National Aeronautics and Space Administration

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

Principal Investigator: David Bugby (353)

Co-Investigators: Jose Rivera (353), Pamela Clark (382), Sharon Kedar (335), Carol Raymond (410)

Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Architecture for Thermal Enclosure of Moon Instrument Suites**

OBJECTIVE

The primary objective of the ARTEMIS-T research project is to develop a fully-passive, non-radioisotope instrument architecture that enables sustained high value measurements over extended lunar day/night temperature/power cycles. Instrument types include magnetometers, seismometers, & IR spectrometers. The primary instrument to be accommodated is the JPL SVH magnetometer under development by ARTEMIS-M (sister task led by Dr. Carol Raymond).

APPROACH

As shown below (see STRATEGY), the ARTEMIS-T approach for developing extended-life designs for lunar magnetometer, seismometer, & IR spectrometer enclosures is to integrate into each instrument package the thermal control features shown below (see PROBLEM and TECHNOLOGIES) with MarCO cubesat C&DH, power, telecom, batteries, and solar panels. In FY22, a full-size ARTEMIS-T enclosure with key SVH magnetometer features will be TVAC-tested.

RESULTS

In FY21, magnetometer (M), seismometer (S), and IR spectrometer (I) enclosure designs/analyses were developed/conducted commensurate with project funding. The results are described on the panels below for the 6 ARTEMIS-T tasks. Two architectures were developed, one for low latitude (LL) lunar sites and the other for high latitude (HL) lunar sites. PALETTE thermal tools plus MarCO C&DH, power, telecom, batteries, solar cells enable self-sufficiency.

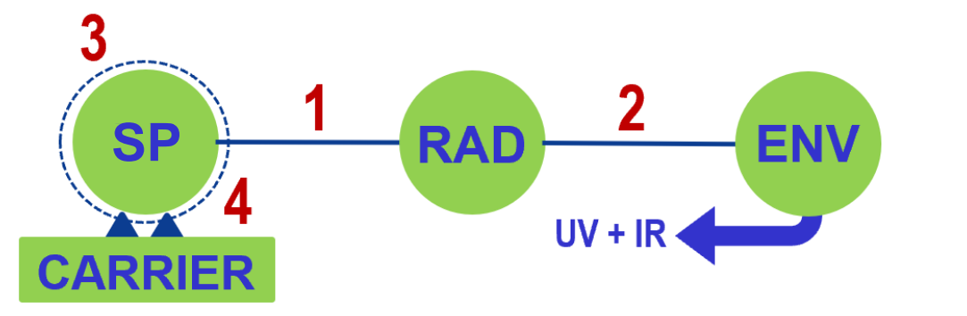
SIGNIFICANCE

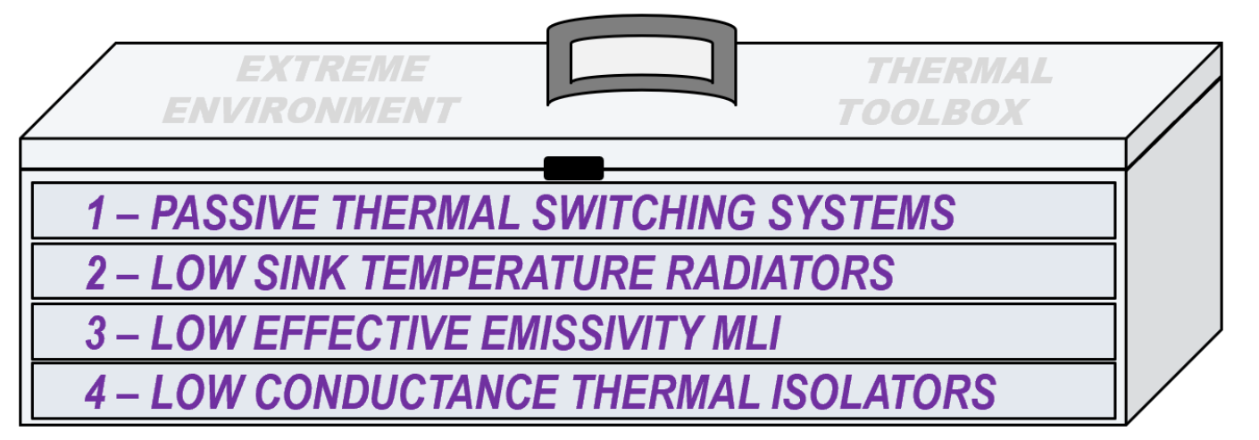
ARTEMIS-T has already paid dividends for JPL as the Farside Seismic Suite (FSS) was selected to fly on a CLPS mission to Schrodinger Basin on the lunar farside in 2024. FSS uses the ARTEMIS-T high latitude (HL) architecture. Another mission stemming from ARTEMIS-T is Lunar Night Survival (LNS), which will fly on a CLPS mission to Gruithuisen Domes on the lunar nearside in 2025. LNS uses the ARTEMIS-T low latitude (LL) architecture, which includes a PRR.

PROBLEM: *Operation in Extreme Environments*

We want to use one of these …	*Carrying one or more of these …*	*To operate and stay within temperature limits, in Extreme Environments such as these …*	*Using a thermal control architecture that is …*
Rover ***Lander*** ***Orbiter*** ***Flyer*** ***Airship***	***Science Payload (SP) 253-313 K***	***Moon (50-400 K, Vac)*** ***Mars (148-293 K, Non-Vac)*** ***Europa (53-113 K, Vac)*** ***Titan (90-94 K, Non-Vac)*** ***Io (105-123 K, Vac)*** ***Venus 70-30 km (173-473 K, Non-Vac)***	***Low Power*** ***Lightweight*** ***Passive*** ***Compact*** ***Reliable*** ***Affordable*** ***Radioisotope-Free***

Extreme Environment operability/survivability requires 4 improved thermal toolbox elements …

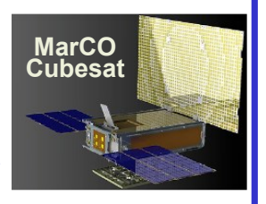




- *1 – PASSIVE THERMAL SWITCHING SYSTEMS*
- *2 – LOW SINK TEMPERATURE RADIATORS*
- *3 – LOW EFFECTIVE EMISSIVITY MLI*
- *4 – LOW CONDUCTANCE THERMAL ISOLATORS*

STRATEGY: *Extended-Life Lunar Operation*

SPs depend on CLPS landers …	*Science instrument focus at JPL …*	*Lunar surface conditions and design constraints that make day/night survival so challenging …*	*How to become CLPS lander independent …*
Initial CLPS Landers and their SPs will not Survive Lunar Night	***Self-Sufficient Science Payloads that are Capable of Operating Over Multiple Lunar Day/Night Cycles***	- Daytime highs of 400 K - Days that last 15 Earth days - Nighttime lows of 50 K - Nights that last 15 Earth days - Solar/battery power only - No radioisotope heat/power	*Add Cubesat-Based* ***C&DH Telecom Power Batteries*** *to SP Thermal Design*



CLPS Providers
- Astrobotic Technology
- Blue Origin
- Ceres Robotics
- Deep Space Systems
- Draper Laboratory
- Firefly Aerospace
- Intuitive Machines
- Lockheed Martin Space
- Masten Space Systems
- Moon Express
- Orbit Beyond
- Sierra Nevada Corp
- SpaceX
- Tyvak Nano-Sat Syst.

Seismometers
Simplest Packaging
SP Completely Inside
Trans. Func. 1.0 < 3 Hz

Magnetometers
More Complex Packaging
External Booms/Wires
External Heated Sensors

IR Spectrometers
Most Complex Packaging
2-Axis Gimbals/Motors
Mechanical Cryocoolers

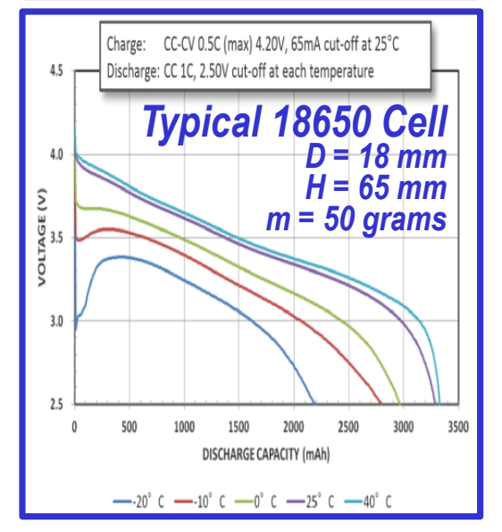
HEAT LOSS FLUX (q_{LOSS}) LUNAR NIGHT KPP

HOW q_{LOSS} AFFECTS N_{BATT}		
A_{SP}	1	m²
ε*	0.02	-
T_{INT}	300	K
T_{EXT}	73	K
$G_{ISOLATOR}$	0.002	W/K
N	8	2 per corner
q_{LOSS}	12	W/m²
I_{CELL}	3000	mA-hour
E_{CELL}	9	W-hour
N_{BATT}	480	

RADIATOR SINK TEMP (T_{SINK}) LUNAR DAY KPP

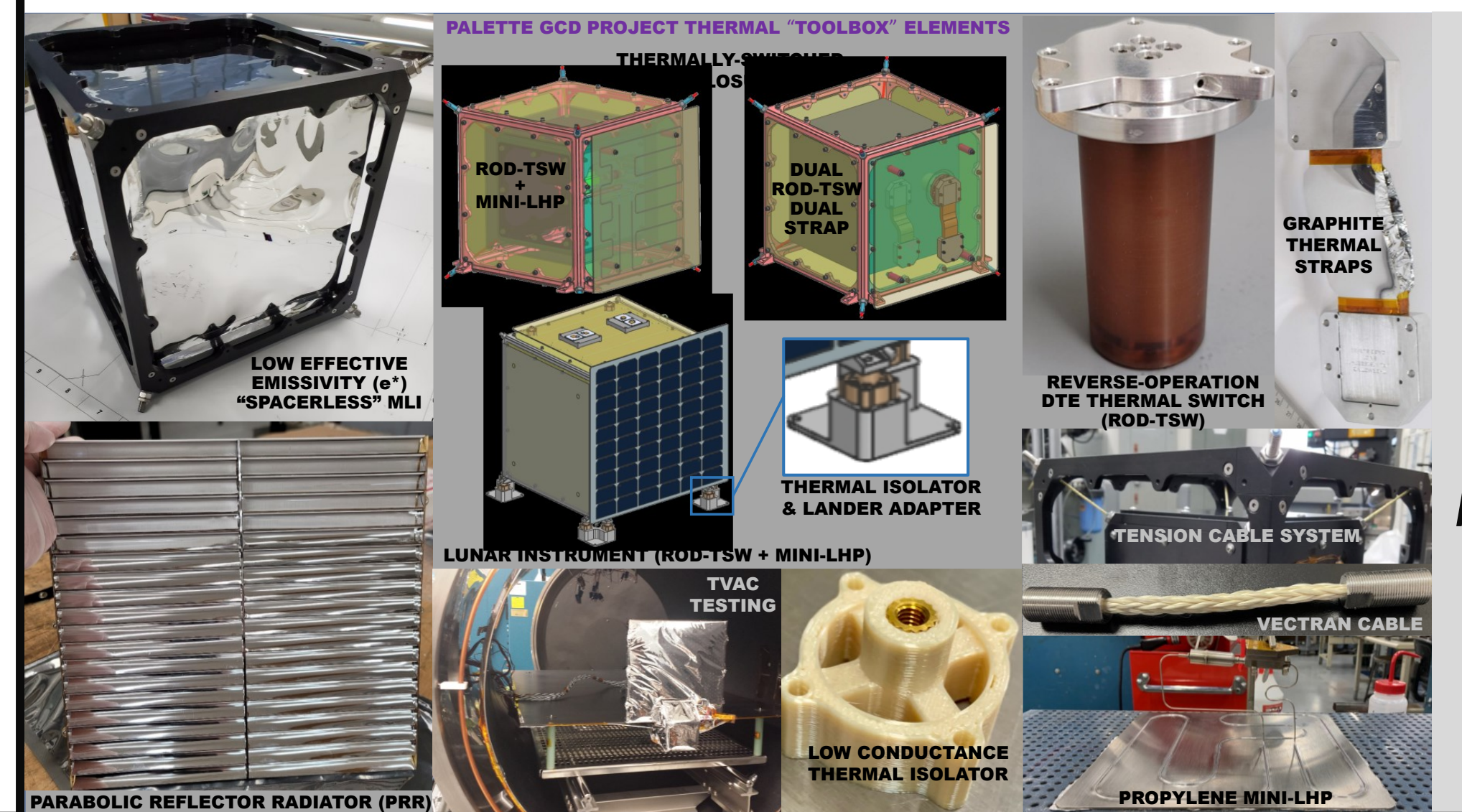
HOW T_{SINK} AFFECTS A_{RAD}		
Q_{MAX}	24	W
$ε_{RAD}$	0.85	
T_{INT}	300	K
$G_{VCTL,ON}$	5	W/K
T_{RAD}	295	K
T_{SINK}	260	K
A_{RAD}	0.165	m²

PALETTE Goal is to Improve ε*, $G_{ISOLATOR}$, and T_{SINK}



Typical 18650 Cell
D = 18 mm
H = 65 mm
m = 50 grams

TECHNOLOGIES: *Infused into ARTEMIS-T*



Thermally-Switched Enclosures (TSE)

Parabolic Reflector Radiators (PRR)

Spacerless Multilayer Insulation (SMI)

Low-G Thermal Isolators (LTI)

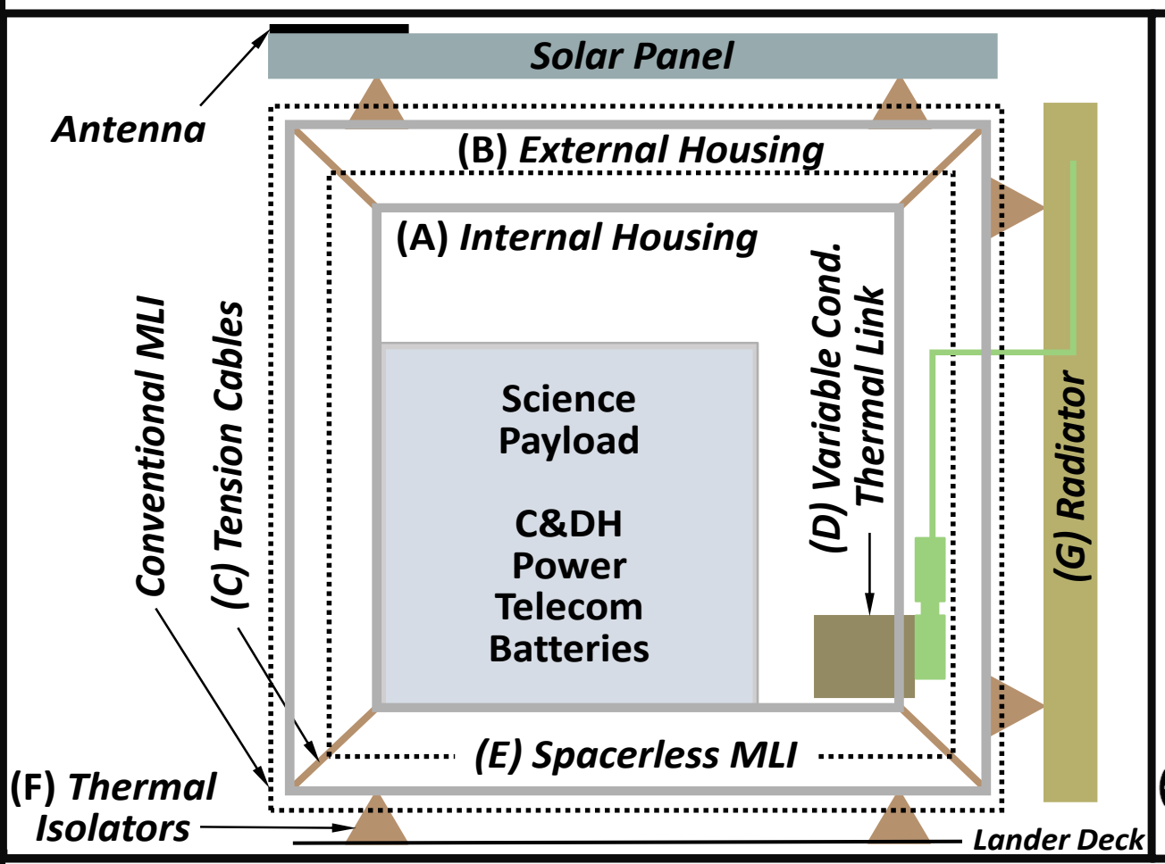
ARTEMIS-T FY21 TASKS

- **TASK 1:** *Architecture Development*
- **TASK 2:** *Magnetometer Enclosure Design/Analyses*
- **TASK 3:** *Seismometer Enclosure Design/Analyses*
- **TASK 4:** *IR Spectrometer Enclosure Design/Analyses*
- **TASK 5:** *Requirements Definition*
- **TASK 6:** *Full-Size Enclosure TVAC Test (FY22 Task*)*

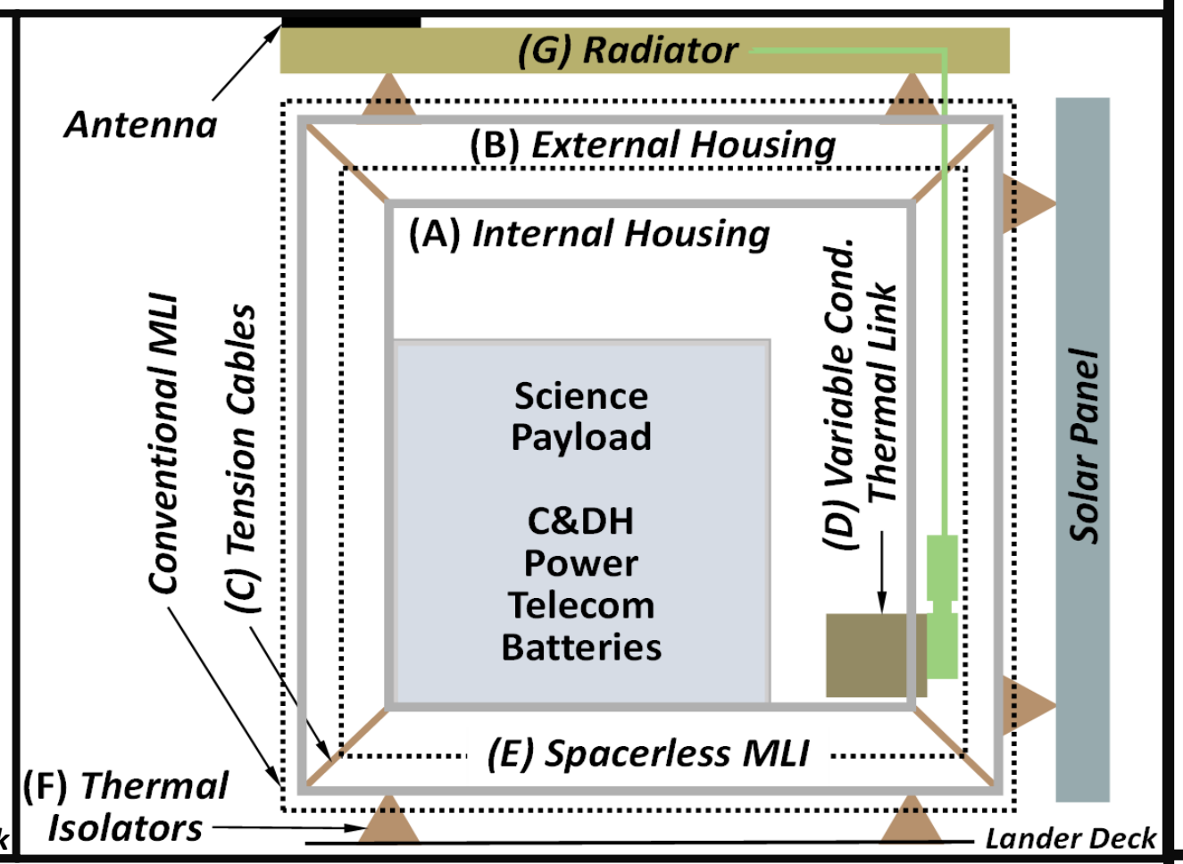
**some work was done on Task 6 in FY21*

TASK 1: *Architecture Development*

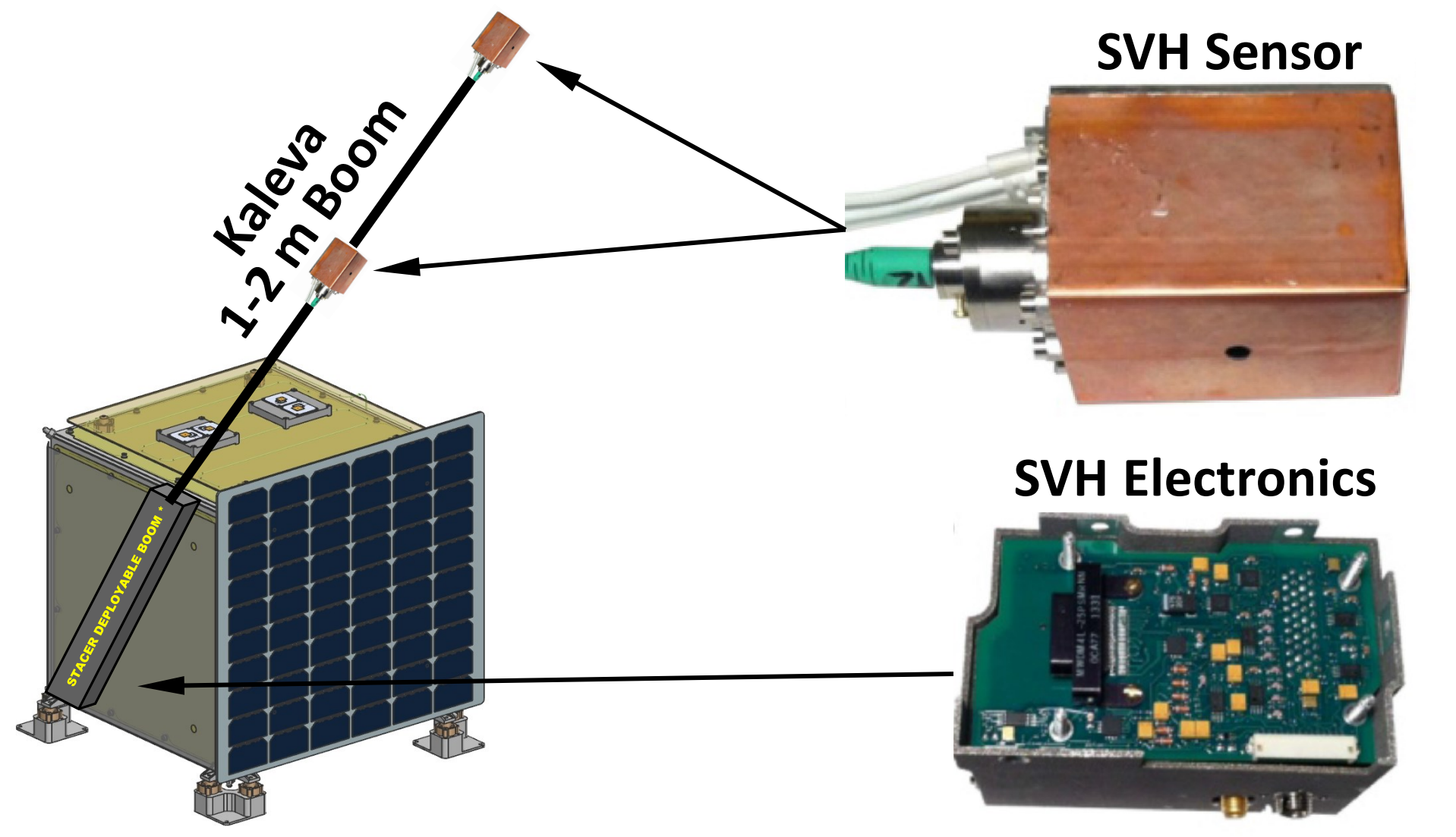
Low Latitude (LL) Lunar Site



High Latitude (LL) Lunar Site

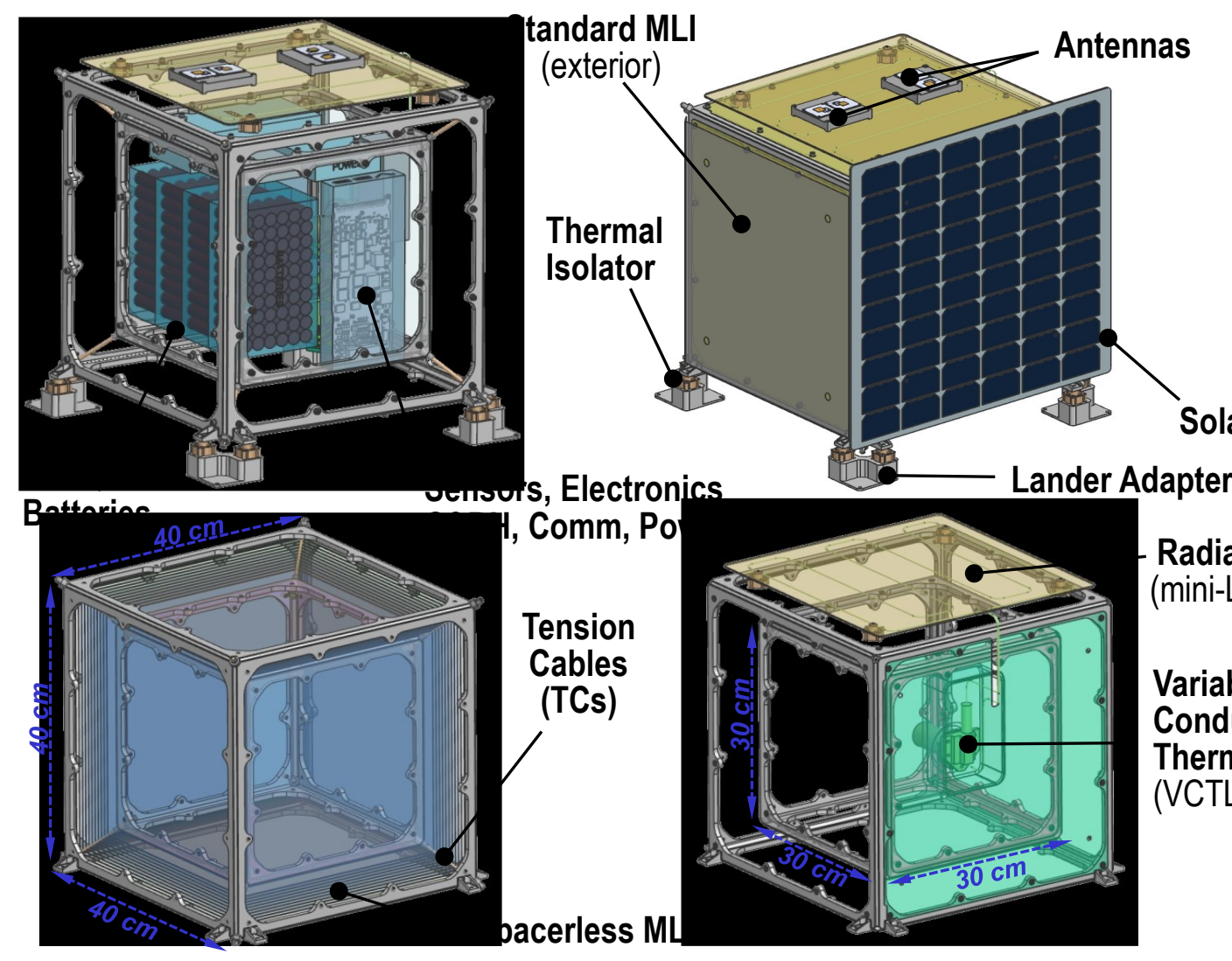


TASK 2: *Magnetometer Enclosure (HL Site)*

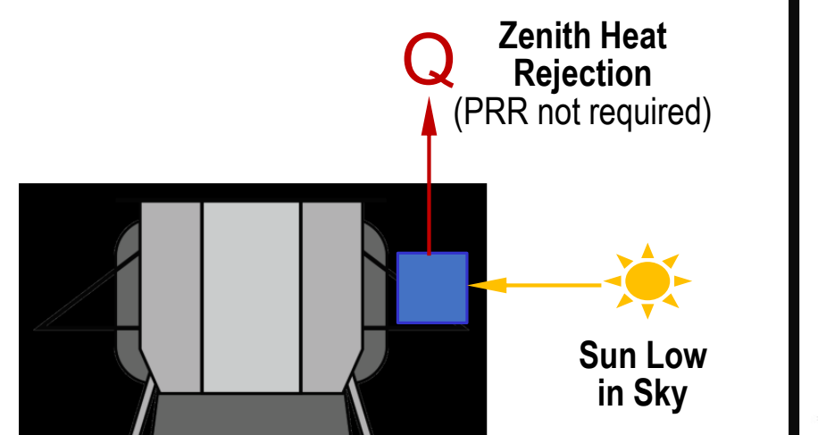


Externally identical to the seismometer design but with an externally mounted deployable Kaleva boom with mid/end-span mounted SVH sensors. Internals also identical to seismometer design except seismometer sensors and electronics are replaced by magnetometer electronics.

TASK 3: *Seismometer Enclosure (HL Site)*

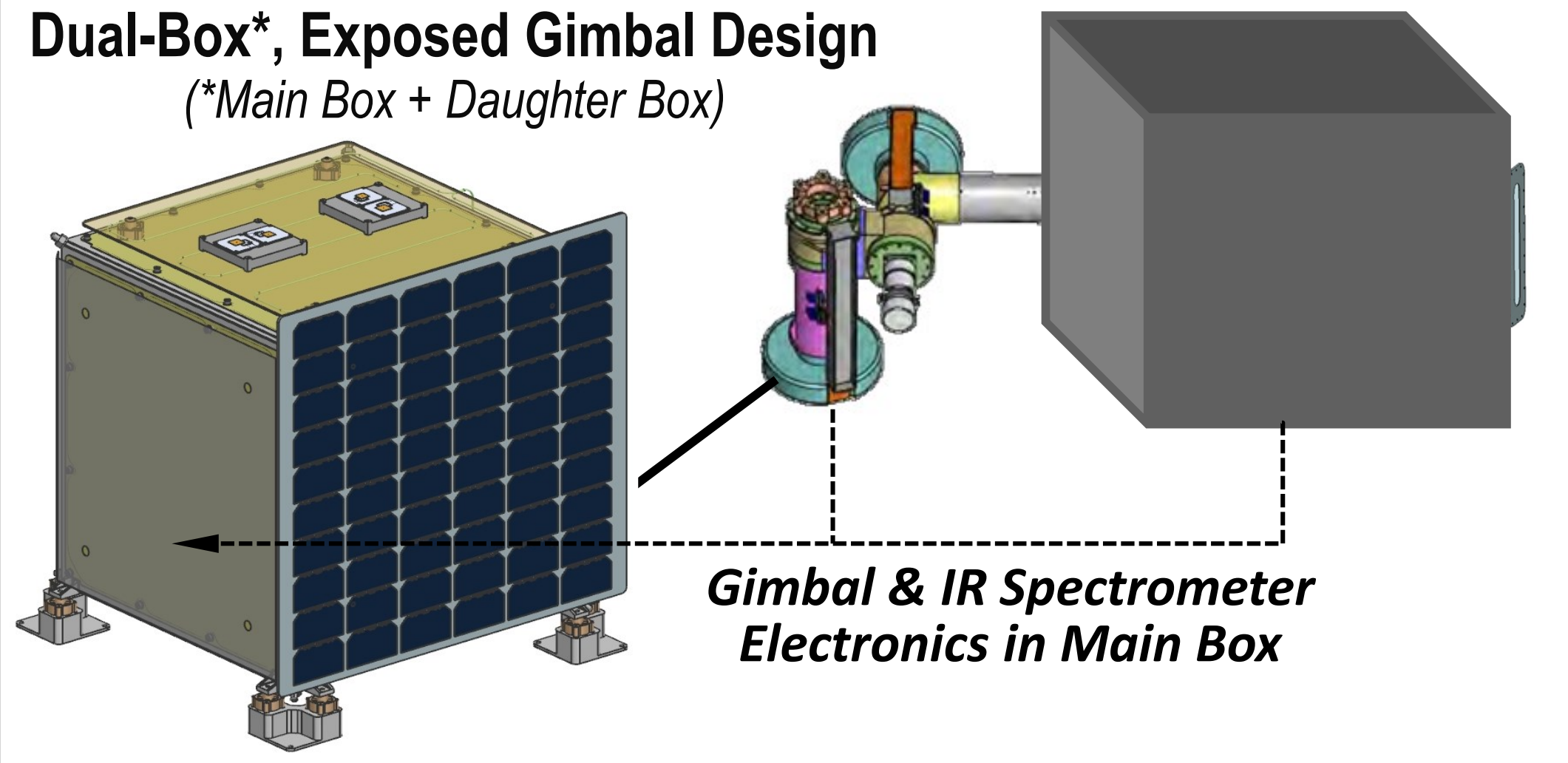


Thermal		**Structural**
QDAY-OP	= 10 W	Hard Mount to Deck
QDAY-COMM	= 20 W	TCs Tuned to Reduce Loads
QNIGHT-OP	= 5 W	Sensor Heads Protected
TDAY	= 318 K	Trans. Function = 1.0 (< 3 Hz)
TNIGHT	= 300 K	Mars Insight Heritage



TASK 4: *IR Spectrometer Enclosure (HL Site)*

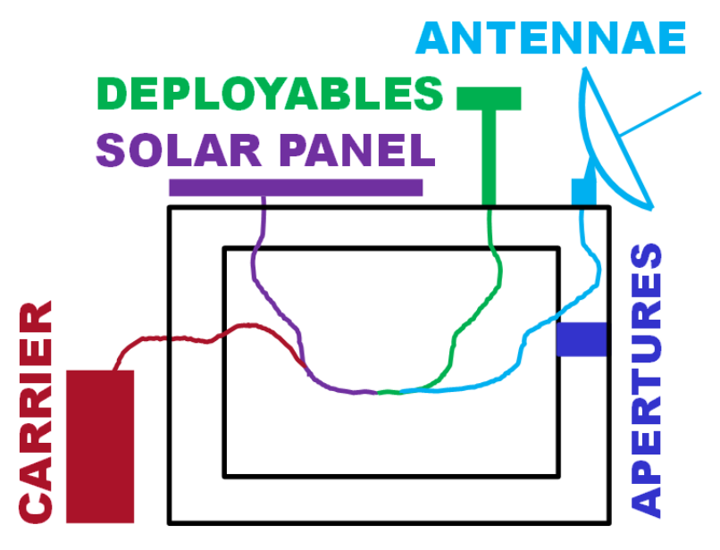
Dual-Box*, Exposed Gimbal Design
*(*Main Box + Daughter Box)*



Externally, dual-box design with main/daughter-boxes, exposed 2-axis gimbal. Internally, within main box are the gimbal & IR spectrometer electronics.

TASK 5: *Requirements Definition*

Instrument Type	Design Considerations	Aperture	Antennae	Solar Panel	Deployable	Carrier I/F
Seismometer	Simplest Packaging SP Completely Inside Trans. Func. 1.0 < 3 Hz		√	√		√
Magnetometer	More Complex Packaging External Booms/Wires External Heated Sensors		√	√	√	√
IR Spectrometer	Most Complex Packaging 2-Axis Gimbals/Motors Mechanical Cryocoolers	√	√	√	√	√



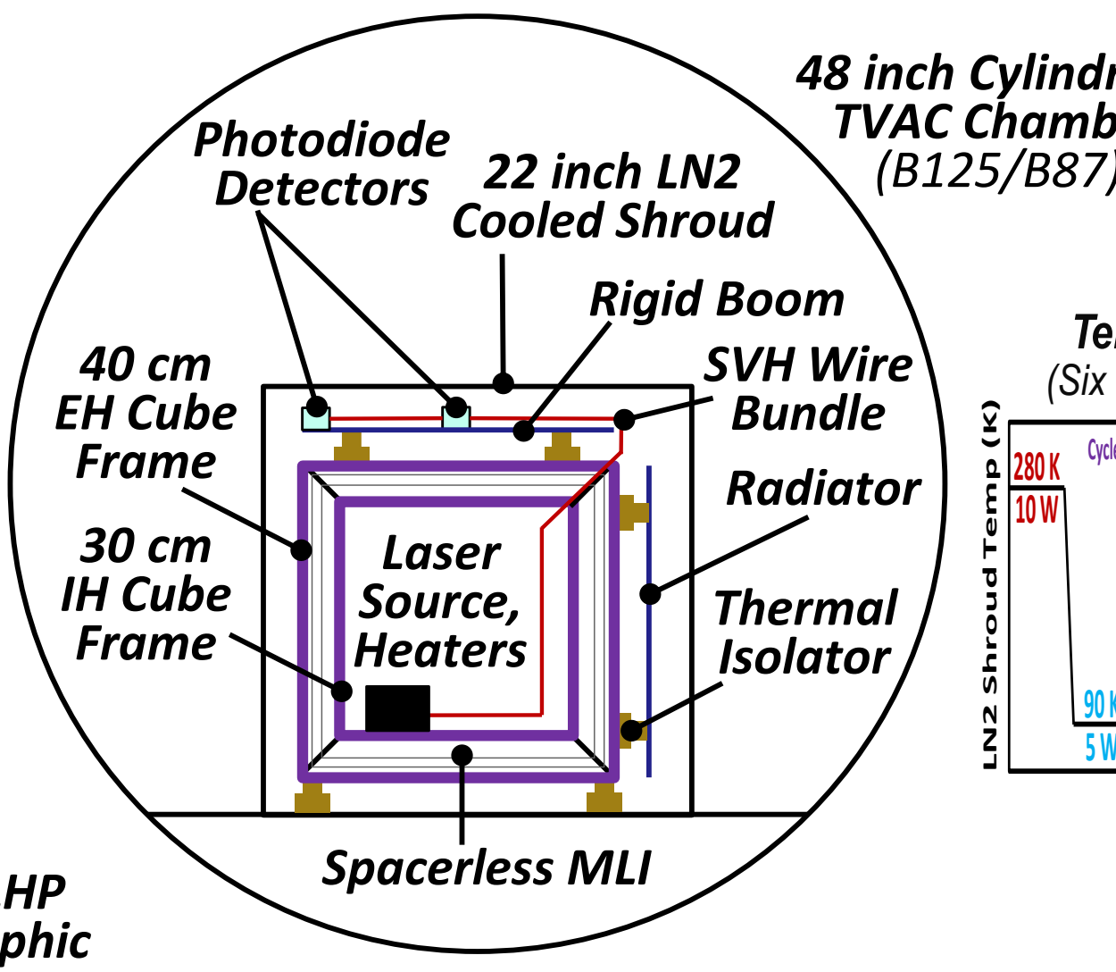
TASK 6: *Full-Size Enclosure TVAC Test (FY22 Task)*

COLD Cycle
Shroud = 90 K
Q_{NIGHT} = 5 W
N_{CYCLES} = 6
Duration = 72 hour*
* includes cool down

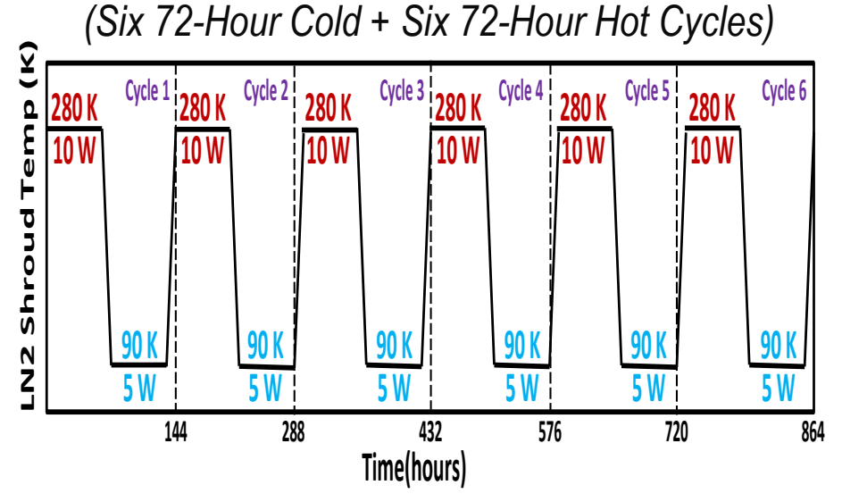
HOT Cycle
Shroud = 280 K
QDAY = 10 W
N_{CYCLES} = 6
Duration = 72 hour*
* includes heat up

ROD-TSW + Mini-LHP Not Included in Graphic

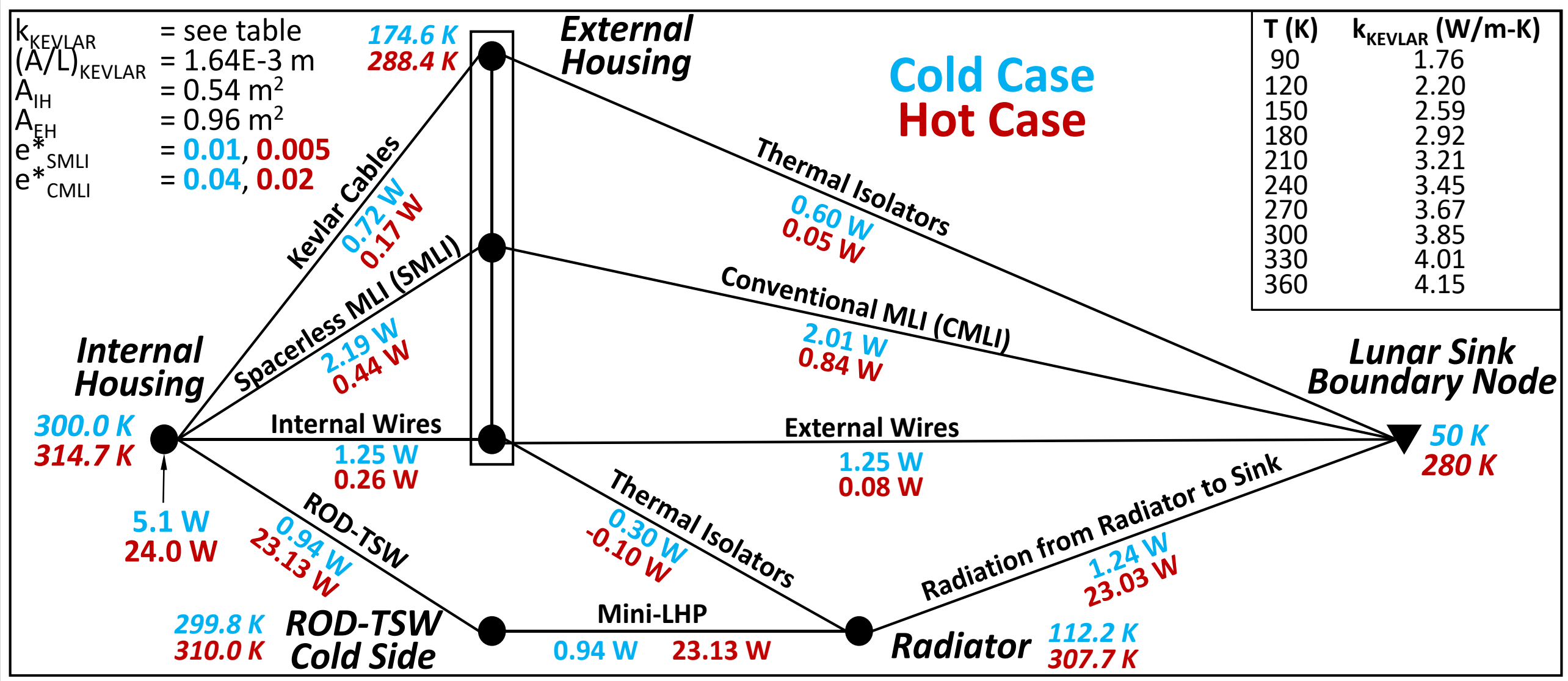
48 inch Cylindrical TVAC Chamber *(B125/B87)*



Tentative Cold/Hot Test Cycle Plan
(Six 72-Hour Cold + Six 72-Hour Hot Cycles)



THERMAL ANALYSIS: *Seismometer (HL Site)*

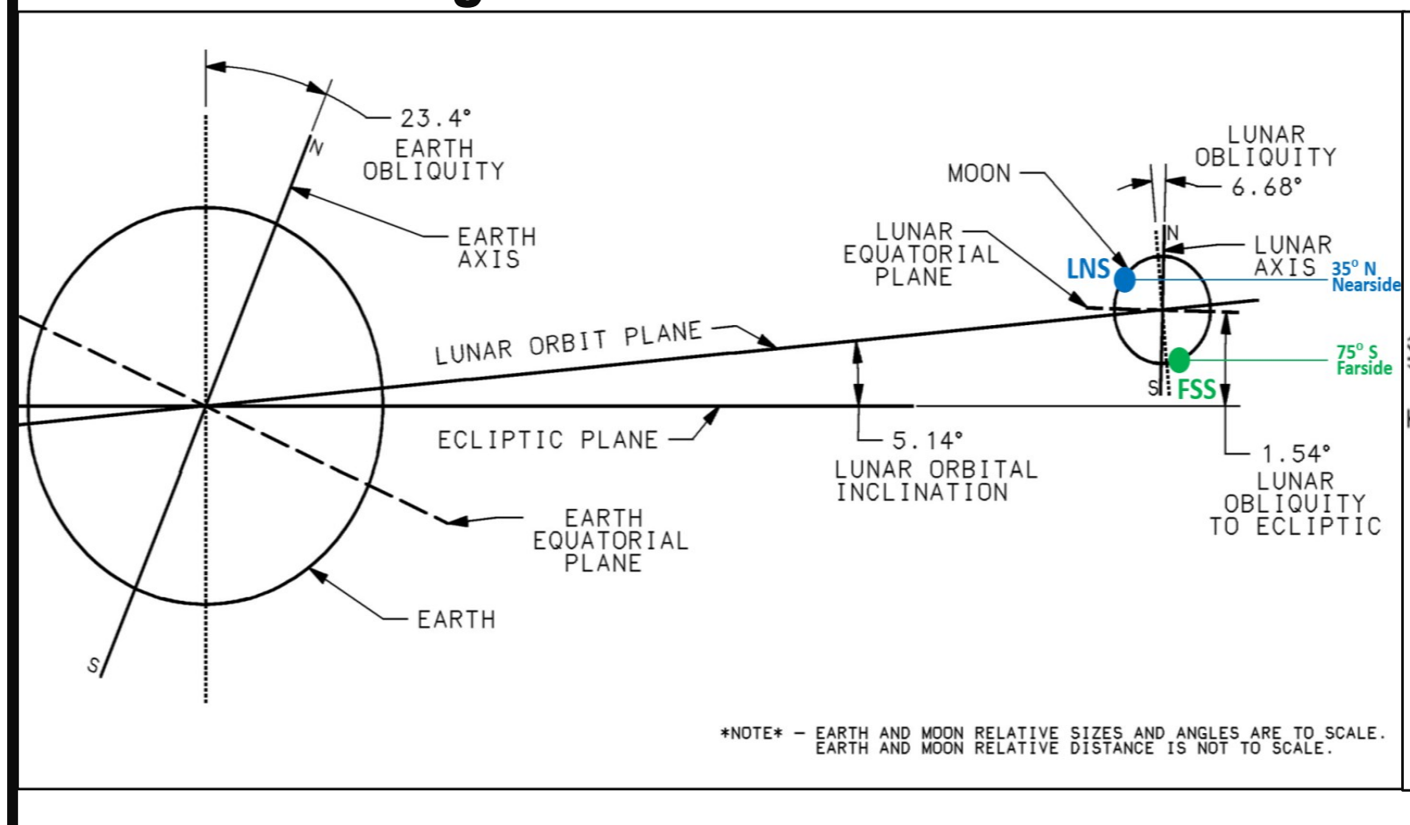


k_{KEVLAR} = see table
$(A/L)_{KEVLAR}$ = 1.64E-3 m
A_{IH} = 0.54 m²
A_{EH} = 0.96 m²
e^*_{SMLI} = 0.01, 0.005
e^*_{CMLI} = 0.04, 0.02

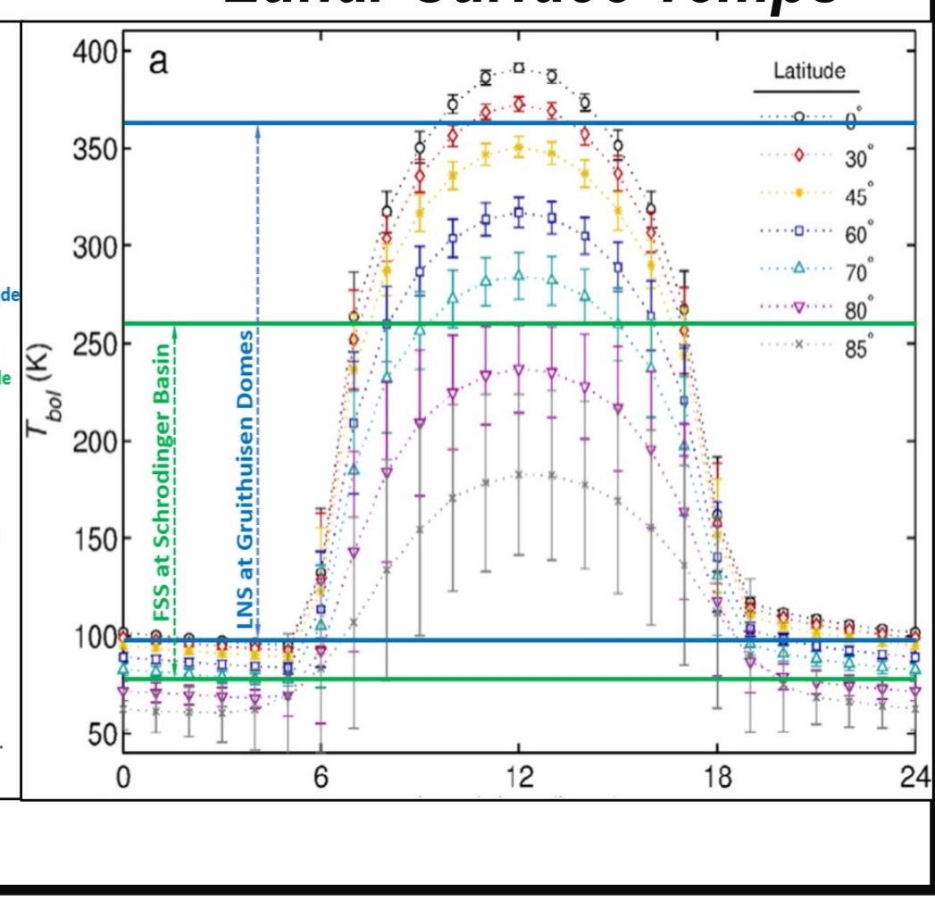
T (K)	k_{KEVLAR} (W/m-K)
90	1.76
120	2.20
150	2.59
180	2.92
210	3.21
240	3.45
270	3.67
300	3.85
330	4.01
360	4.15

MISSION INFUSION: *FSS and LNS*

Landing Sites on Lunar Surface



Lunar Surface Temps



PUBLICATIONS

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.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Manager Contact
Email: David.C.Bugby@jpl.nasa.gov

Clearance Number:
RPC/JPL Task Number: R19035