2020 Interplanetary Small Satellite Conference

Thermal Toolbox Elements for Lunar/Planetary Extreme Environments

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PROBLEM

Science Payload Thermal Control in Extreme Environments

We want to use one of these …

Rover
Lander
Orbiter
Flyer
Airship

Carrying one or more of these …

Science Payload (PL) 253-313 K

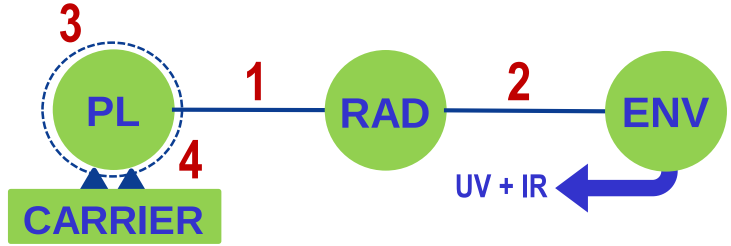
To operate and stay within temperature limits, in Extreme Environments such as these …

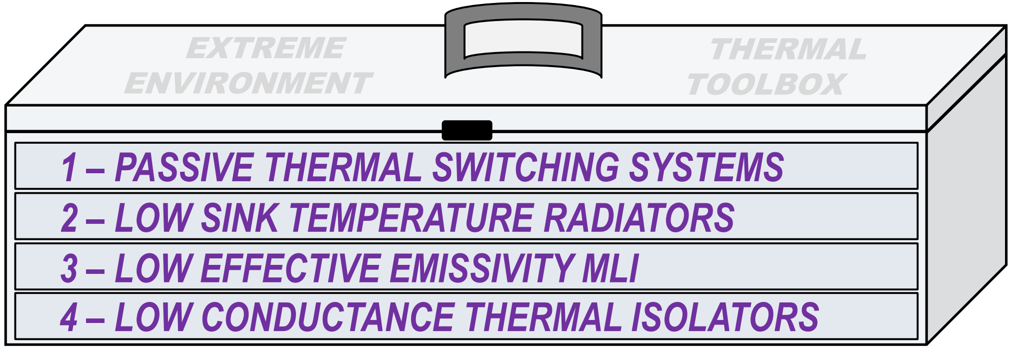
Moon	(100-380 K,	Vac)
Mars	(148-293 K,	Non-Vac)
Europa	(53-113 K,	Vac)
Titan	(90-94 K,	Non-Vac)
Io	(105-123 K,	Vac)
Venus 70-30 km	(173-473 K,	Non-Vac)

Using a thermal control architecture that is …

Low Power
Lightweight
Passive
Compact
Reliable
Affordable
Radioisotope-Free

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



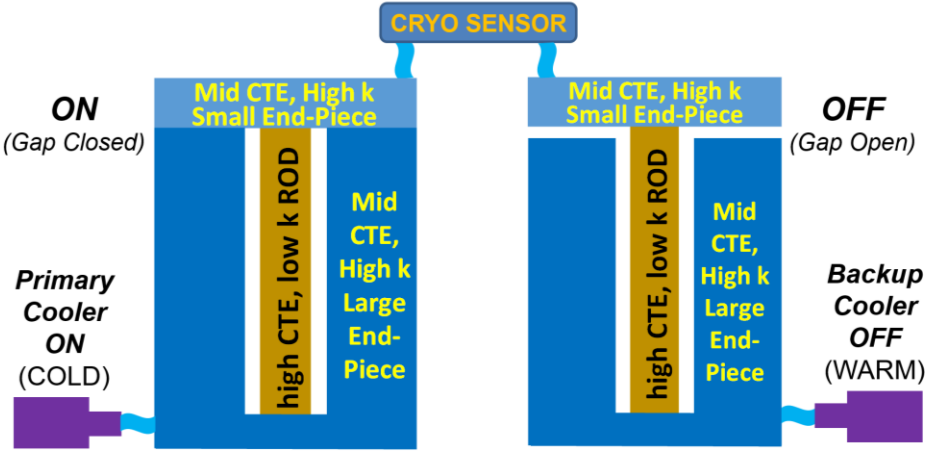


1 – PASSIVE THERMAL SWITCHING

Differential Thermal Expansion (DTE) Actuation

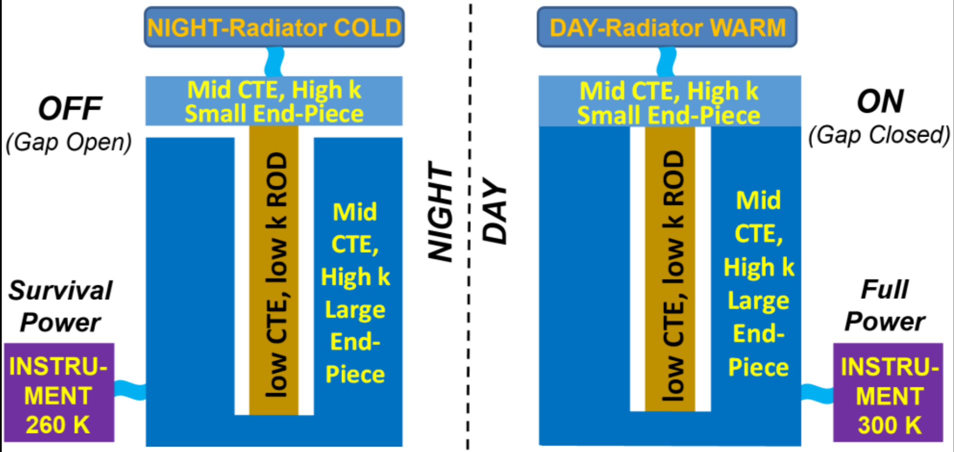
Normal-Operation

For applications that must **KEEP HEAT OUT**, such as a dual cryocooler system or Curiosity SAM, a ***Normal-Operation DTE Thermal Switch*** has a LOW k ROD with a ***Higher CTE*** than the HIGH k END-PIECES.



Reverse-Operation

For applications that must **KEEP HEAT IN**, such as lunar instruments, the new JPL-Developed ***Reverse-Operation DTE Thermal Switch*** needs a LOW k ROD with a ***Lower CTE*** than the HIGH k END-PIECES.



Swales Aerospace 2002

- *Flown on Mars Curiosity SAM Instrument in 2012*
- *SAM thermal switch launched closed at room temp*
- *Typical normal-op design has open gap at room temp*
- *Vibration test at JPL in 2016 reduced ON conductance*

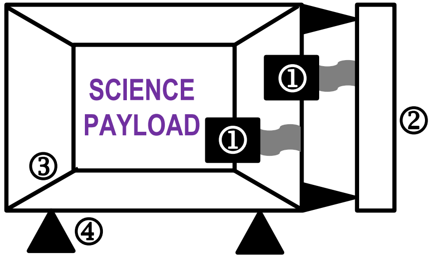
JPL 2017

- *Advanced to TRL6 in 2018 (vibe test OK)*
- *Integral to JPL internal initiative called ARTEMIS*
- *Integral to NASA GCD Project called **PALETTE***
- *Two units to fly on Astrobotic Peregrine lander*

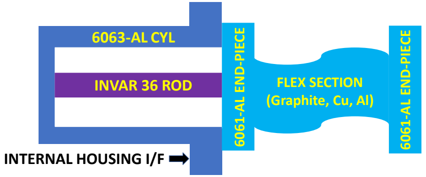
1 – PASSIVE THERMAL SWITCHING (cont'd)

Hyper-Isolative Passive Thermally-Switched Architectures

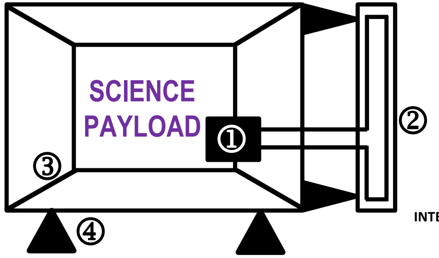
A. Dual Thermal Switching Enclosure with Reverse-Operation DTE Thermal Switches (ROD-TSWs)



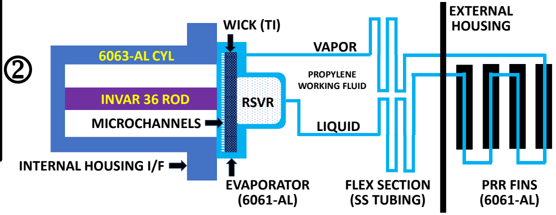
PALETTE NASA GCD New Idea



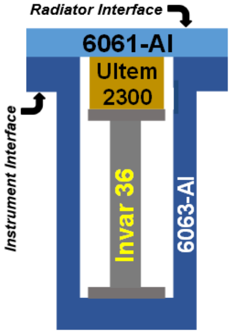
B. Dual Thermal Switching Enclosure with Combined ROD-TSW, Mini Loop Heat Pipe (mini-LHP)



PALETTE NASA GCD New Idea



ROD-TSW DESIGN-1: *Compact Mounting Flange*

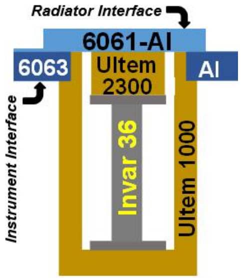


Measured Performance

GON	= 5 W/K
GOFF	= 0.002 W/K
G-Ratio	= 2500
TON/OFF	= 273 K

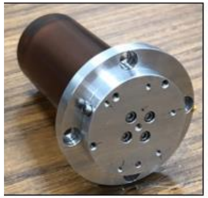
Envelope: L = 126 mm, D (max) = 35 mm
Mass: 137 grams

ROD-TSW DESIGN-2: *Heritage Mounting Flange*



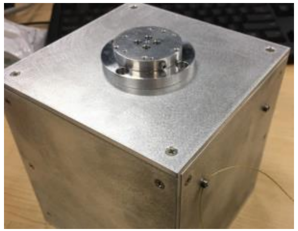
Measured Performance

GON	= 5 W/K
GOFF	= 0.002 W/K
G-Ratio	= 2500
TON/OFF	= 283 K



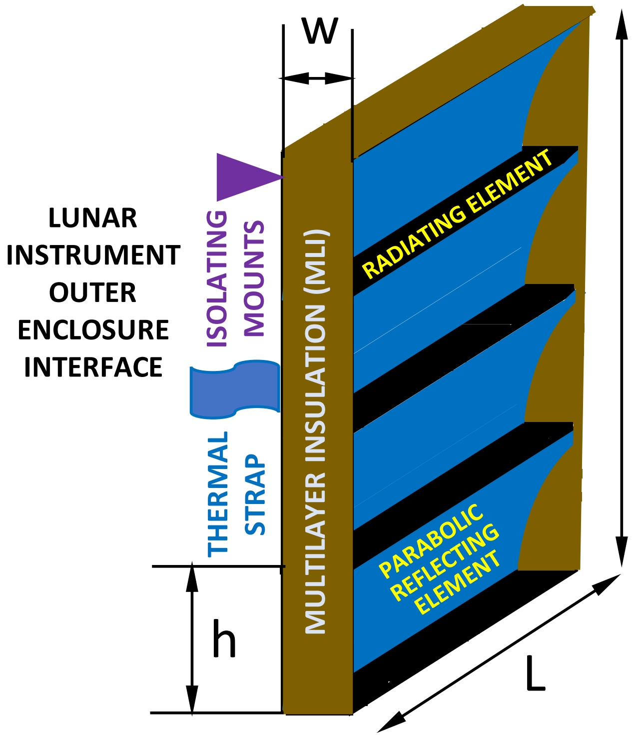
Envelope: L = 86 mm, D (max) = 55 mm
Mass: 142 grams

LEGEND
① *Thermal Switch*
② *Radiator (PRR)**
③ *Kevlar Cables/MLI**
④ *Thermal Isolator**
** shown later*



2 – LOW SINK TEMP RADIATORS

Parabolic Reflector Radiators (PRRs) Provide Low Sink Temperature



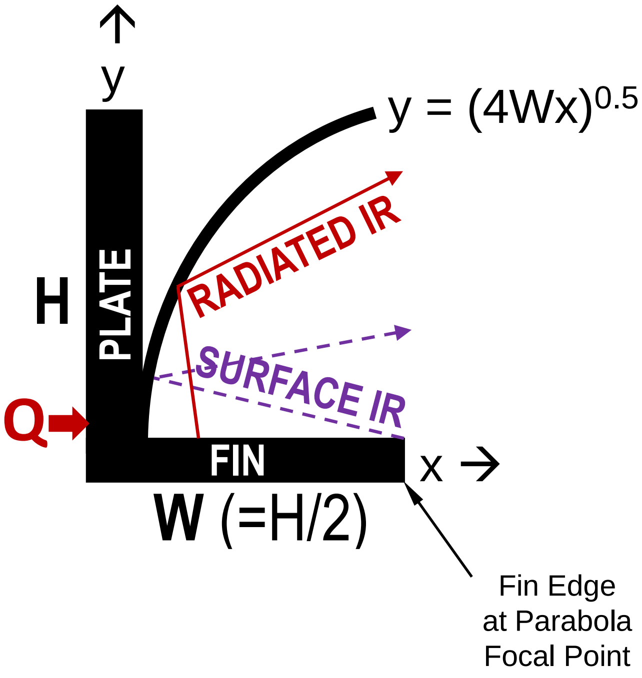
$H = N\ h$

N = number of PRR elements

h = height of one PRR element

w = width of one PRR element

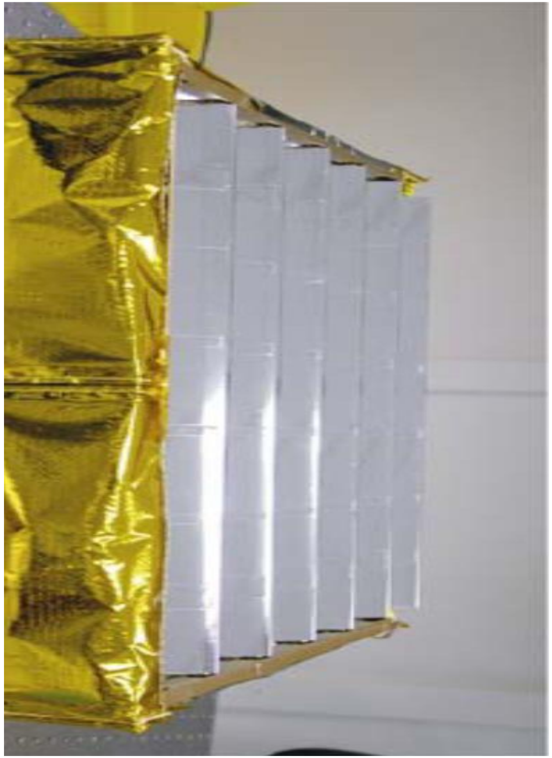
h = 2 w so end of PRR radiating element is at focal point of parabola

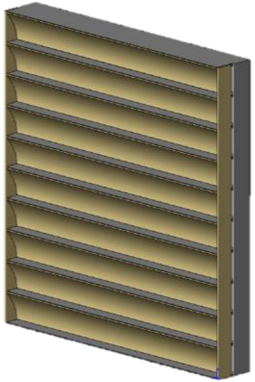


2 – LOW SINK TEMP RADIATORS (cont'd)

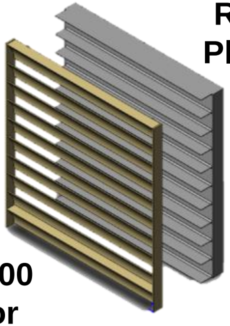
3D-Printed PRRs Reduce Fabrication Costs, Provide Low Sink Temp

M3 Cryogenic PRR Cost >> $100K





2-Piece Ambient PRR Design Fully 3D-Printable

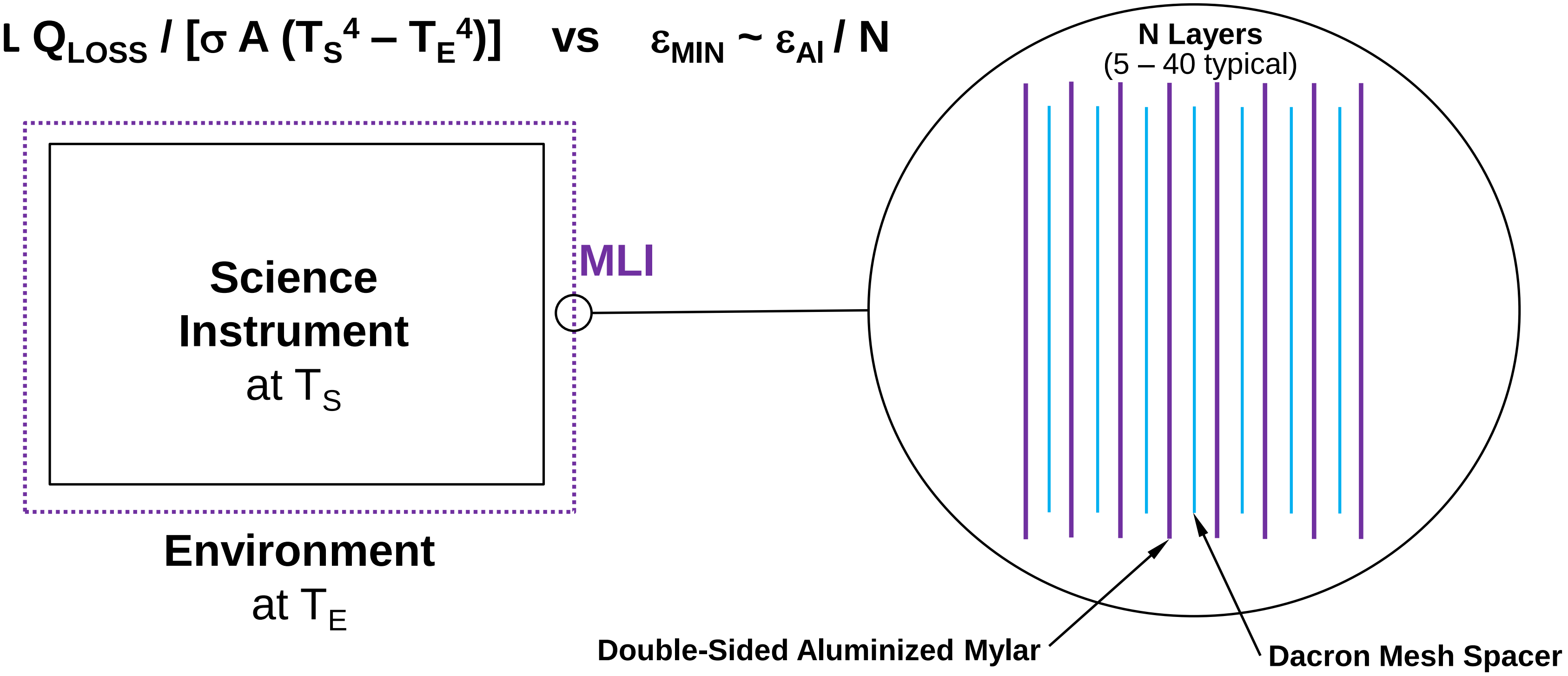


Ambient PRR to Cost << $20K

3 – LOW EFFECTIVE EMISSIVITY MLI

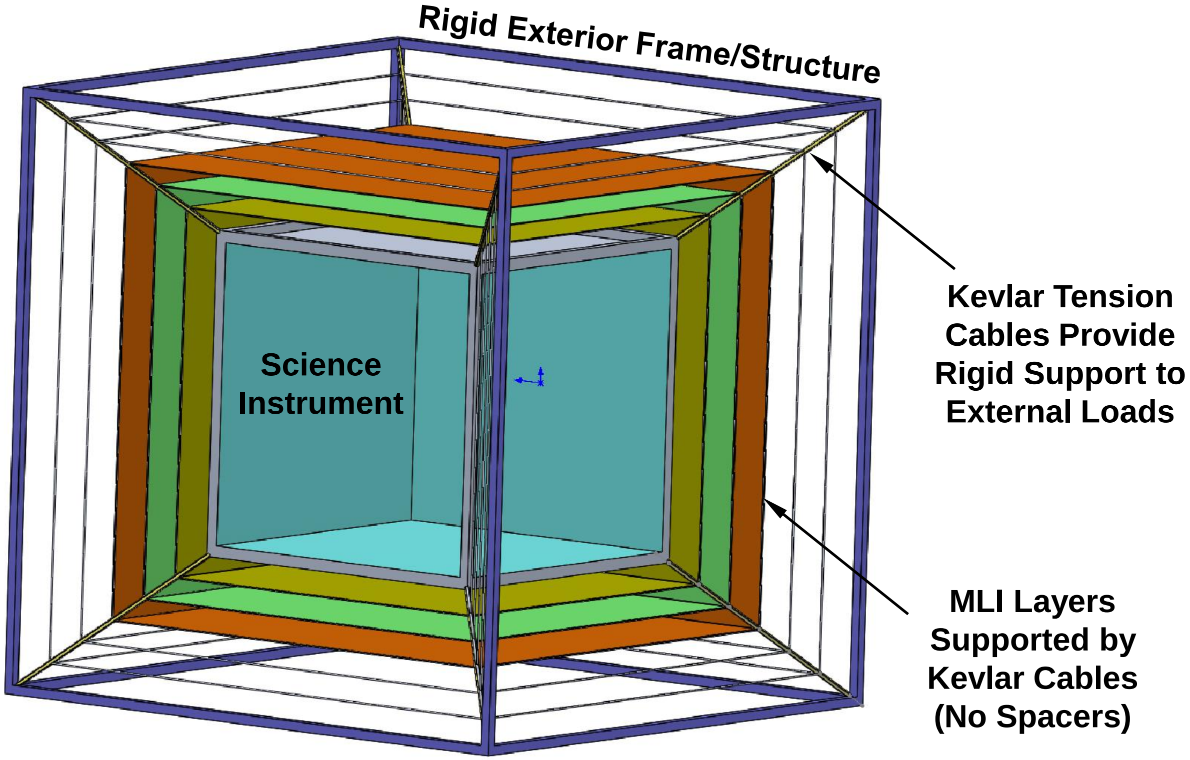
MLI with Spacers Typically has ε^* >> 0.02 despite Al-Mylar ε_{Al} = 0.03 on Both Sides

$\varepsilon^* \; L \; Q_{LOSS} \,/\, [\sigma \; A \; (T_S^4 - T_E^4)]$ vs $\varepsilon_{MIN} \sim \varepsilon_{Al} \,/\, N$



3 – LOW EFFECTIVE EMISSIVITY MLI (cont’d)

“Spacerless” MLI Construction: *Performance Target $\varepsilon^* \ll 0.01$*

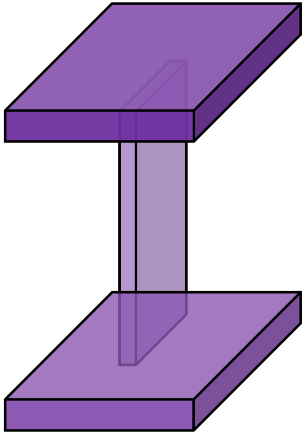


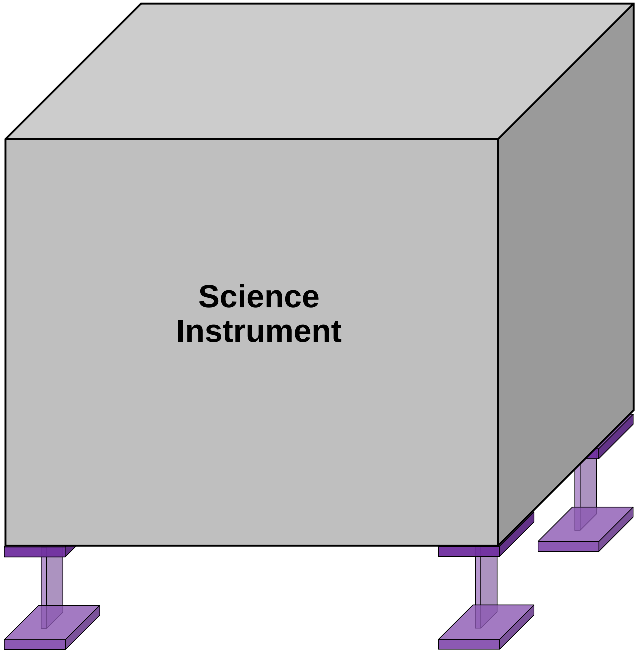
Spacerless MLI Demo Unit to be Tested When JPL Reopens

4 – LOW G THERMAL ISOLATORS

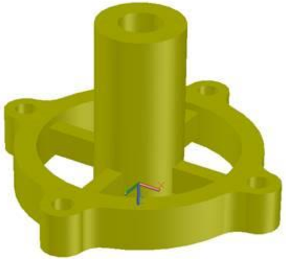
Concepts to Outperform Blade Flexures: *Performance Target is G << 0.001 W/K*

Notional Metallic Blade Flexure Thermal Isolator

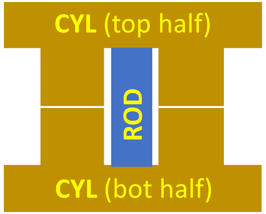




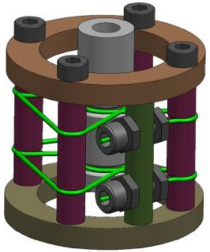
3D-Printable Ultem 1000 Thermal Isolator



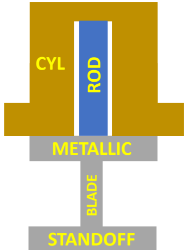
ROD-TSW Based Thermal Switching Isolator Concept 1



Kevlar Tension Cable Supported Thermal Isolator



ROD-TSW Based Thermal Switching Isolator Concept 2

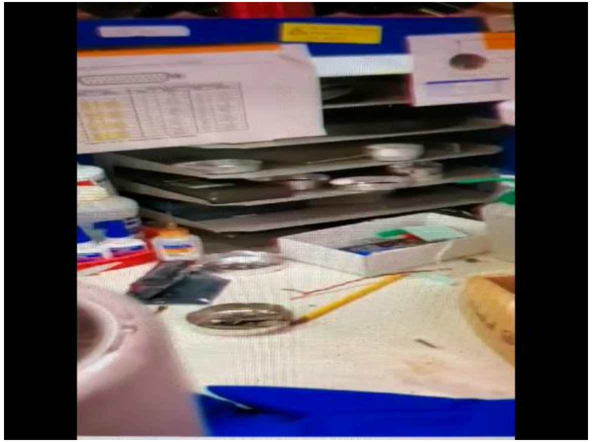


SUMMARY / FUTURE WORK

- Operation and survival in extreme environments like the moon (without radioisotopes) requires an improved thermal toolbox.
- JPL is currently using internal funds to develop thermal enclosure designs for stand-alone solar/battery-powered lunar magnetometers, seismometers, and IR spectrometers.
- In parallel, JPL was recently awarded a 3-year project (PALETTE) by NASA GCD program office to develop advanced thermal toolbox elements for future instruments operating in extreme (planetary/lunar) environments.
- PALETTE intends to provide thermal engineers with a full “palette” of TRL6 or higher thermal toolbox elements, focusing on: 1-enclosures; 2-radiators; 3-insulation/MLI; 4-thermal isolators; 5-gimbals; 6-thermal switches; 7-thermal transport devices; 8-thermal storage devices; 9-deployables/antennae; and 10-low heat loss feed-throughs.
- Work on PALETTE is just getting started and work on the internal JPL program (known as ARTEMIS-T) is midway through the first year of a 3-year project.
- JPL also working on Extended Stroke ROD-TSW for non-vacuum and vacuum environments using DTE between Ultem 1000 and (negative CTE) Allvar … movie shows large 2 mm gap formed when demo unit partly submerged in LN2

Extended Stroke ROD-TSW Demo Unit Creates 2 mm Gap When Partly Submerged in LN2

(1-Minute Movie)



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