Jet Propulsion Laboratory
California Institute of Technology

Performance of Multi-Layer Insulation for Spacecraft Instruments at Cryogenic Temperatures

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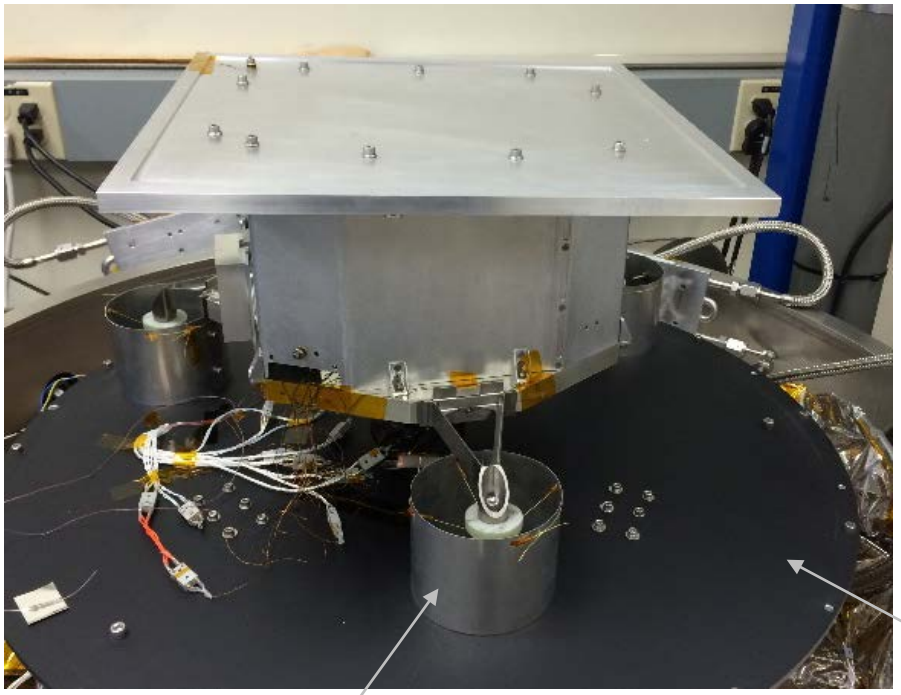
Goals of study

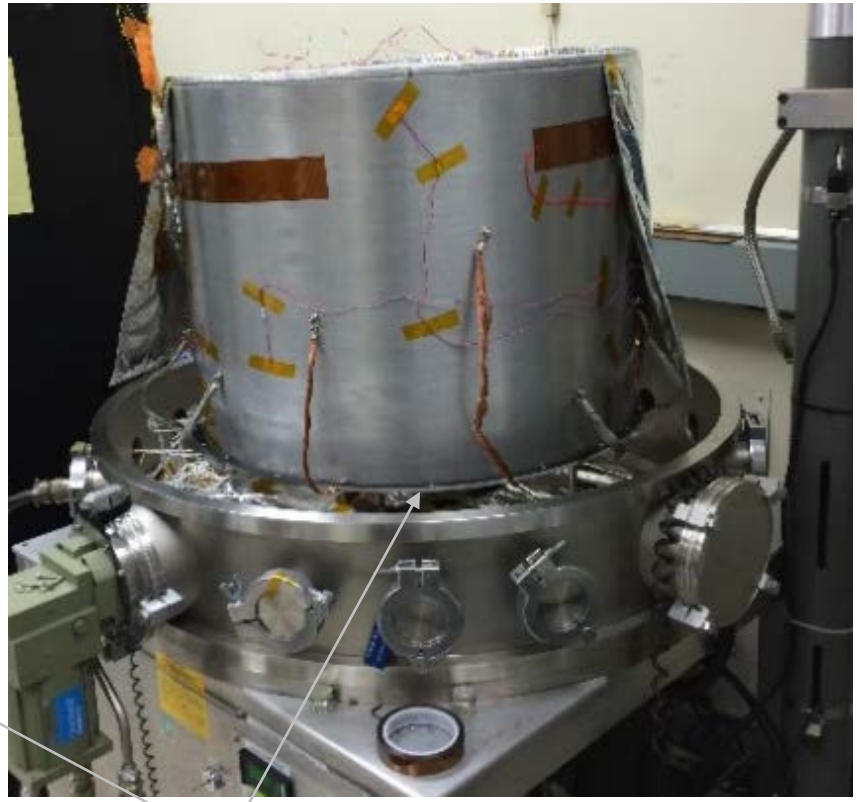
- Develop new multilayer insulation designs for application in cryogenic instruments
- Determine the effectiveness of newly-designed blankets
  - Direct, accurate measurements of heat flow and temperature to characterize blankets in terms of effective emissivity: $\epsilon^* = \frac{\dot{Q}}{A\sigma(T_h^4 - T_c^4)}$
  - Experiments with a realistic cryogenic instrument that includes convex features and egresses
- Draw conclusions about design principles

Experimental apparatus

Moon mineralogy mapper (M^3) instrument mass mockup in vacuum chamber



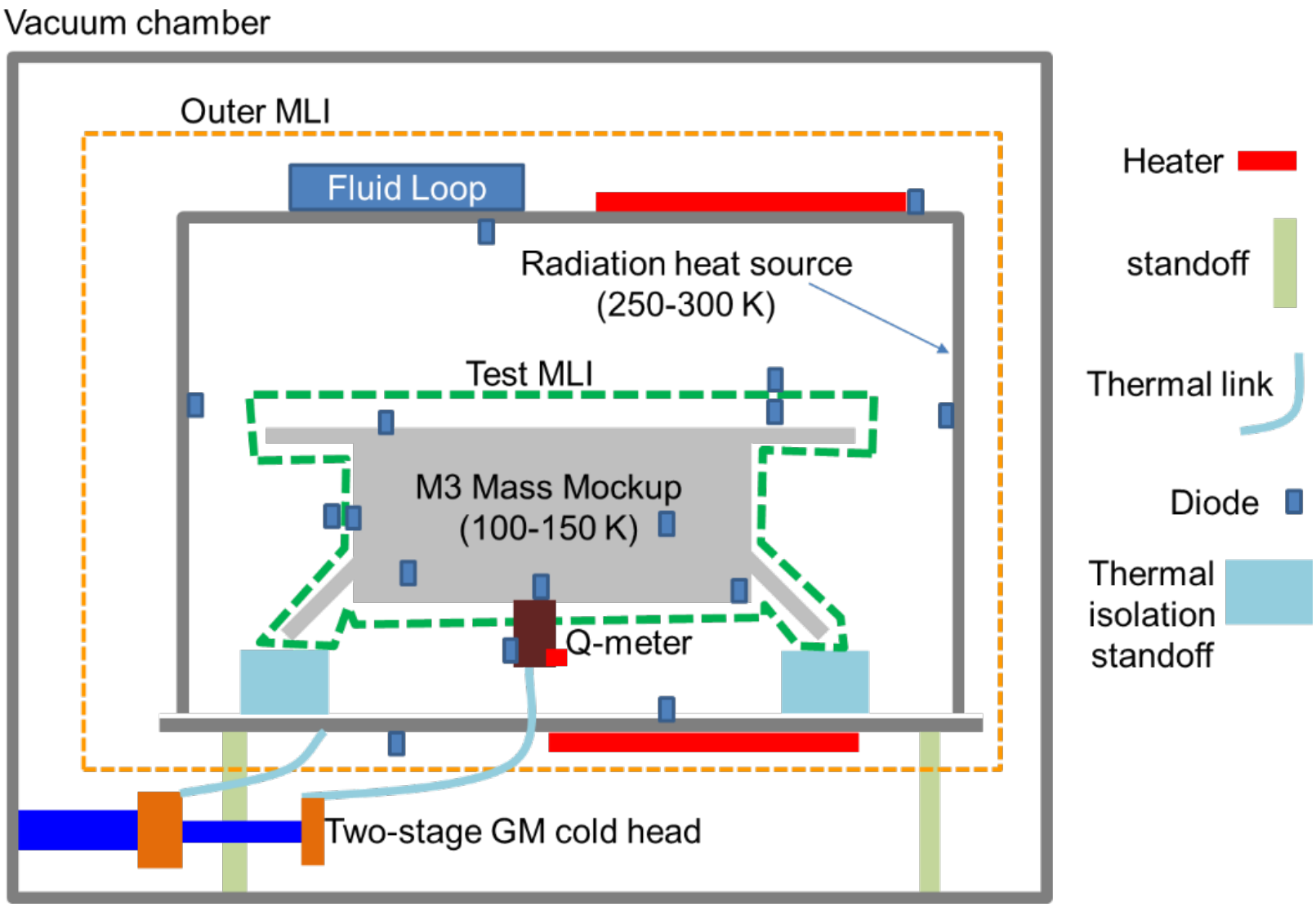
Aluminum cylinder (painted black on inside) is temperature-controlled radiation heat source



Thermal isolation standoff

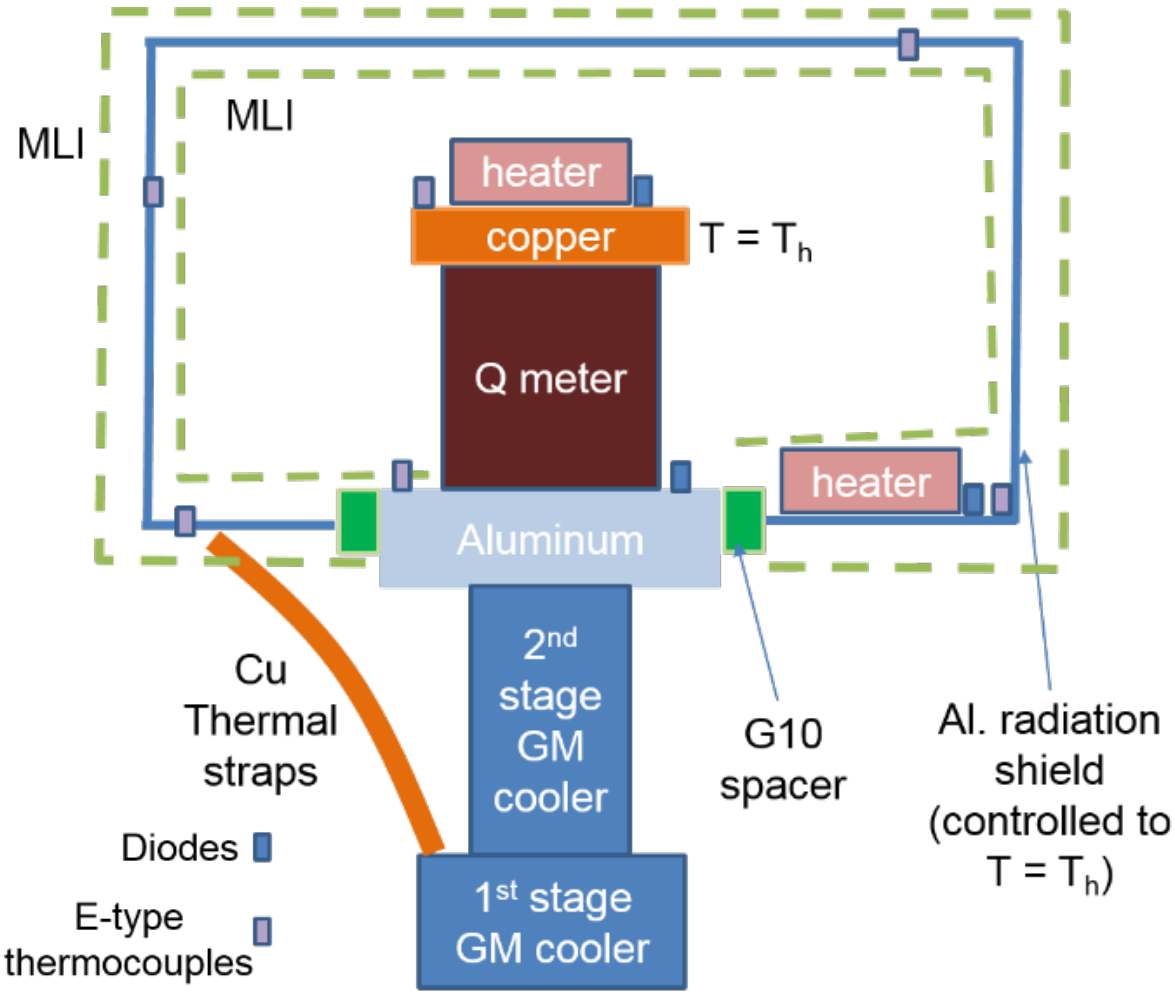
Black baseplate held at same temperature as cylinder

Experimental apparatus



ϵ^* measurement method

Q meter and calibration

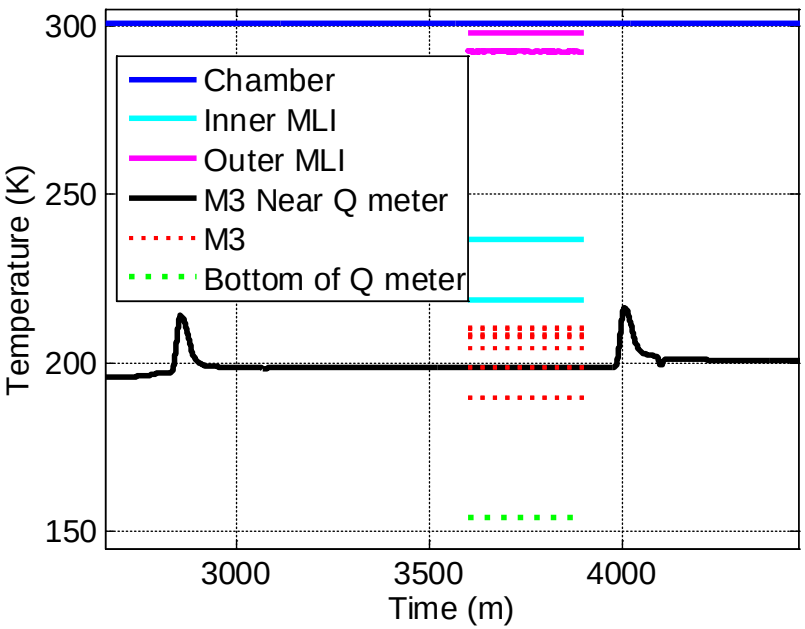


- Q meter is slug of "German Silver" with diodes on both ends
- Difference in voltage across diodes on the ends of the Q meter is proportional to heat flow
- Known heat load applied to heater used to calibrate Q meter over range of temperatures

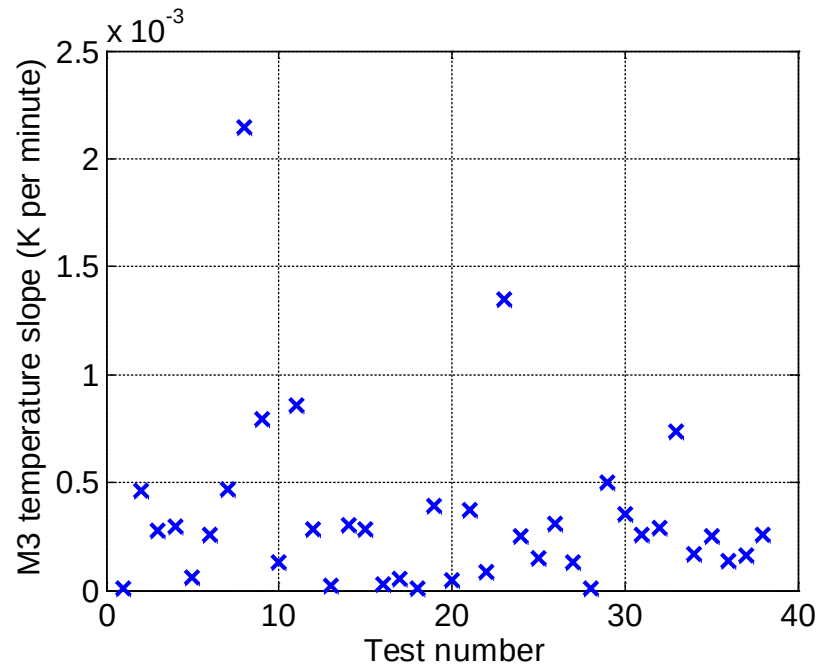
ϵ^* measurement method

Definition of steady-state

ϵ^* data from time-averaged measured steady-state temperature



Steady-state temperature achieved when $\frac{\Delta T}{\Delta t} < 2.5 \times 10^{-3} \frac{K}{min}$



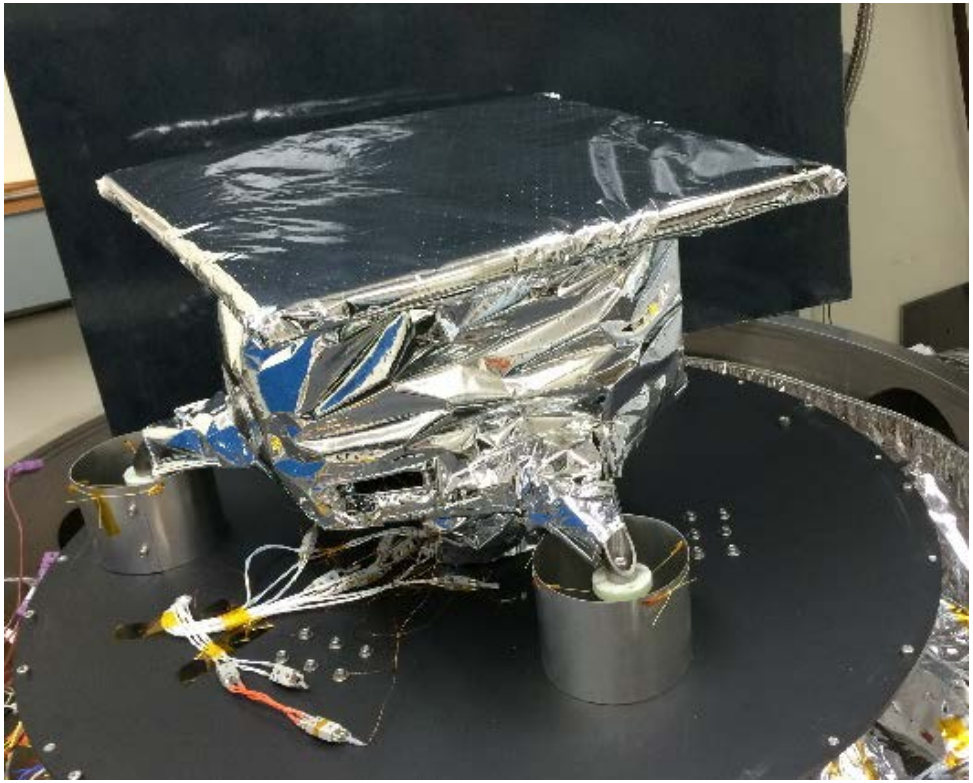
Similar definition for measured steady-state heat flow: $\frac{\Delta V}{\Delta t} < 2 \times 10^{-3} \frac{mV}{min}$

Blanket designs

- Baseline blankets (“JPL standard”): 15 reflectors, 15 spacers, taped and sewn edges with both aluminized and black outer layers
- Blanket with 25 layers
- Oversized blanket (to avoid overlap of seams)
- Blankets with edges unbound
  - No spacers (contamination hazard with unbound edges)
  - Tested different reflectors
  - Layers held together with minimal number of single stitches
- Blanket with glass spacer, and blanket with integrated spacer/reflector

Blankets with taped and sewn edges

Standard JPL blanket with aluminized outer layer



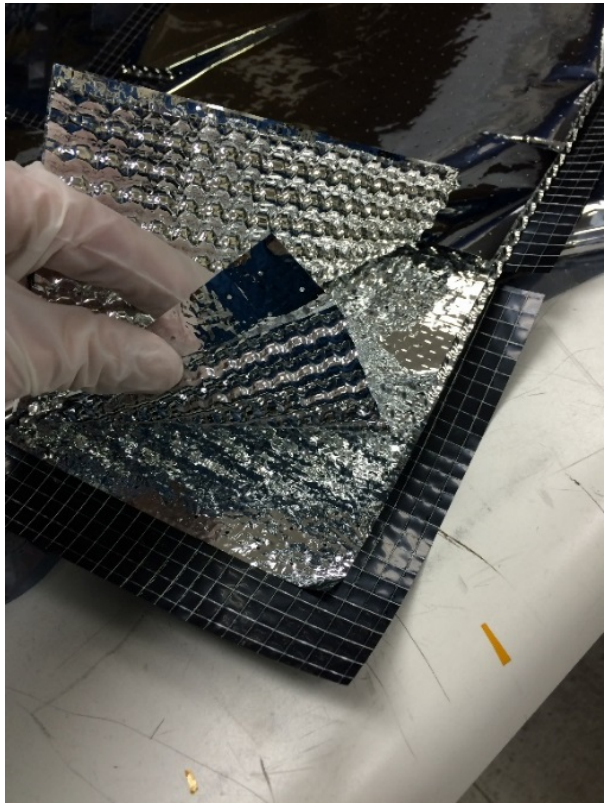
Oversized blanket with black outer layer

Blankets with unbound edges

Inner layers

Embossed double-aluminized Kapton reflector

Dimpled double-aluminized Mylar reflector



Glass-backed aluminized Dacron

Blankets with unbound edges

Stitch detail

Outer layer of blanket

Single stitch

Inner layer of blanket

Blanket designs

Details and number designators

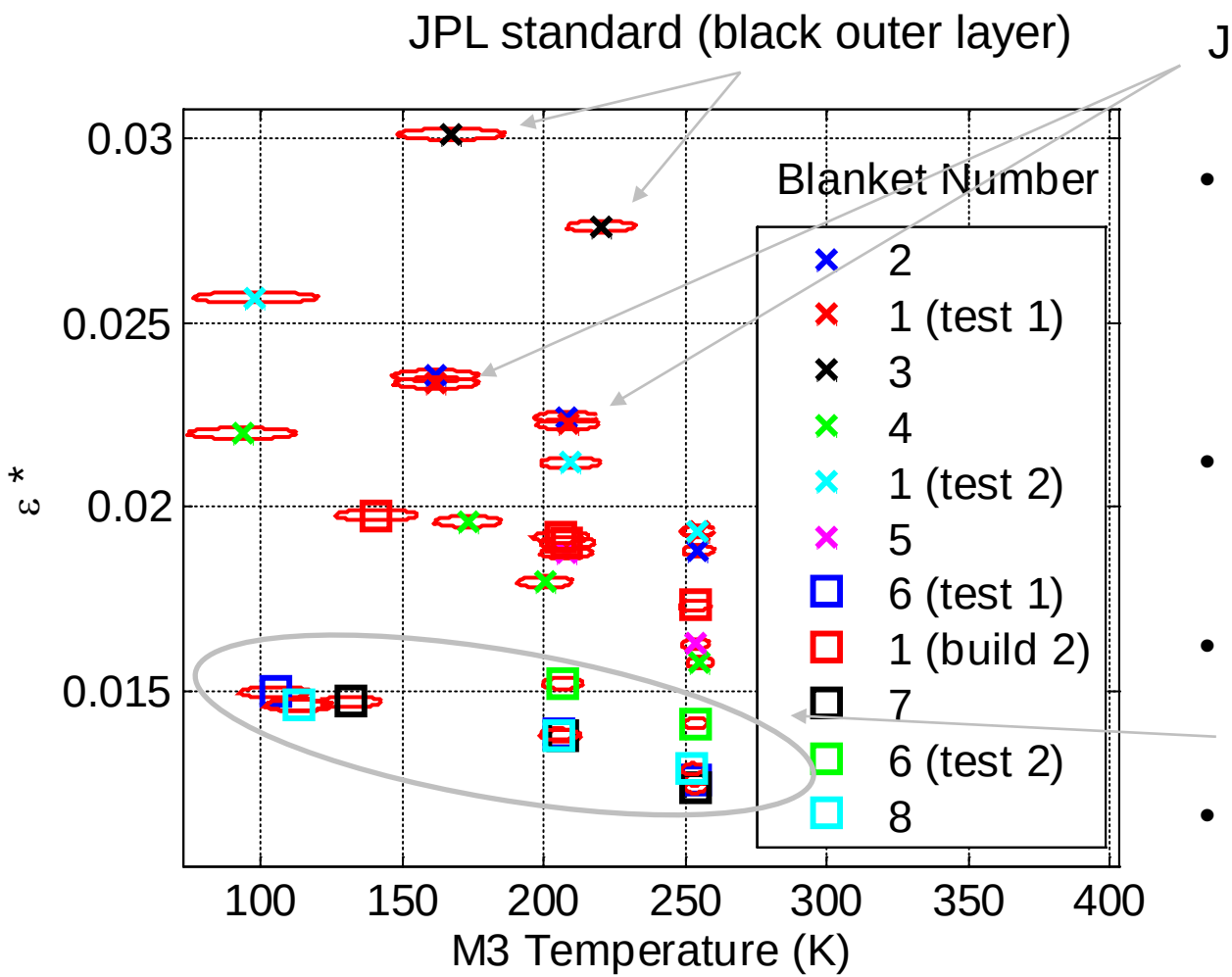
Blanket Number	Reflector	Spacer	Number of internal reflectors	Inner Layer	Outer Layer	Edges	Mass (g)	Thick. (inches)
1	¼ mil DAM	Dacron net	15	1 mil DAM	1 mil DAM	Taped/sewn (silver tape and white thread), regular	300	0.11
2	¼ mil DAM	Dacron net	25	1 mil DAM	1 mil DAM	Taped/sewn (silver tape and white thread), regular	426	0.18
3	¼ mil DAM	Dacron net	15	1 mil DAM	Black Kapton	Taped/sewn (black tape and black thread), regular	329	0.12
4	¼ mil DAM	Glass Spacer	25	1 mil DAM	1 mil DAM	Taped/sewn (silver tape and white thread), regular	289	0.09

Blanket designs

Details and number designators

Blanket Number	Reflector	Spacer	Number of internal reflectors	Inner Layer	Outer Layer	Edges	Mass (g)	Thick. (inches)
5	¼ mil DAM	Dacron net	15	1 mil DAM	Black Kapton	Taped/sewn (black tape and black thread), extended	448	0.12
6	Embossed DAK	None	25	1 mil DAM	Black Kapton	Unbound	343	0.03
7	2 layers Dimpled DAM and 3 layers embossed DAK	None	5	1 mil DAM	Black Kapton	Unbound	193	0.15
8	Glass-backed Al Dacron	Integrated	8	1 mil DAM	Black Kapton	Unbound	333	0.04

Data – 300 K radiation heat source

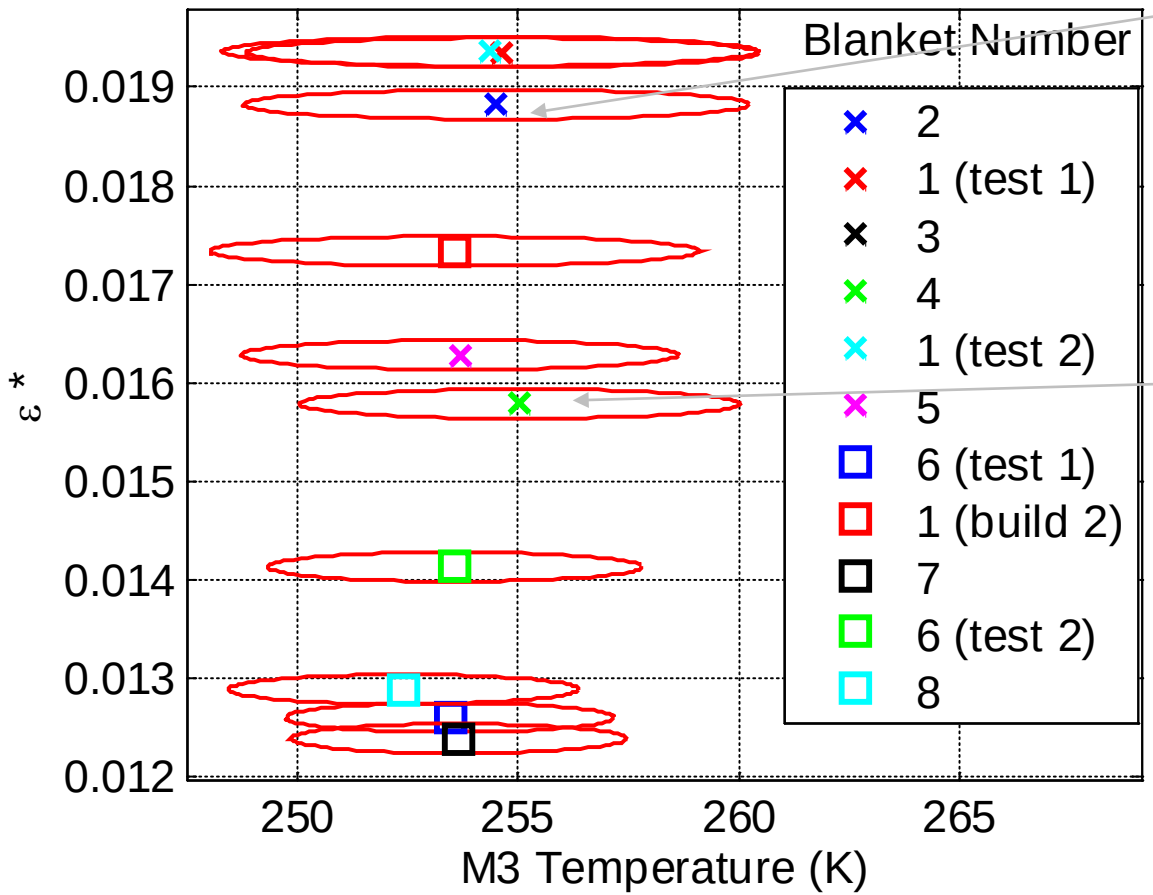


- JPL standard blanket with aluminized outer layer significantly better than same blanket with black outer layer
- Implies significant heat transfer through seams

- Blankets with unbound edges are superior to other blankets
- Superiority of these blankets more significant at lower M^3 temperatures

Data – 300 K radiation heat source

Detail of data for M^3 temperature = 250 K

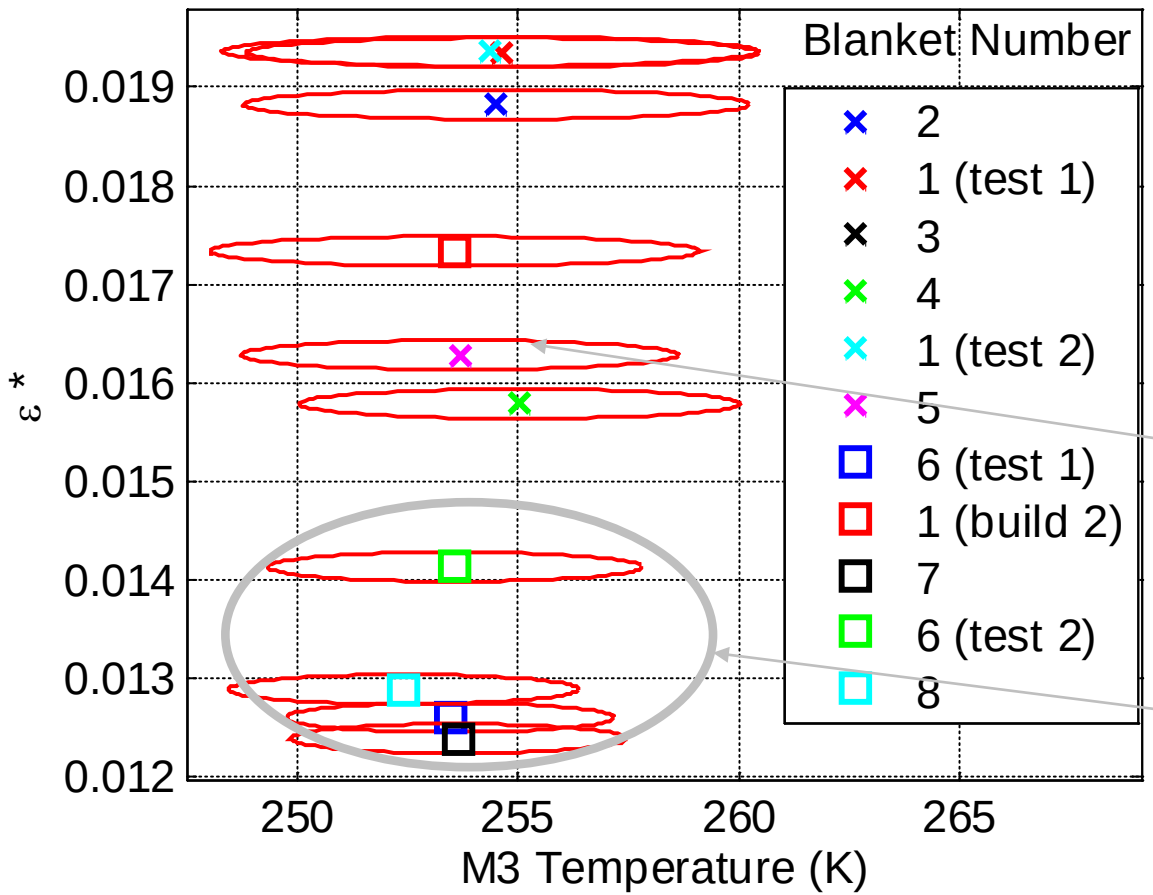


25 layers (aluminized outer layer) did not improve performance over 15 layers (blanket 1)

Low-mass glass spacer combined with increase in number of layers improved performance over 15-layer JPL standard blanket (blanket 1)

Data – 300 K radiation heat source

Detail of data for M^3 temperature = 250 K



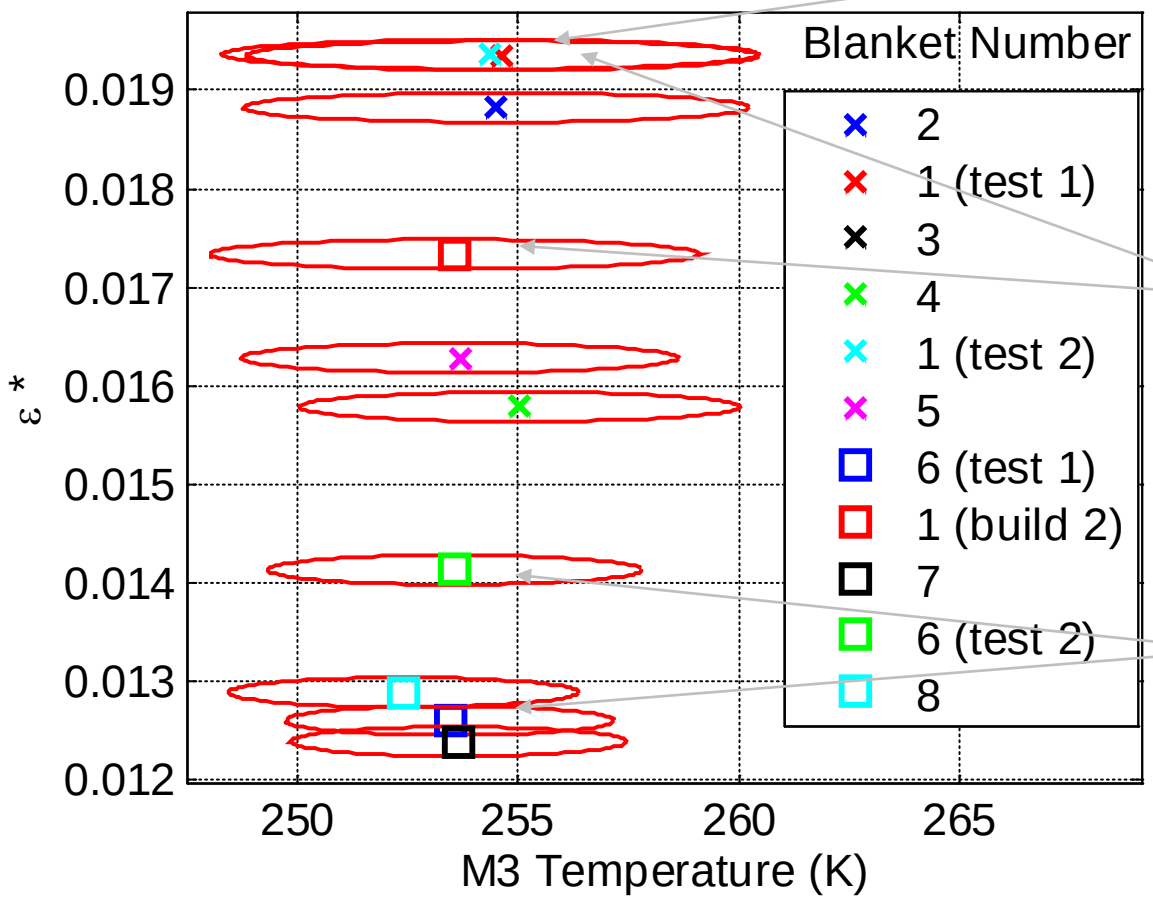
Compare these blankets with JPL standard, black outer layer ($\epsilon^* = 0.027$)

Increasing blanket size to avoid overlapping seams improved performance

Blankets with unbound edges and black outer layers significantly outperform

Data – 300 K radiation heat source

Detail of data for M^3 temperature = 250 K

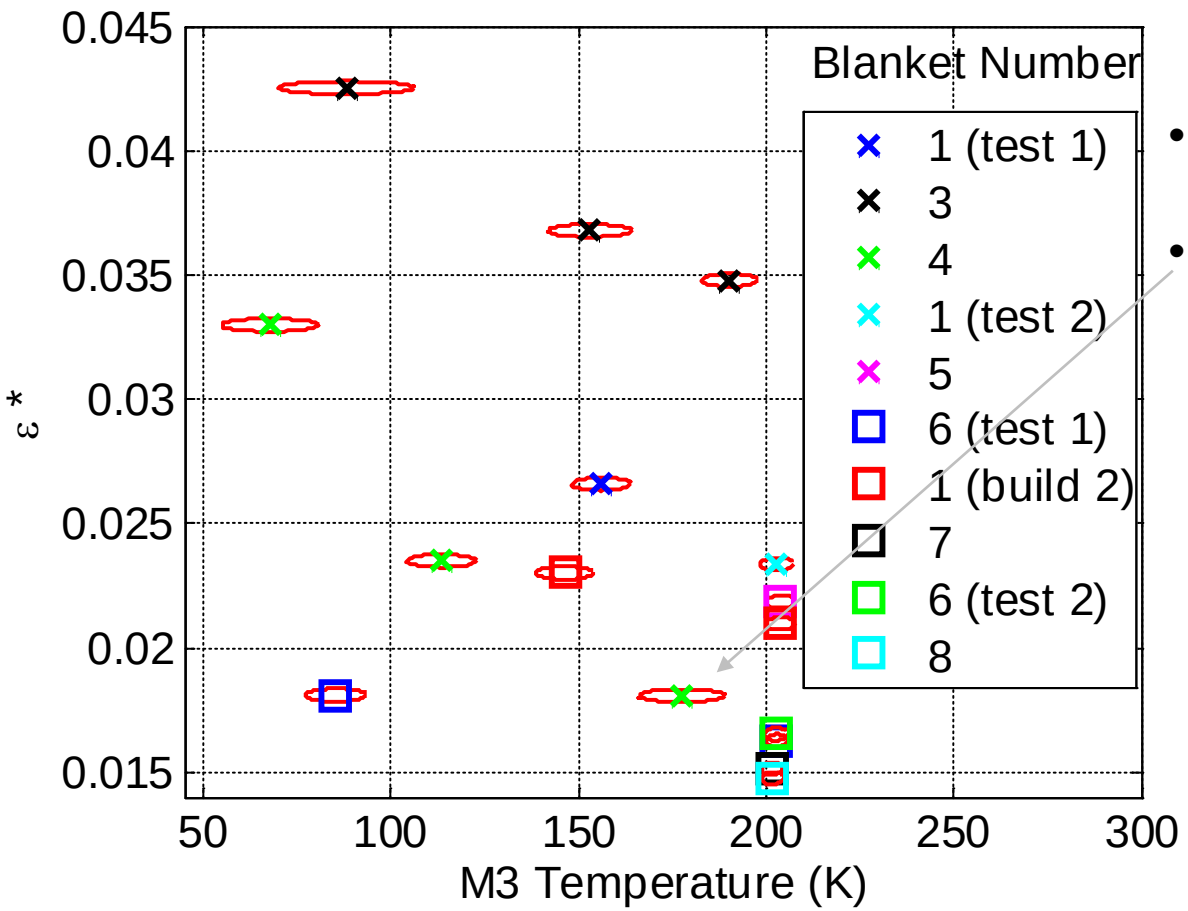


With M^3 at 250 K blanket 1 ϵ^* difference within uncertainty between installations

Blanket 1 ϵ^* differs ~0.002 between builds

Blanket 6 ϵ^* differs ~0.001 between installations

Data – 250 K radiation heat source



- Trends are the same as for 300 K radiation heat source
- Blanket 4 (glass spacer with 25 layers) shows significant performance improvement relative to Dacron spacer at these temperatures

Conclusions

- Increasing the number of layers did not improve performance
- Oversizing the blanket and using a low-mass glass spacer improved performance
- Using no spacer and leaving the edges of the blankets unbound improved the performance by about 50% (from $\epsilon^* = 0.03$ to $\epsilon^* = 0.015$)
- The performance enhancement increased with decreasing temperatures, so this improvement is especially relevant for cryogenic applications
- Installation-to-installation variability and build-to-build variability was significant

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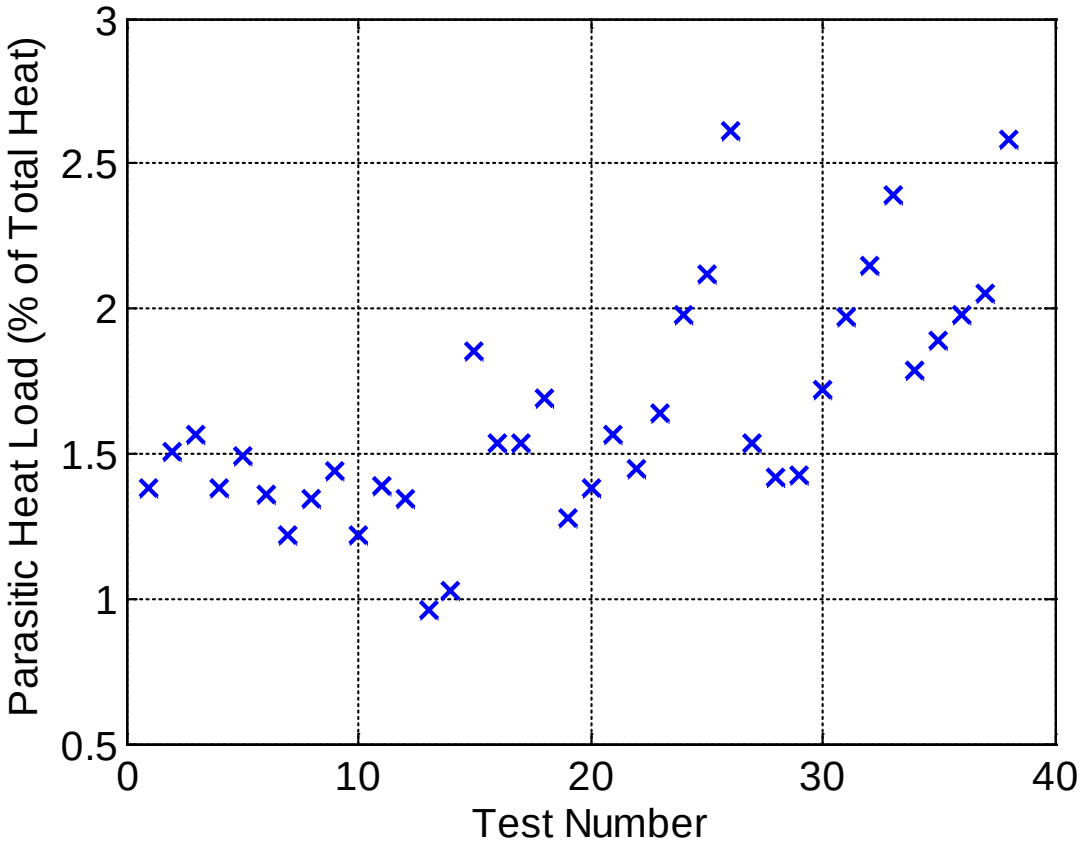
Backup

Thermal isolation standoff

Image of thermal isolation standoff and foot of M3 with bolt to keep foot centered on G-10 landing pad. The entire M3 mass is suspended on Kevlar threads.

Parasitic heat load as % of total measured heat transfer (model results)

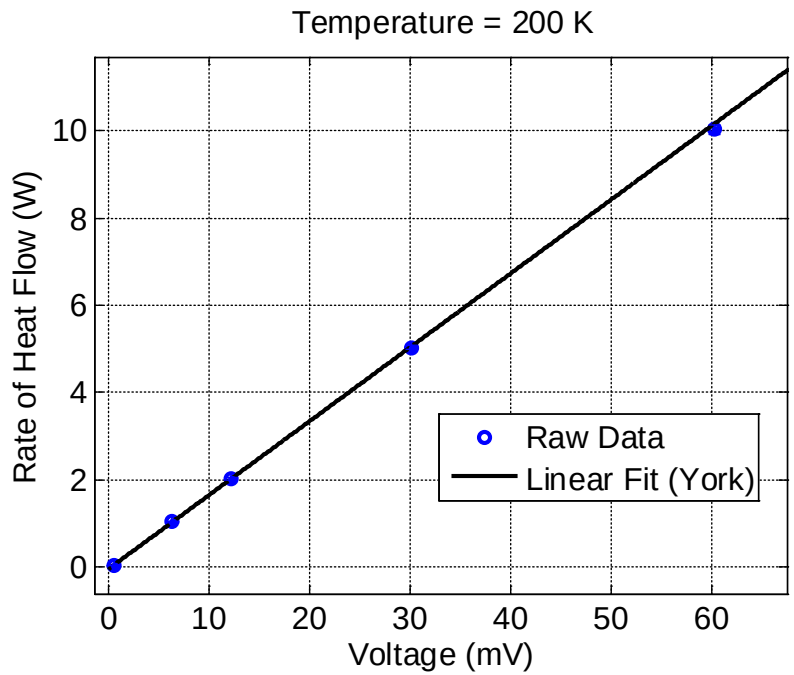


Blanket Materials

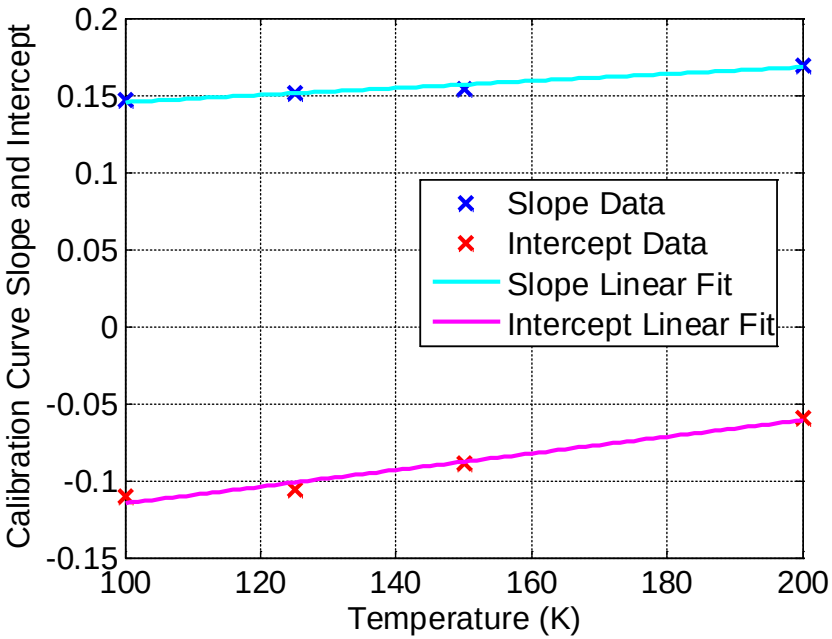
Name	Material	Manufacturer	Part Number	Emissivity	Thickness (inches)	Weight (g/m2)
¼ mil DAM	Double aluminized perforated Mylar	Dunmore Corporation	DE023	≤0.04	0.00024	8.3
1 mil DAM	Double aluminized perforated Mylar	Dunmore Corporation	MO08721	≤0.04	0.00092	32
Embossed DAK	Double aluminized perforated Kapton-HN	Dunmore Corporation	DE293	Unknown	0.0003	Unknown
Black Kapton	Reinforced (200 denier Nomex) black 100XC Kapton	ORCOFILM	KN-90D	≥0.81	0.001 (film only)	56 (max.)
Dimpled DAM	Double aluminized Mylar	Unknown	Unknown	Unknown	0.0015 (film) / 0.064 (pk to valley)	Unknown
Glass-backed Dacron	Double aluminized Dacron	Dunmore Corporation	500 DUN-LAM	0.03 / 0.6	0.005	Unknown
Dacron net	Polyester	Apex Mills	B2A	Unknown	0.007	14.9
Glass spacer	Glass tissue	Technical Fibre Products	Supacool T 50121A	Unknown	0.004	10
Black tape	Black ‘E7’ Polyimide / 966 PSA / 108 Fiberglass / 966 PSA	Dunmore Corporation	DM141-1	0.84	0.007	38.9
Silver tape 1	Aluminum / polyester / 966 PSA	Dunmore Corporation	DM146-2	≤0.04	0.00092	32.4
Silver tape 2	Aluminum / Polyimide / 966 PSA / 108 Fberglass / 966 PSA	Dunmore Corporation	DM105-1	≤0.62	0.007	199.8
Black thread	Polyester	Gudebrod Inc.	E polyester 1LB KS Black 1111	Unknown	Unknown	Unknown
White thread	Polyester	GudeBrod Inc.	E polyester white #2261	Unknown	Unknown	Unknown

Q meter calibration curves

Calibration curve for single temperature (1 of 4 temperatures)



Slope and Intercept for Q meter calibration as function of temperature



More data

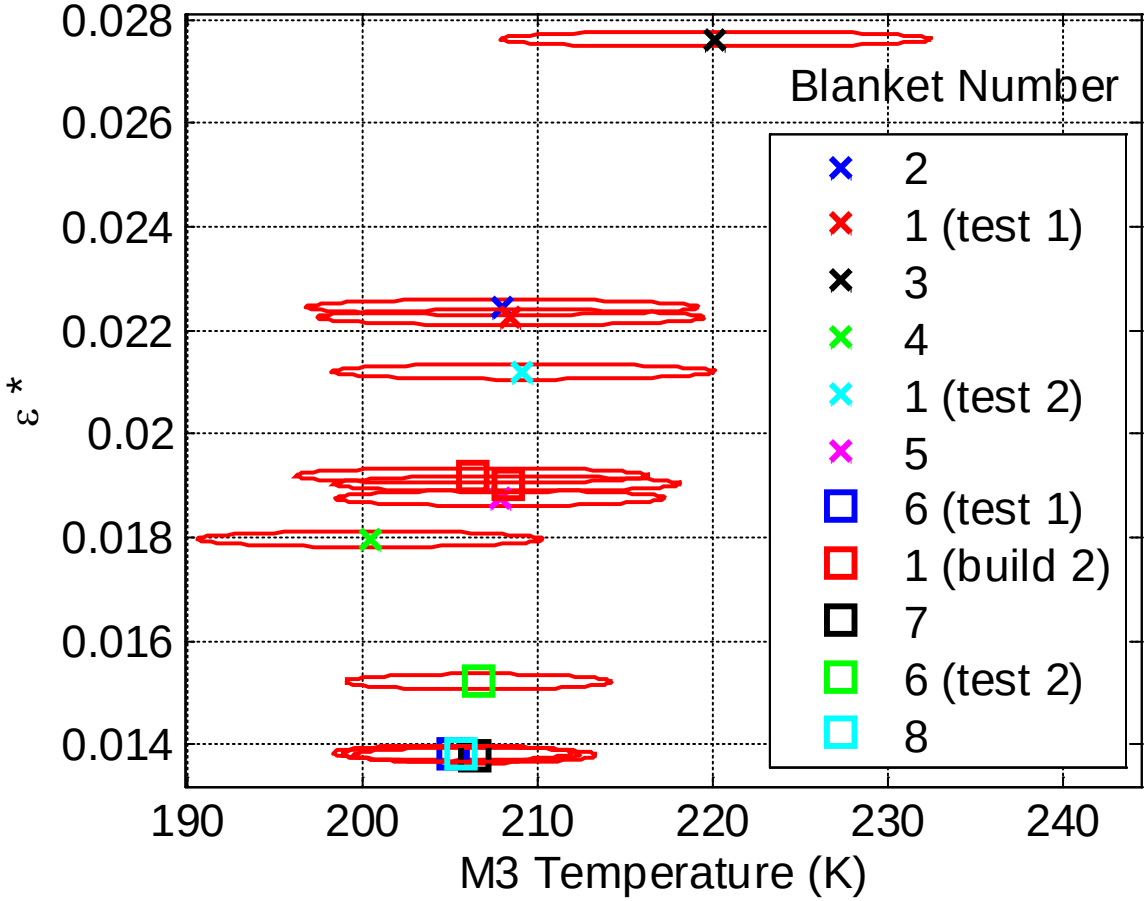


Figure 20. Blanket ϵ^* as a function of M3 temperature for a chamber temperature of 300 K - view of data for M3 temperature = 200 K. Refer to Table 1 for description of blankets.

More data

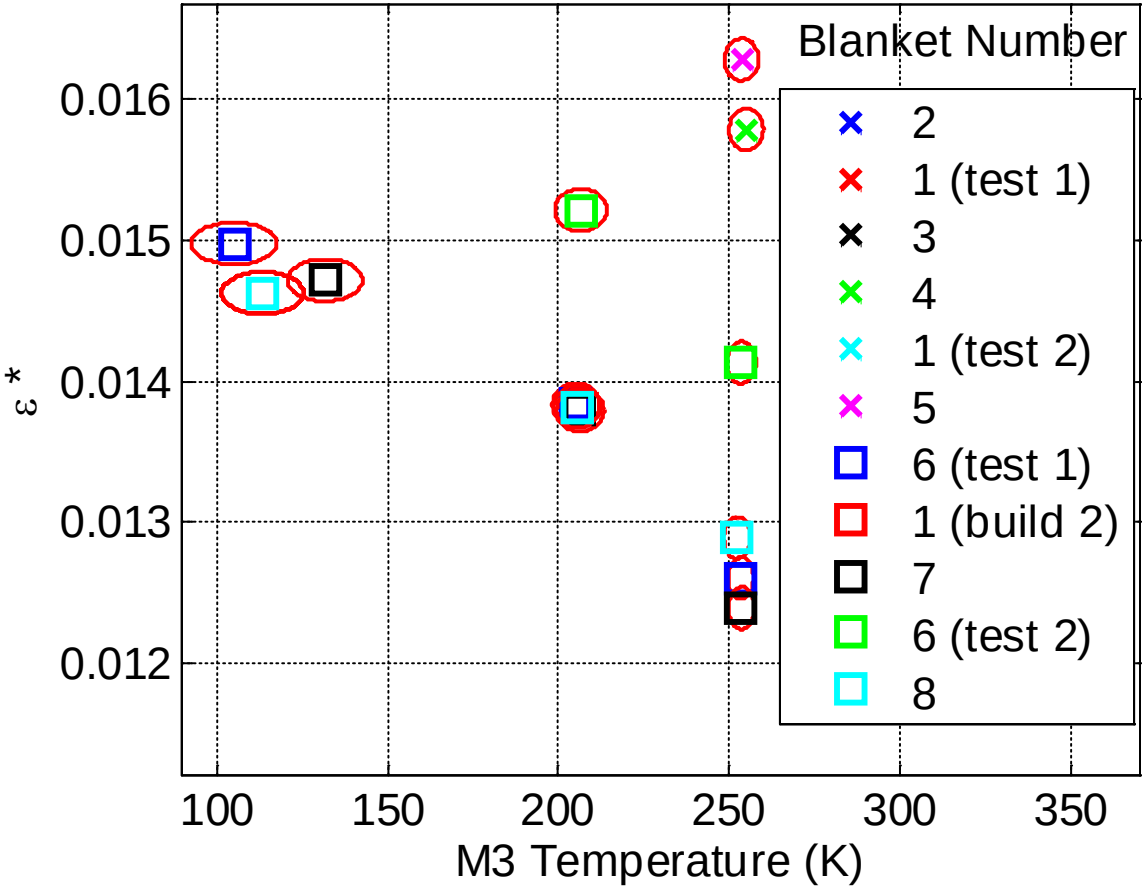


Figure 21. Blanket ϵ^* as a function of M3 temperature for a chamber temperature of 300 K - view of best performing blankets. Refer to Table 1 for description of blankets.

More data

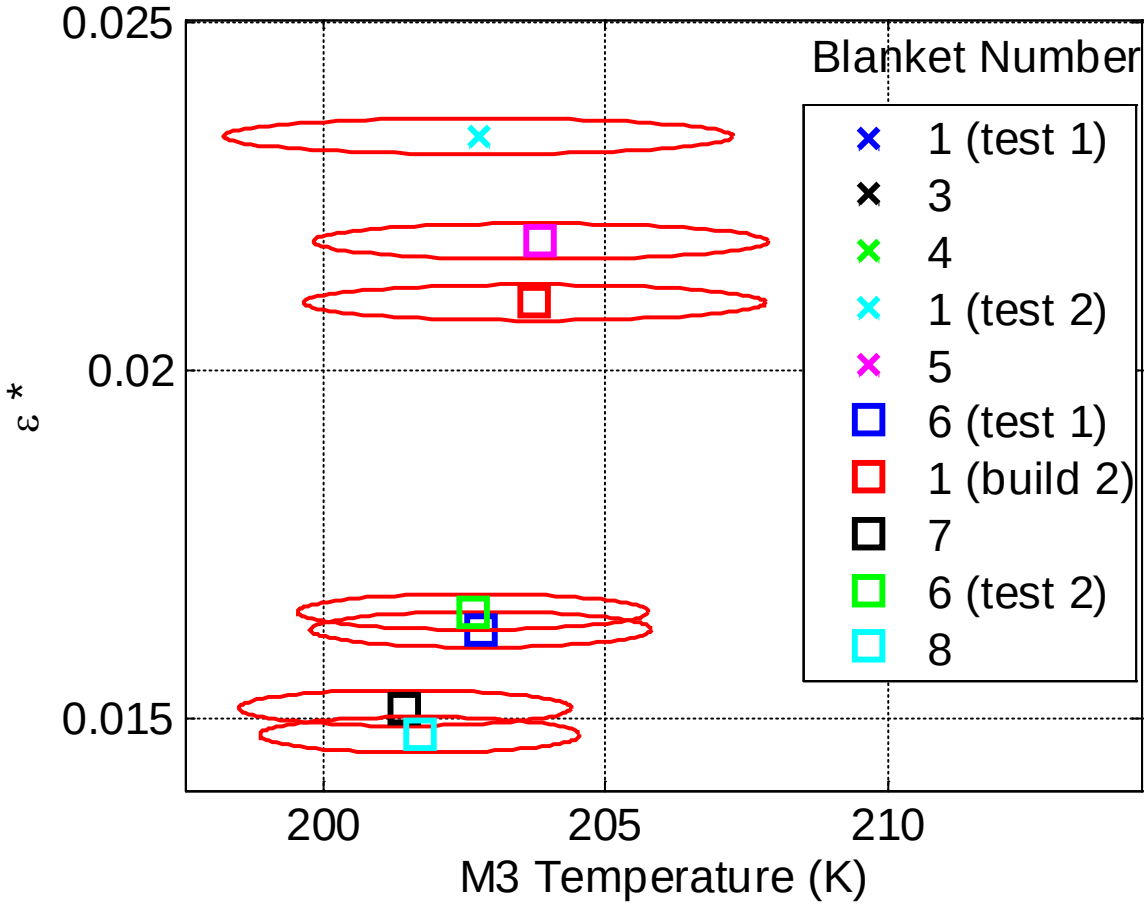


Figure 23. Blanket ϵ^* as a function of M3 temperature for a chamber temperature of 300 K - view of view of data for M3 temperature = 200 K.

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