Science Mission Directorate

Lunar Occultation Spectroscopic Telescope Array

(LunOSTAR) Program Level Requirements

RIDDLE AERONAUTICS
and
SPACE ADMINISTRATION

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1. Scope

NASA Gateway program. The Gateway Program's goal (formerly known as the Lunar Orbital Platform-Gateway) is building a small, human-tended space station orbiting the Moon that will provide extensive capabilities to support NASA's Artemis campaign. Built with international and commercial partnerships, Gateway's capabilities for supporting sustained exploration and research in deep space include docking ports for a variety of visiting spacecraft, space for crew to live and work, and on-board science investigations to study heliophysics, human health, and life sciences, among other areas. Gateway will be a critical platform for developing technology and capabilities to support Moon and Mars exploration in the coming years.

The *LunOSTAR* mission. This document identifies the mission, science and programmatic (funding and schedule) requirements for the development and operation of the *Lunar Spectroscopic Telescope Array* (*LunOSTAR*) Observatory, a mission project funded by the Riddle Aeronautics and Space Administration (RASA). The *LunOSTAR* mission will be a payload that is deployed from Gateway at LaGrange Point L2.

Once the Gateway delivery vehicle is on orbit and berthed, the Gateway crew is responsible for transferring the integrated hardware assembly from the visiting vehicle to the on-orbit stowage location until it is time to deploy *LunOSTAR*.

Requirements begin in Section 4. Sections 1, 2, and 3 are intended to set the context for the requirements that follow.

Program authority is delegated from the RASA Associate Administrator of the Science Mission Directorate (AA/SMD). RASA is ultimately responsible for the scientific success of the *LunOSTAR* Project. The Project encompasses the design, development, test, mission operations, and data verification tasks and coordinates the work of all contractors and investigators.

2. Science Definition

2.1 *LunOSTAR* Science Objectives

This document establishes the framework of requirements for a 6U CubeSat satellite mission with the goal to perform Lunar Occultations of the Sun within the context of the circular restricted three-body problem (CR3BP) of the Earth-Moon system. This is achieved by exploiting the geometrical relationships between the Earth, Moon, and an observatory orbiting around LaGrange Point L4.

Linear state-feedback control methodology is be used to stabilize short-period orbits under the presence of the gravitational effect of the Sun, Solar radiation pressure, and the Lunar orbital eccentricity.

Given the unprecedented near-ultraviolet (NUV) angular resolution achieved by an observatory at L4, this mission establishes a framework for a remote sensing observatory for Solar activity, thereby enabling the monitoring of the entire hemisphere of Solar radiation, and to study different astrophysical issues via Lunar Occultations. The lack of lunar atmosphere, stable background, and low-mass observatory provides the perfect environment for high sensitivity and good angular resolution of the solar corona.

The following primary science objectives support this goal:

OBJECTIVE 1: From LaGrange Point L4, establish a Short-Period Orbit (SPO) that possesses the longest observational time of the Solar corona. The observatory must have a low angular velocity with respect to the Moon for efficient Lunar Occultation (LO) studies.

OBJECTIVE 2: Observe, record, and transmit to earth the solar corona data in the NUV wavelengths.

2.2 Science Instrument Payload Summary Description

The baseline payload configuration consists of two focusing telescopes that are aligned to view the solar corona. The telescopes are comprised of optics assemblies and associated focal plane modules that are maintained in position on-orbit. The optics function like lenses, and the focal plane detector modules like digital film. Telescopes may be used for redundancy or stereoscopic imaging; telescopes image the field of view; the images are co-added on the ground to attain the full instrumental sensitivity. The detectors register the interaction position, time, and energy of the light, and images are built up on the ground. Note: deployable mast that extends from the Observatory may be utilized to accommodate additional focal length.

3. Project Definition

3.1 Project Organization and Management

The Principal Investigator (PI) at RASA is the Technical Authority (TA) and responsible for the overall success of the *LunOSTAR* Project. The PI is accountable to the RASA SMD for the scientific and programmatic success. The PI may choose to delegate day-to-day management of the *LunOSTAR* project to the *LunOSTAR* Project Manager (PM) at RASA. The PI and the PM are responsible for certifying *LunOSTAR* flight readiness to RASA's Science Mission Directorate.

3.2 Project Acquisition Strategy

The payload development, systems engineering support and technical oversight will be led by the PI and PM. Major payload components are as follows:

- Instrument Structure and optional Extendable Mast
- Optics Modules
- Optics glass segments for focal plane assembly, electronics, and metrology

The PI and PM will also oversee

- Observatory bus
- Observatory level integration and test
- Mission Operations

4. Mission Requirements

4.1 Baseline Mission Requirements

The *LunOSTAR* baseline mission is defined as the nominal operation of the *LunOSTAR* observatory (in the configuration specified at the time of the Critical Design Review) for a nominal period of 25 months following deployment from Gateway. It is comprised of five phases:

1. Design, Assembly, Integration, Test, Delivery. This phase encompasses all the work to deliver LunOSTAR to the Launch Service Provider. The launch service and delivery to the Lunar Gateway is handled as a separate contractual action and is not part of these Program Requirements.
2. Gateway deployment to LaGrange Point L4. This phase delivers *LunOSTAR* from the Lunar Gateway to a station keeping position at LaGrange Point L4.
3. In-orbit checkout (IOC). The IOC phase is the period during which the observatory is activated and brought to a state of nominal science operations and is expected to be ≤ 1 month in duration.
4. Baseline science mission. The baseline science mission is defined as the period during which the *LunOSTAR* science observing plan is executed; during this phase, the full set of mission science objectives and the baseline mission science requirements shall be accomplished.
5. End of mission disposal. This is defined as the period after all mission science is complete.

4.1.1 Baseline Science Mission Requirements

This section defines the science requirements imposed on *LunOSTAR* corresponding to the complete set of mission scientific objectives described in § 2.1.

Scientific results obtained from other ground- and space-based observatories in the interim between approval of this document and *LunOSTAR*'s launch may influence the mission's optimal observing strategy. In view of this fact and the exploratory nature of the *LunOSTAR* mission, the requirements specified below reflect the current state of the field and may be revised prior to launch to optimize the scientific return from *LunOSTAR*. If this occurs, this appendix will be updated to reflect the changes and submitted for approval through the Astrophysics Division to the SMD AA.

Achievement of the baseline mission science objectives outlined in § 2.2 imposes the following baseline mission scientific requirements (BSR) on the mission:

BSR1: The baseline science mission shall be a minimum of 24 months in duration.

BSR2: *LunOSTAR* shall perform a minimum of five occultation opportunities of the entire hemisphere of the Sun in the NUV wavelength of interest as viewed from LaGrange Point L4.

BSR3: *LunOSTAR* shall maximize solar corona occultation time while maintaining a low angular velocity with respect to the Moon.

4.1.2 Baseline Mission Technical Requirements

In order to address the *LunOSTAR* primary science objectives described in § 2.1 and satisfy the corresponding baseline mission science requirements specified in § 4.1.1, the *LunOSTAR* mission shall meet the following baseline technical requirements (BTR):

BTR1: The *LunOSTAR* observatory and associated ground support system shall be designed and fabricated to sustain science operations at the level required to achieve the baseline mission science requirements defined in § 4.1.1.

BTR2: The *LunOSTAR* observatory shall have an angular resolution with half power diameter ≤ 3 arcseconds (See References 13 and 14).

BTR3: The *LunOSTAR* observatory shall have the capability to measure solar radiation over the NUV range of 300-400nm (See References 13 and 14).

4.1.3 Baseline Mission Data Requirements

The *LunOSTAR* mission's data requirements are as follows:

BDR1: The *LunOSTAR* science operations system shall collect and make available to the Science Operations Center (SOC) > 95% of all data collected by the observatory.

BDR2: All data files, calibration files, and software tools required for analysis of the LunOSTAR science data shall be delivered to the PI within one week of validation by the LunOSTAR science operations system.

4.1.4 Baseline Mission Success Criteria

The baseline mission success criteria are met when the Baseline Mission Science Requirements are satisfied.

4.2 Orbit Requirements

ORB1: *LunOSTAR* shall be deployed from the NASA Gateway at the L2 LaGrange Point within the station's Near-Rectilinear Halo Orbit (NRHO). Reference NASA Gateway System Requirements, Document No: DSG-RQMT-001, Requirement L2-GW-0163 NRHO Orbit.

ORB2: The *LunOSTAR* deployment readiness date is nominally planned for no later than 31 December 2026. Deployment shall be from NASA's Gateway at L2.

ORB3: *LunOSTAR* shall arrive at its nominal short-period orbit within the Umbra of the Moon.

ORB4: The spacecraft's orbital period around L4 should be close to the orbital period of the Moon around the Earth.

ORB5: The attitude of the spacecraft should be controlled within ± 10 arcseconds during each occultation opportunity.

4.3 Observatory Requirements

OR1: Mission Elapsed Time (MET) shall start at the moment of CubeSat deployment from the Gateway.

OR2: Upon completion of all mission science, will be *LunOSTAR* passivated such that no power will be provided to any components.

OR3: *LunOSTAR* shall not have detachable parts during deployment, mission operations, or end-of-life and comply with NASA space debris mitigation guidelines as documented in NASA Technical Standard NASA-STD-8719.14A.

OR4: *LunOSTAR* shall be a 6U CubeSat.

OR5: *LunOSTAR* shall comply with the General Environmental Verification Standard (GEVS) Appendix B - Environmental Verification for CubeSats Companion to GSFC-STD-7000 (General Environmental Verification Standard).

OR6: *LunOSTAR* shall be capable of mission science in the lunar orbital environment as shown via thermal analysis.

OR7: A PANTONE formatted graphic shall be created which represents the purpose of the *LunOSTAR* mission.

OR8: All cells / batteries on *LunOSTAR* shall adhere to the design and testing requirements for spacecraft flight onboard or near the ISS as derived from the NASA requirement document JSC 20793 Crewed Space Vehicle Battery Safety Requirements.

OR9: *LunOSTAR* shall be passive and self-contained from the time of integration up to the time of deployment. Note: No charging of batteries, support services, and or support from the Gateway crew is provided.

OR10: *LunOSTAR* shall comply with NASA-STD-6016, Revision dated 07-11-2008, Section 4.2, Standard Materials and Processes Requirements for Spacecraft, and applicable NASA guidelines for hazardous materials. Beryllium, cadmium, mercury, silver or other materials shall not be used.

5. Mission Cost Requirements

5.1. Cost Cap

LunOSTAR project funding is capped at $1million US Dollars for design, development, mission operations, and data analysis and archiving of the observatory. The Launch, launch vehicle, and Gateway integration and accommodation costs are not included under this cap and are outside of the scope of this document.

6. Mission Facilities

The *LunOSTAR* project shall utilize the Gateway capability to deploy CubeSats, as defined in the Gateway System Requirements Document, DSG-RQMT-001, Revision Baseline, requirement L2-GW-0270 Satellite Deployment.

7. Public Outreach and Education

The *LunOSTAR* project shall develop an Education and Public Outreach Plan. Science images shall be made available for outreach purposes within one month of the end of in-orbit checkout.

8. Mandatory Compliance Documents

1. CubeSat Design Specification (1U – 12U), REV 14.1 CP-CDS-R14.1.
2. NASA General Environmental Verification Standard (GEVS), GSFC-STD-7000B.
3. FED-STD-209E, Clean Room and Work Station Requirements, Controlled
4. Environments
5. NASA-STD-6016, Revision dated 07-11-2008, Section 4.2, Standard Materials and Processes Requirements for Spacecraft
6. NASA Reference Pub. 1124, Outgassing Data for Selected Spacecraft Materials

9. Reference Documents

1. "Controlled Short-Period Orbits around Earth-Moon Equilateral Libration Points for Lunar Occultations": Khushboo Patel, Luis E. Mendoza Zambrano, David Canales, Riccardo Bevilacqua, Stephen Eikenberry, Octavi Fors, José María Gómez, Andrea Richichi. Accepted to Acta Astronautica, May 8, 2023.
2. NASA's Gateway Program. https://www.nasa.gov/gateway/overview
3. Human Exploration and Operations Directorate Requirements, HEOMD-004
4. Gateway System Requirements. https://ntrs.nasa.gov/api/citations/20190029153/downloads/20190029153.pdf
5. Commercial Lunar Payload Services (CLPS) Deliveries. https://science.nasa.gov/lunar-discovery/deliveries
6. Near-rectilinear halo orbit. https://en.wikipedia.org/wiki/Near-rectilinear_halo_orbit
7. Cubesat deployment from a near rectilinear halo orbit. https://ntrs.nasa.gov/citations/20210024146
8. NASA cubesat to test lunar Gateway orbit. https://spacenews.com/nasa-cubesat-to-test-lunar-gateway-orbit/
9. CAPSTONE: A pathfinding moon CubeSat for the Artemis program.

https://www.space.com/capstone-moon-cubesat-mission
10. Process for Limiting Orbital Debris. NASA-STD-8719.14C
11. Crewed Space Vehicle Battery Safety Requirements. JSC 20793
12. Doroba, S.; Kale, R.; Canales, D.; Cho, H.; Eikenberry, S.; Fors, O.; Gomez, J. M.; Richichi, A.; Leveraging the moon and stable libration point orbits around L4/L5 to observe the Solar corona; 33rd AAS/AIAA Spaceflight Mechanics Meeting, Austin, Texas; January 2023 (Accepted).
13. PROBA-3 (Project for On-Board Autonomy-3). https://www.eoportal.org/satellite-missions/proba-3#ff-technology
14. PROBA-3 – Formation flight with view of the Sun. https://www.mps.mpg.de/6884329/proba-3#:~:text=This%20configuration%20allows%20observations%20of,a%20resolution%20of%202.8%20arcseconds

10. Terms and Definitions

Throughout this document, one of three different operational words are used; their associated definitions are.

“Shall” is used to denote requirements that must be met and will need formal verification.

“Should” is used to denote a strong recommendation or a suggestion to make formal verification of another requirement easier.

“Will” statements serve to indicate events that the spacecraft developers should be prepared for and represent “best effort” to accomplish.

“Note” is used to denote a recommendation or advice meant to aid the CubeSat Developer.

In the event conflicts arise between documents, this document’s requirements take precedence.