



# **ARCSTONE: Calibration of Lunar Spectral Reflectance from Space**

## **ESTO InVEST-20-001**

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# Moon: Accurate Source for Calibration On-orbit

*For a small investment → a cost saving, enabling, and permanent solution*

Calibration reference: Empirical model of Lunar Spectral Irradiance (entire disk)



Reflectance of Lunar surface stable to  $< 10^{-8}$  / year

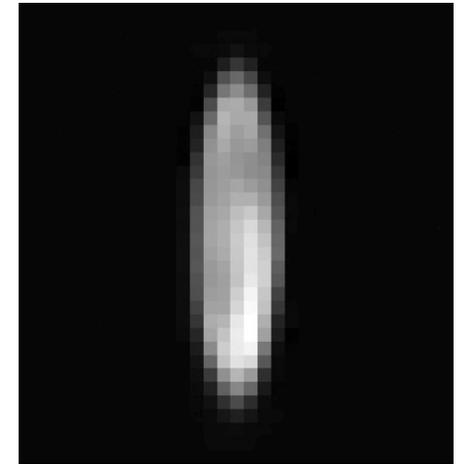
- Accuracy of current Lunar Model (ROLO): 5 – 10%

## EOS On-Orbit Calibration Need:

**Absolute accurate spectral irradiance for all lunar phase and libration states !**

### Expected Impacts:

- Quality of data products
- Long-term consistency
- Handling data gaps
- Reduces instrument size, mass, power
- Reduce complexity
- Accurate CubeSat sensors



Lunar image by SeaWiFS

# ARCSTONE Objectives

## Long-term Objective:

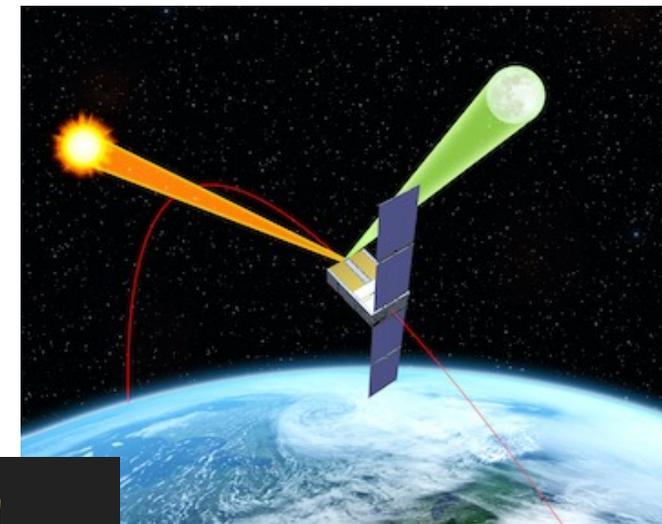
- To enable on-orbit high-accuracy absolute calibration for the past, current, and future reflected solar sensors in LEO and GEO by providing lunar spectral irradiance as function of satellite viewing geometry and specified wavelength.

## IIP Objective (complete):

- To design, build, calibrate and validate a prototype instrument, demonstrate *form-fit-function for a 6U observatory with compliance in size, mass, power, and thermal performance.*

## InVEST Objective:

- To demonstrate high-accuracy measurements of lunar spectral reflectance,  $< 0.5\%$  ( $k=1$ ), by building a flight instrument, integrating payload with 6U CubeSat, operating it in LEO for 6 months, validation and data analysis.



ARCSTONE FSR Concept: Accurate measurements of Lunar Irradiance from Space with an Instrument flying on 6U CubeSat (courtesy BCT) in LEO.

ARCSTONE payload design

TRL<sub>current</sub> = 5 (IIP)

TRL<sub>out</sub> = 7 (InVEST)

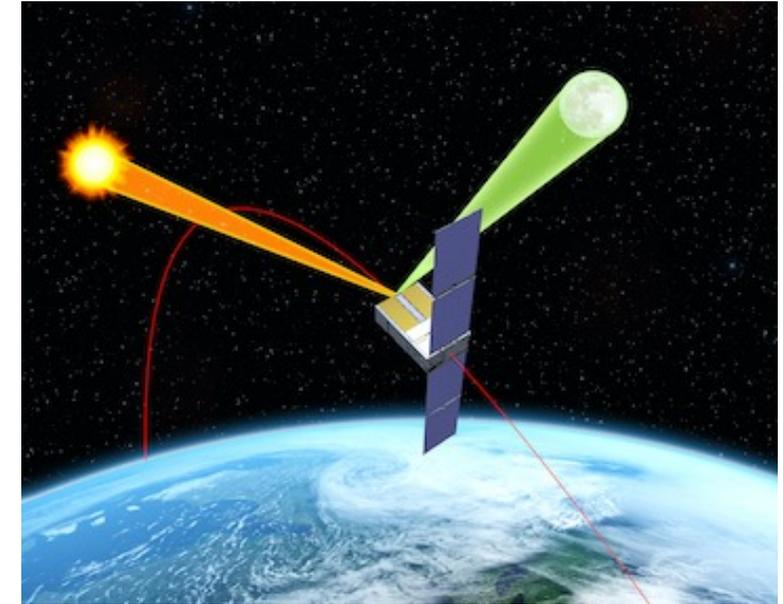
# ARCSTONE InVEST Project Outline

## Key Parameters:

- Data to collect: Lunar spectral reflectance every 12 hours
  - For  $-90^\circ < \text{Lunar Phase Angles} < 90^\circ$  (2 weeks out of 4) required
  - For  $-135^\circ < \text{Lunar Phase Angles} < 135^\circ$  (3 weeks out of 4) demonstration
- Combined uncertainty of lunar reflectance  $< 0.5\%$  ( $k=1$ )
- Spectrometer with single-pixel field-of-view about  $0.7^\circ$
- Spectral range from 350 nm to 2300 nm, contiguous spectral sampling at 4 nm
- *Sun synchronous orbit at 500 km altitude, 6 months flight time*
- *Launch by SpaceX Falcon-9 (Transporter-14 mission), planned for 6/15/2025*
- *CubeSat deployer and LV integration by Maverick Space systems*

## Key Technologies to Enable the Concept:

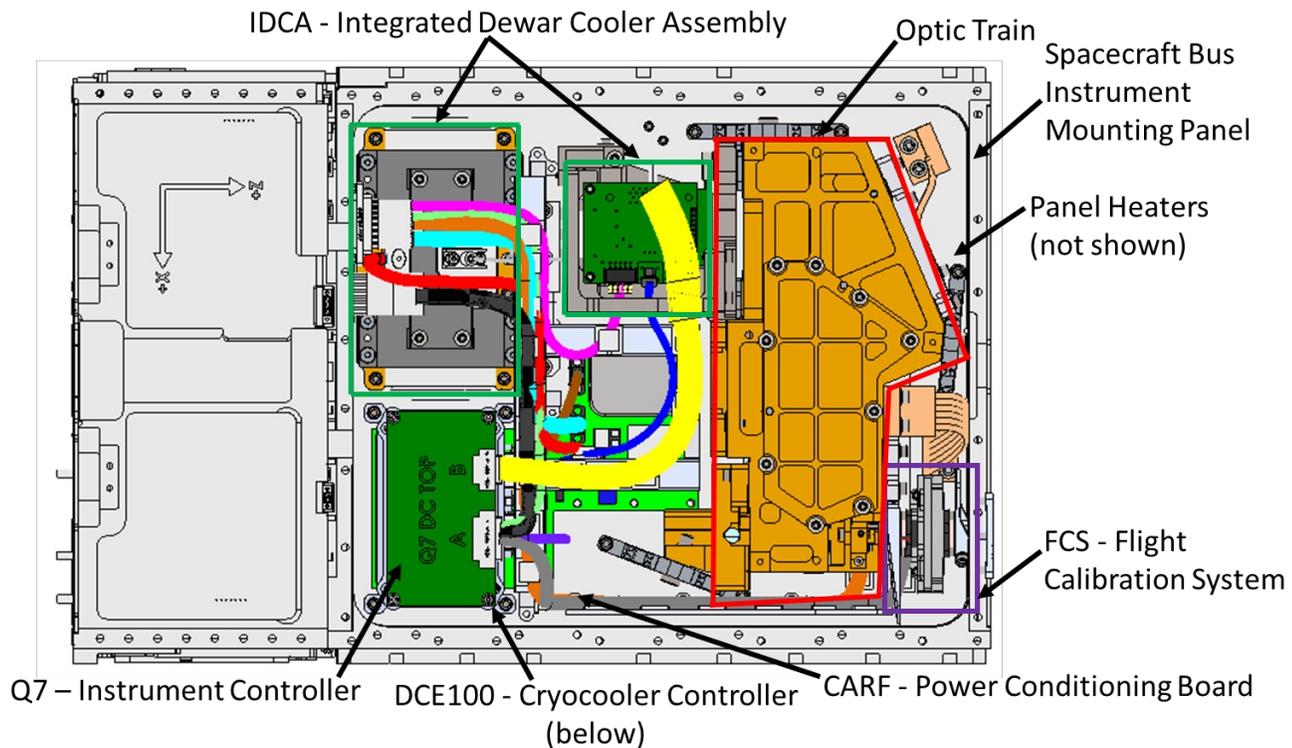
- Approach to orbital calibration via referencing Sun (TSIS measurements):  
Demonstration of lunar and solar measurements with *the same optical path using integration time to reduce solar signal*
- Pointing ability of spacecraft now permits obtaining required measurements *with instrument integrated into spacecraft.*



6U CubeSat Spacecraft Bus:  
courtesy of Blue Canyon Technologies (BCT)

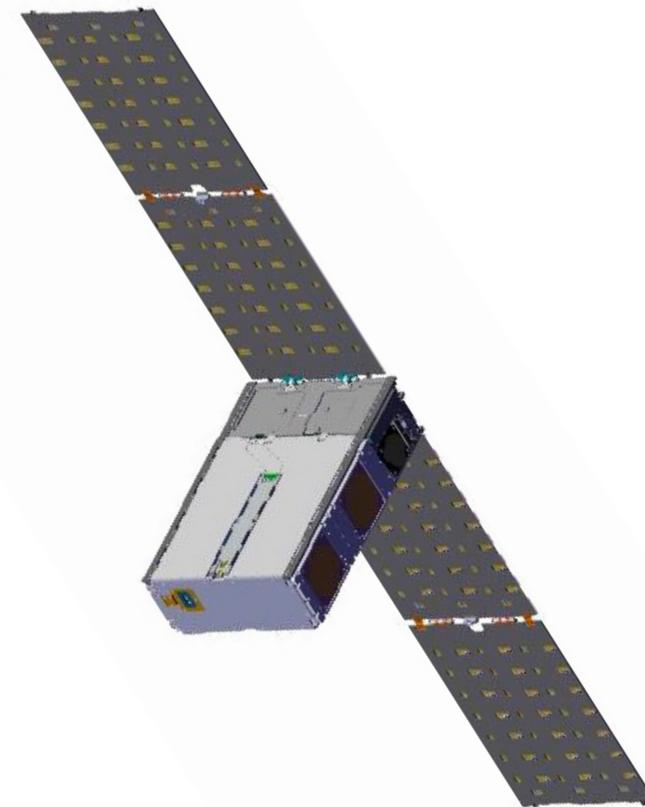
BCT 6U XB6 Spacecraft pointing:  
Accuracy  $0.002^\circ$  (1-sigma) in 3 axis  
Stability 1 arc-sec over 1 sec

# ARCSTONE: Space Segment Design



ARCSTONE payload integrated into 4U space

- Detector operating temperature = 140°K
- Optics bench operating temperature = -3°C



BCT XB6: 6U CubeSat  
Courtesy of Blue Canyon Technologies (BCT)

## ARCSTONE InVEST: Payload Status / Fab & Assembly

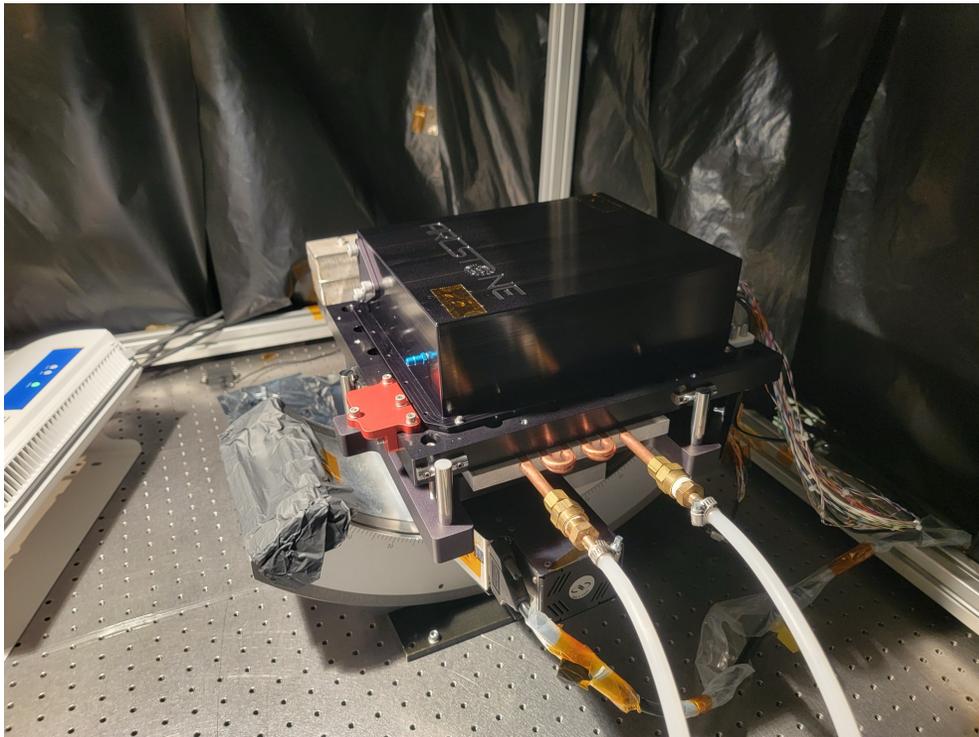
- **Payload fabrication completed:**
  - Resonon (optics, metallic parts)
  - NASA GSFC (black paint)
  - Creare (ARF board)
  - Xiphos (Q7 and Interface boards)
  - LASP (Flight Calibration System)
  - NASA LaRC (harnesses)
- **Payload optomechanical assembly and alignment completed (Resonon):**
  - Optomechanical assembly and alignment testing
  - Electronics and cabling assembly
  - Functional testing of fully assembled payload
- **Payload electronics and cabling assembly completed (NASA LaRC):**
  - All flight electronics and harnessing
  - Automated Payload Functional testing



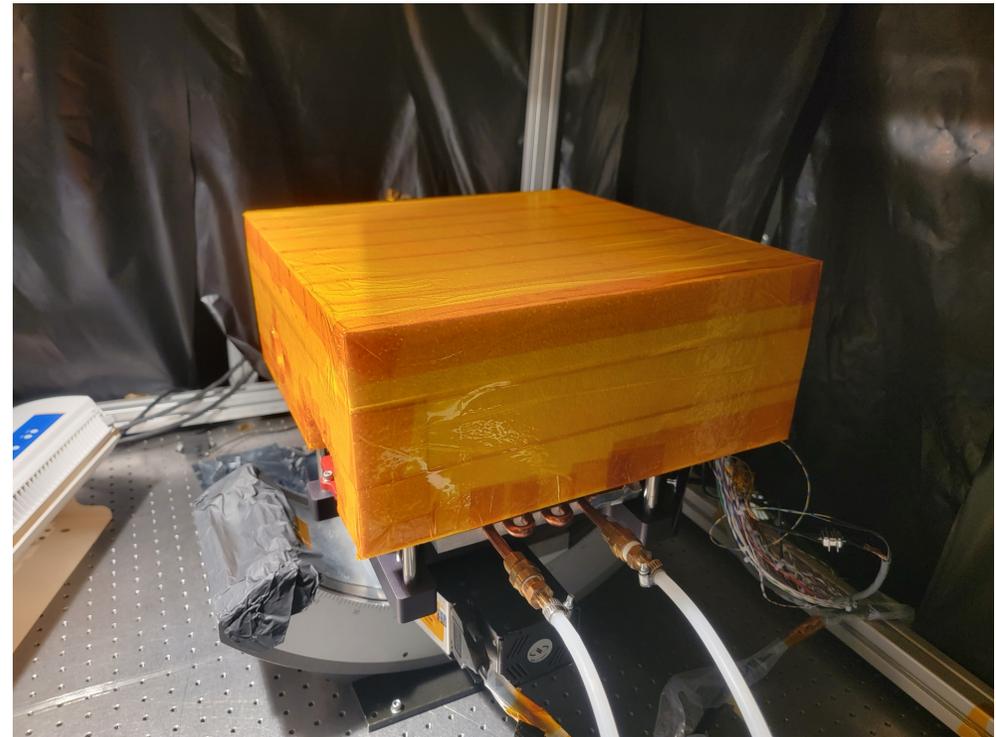
ARCSTONE Payload and BCT Bus EDU: fully assembled and functionally tested at LaRC laboratory

## ARCSTONE InVEST: Payload Status / Characterization

- **Instrument Characterization in Progress:**
  - Objective is to meet the uncertainty requirements



ARCSTONE Payload setup at LASP “black room”

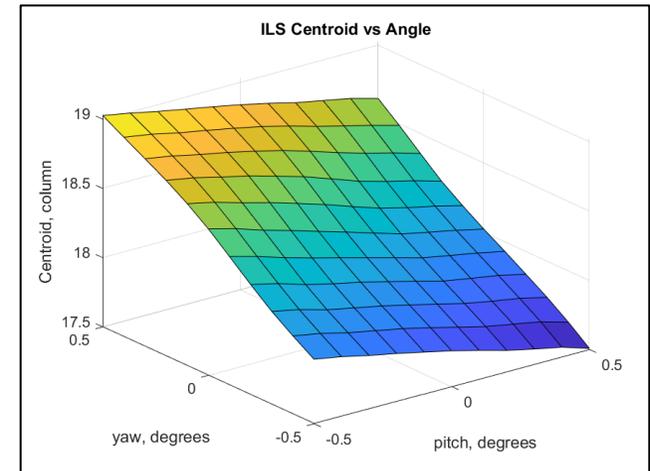
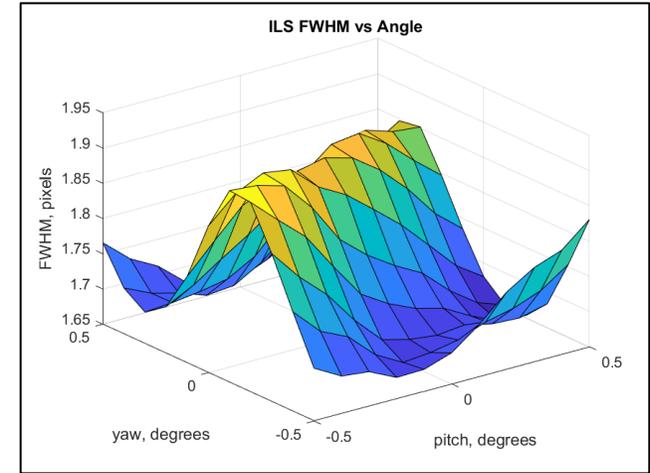


ARCSTONE Payload setup at LASP “black room”: insulated

# ARCSTONE InVEST: Payload Status / Characterization

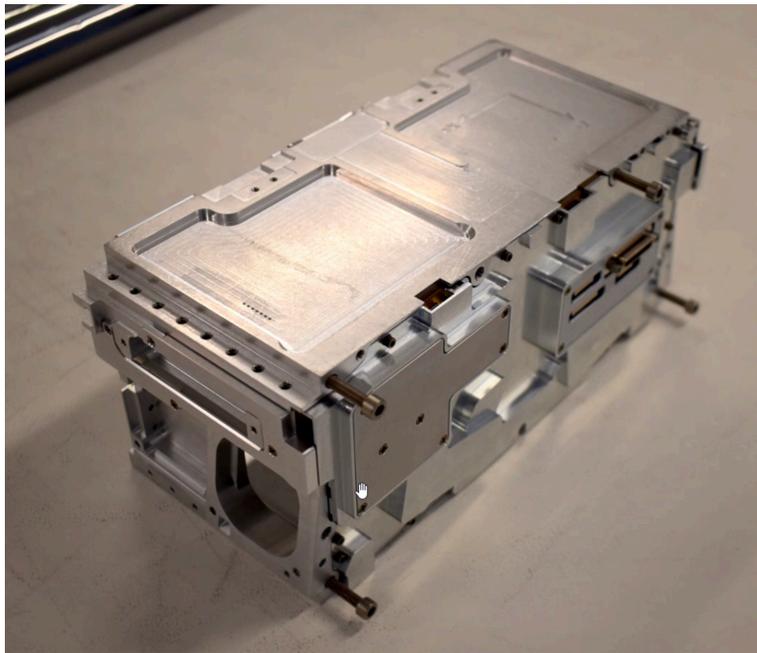
- **Planned Characterization Activities:**
  - **Boresight (Field of View/Vignetting) [complete]**
  - **Thermal Background (Dark) Signal [complete]**
  - **Instrument Line Shape (ILS) vs. Temperature [complete]**
  - **Stray Light and Scatter [complete]**
  - **Dispersion [complete]**
  - **ILS vs. Angle vs. Wavelength [in-progress]**
  - **Polarization Sensitivity [in-progress]**
- **Planned completion by mid-June 2024**

ILS vs Angle – 408nm

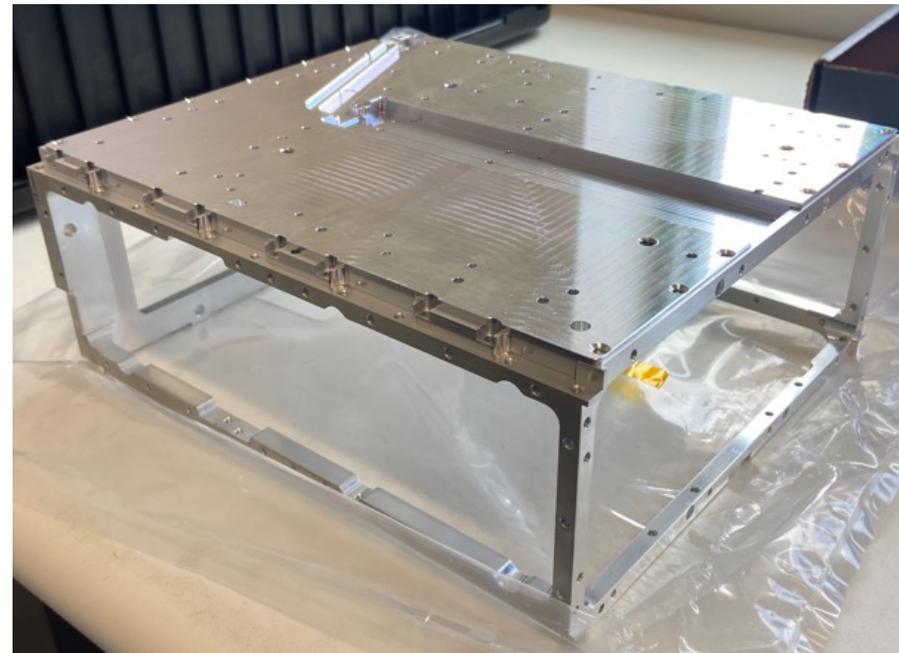


## ARCSTONE InVEST: BCT Bus Status / Fab and Assembly

- **BCT XB6 spacecraft status:**
  - XB1 Completed and in storage from November 1, 2023
  - 6U Chassis completed
- **XB1 EDU completed in July 2023**
  - Supports flight software and CONOPS development & testing
  - Functionally tested at LaRC with fully assembled flight payload



ARCSTONE Deliverable XB1 EDU



ARCSTONE +Y Bus Panel with Chassis



# ARCSTONE InVEST: Manifested Launch by SpaceX

## Maverick/SpaceX Launch (managed by NASA CSLI):

- Monthly meetings with CSLI/Maverick/SpaceX
- *ICD for CubeSat deployer approved and signed:*
  - *Maverick's Tab-based 6U CubeSat dispenser with isolators*
  - *Over 50% Reduction in gRMS Environment Transmission*
- Launch by SpaceX:
  - Transporter-14 mission (Falcon-9)
  - Integrator: Maverick Space Systems
  - Readiness date: April 15, 2025
  - Expected launch date: June 15, 2025 from Vandenberg SFB, CA
  - SSO at 500 km altitude (LTAN is TBD)



RIDESHARE PAYLOAD USER'S GUIDE

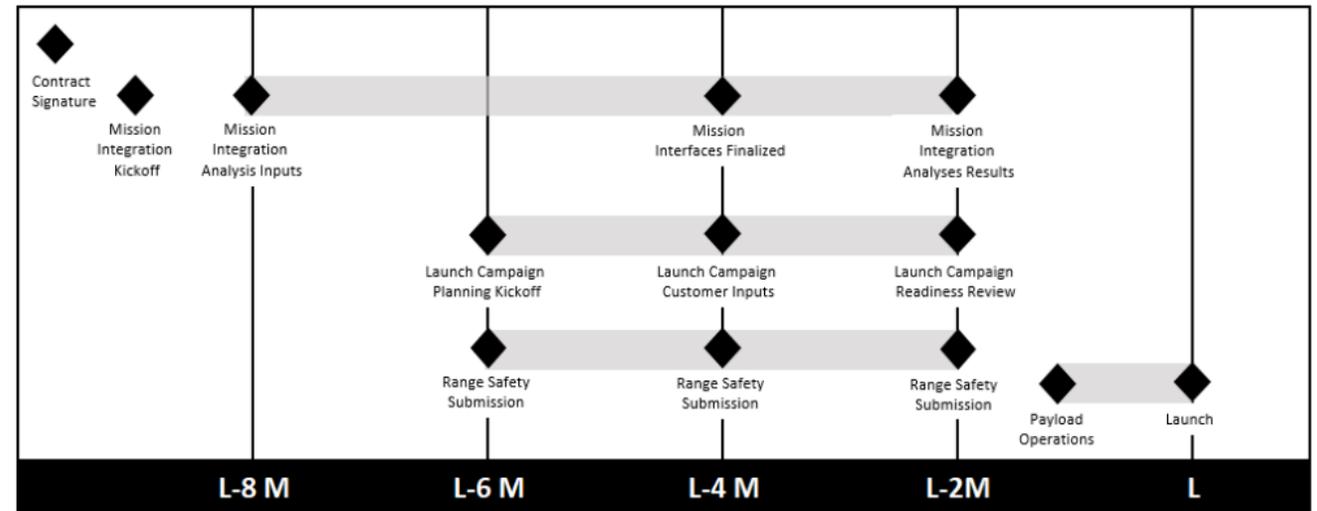
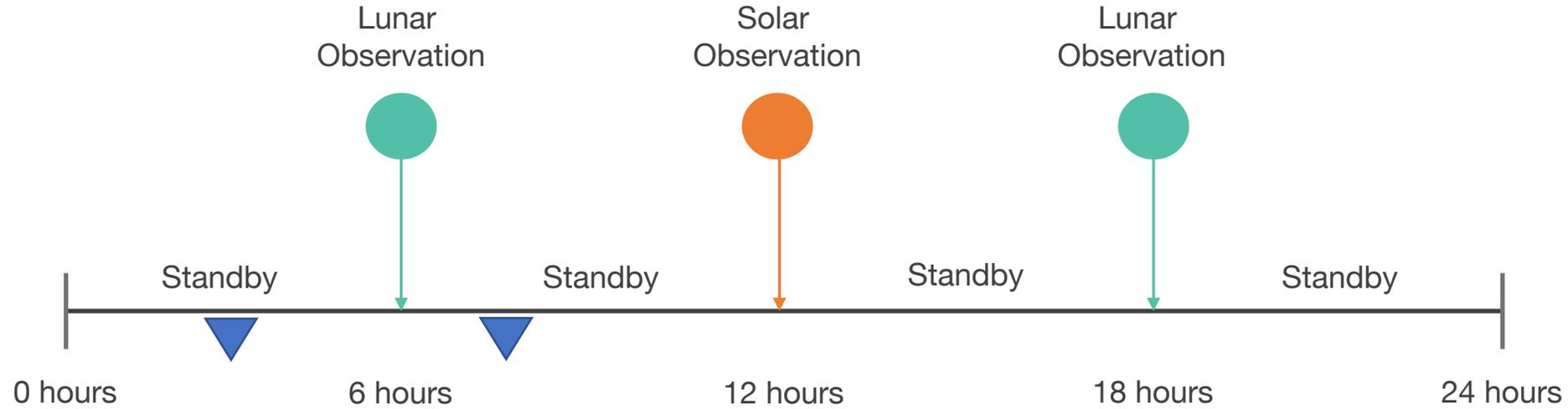


Figure 1-2: Typical Rideshare Program Schedule





# ARCSTONE InVEST: Day In The Life (DITL) for Nominal Operations Lunar Phase Angle from $-0.5^\circ$ to $-90^\circ$ and from $0.5^\circ$ to $90^\circ$



▼ = Downlink / Uplink

### Lunar Observation Sequence:

- Dark Frames
- Lunar measurements
- Spectral Calibration
- Int. time = 16 sec
- Cryocooler temp. at 140K

### Solar Observation Sequence:

- Dark Frames
- Solar measurements
- Spectral Calibration
- Int. time = 40 micro sec
- Cryocooler temp. at 140K

## ARCSTONE InVEST: Planned Data Products

Product	Contents	Level
Bus data	Bus time-ordered telemetry	Level-0
Instrument Engineering Data	Instrument engineering time-ordered telemetry	Level-0
Calibration Data	Sun, dark, cold, spectral calibration time-ordered telemetry	Level-0
Lunar Data	Moon time-ordered telemetry	Level-0
Lunar Measurements	Calibrated lunar spectral reflectance and irradiance	Level-1

- ARCSTONE data and algorithms → ATBD for Level-0 and Level-1 data products
- Main two approaches:
  - (1) ratioing spectrometer
  - (2) absolute calibration to SSI (TSIS-1/2)
- Data Analysis and Validation:
  - Focus on measurement uncertainty for lunar reflectance and irradiance
  - Lunar modeling for data validation



## ARCSTONE InVEST: Summary and Path Forward

***Lunar Calibration* offers a cost-efficient approach to accomplish the necessary calibration accuracy, stability, and inter-consistency of multiple sensors in reflected solar (VSWIR) in LEO and GEO:**

- Collaboration with ROLO, Air LUSI, MLO LUSI, SLIM and LIME projects
- Participation in the GSICS activities
  
- Currently ARCSTONE is at TRL 5+ (June 2024):
  - Design completed
  - Bus and payload fabrication and assembly completed
  - Functional tests completed
  
- Instrument Characterization by mid-June 2024
- Payload ConOps Simulation Testing by end of July 2024
- Payload and Bus I&T by end of December 2024
- Spacecraft Delivery to LV Integrator by mid April 2025
- Launch in mid-June 2025
- Space flight for 6 months in June – December 2025
- Initial release Level-1 data product with uncertainty budget analysis (2026)



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## Recent Publications:

Swanson, R., C. Lukashin, M. Kehoe, M. Stebbins, H. Courrier, T. Jackson, M. Cooney, G. Kopp, P. Smith, C. Buleri, T. Stone, “The ARCSTONE Project to Calibrate Lunar Reflectance,” *IEEE Aerospace Proceedings*, 2020

Available online: <https://ieeexplore.ieee.org/abstract/document/9172629>

Stone, T.C., H. Kieffer, C. Lukashin, K. Turpie, “The Moon as a Climate-Quality Radiometric Calibration Reference,” *Remote Sens.*, 12, 1837, 2020

Available online at <https://www.mdpi.com/2072-4292/12/11/1837>

Website <http://arcstone.larc.nasa.gov>



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**THANK YOU !**