# A Tunable Multi-Environment Multilayer Insulation for in-air, in-space and on-Mars performance

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Space Cryogenics Workshop
July 2017

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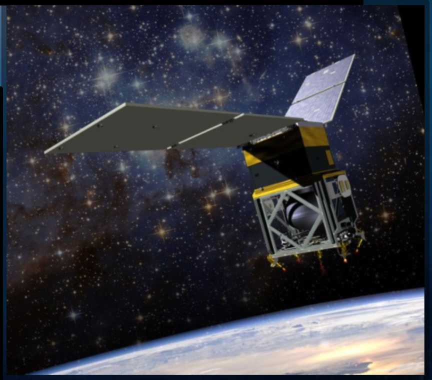
- *Providing innovative thermal solutions for improved energy efficiency for aerospace and commercial uses.*

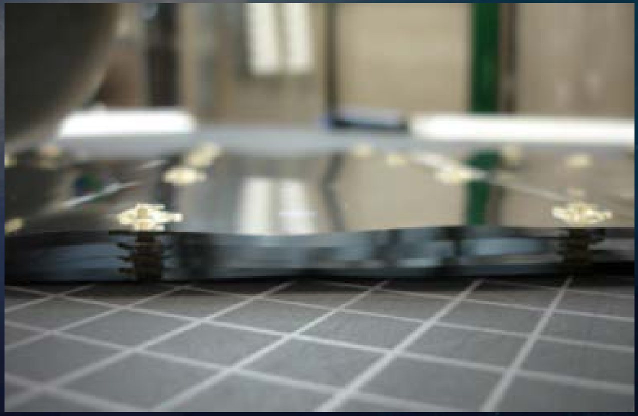


- Quest has been funded by the NASA SBIR program
- Strong NASA multicenter support for our innovative technologies
- Quest technologies are in the NASA Thermal Management Systems Technology Roadmap, and help solve critical needs for space exploration and Mars missions.

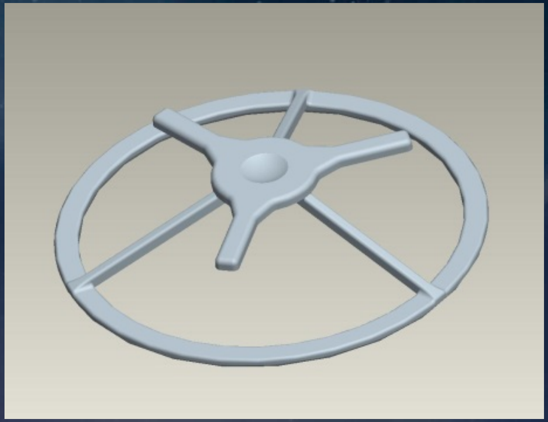
# Quest Discrete Spacer Technology

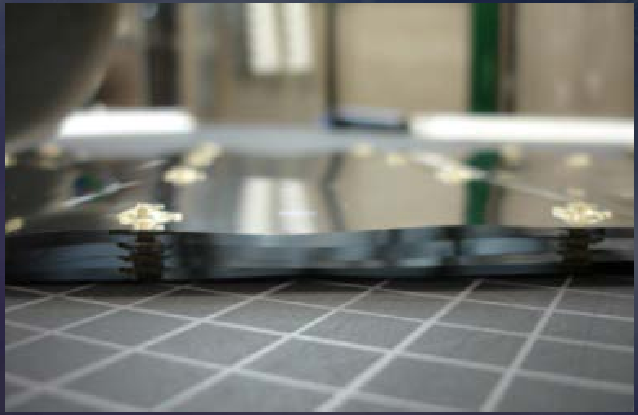
- Discrete spacer technology used in *Integrated MLI (IMLI)*
  - Polymer spacers with low thermal conductance replace netting
  - Spacers enable precise control over layer spacing and density
  - Spacers can provide varying structural support
  - Provides a robust, structural MLI
  - Patented technology developed by Quest Thermal & Ball Aerospace


Integrated MLI Concept



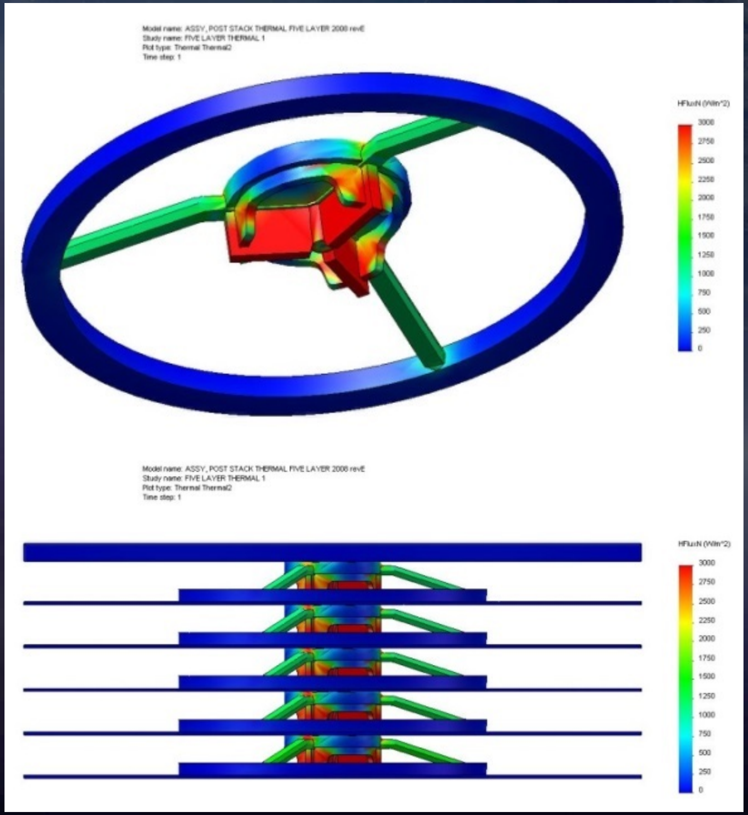
# Quest Discrete Spacer Technology

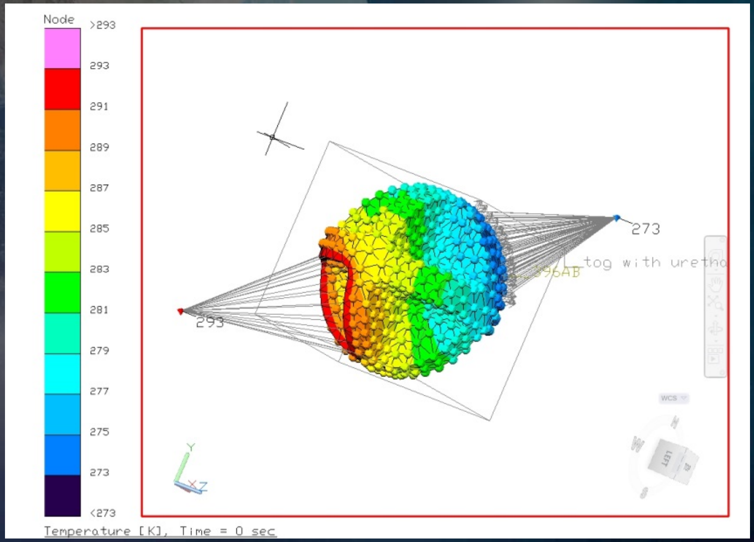




# Quest Discrete Spacer Technology

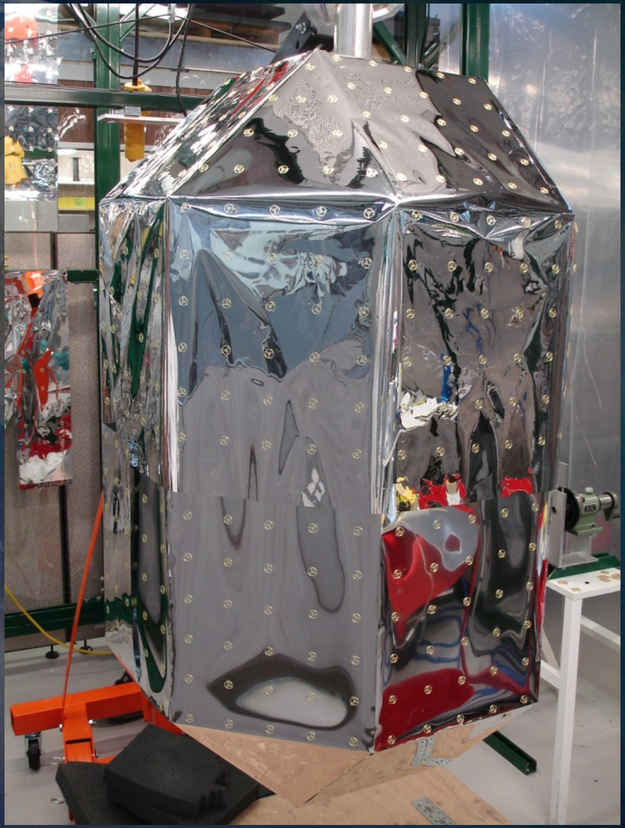
- Discrete spacers
  Modeled and analyzed via FEA and Thermal Analysis Kit for structural strength and heat flow

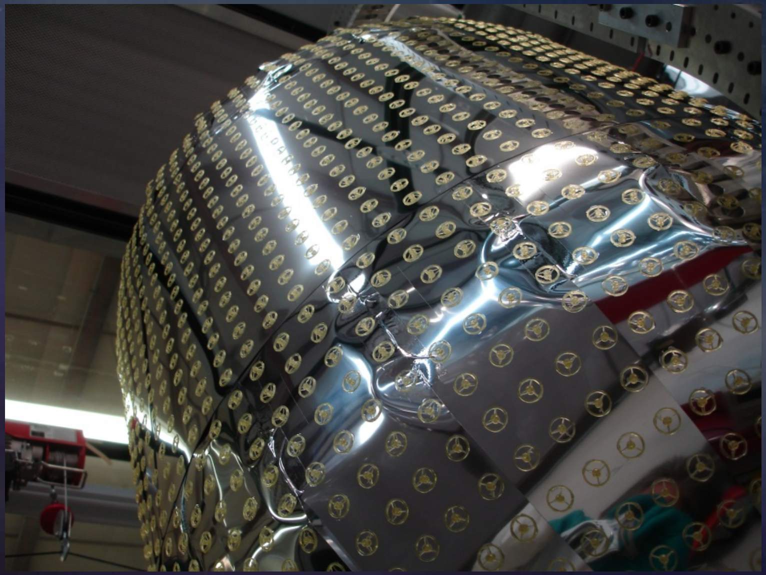


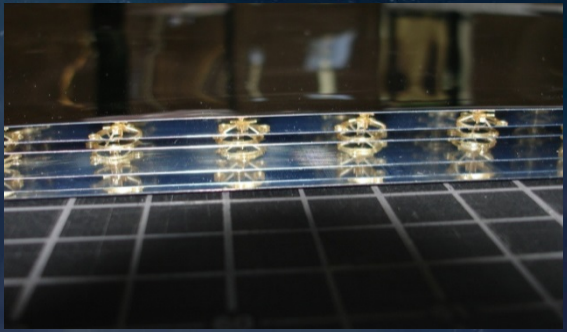
# Quest Discrete Spacer Technology

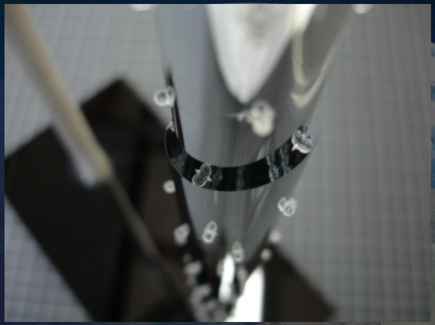
- Discrete spacer systems installed on tanks and tested via boiloff calorimetry

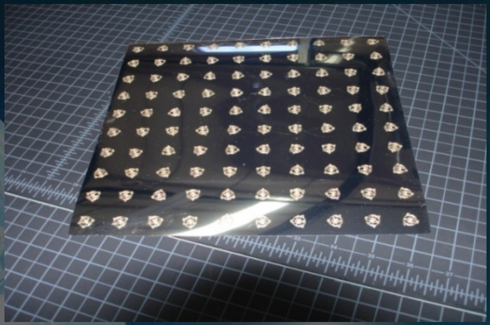


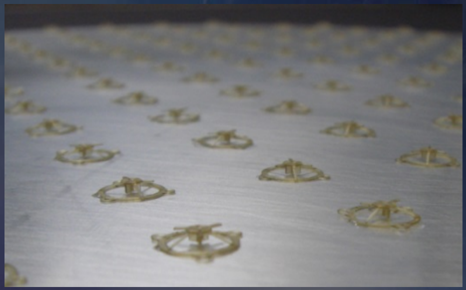


# Quest Discrete Spacer Technology



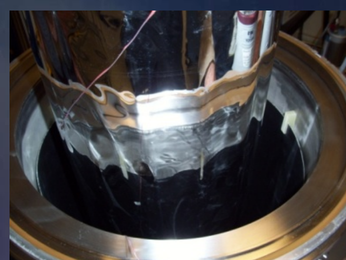






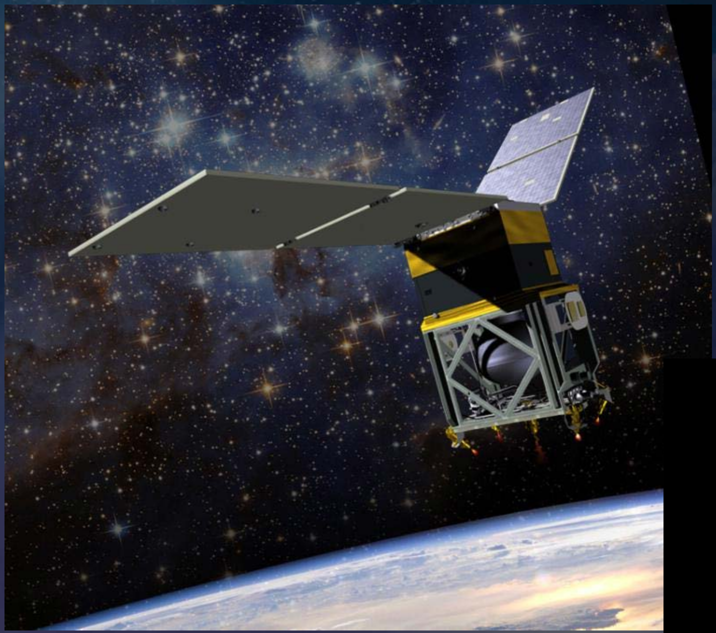
Quest has developed various custom thermal spacers for specific applications. These include the IMLI spacer, LRMLI spacer, WMLI spacer and HPI spacer (all patented or in prosecution). Quest spacers enable structural insulation with unique properties.

# IMLI Performance Measured on Quest/Ball/NASA Calorimeters

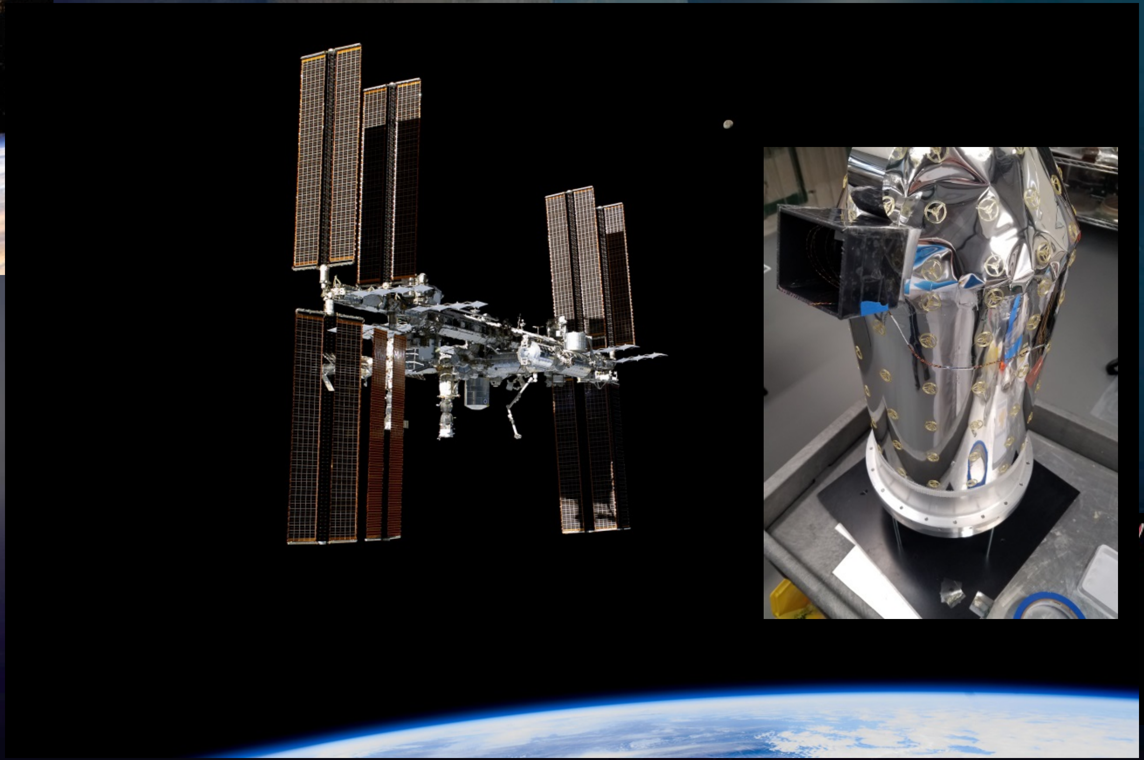



- Tested at NASA, Ball Aerospace and at Quest Thermal
- IMLI 20-layer blanket heat flux 0.41W/m$^2$ (77K-295K, 3.6cm)
- Up to 50% lower heat leak per layer than typical netting
- SBIR Phase III program, TRL6

# IMLI will fly on two NASA missions



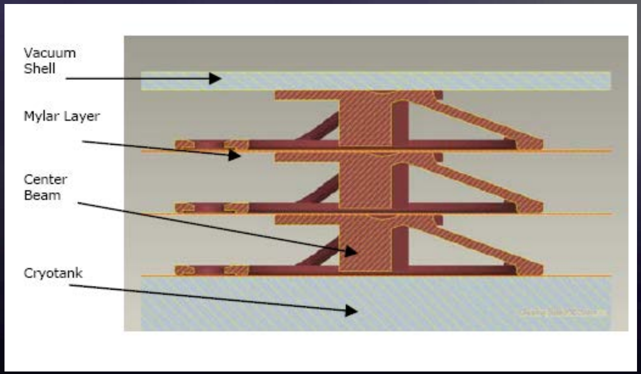
IMLI will reach TRL9 in 2017 with a first spacecraft flight on the NASA/Ball Aerospace GPIM mission.



IMLI will fly on the NASA RRM3 ISS flight experiment in 2017-2018.

# Load Responsive MLI

- Load Responsive MLI uses dynamic spacers that compress to support an external load and disconnect with no load:
  - 32mg dynamic spacers can support up to 90 lb-force each
  - Supports lightweight vacuum shell for in-air operation
  - Provides high performance in-air and on-orbit, SOFI replacement
  - Ideal insulation for LH2 tanks in air
- Numerous application of discrete spacers…




# Load Bearing MLI insulation completes multi-center NASA test program

LBMLI is a robust, structural insulation that uses Load Responsive spacers to support external loads such as an actively cooled thermal shield and external insulation.

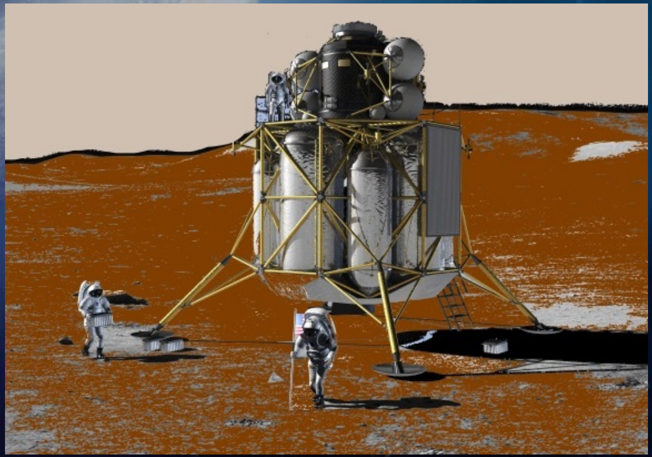
- Provided 51% less heat leak per layer than conventional MLI with tank standoffs

# TA14 Roadmap

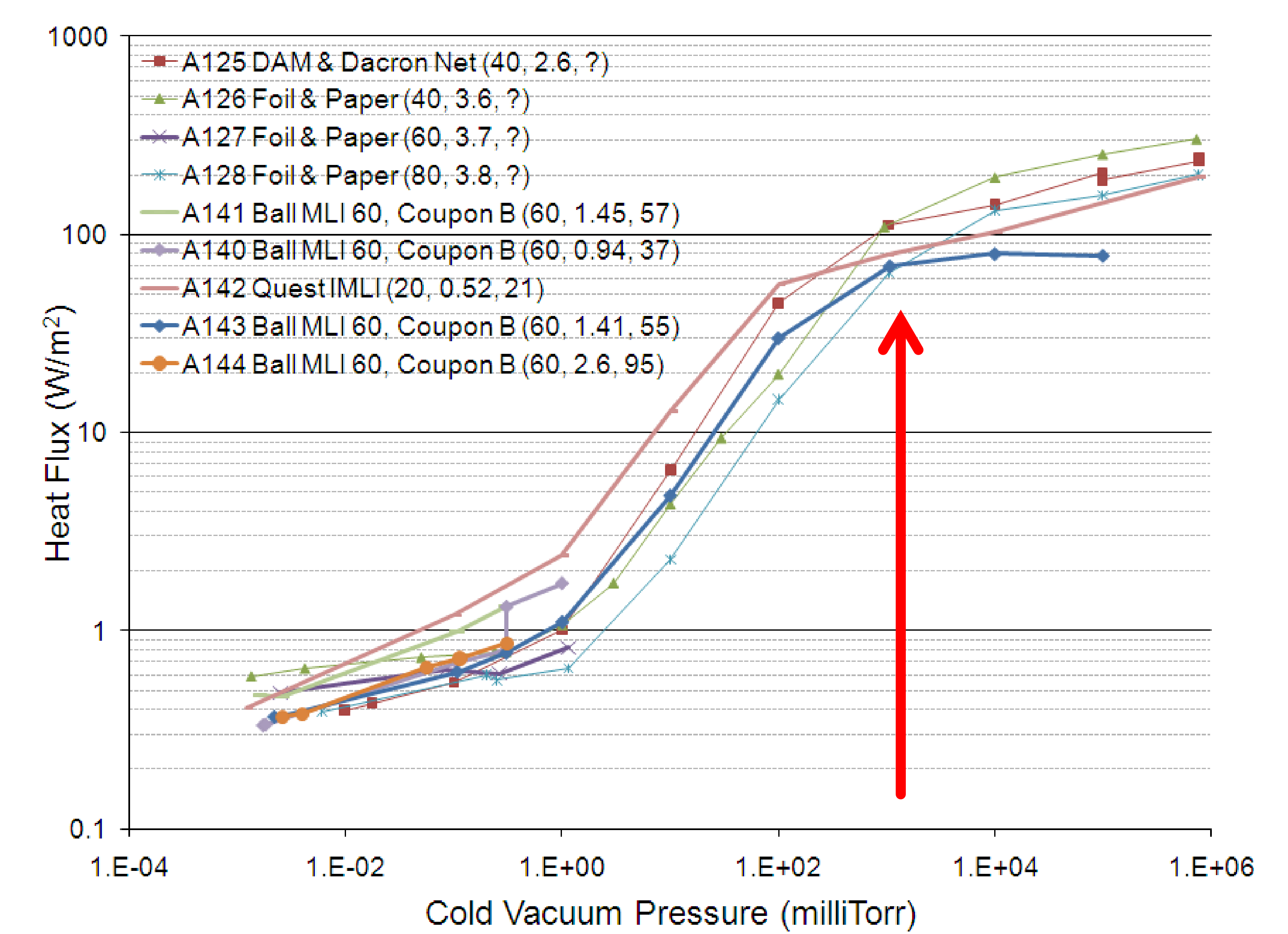
- A single insulation solution responsive to thermal loads from launch (one atm), ascent, and on orbit is required.
- Expand MLI concepts so the outer layer is capable of supporting a vacuum while on Earth, compressing while being supported by an advanced spacer system.
- Insulation that can be integrated with broad area coolers or vapor-cooled shields for large tanks
- Low Thermal Conductivity Structural Supports: methods for minimizing or eliminating this loss are needed.
- Insulation with Micrometeoroid Orbital Debris (MMOD) Protection.

# NASA SBIR 2015 topic

- "Lightweight, multifunctional cryogenic insulation systems that can survive exposure to the free stream during the launch/ascent environment in addition to high performance less than 0.5 $W/m^2$ (with a warm boundary of 220 K) on orbit or <5 $W/m^2$ on Mars surface."

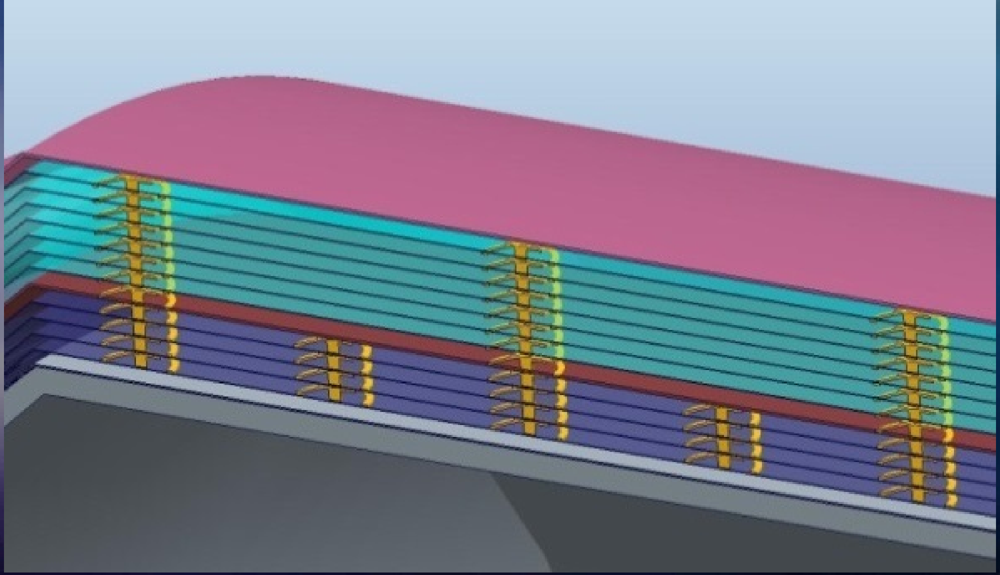


# MLI on Mars surface



# Quest Hybrid LRMLI

- **Quest multi-functional MLI:**
- durable Launch Vehicle outer layers (for high performance on-orbit)
- Load Responsive inner layers (for high performance in-Earth atmosphere and on-Mars)



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# Quest Hybrid LRMLI

**New goals were established:**

- <1.0 W/m$^2$ on-Mars
- <0.5 W/m$^2$ in-space
- < SOFI heat leak (~289 W/m$^2$) prelaunch from Earth
- Minimal mass
- No aero launch loads to be considered at this time (a Mars lander would launch inside a fairing)

# Discrete spacers

Can the structural strength of discrete spacers be matched to the structural load and heat leak needed?

# MEMLI configurations

| 2" Spacing LRMLI Posts | | Heat Flux | | |
|---|---|---|---|---|
| # of Post Layers | 1 Atm @295-105 GN2 filled | 7torr @210-105 | 4.5torr @ 210-105 | Orbit @ 210-105 |
| 8 | 132.5 | 0.85 | 0.7395 | 0.34 |
| 9 | 123.8 | 0.76 | 0.6612 | 0.306 |
| 10 | 116.3 | 0.693 | 0.60291 | 0.277 |

| 2" spacing IMLI Posts | | | | |
|---|---|---|---|---|
| # of Post Layers | 1 Atm @295-105 GN2 filled | 7torr @210-105 | 4.5torr @ 210-105 | Orbit @ 210-105 |
| 8 | 132.5 | 0.31 | 0.31 | 0.31 |
| 9 | 123.8 | 0.28 | 0.28 | 0.28 |
| 10 | 116.3 | 0.25 | 0.25 | 0.25 |

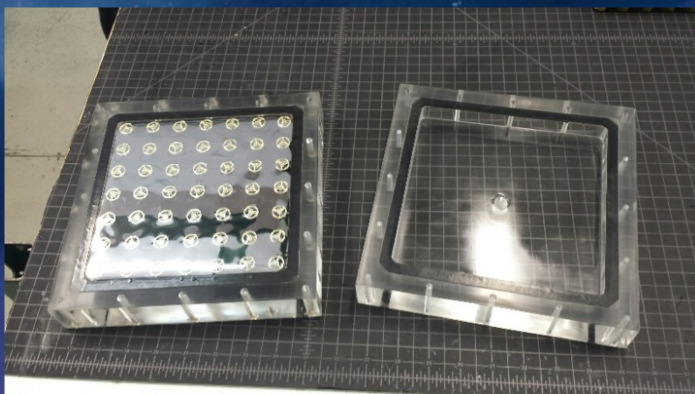
| 1" spacing IMLI Posts | | | | |
|---|---|---|---|---|
| # of Post Layers | 1 Atm @295-105 GN2 filled | 7torr @210-105 | 4.5torr @ 210-105 | Orbit @ 210-105 |
| 8 | 132.8 | 0.7 | 0.7 | 0.7 |
| 9 | 124.1 | 0.6 | 0.6 | 0.6 |
| 10 | 116.55 | 0.54 | 0.54 | 0.54 |

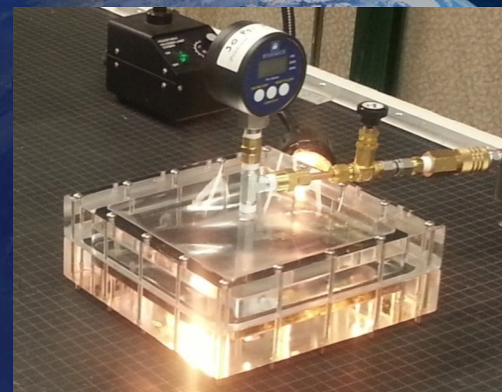
# MEMLI configurations

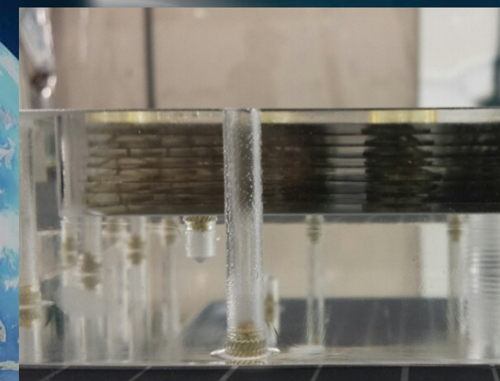
| Sample | | 0.002 Al | 0.005 DAM | 0.002 Al/0.003 SAK | 0.002 DAM | 0.003 SAK | 0.001 Al/ 0.003 SAK |
|---|---|---|---|---|---|---|---|
| 1 | 9L (LR post @ 2") 1mil | | | | | | |
| 2 | 9L (LR post @ 2") 2mil | | | | | | |
| 3 | 9L (LR post @ 2") 5mil | | | | | | |
| 4 | 9L (IMLI post @ 1") 1mil | | | | | | |
| 5 | 9L (IMLI post @ 1") 2mil | | | | | | |
| 6 | 9L (IMLI post @ 1") 5mil | | | | | | |
| 7 | 9L (IMLI post @ 2") 2mil | | | | | | |
| 8 | 9L (IMLI post @ 2") 5mil | | | | | | |

A Trade Study was performed with 48 different configurations; six possible hermetic layers (metalized films to aluminum/film laminates); three different radiant barrier films (1, 2, or 5mil); and three different spacer types and spacing (LRMLI @ 2”, IMLI @ 1” and IMLI @ 2”).

# MEMLI configurations







Small coupons were built and pressure tested to observe structural strength, attempting to fine tune support to on-Mars pressure.

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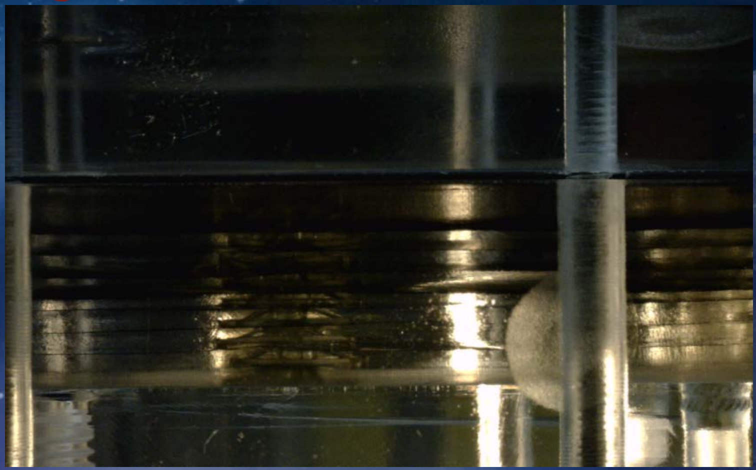
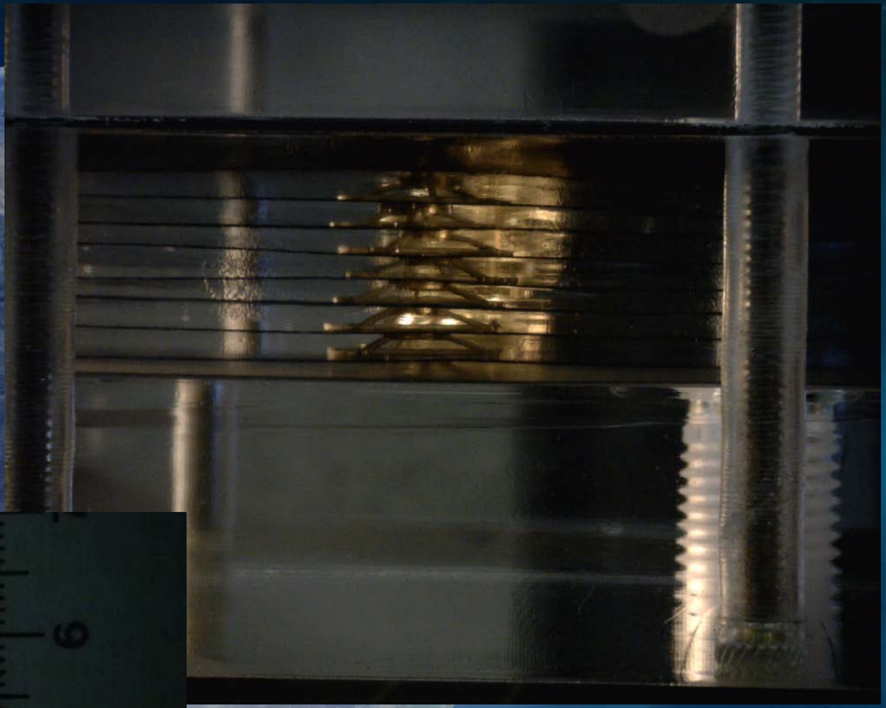
# MEMLI configurations





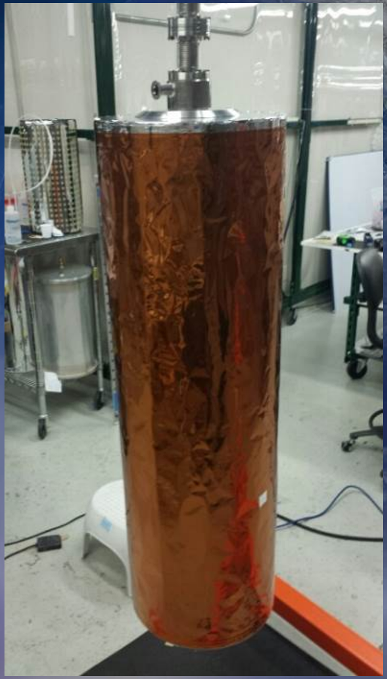
Left top: IMLI spacers at 2” grid with 2mil DAM at 0.18psi.
Right: IMLI spacers at 2” grid with 5mil DAM at 0.18psi.
Left bottom: LRMLI spacers at 2” grid with 5mil DAM at 0.18psi.

# On-Mars surface

## Multi-Environment MLI

- a ***lightweight, novel vacuum shell and inner layers were designed*** that would only support Mars atmospheric pressure (0.087 psi, 600 Pa) and would use ***widely spaced polymer spacers for lower heat leak***.
- ***a ventable/sealable vacuum shell was conceptually designed*** that will be purged with $GN_2$ on Earth (prelaunch), vented to space during in-space cruise, and sealed to retain hard internal vacuum in the 5 torr $CO_2$ Mars atmosphere.

# MEMLI prototype



# MEMLI prototype

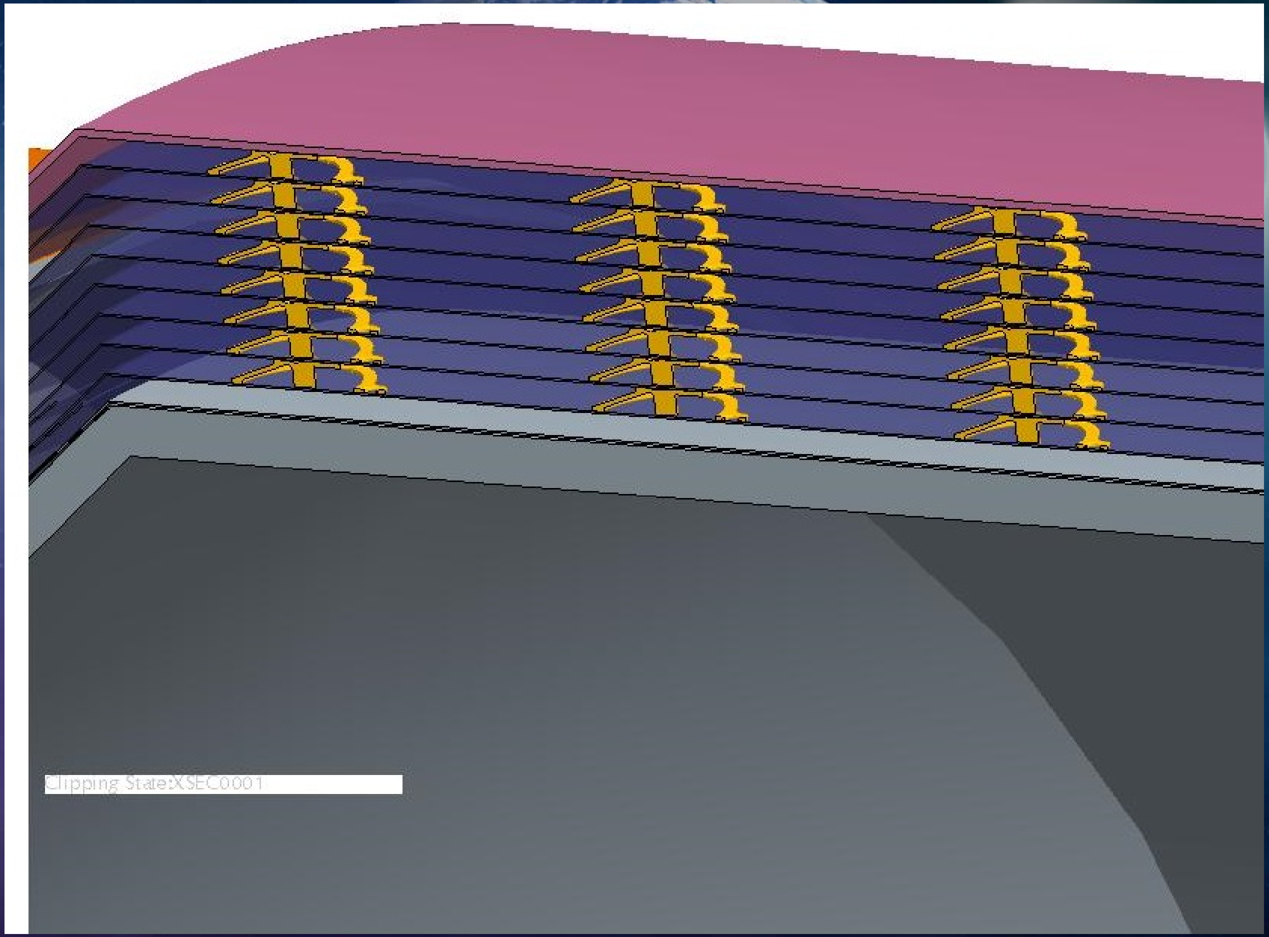
**The MEMLI prototype measured heat fluxes (at 77K, 295K) were:**

| ***Condition*** | ***Q (77 – 295K)*** | ***e**** | ***Calculated heat flux (105 – 210K) ‡*** |
|---|---|---|---|
| **In-space (high vacuum)** | **1.03 W/m$^2$** | **0.00242** | **0.250 W/m$^2$** |
| **On-Mars (4.5 torr $CO_2$)** | **4.18 W/m$^2$** | **0.00978** | **1.01 W/m$^2$** |
| **in-air (purged with $GN_2$)** | **128 W/m$^2$** | **0.299** | **127 W/m$^2$ †** |

‡ Heat flux calculated using measured e* and new boundary temperatures of 105K cold boundary for $LCH_4$ and 210K warm boundary

† Earth ascent boundary temperatures assumed to be 105K cold, 295K warm

# MEMLI concept 2.0



# MEMLI thermal modeling

| 2" Spacing LRMLI Posts | Heat Flux in W/m² | | |
|---|---|---|---|
| | 1 Atm @295-105 GN2 filled | 4.5torr @ 210-105 | in-vac@210-105 |
| | 124 | 0.66 | 0.31 |
| 2" spacing IMLI Posts | | | |
| | 1 Atm @295-105 GN2 filled | 4.5torr @ 210-105 | in-vac@210-105 |
| | 124 | 0.28 | 0.28 |
| 1" spacing IMLI Posts | | | |
| | 1 Atm @295-105 GN2 filled | 4.5torr @ 210-105 | in-vac@210-105 |
| | 124 | 0.60 | 0.60 |