On-Orbit Absolute Radiance Standard for Future IR Remote Sensing Instruments

Work Conducted Under a NASA IIP

Fred A. Best, Henry E. Revercomb (PI), Robert O. Knuteson, Douglas P. Adler, P. Jonathan Gero, Claire Pettersen, Joseph K. Taylor

University of Wisconsin
Space Science and Engineering Center

NASA Earth Science Technology Forum
Pasadena, CA
June 21-23, 2011

SSEC

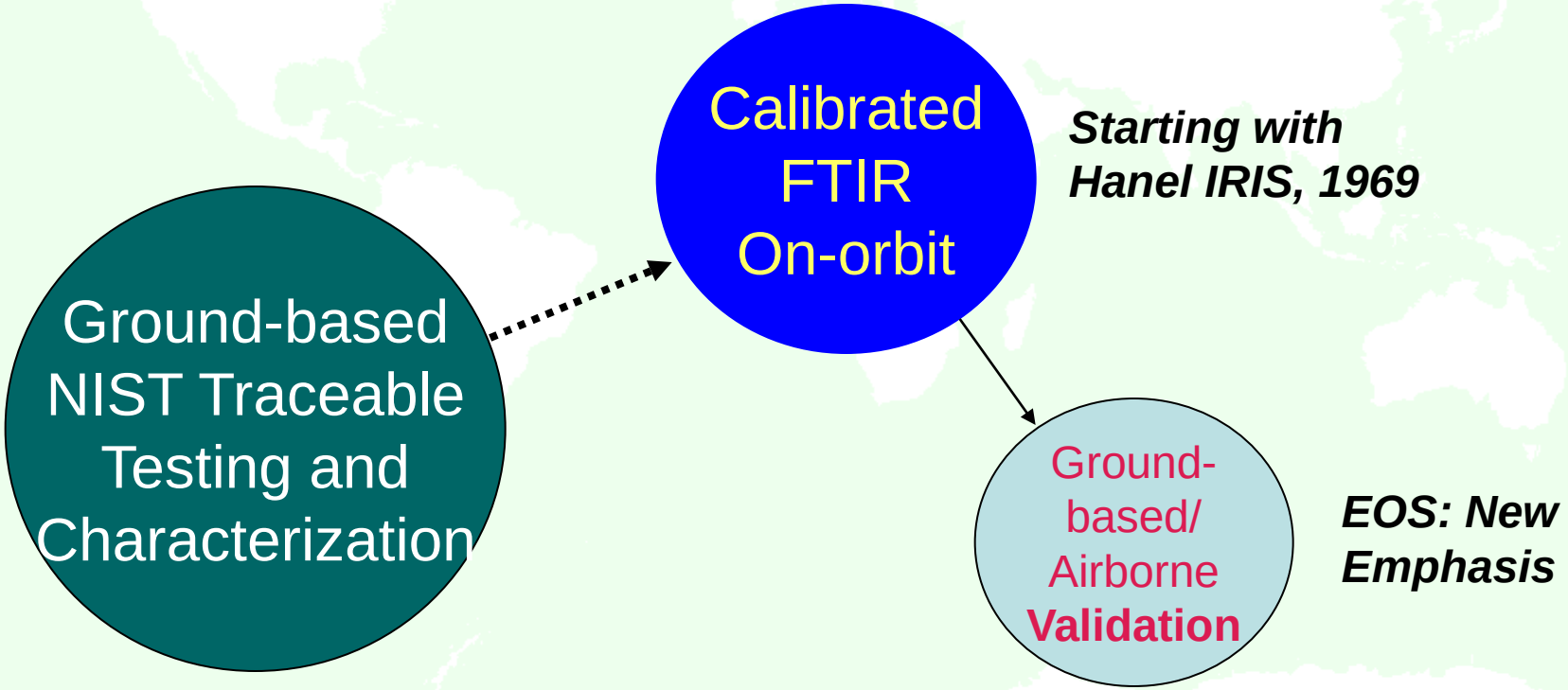
THE UNIVERSITY of WISCONSIN MADISON

Topics

- Overview of UW/Harvard IIP Technology Developments for CLARREO
- OARS (On-orbit Absolute Radiance Standard)
  - Temperature Calibration: *Miniature Phase Change Cells*
  - Emissivity Measurement: *Heated Halo*

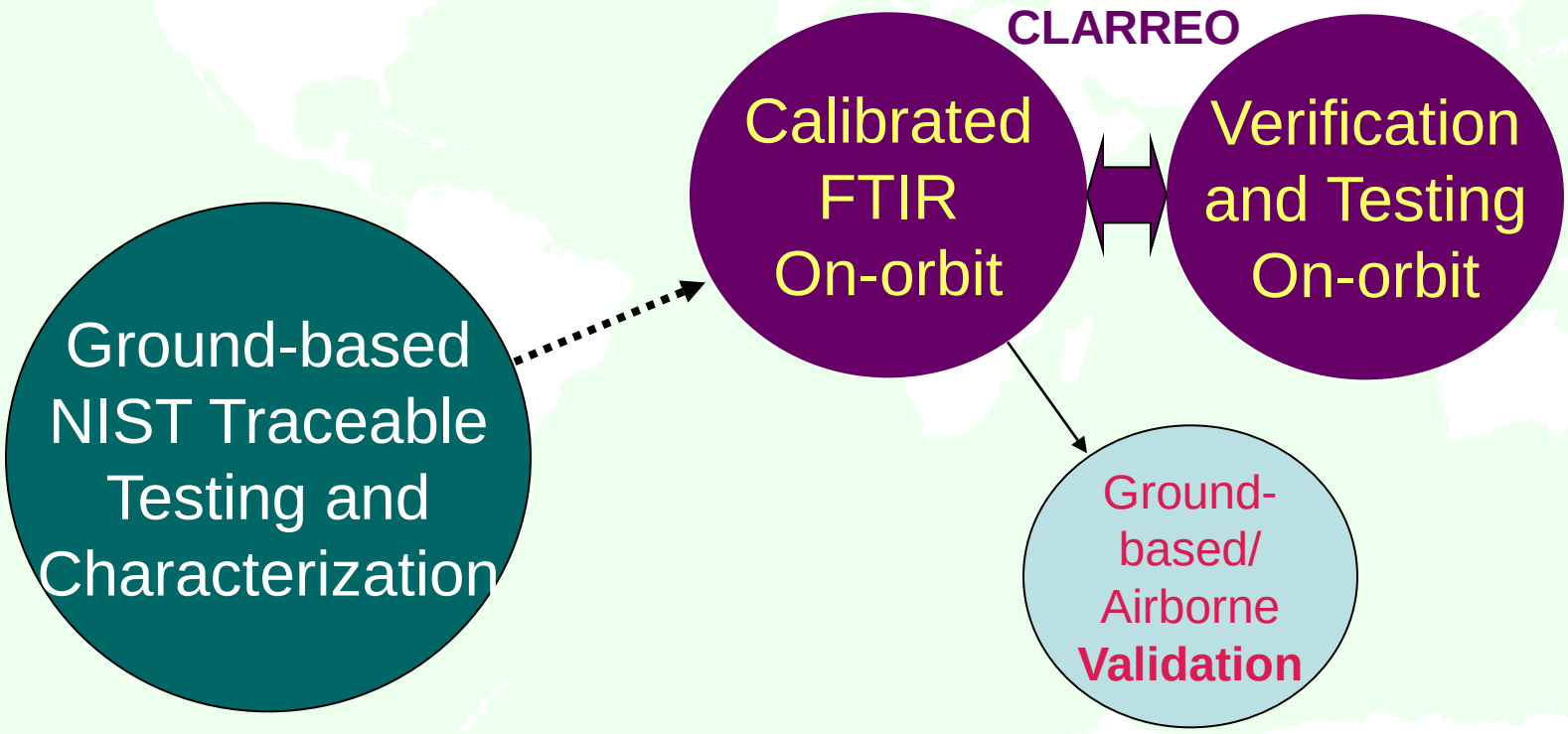
Introduction

➢ In the Infrared, decades of progress in calibrated FTIR brought us to this step



Introduction

➢ New developments for CLARREO provide a strong foundation for this step (TRL-6)



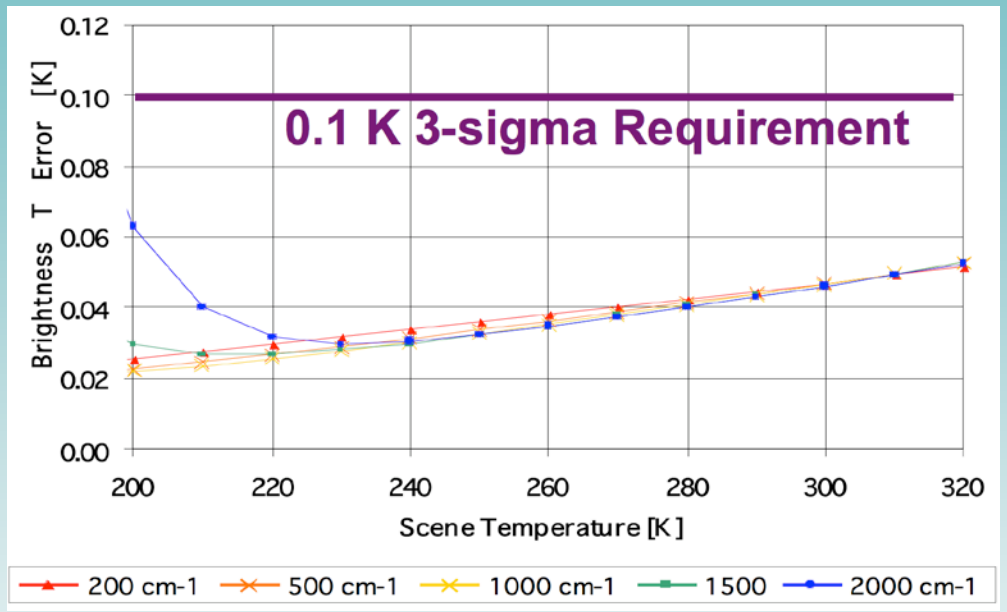
CLARREO Radiometric Performance

Calibration Model Parameters and assumed uncertainties

T_{bb}	300 K
δT_{bb}	0.045 K
E_{bb}	0.999
δE_{bb}	0.0006
T_{str}	285 K
δT_{str}	5 K
$\delta T_{telescope}$	0.02 K

*

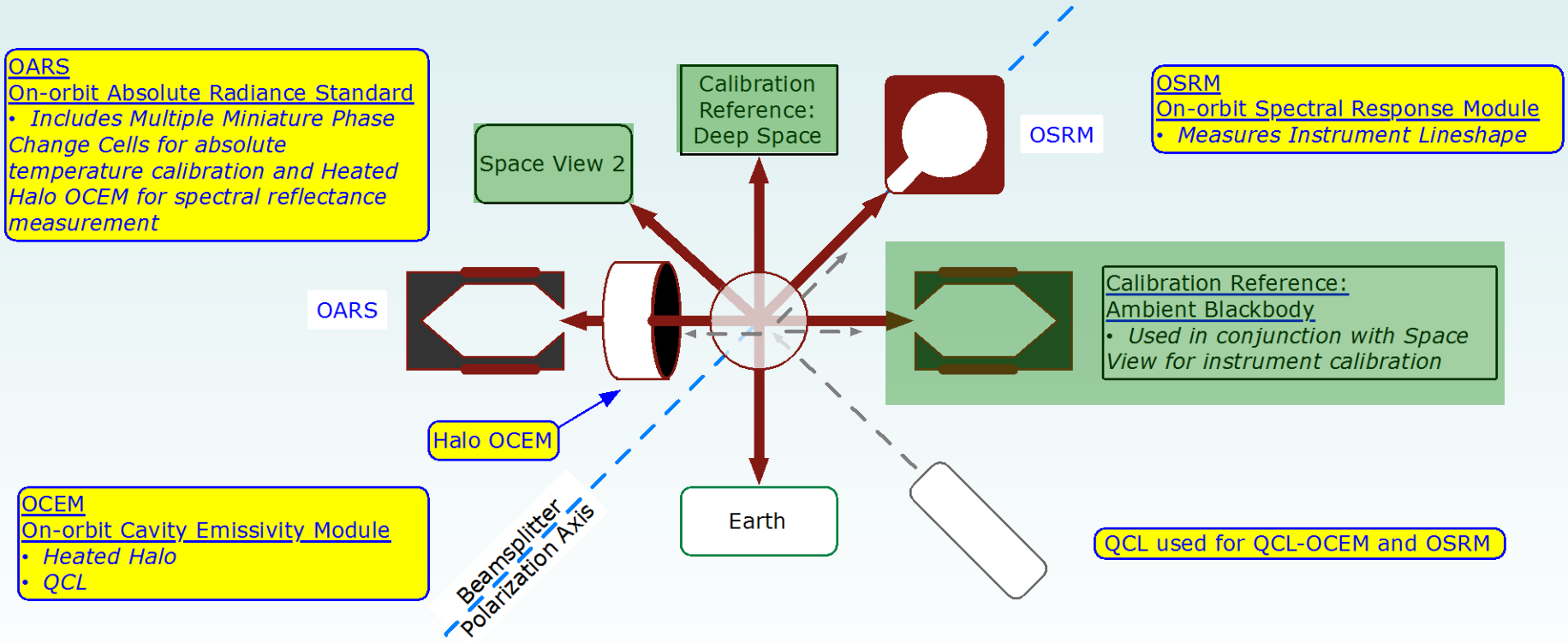
**Blackbody performance Demonstrated with UW-developed GIFTS Blackbody.*



Estimated 3-sigma calibrated brightness temperature uncertainty shown as a function of scene brightness temperature, based on use of the AASI.

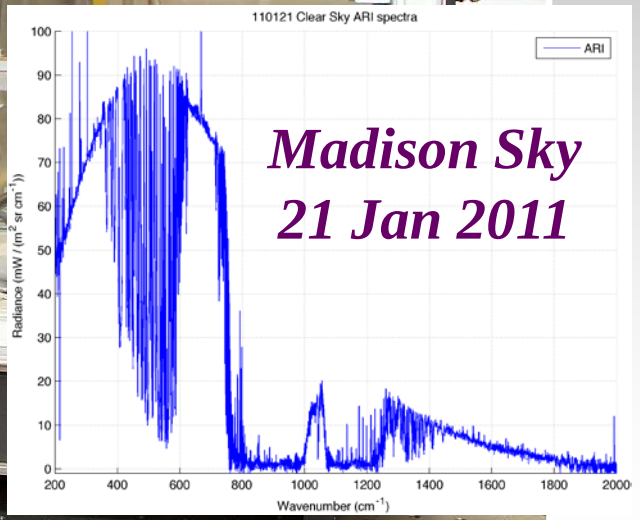
The uncertainty of the blackbody radiating temperature (45 mK, 3-sigma) dominates, except for large wavenumbers at cold temperatures where the assumed telescope temperature change of 20 mK between earth and calibration views becomes important. We assumed an emissivity of 0.999 with 0.0006 uncertainty and a blackbody temperature of 300 K, while the instrument is at 285 K.

Test and Validation Subsystem



Absolute Radiance Interferometer (ARI) Breadboard-1 Based on ABB FTS

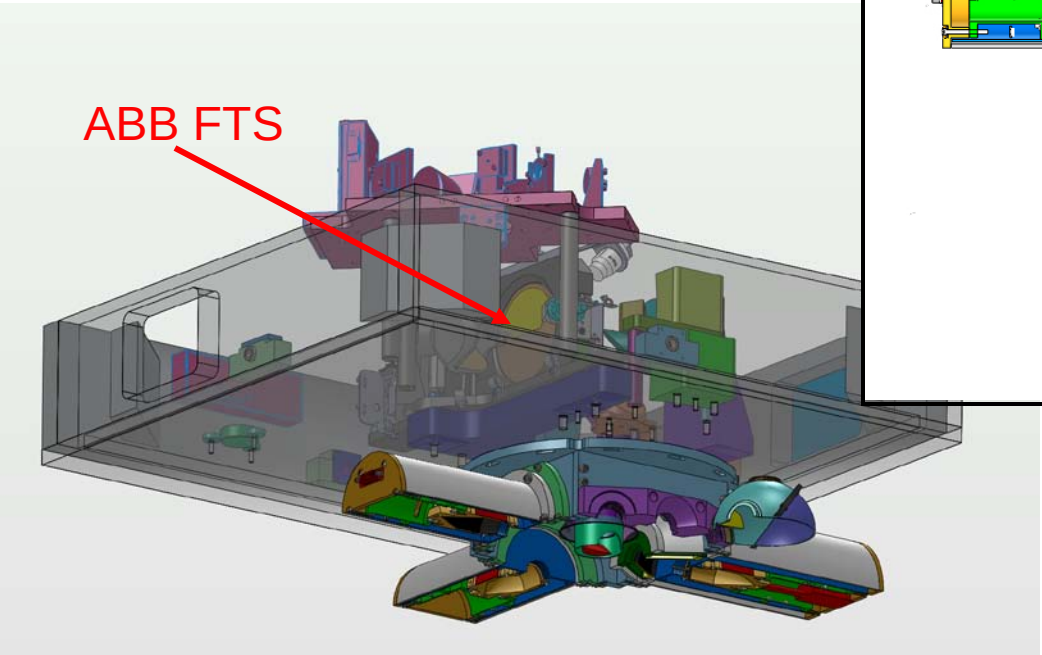
AERI Front-End
With Blackbodies

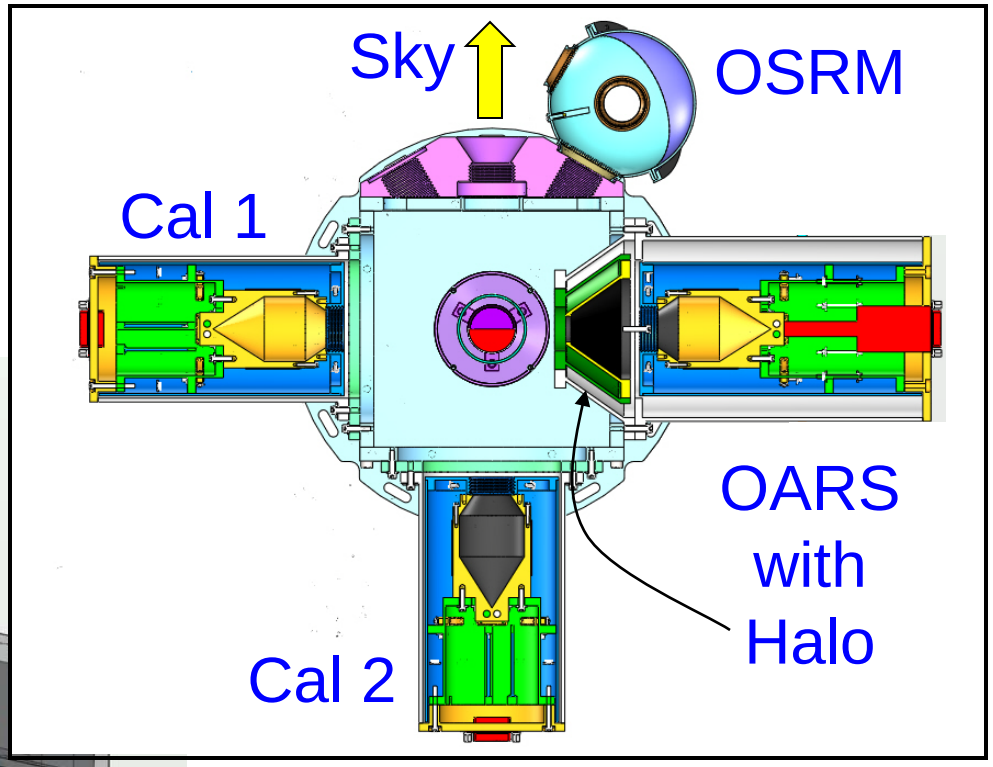


Breadboard 2: Flight-like Configuration

1.2” aperture Sources

45° Gold Scene Mirror selects source





OARS: On-orbit Absolute Radiance Standard

OSRM: On-orbit Spectral Response Module

Temperature Calibration: Miniature Phase Change Cells

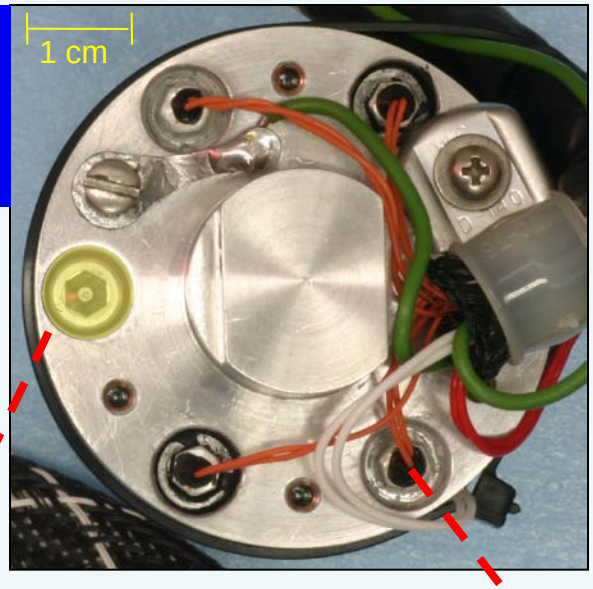
- Miniature Phase Change Cell Concept
- Summary of IIP Work

SSEC Engineering Test Cavity

(configured for melt tests)

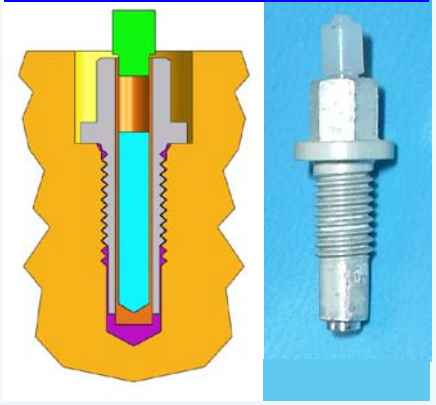
Blackbody Cavity

(aft view)

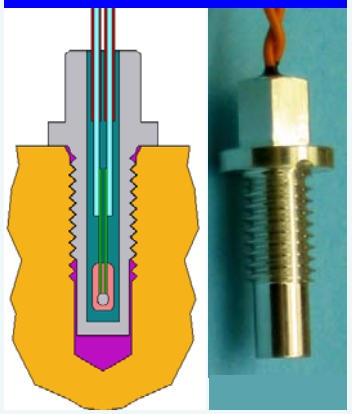


Three or more will characterize the thermistor sensors

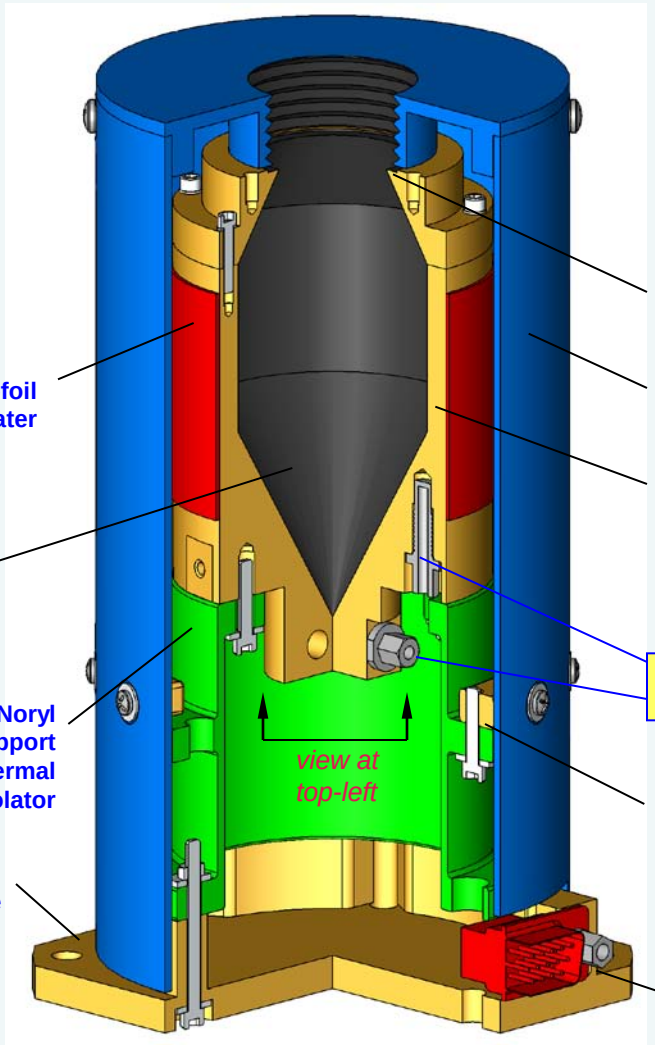
Melt Material



Thermistor

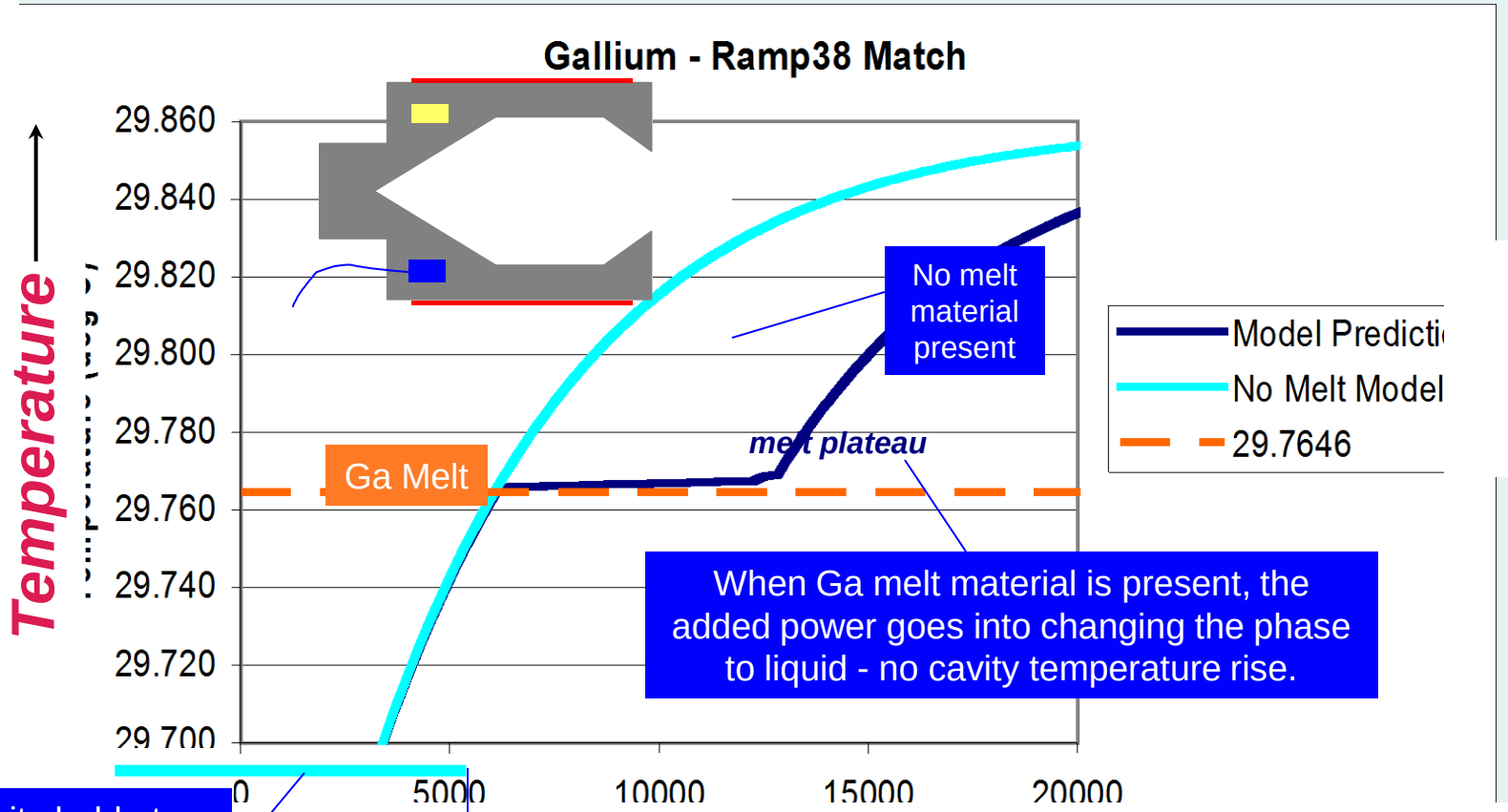


GIFTS Blackbody

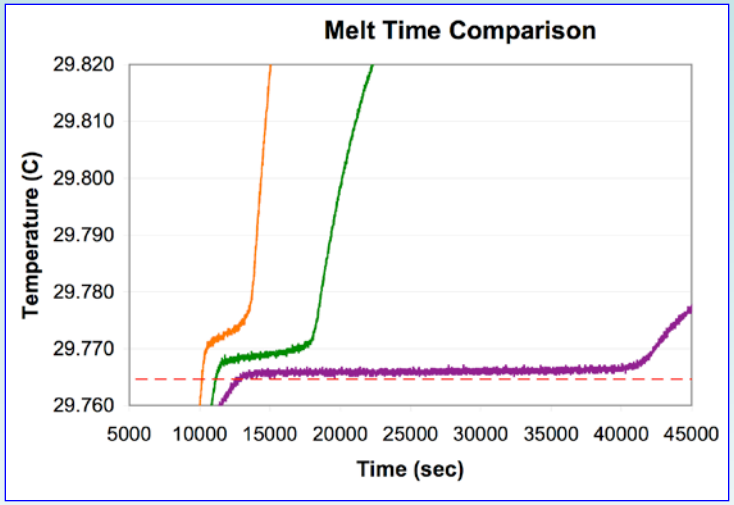


Phase Change Material Implementation

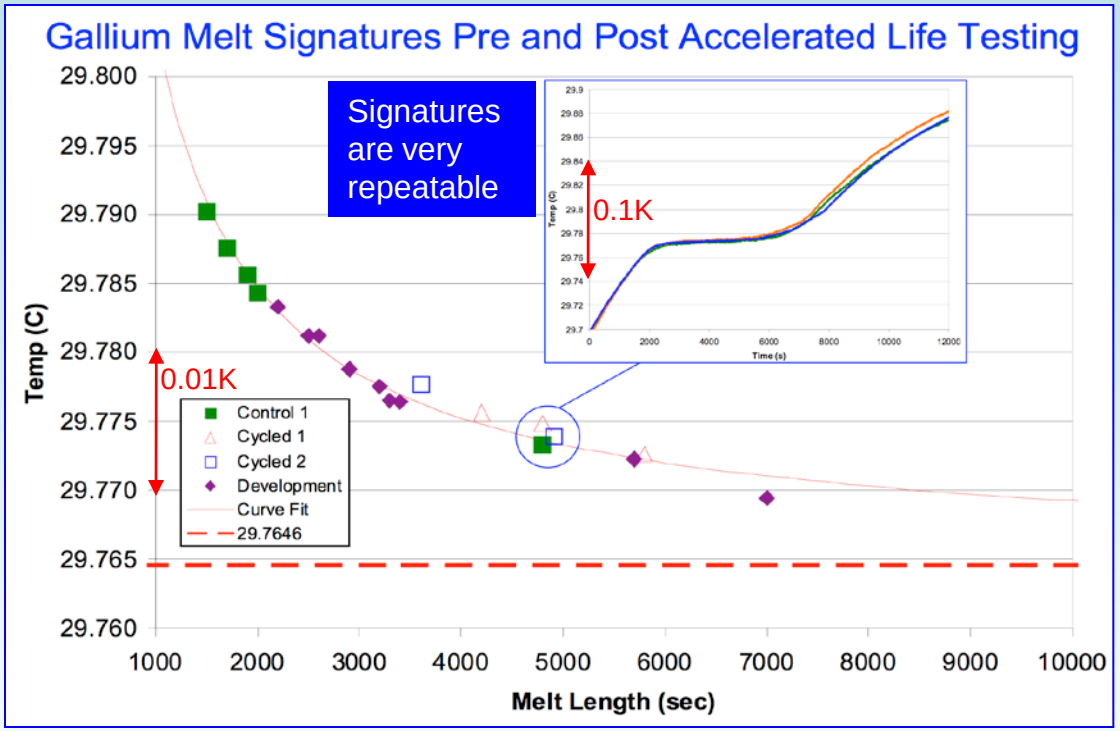
Anatomy of a Melt Signature



Signature Dependence on Melt Length



Melt curves that are flatter and approach the theoretical melt temperature are obtained with longer melt times.

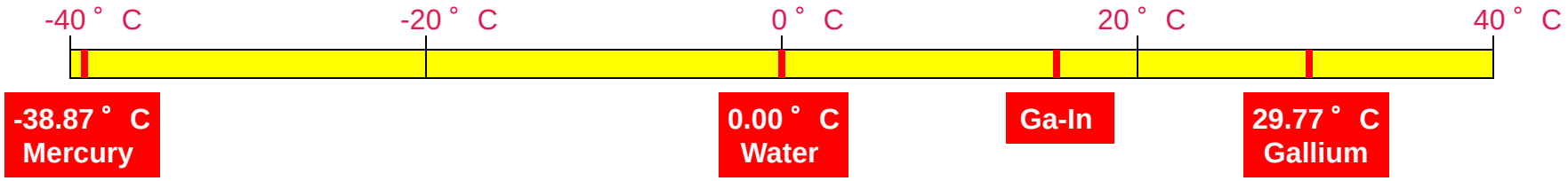


Mid-melt temperature vs melt length relationship is stable and can be very well characterized.

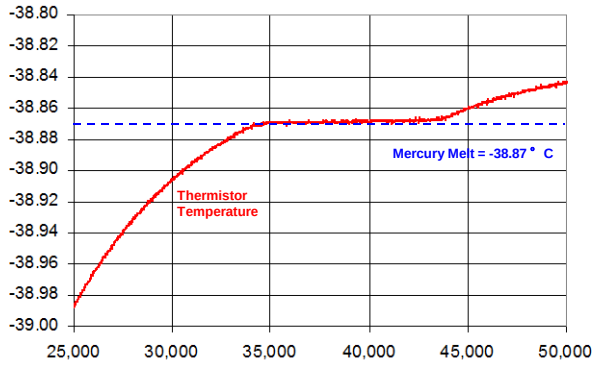
This was the technology brought into the NASA IIP for refinement

Measured Melt Signatures

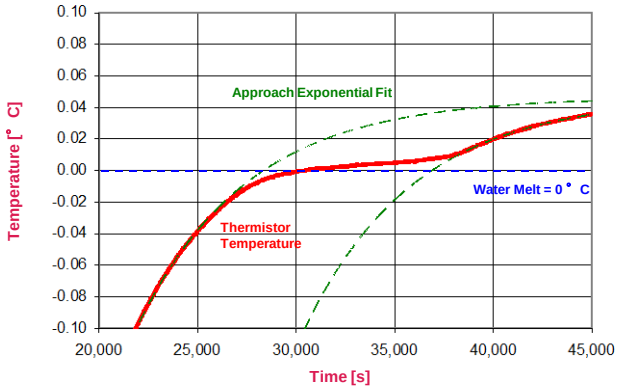
(using GIFTS BB Configuration)



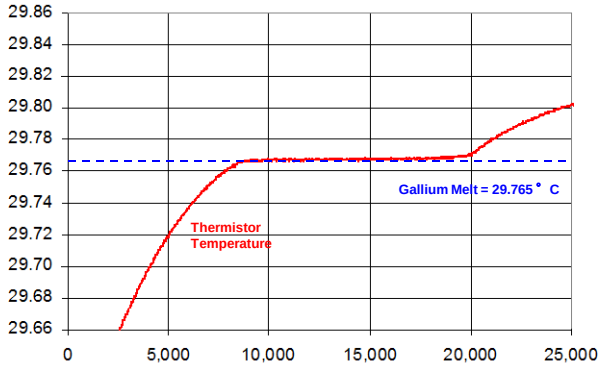
Mercury Melt (test data)



Water Melt (test data)



Gallium Melt (test data)



Melt Signatures Provide Absolute Temperature Calibration Accuracies Better Than 10 mK

End-to-end System Calibration

Steinhart-Hart Relationship

- Traditional Steinhart-Hart Relationship

$$T = \frac{1}{A + B \bullet \ln(R) + C \bullet (\ln(R))^3}$$

- Establishing A, B, & C with three melt points:

$$\begin{vmatrix} A \\ B \\ C \end{vmatrix} = \begin{vmatrix} 1 & \ln R_{Ga} & (\ln R_{Ga})^3 \\ 1 & \ln R_{H_2O} & (\ln R_{H_2O})^3 \\ 1 & \ln R_{Hg} & (\ln R_{Hg})^3 \end{vmatrix}^{-1} \bullet \begin{vmatrix} T_{Ga}^{-1} \\ T_{H_2O}^{-1} \\ T_{Hg}^{-1} \end{vmatrix}$$

Benefits of This Novel Approach

- Absolute temperature calibration is provided on-orbit on-demand.
- Concept is simple and requires very little mass.
- Implementation requires straight-forward modification of an existing flight hardware design (GIFTS).
- Very high accuracy is obtained – each temperature calibration point associated with a melt material can be established to well within 10 mK, and more accuracy is obtainable with longer melt times.
- Scheme provides temperature calibration of all the blackbody cavity thermistor sensors, over a significant temperature range – allowing normal blackbody operation at any temperature within this range.

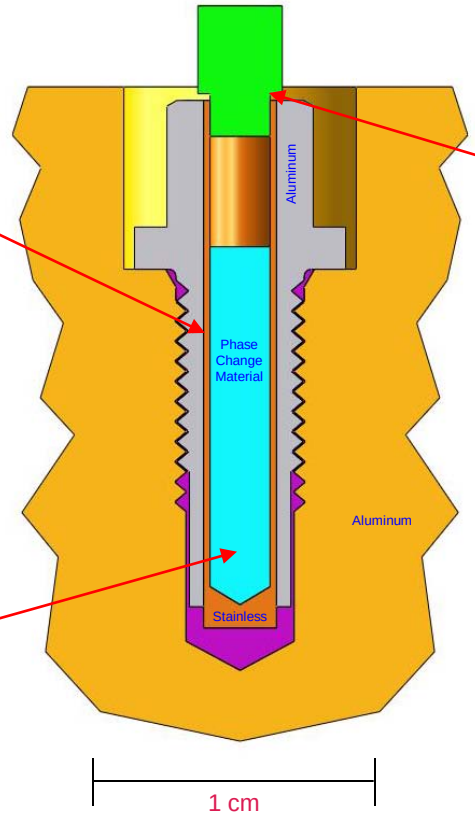
Areas of Focus For NASA IIP

What do we have to do to make this technology more Flight-Ready?

Material Compatibility

The containment material must be "inert" to the (Ga, H_2O, and Hg) phase change materials so that there will be no dissolution that can alter the melt temperature.

In addition, the containment material must not be susceptible to Liquid Metal Embrittlement.



Sealing Techniques

The phase change materials must be sealed in their housings with an inert gas. The seal must be designed for a differential pressures of one atmosphere, and for a temperature range from 180 to 330 K. Seal integrity must last 5 to 10 years.

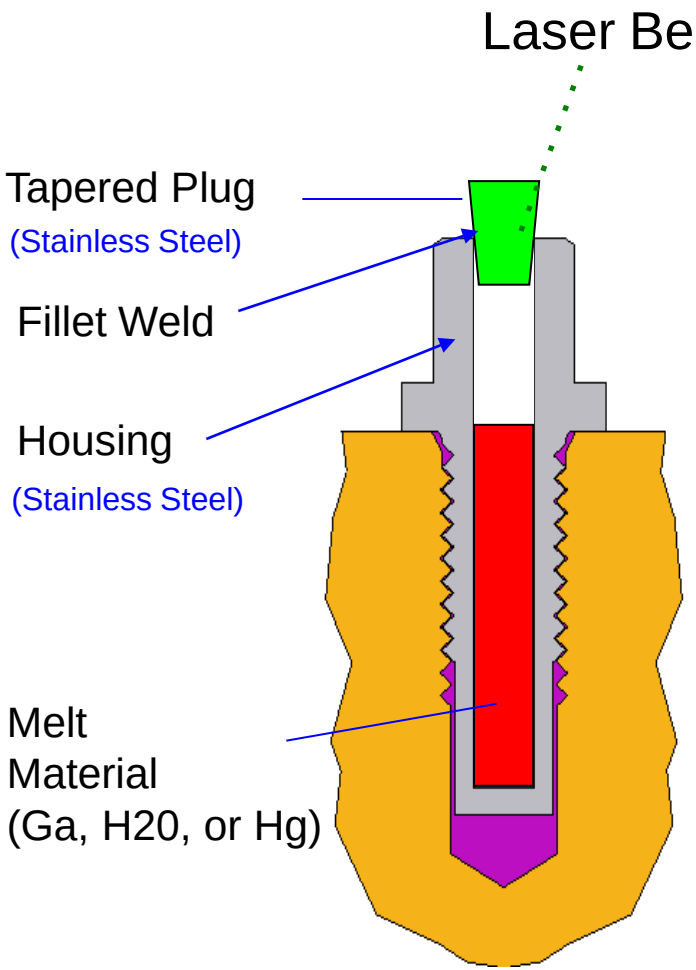
Zero-G Affects

Confinement geometry must allow Surface Tension forces to dominate Gravitational forces, in order for the characterizations and calibrations conducted under 1-G to transfer to the Zero-G environment.

Mechanical Stress

Issues related to freezing expansion of Ga and H_2O must be accounted for.

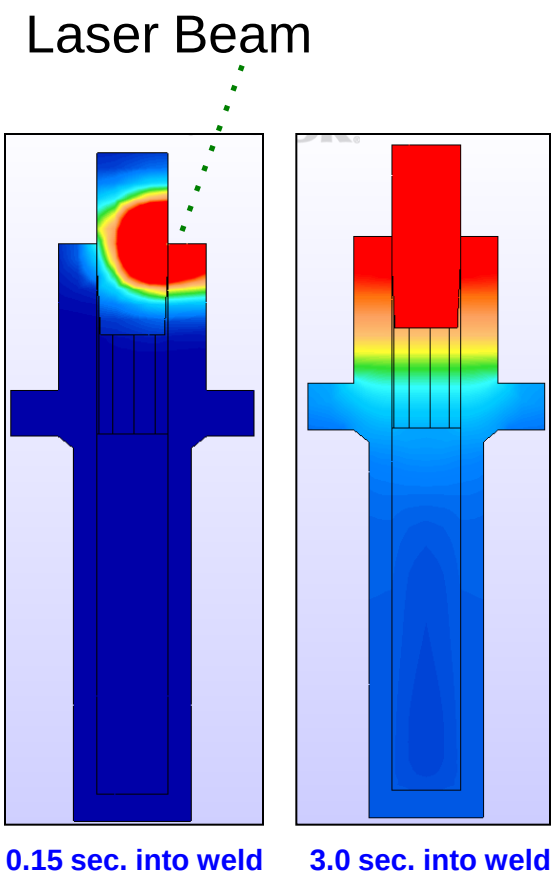
Sealing Technology – Welded Cap



Preco, Inc. precision laser welding

60 Watts
20” per minute*
20° off rotation axis
µm level accuracy

*0.9 seconds of power applied

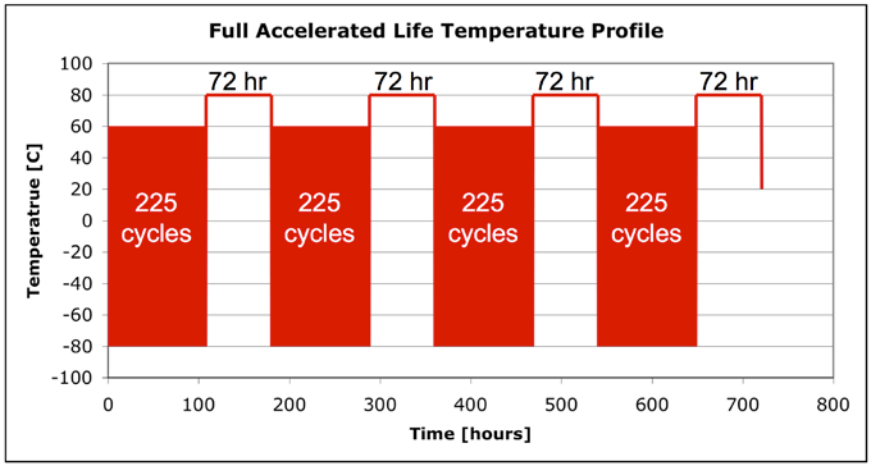


0.15 sec. into weld **3.0 sec. into weld**

Thermal Model shows max water temp. during weld is <45 ° C, 3 sec. after initiation of weld.

Full Accelerated Life Test Flow

- 900 full cycles (~-80 to +60 ° C)
- 12 days at +80 ° C



Witness Sample

Test Sample

Melt Signature Tests

Melt Signature Tests

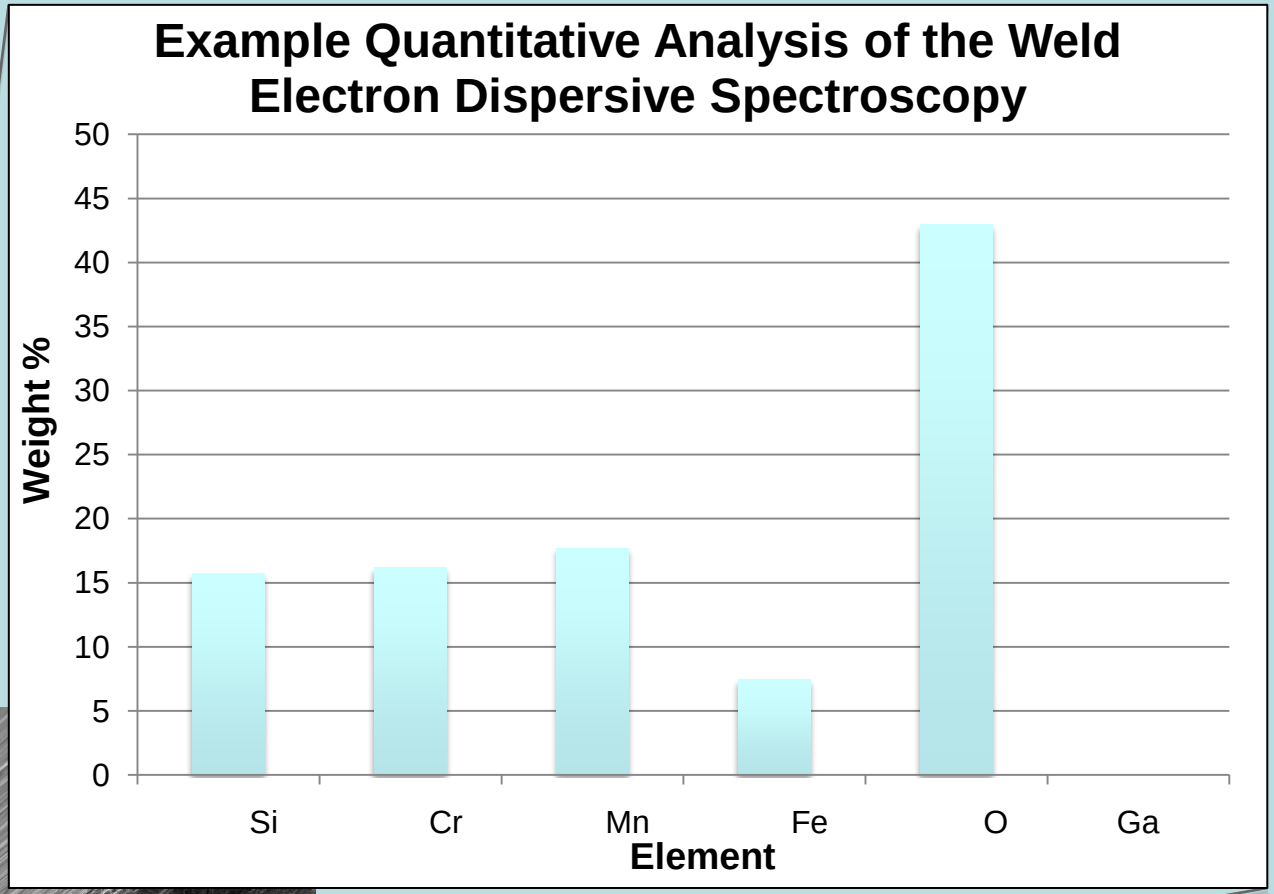
Rapid Full-Temperature Cycling

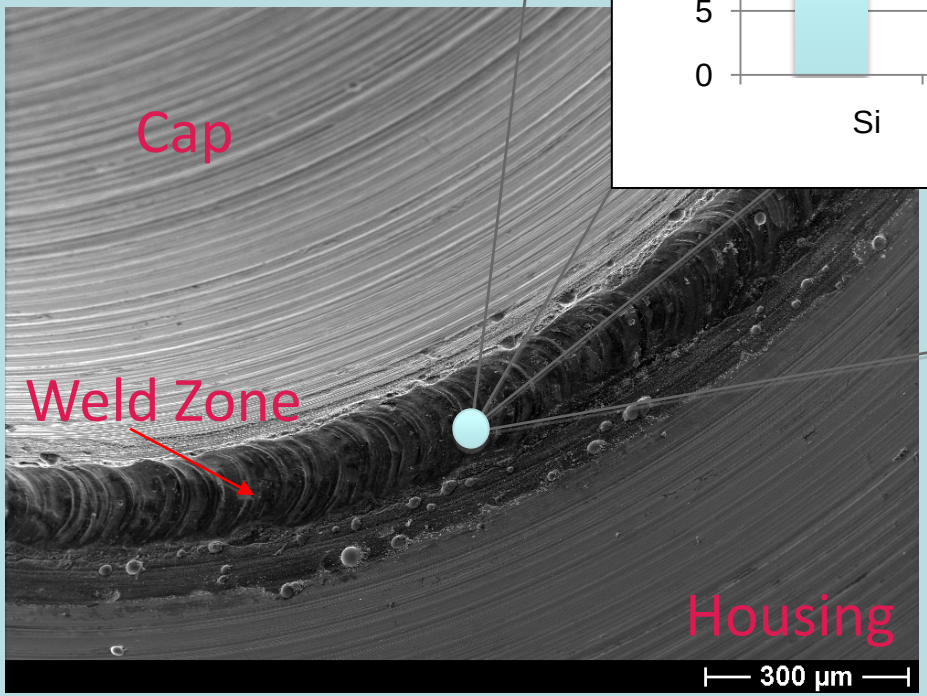
Accelerated Life At Elevated Temperature

Melt Signature Tests

Housing Analysis SEM/EDS

Melt Analysis TXRF





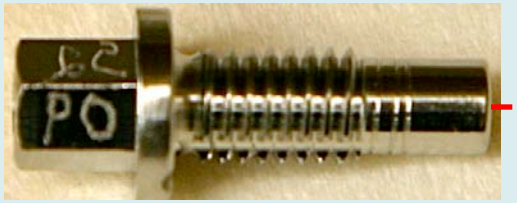
- EDS on the weld shows:
  - No presence of gallium
  - A silicon, chromium, manganese, iron oxide

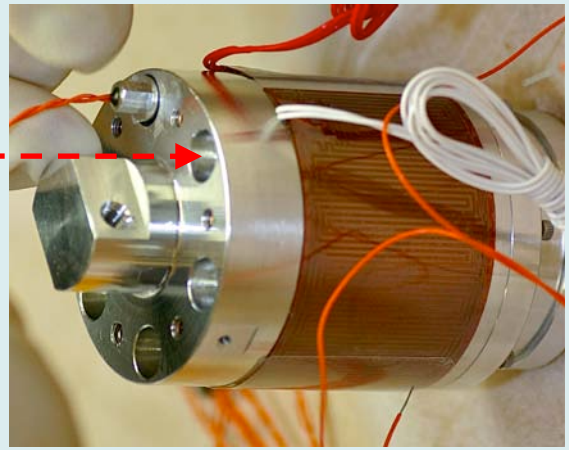
Summary of Phase Change Material Status

	Material	Melt Point [°C]	Liq. >>Solid	LME Possible	Signatures (TEC)	Accelerated Life Test - Unsealed	Accelerated Life Test - Welded	Signatures (Blackbody)
Original IIP	**Gallium**	29.7	Expands	Yes	X	X	X	X
	Water	0.0	Expands	No	X	X	X	X
	Mercury	-38.9	Contracts	Yes	X	X	X	X
ISS	**Gallium-Indium**	16.5	Expands	Yes	X			
	Gallium-Tin	20.5	Expands	Yes	X			

TEC Configuration

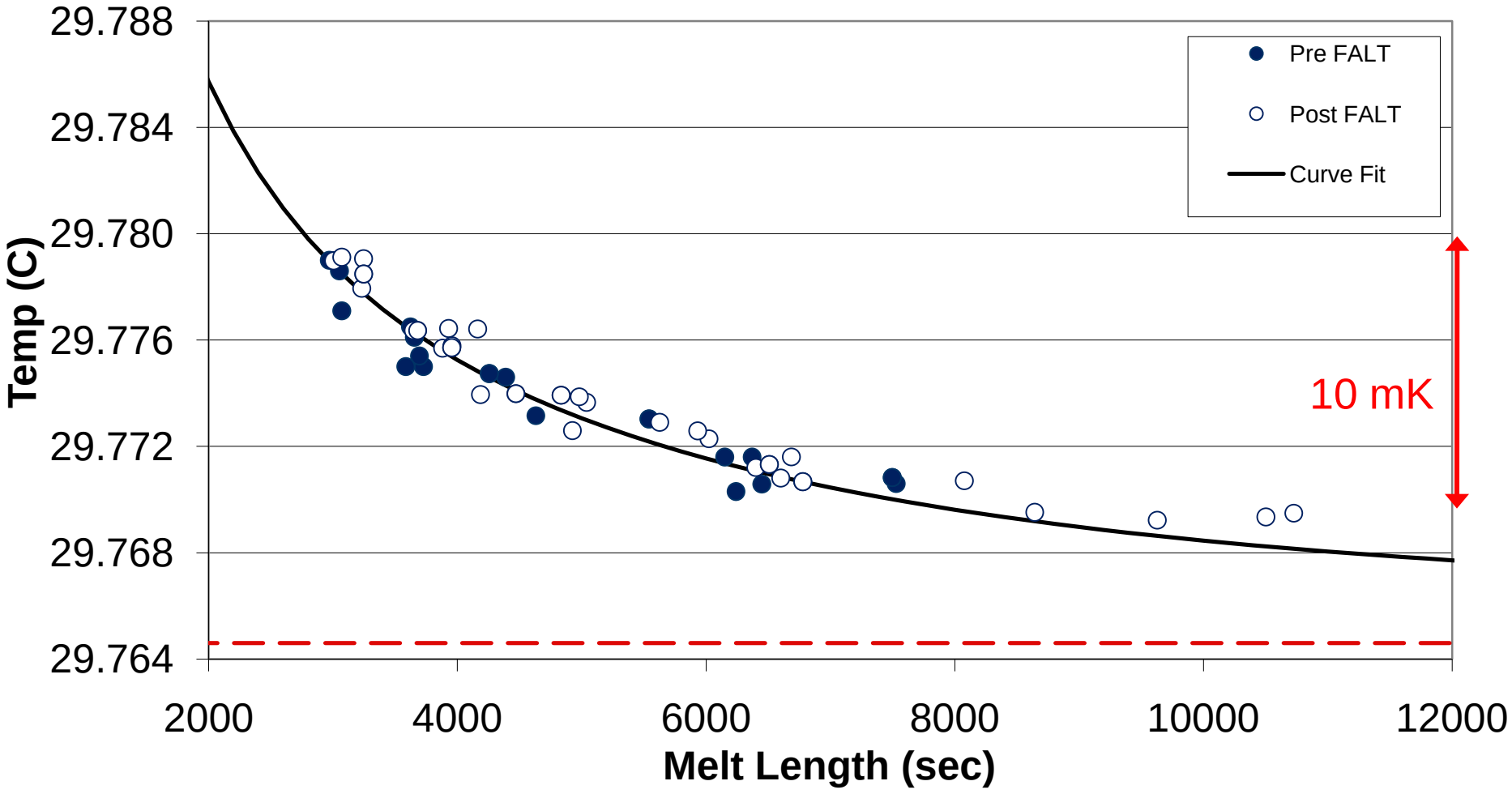
Accelerated Life Configuration





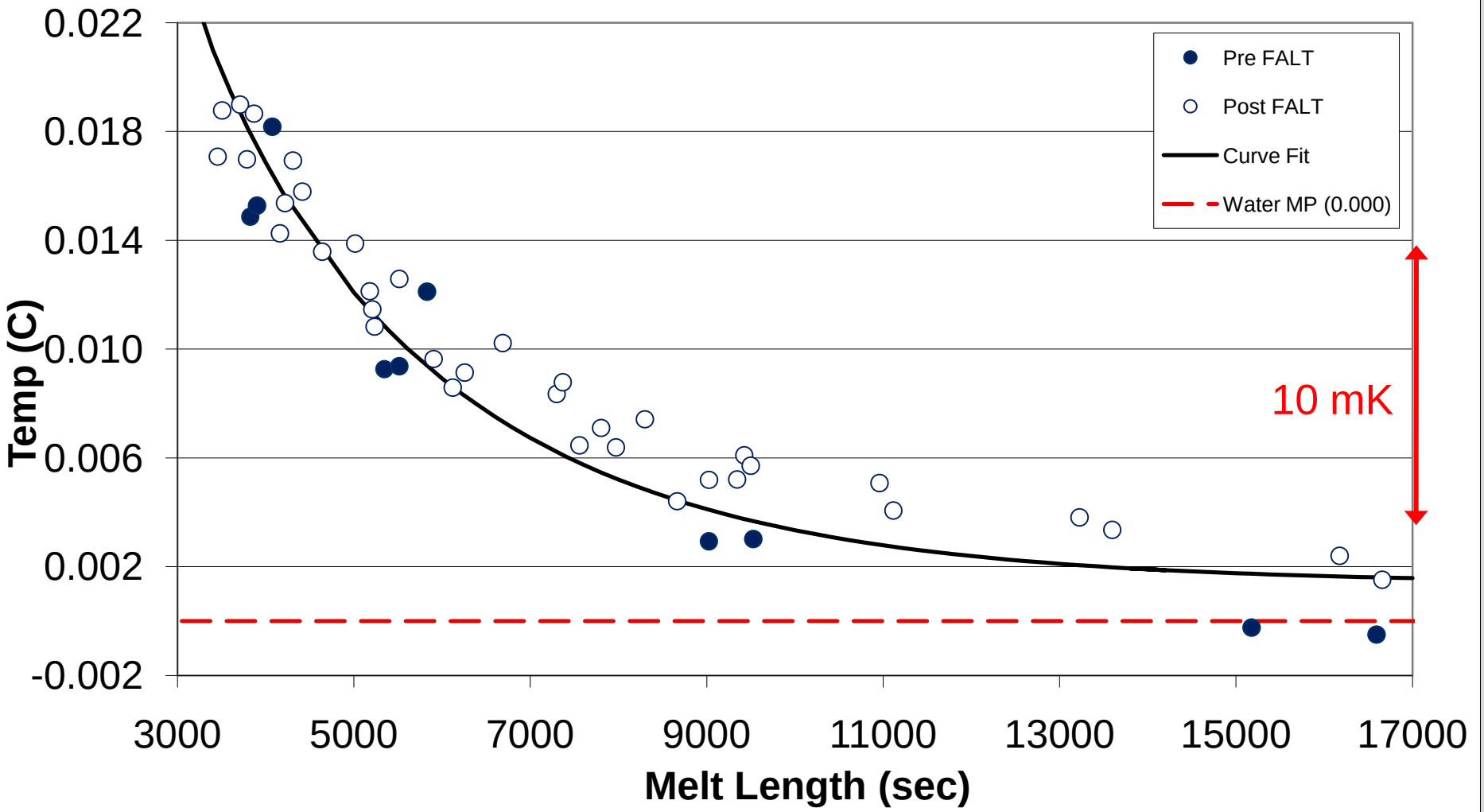
Blackbody Configuration

Gallium Mid-Melt Temperature for Various Melt Lengths



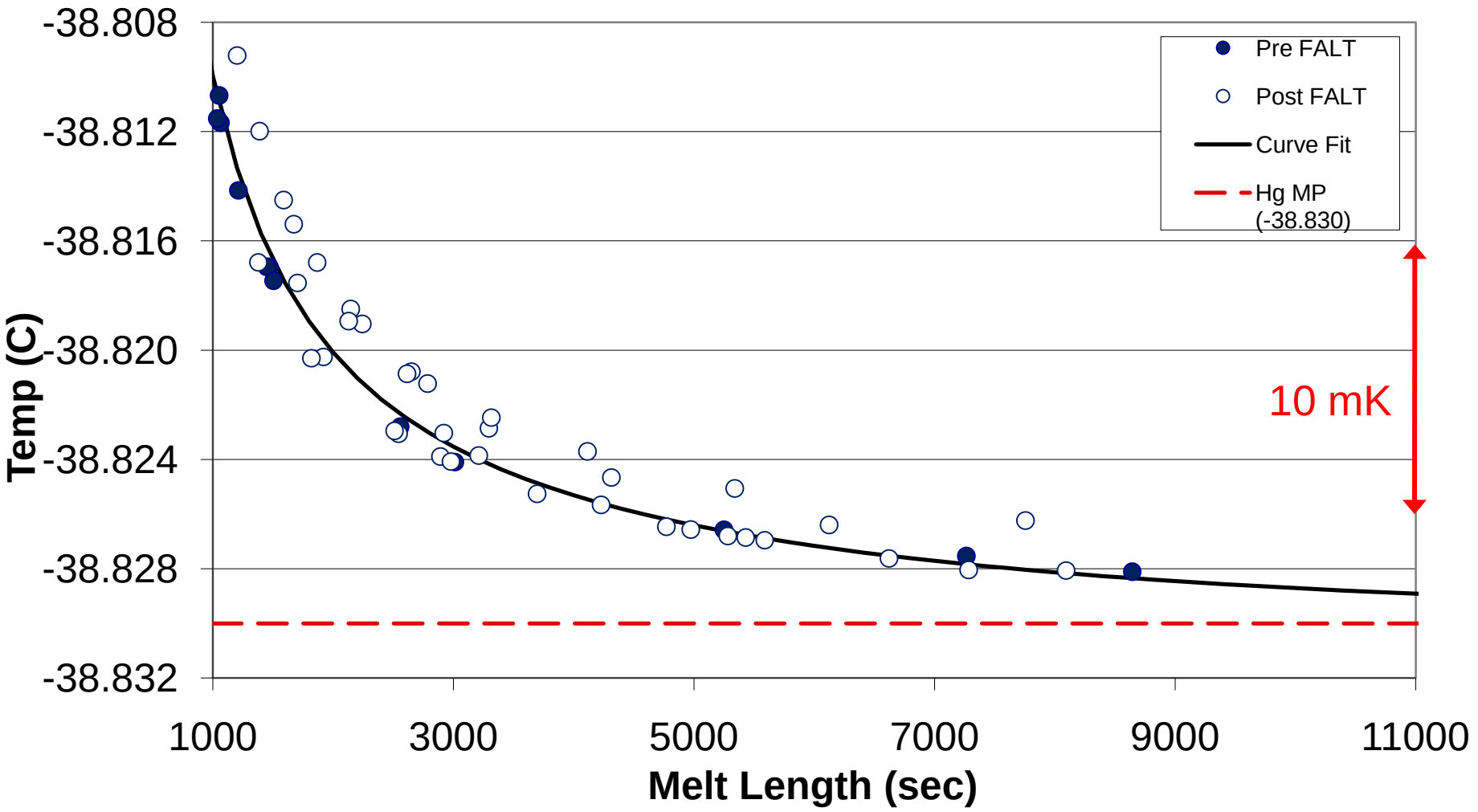
- Data is comprised of six different housings
- Pre and post-FALT, and multiple orientations are included
- Two housings were run upside-down

Water Mid-Melt Temperature for Various Melt Lengths



- Data is comprised of three different housings
- Pre and post-FALT, and multiple orientations are included
- Housings were run in normal configuration and upside down

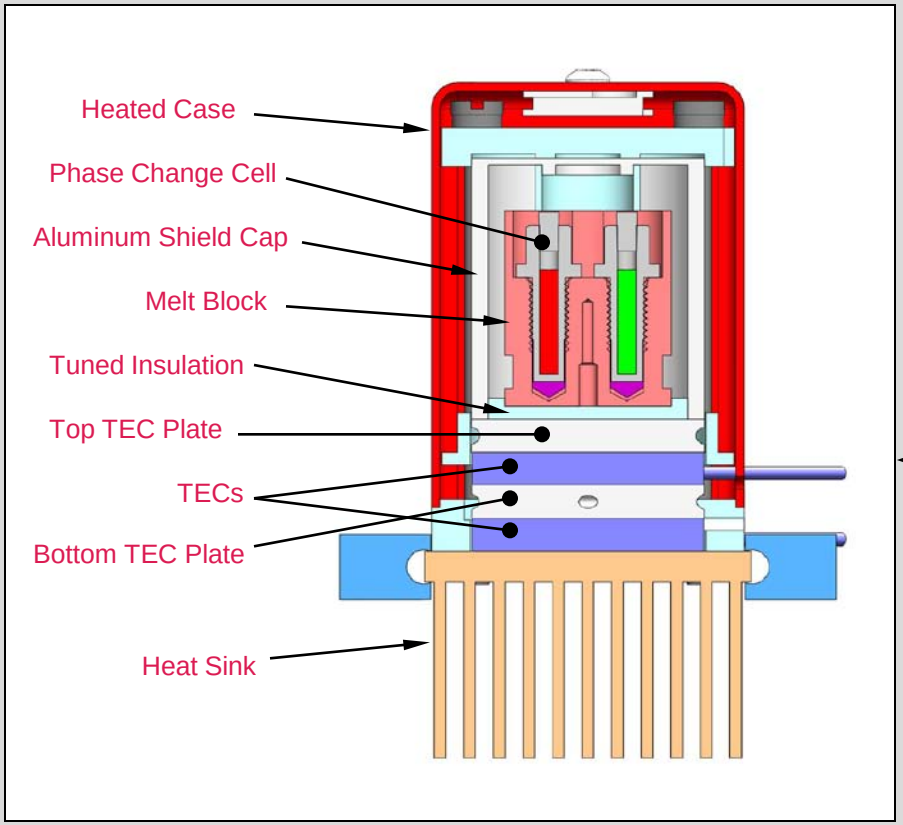
Mercury Mid-Melt Temperature for Various Melt Lengths



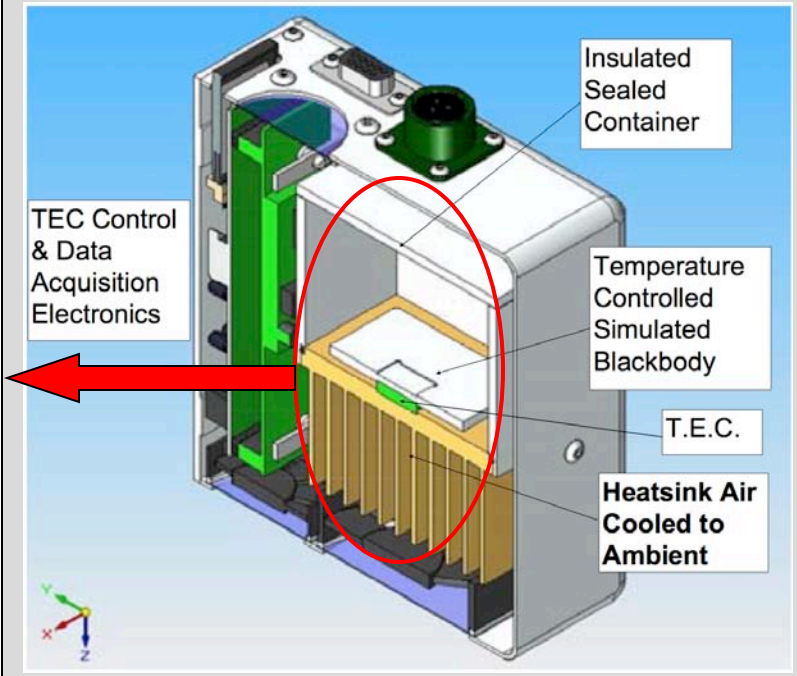
- Data is comprised of four different housings
- Pre and post-FALT and multiple orientations are included
  - Two housings were run on their sides

UW-SSEC Phase Change Cell Demo on ISS

Martin Mlynczak, PI; Shane Topham, SDL Lead



UW-SSEC Multiple Phase Change Experiment

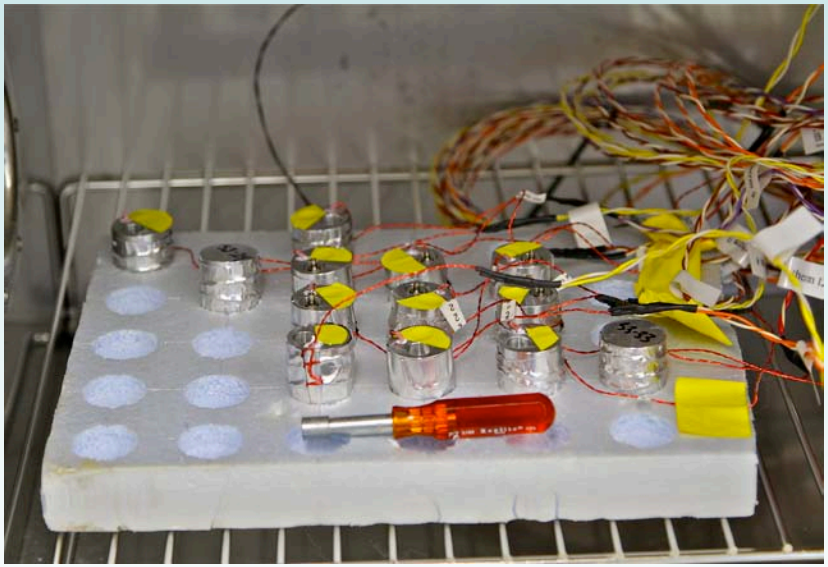


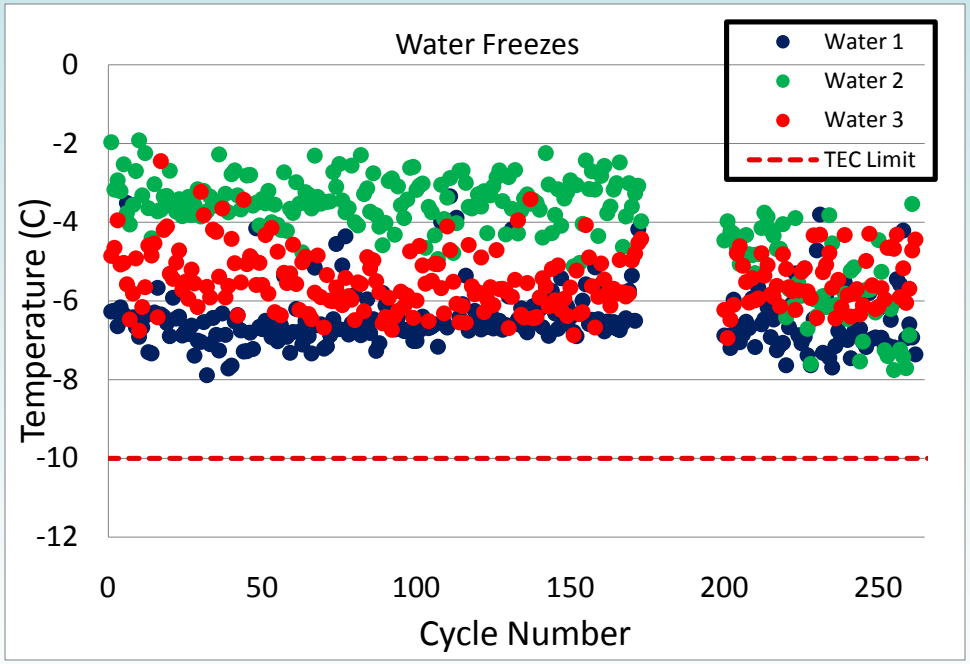
SDL Experiment Support Package for ISS

- Three phase change materials to be used: Gallium, Gallium Eutectic, and Water
- Demonstration will use the Utah State SDL Experiment Support Package
- Signatures of different duration will be obtained and compared with those obtained in one-G

Supercooling Statistics

- Samples were cycled from ~50C to -30C
- Freezes were recorded
- Cycles 200 – 274 are post warm-soak

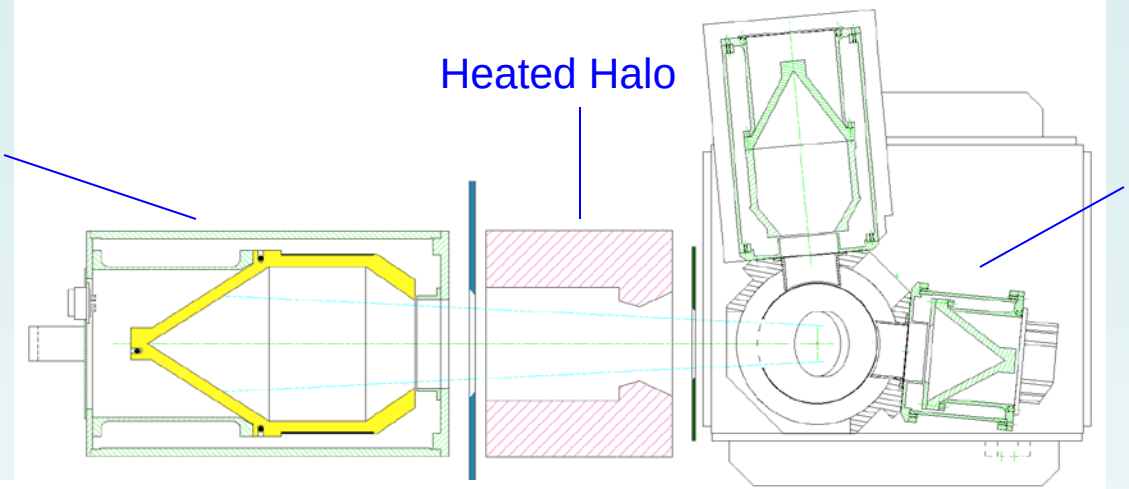


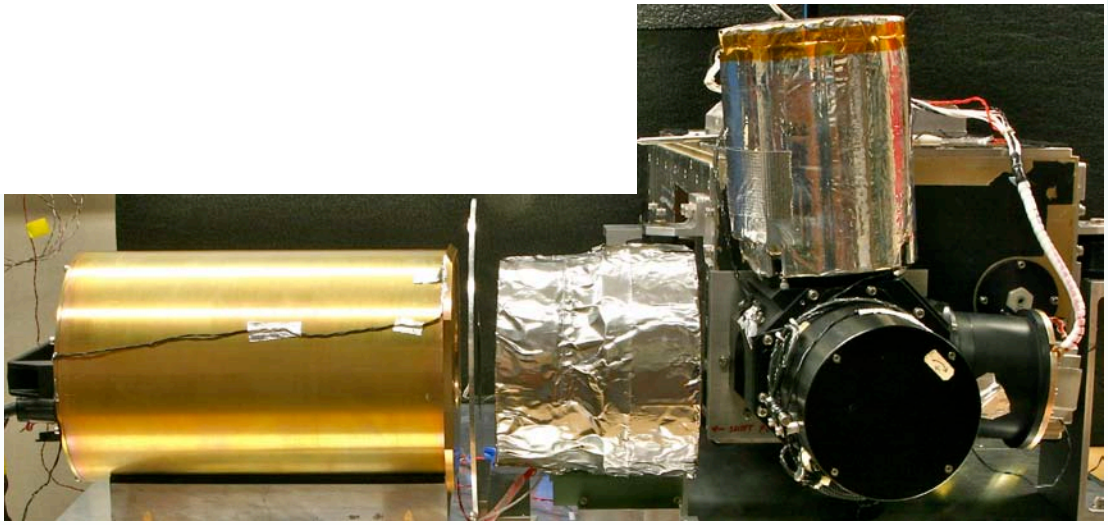


- Water with AgI froze above the TEC limits
- Did not seem to drift over time to lower freezes

Heated Halo

Heated Halo Test Configuration



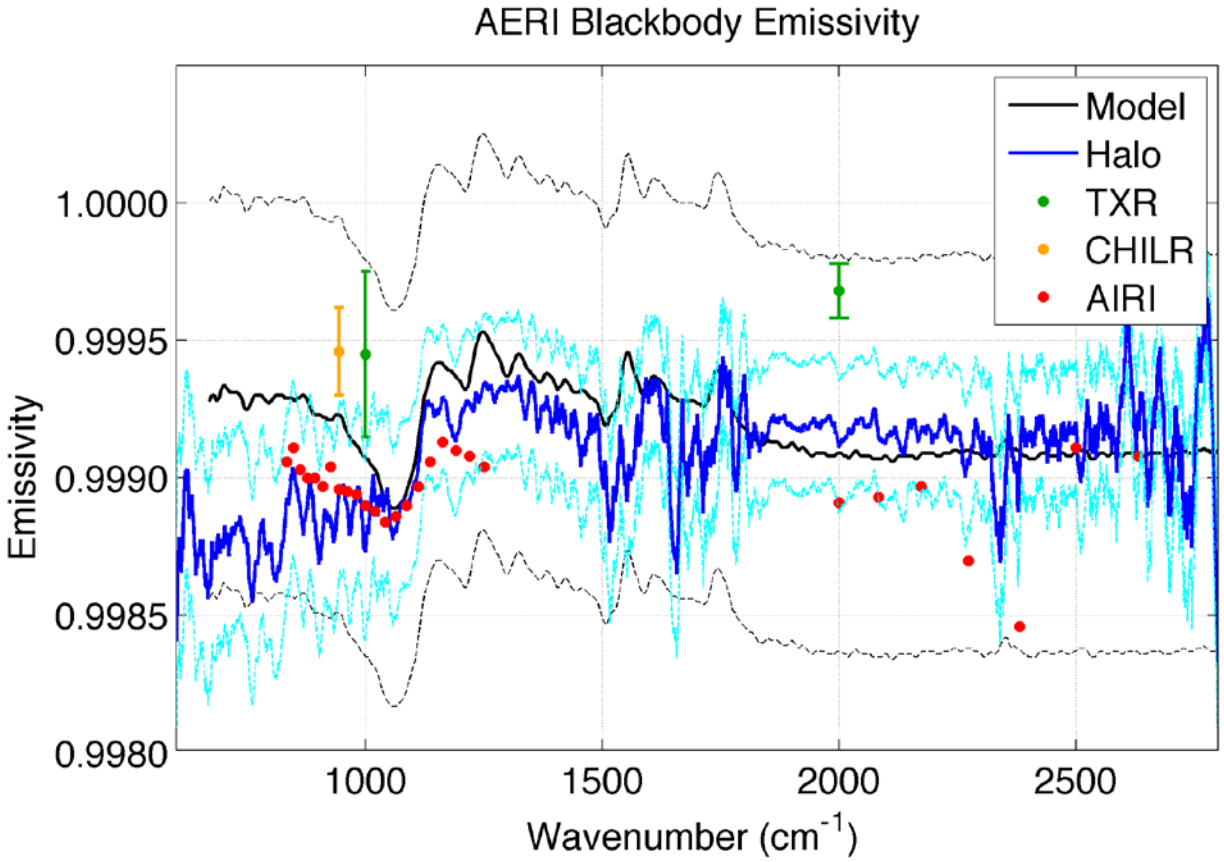


$$R_{obs} = \varepsilon \bullet B(T_{bb}) + (1-\varepsilon) \bullet [F \bullet B(T_{halo}) + (1-F) \bullet B(T_{room})]$$

Direct radiance from BB

Reflected radiance from BB

Emissivity Measurement Comparison

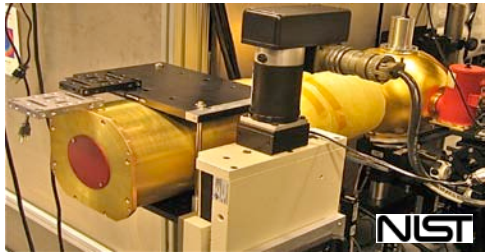


Comparison with NIST measurements

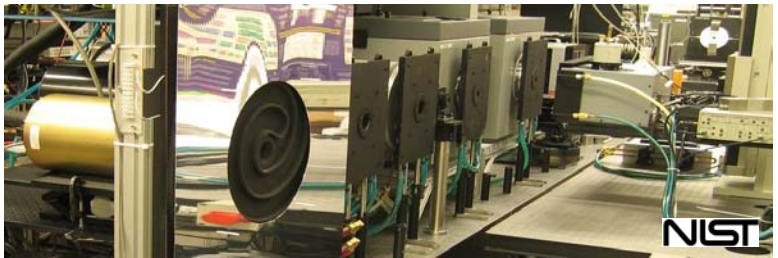
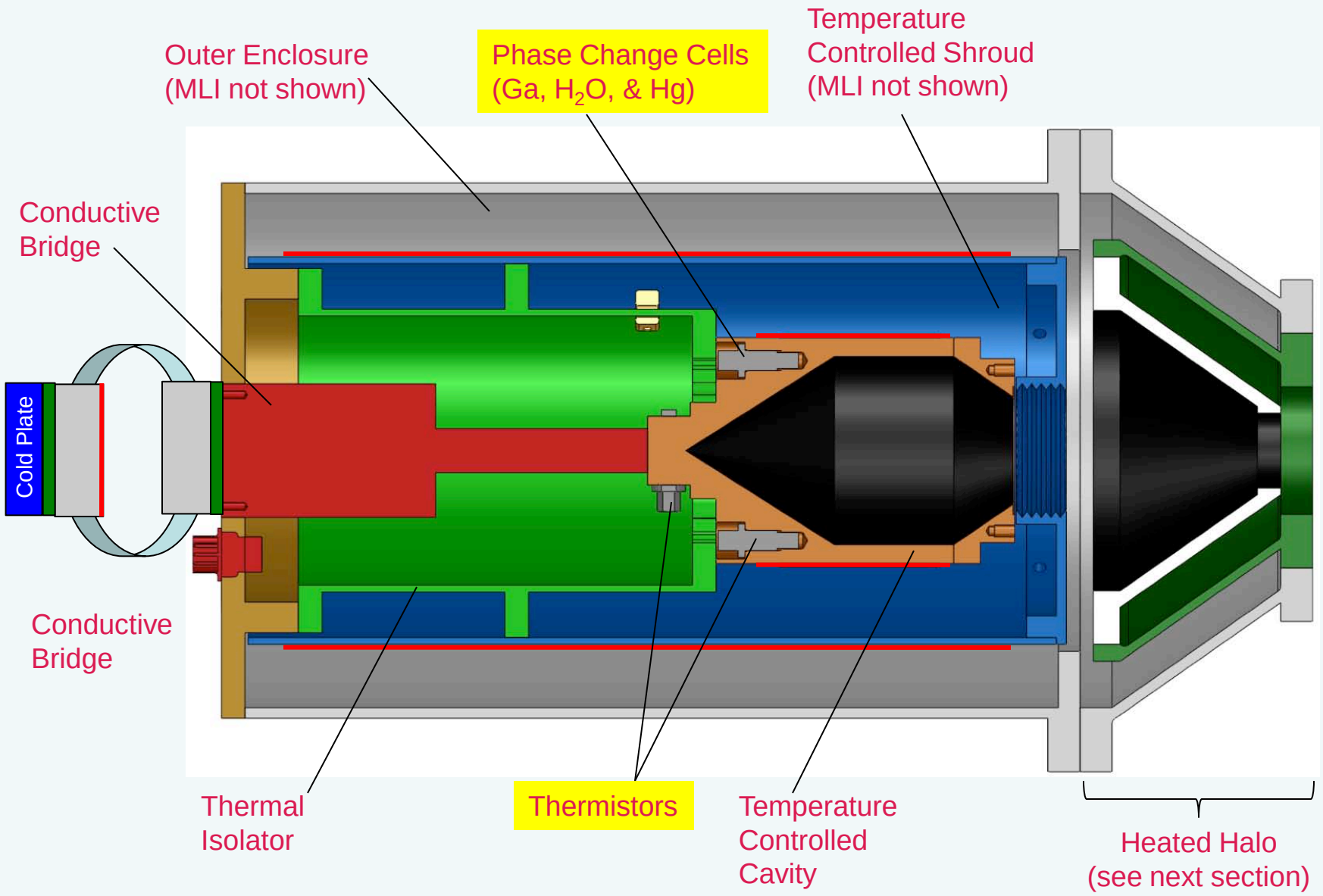
Continued work corroborates earlier results and helps reduce uncertainty

UW Heated Halo

NIST CHILR



NIST AIRI



OARS Design Based on GIFTS Blackbody