National Aeronautics and Space Administration

# Thermal Technology Development for the ARTEMIS Initiative (ARTEMIS-T)


## Principal Investigator: David Bugby (353); Co-Investigators: Jose Rivera (353) Carol Raymond (410), Neil Murphy (326), Sharon Kedar (335)


Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Architecture for Thermal Enclosure of Moon Instrument Suites - Strategic Initiative Leader: Ying Lin

### PROJECT OBJECTIVES (FY20-FY22)

***PRIMARY:*** Develop passive (radioisotope-free) lunar instrument thermal enclosure architecture for operation over multiple lunar day/night temp/power cycles
***SECONDARY-1:*** Develop carrier-independent, extended-life thermal enclosure designs for lunar magnetometers, seismometers, and IR spectrometers
***SECONDARY-2:*** Infuse PALETTE GCD project technologies including thermally-switched enclosures, spacerless MLI, thermal isolators, Vectran tension cables
***RATIONALE:*** Provide JPL with ***Strategic Competitive Advantage*** in responding to lunar instrument AOs, as extended-life capability will likely be highly valued

### FY22 OBJECTIVES

1. Complete the design/fabrication of a lunar magnetometer thermal enclosure (LMTE) for thermally managing the ARTEMIS-M Vector He Magnetometer (VHM)
2. Conduct a 36-day TVAC test to verify LMTE/VHM lunar day/night performance (conducted in JPL Building 125/B87)
3. Ensure that the LMTE/VHM system is ready to submit as a stand-alone lunar instrument proposal in the very near future

### BACKGROUND

- In FY19, the submitted ARTEMIS-T SR&TD and PALETTE NASA GCD proposals were nearly identical, thinking (at most) just one would be awarded
- However, both were indeed awarded, creating a need to re-plan ARTEMIS-T for project differentiation
- As directed by JPL 4X management, ARTEMIS-T changed course to Instrument Accommodation; PALETTE stayed on its Technology Development course
- The two projects have proceeded in parallel over the last 3 years, with significant achievements on both projects

### APPROACH TO EXTENDED-LIFE LUNAR OPERATION ON LIMITED-LIFE CLPS LANDERS

- Add C&DH, power, telecom, and batteries to a science payload (SP) and mount all that equipment within an internal housing (IH)
- Conductively isolate the IH from an external housing (EH) using Vectran tension cables (VTC) and conductively isolate the EH from the carrier
- Radiatively isolate the SP using nested boxes of double-aluminized Mylar hanging from the VTCs, which is known as "Spacerless MLI"
- Thermally link the IH to the radiator with a Reverse-Operation DTE Thermal Switch (ROD-TSW) in series with a propylene mini-LHP

### APPROACH TO MEETING ARTEMIS-T FY22 OBJECTIVES

- Design, build, assemble, and integrate the list of items in the table directly below this panel labeled "DESIGN/BUILD ELEMENTS"
- To overcome a high supplier quote, ARTEMIS-T built a mini-LHP (which did not work); as a backup, the design was modified to accept the PALETTE mini-LHP
- Overall assembly benefited from previous PALETTE experience, including building internal/external housings (IH/EH) out of corner/rail pieces as a cost-saver
- Incorporating the VHM sensor/electronics was a joint effort with ARTEMIS-M requiring building/integrating the set of cables (C1-C4) in the diagram below

### RESULTS

- Test results for COLD cycles 2-4, and HOT cycles 3-4 are provided below in the results panel along with discussions of the thermal behavior of the system
- The system provided totally passive thermal control of VHM sensor/electronics except for brief periods of user intervention as described on the results panel

### SIGNIFICANCE → *JPL NOW HAS A DISTINCT STRATEGIC COMPETITIVE ADVANTAGE IN PROPOSING EXTENDED-LIFE LUNAR INSTRUMENTS*

- ARTEMIS-T seismometer thermal enclosure design was instrumental in JPL winning the $40M Farside Seismic Suite (FSS) proposal
- FSS will take the Mars Insight-based VBB and SP seismometers to the lunar farside in 2025 (PI-Mark Panning, Deputy PI-Sharon Kedar)
- ARTEMIS-T magnetometer thermal enclosure design will be proposed very soon in response to a new lunar instrument AO (PI-Carol Raymond)
- Other lunar opportunities from ARTEMIS-T include LuSEE-Night led by UC Berkeley (PI-Stuart Bale) and LCRT, led by JPL (PI-Saptarshi Bandyopadhyay)

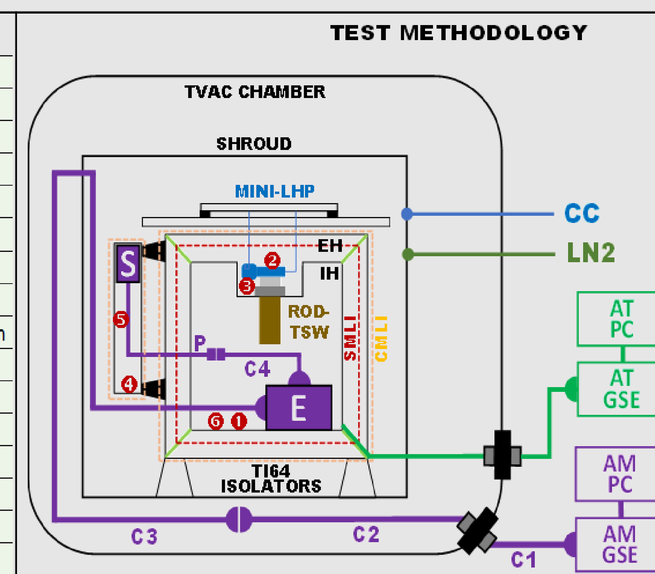

### ACKNOWLEDGEMENTS → *KEY PERSONNEL THAT HAVE CONTRIBUTED MIGHTLY TO ARTEMIS-T (AND ARTEMIS-M) SUCCESS*

- ***Engineering:*** David Pierce, Bob Kovac, Kris Stone, Bart Patel, Kurt Gonter, Joanna Farias, Nik Schwarz, Kevin Anderson, Jason Kempenaar
- ***Management:*** Satish Khanna, Ying Lin, Tim O'Donnell, Brian Lim, Garry Burdick, Sabrina Feldman, Virgil Mireles, Gani Ganapathi, Chuck Phillips


### TEST REQUIREMENTS

| Subsystem | Item | Requirements *(path to flight)* |
|---|---|---|
| ARTEMIS-T | Int./Ext. Housings (IH/EH) | IH fits ARTEMIS-M + FSS non-payload items |
| | ROD-TSW Thermal Switch | 273 K actuation, 5 W/K ON, 0.002 W/K OFF |
| | Propylene Mini-LHP | Function as loop thermosyphon or mini-LHP |
| | Vectran tension cables (VTC) | 11/36 kN operating/ultimate load |
| | Spacerless MLI (SMLI) | e* < 0.002 (between IH and EH) |
| | Conventional MLI (CMLI) | e* < 0.02 (outside of EH and rigid tube) |
| | Thermal Isolating Mounts (Ti64) | G < 0.01 W/K, 50 kg instrument, GEVS |
| | Solar Panel Simulator | Provides appropriate cold case heat leak path |
| | Rigid Sensor Tube | 0W, -173C/100C op, -183C/110C n-op |
| | Heaters/Temp Sensors | Sufficient to simulate flight instrument |
| ARTEMIS-M | VHM Sensor | 0.3W, -30C/80C op, -40C/100C n-op |
| | VHM Electronics Box | 3.9W/1.4W, 0C/40C op, -20/50C n-op |
| | GSE Cables C1, C2, C3, C4 | < 0.02 W/K,-173C/100C op, -183C/110C n-op |
| TVAC I&T | Integration Plate | Integration plate rests on shroud bottom |
| | Shroud (LN2, CC Cooling) | LMTE test assembly fits within shroud |

### TEST METHODOLOGY

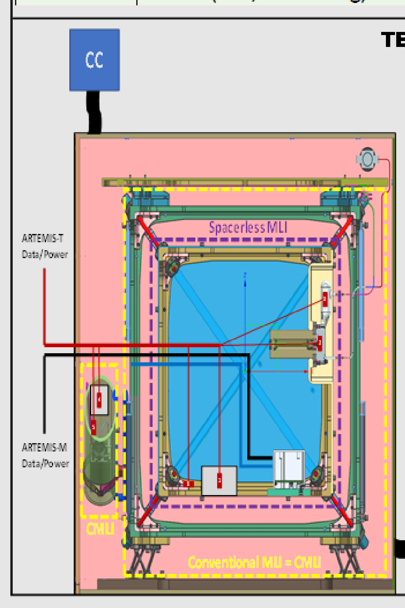



**HOT Case**
1. SHROUD AT 280 K
2. ❶ + ❹ = 8.05 W
3. E = 2.25 W
4. S = 0.15 W
5. ❻ = 0.15 W
6. ❷, ❸ AS NEEDED*
7. ❺ = 0.0 W

**COLD Case**
1. SHROUD AT 90 K
2. ❶ + ❹ = 3.05 W
3. E = 2.25 W
4. S = 0.15 W
5. ❻ = 0.15 W
6. ❷, ❸ AS NEEDED*
7. ❺ = AS NEEDED**

* FOR STARTUP/RESTART
** FOR SENSOR SURVIVAL

### TEST SETUP




Six (6) Power Supplies Needed for ARTEMIS-T Heaters Below
1. Elec Box Simulator — 3 Minco HK6900, 0.5" x 1", 210/3 ohms
2. Evaporator Starter — 3 Minco HK6900, 0.5" x 1", 210/3 ohms
3. Reservoir Set-Point — 1 Minco HK6900, 0.5" x 1", 210 ohms
4. Sensor Simulator — 1 Minco HK6900, 0.5" x 1", 210 ohms
5. Sensor Survival — 1 Minco HK6900, 0.5" x 1", 210 ohms
6. Comm Simulator — 3 Minco HK6900, 0.5" x 1", 210/3 ohms

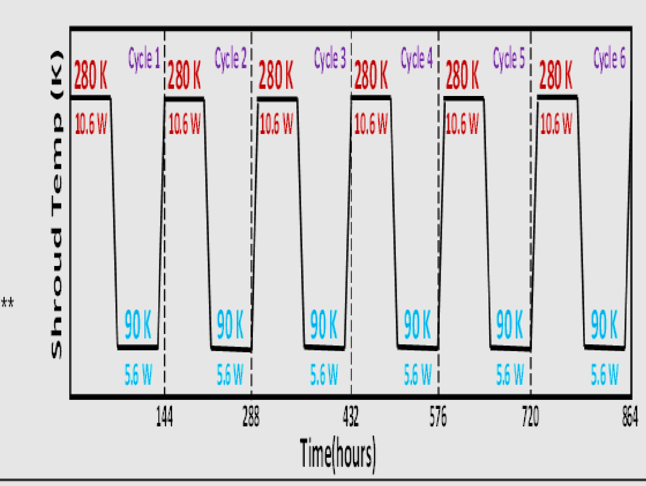
... wire all with low k wire leads as was done for PALETTE

NOTE: ARTEMIS-M is providing their own data/power system

### TEST PROFILE

HOT Cycle
Shroud = 280 K
$Q_{IH}$ = 10.3 W
$Q_{sensors}$ = 0.3 W
$N_{cycles}$ = 6
Duration = 72 hour*
* includes heat up

COLD Cycle
Shroud = 90 K
$Q_{IH}$ = 5.3 W
$Q_{sensors}$ = 0.3 W + QC**
$N_{cycles}$ = 6
Duration = 72 hour*
* includes cool down
** survival power (if needed)

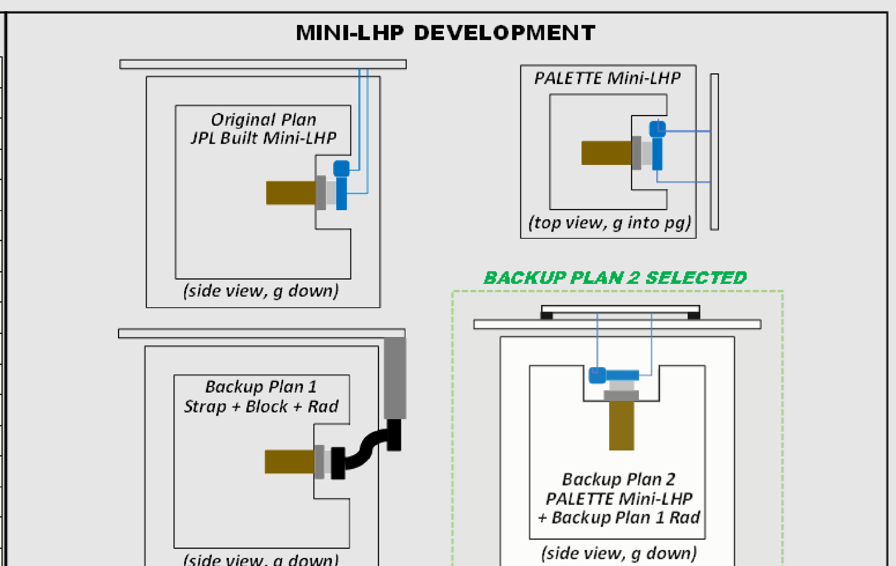



### DESIGN/BUILD ELEMENTS

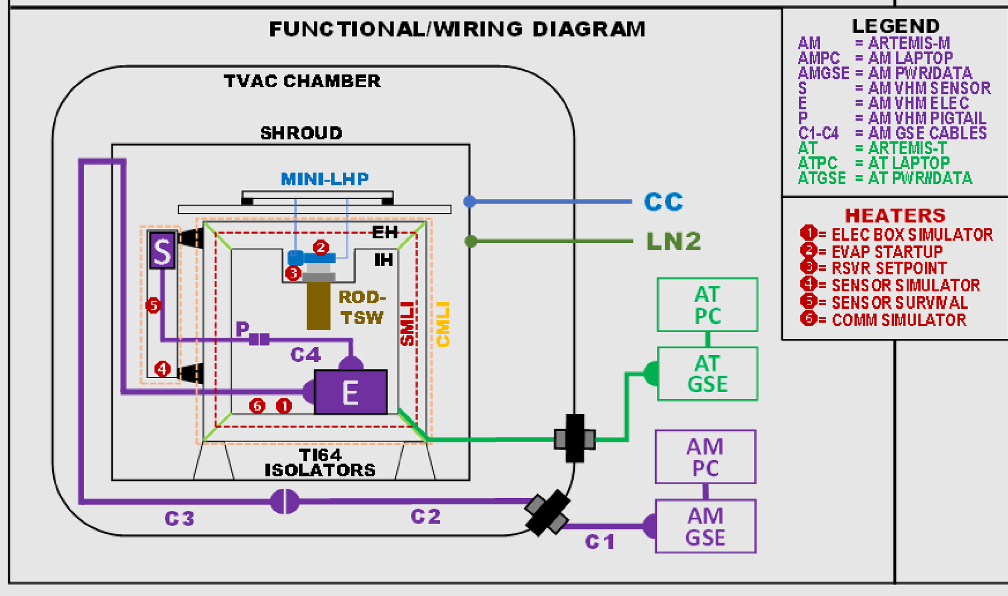
| Subsystem | Element | Design | Heritage* |
|---|---|---|---|
| ARTEMIS-T | Int./Ext. Housings (IH/EH) | 30/40 cm cubes, corner/rail build | P |
| | ROD-TSW Thermal Switch | Ultem body, 1.8 mil pre-stretch | R, P, F |
| | Propylene Mini-LHP | PALETTE unit made by Aavid | P |
| | Vectran Tension Cables (VTC) | 0.25" OD made by Applied Fiber | P, F |
| | Spacerless MLI (SMLI) | 7 layers, from FSS prototype | P, F |
| | Conventional MLI (CMLI) | 20 layers | SF |
| | Thermal Isolating Mounts | Ti64, from FSS prototype | F |
| | Solar Panel Simulator | 6061 Aluminum plate | SF |
| | Rigid Sensor Tube | G10, McMaster-Carr | SG |
| | Heaters/Temp Sensors | Kapton film, Minco HK6900/PRTs | SG |
| ARTEMIS-M | VHM Sensor | CuSP flight spare | C |
| | VHM Electronics Box | CuSP flight spare | C |
| | GSE Cables C1, C2, C3, C4 | 25 wires, 26 gauge Cu, brass wrap | SG |
| TVAC/I&T | Integration Plate | 6061 Aluminum plate | SG |
| | Shroud (LN2, CC Cooling) | 56 cm cube, 0.25" thick, 6061 Al | SG |

* P = PALETTE, R = R&TD, F = FSS, SF = Standard Flight, SG = Standard GSE, C = CuSP

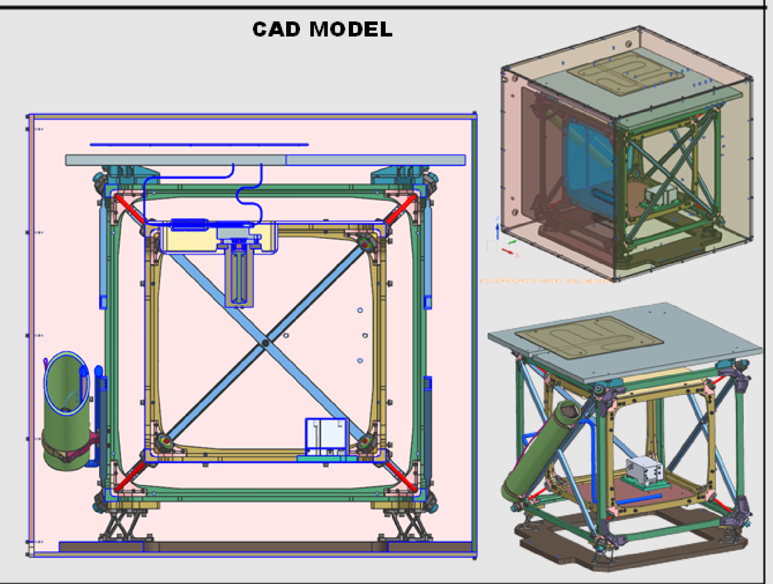
### MINI-LHP DEVELOPMENT



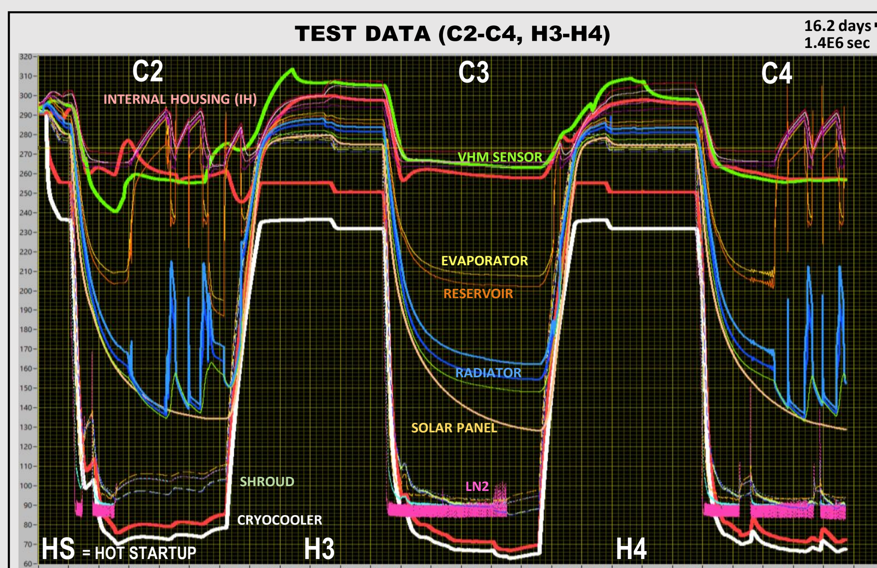

### FUNCTIONAL/WIRING DIAGRAM




### CAD MODEL



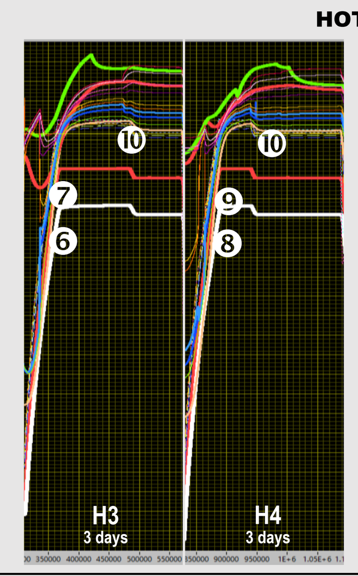
### TEST DATA (C2-C4, H3-H4)




### COLD CASES (C2-C4)


❶ During C2, mini-LHP loss of circulation leads to IH temp rise; restart required to avoid over temp
❷ Circulation restarted by first briefly applying evaporator startup heater and then applying a small amount of reservoir heater power
❸ During C3, the early application of reservoir heater power was able to suppress the loss of circulation
❹ During C4, the early application of reservoir heater power was NOT able to suppress loss of circulation
❺ Later in C4, circulation was restarted by using a procedure similar to that used in step 2

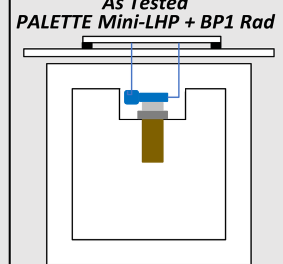
### HOT CASES (H3-H4)




❻ During H3, mini-LHP circulation stopped during the transient heating step
❼ Application of the evaporator startup heater was able to easily restart the mini-LHP ... later in H3, startup heater was transitioned to IH power
❽ During H4, mini-LHP circulation stopped during the transient heating step
❾ Application of the evaporator startup heater was able to easily restart the mini-LHP ... later in H4, startup heater was transitioned to IH power
❿ During both H3 and H4, shroud temp reduced from 280 K to 275 K to prevent IH mounting plate with VHM electronics from exceeding 310 K

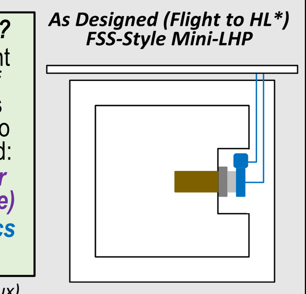
### TECHNICAL ISSUES → BECOMING FLIGHT READY

*As Tested PALETTE Mini-LHP + BP1 Rad*



***Is ARTEMIS-T Flight Ready?***
Yes, system close to HL* flight ready except for the issue of ***circulation loss***. Mitigations listed below reduce risk, but to eradicate risk, 2 steps needed:
***1-Add weak evap. to radiator conductor (10 gauge Cu wire)***
***2-Develop/demonstrate procs that ensure in-flight restarts***

*As Designed (Flight to HL*) FSS-Style Mini-LHP*

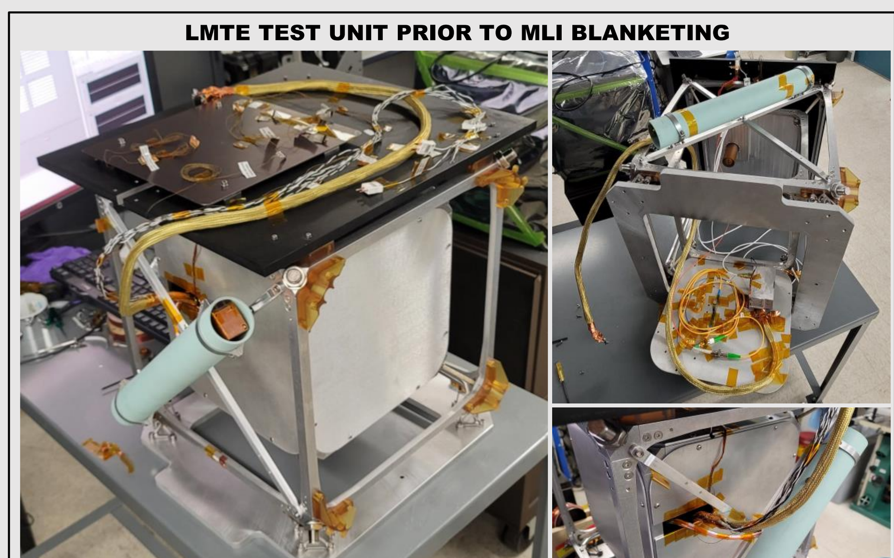


* HL = High Latitude (Mini-LHP in Reflux)

**As-Tested Circ. Loss Factors**
- ***Horizontal*** rsvr.-evap. layout
- ***Rapid*** shroud dT/dt transitions
- Mini-lhp designed for ***1 W min.***
- Rsvr. sized for ***243 K*** min oper.
- Lines sized for ***243 K*** min. oper.
- Charged for ***243 K*** min. oper.

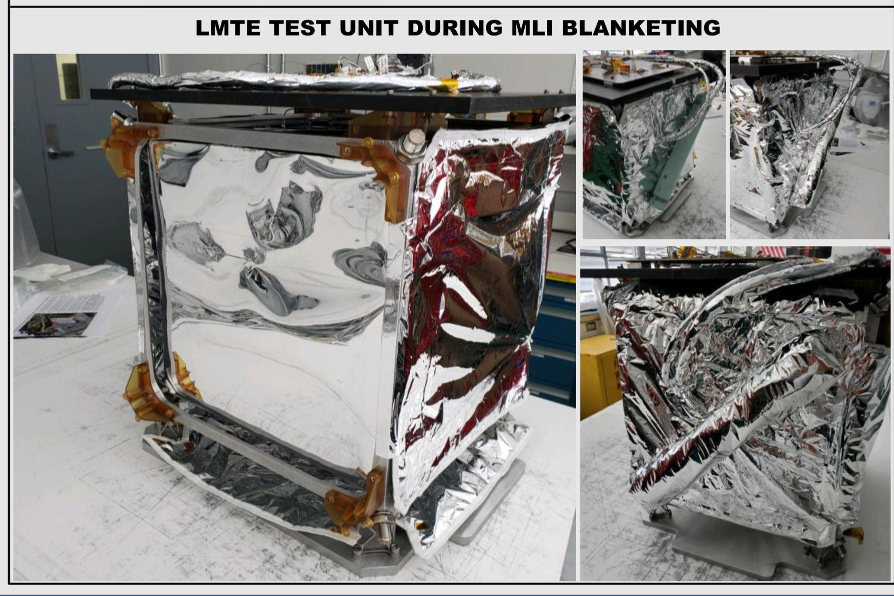
**Flight Unit Circ. Loss Mitigation**
- ***Vertical*** rsvr.-evap. layout
- ***Flight*** shroud dT/dt transitions
- Mini-lhp designed for ***<1 W min.***
- Rsvr. sized for **100 K** min oper.
- Lines sized for **100 K** min. oper.
- Charged for **100 K** min. oper.

### LMTE TEST UNIT PRIOR TO MLI BLANKETING

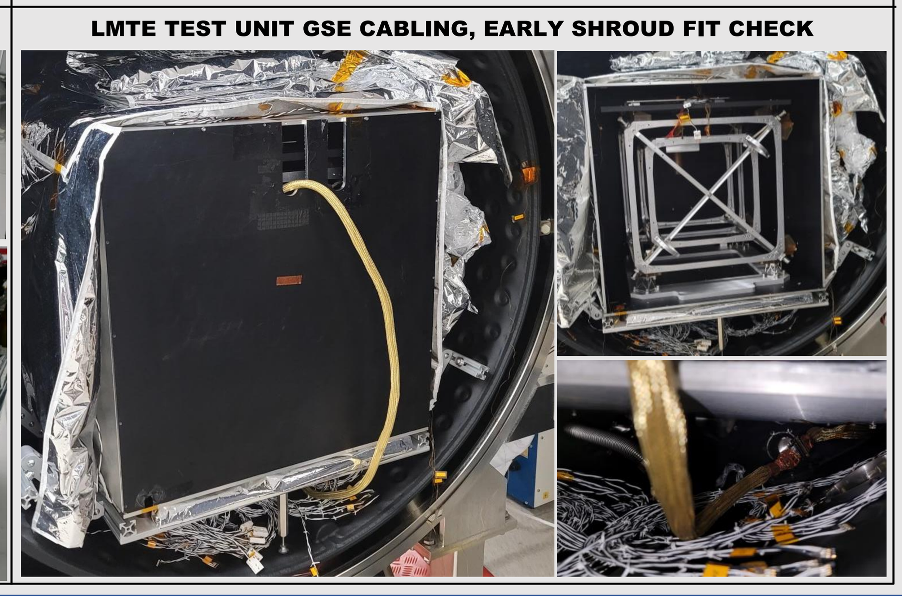


### LMTE VHM SENSOR ON ULTEM PLANK WITHIN G10 TUBE

### LMTE TEST UNIT DURING MLI BLANKETING

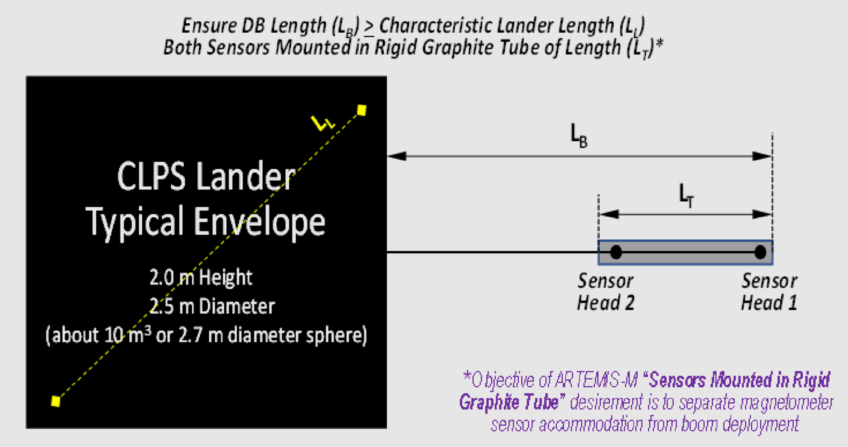


### LMTE TEST UNIT GSE CABLING, EARLY SHROUD FIT CHECK



### MAGNETOMETER INSTRUMENT DESIREMENTS

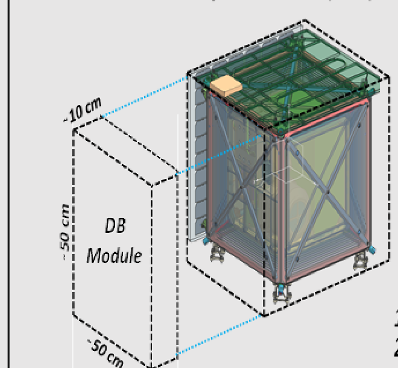
*Ensure DB Length ($L_B$) ≥ Characteristic Lander Length ($L_L$)*
*Both Sensors Mounted in Rigid Graphite Tube of Length ($L_T$)**




**Objective of ARTEMIS-M "Sensors Mounted in Rigid Graphite Tube" desirement is to separate magnetometer sensor accommodation from boom deployment*

### THERMAL MANAGEMENT DESIREMENTS

*Add DB Module to One Side of ARTEMIS-T Magnetometer Enclosure*
*System Attaches (Bolts) to External Housing Frame or Closeout Plate*




*DB Module Candidates*
1. Conventional Hinged Tubes (THEMIS)
2. Nested Tube/Stacer (DEMETER)
3. Rollable Tubular (JWST)
4. Expandable Truss (CASSINI, GOES-R)
5. Tape-Spring Hinged Tubes (MARSIS)

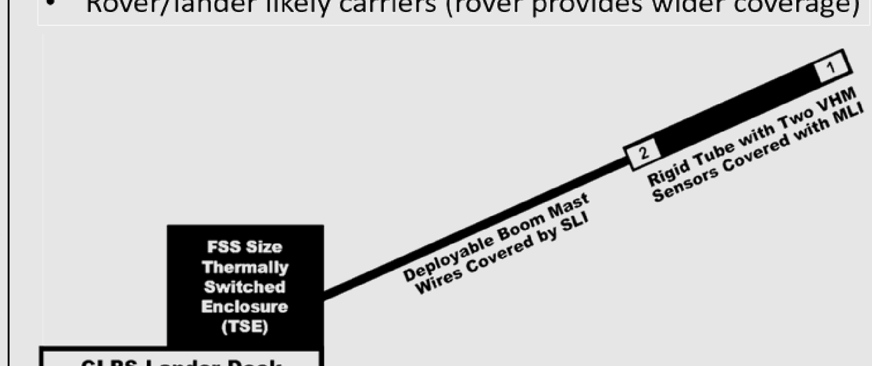
*DB Design Simplification Measures*
1. *Minimize $L_B$ (need ARTEMIS-M modeling results)*
2. *Minimize $L_T$ (need ARETMIS-M modeling results)*

### DEPLOYABLE BOOM OPTIONS

| Type | Example 1 | Example 2 | Example 3 | Example 4 | Example 5 |
|---|---|---|---|---|---|
| Hinged Tubes | THEMIS | JUICE | Mariner 10 | FAST | VEX-MAG |
| Nested Tubes | DAEDALUS | UoSAT-12 | DEMETER | ELFIN | MAVEN |
| Rollable Tubular | JWST | SELENE | FalconSat3 | WISP | ISIS |
| Expandable Truss | CASSINI | GOES-R | ECM | Voyager | WIND/POLAR |
| Tape-Spring | MARSIS (Contains Lecture by S. Pellegrino) | ST5 | FedSat | Idea 1 (non-flight) | Idea 2 (non-flight) |

### LUNAR VHM LANDING SITE DRIVERS, BASELINE FLIGHT CONCEPT

- Swirls and Nectarian-aged (3.8-3.9 Ga) basins
- Surface locations (maria) younger than 2.5 Ga
- Closeness to Apollo, other landers
- Rover/lander likely carriers (rover provides wider coverage)





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## Publications:


1. Bugby, D., Rivera, J., and Lin, Y., "Instrument Thermal Management for Lunar Night Survival without Radioisotopes", 50th International Conference on Environmental Systems, ICES-2021-414, 12-15 July 2021.
2. Bugby, D., Rivera, J., Britton, S., "Lunar Night Survivability of Science Payloads Using PALETTE Thermal Technologies", 2022 Spacecraft Thermal Control Workshop, On-Line Virtual Meeting, 24-26 May 2022.
3. Bugby, D., Rivera, J., Britton, S., "Lunar Night Survivability of Cryocooled Instruments Using PALETTE Thermally-Switched Enclosures", International Cryocooler Conference (ICC), Bethlehem, PA, 27-30 June 2022.
4. Bugby, D., Rivera, J., Britton, S., "Planetary and Lunar Environment Thermal Toolbox Elements (PALETTE) Project Year Two Results", 2022 International Conference on Environmental Systems (ICES), St. Paul, MN, 10-14 July 2022.
5. Bugby, D., "Passive Thermal Management Technologies for Lunar Day/Night Survivability", Lunar Surface Innovation Consortium, Low Temperature Sub-kW Power and Energy Storage for the Lunar Surface Workshop, 28 July 2022.
6. Bugby, D., Rivera, J., "Lunar Night Survivable Architecture for Self-Sufficient Science Payloads", International Planetary Probe Workshop (IPPW 2022), Santa Clara, CA, 29 August to 2 September 2022.



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