RPC 2020

Virtual Research Presentation Conference

Thermal Technology Development for the ARTEMIS Initiative

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Program: Strategic Initiative

Assigned Presentation # RPC-143

Tutorial Introduction

ARTEMIS = Architecture of a Thermal Enclosure for Moon Instrument Suites
TASK1: Thermal Technology Development for the ARTEMIS Initiative (ARTEMIS-T)
TASK2: Magnetometer Technology Development for the ARTEMIS Initiative (ARTEMIS-M)

OBJECTIVE: To develop a passive thermal management system for future JPL lunar surface science instruments.

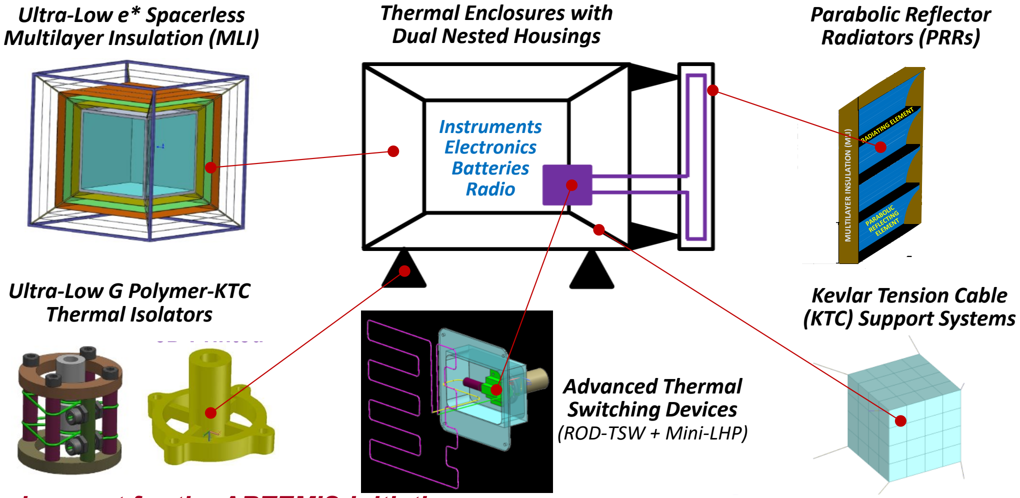
INSTRUMENTS: This project targets magnetometers, seismometers, and IR spectrometers.

APPROACH: Five key "thermal toolbox" elements were combined into a single thermal management system:

- ❑ Dual nested thermally-switched enclosures supported by Kevlar tension cables (KTC);
- ❑ Parabolic reflector radiators (PRRs) that attain a low radiative sink temperature even at lunar noon at low lunar latitudes;
- ❑ Ultra-low effective emissivity (e*) "spacerless" MLI that minimizes lunar night radiative heat losses;
- ❑ Ultra-low conductance (G) polymer-KTC thermal isolators that minimize lunar night conductive heat losses;
- ❑ Additional thermal features necessary for the three instrument types or instrument suites combinations resulting therefrom.

Lunar Thermal Challenges

- Daytime highs of > 130 °C
- Days that last 15 Earth days
- Nighttime lows of < -200 °C
- Nights that last 15 Earth days
- Solar/battery power only
- No radioisotope heat/power



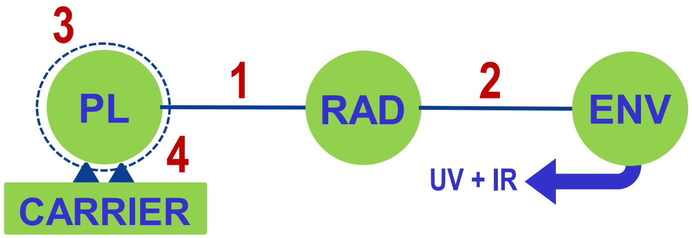
Thermal Technology Development for the ARTEMIS Initiative

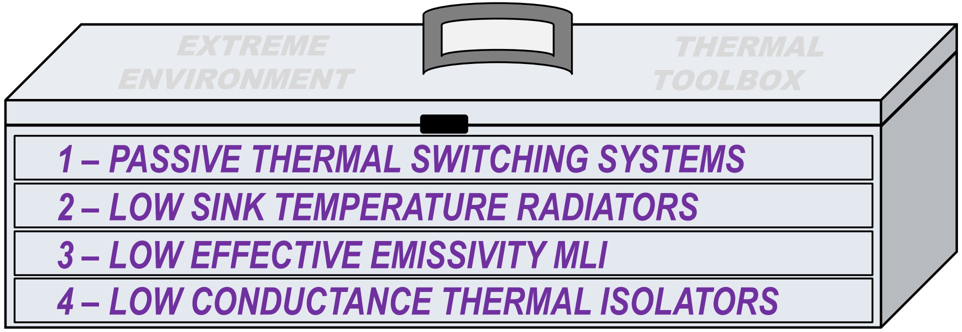
Problem Description

Science Payload Thermal Control 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 (PL) 253-313 K***	***Moon (100-380 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***

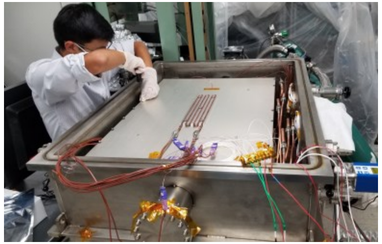
Extreme Environment operability/survivability requires 4 improved thermal toolbox elements …





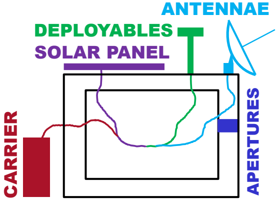
Methodology

1. Design/build breadboard test articles, conduct tests to verify each of the new "thermal toolbox" elements
   a) Thermally-switched enclosures
   b) Parabolic reflector radiators (PRRs)
   c) Ultra-low e* "spacerless" MLI
   d) Ultra-low G thermal isolators



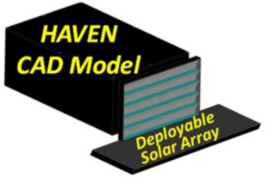
Planned thermal vacuum chamber tests with liquid nitrogen shroud discontinued due to PALETTE NASA/GCD award and its very similar task structure. In March of 2020, **ARTEMIS-T changed course from a tech-dev project to an Instrument Accommodation project (see 3)**. Tests completed by PALETTE.

2. Assemble database of thermal requirements and design information on the targeted instruments
   a) Magnetometers
   b) Seismometers
   c) IR Spectrometers



In addition to defining instrument components and temperature requirements, focus is also on defining number, type of protrusions through MLI due to apertures, antennae, deployables, solar panels, carrier interfaces, etc.

3. Apply new thermal toolbox elements to develop specific designs for targeted instruments/suites
   a) Magnetometers
   b) Seismometers
   c) IR Spectrometers



New ARTEMIS-T Instrument Accommodation or **ARTEMIS-T-IA** work thrust involves approximate packaging of lunar magnetometer, seismometer, IR spectrometer payloads into a 30 cm cube enclosure. HAVEN is a NASA PRISM proposed platform modified for this effort.

4. Carry out test demonstrations of the technology
   a) Magnetometers (JPL Scalar Vector Helium-SVH)

This is a FY22 activity.

Results: Thermally-Switched Enclosure

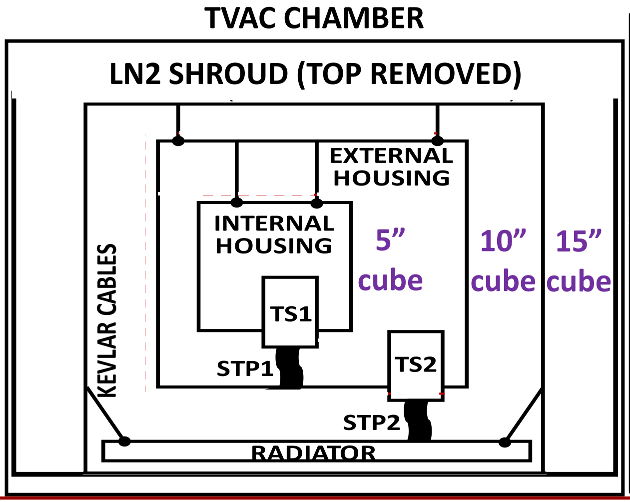
OBJECTIVE: Design, build, and test a thermally-switched enclosure test article and testbed.

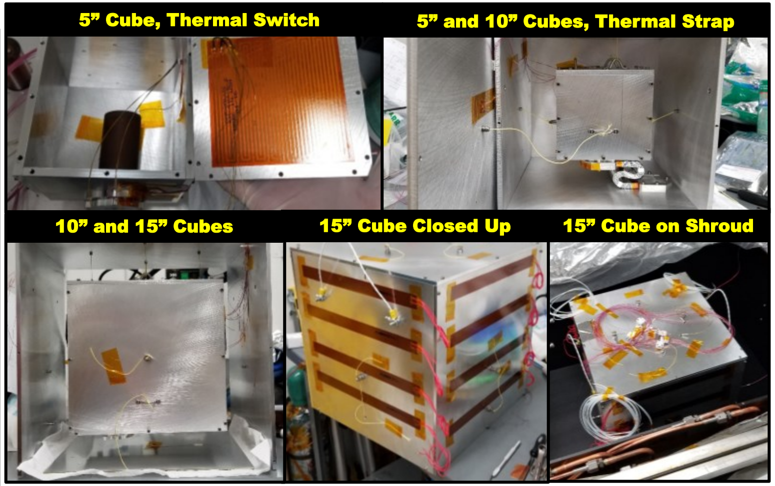
SETUP: 5” Al cube with thermal switch/strap connection to 10” Al cube with thermal switch/strap connection to radiator. Radiator views bottom of 15” Al cube. 15” Al cube cooled by LN2 shroud.

PROCEDURE: Shortcuts taken to save time. No shroud top to fit in TVAC. No MLI. 15” cube rested on shroud bottom. Shroud at 190 K, Q = 1 W for cold case. Shroud at 300 K, Q =10 W for hot case.

ANALYSIS: TD thermal models created (post-test) to correlate to test data. Using e* = 0.07, 5” cube predicted to run at 256 K in cold case and 331 K in hot case. Actuals were 256 K and 351 K.

RESULTS: Due to test-accelerating shortcuts, the heat loss flux was increased, thus KMM1 lunar night heat loss flux computed to be 14 W/m^2 vs. 6 W/m^2 goal. With MLI (e* = 0.03), KMM1 would have met goal.





Key Measurable Metric KMM1 is the Lunar Night Heat Loss Flux

$q_{HEAT\ LOSS} < 6\ W/m^2$

Results: Parabolic Reflector Radiator (PRR)

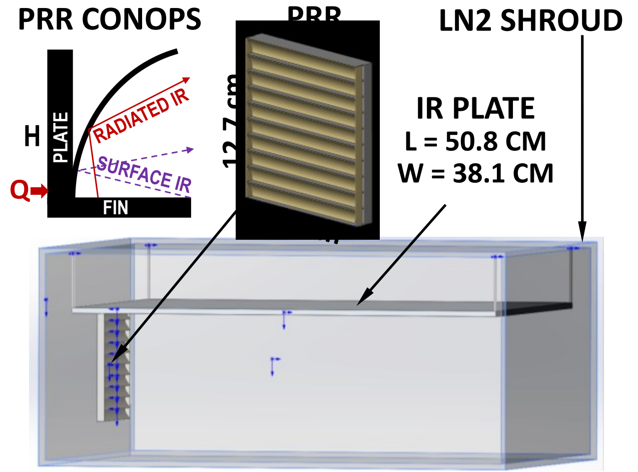
OBJECTIVE: Design, build, and test a parabolic reflector radiator (PRR) test article and testbed.

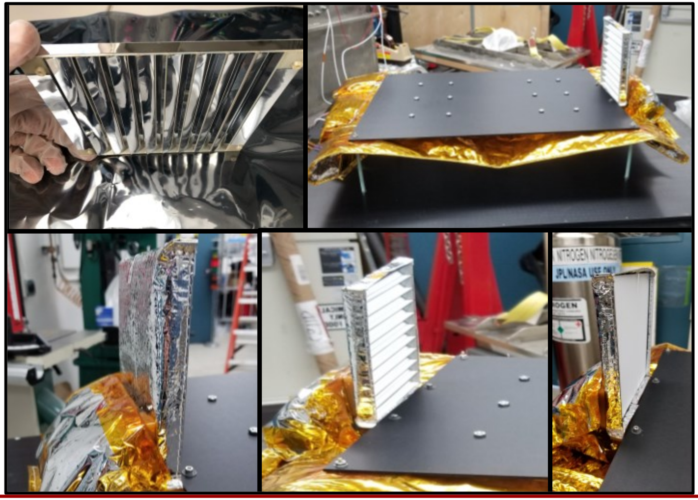
SETUP: PRR test article (12.7 cm x 12.7 cm frontal area with MLI on back) mounted upside down adjacent to heated IR plate (50.8 cm x 38.1 cm) that simulates lunar surface IR. LN2 shroud surrounds setup.

PROCEDURE: Cold case only (no time for hot case), LN2 shroud cooled to 90 K, IR plate heated to 400 K, Q to PRR 0, 1, 2 W, steady-state achieved at each power level.

ANALYSIS: Pre-test predictions carried out with 2 types of models … ***Excel Model*** -66.9 C at 0 W, -28.5 C at 1 W, -2.1 C at 2 W … ***TD Model*** -88.0 C at 0 W, -33.0 C at 1 W, 0.0 C at 2 W.

RESULTS: PRR steady-state temps: 0 W -55 C (218 K), 1 W -24 C (249 K), 2 W 0 C (273 K). Flat plate at 0 W 8 C (281 K). PRR KMM2a rad sink temp TS < 280 K easily achieved.





Key Measurable Metric KMM2a is the Lunar Noon Sink Temperature TS < 280 K

Results: Ultra-low e* “Spacerless” MLI

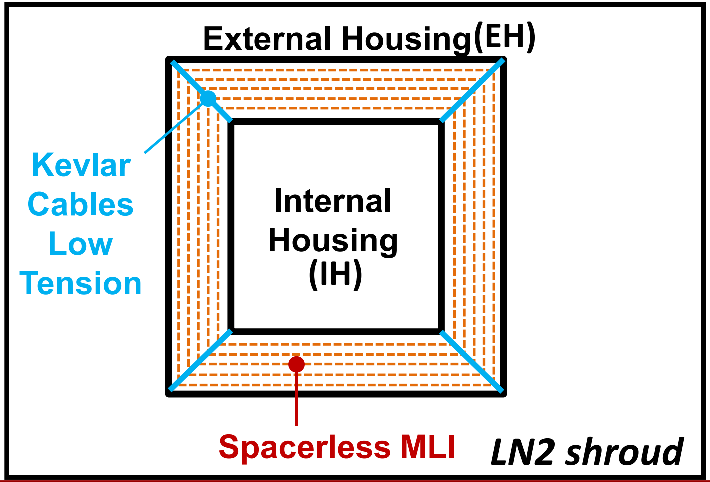
OBJECTIVE: Design, build, and test a low e* “spacerless” MLI test article and testbed.

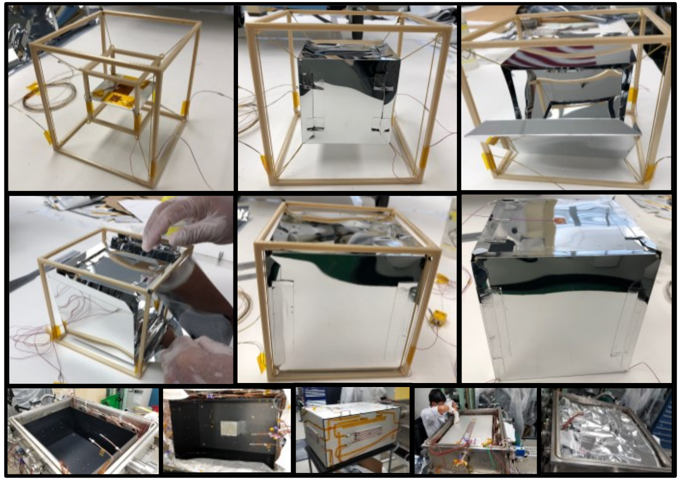
SETUP: The test article has an 8 cm internal housing (IH) supported by Kevlar cables from a 15 cm external housing (EH) with 6 MLI layers hung from the cables, and an Al plate + heater installed within the IH cube.

PROCEDURE: Cold case only (no time to run the hot case), LN2 shroud cooled to 90 K, Q = 0.3 W applied to Al plate suspended within internal housing cube, small adjustments thereto until steady-state achieved.

ANALYSIS: Effective emissivity (e*) of MLI computed with the equation $e^* = (Q/A_{IH})/[\sigma(T_{IH}^4 - T_{EH}^4)]$. Based on measured T_{IH}, e* can be determined. If T_{IH} = 346 K, e* = 0.005. If T_{IH} = 257 K, e* = 0.020.

RESULTS: Actual Q = 0.27 W, T_{IH} = 358 K, resulting e* = 0.0047. Thus, KMM3 achieved. ***Caveat:*** future e* tests should use black IH, EH boxes instead of small internal heated plate.





Key Measurable Metric KMM3 is the MLI Effective Emissivity e* < 0.01

Results: Ultra-low G Thermal Isolators

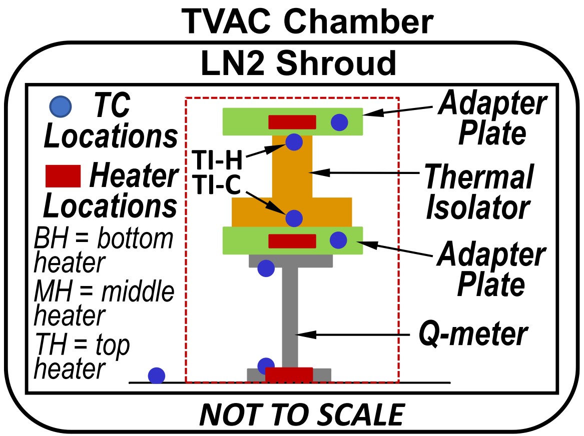
OBJECTIVE: Design, build, and test a low conductance (G) thermal isolator (TI) test article and testbed.

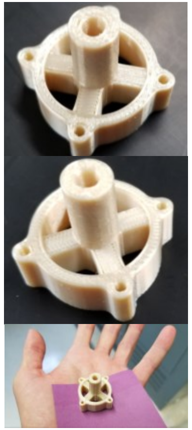
SETUP: Mount flat plate (see green below) to warm end of test article, mount another flat plate to warm end of q-meter, mount cold end of test article to q-meter adapter plate and instrument as shown below.

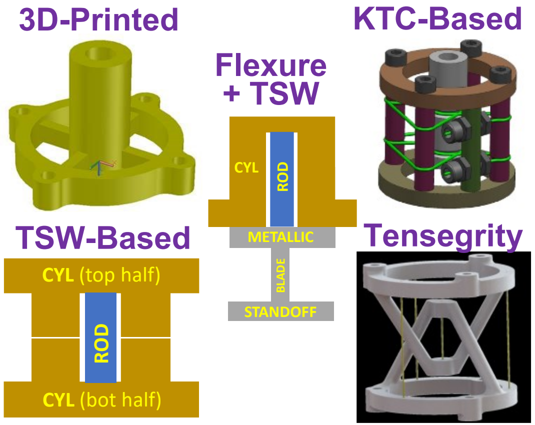
PROCEDURE: Cool q-meter bottom to 92 K with LN2, and keep steady with BH. Vary MH to calibrate q-meter. After calibration, add 0.1 W to TH, wait for steady-state. G = Q_{QM}/DT (Q_{QM} from calibration curve)

ANALYSIS: Get Q from calibration curve (Q_{QM}). For the purposes of explaining the process, guess Q_{QM} = 0.1 W. G = $Q_{QM}/(T_{TI\text{-}H} – T_{TI\text{-}C})$. If G = 0.001 W/K, then $T_{TI\text{-}H}$ = 190 K. If G = 0.0005 W/K, then $T_{TI\text{-}H}$ = 290 K

RESULTS: This test was not completed in the time available, although an all Ultem thermal isolator was 3D-printed. Two main options: 3D-printed and KTC-based. Both have analytical KMM4 G << 0.001 W/K.

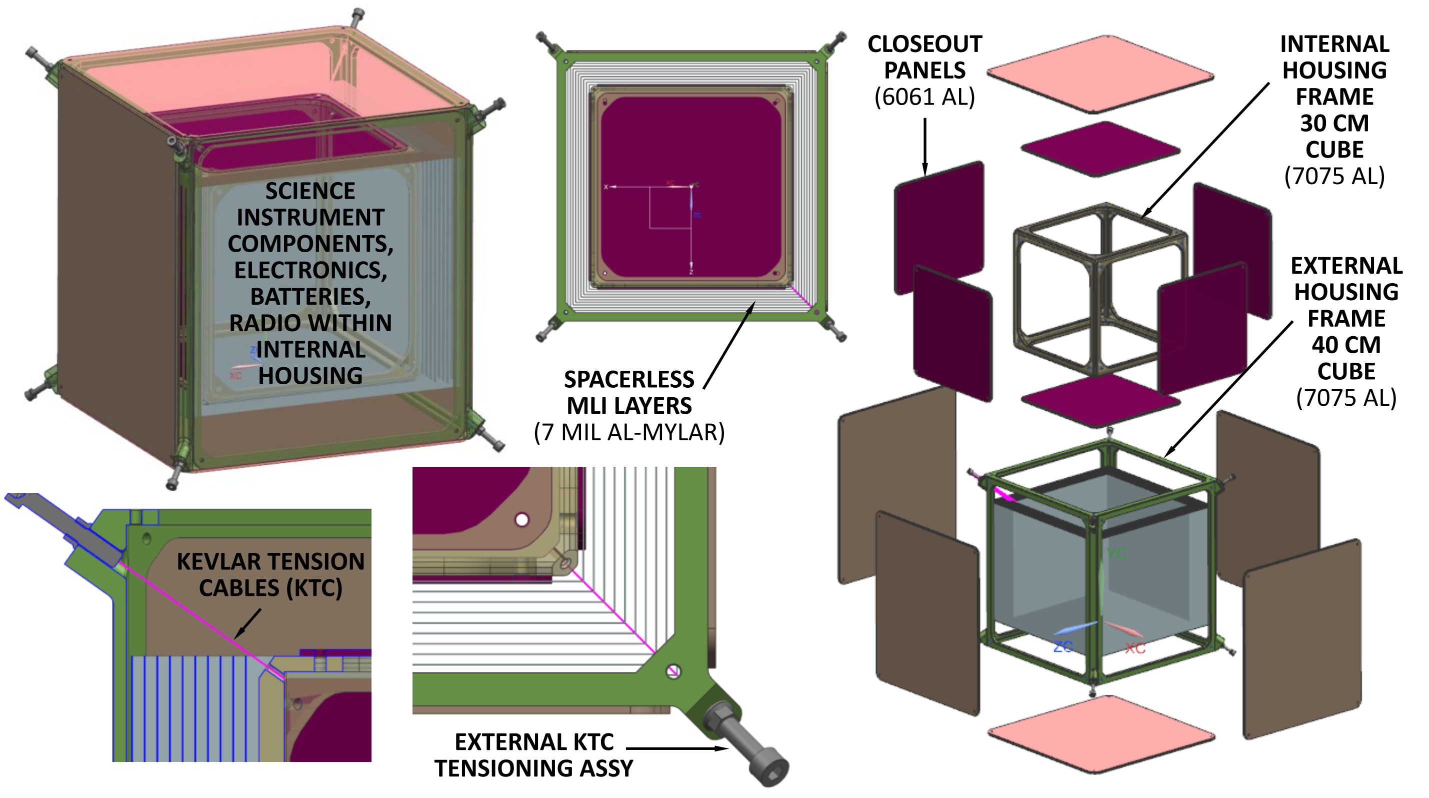






Key Measurable Metric KMM4 is the Thermal Isolator Conductance G < 0.001 W/K

Results: ARTEMIS-T Enclosure CAD Models

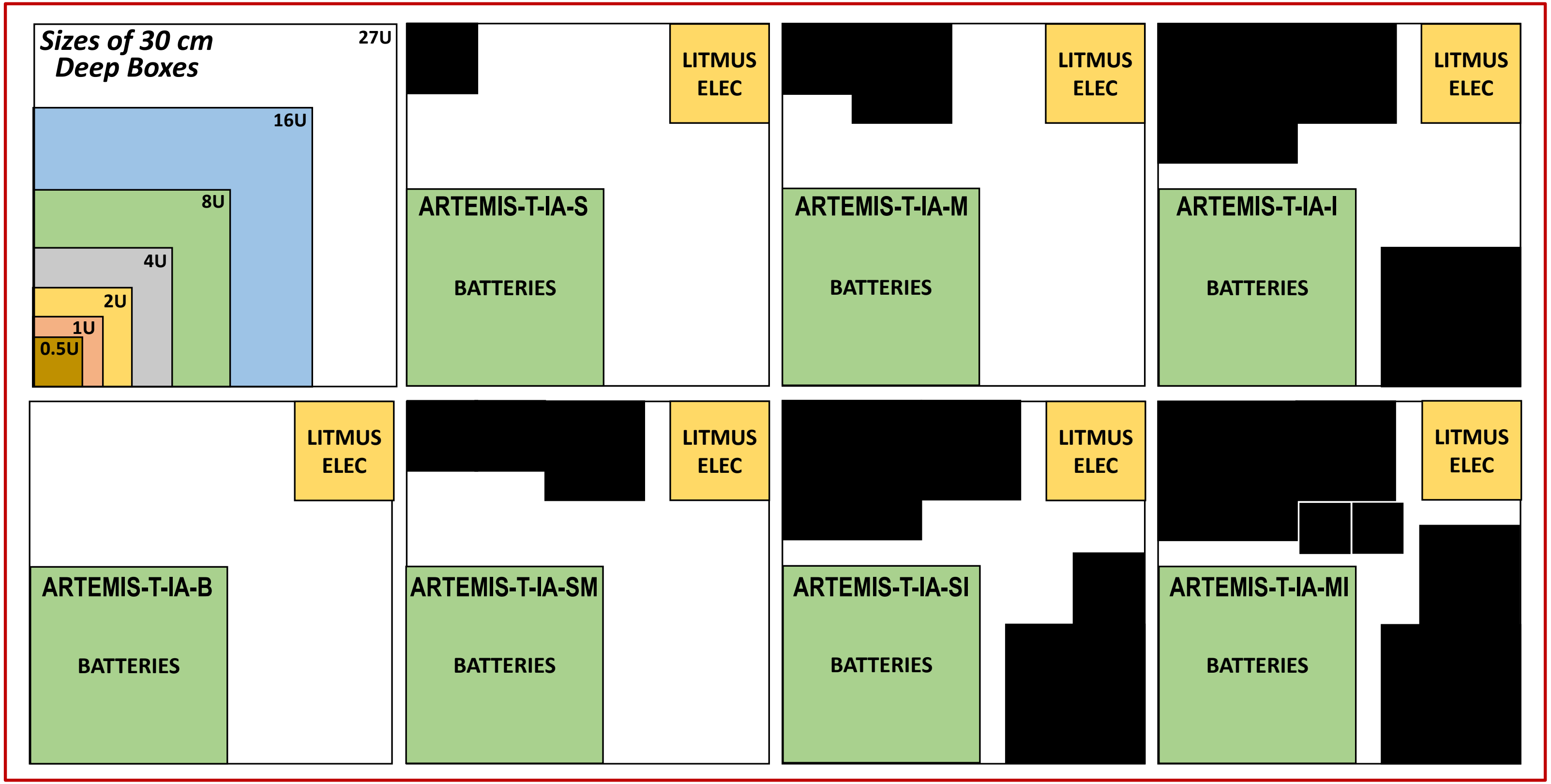


Results: Instrument/Suite Design Information

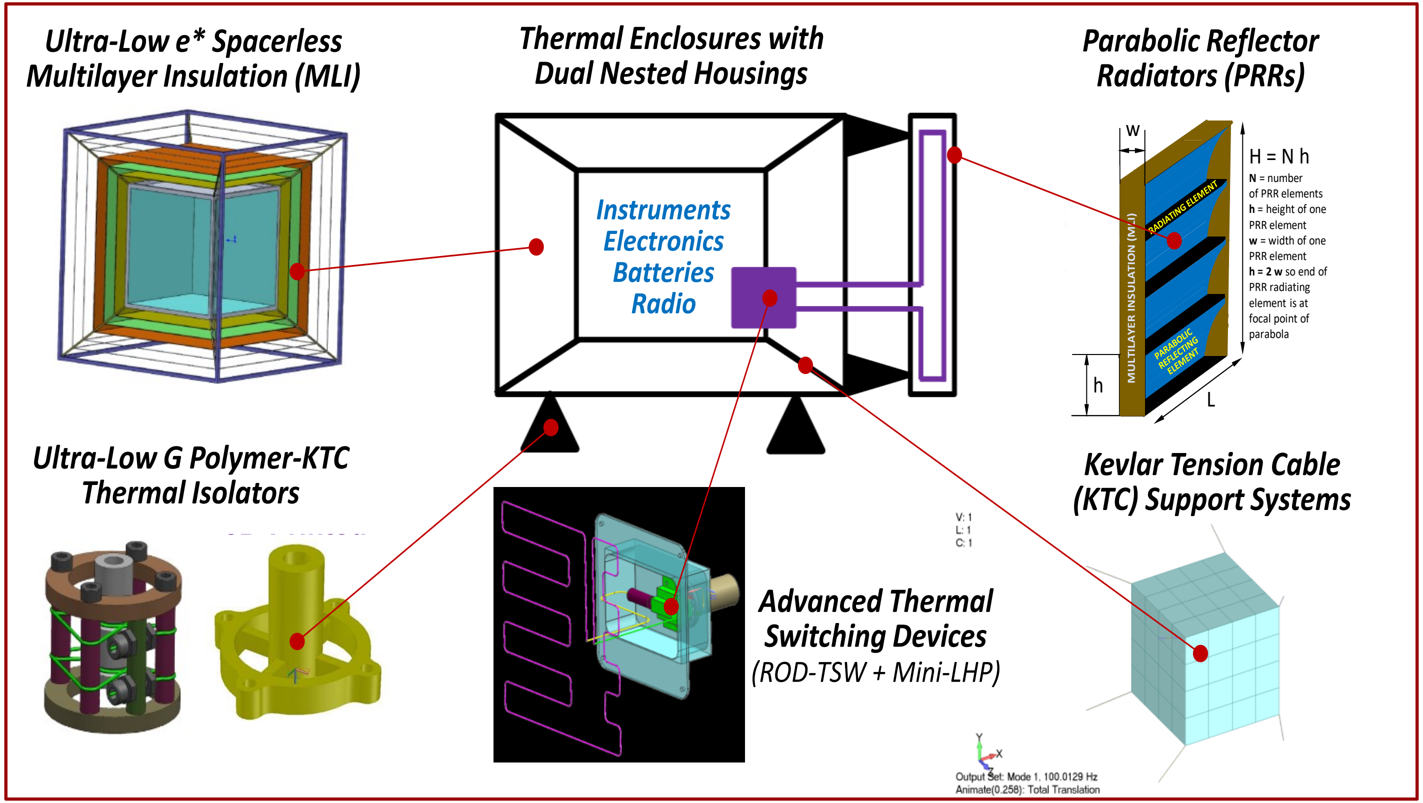
Name	Items Comprised Within ARTEMIS-T-IA Internal Housing	Basis for Science Instrument*	Size (U)	QON (W)	Mass (kg)	Day CONOPS	Night CONOPS	DATA (bps)
ARTEMIS-T-IA-B	LITMUS Electronics	NPLP/LITMUS, PRISM/HAVEN	2.0	2.0	2.5	ON	Survival	400**
ARTEMIS-T-IA-S	Seismometer	PRISM/LSP	1.0	3.0	1.0	ON	ON + Survival	2400
ARTEMIS-T-IA-M	Magnetometer	PRISM/MILI	3.0	3.5	3.0	ON	ON + Survival	50
ARTEMIS-T-IA-I	IR Spectrometer	PRISM/SILVIR	10.0	20.0	10.0	ON	Survival	750
ARTEMIS-T-IA-SM	Seismometer + Magnetometer	PRISM/LSP+PRISM/MILI	4.0	6.5	4.0	ON	ON + Survival	2450
ARTEMIS-T-IA-SI	Seismometer + IR Spectrometer	PRISM/LSP+PRISM/SILVIR	11.0	23.0	11.0	ON	ON + Survival	3150
ARTEMIS-T-IA-MI	Magnetometer+IR Spectrometer	PRISM/MILI+PRISM/SILVIR	13.0	23.5	13.0	ON	ON + Survival	800

* NPLP = NASA Provided Lunar Payloads
PRISM = Payload and Research Investigations on the Surface of the Moon
LSP = Lunar Seismic Package
MILI = Magnetometer Investigation of the Lunar Interior
SILVIR = Surface Imaging of Lunar Volatiles in the IR
LITMUS = Lunar Instrument Thermal Management Ultra-isolation System
HAVEN = Hyper-isolative Autonomous Variable-conductance ENclosures
** Radio will need to be upgraded from LITMUS Lithium UHF radio

Results: Instrument/Suite Packaging in 30 cm Cube



Results: PALETTE Technologies Used



Publications and References

ARTEMIS-T Related Presentations/Papers

(URS approved; from slide show mode double click to open PPTX files; from normal mode double click to open DOCX file)

ICES-2020-145

High Performance Thermal Switch for Lunar and Planetary Surface Extreme Environments

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This paper describes a high performance thermal switch for lunar/planetary extreme environments. This device has been given the name Reverse-Operation DTE Thermal Switch (or ROD-TSW). Two different prototypes were designed, built, and tested. Their basis of operation is the mating/de-mating of parallel flat metal surfaces driven by the differential thermal expansion (DTE) between mid-to-high CTE metal/polymer or metal-only end-pieces and a low CTE, low thermal conductivity (k) metal/polymer support rod. The requirements were to be fully ON above 300 K and fully OFF below 260 K. A series of four tests were carried out to verify/qualify the prototypes. In the first (non-vacuum) test, the thermal switches were cooled with freeze-spray and the non-conductive rod in the OFF thermal path allowed electrical resistance to confirm the 273 K as-designed ON/OFF actuation temperature. In the second (vacuum) test, a calibrated Q-meter was used, which indicated 5 W/K ON, 0.002 W/K OFF conductance (2500:1 ON/OFF ratio). To increase readiness to TRL6, a vibration test with pre/post thermal cycling followed by a 36-day test in a relevant environment were also carried out. This paper describes the development program and on-going related work at JPL.

Nomenclature

CTE	=	coefficient of thermal expansion (K^{-1})
DTE	=	differential thermal expansion
ε^{*}	=	effective emissivity
G	=	conductance (W/K)
GEVS	=	Goddard environmental verification standard
k	=	thermal conductivity ($Wm^{-1}K^{-1}$)
MER	=	Mars Exploration Rover
QM	=	Q-meter
RHU	=	radioisotope heater unit
ROD-TSW	=	reverse-operation DTE thermal switch
TS	=	thermal strap
TSW	=	thermal switch

I. Introduction

OVER the next several years, NASA and the commercial sector are reportedly planning lunar/planetary exploration missions that will require a new class of surface science instruments that can make sustainable high-value measurements over an extended number of day/night temperature/power cycles. Instruments that can provide this capability without radioisotopes, by combining advanced thermal management capabilities and solar/battery power, will have a higher likelihood of NASA selection and mission implementation due to their: *(1) lower cost, easier/faster producibility, and reduced public scrutiny*, as they will have avoided radioisotope heat sources, which are costly, relatively scarce, and (from a lay perspective) environmentally risky; and *(2) extended operability/survivability*, which will enable them to generate science data over a long period of time that will likely extend well beyond the operational lifetimes of early commercial lunar/planetary landers (or rovers) upon which they will reside.

To support this new class of instruments, including magnetometers, seismometers, IR spectrometers, various other instruments, and instrument suites, JPL is developing several improved thermal management "toolbox" elements

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