Mission Objective	Scope of Success Criteria
MSC-1	MO-1	Helium-3 proxy detection and quantification performance
MSC-2	MO-2	H_2O / hydration indicator detection and characterization
MSC-3	MO-3	Surface and subsurface property characterization for resource assessment
MSC-4	MO-4	Reusable, modular, and cost-balanced system architecture
MSC-5	MO-5	Coordinated position, navigation, and timing with the Lunar Lander
MSC-6	MO-6	Generation of georeferenced maps and mission data products
MSC-7	MO-7	Compatibility and integration with the Astrobotic Griffin lander

Each Mission Success Criterion group defines objective-level success and serves as the direct parent for system requirements.

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System Requirement	Header

SR-1	Sensing and Measurement
SR-1.1	Sensing and Measurement Requirements
SR-1.2	Spatial Coverage and Resolution
SR-1.3	Data Processing & Modeling
SR-1.4	Uncertainty & Confidence
SR-1.5	Data Products & Archiving

SR-1.1.1	Helium-3 Abundance Tooling
SR-1.1.1.A	Alpha Particle X-Ray Spectrometer (APXS) Requirements
SR-1.1.1.B	Multispectral Imaging (MSI) Camera Tool Requirements
SR-1.1.1.C	Flux Magnetometer (FMAG) Tool Requirements
SR-1.1.1.D	Electrostatic Analyzer (ESA) Tool Requirements
SR-1.1.1.E	Neutral Particle Detector (NPD) Tool Requirements
SR-1.1.1.F	Automated Grain Analyzer (AGA) Tool Requirements

SR-1.1.2	H2O Abundance Tooling
SR-1.1.2.A	Lunar Penetrating Radar Requirements

AURORA Tooling Property Data:

Helium -3:

Subsurface Density:

- Lunar Penetrating Radar (LPR)

Grain Size:

- Automated Grain Size Analyzer
- Multispectral Imaging Camera

Water :

Dielectric contrast:

- Lunar Penetrating Radar (LPR)

TiO2 Content :

- Alpha Particle X-Ray Spectrometer (APXS)
- Magnetic Anomalies (Negative Correlation)
- Fluxgate Magnetometer
- Solar Wind Flux
- Electrostatic Analyzer (ESA)
- Neutral Gas Flux
- Neutral Particle Detector (NPD)

[illegible]

Subsystem	Primary Responsibility	Owned Requirement Domains
Instrumentation / Payload	Science sensing and measurement tools	SR-1 (Sensing & Measurement), SR-2 (Resource Characterization), tool-level SR-1.1.x
Subsurface Scanning	Subsurface structure and volatile indicator detection	SR-1.1.2, SR-2.1, SR-2.2 (LPR-driven requirements)
Structures	Mechanical integrity, mounting, and modular interfaces	SR-4 (Reuse & Modularity), SR-7 (Griffin mechanical integration)
Thermal	Thermal control and survivability across lunar environments	SR-4.4 (Environmental survivability), SR-7.4 (Griffin thermal constraints)
Electrical Power System (EPS)	Power generation, storage, and distribution	SR-4 (Reuse impacts), SR-7.2 (Griffin power interface), EPS-allocated SRs

[illegible]

Subsystem	Primary Responsibility	Owned Requirement Domains
Computer / Avionics (COMP)	Data processing, fusion, storage, and control	SR-1.3, SR-1.4, SR-1.5, SR-6 (Data Products & Archiving)
Communications (COMM)	Data transfer, lander relay, and interfaces	SR-5.5 (PNT data exchange), SR-7.3 (Griffin comms interface)
Guidance, Navigation & Control (GNC)	Position, navigation, timing, and frame alignment	SR-5 (PNT & Lander Coordination)
Radiation	Radiation environment assessment and survivability	SR-4.4.2 (Cumulative radiation exposure)
Griffin / Lander Interface	External system integration and constraint management	SR-7 (Interface requirements), Assumptions & Constraints (AC-1 to AC-6)

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- Mitigation approach for each top risk
  - Ensuring System requirements are met will mitigate the risk factors
  - R-7: Explicit TBD/TBR closure plan; sensitivity-based prioritization; phased resolution
  - R-13: Patching gaps in data where momentary data-loss occurs due to failure with numerical estimation and filtering. Ensuring robust communications to mitigate error.
- What reduces likelihood vs consequence

Risk Area	Likelihood Reduction	Consequence Reduction
Griffin power	Conservative EPS sizing, duty cycles	Reduced science rate
Mass growth	Mass margins, early estimates	Descoping non-critical payloads
Data downlink	Bounded data products	Onboard storage, delayed downlink
Thermal survival	Passive thermal design	Reduced operational timeline
Interface mismatch	Early ICDs	Manual operational constraints

- What remains after mitigation
  - Re-scan data if data-loss is critical, could take away from available mission time.

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- **Top Driving Requirements:**
  - Communications of data between lander and systems on Earth, implementing error detection systems to mitigate corrupt data. **(SR-COMM.1, SR-COMM.9)**
  - Instrumentation/sensors **(SR-1.1, SR-1.1.3.1, SR-1.3, SR-1.4)**
  - Power allocation and consumption **(PWR-03, PWR-06)**
  - Auto/Semi-Autonomous Control of Lunar Lander Vehicle **(SR-GNC.1, SR-5.1.1, SR-5.3)**
  - Mesh metrics together to create a probable reserve model **(SR-6)**
  - Data Validation– Making sure the Data sent is not corrupted **(SR-5.6)**
  - The system shall incorporate lifecycle cost considerations into the design to support economically viable reuse and refurbishment. **(SR-4.2)**

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- 1. Framework Selection: NASA cFS
- **Action:** Adopted **NASA Core Flight System (cFS)** as the flight software architecture.
- **Why:** Provides flight-proven fault protection (Health & Safety app) and modularity (SR-4.3) out of the box, reducing development risk compared to a custom solution.
- 2. Data Standardization (PDS4 & PRM)
- **Action:** Defined a strict **Master File Naming Convention** and a **Universal Binary Header** mapped to PDS4 standards.
- **Why:** Ensures all science data is legally admissible for the **Proven Reserve Model (PRM)** by guaranteeing traceability (MSC-6.4) and enables automated generation of archival labels.
- 3. Hardware Architecture Selection
- **Action:** Conducted trade study comparing Heritage (RAD750) vs. Modern (VIPER/Ingenuity) architectures.
- **Decision:** Selected a **COTS Architecture** (ARM v8 + 2 TB NVMe) for the prototype phase.
- **Justification:** The Lunar Penetrating Radar (LPR) generates ~170 GB/day of raw data. We prioritized high-speed buffering (NVMe) to validate algorithms now, with a path to a **Split -Architecture** (Rad-Hard Supervisor + Rad-Tolerant Compute) for the final flight unit.
- 4. Data Lifecycle Strategy
- **Action:** Defined a Store-and-Forward state machine using the **cFS CFDP** application.
- **Why:** Manages the downlink bottleneck by prioritizing map products over raw data, while guaranteeing data integrity (CRC32) and automated retransmission during comms outages (DR-7.3.4).

Metric	Heritage (Perseverance)	NASA VIPER (Modern Lunar)	Our Prototype (Target)
CPU Speed	200 MHz	Split: Rad-hard + FPGA	1.5 GHz (ARM)
RAM	256 MB	1 GB	8 GB LPDDR4
Storage	16 GB Flash	~ 1 TB	2 TB NVMe
Cost	$200,000+	High (Class C)	< $500
Primary Optimization	Radiation Survival	Hardware Acceleration	Algorithm Validation