

Advanced On-orbit Blackbodies - Paving the Way For CLARREO

SSEC Blackbody Heritage, NIST Connections, & New Developments

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Advanced On-Orbit Blackbodies

Slide 1



Presented as part of the Anderson CLARREO Team Vision

Addressing Technical Readiness



Topics

- **CLARREO Perspective, an Introduction**
- **SSEC Blackbody Heritage & the NIST Connection**
- **GIFTS Blackbody**
- **CLARREO Blackbody – New concepts for absolute calibration on orbit**
 - Phase Change Temperature Standard
 - Emissivity Measurements



CLARREO Perspective an Introduction

**It is time to apply spectrally resolved IR radiances
as a new paradigm for observing climate change**

**High spectral resolution has been successfully
demonstrated over the last 20 years, setting the stage**

Aircraft—HIS/Scanning HIS(1985/1998-), ARIES(1996-),
NAST-I(1998-), INTESA(1998-)

Ground-based—AERI/MAERI(1990-)

Spaceborne—*IR Sounders*: AIRS(2002-), IASI(2006-), CrIS(2009)
Very High Res: IMG(1996/97), MIPAS(2002-), ACE(2003-),
TES(2004-)



A Key for high absolute accuracy is coupling superior references with high spectral resolution

- There is a fundamental calibration advantage to separating the spectral domain into many small pieces that are each calibrated (Goody and Haskins, 1998)
- Many IR instrument uncertainties are traceable to spectral uncertainties or instrument-to-instrument differences (e.g. filter radiometers)
- High spectral resolution allows the atmosphere itself to be used as a highly accurate spectral reference



Rationale for the Fourier Transform Spectrometer choice for simple, inexpensive CLARREO instrument

- **Very broad spectral coverage:** Can be achieved from each single detector, leading to a very simple optical and detector configuration
- **Highly reproducible spectral scale from instrument-to-instrument:** Requires Nyquist sampling, naturally provided by FTS
- **Spectral Instrument line shape (ILS) Stability:** Controlled by integrated on-orbit laser-based metrology system and insensitive to geometry, greatly simplifying thermal design (no need for precise thermal control)
- **ILS knowledge:** The ILS for uniform scenes* is established by a small set of wavelength independent parameters and is testable on-orbit (AIRS ILS functions for each channel were determined with an FTS in T/V testing)



CLARREO Mission Requirements

Form outline of the rest of the talk

- **Pre-launch Calibration/Validation:**
Characterization against NIST primary infrared standards and evaluation of flight blackbodies with NIST facilities
- **On-orbit Calibration:**
Onboard warm blackbody reference (~300K), with phase change temperature calibration, plus space view
- **Validation, On-orbit:**
On-orbit, variable-temperature standard blackbody, referenced to absolute physical standards

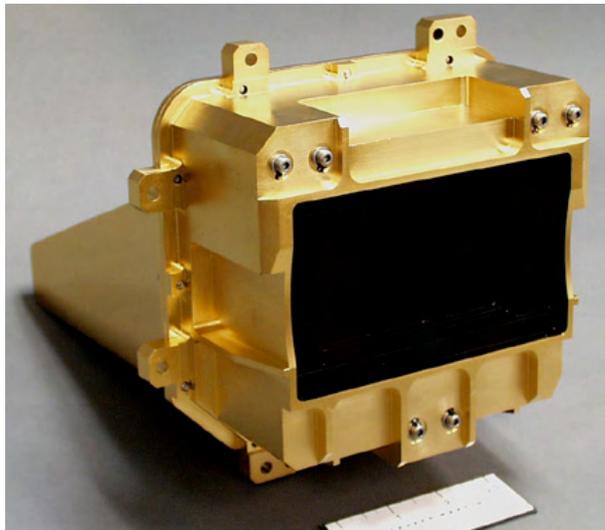


AIRS, IASI, CrIS Cavity Blackbodies represent a big step in the right direction

AIRS (JPL/ABB Bomem)

$\epsilon > 0.999$

Tcalibration 50 mK



IASI (Cnes/Alcatel-Alenia Space)

$\epsilon > 0.996$; Tstability 50 mK



CrIS (ITT)

$\epsilon > 0.995$;

$\delta T < 80$ mK



But they don't go all the way for climate: Extremely high Accuracy, plus on-orbit verification are key for CLARREO

UW SSEC Blackbody Heritage and Connections to NIST



SSEC Blackbody Heritage & Ties to NIST

Ground-based



AERI

High-altitude Aircraft



S-HIS

Spaceflight



GIFTS

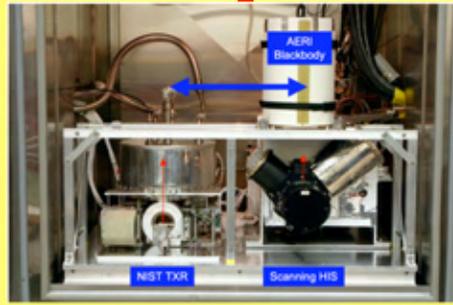
NIST
Waterbath
Blackbody



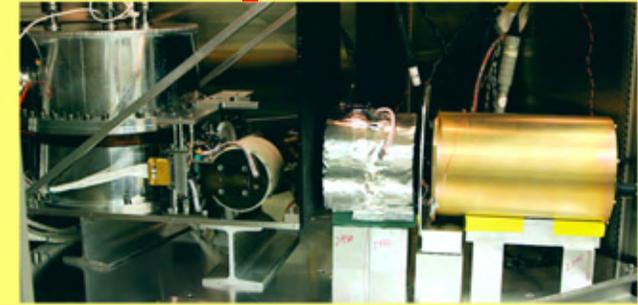
NIST
TXR



< 0.06 K error (293 to 333 K)



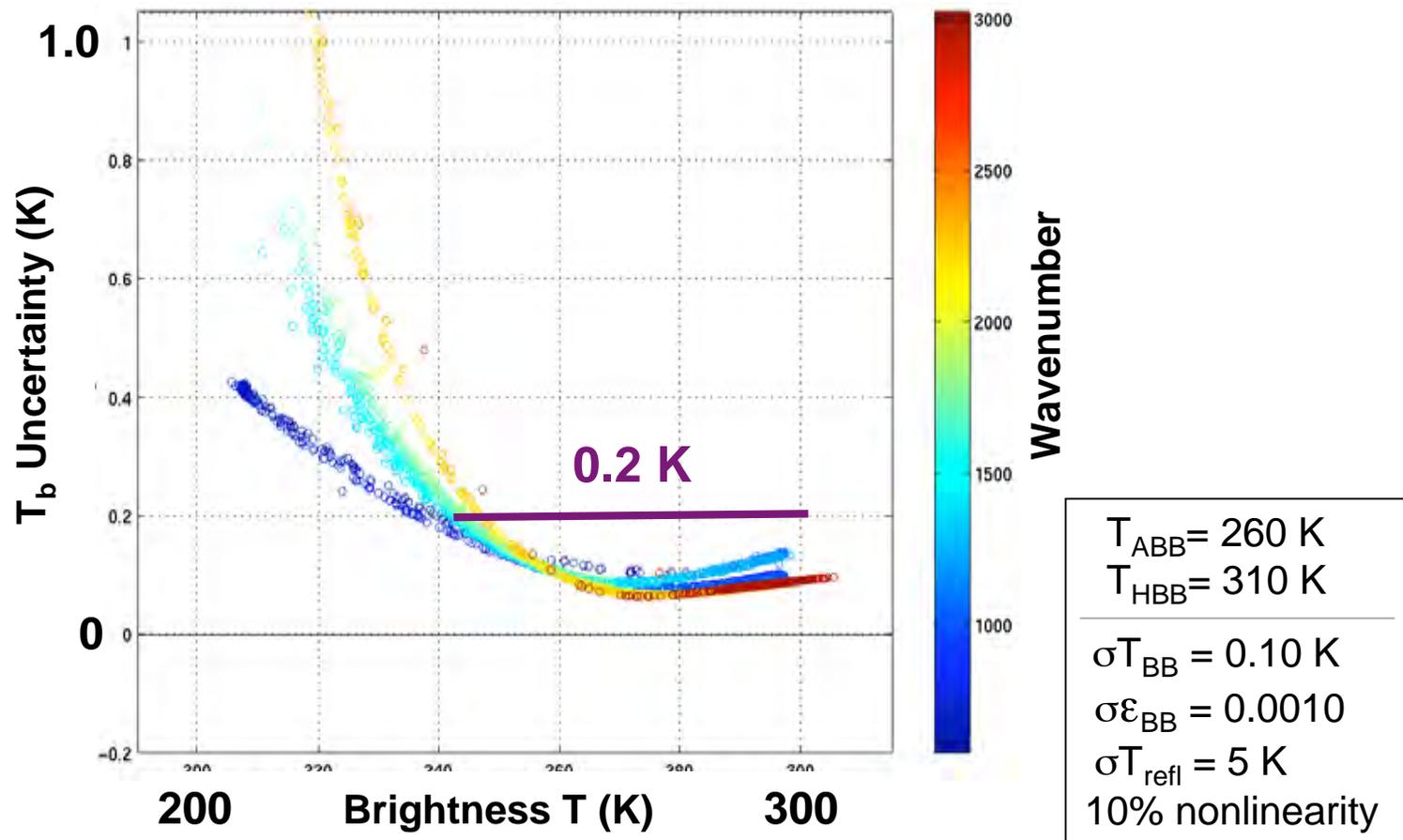
< 0.06 K error (220 to 333 K)



$\epsilon > 0.9994$ (within estimated uncertainty)

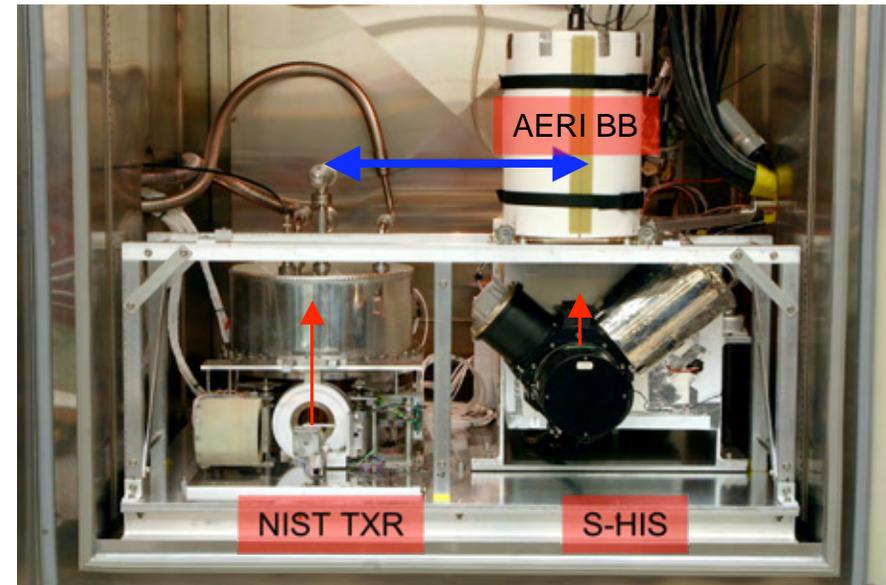
S-HIS Absolute Radiometric Uncertainty for typical Earth scene spectrum

****Formal 3-sigma absolute uncertainties, similar to that detailed for AERI in Best et al. CALCON 2003**

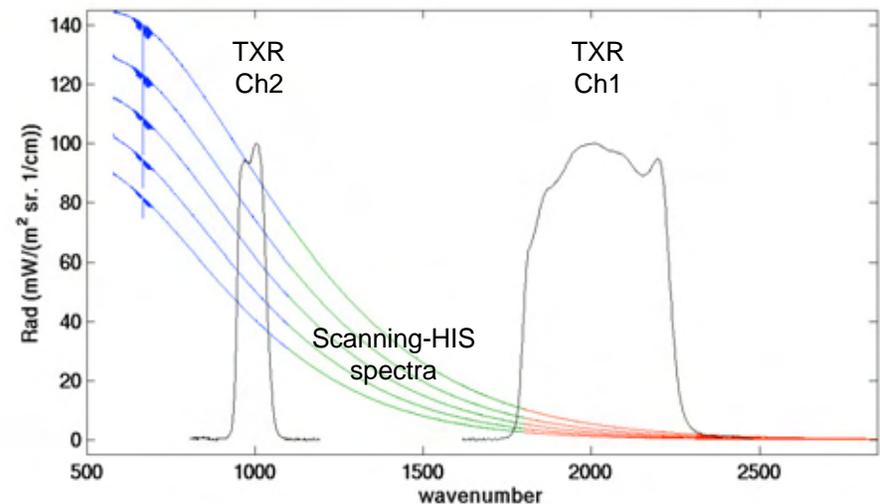
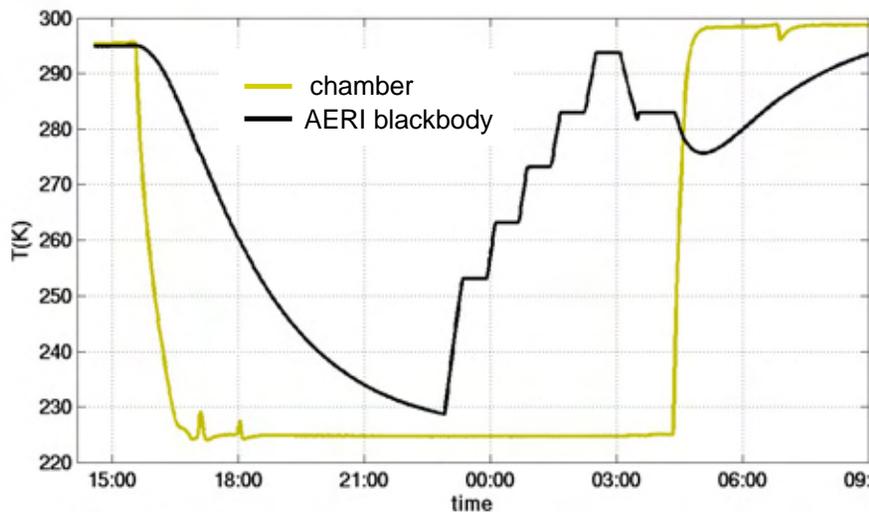


NIST TXR tests of Scanning HIS Radiance Calibration & AERI Blackbody Radiance Knowledge

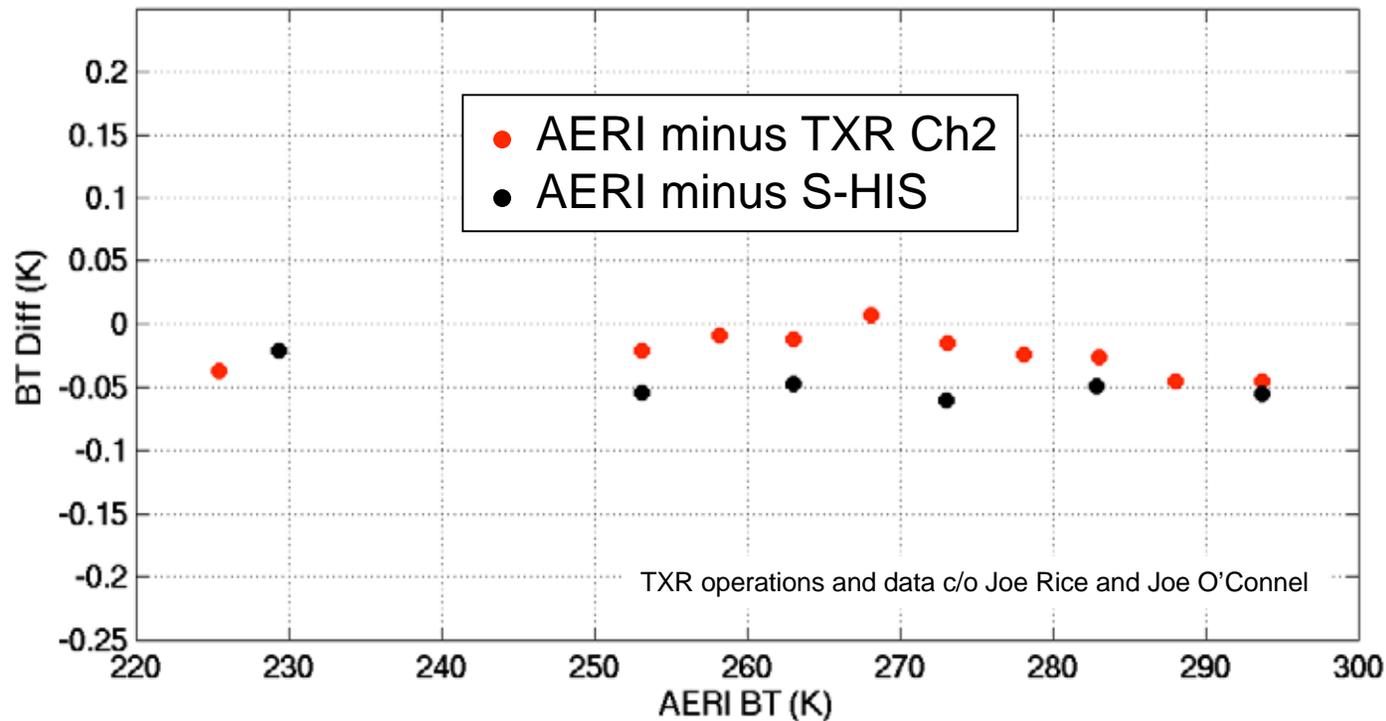
Plan: perform **periodic end-to-end radiance evaluations** under flight-like conditions with NIST transfer sensors such that satellite validation analyses are traceable to the NIST radiance scale



January 2007, testing at UW/SSEC



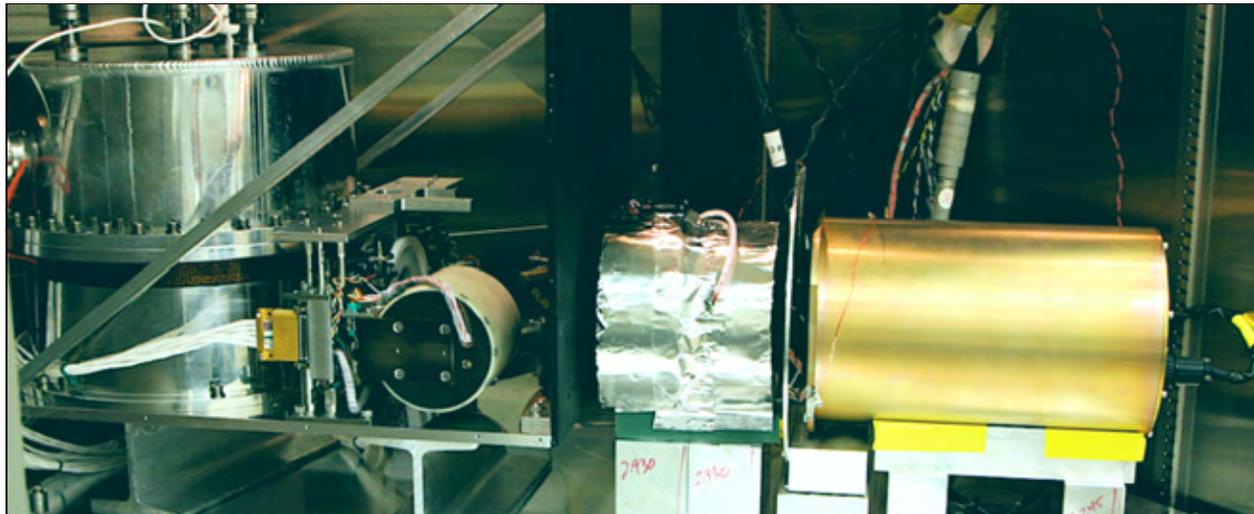
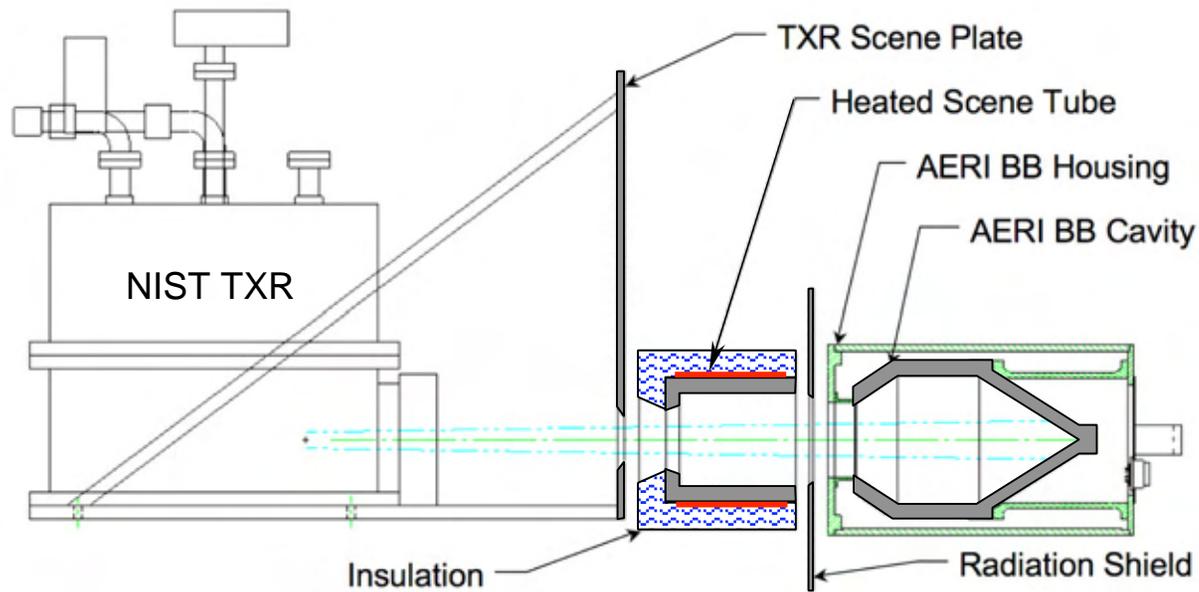
UW-SSEC/NIST 10 μm results from January 2007



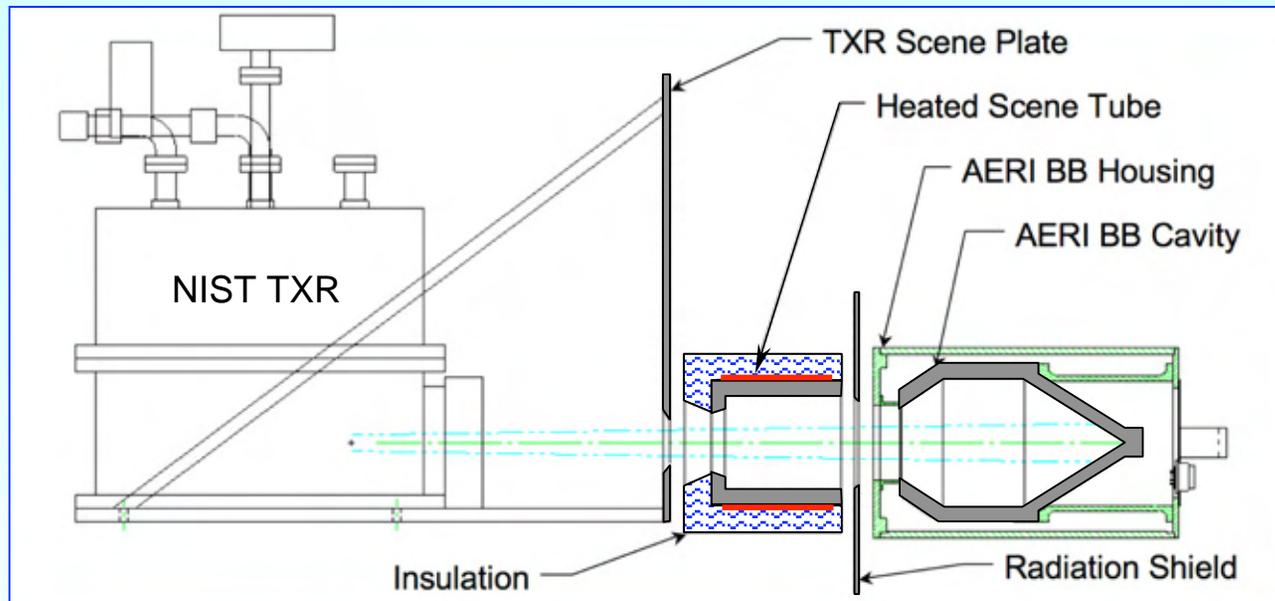
- mean agreement between TXR and S-HIS of ~ 30 mK, well less than propagated 3-sigma uncertainties
- TXR uncertainty (at this stage of processing) is ~ 0.2 K
- larger mean diffs (~ 0.15 K) in Ch1 under investigation



AERI Blackbody Reflectance Test with NIST TXR



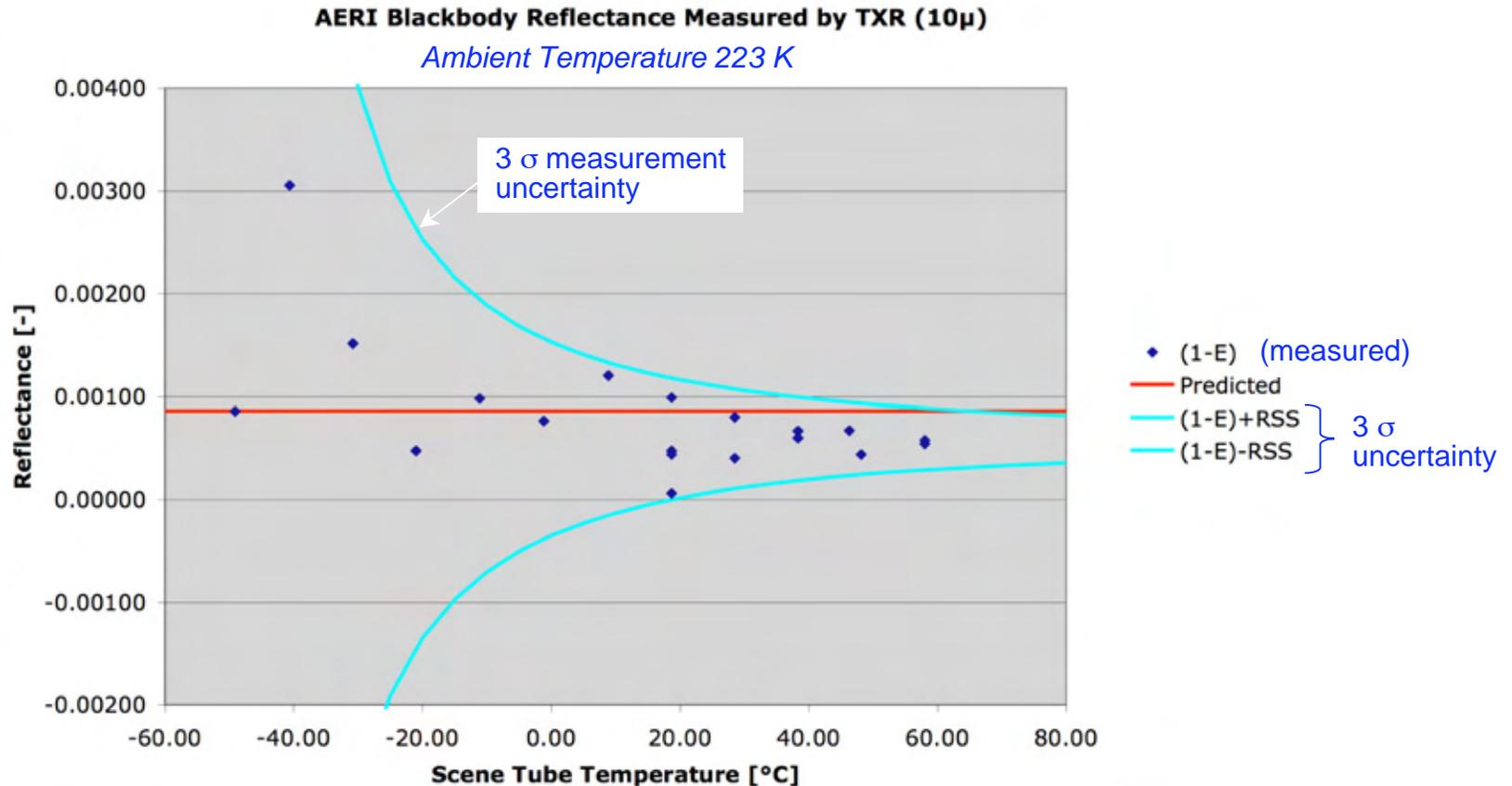
AERI Blackbody Reflectance Test



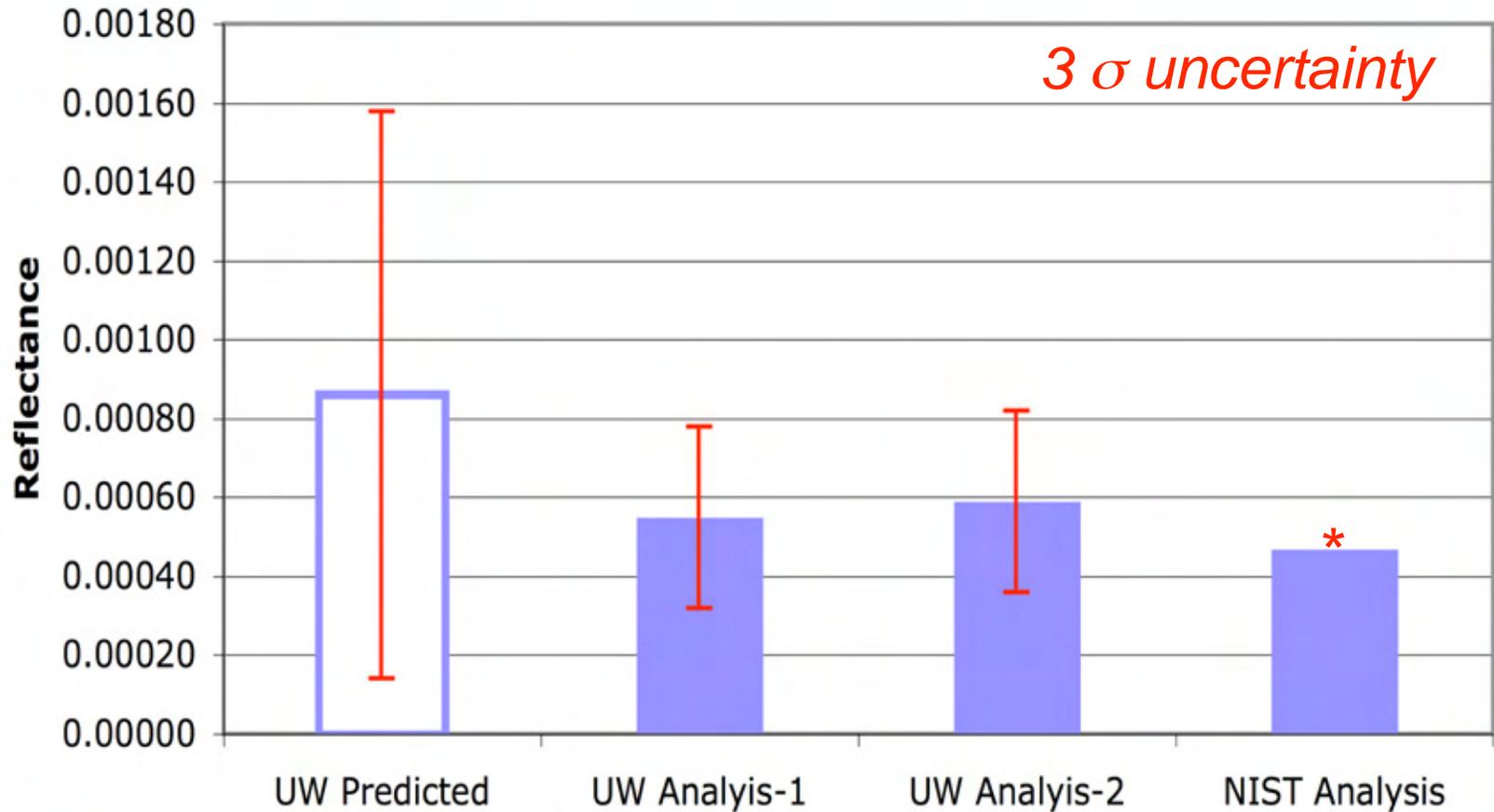
$$M_{txr} = \underbrace{\varepsilon \cdot B(T_{bb})}_{\text{direct radiance from BB}} + (1 - \varepsilon) \cdot \underbrace{[F \cdot B(T_{tube}) + (1 - F) \cdot B(T_{bg})]}_{\text{reflected radiance from BB}}$$

Plan to apply on-orbit for CLARREO

AERI BB 10 μm Reflectance Analysis



AERI BB 10 μm Reflectance Results



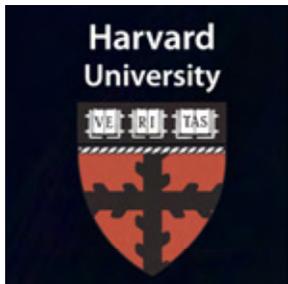
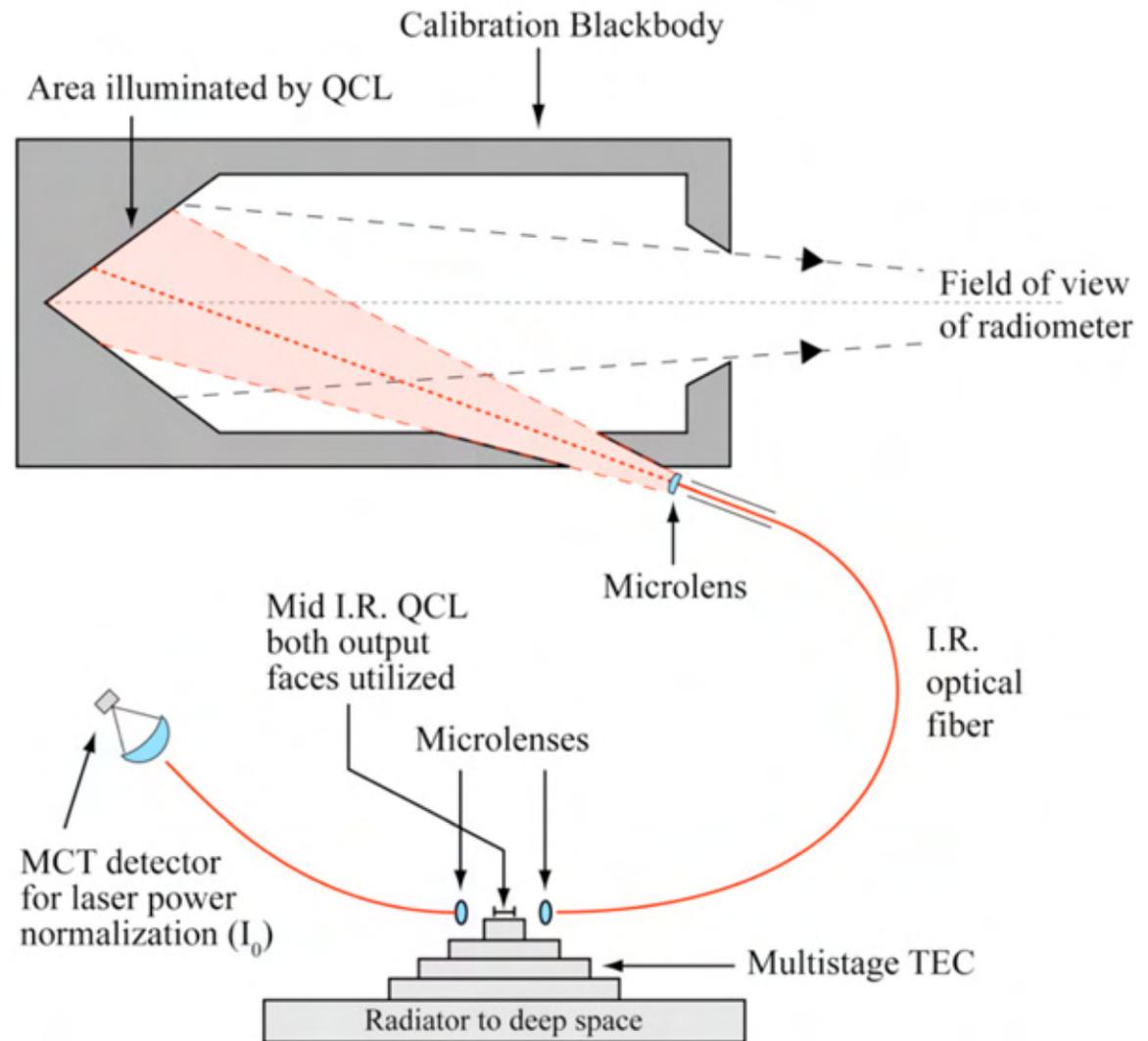
*NIST analysis still being conducted

Updated July 07



On-Orbit BB Reflectance and ILS test

Quantum Cascade Laser source used for both tests—
Separate MCT used to monitor laser power



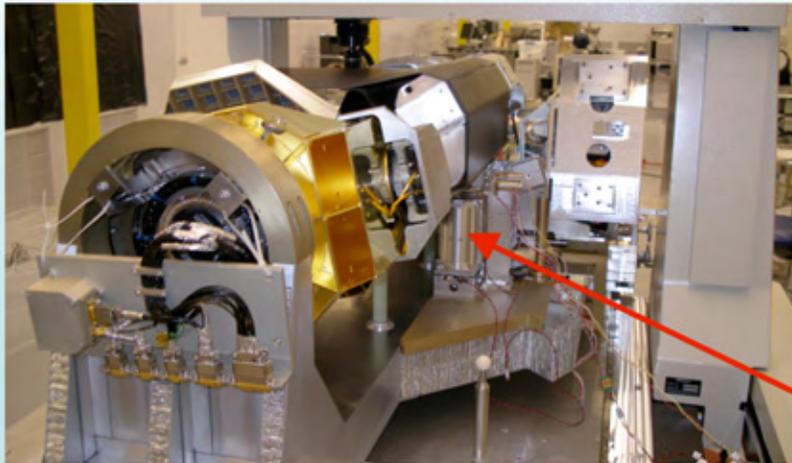
GIFTS Blackbody



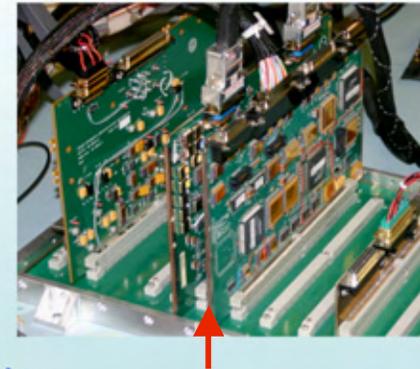
UW-SSEC Developed GIFTS EDU Blackbody

Performance Significantly Exceeds Specifications

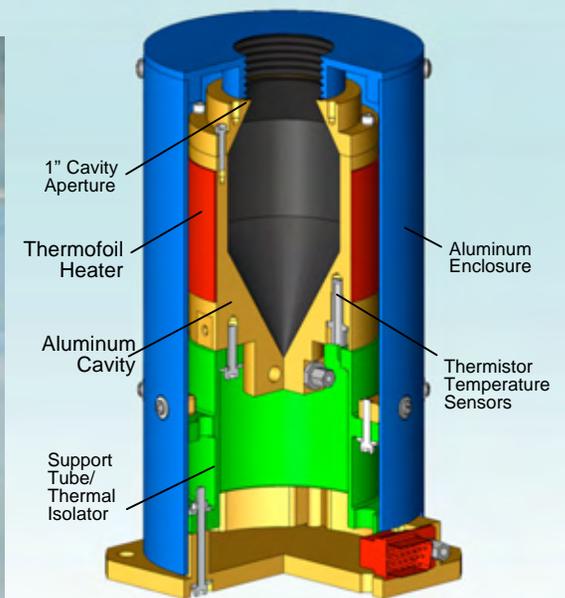
GIFTS Engineering Development Unit



Blackbody Controller Card



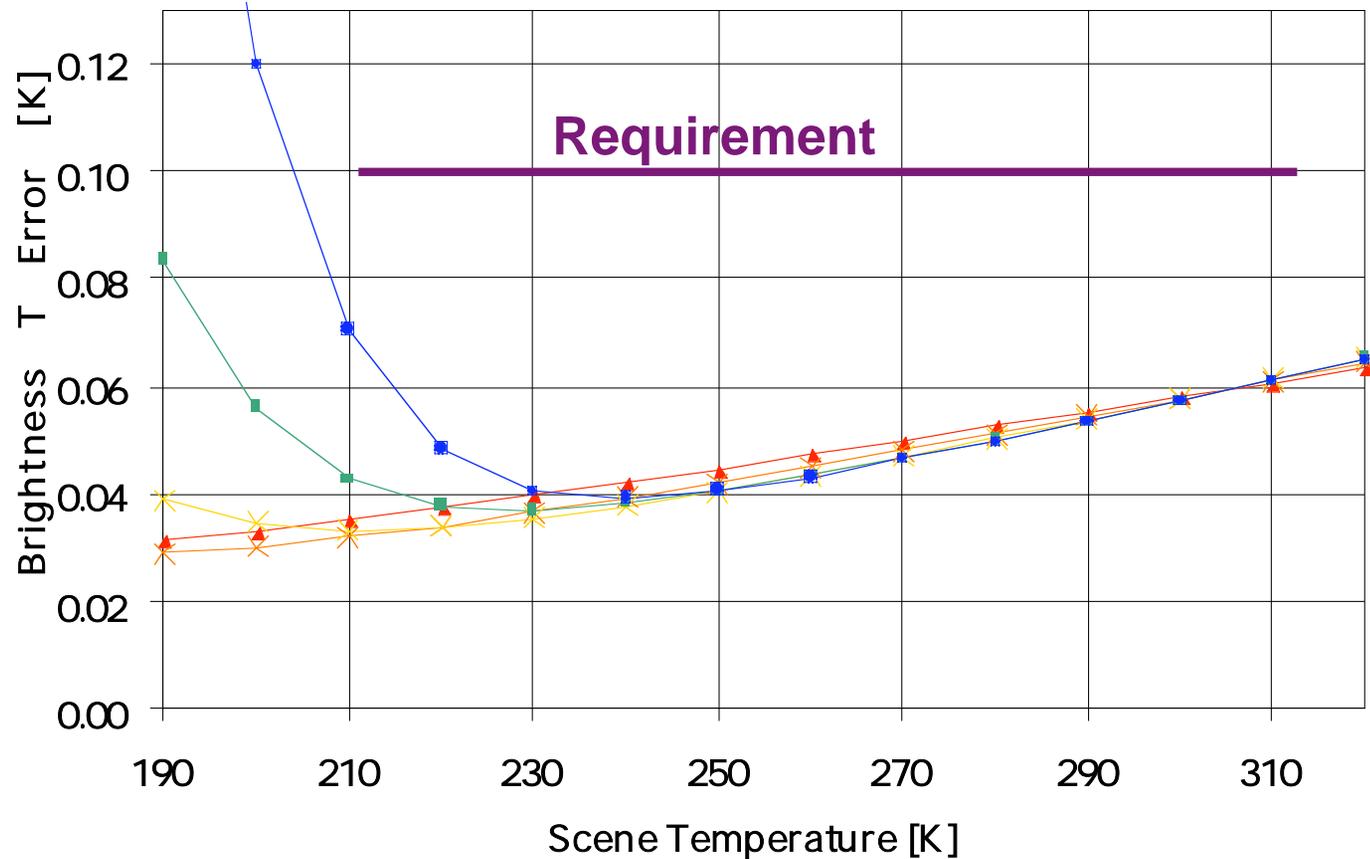
Blackbody (2)



Key Parameter	Specification	As Delivered
Measurement Range	233 to 313 K	233 to 313 K
Temperature Uncertainty	< 0.1 K (3 σ)	< 0.056 K
Blackbody Emissivity	> 0.996	> 0.999
Emissivity Uncertainty	< 0.002 (3 σ)	< 0.00072
Entrance Aperture	1.0 inch	1.0 inch
Mass (2 BBs + controller)	< 2.4 kg	2.1 kg
Power (average/max)	< 2.2/5.2 W	2.2/5.2 W

CLARREO Performance based on GIFTS Spaceflight Blackbody Design

$T_{\text{HBB}}=300\text{K}$, $T_{\text{Structure}}=285\text{K}$, $\delta T_{\text{Telescope}}=0.02\text{K}$, $\epsilon_{\text{Space}}=0.00010$



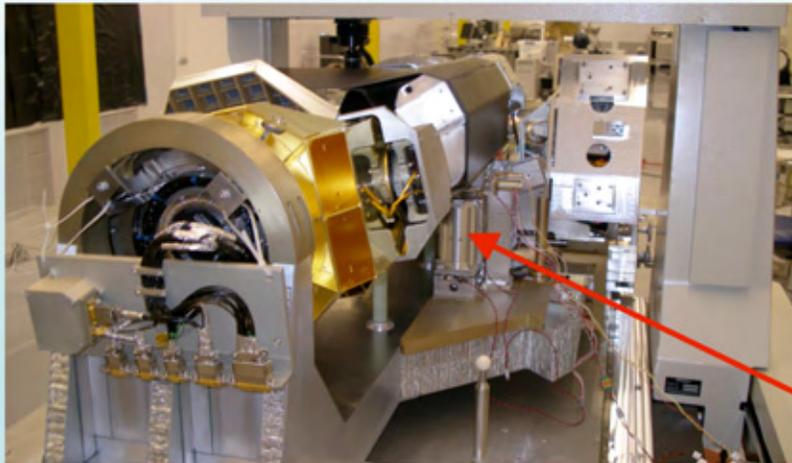
—▲— 200 cm-1 —×— 500 cm-1 —×— 1000 cm-1 —■— 1500 —■— 2000 cm-1



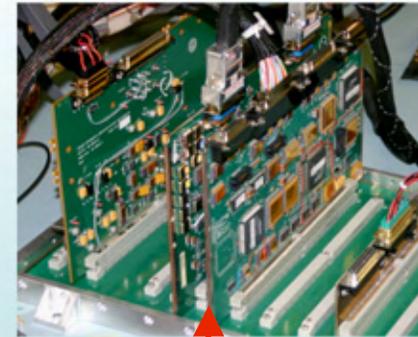
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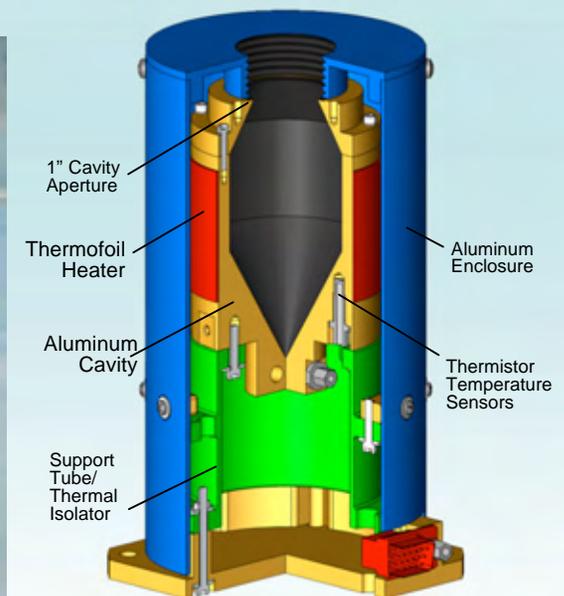
GIFTS Engineering Development Unit



Blackbody Controller Card

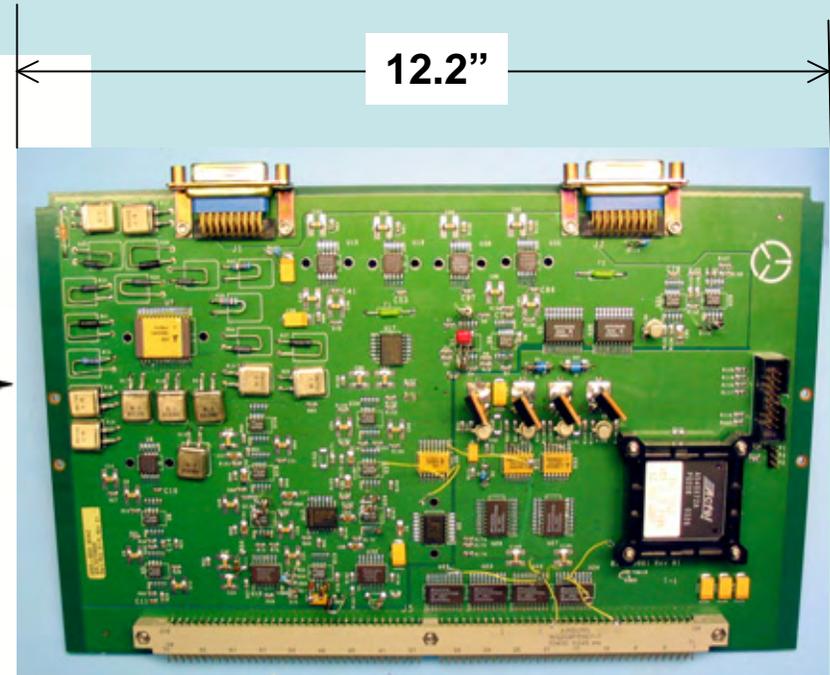
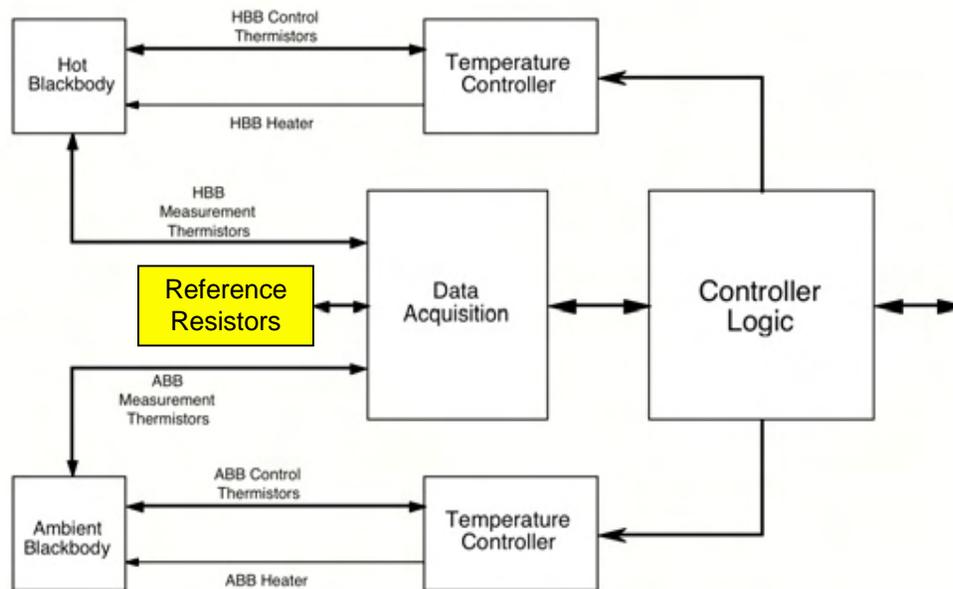


Blackbody (2)



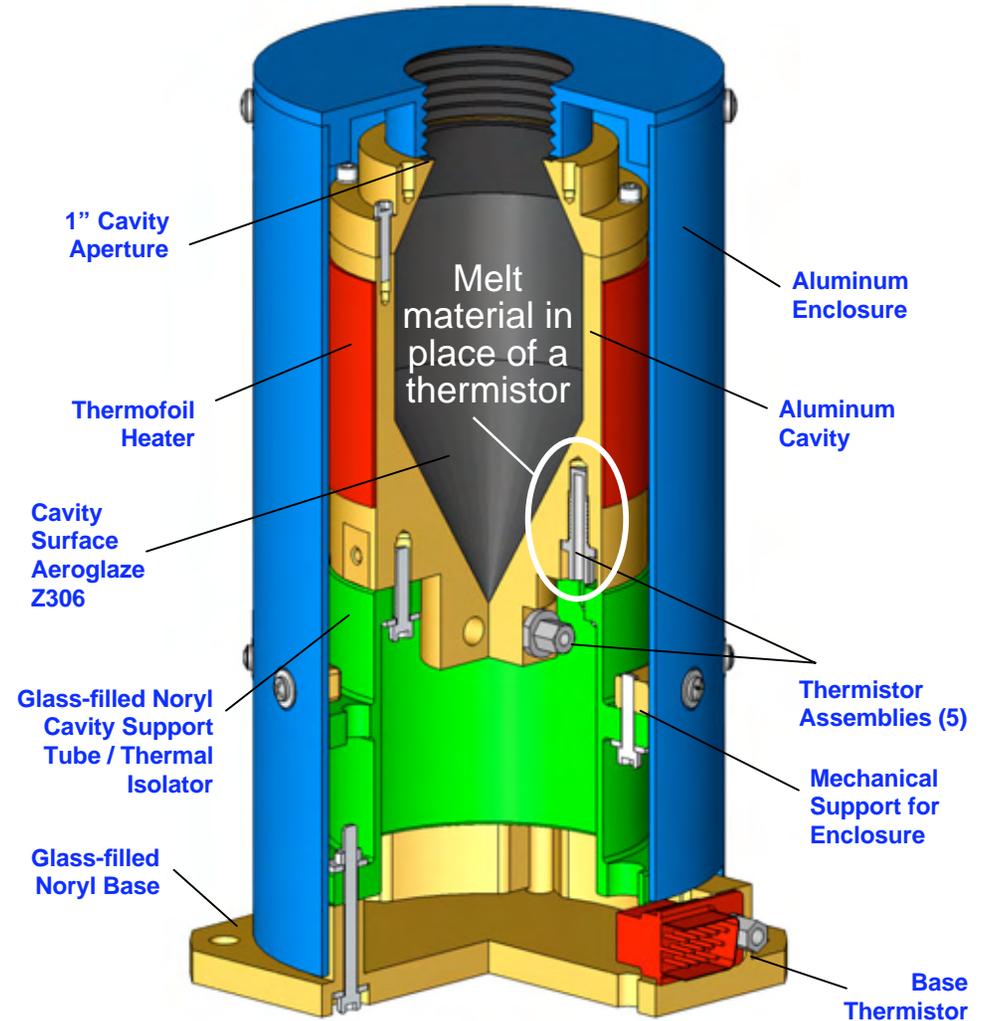
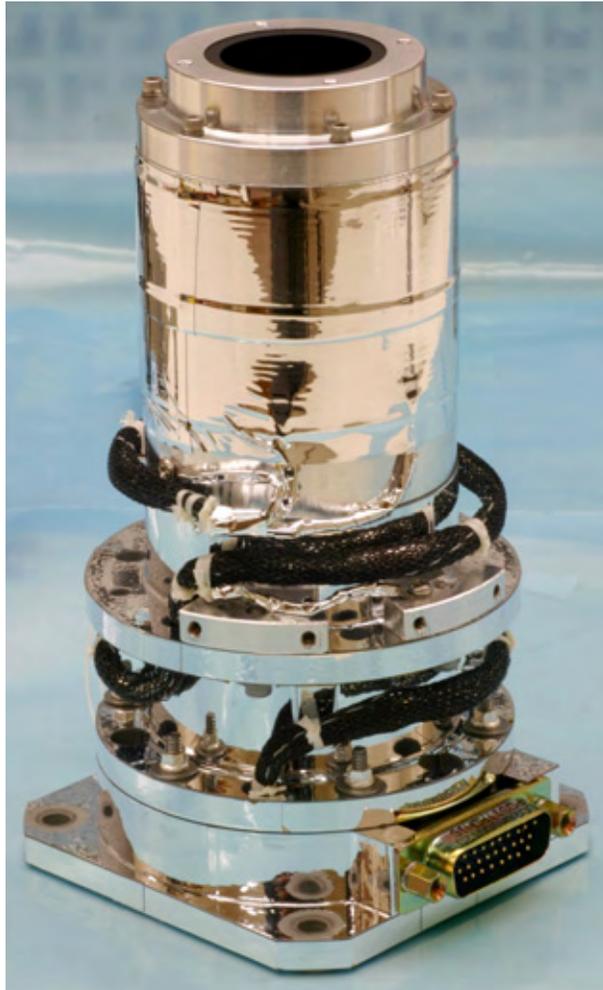
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GIFTS Blackbody Controller



Existing GIFTS Blackbody Controller independently measures and controls temperatures of two blackbodies to within about 1 mK (3 sigma). Thermistor resistance measurement uses “Reference Resistors” to provide (resistance measurement) self calibration.

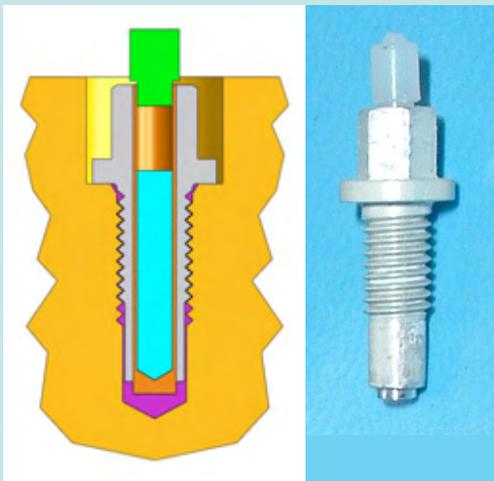
GIFTS Blackbody



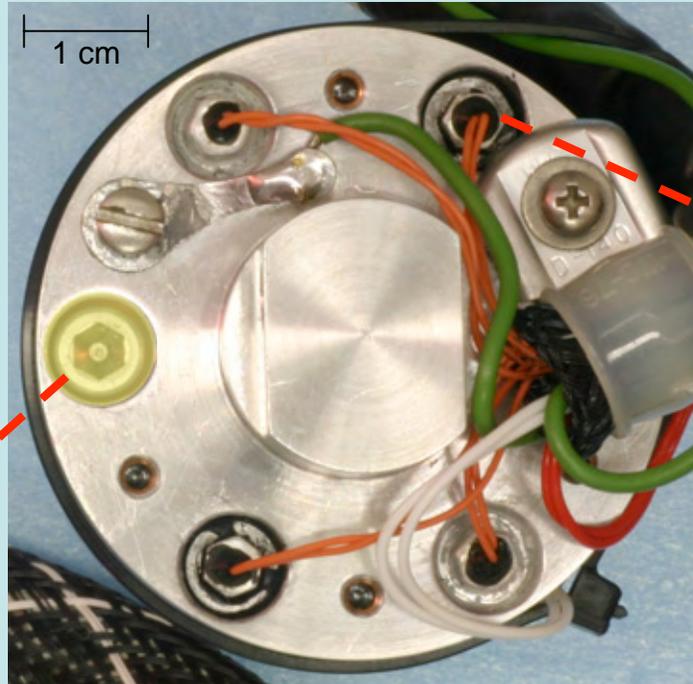
SSEC Engineering Test Cavity

(configured for melt tests)

Melt Material

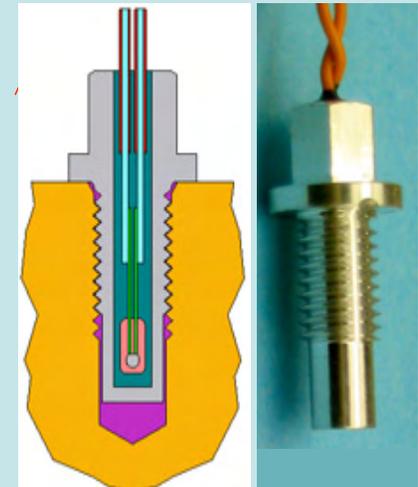


0.38 g of Ga melt material placed into thermistor housing modified with stainless steel sleeve and nylon plug.



Blackbody Cavity

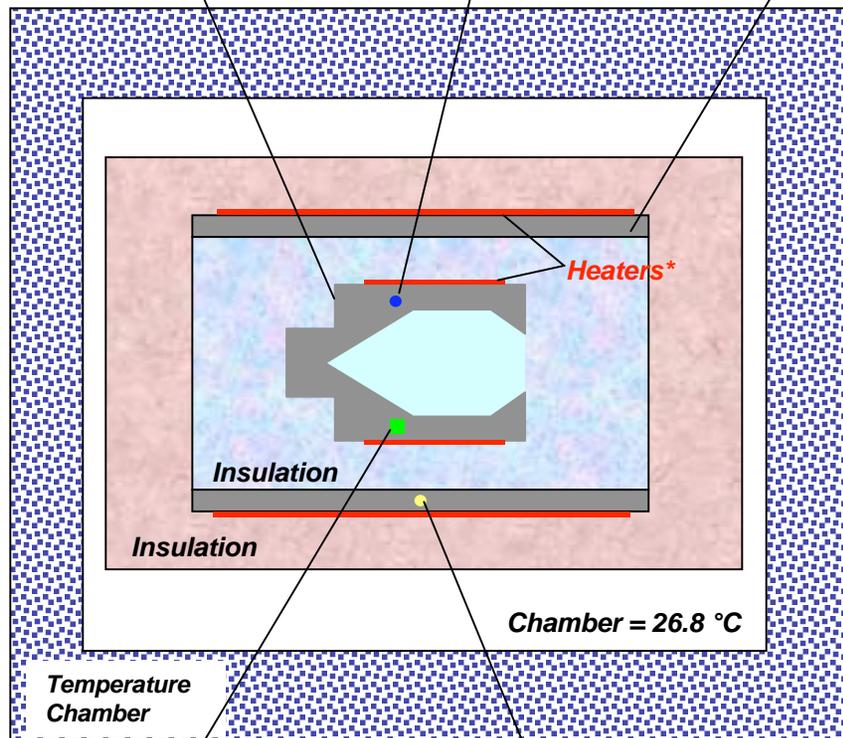
Thermistor



Thermistor potted into custom housing then threaded into aluminum cavity.

Gallium Melt Scheme

Blackbody Cavity Blackbody Thermistor Enclosure

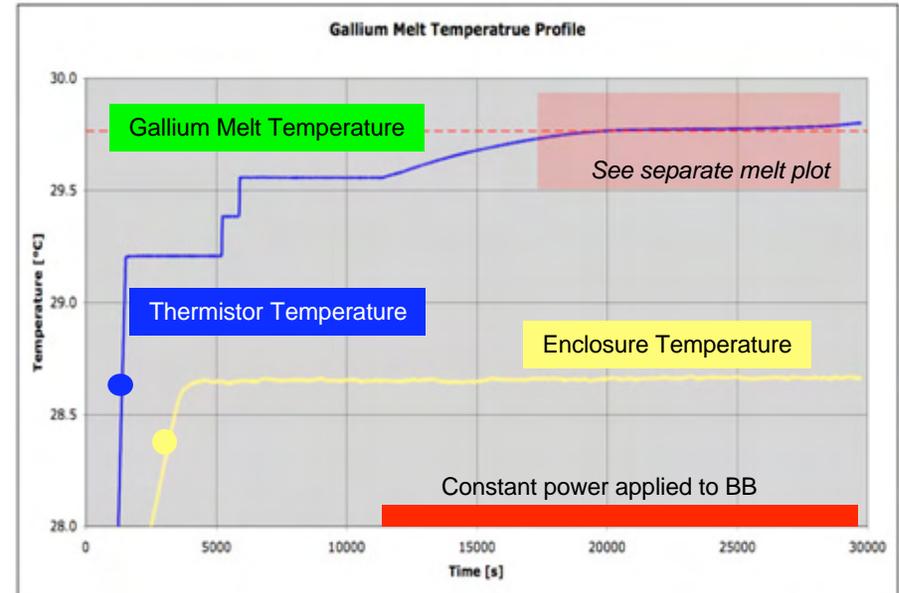


< 1 g Gallium

Enclosure Thermistor

**Heaters are independently controlled*

Blackbody aperture is 1." Schematic not to scale.



Blackbody temperature stability is achieved at a temperature 0.16 °C under the Ga melt point using the Blackbody Controller constant temperature mode. There is very tight control of the surrounding temperature environment using independently controlled enclosure and chamber heaters.

For the melt temperature ramp, the Blackbody Controller applies 0.125 W in the constant power mode. The Blackbody temperature increases exponentially, until the melt plateau is reached during which the applied power goes into melting the Gallium. Melting occurs over a period of 11,000 s.



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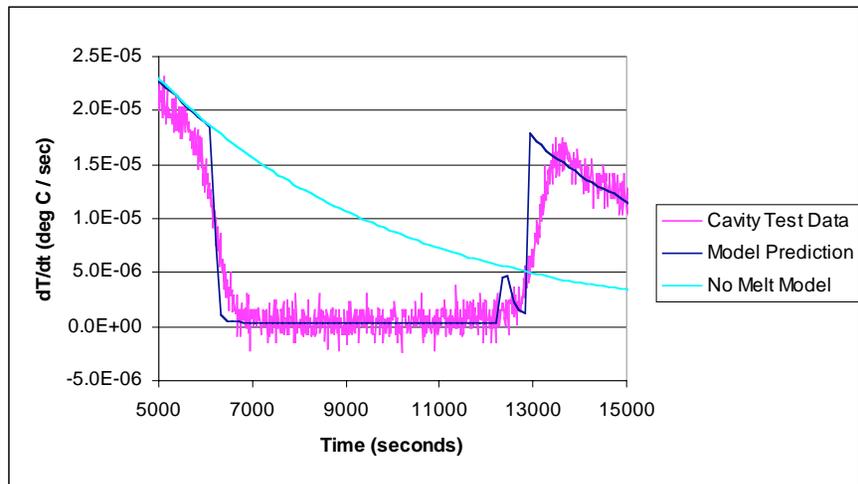
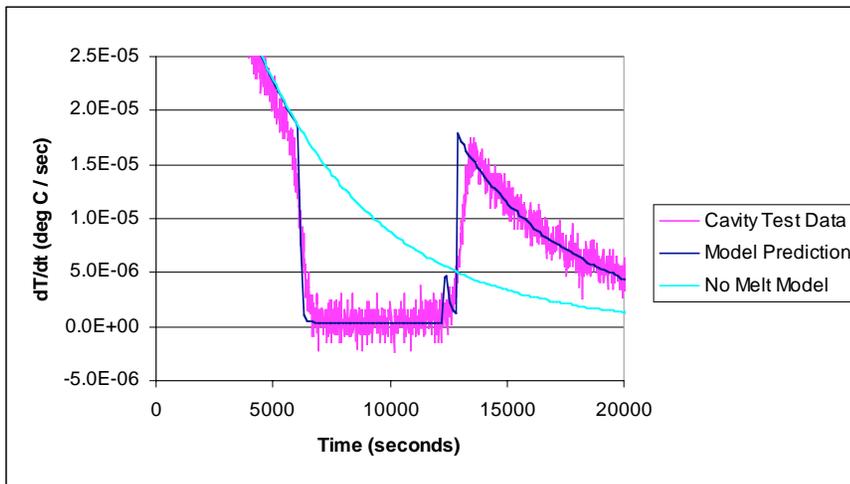
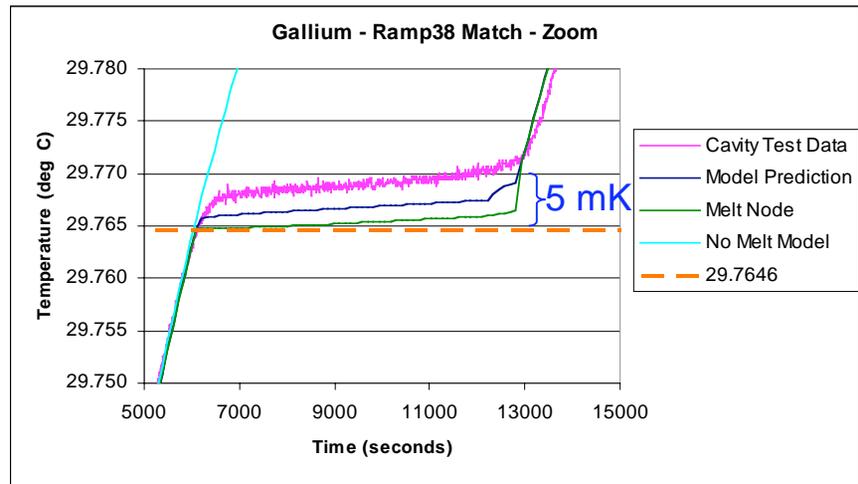
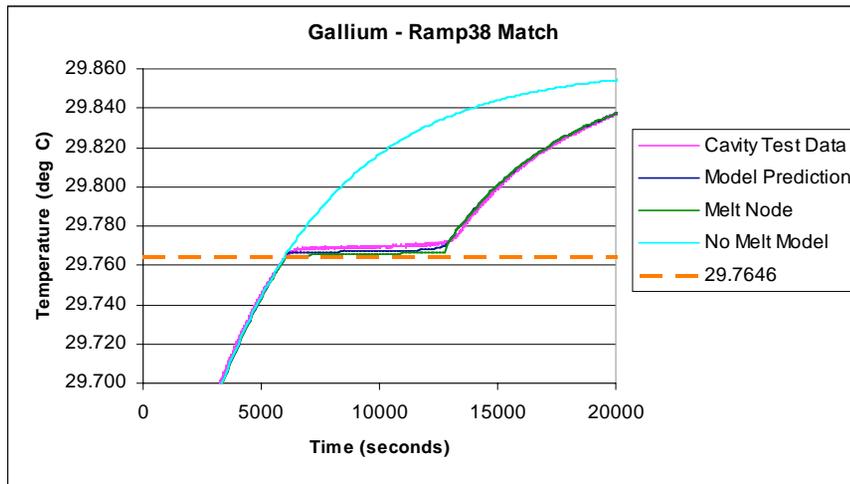
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Test Results and Model Correlation



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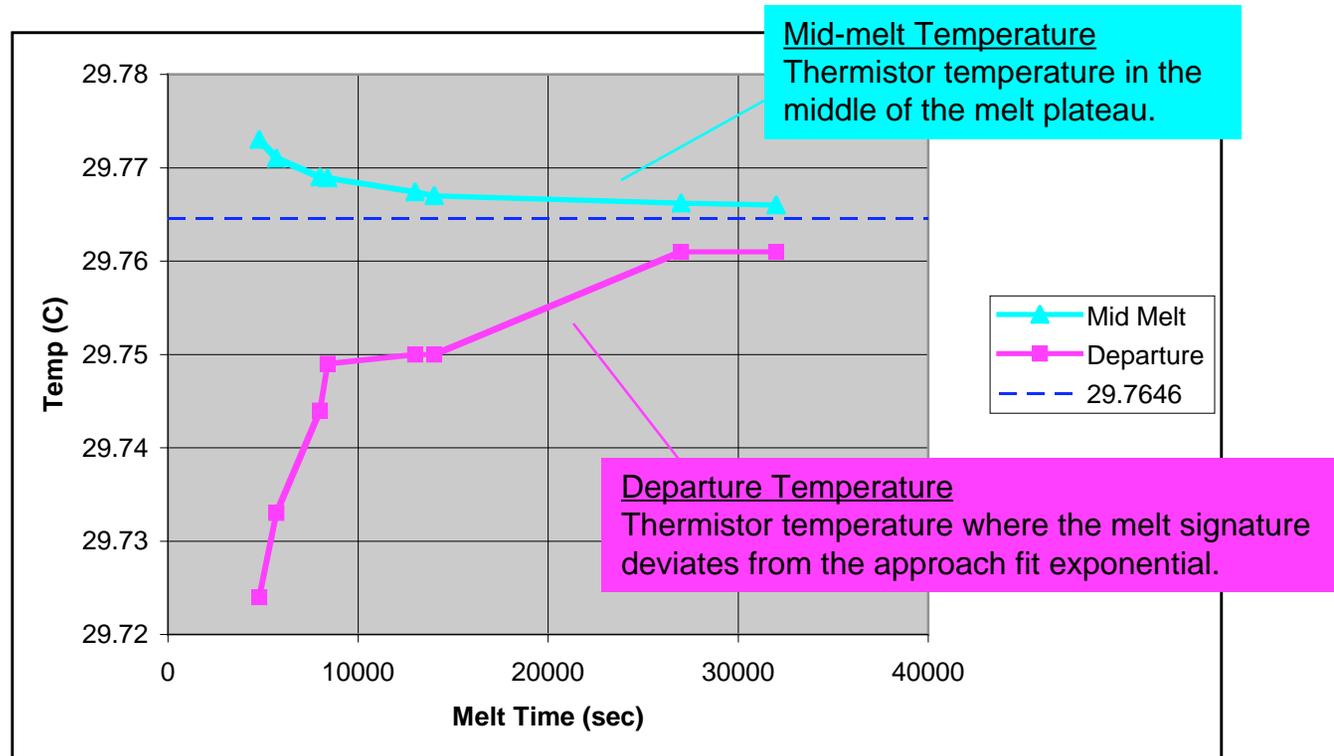
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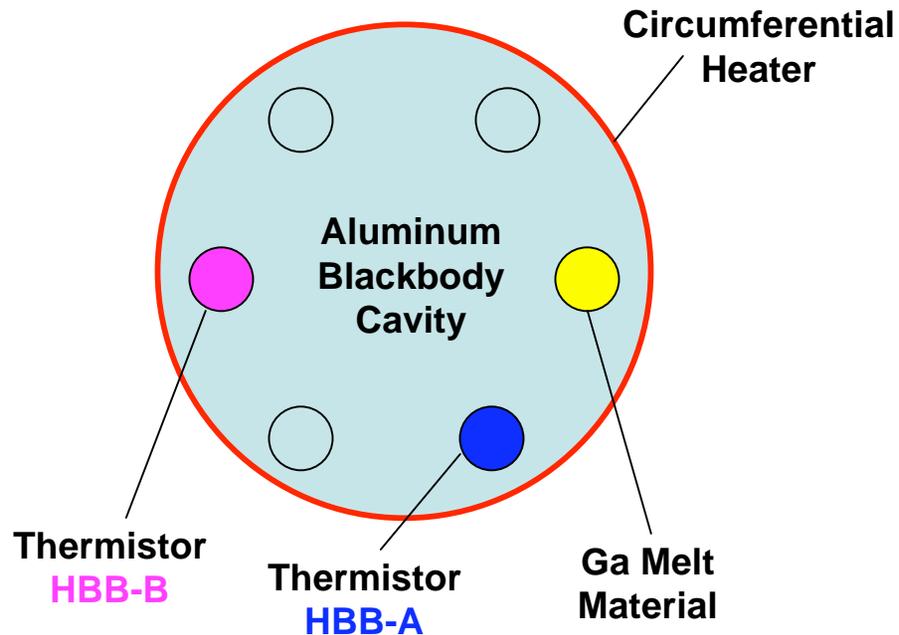


Effect of Melt Rate on departure and mid-melt temperatures for Gallium

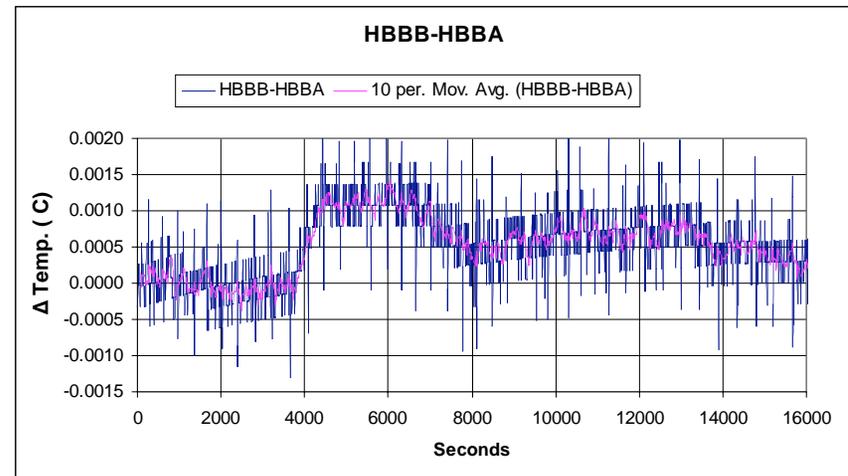
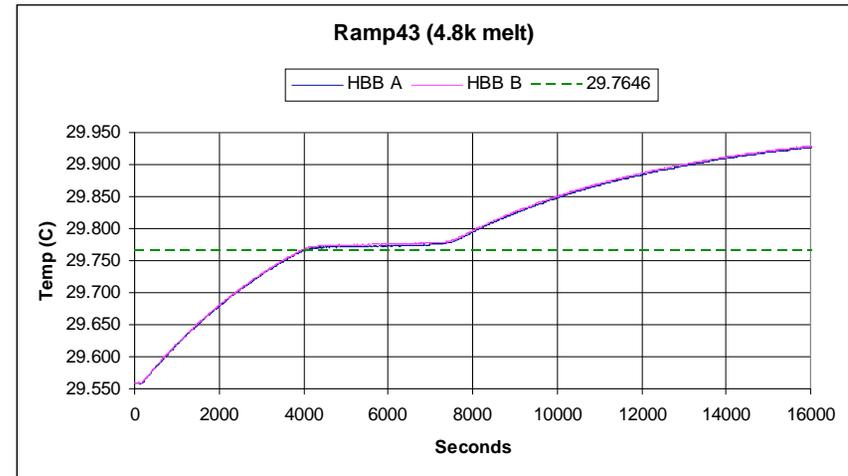


Lower ramp rates (longer melt times) lead to reduced differences between thermistor temperature and the Gallium melt point.

Cavity Gradient Measured During Melt



Temperature gradient between spatially separated temperature sensors only $\sim 1.2\text{mK}$, even during “fast” 4800 sec. melt.



Thermistor Calibration Relationship

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

- Regression fit to N points (R_i, T_i) , when 3 or more points are available:

$$\begin{vmatrix} N & \sum \ln(R_i) & \sum (\ln(R_i))^3 \\ \sum \ln(R_i) & \sum (\ln(R_i))^2 & \sum (\ln(R_i))^4 \\ \sum (\ln(R_i))^3 & \sum (\ln(R_i))^4 & \sum (\ln(R_i))^6 \end{vmatrix} \cdot \begin{vmatrix} A \\ B \\ C \end{vmatrix} = \begin{vmatrix} \sum (1/T_i) \\ \sum (1/T_i) \cdot (\ln(R_i)) \\ \sum (1/T_i) \cdot (\ln(R_i))^3 \end{vmatrix}$$

$$[R] \cdot \begin{vmatrix} A \\ B \\ C \end{vmatrix} = [Z] \qquad \begin{vmatrix} A \\ B \\ C \end{vmatrix} = [R]^{-1} \cdot [Z]$$

Implementation

(GIFTS Blackbody Embodiment)

- Small quantities of Water, Gallium, Mercury, and possibly additional materials are imbedded in the blackbody cavity, providing three or more known temperature reference points.
- The thermistors are interleaved in the cavity between these reference materials.
- Temperature calibration points are established by sequentially passing through the phase change points of the reference materials and identifying their melt signatures.
- During the temperature ramps, the thermistor resistances corresponding to the phase change points are measured.
- The thermistors are fully characterized by three temperature calibration points (Steinhart & Hart Coefficients).
- The blackbody is calibrated over a significant range of temperature and can operate at any point within this range.



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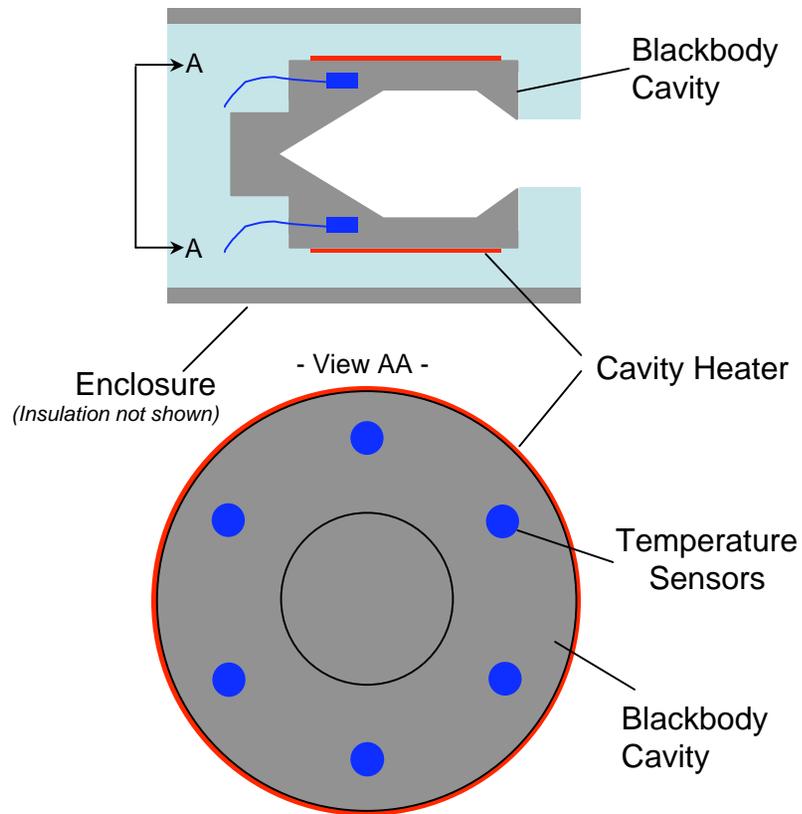
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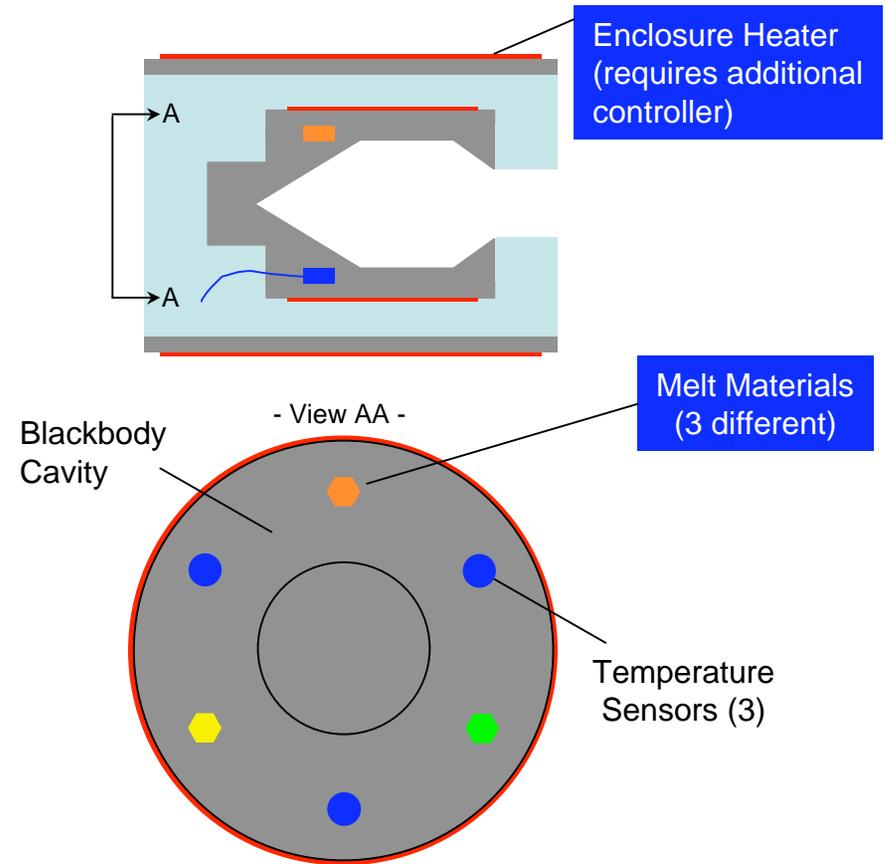
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Implementation Into a GIFTS Type Blackbody Requires Small Changes



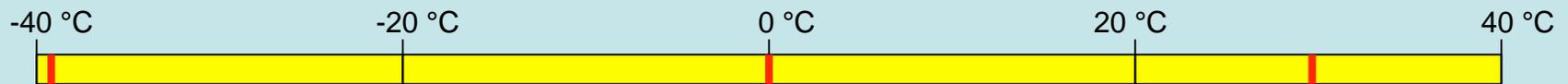
GIFTS Blackbody Configuration



Changes For Absolute Calibration

Measured Melt Signatures

(using GIFTS BB Configuration)

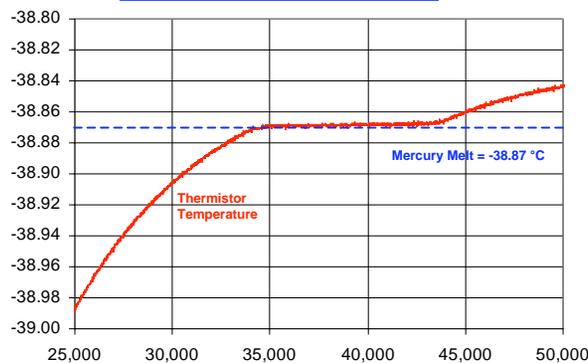


-38.87 °C
Mercury

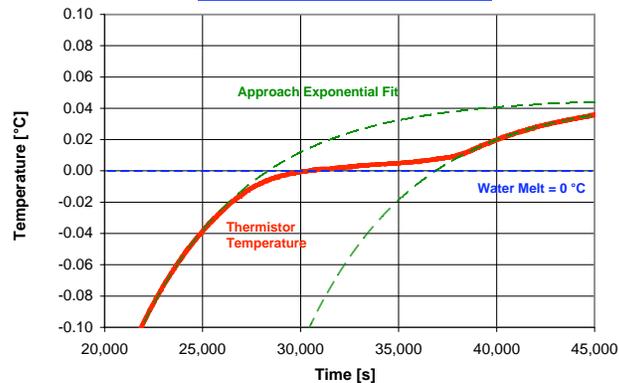
0.00 °C
Water

29.77 °C
Gallium

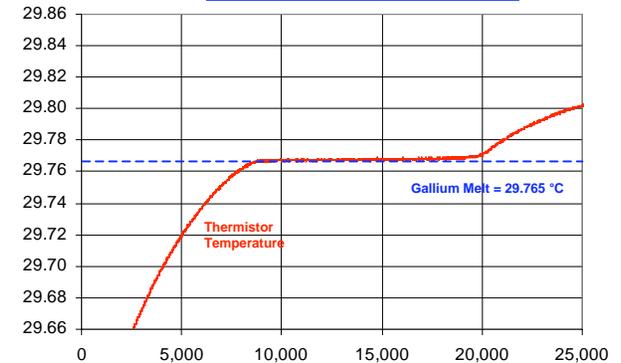
Mercury Melt (test data)



Water Melt (test data)



Gallium Melt (test data)



Distinct signatures realized in each case. The water signature is least distinct, due to its low thermal conductivity. Signatures become more distinct and have plateaus closer to the melt temperature when:

- melt times are lengthened (less power applied through ramp).
- quantity of melt material is increased.
- contact area of melt material is increased



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Benefits This Novel Approach

- Absolute temperature calibration (better than 10 mK, 3 sigma) over a large temperature range provided, on demand, on-orbit.
- Simple and very low mass
- Implementation requires very little modification of an existing flight hardware design.
- Provides temperature calibration of all the blackbody cavity thermistor temperature sensors over a significant temperature range – allowing normal blackbody operation at any temperature within this range.
- Very accurate – 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.



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