On-Orbit Absolute Radiance Standard for the Next Generation of IR Remote Sensing Instruments

Work Conducted Under a NASA IIP

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University of Wisconsin
Space Science and Engineering Center

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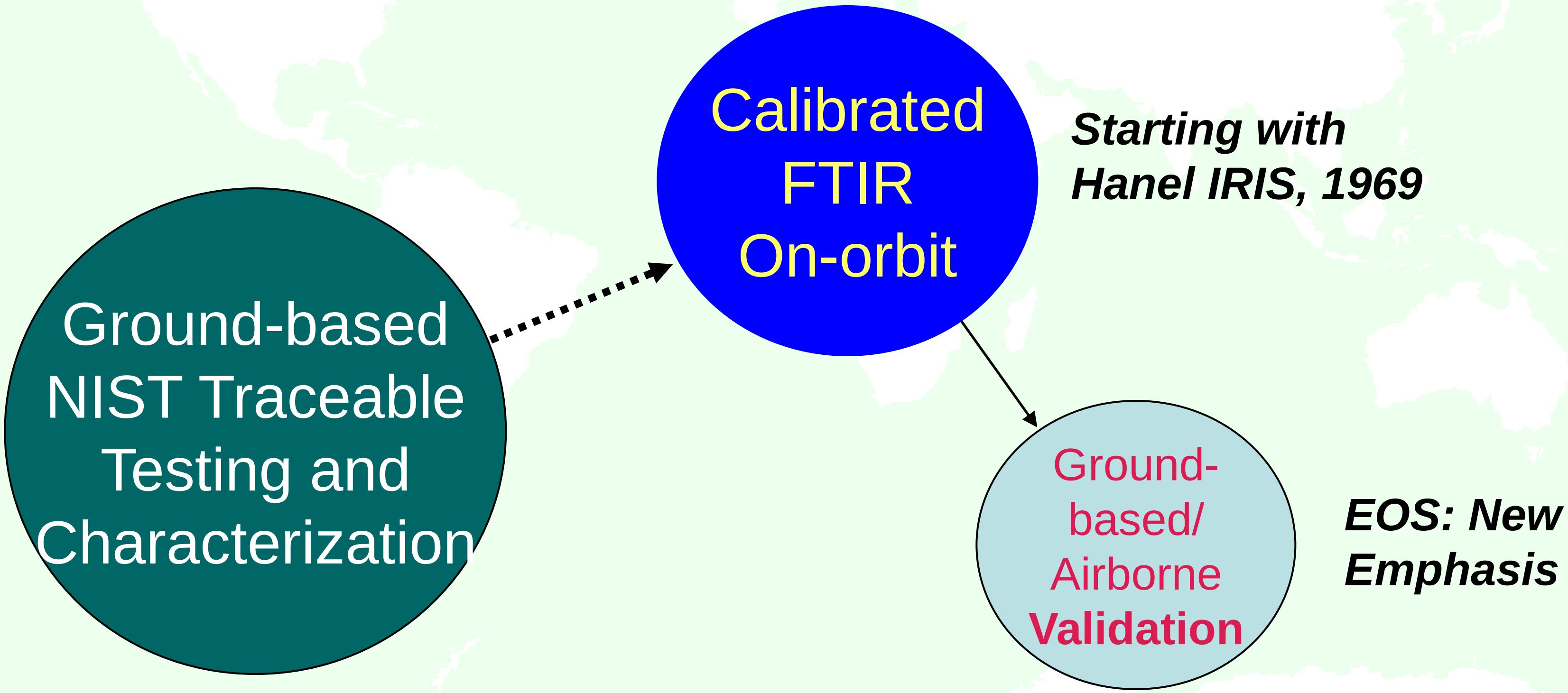
Topics

- On-Orbit Verification and Testing
  - Motivation
  - Required / Expected Performance
  - OARS (On-orbit Absolute Radiance Standard)
    - Temperature Calibration: *Miniature Phase Change Cells*
    - Emissivity Measurement: *Heated Halo – Jon Gero*
- Miniature Phase Change Cells
  - Concept
  - Focus of NASA IIP
  - Accelerated Life Test
  - Demonstration in Microgravity
- Integration to OARS and System-Level Testing with Absolute Radiance Interferometer

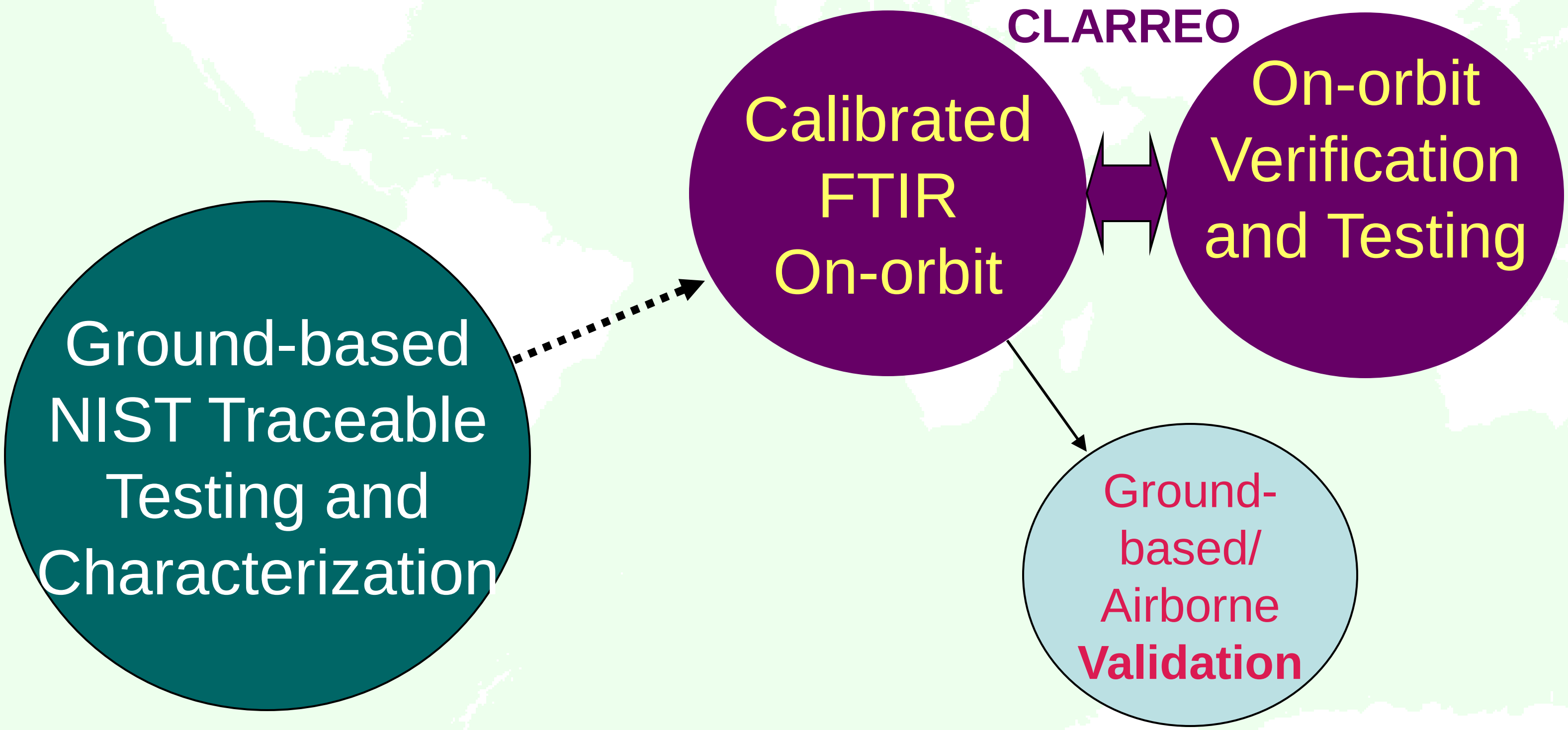
Introduction

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

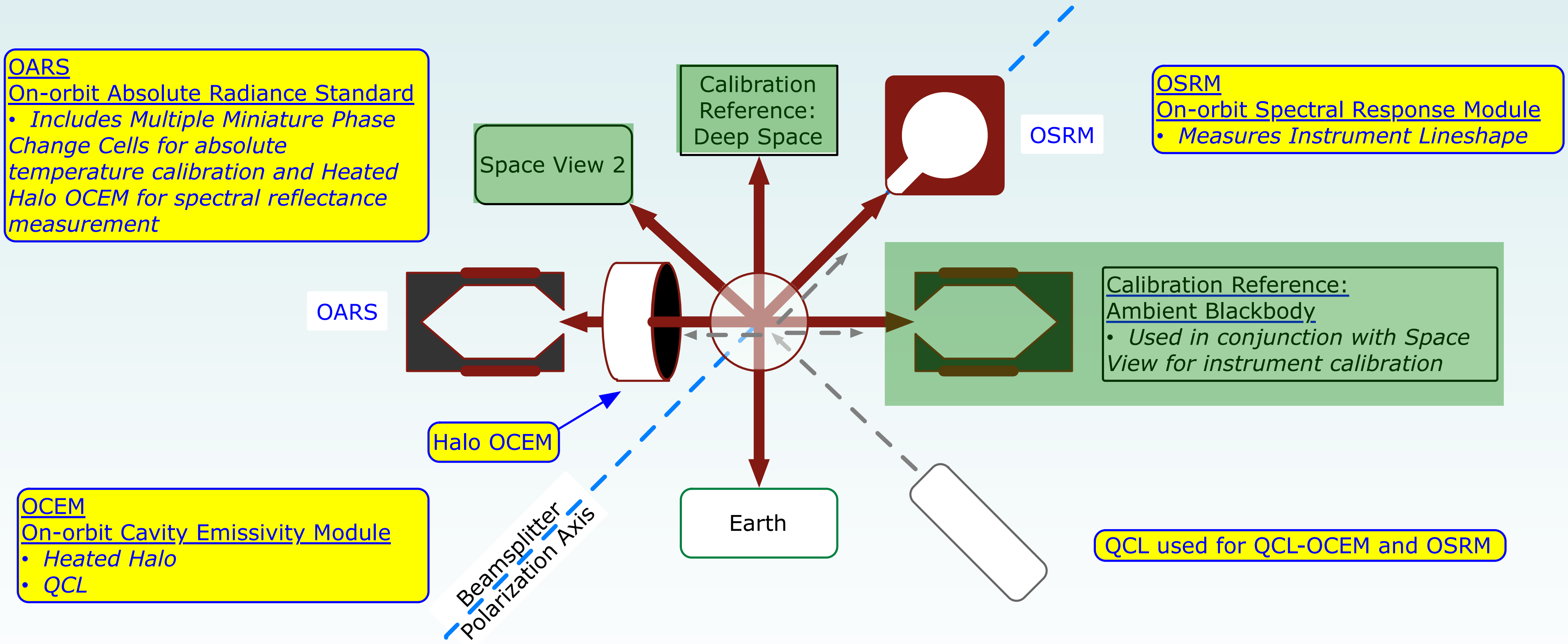


Introduction

- New developments for CLARREO under a NASA IIP provide a strong foundation for this step (TRL-6)

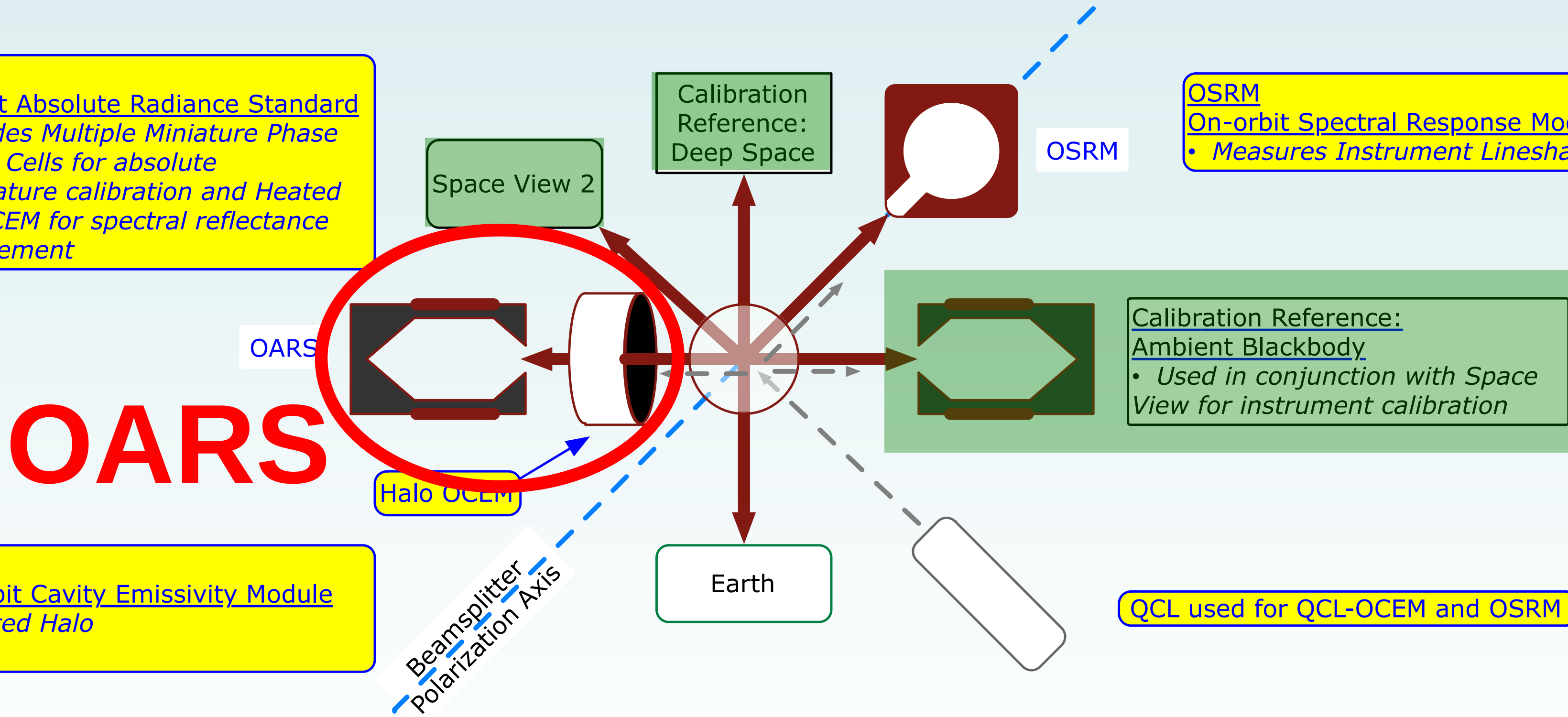


On-Orbit Verification and Test System



On-Orbit Verification and Test System

[OARS](#)
[On-orbit Absolute Radiance Standard](#)
- *Includes Multiple Miniature Phase Change Cells for absolute temperature calibration and Heated Halo OCEM for spectral reflectance measurement*

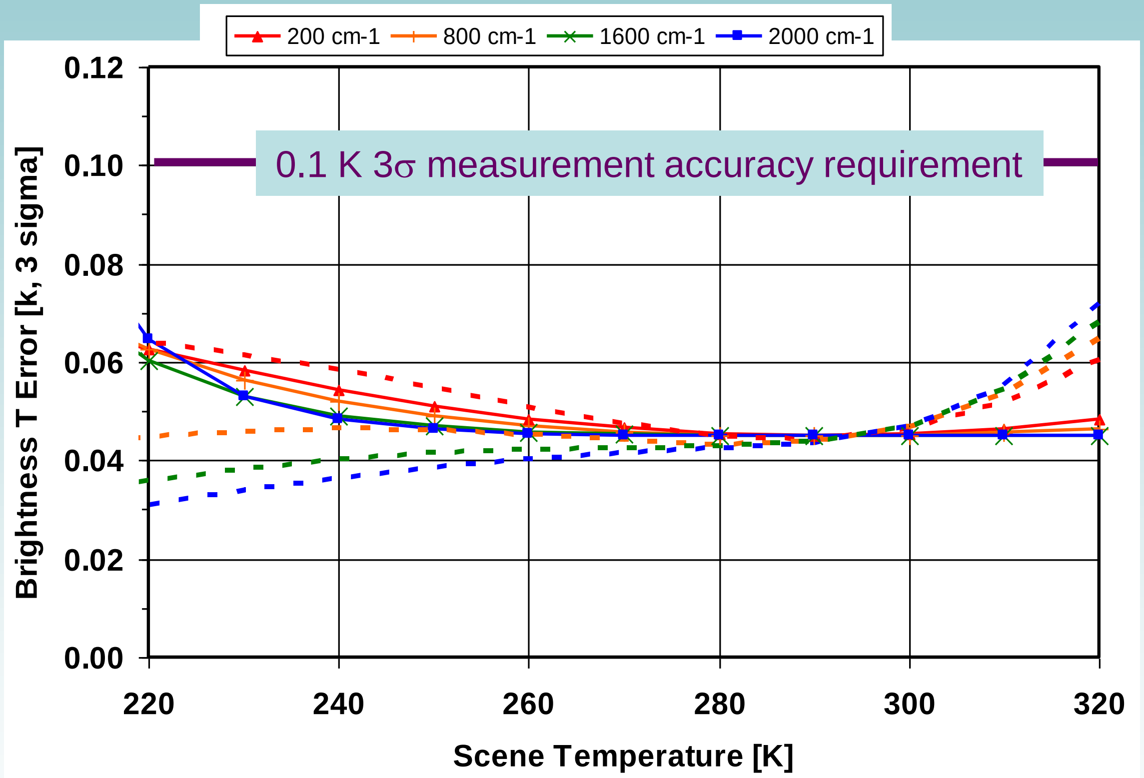


OSRM
On-orbit Spectral Response Module
- *Measures Instrument Lineshape*

OCEM
On-orbit Cavity Emissivity Module
- *Heated Halo*
- *QCL*

QCL used for QCL-OCEM and OSRM

CLARREO Radiometric Performance

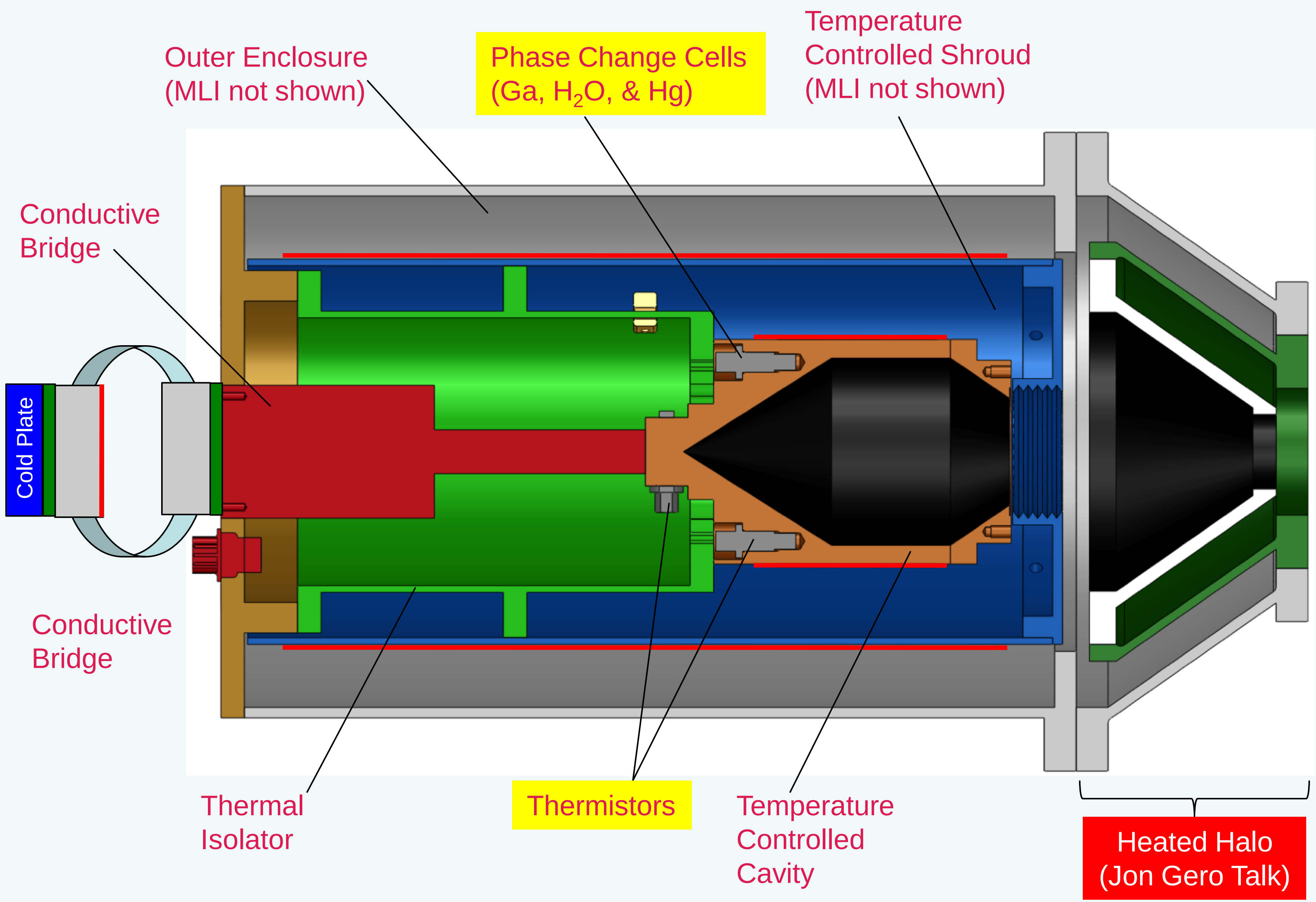


	Value	Uncertainty
Temperatures		
Calibrated FTS	290 K	2.000 K
ABB	295 K	0.045 K
OARS	220 to 320 K	0.045 K
ABB Emissivity	0.999	0.0006
OARS Emissivity		
@200 cm^{-1}	0.999	0.0006
@800 cm^{-1}	0.999	0.0004
@1600 cm^{-1}	0.999	0.0002
@2000 cm^{-1}	0.999	0.0001

- - - - - -	Calibrated FTS
———	OARS

The OARS emissivity is determined from T/V testing with a very high emissivity source. The independent uncertainties are root-sum-squared and the CFTS uncertainty includes a nonlinearity of 0.03% (after correction).

OARS Design Concept
Based on GIFTS Blackbody



Temperature Calibration Using Miniature Phase Change Cells

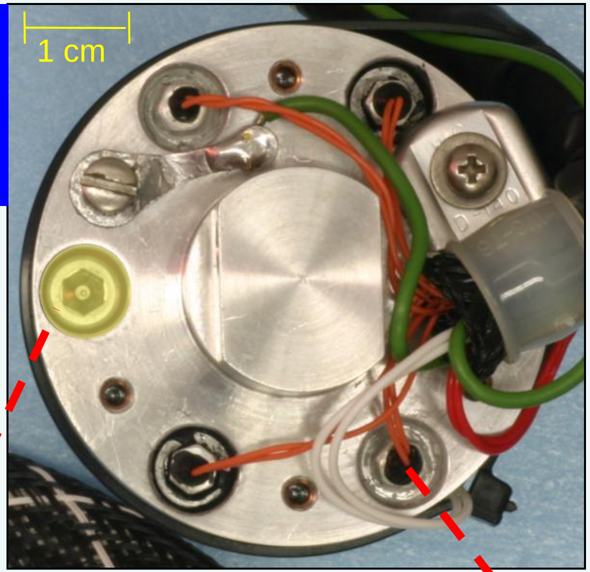
- Miniature Phase Change Cell Concept
- Summary of IIP Work

SSEC Engineering Test Cavity

(GIFTS Style Blackbody configured for melt tests)

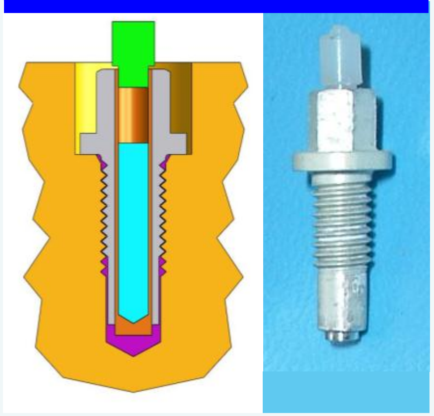
Blackbody Cavity

(aft view)

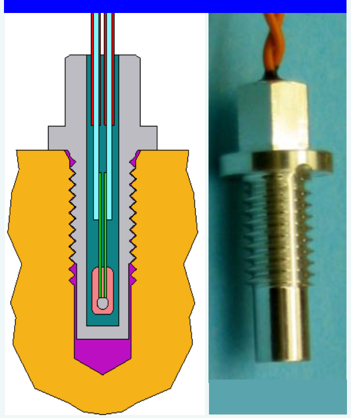


Three or more will characterize the thermistor sensors

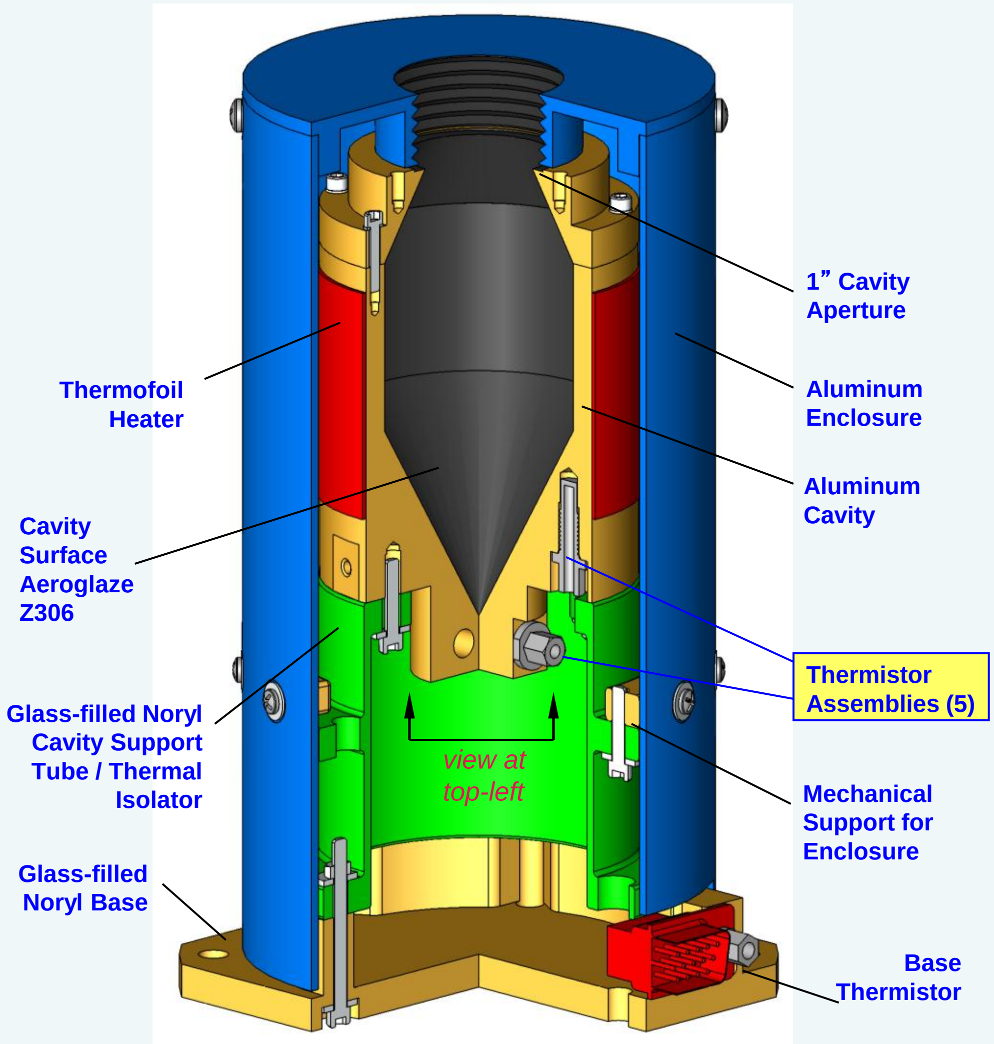
Melt Material



Thermistor

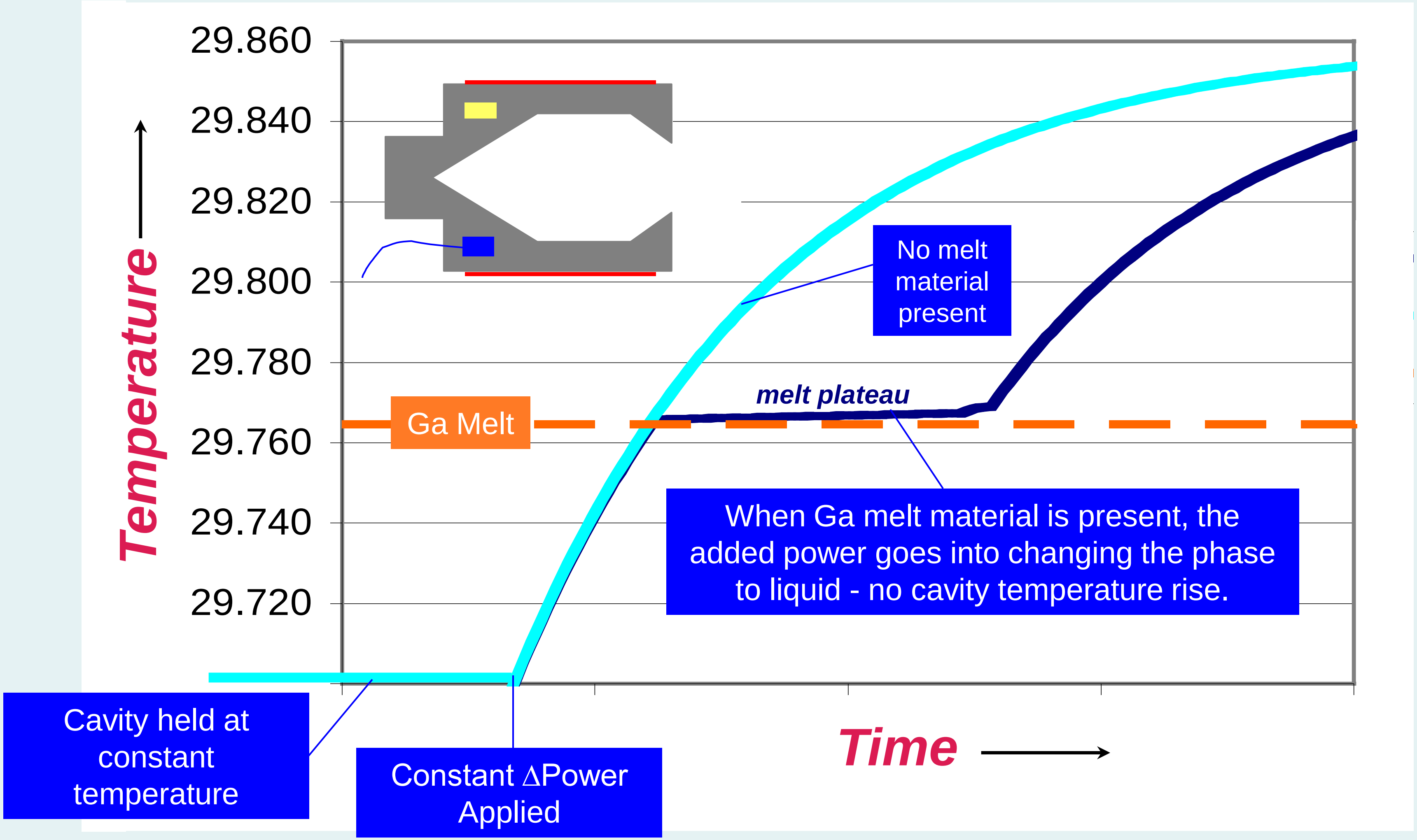


GIFTS Blackbody

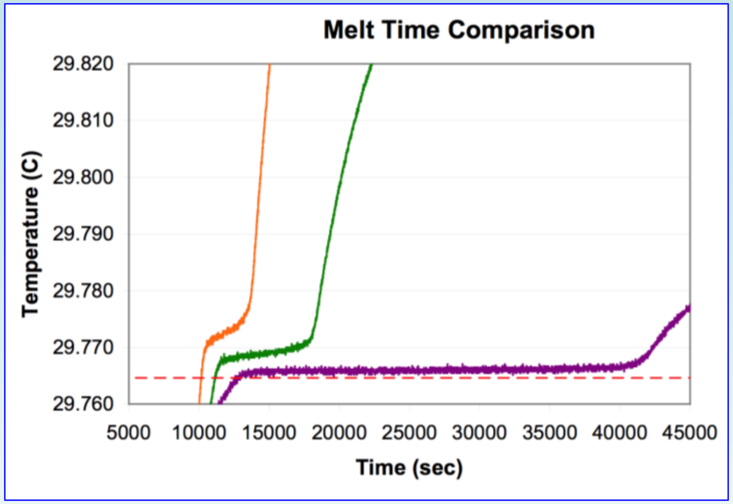


Phase Change Material Implementation

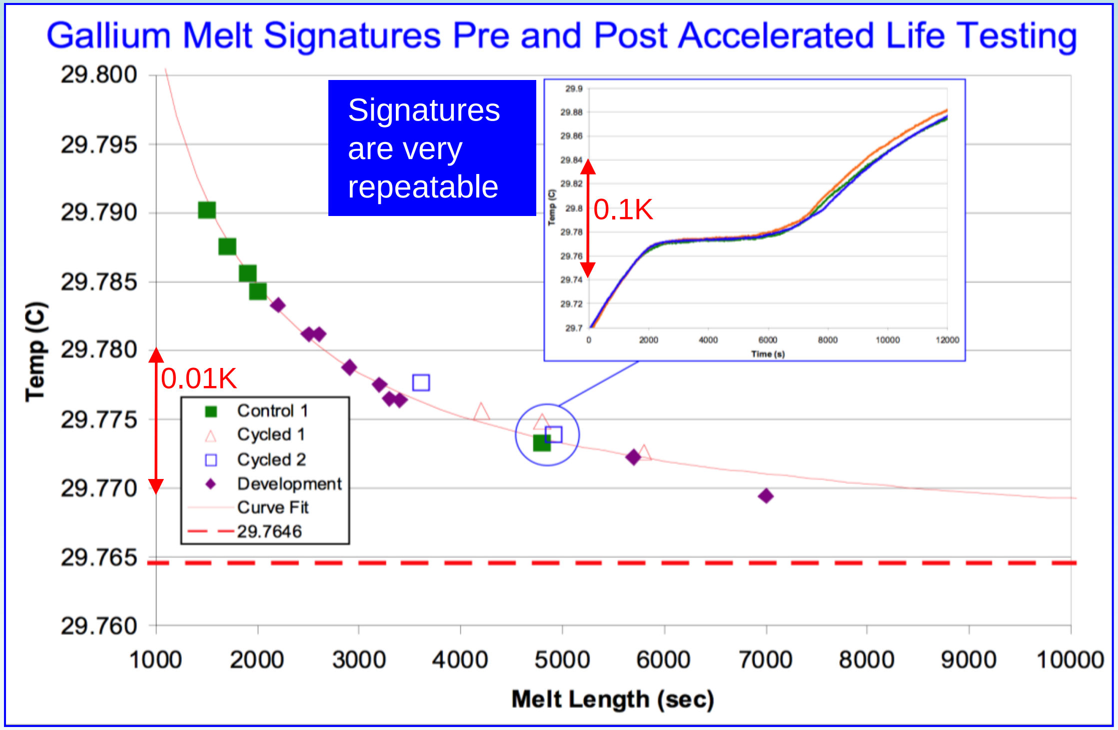
Anatomy of a Melt Signature



Signature Dependence on Melt Length



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

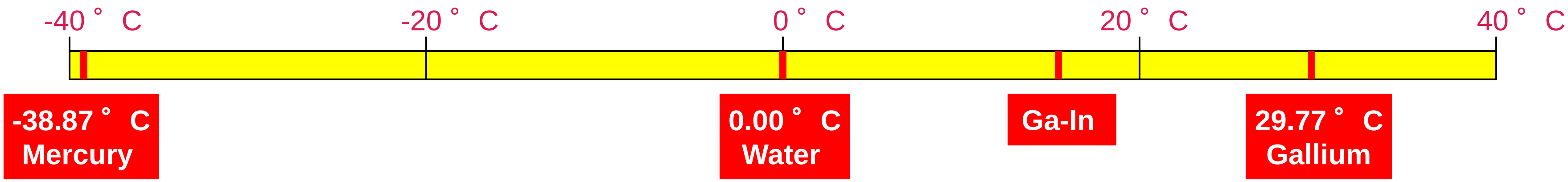


Mid-melt temperature vs melt length relationship is stable and can be very well characterized.

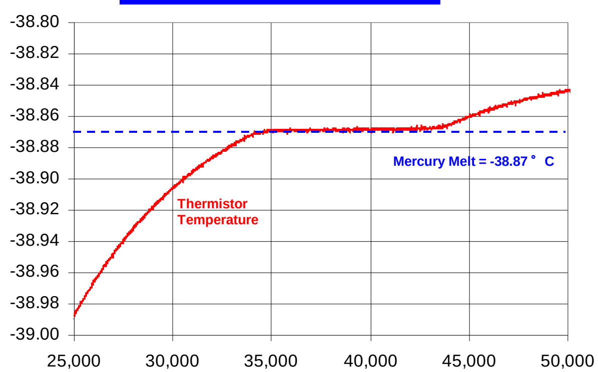
This was the technology brought into the NASA IIP for refinement

Measured Melt Signatures

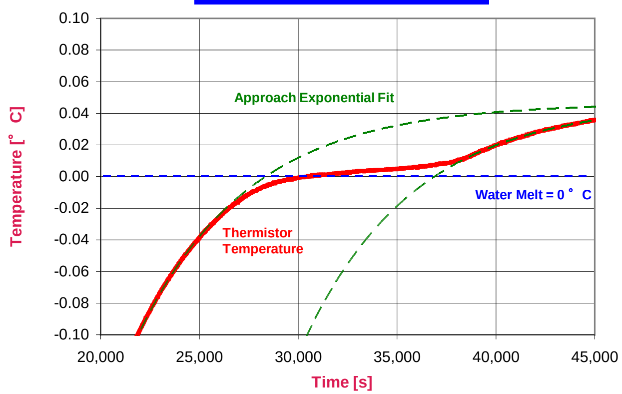
(using GIFTS BB Configuration)



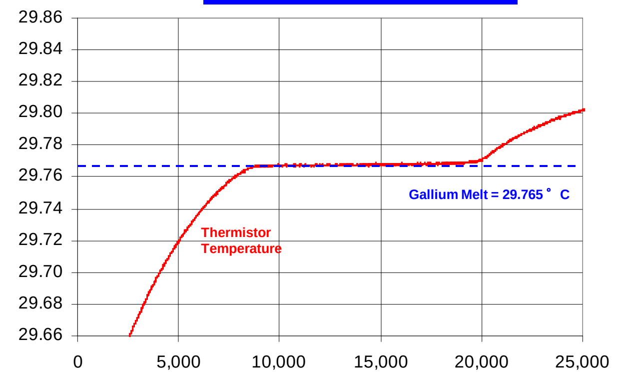
Mercury Melt (test data)



Water Melt (test data)



Gallium Melt (test data)



Melt Signatures Provide Absolute Temperature Calibration Accuracies Better Than 10 mK

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End-to-end System Calibration
Steinhart-Hart Relationship

- Traditional Steinhart-Hart Relationship

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

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

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

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.

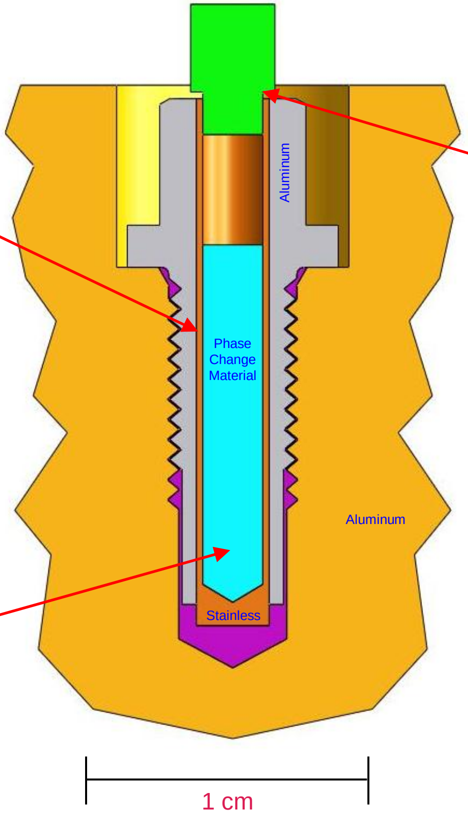
Areas of Focus For NASA IIP

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.

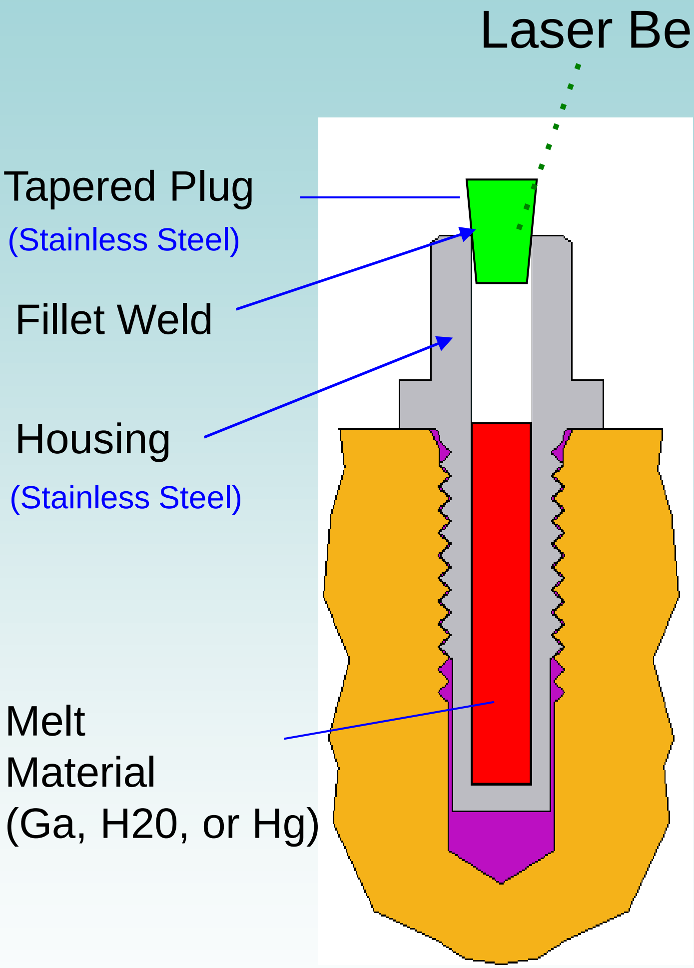
Zero-G Affects

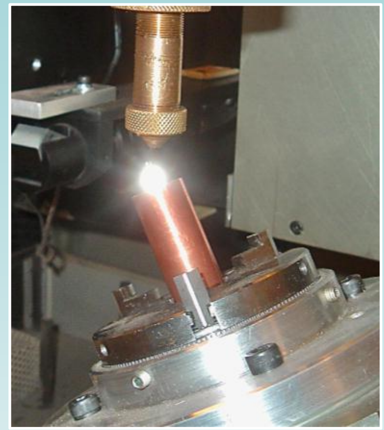
Confinement geometry must allow Surface Tension forces to dominate Gravitational forces, in order for the characterizations and calibrations conducted under 1-G to transfer to the Zero-G environment.

Mechanical Stress

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

Sealing Technology – Welded Cap

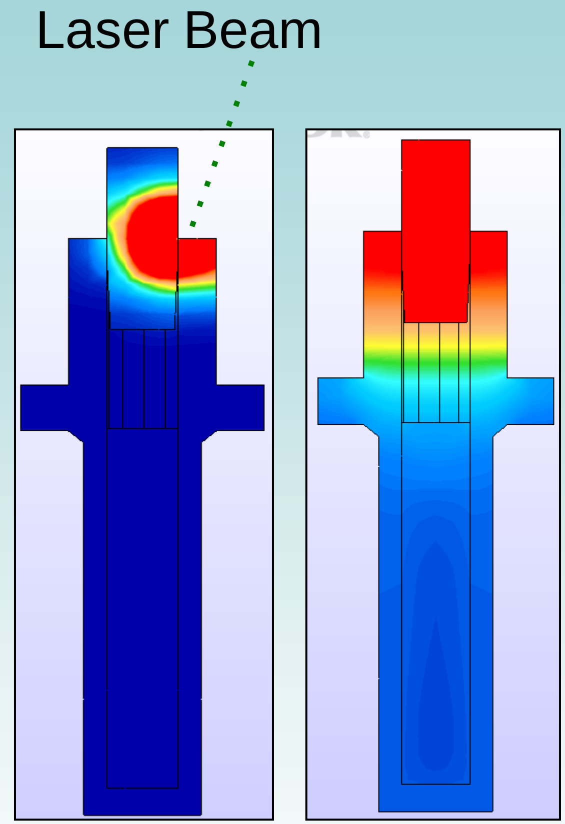




Preco, Inc. precision laser welding

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

*0.9 seconds of power applied

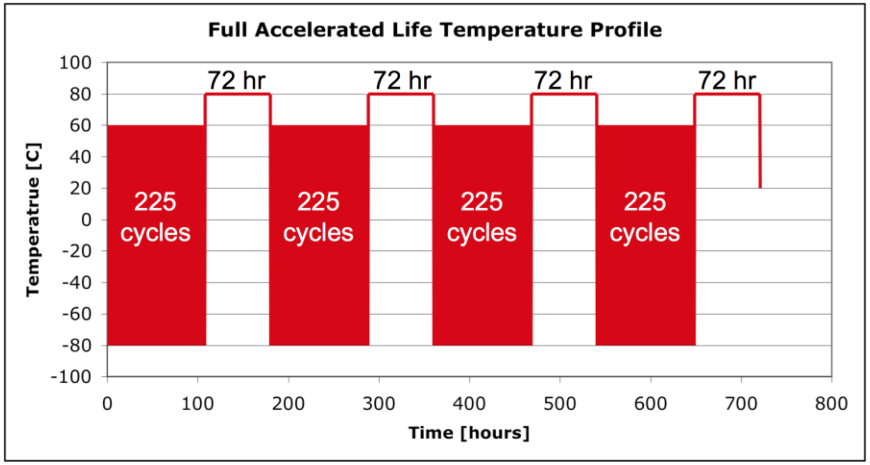


0.15 sec. into weld **3.0 sec. into weld**

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

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SEM Inspection Methods

Housing

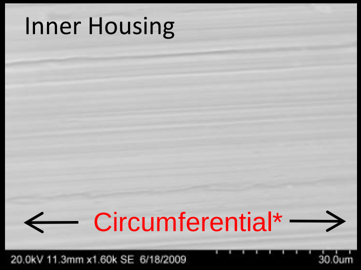
Scanning Electron Microscopy

SEM Mode	To Look For	
Secondary Electrons	Morphology (cracks)	*Below Left*
Backscattered Electrons	Element Mapping (LME)	*Below Center*
Energy Dispersive Spectroscopy	Diffusion	*Below Right*

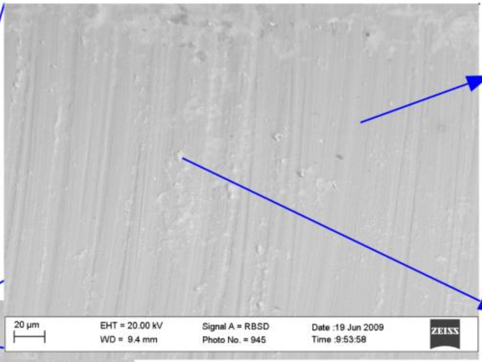
Findings for Gallium

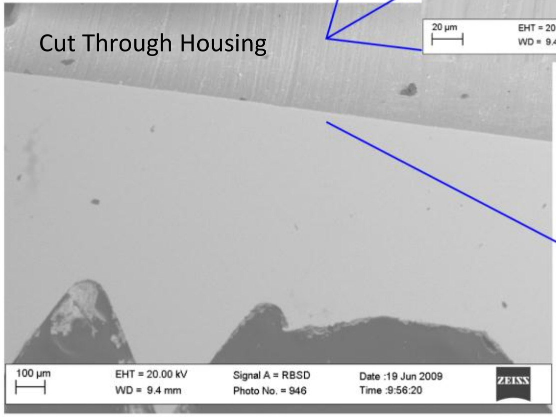
- No Gallium/LME present in the polished cross-section.
- No evidence of diffusion of Gallium microstructure.
- Small spots on inner surface are Gallium.

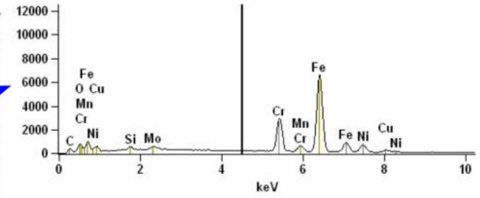
Secondary Electrons

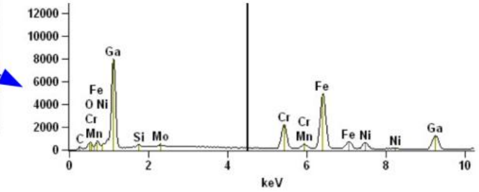


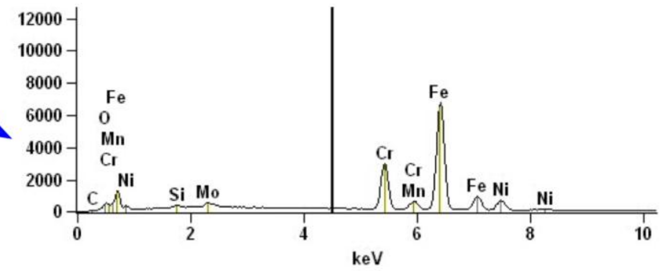
Backscattered Electrons / EDS



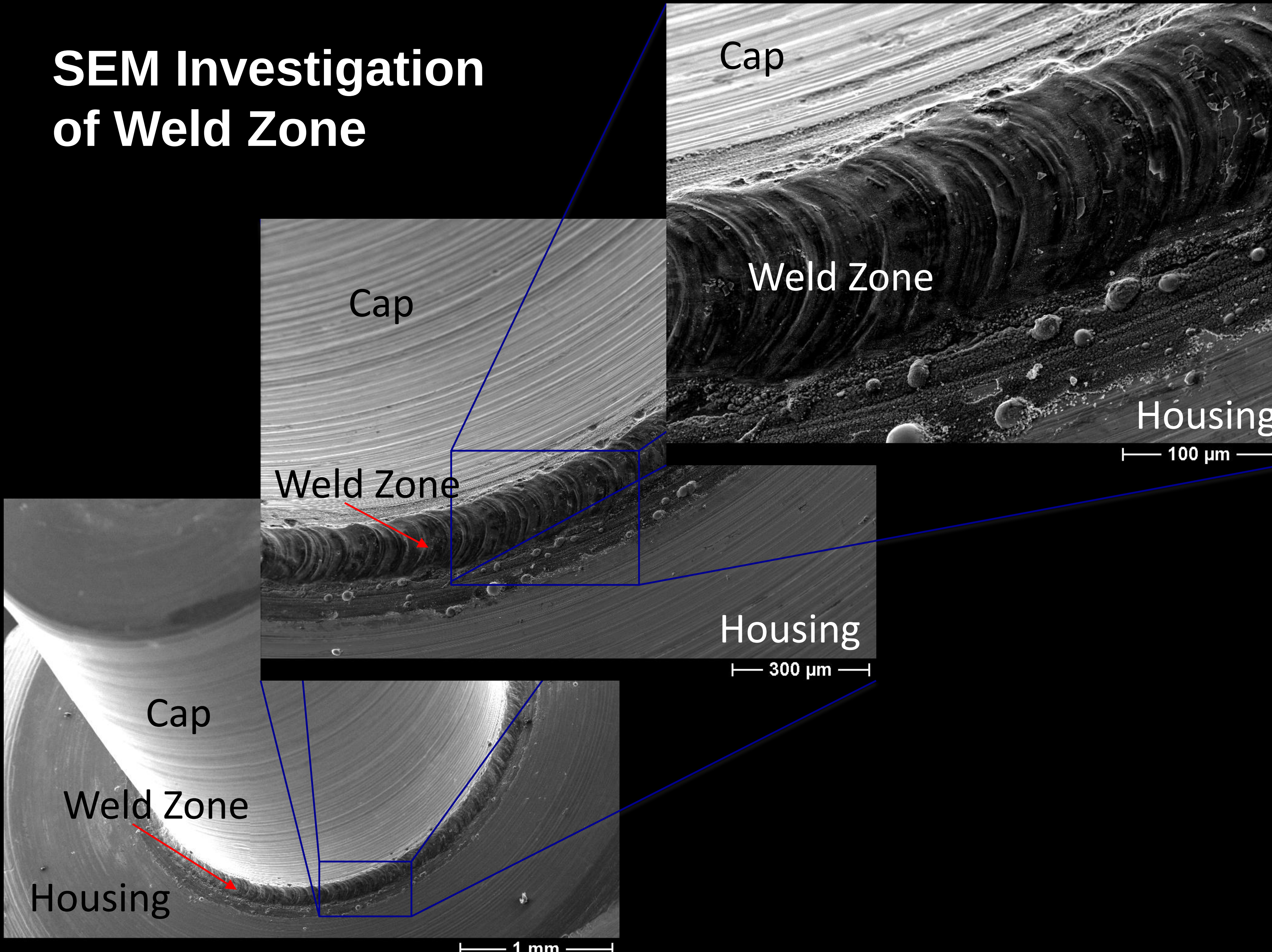








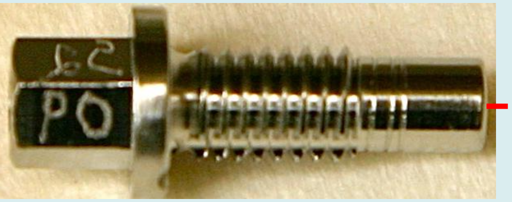
SEM Investigation of Weld Zone



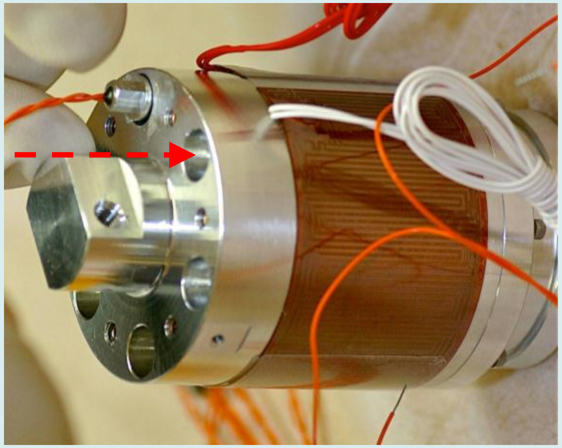
Summary of Phase Change Material Status

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

TEC Configuration

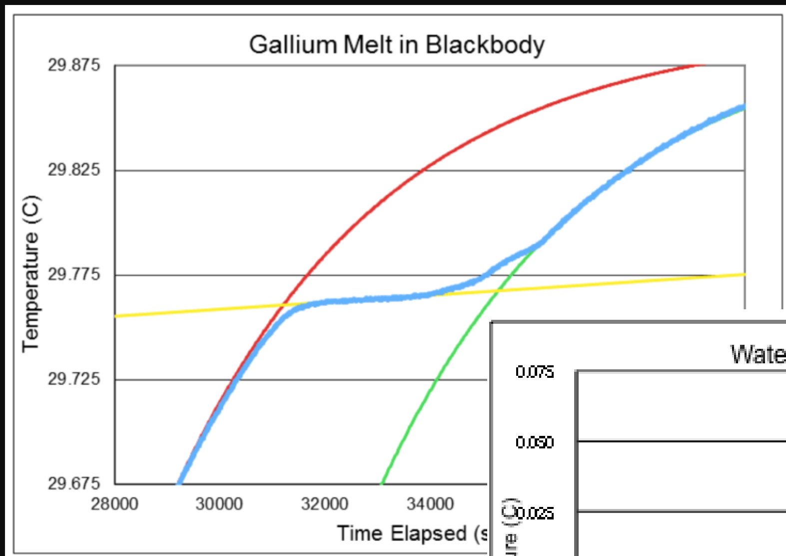


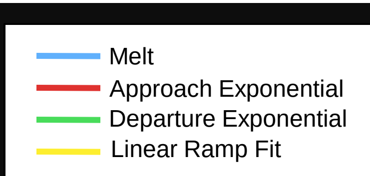
Accelerated Life Configuration

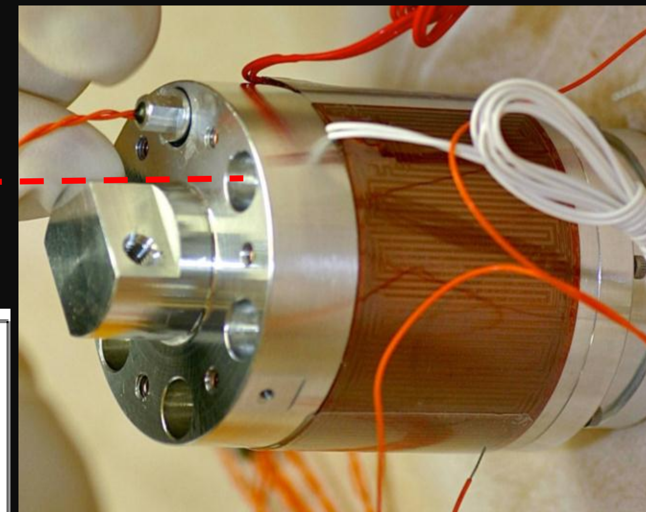


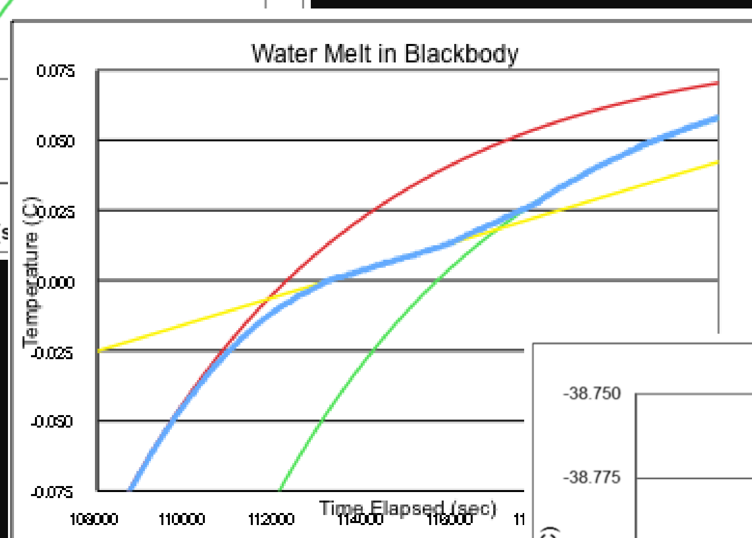
Blackbody Configuration

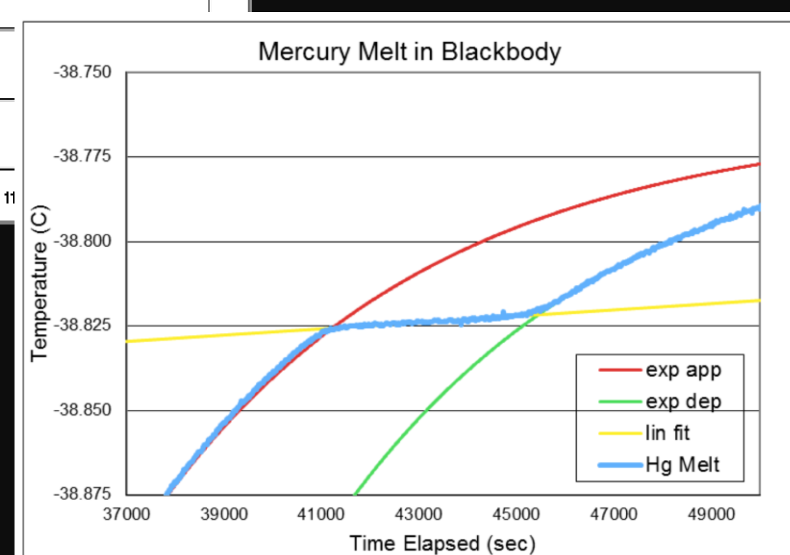
Signatures in Blackbody





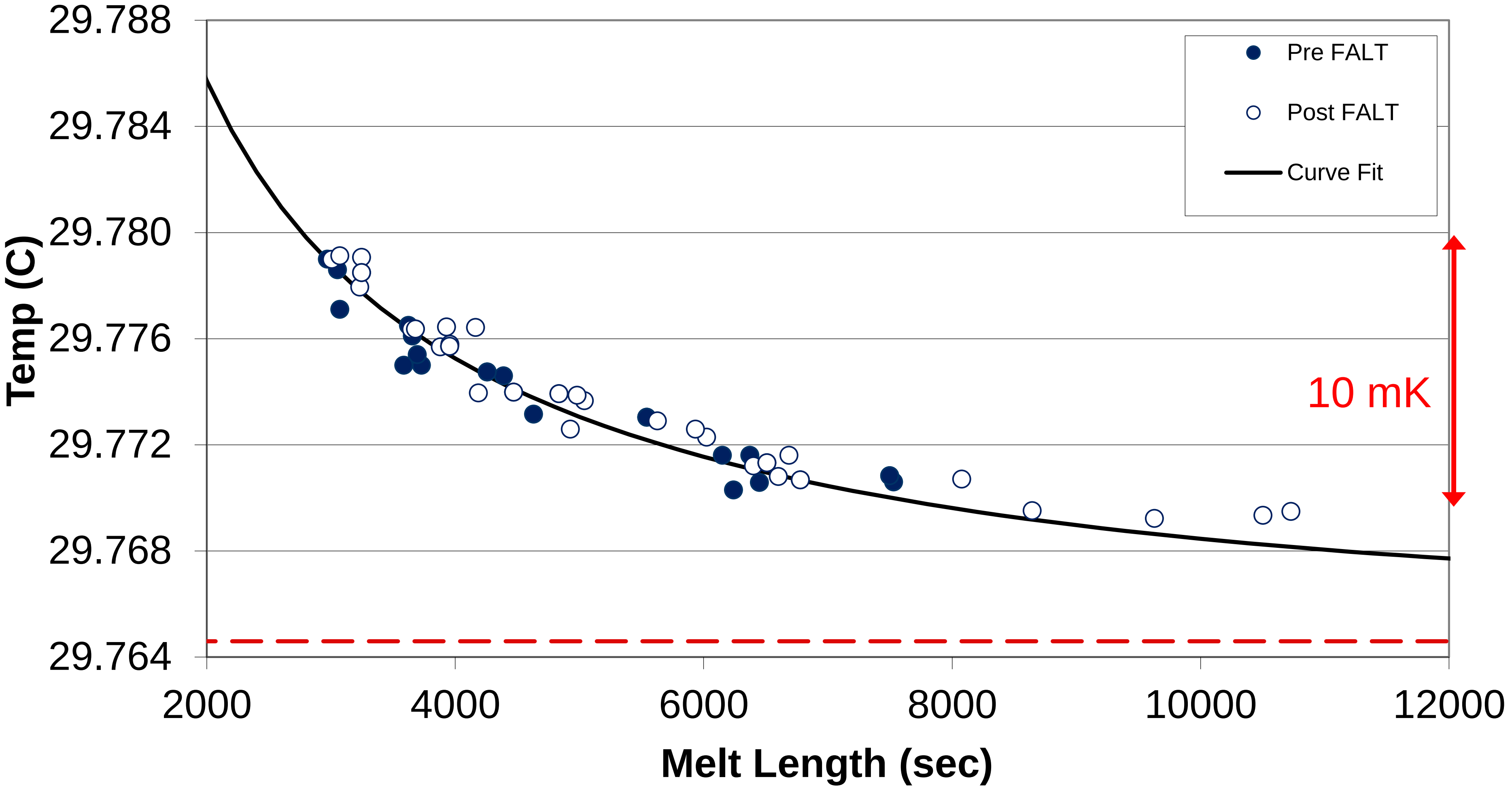






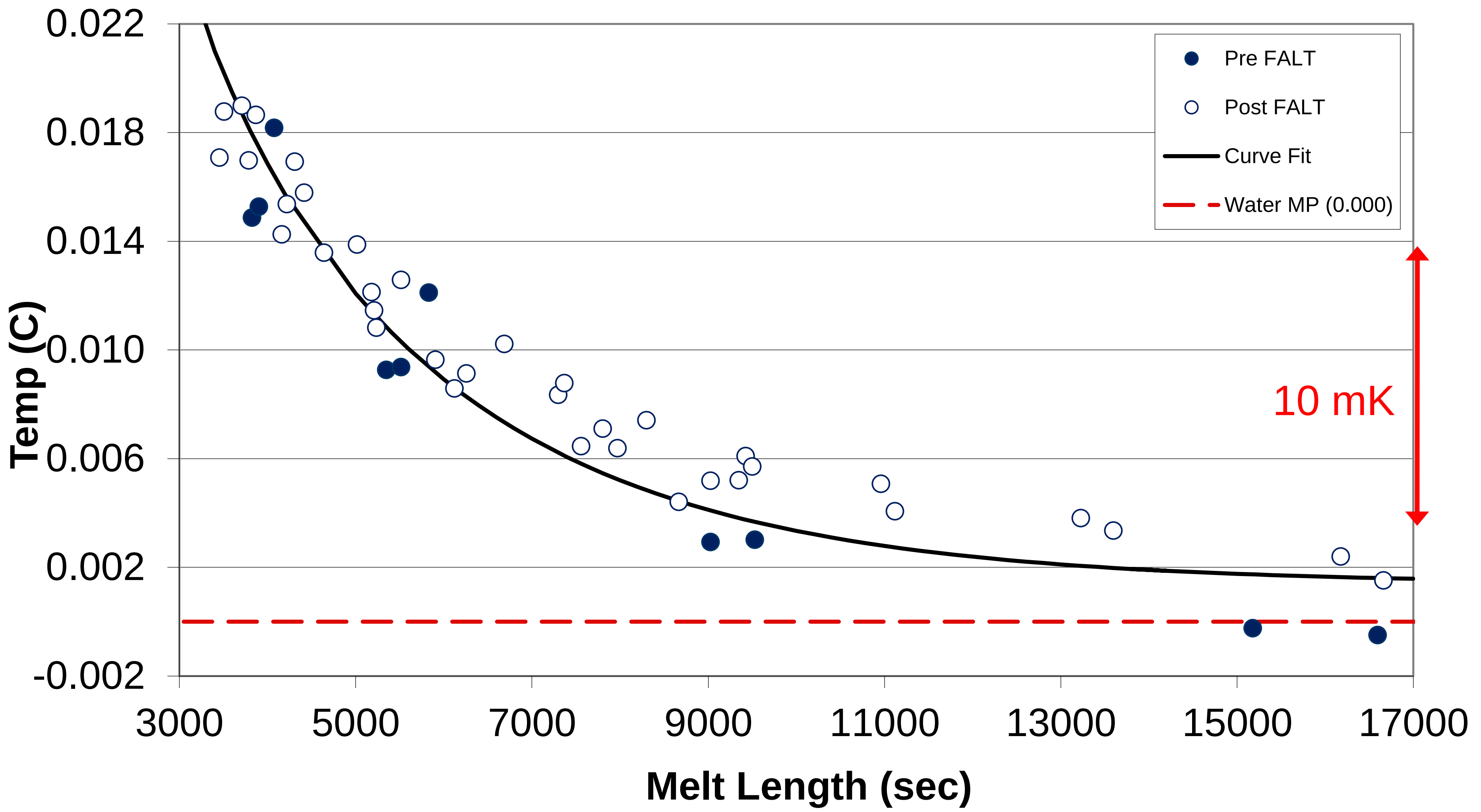
Miniature Phase Change Cells Integrated Into Blackbody and Signatures Obtained

Gallium Mid-Melt Temperature for Various Melt Lengths



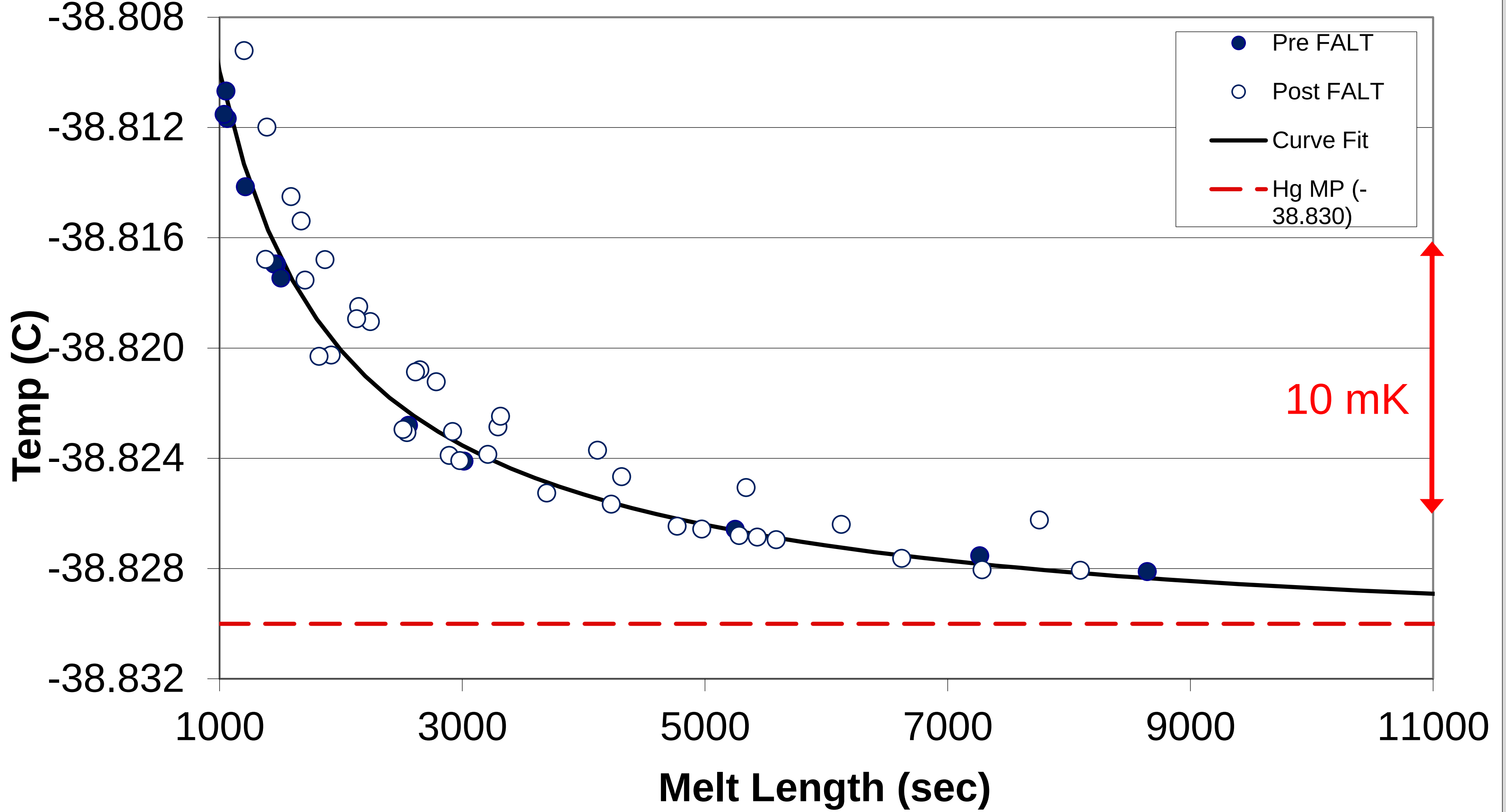
- Data is comprised of six different housings
- Pre and post-FALT, and multiple orientations are included
- Two housings were run upside-down

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

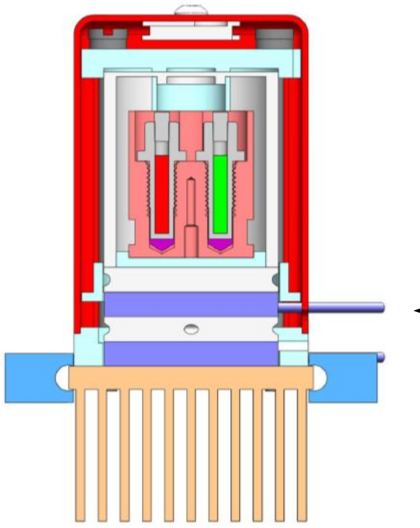


- Data is comprised of four different housings
- Pre and post-FALT and multiple orientations are included
  - Two housings were run on their sides

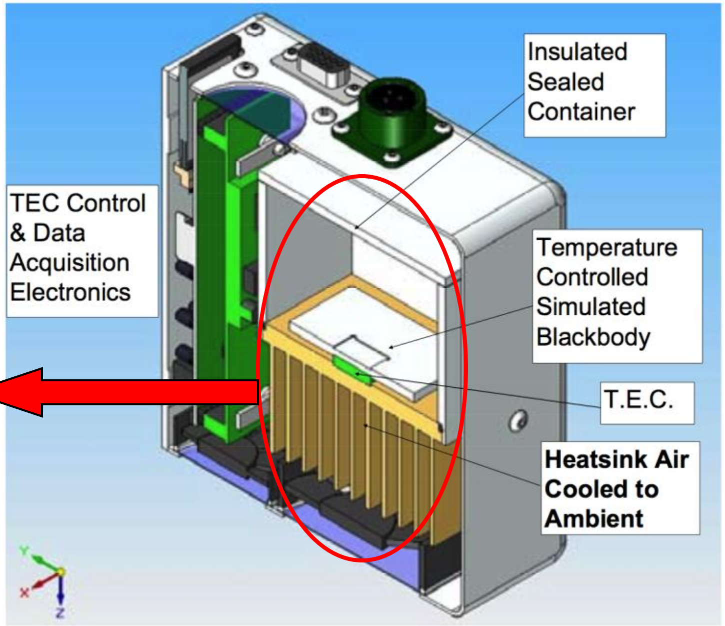
Demonstration in Microgravity

UW-SSEC Phase Change Cell Demo on ISS

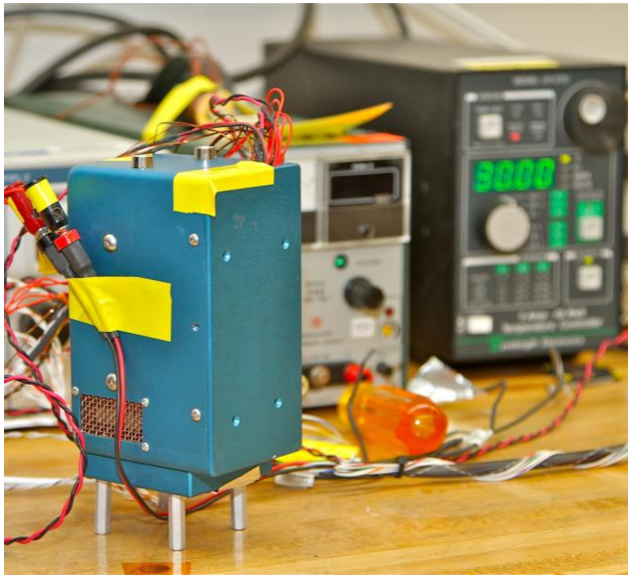
Martin Mlynczak, PI; Shane Topham, SDL Lead



UW-SSEC Multiple Phase Change Experiment



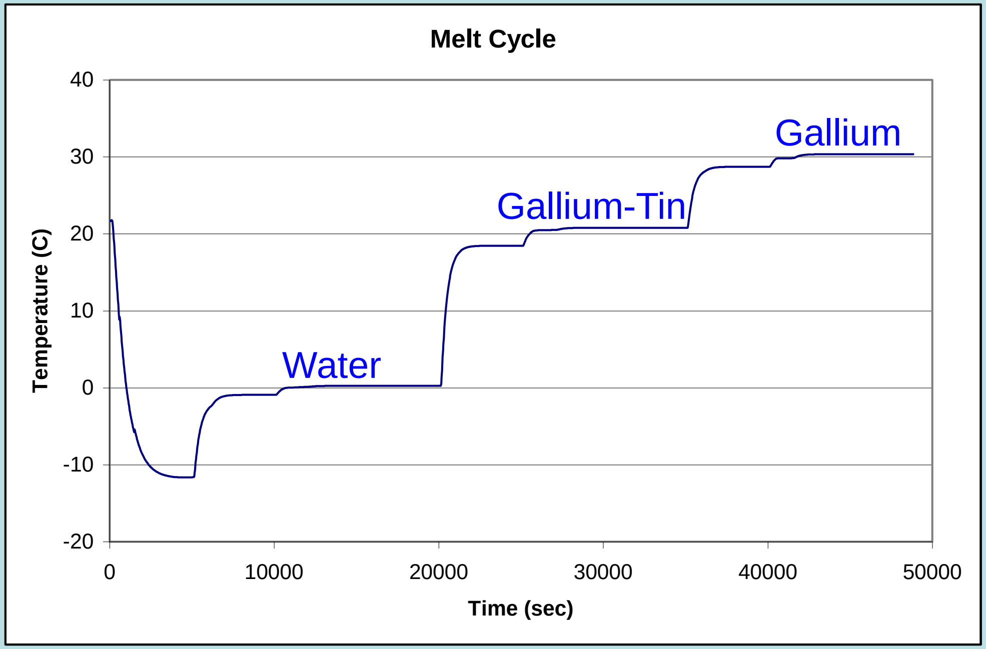
SDL Experiment Support Package

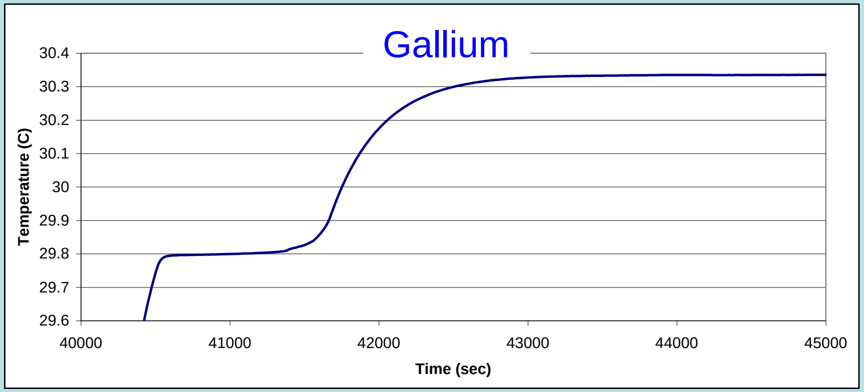


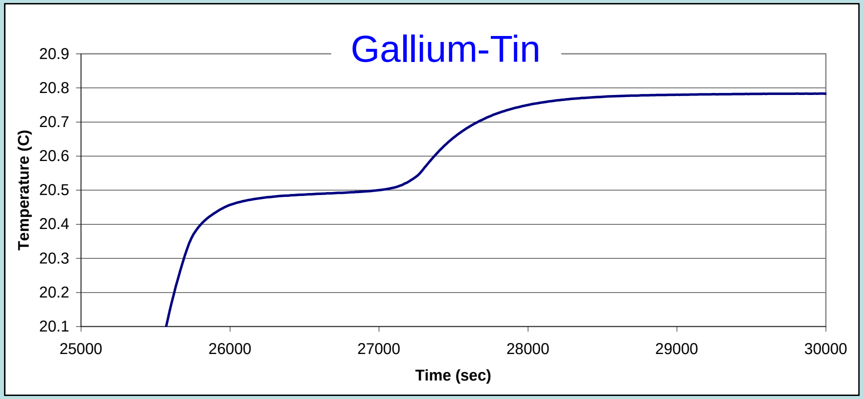
UW Lab Testing

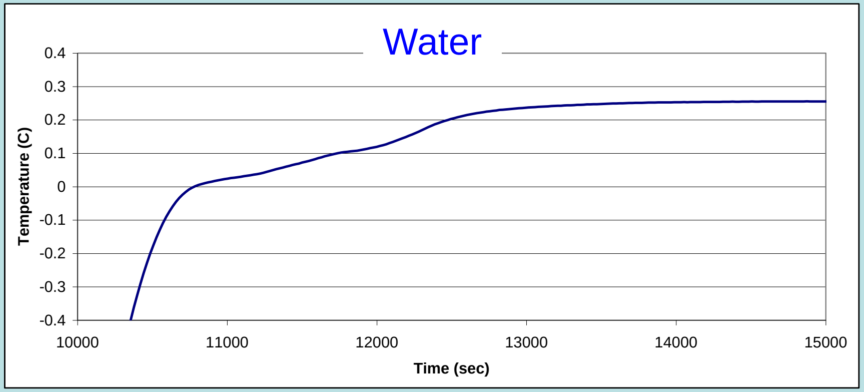
- Utah State Space Dynamics Lab (SDL) has developed an ISS experiment for their single phase change cell demonstration.
- UW is developing a multiple phase change cell with three different phase change materials compatible with SDL hardware (Ga, GaSn, H_2O)
- This will allow validation of this calibration approach in microgravity.

UW-SSEC Phase Change Cell Demo on ISS





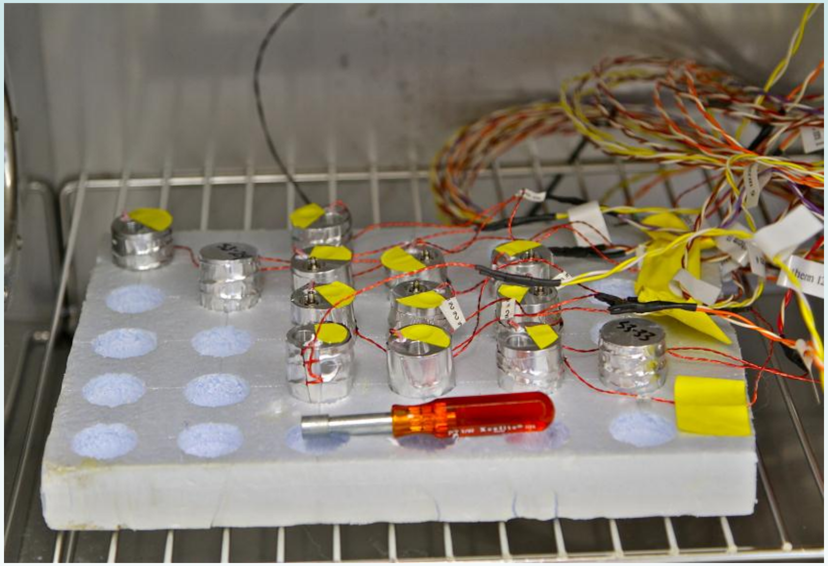


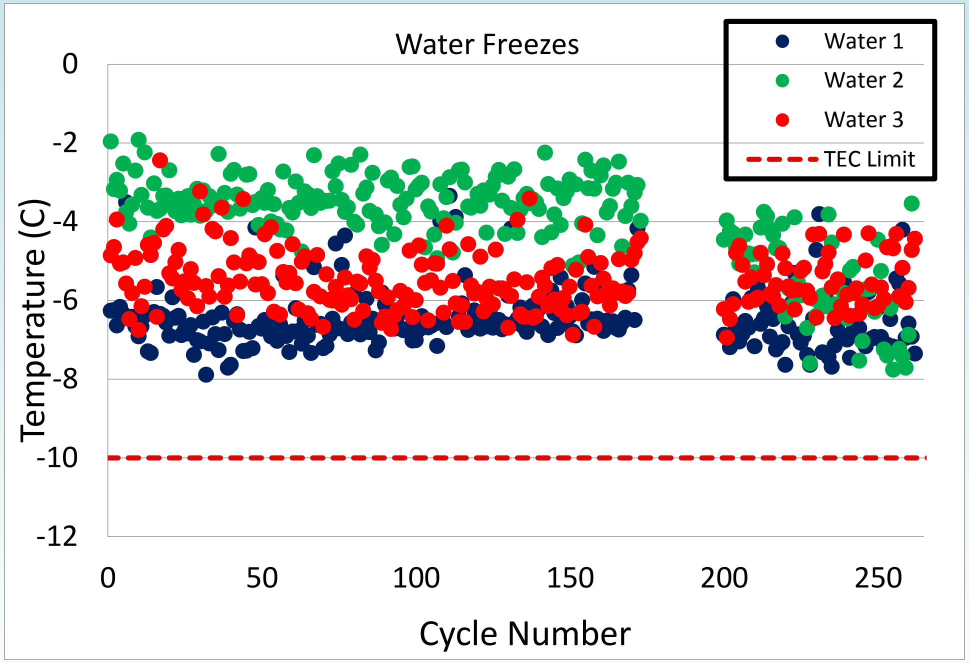


- Completed development of hardware optimized for low temperatures to ensure freezing of supercooling melt materials – improved from -5C to -15C
- Obtained signatures with Water, Ga-In Eutectic, and Ga using UW electronics
- Tested and calibrated using SDL electronics
- End-to-end testing using SDL electronics

Supercooling Statistics

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



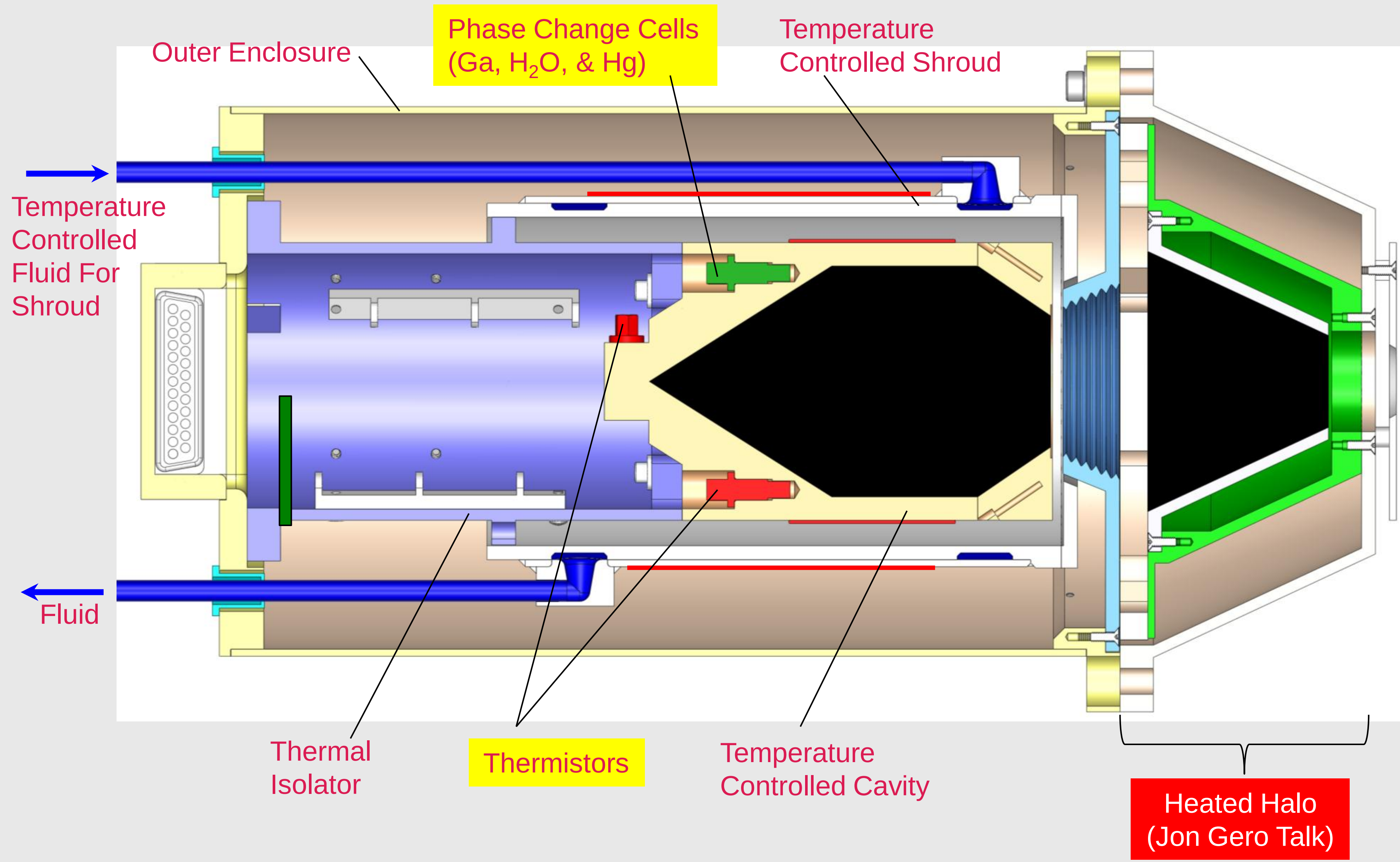


- Water with AgI froze above the TEC limits
- Did not seem to drift over time to lower freezes

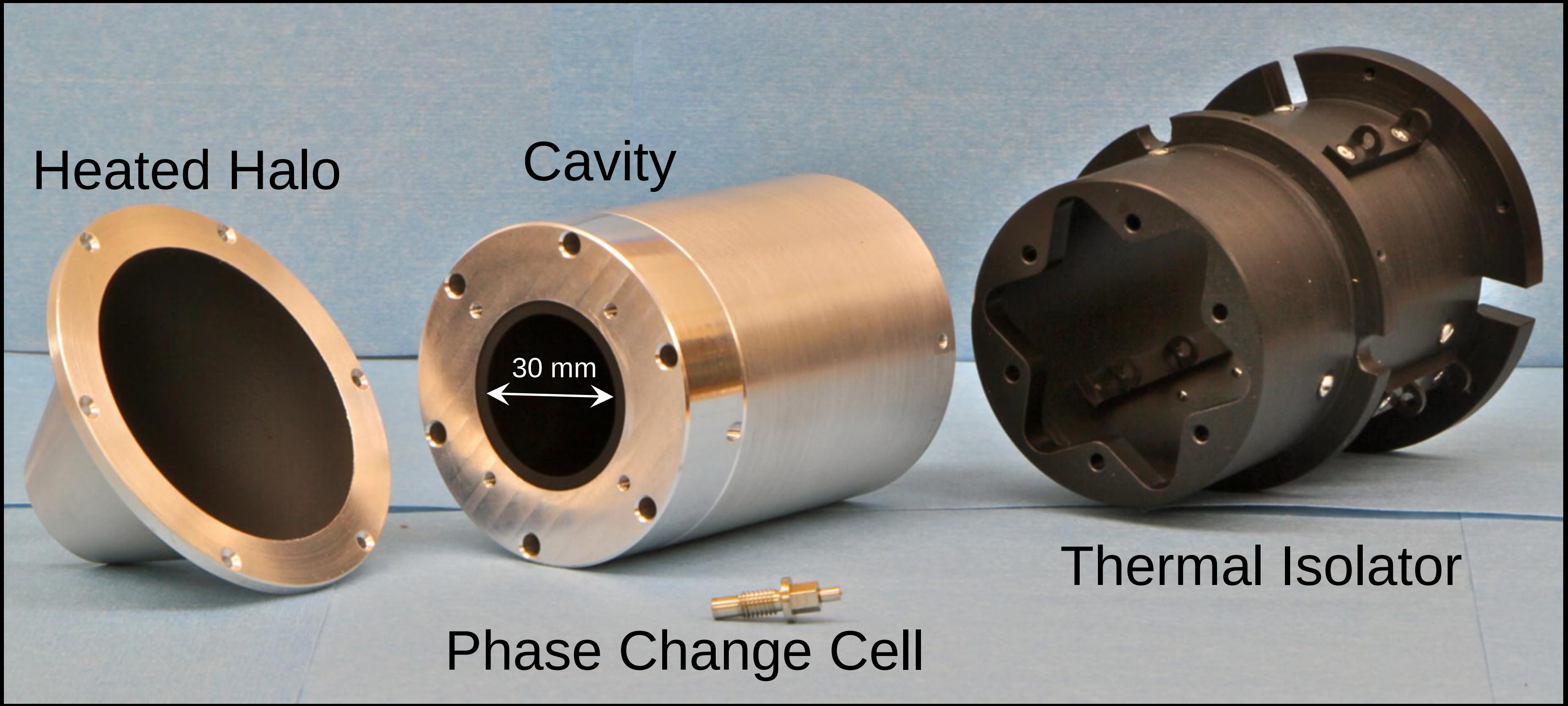
OARS Assembly and Integration to Absolute Radiance Interferometer

OARS Design Based on GIFTS Blackbody

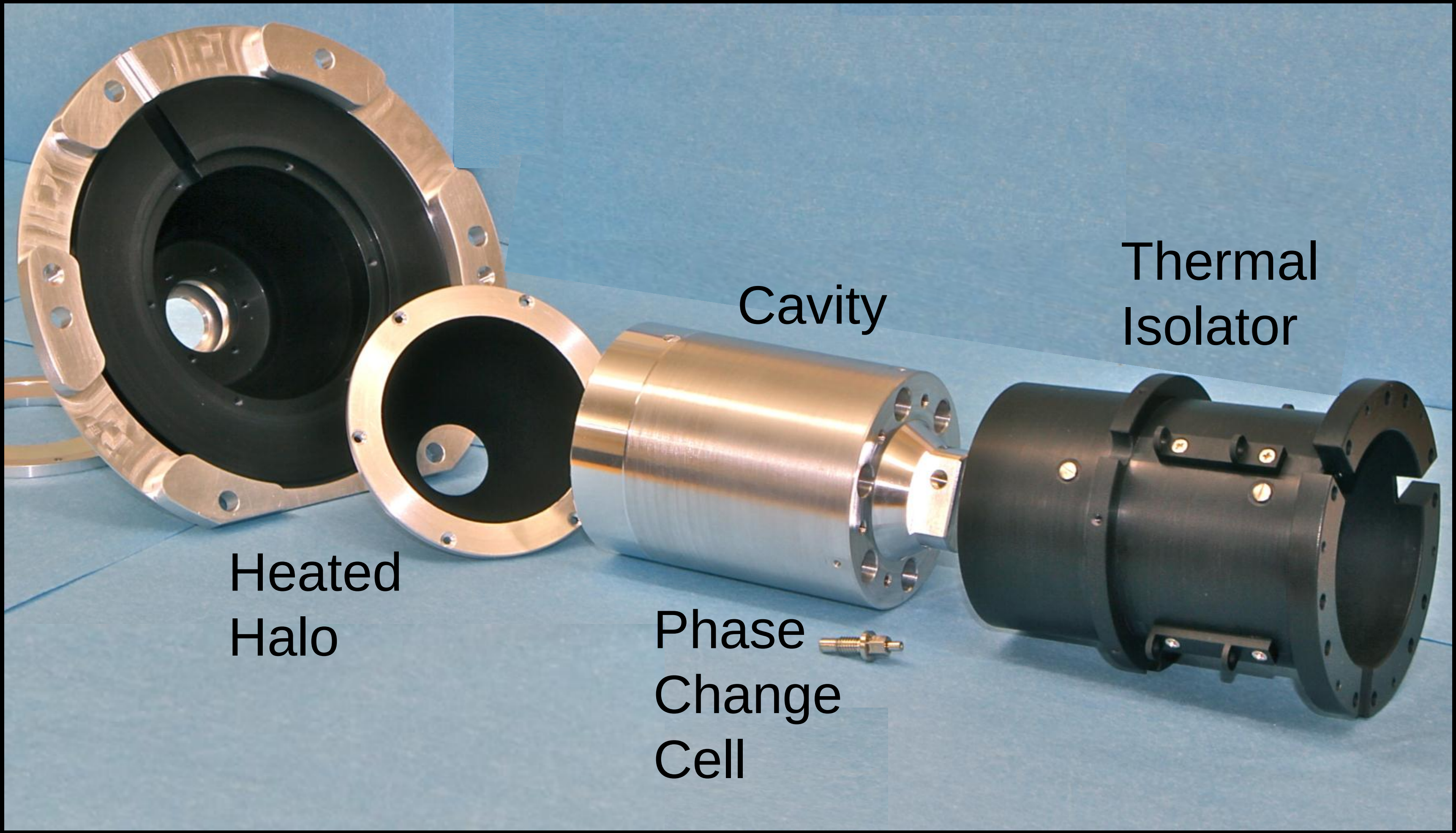
(designed for operation in lab environment)



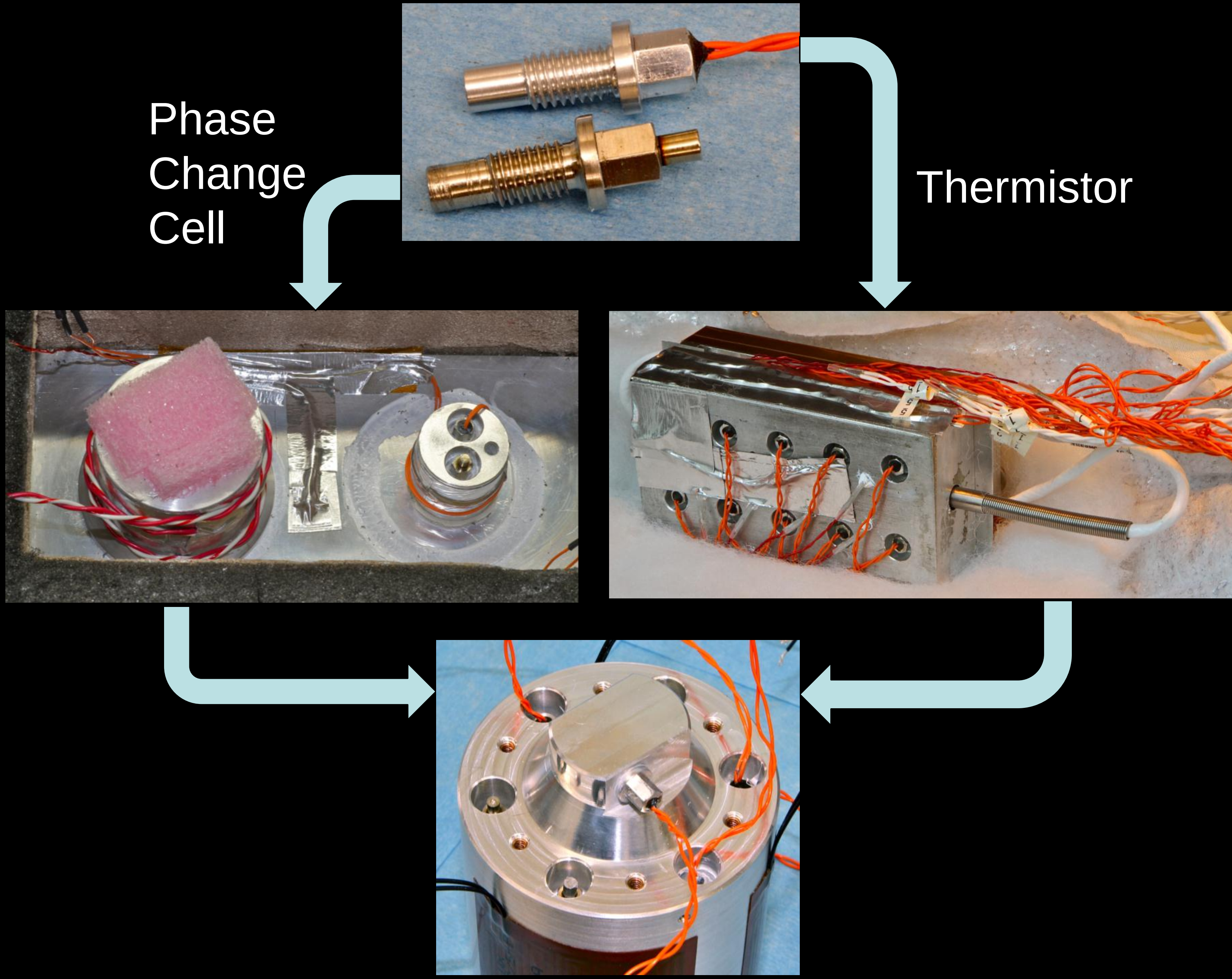
OARS Cavity, Isolator, and Heated Halo



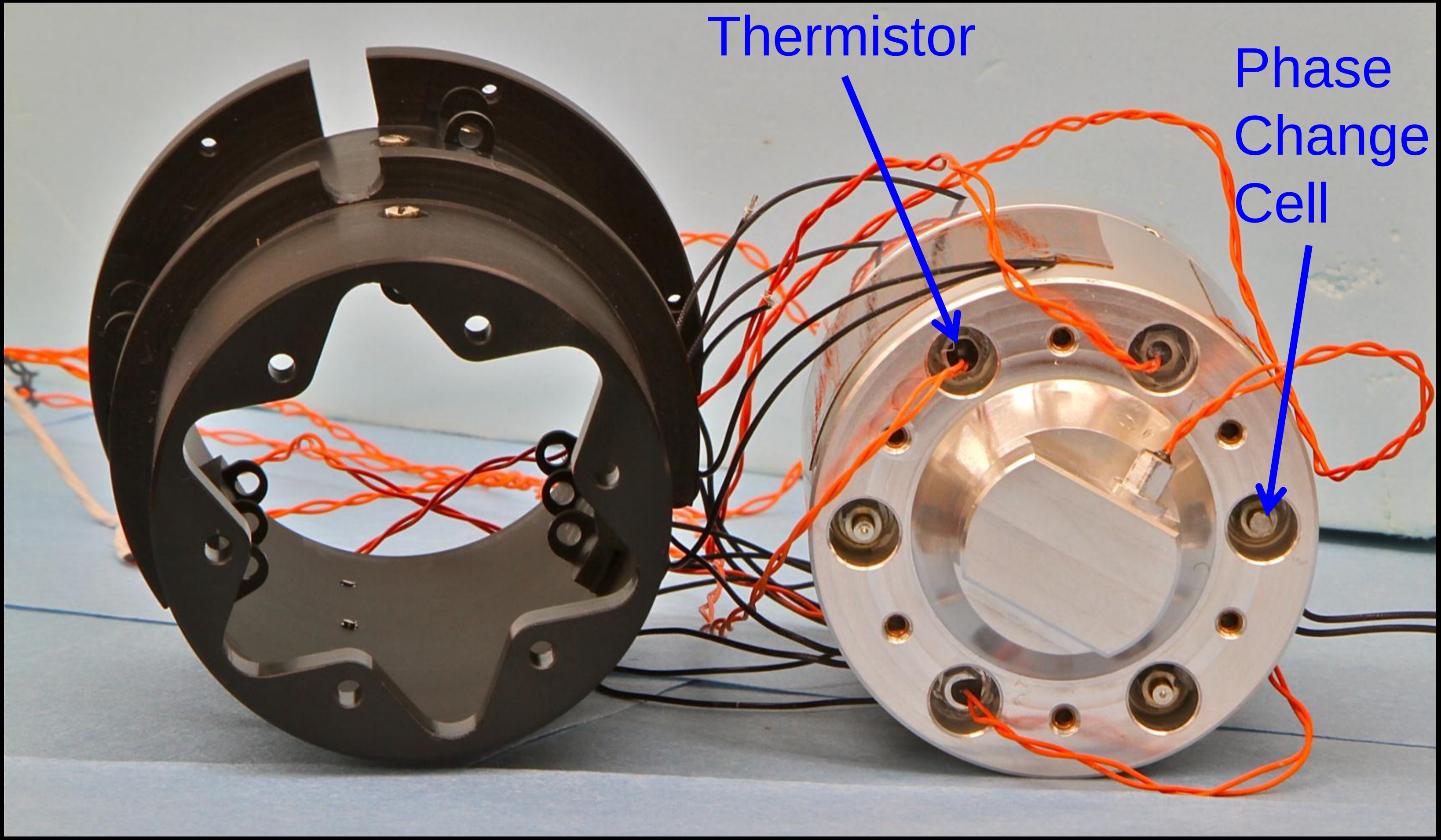
OARS Cavity, Isolator, and Heated Halo



Thermistor Calibration


Phase
Change
Cell
Thermistor

OARS Cavity and Thermal Isolator



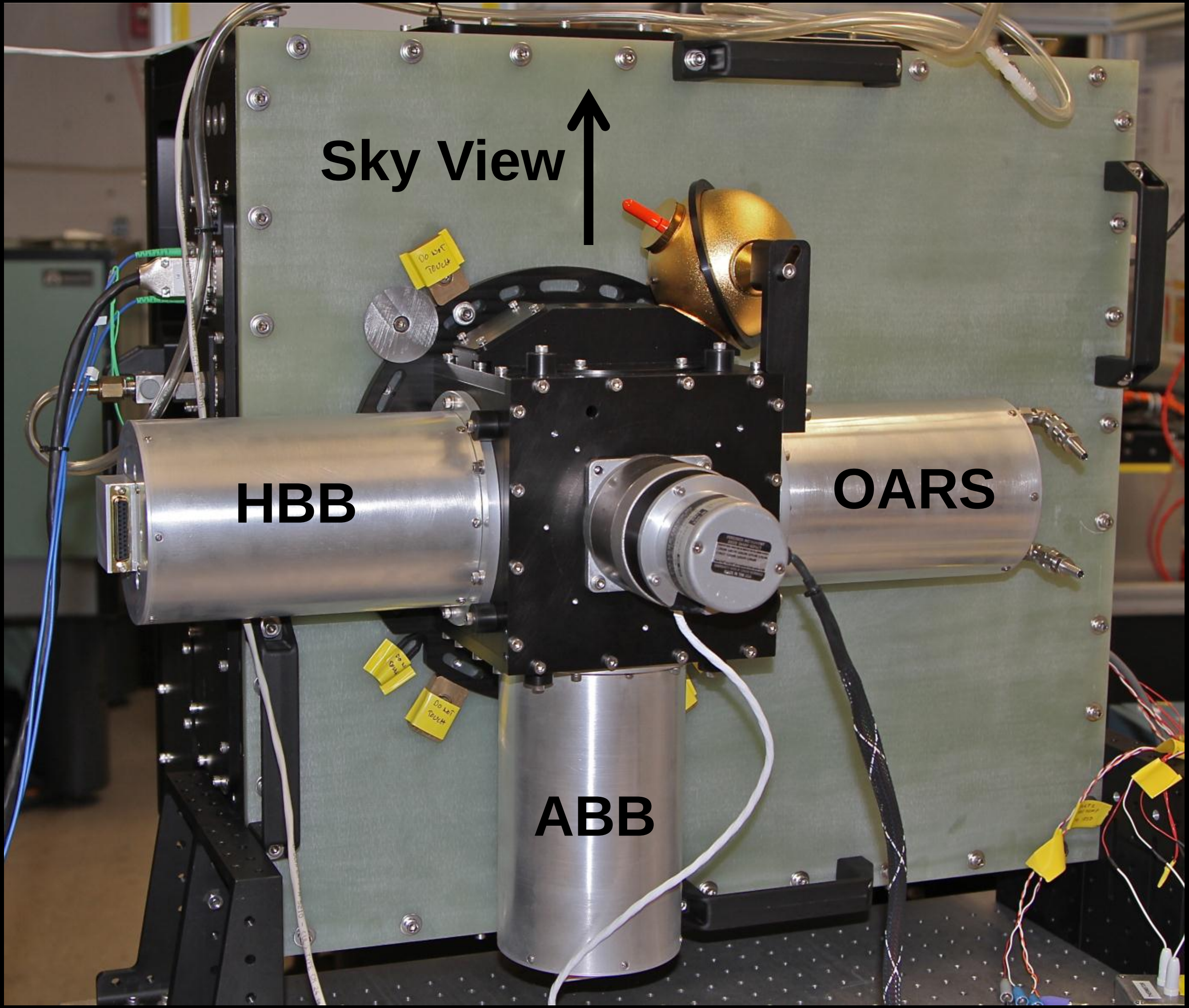
Cavity Thermal Isolator

Looking into Aft Of Cavity

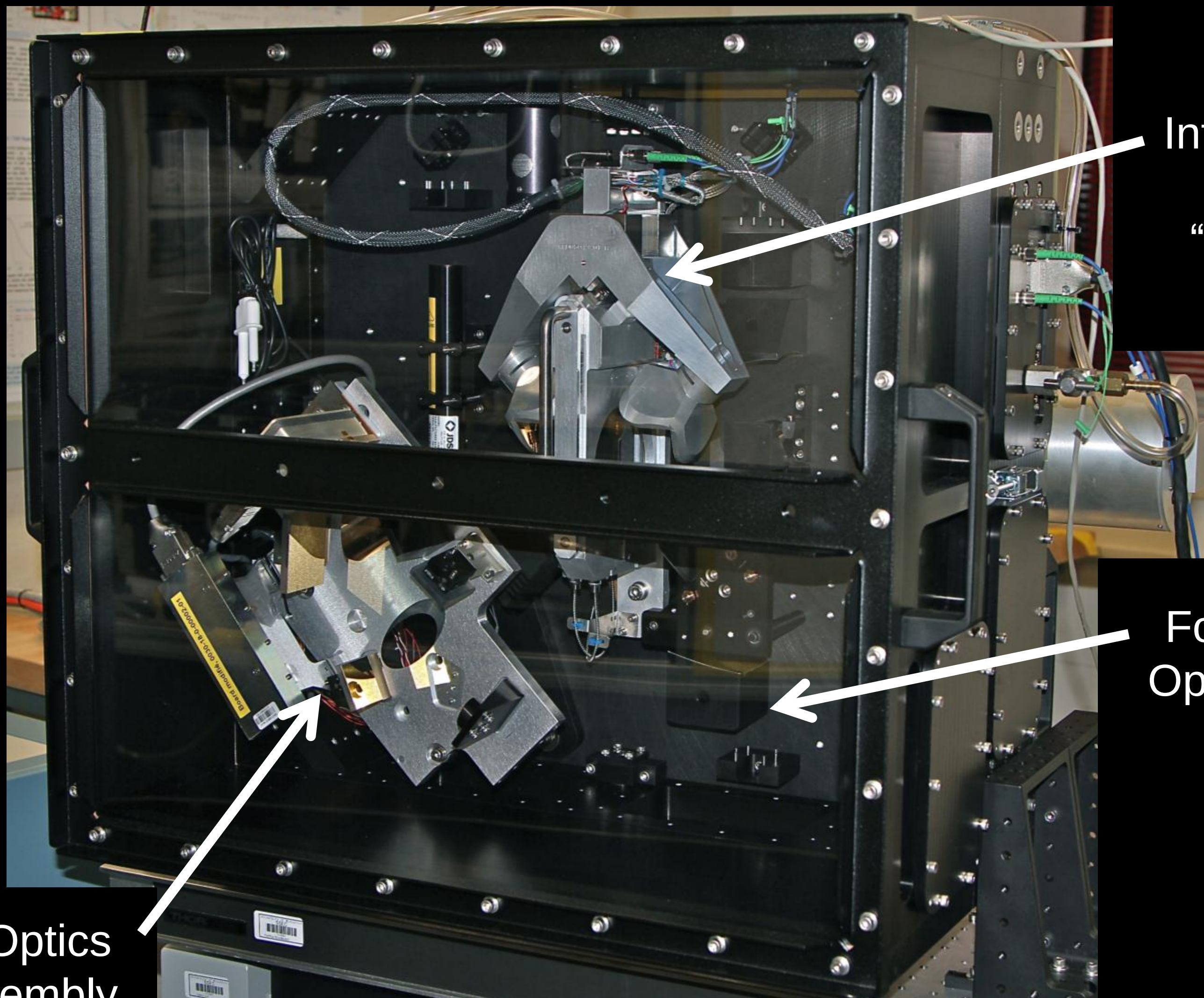
OARS Assembly

Heated Halo & Halo Insulator | Cavity | Inner Shield & Isolator | Outer Case

ARI Breadboard



ARI Breadboard



Conclusions

- Significant progress has been made toward the development of an Absolute Radiance Source that can be used on future IR Remote Sensing Instruments.
- The demanding performance parameters required for a CLARREO type mission are being demonstrated in a relevant environment.
- An upcoming demonstration in the microgravity environment of the ISS will be the last hurdle needed to qualify the design for a flight mission.