Calibration of the Scanning High-resolution Interferometer Sounder (S-HIS) Infrared Spectrometer: Blackbody Reference Standards (Part 2)

Hank Revercomb and Fred Best

University of Wisconsin-Madison,
Space Science and Engineering Center

SSEC

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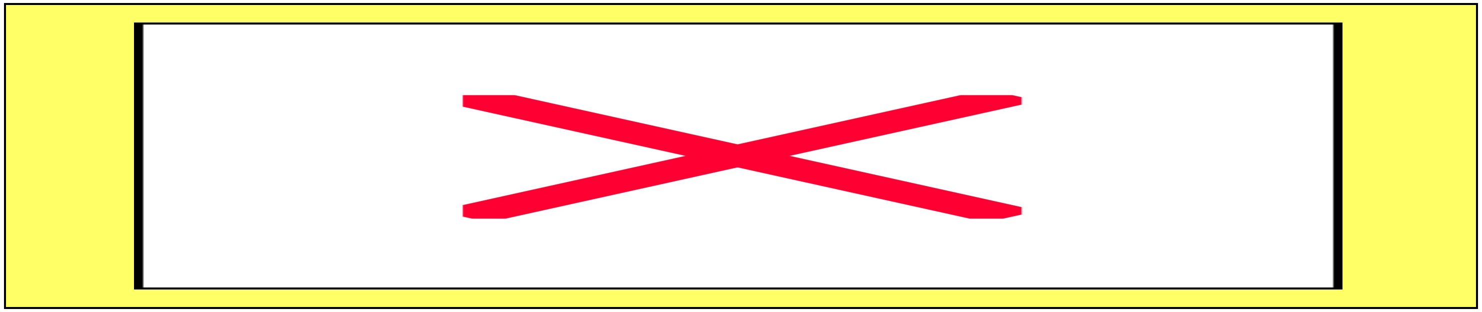
Utah State, 22 August 2005

Topics

- Blackbody system top-level requirements
- System description
- Temperature calibration
- Emissivity
- End-to-end Verifications & Checks
- Future plans

Blackbody System Top-level Requirements

S-HIS Calibration Equation



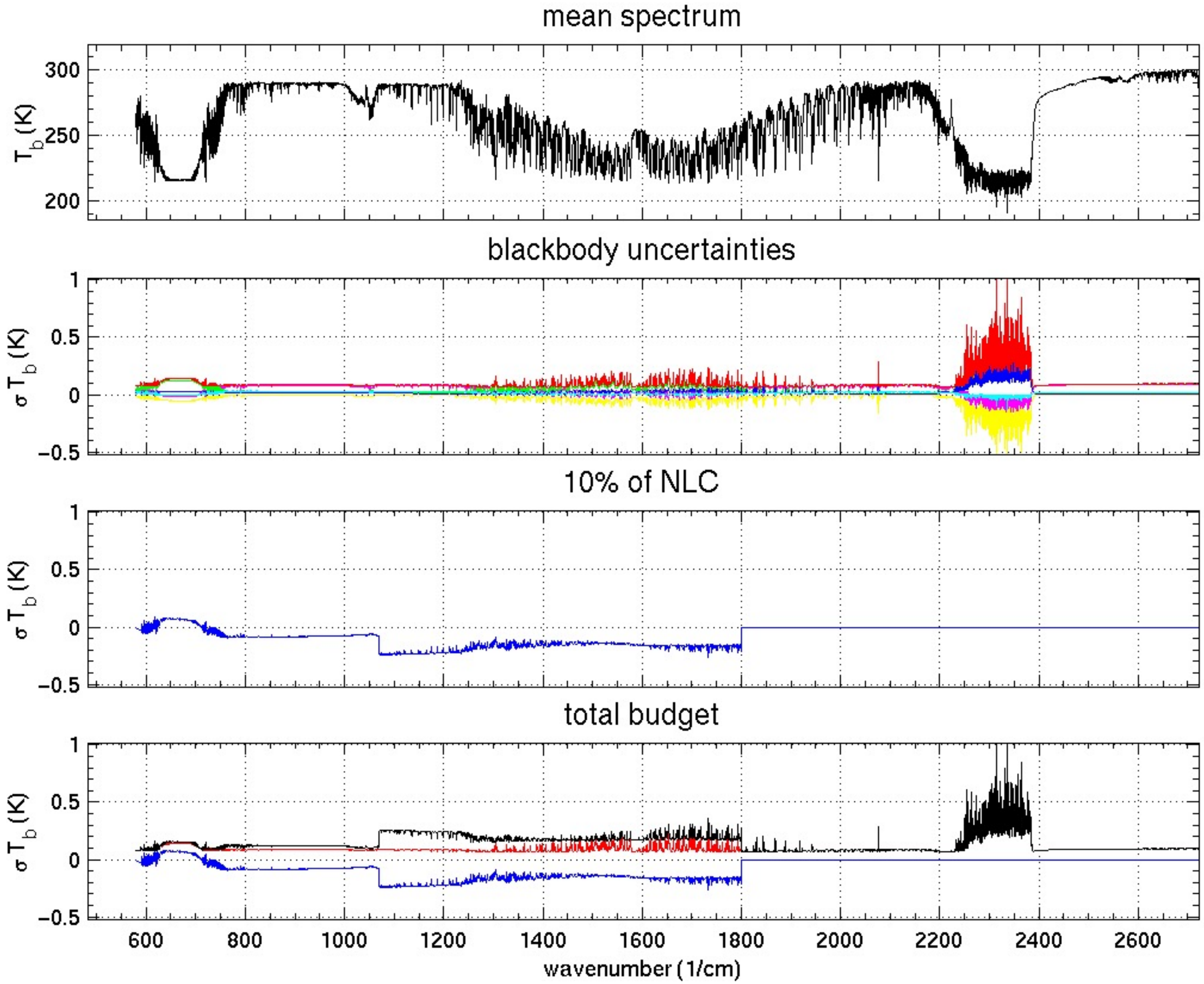
- N is the calibrated spectral radiance
- B_H is the effective Planck emission for the hot blackbody
- B_A is the effective Planck emission for the ambient blackbody
- C_S is the complex spectrum for the sky view
- C_H is the complex spectrum for the hot blackbody view
- C_A is the complex spectrum for the ambient blackbody view
- Re() is the real part of the complex ratio

$$B_{bb} = \varepsilon_{bb} * B(T_{bb}) + (1 - \varepsilon_{bb}) * B(T_{rfl}),$$

where bb=A or H; and T_{rfl} is reflected structure temperature

S-HIS Absolute Radiometric Accuracy Requirement ≤0.5K

Scanning-HIS Radiometric Calibration Budget for 11/16/04 Flight



RSS

$\Delta T_{HBB}=0.1$

$\Delta T_{ABB}=0.1$

$\Delta T_{RFL}=5.0$

$\Delta \varepsilon_{HBB}=0.001$

$\Delta \varepsilon_{ABB}=0.001$

T_{ABB} = 227K

T_{HBB} = 310K

ε_{bb}= 0.998

Top-level Blackbody Requirements

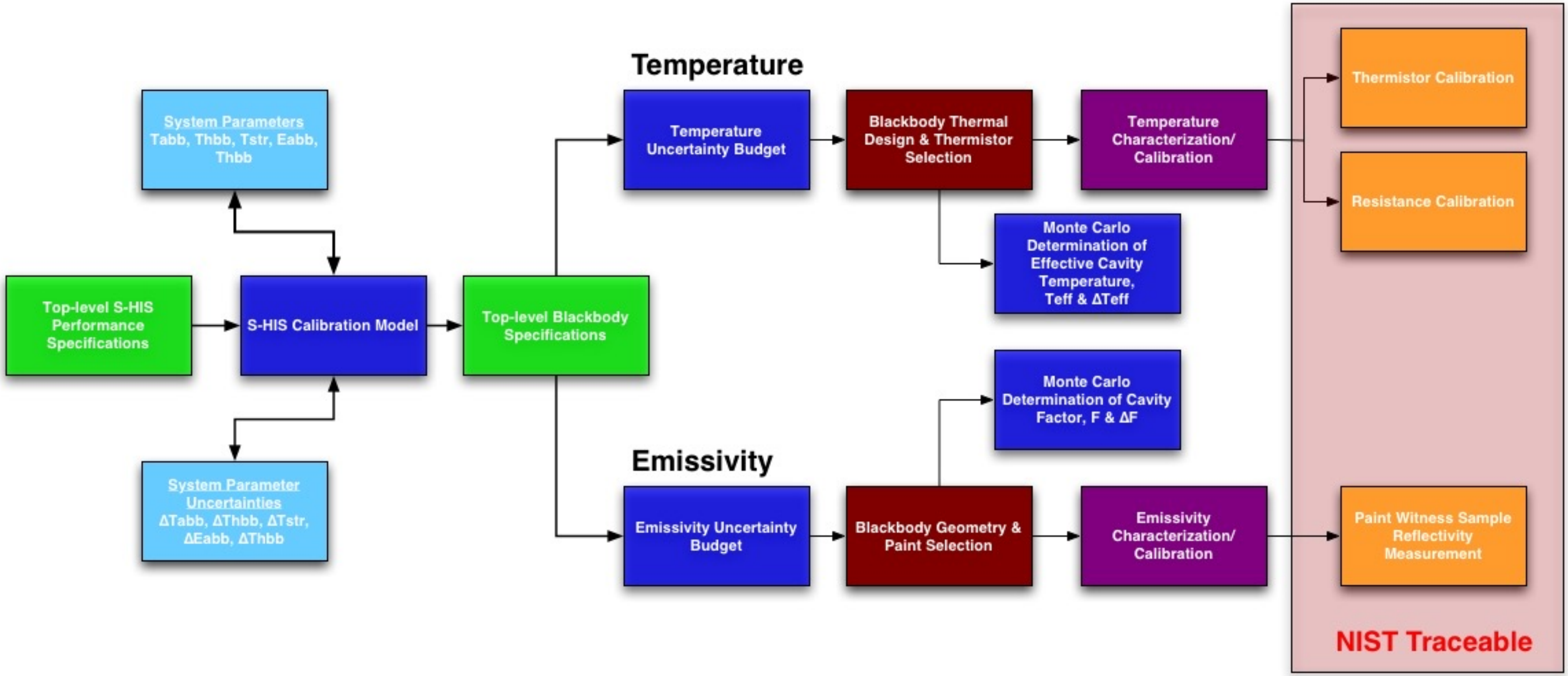
The blackbody system requirements are:

- Temperature knowledge (3 sigma): ±0.1 K
- Emissivity: better than 0.998
- Emissivity knowledge: better than ±0.1%
- Temperature gradient : knowledge within 0.1 K

S-HIS Instrument imposed requirements and allocations:

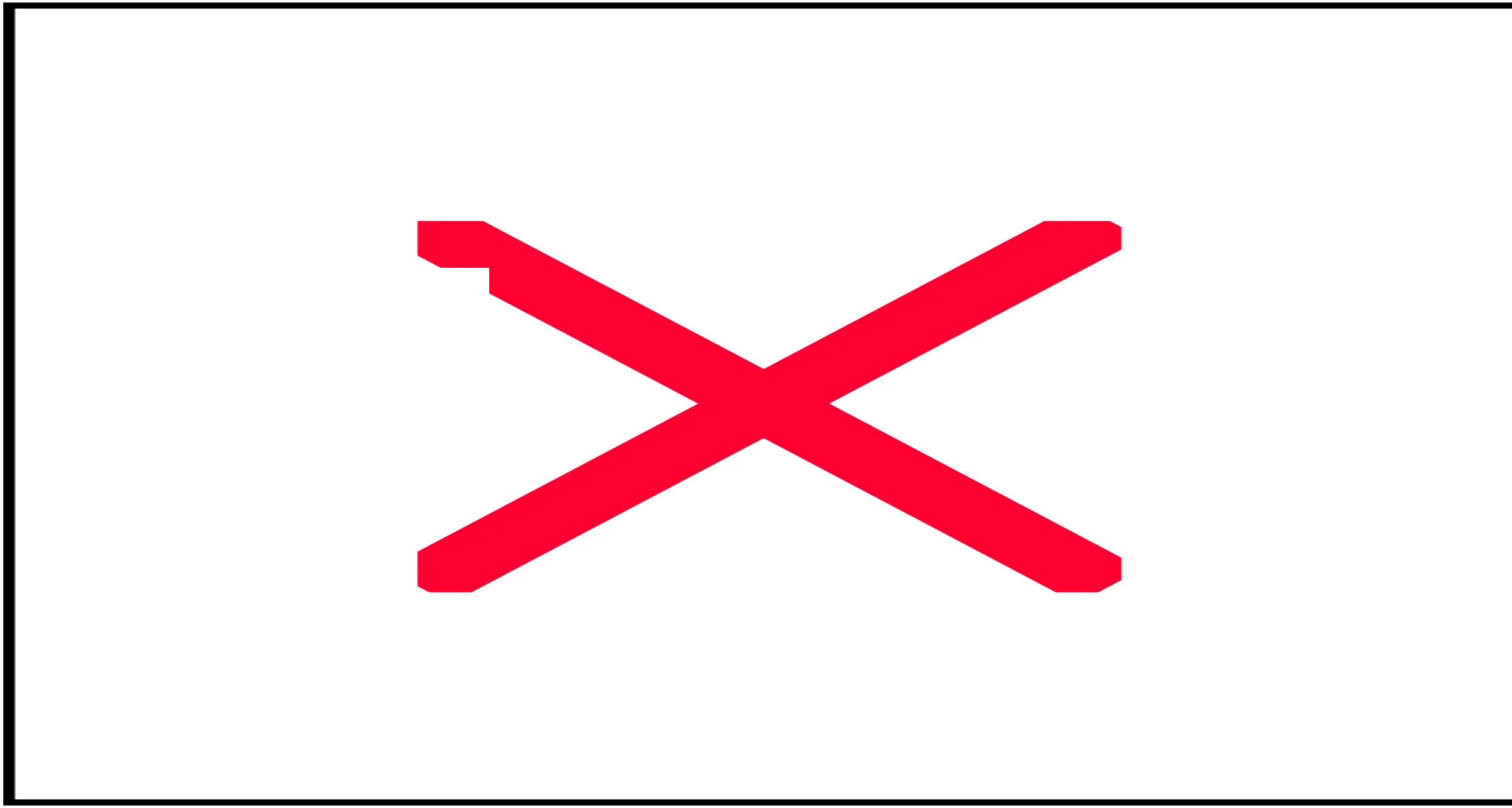
- BB Aperture: 4.06 cm
- BB Envelope 11 cm Dia. X 18 cm
- BB Operating Temperature: 210 to 330 K
- Mass (2 BB's and Controller): < 6.0 lb
- Power (2 BB's and Controller): < 10.0 W

S-HIS Blackbody Calibration Roadmap

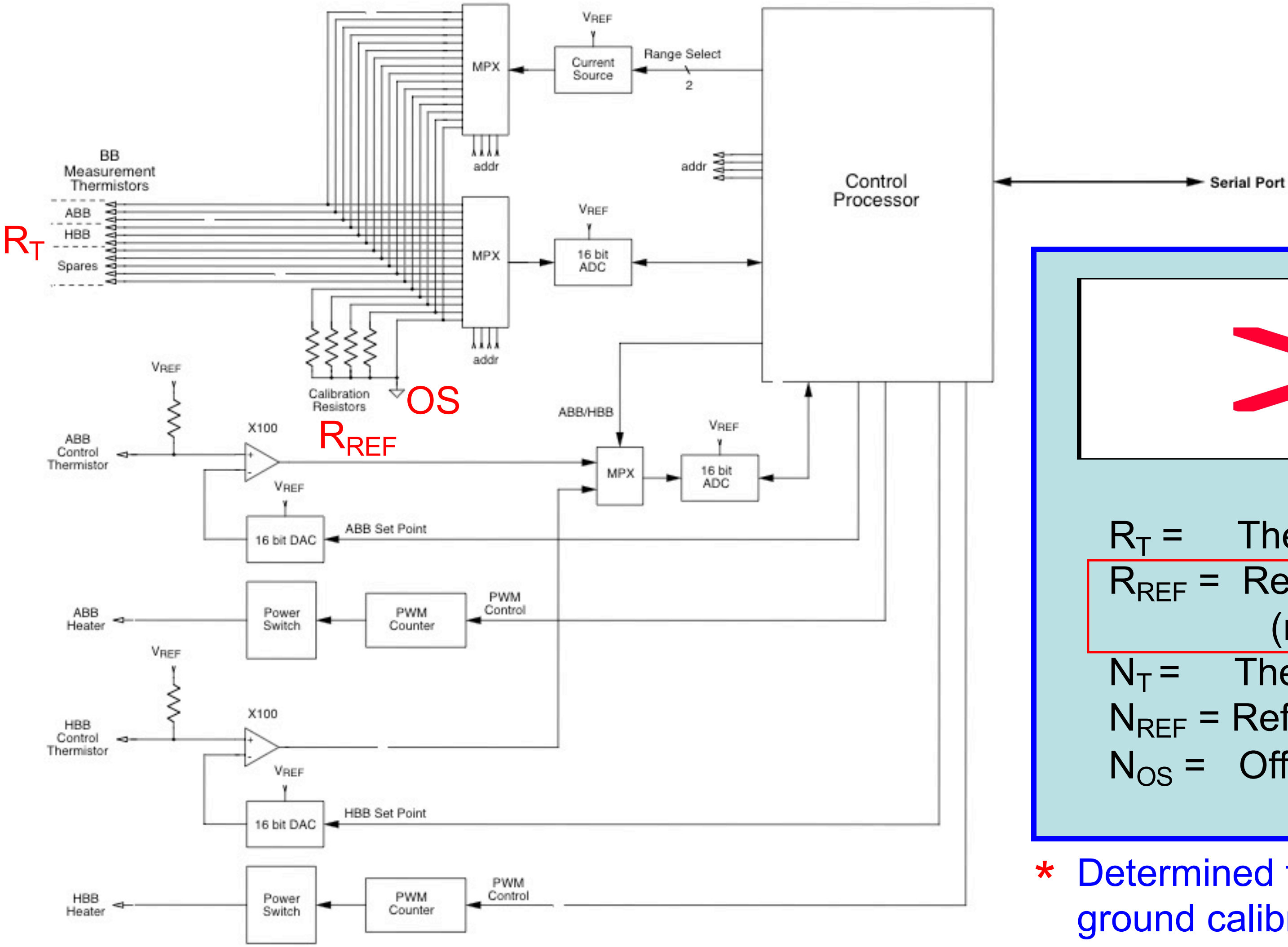


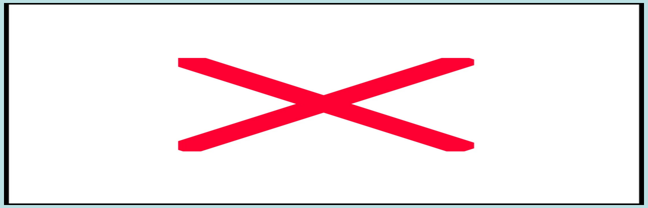
System Description

Blackbody Subsystem



Self-calibrating Thermistor Measurement





R_T = Thermistor Resistance

R_{REF} = Reference Resistor (range specific) *

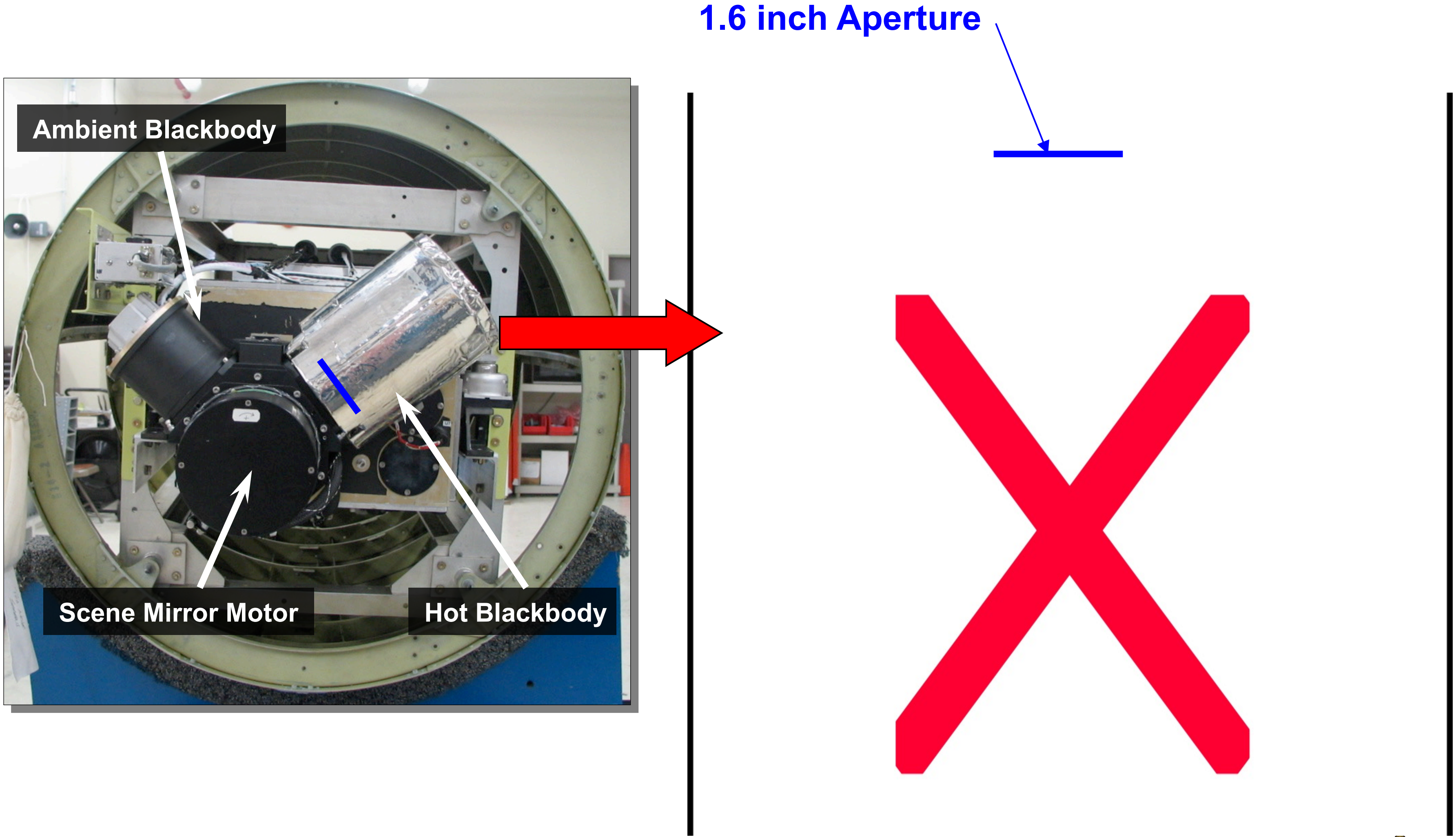
N_T = Thermistor Counts

N_{REF} = Reference R Counts

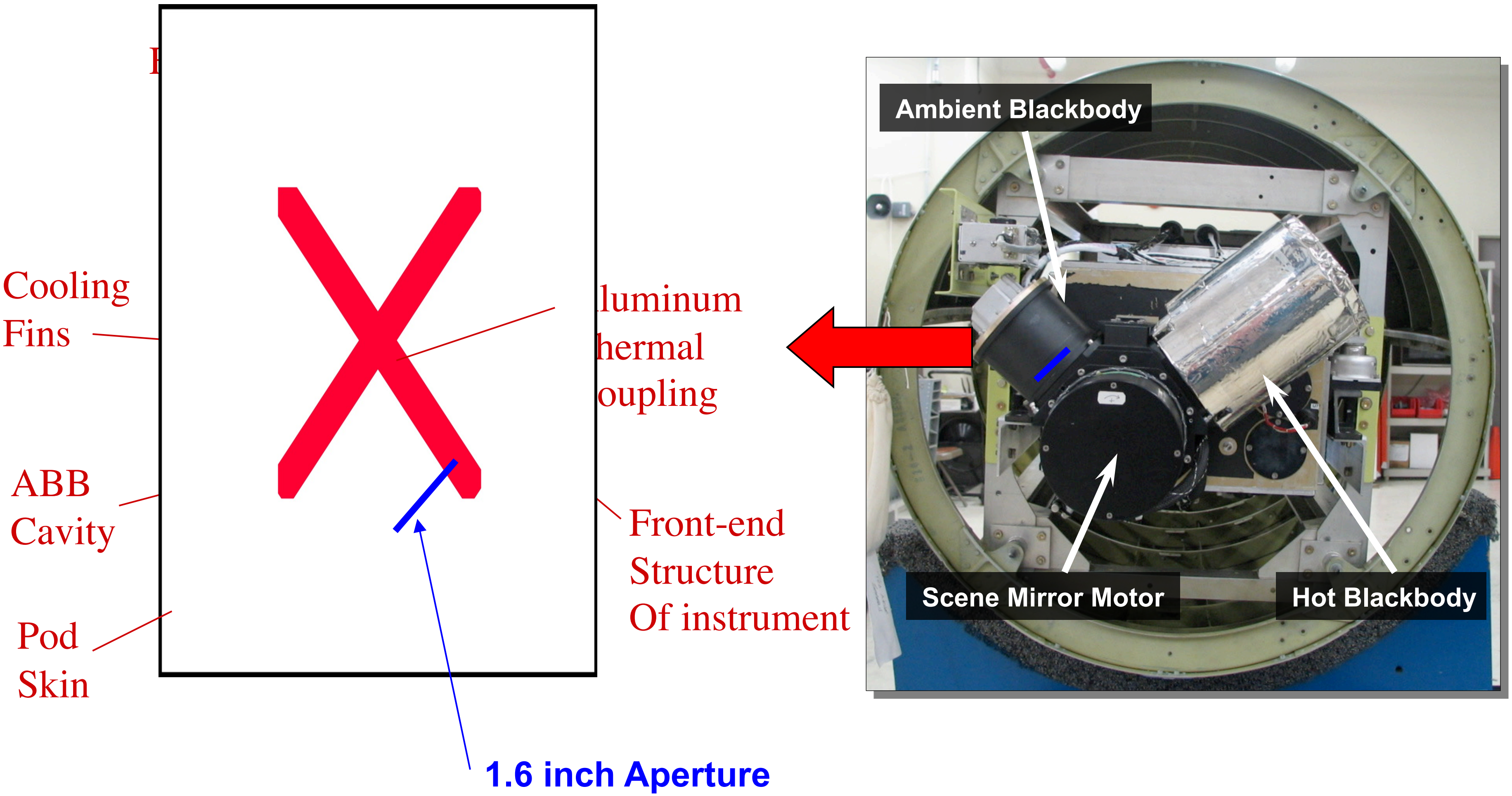
N_{OS} = Offset Counts

* Determined from one-time ground calibration

S-HIS Calibration Blackbodies - HBB



S-HIS Calibration Blackbodies - ABB



Blackbody Top-level Design Choices

- **Cavity Approach**
  - Provides high emissivity (cavity factor near > 39)
  - Emissivity enhancement due to cavity is well characterized
  - Cavity walls provide good conduction (low gradients)
  - Easy to manufacture

- **Chemglaze Z306 Paint**
  - Provides high emissivity that is well characterized and stable
  - Excellent adhesion
  - Provides a hardy surface

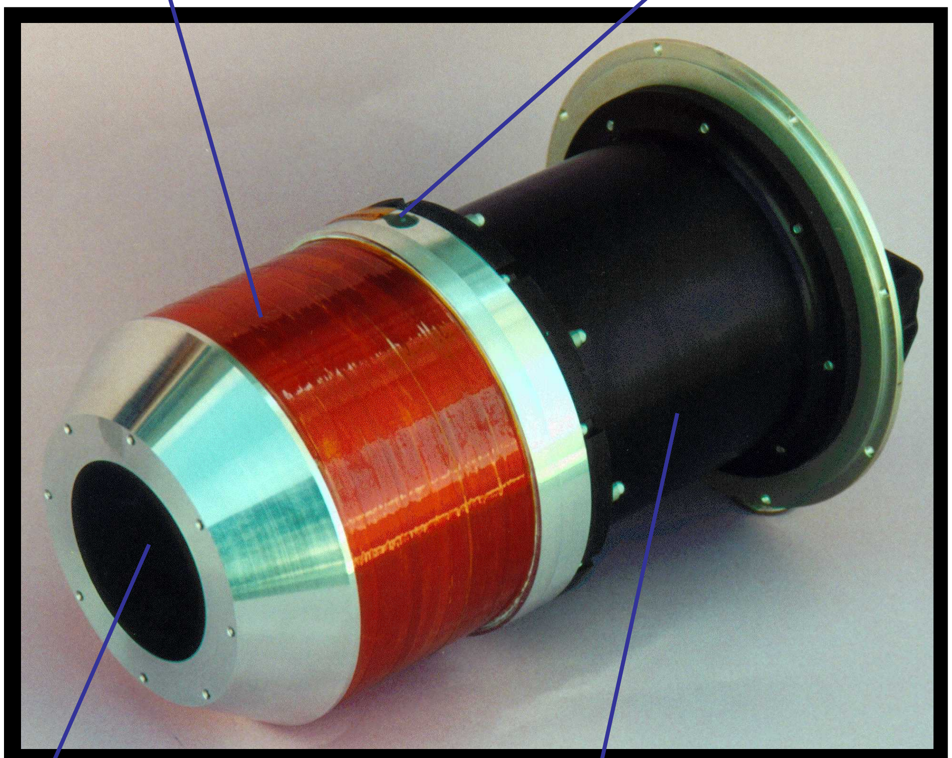
- **Thermistor Temperature Sensors (YSI 46041 Super-stable Precision Thermistors)**
  - Very Stable (0.01 K drift after 100 months at 70 K)
  - Easy to couple thermally to complicated blackbody cavity geometry
  - Reasonably rugged
  - Relatively easy to characterize

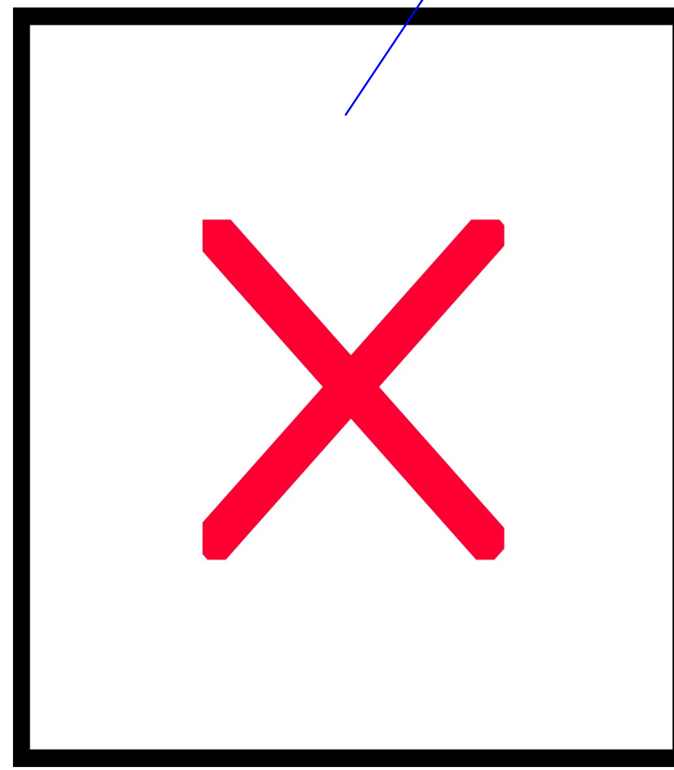
Blackbody Configuration Similar to AERI (shown)

Heater Winding

Thermistor

Wire heatsinking not shown





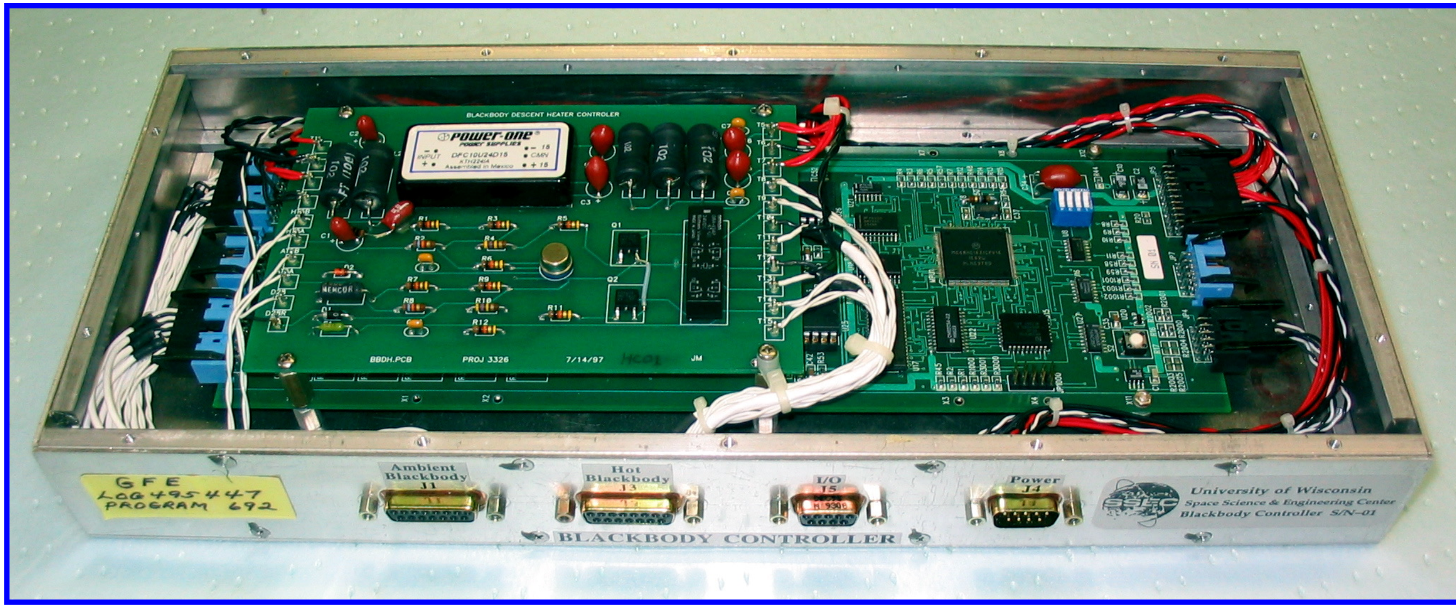
Cavity Aperture
(1.6 inch for S-HIS)

Cavity Support
(Thermal Isolator)

Thermistor Installation

The assembly shown is installed inside an enclosure with fiberglass insulation

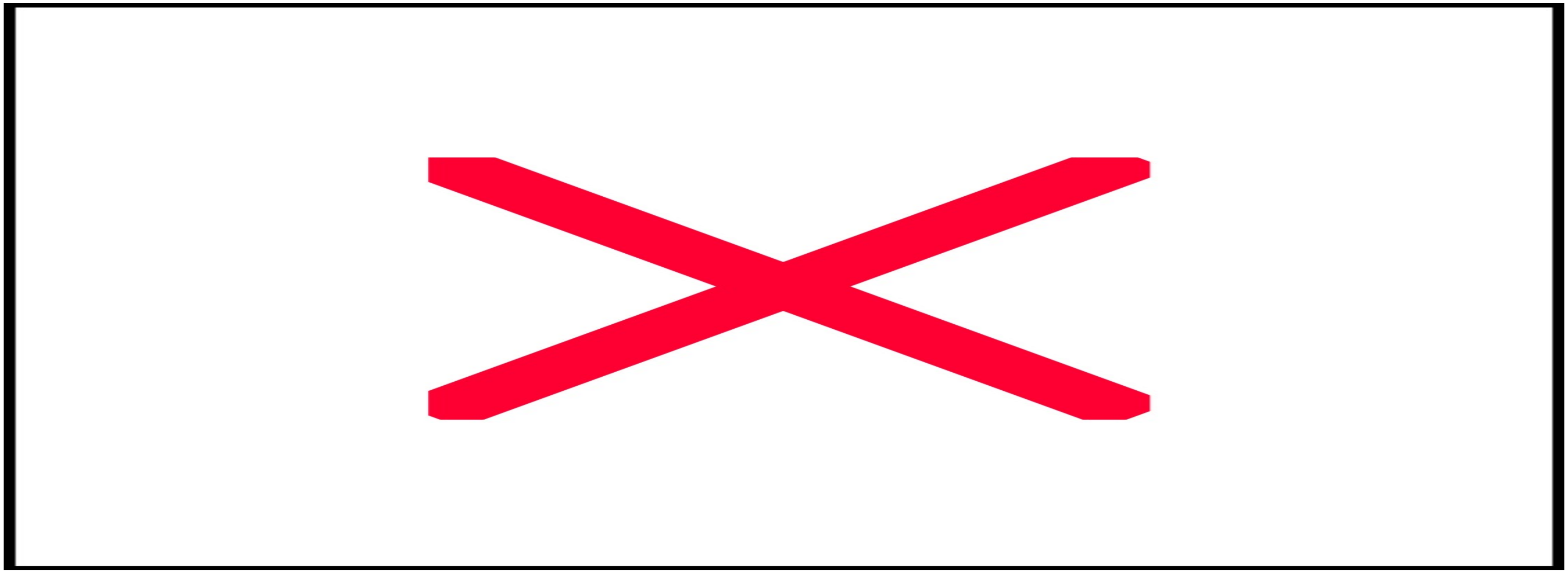
S-HIS Blackbody Controller



Size: 6" x 14" x 1.75"
Weight: <3.0 lb
Power: <2.0 W (not inc. BB htr.)

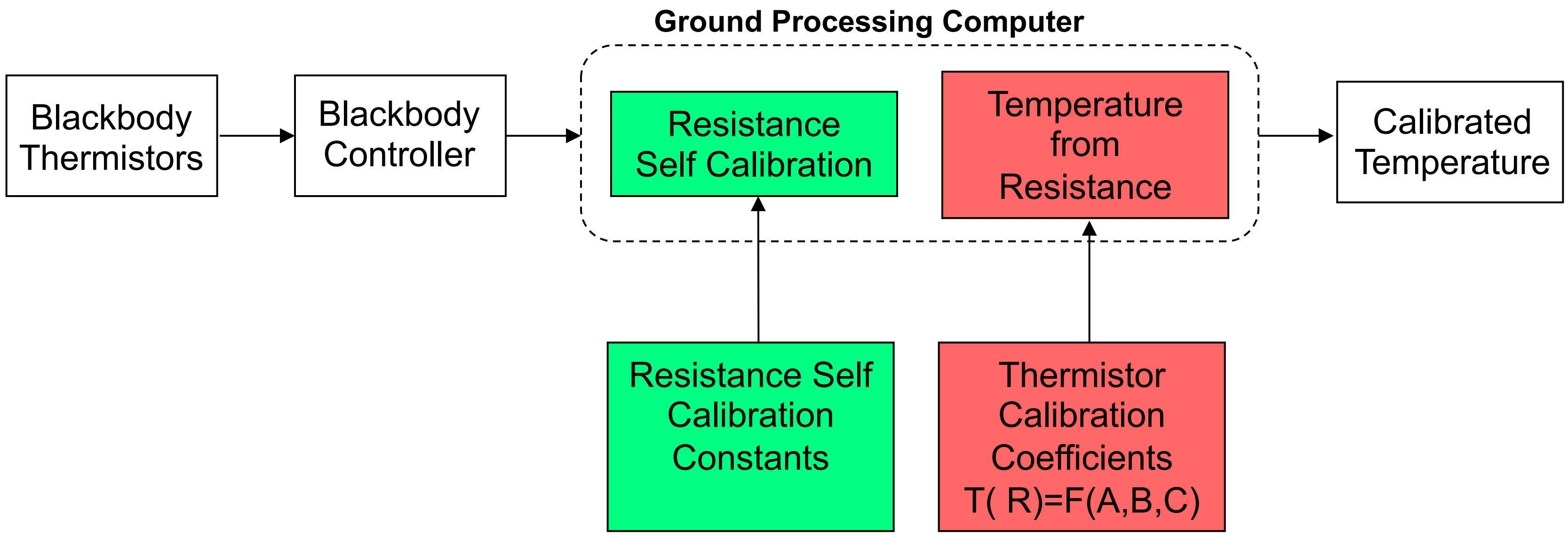
Varied Blackbody System Operating Environments

- For the S-HIS, the key operational environment parameters are shown in the Table below.
- Accommodating such a wide variety of environments with a single instrument design presents significant challenges.

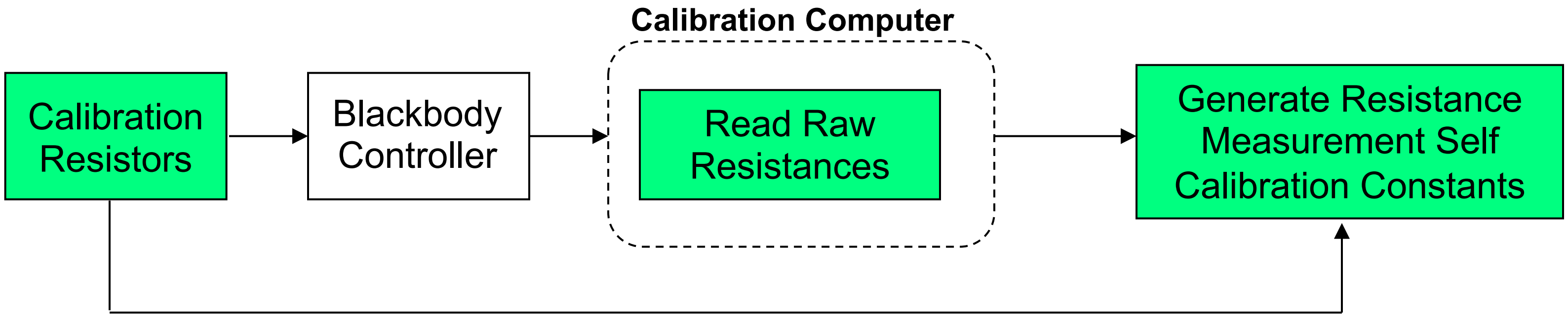


Temperature Calibration

System Reads Thermistor Resistance and Outputs Calibrated Temperature

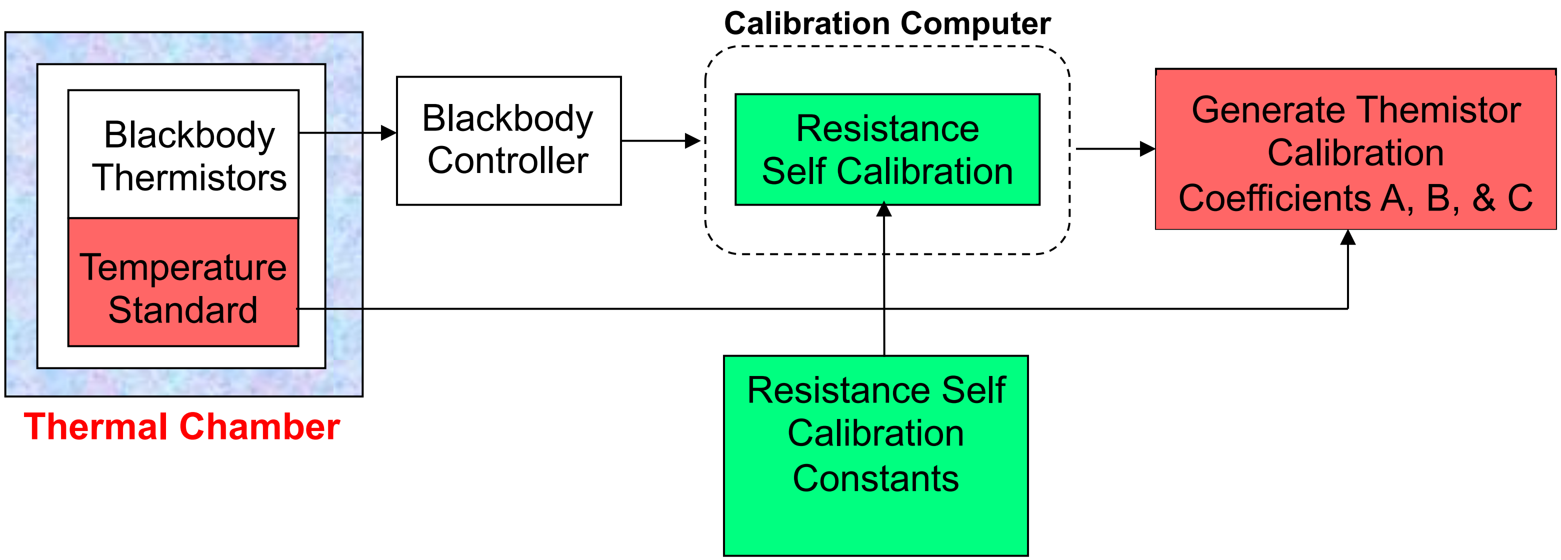


Resistance Calibration of the Blackbody Controller Electronics



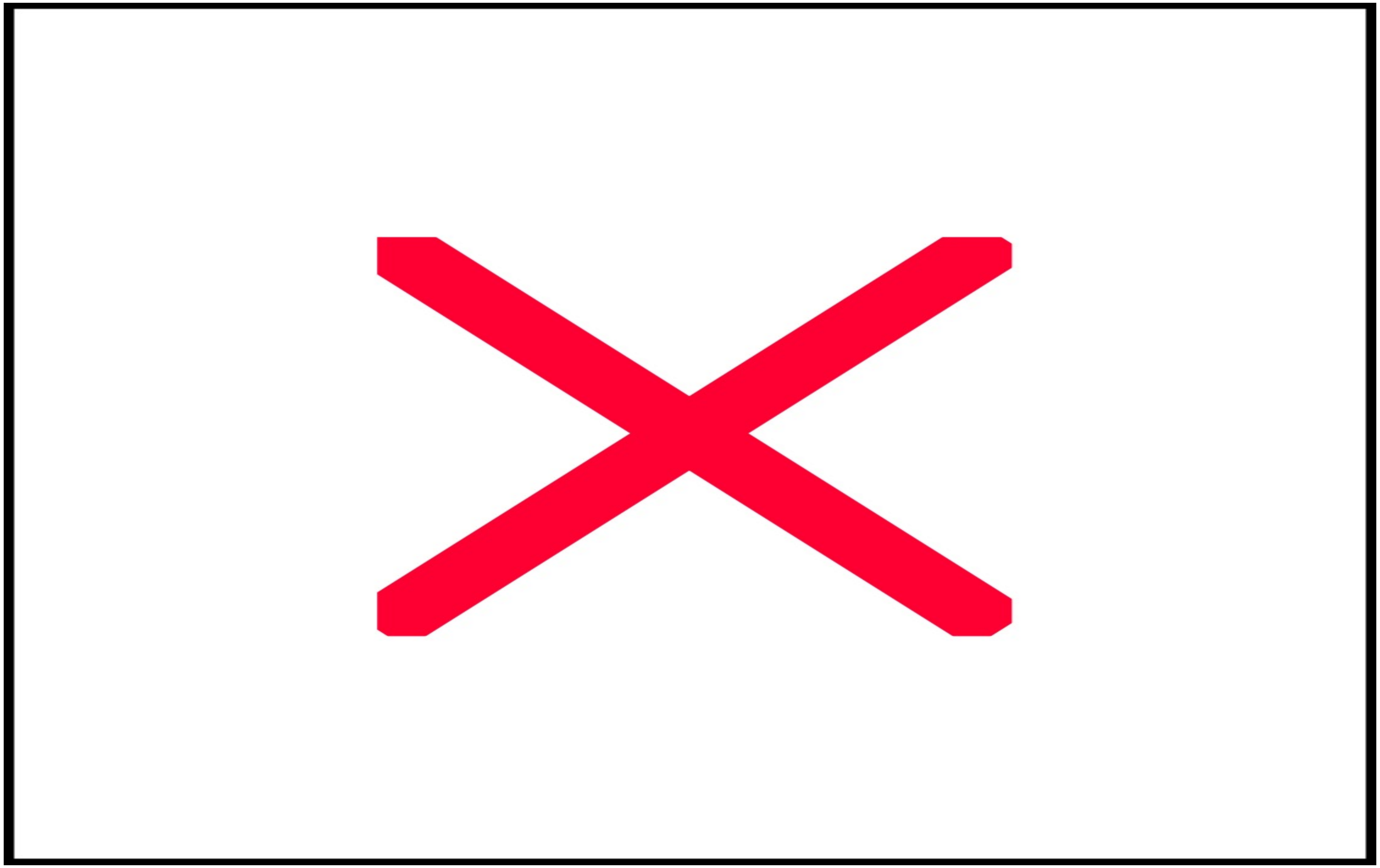
Determining the Constants Needed for Self-calibration

Thermistor Calibration



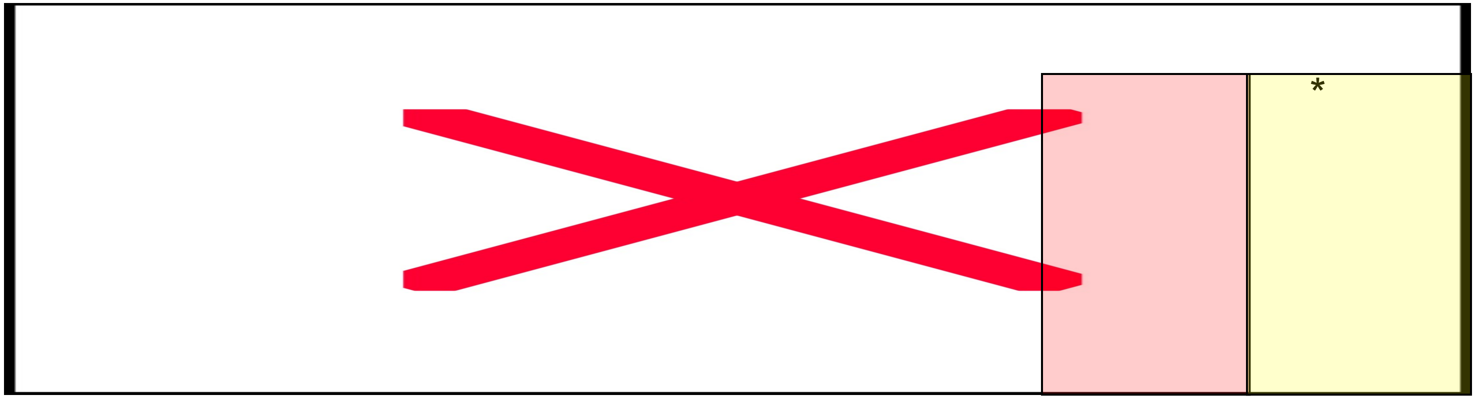
Determining the Thermistor Calibration Constants

Blackbody Temperature Uncertainty Budget

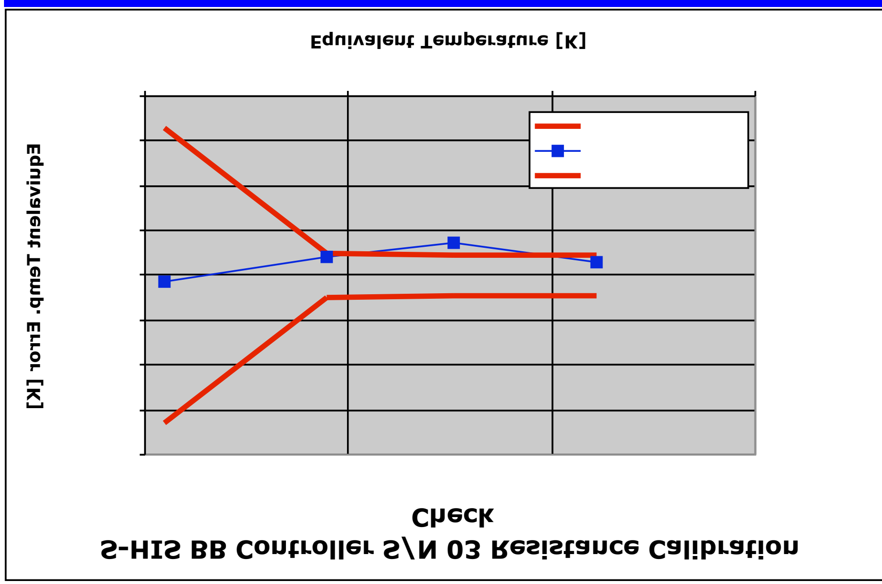


Budget ≤ 0.1 K

S-HIS Blackbody Controller Calibration Change Over 6 Year Period

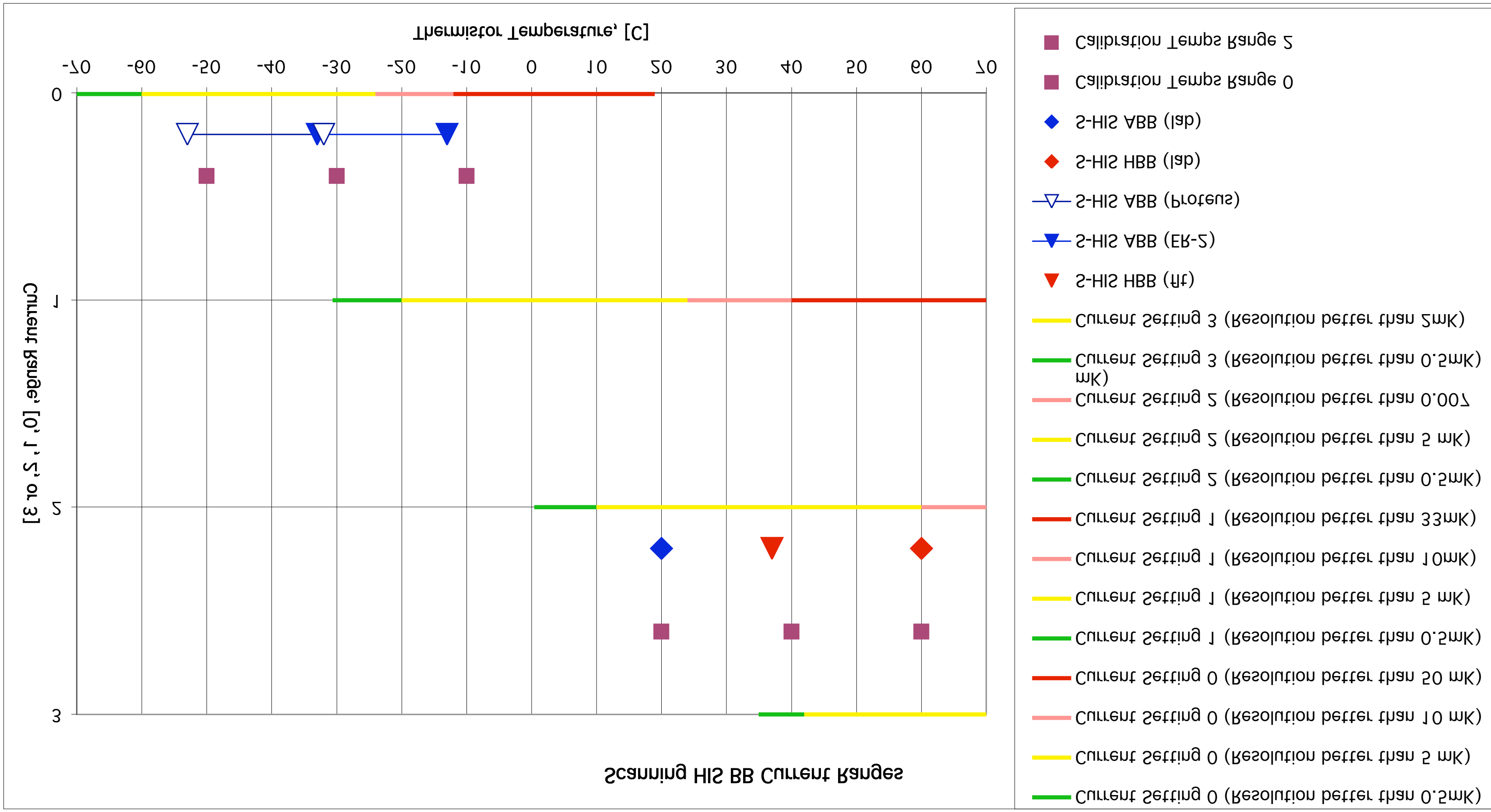


*Calibration Resistors (Rcal) measured using Agilent 7458A DVM, with traceabilty to NIST



- Calibration results shown are from tests conducted at lab temperatures (20 ° C).
- Original Calibration testing with electronics at -50° C, yielded <1 mK differences from lab temperature tests.

S-HIS Blackbody Calibration Temperatures



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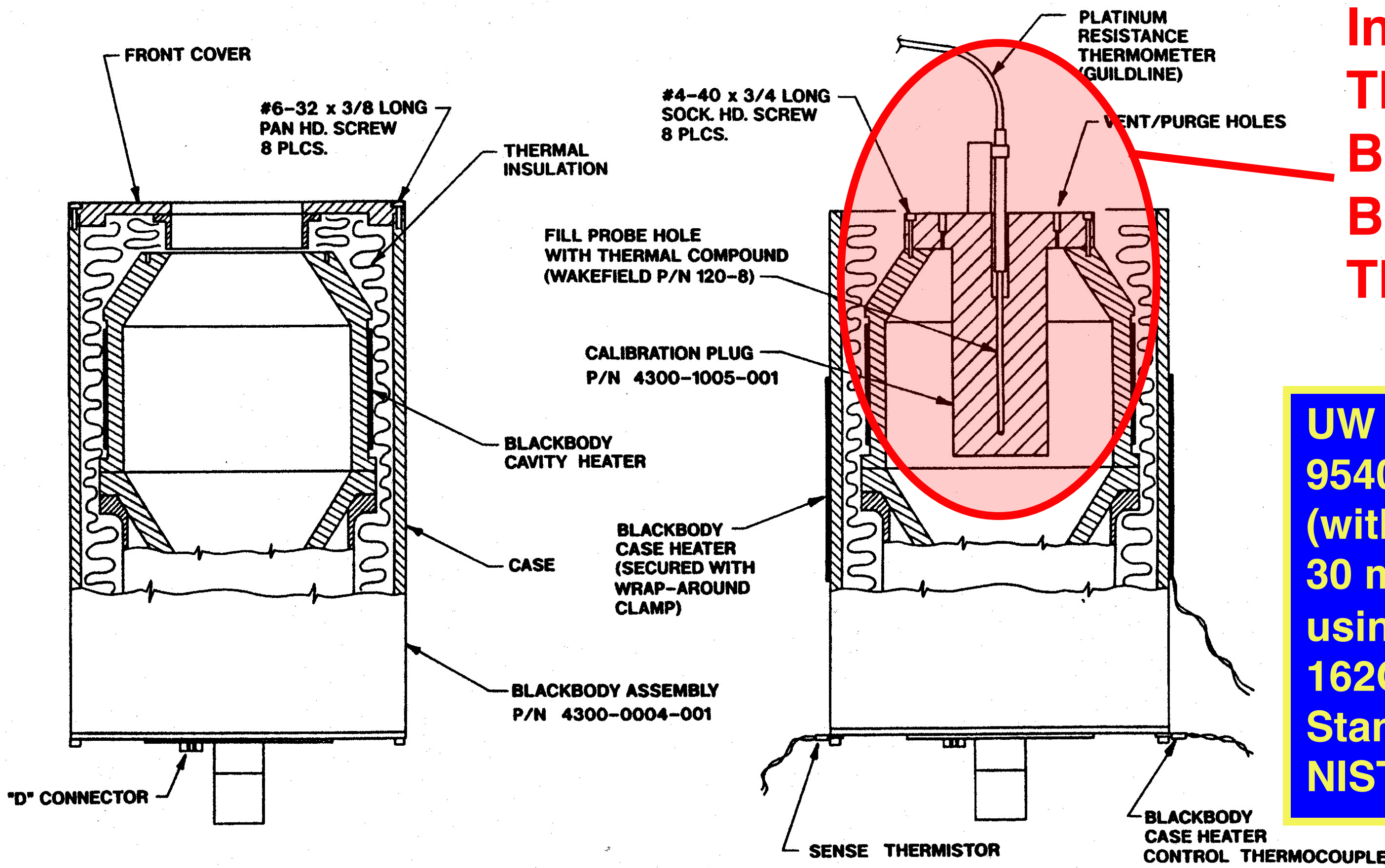
S-HIS Blackbody Temperature Calibration-Probe Traceability & Configuration



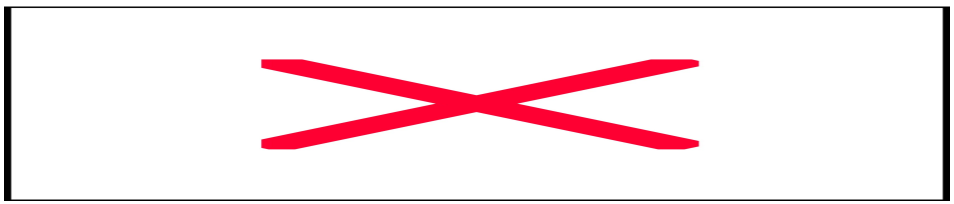
Insures Excellent Thermal Coupling Between PRT and Blackbody Thermistors

UW SSEC Guildline 9540 PRT is calibrated (with an uncertainty of 30 mK) at the factory using a Rosemont 162CE SPRT Primary Standard Traceable to NIST.

Standard Configuration | **Calibration Configuration**

End-to-end System Calibration (1)

- A minimum of three points (R_i,T_i) are collected and fit to the standard Steinhart and Hart Thermistor relationship:



- At each calibration temperature:
  - The T_i come from the Calibration Probe
  - The R_i come from the Blackbody Controller, using the Self Calibration.

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End-to-end System Calibration (2)

Regression fit to points (R_i, T_i),
when more than 3 points are available:

Thermistor Calibration Change Over 3 Year Period

Emissivity

S-HIS BB Radiance Model

$$R(\lambda) = \varepsilon(\lambda) * B(T_{EFF}, \lambda) + (1 - \varepsilon(\lambda)) * B(T_{ENV}, \lambda)$$

where,

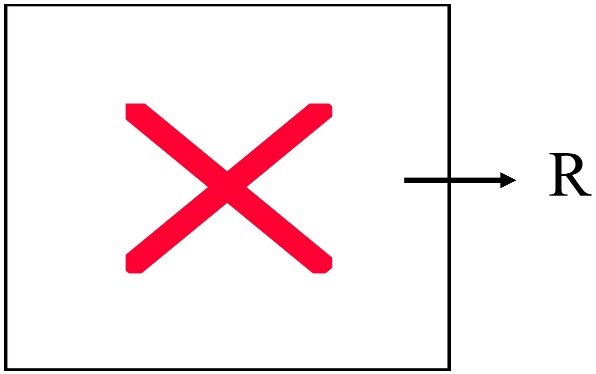
$B(T, \lambda)$ = Planck radiance at T and wavelength λ,

$\varepsilon(\lambda)$ = cavity isothermal emissivity,

$T_{EFF} = w_A * T_A + w_B * T_B$

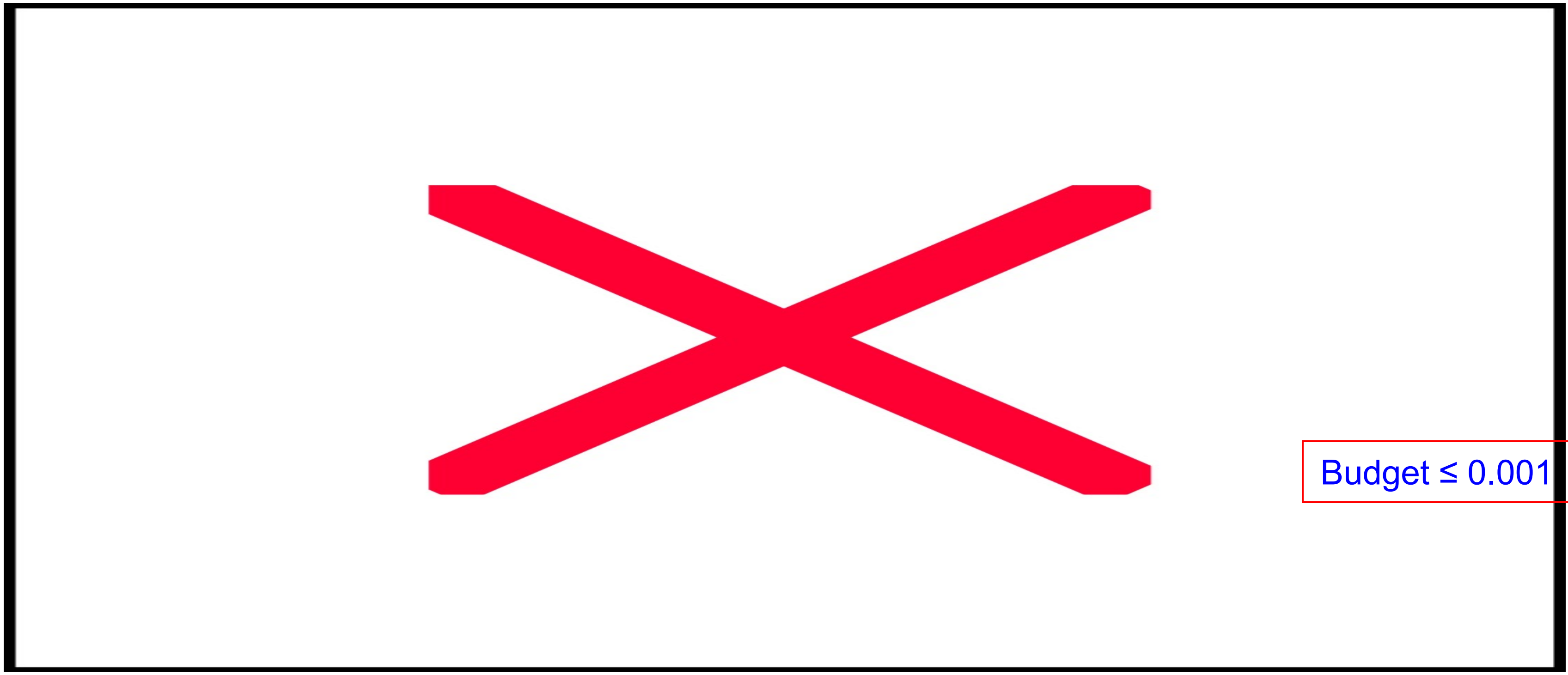
is the effective emitting temperature, and

T_{ENV} = environmental temperature.



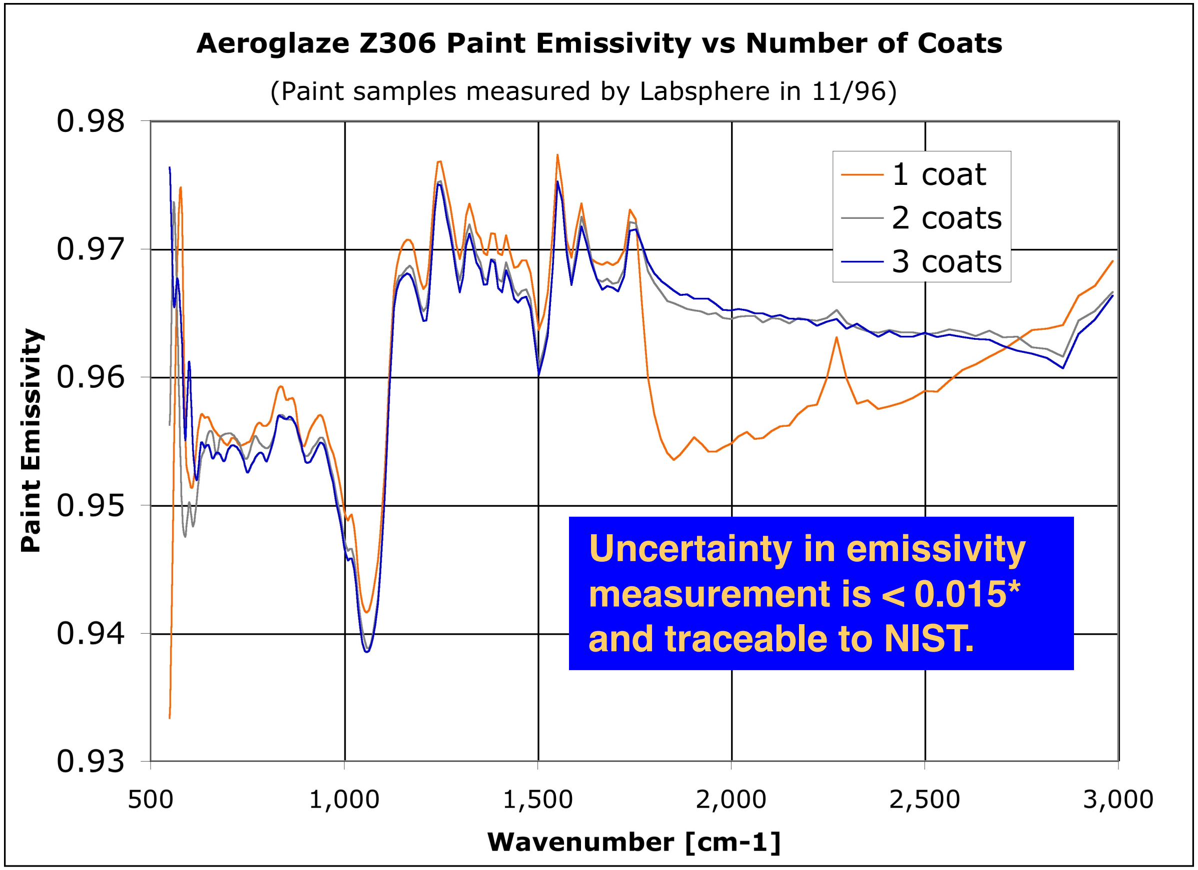
ε, w_A, and w_B are pre-computed using a numerical model while T_A, T_B, and T_{ENV} are measured in flight.

Emissivity Uncertainty Budget

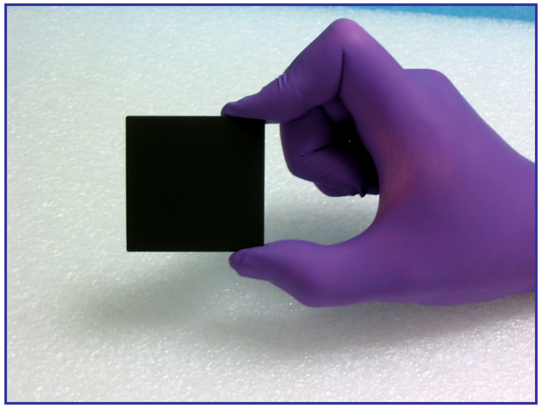


Budget ≤ 0.001

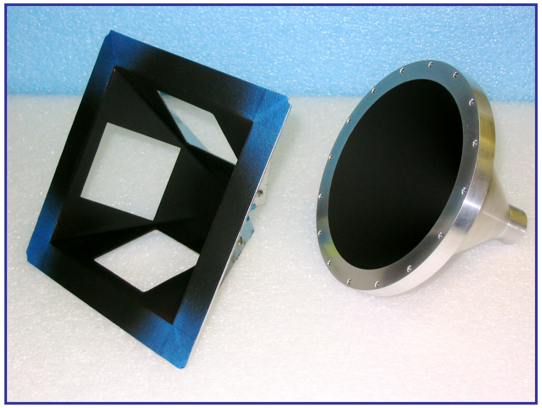
Paint Emissivity Measurement



Uncertainty in emissivity measurement is < 0.015* and traceable to NIST.



Blackbody Paint Witness Sample

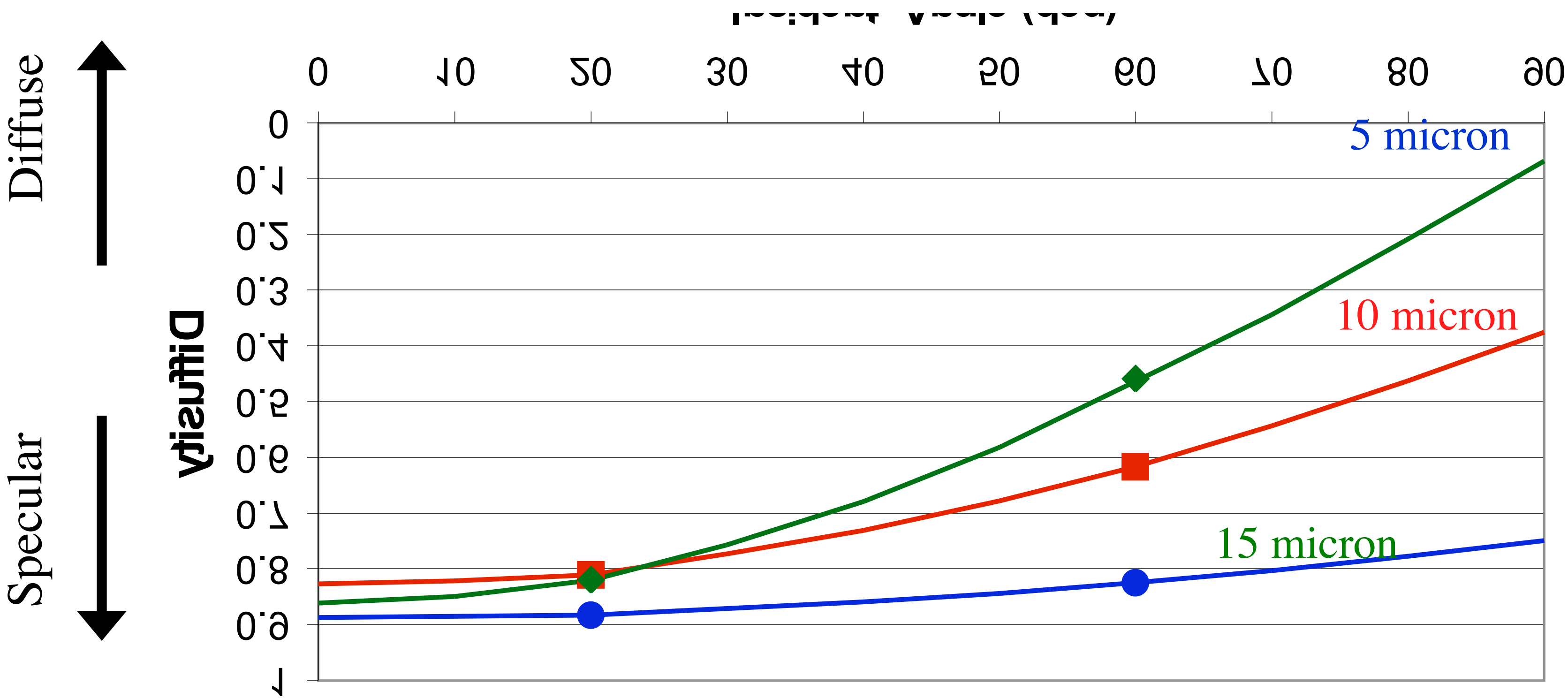


Witness Sample Holder "Mimics" Blackbody Cone Geometry

Paint application variation is taken to be < 1% (3 sigma) of the paint emissivity.

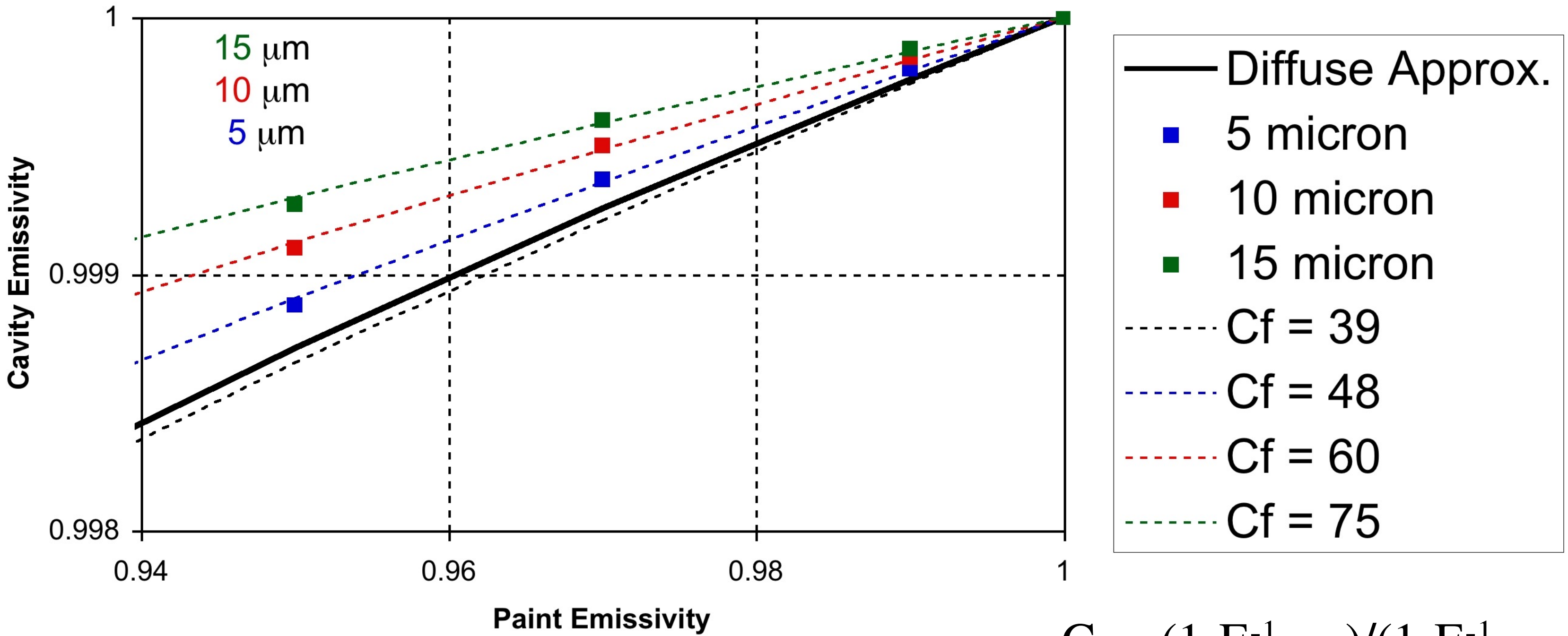
**Labsphere does not quote an accuracy for high emissivity samples. Stated value is conservative. By comparison, NIST stated accuracy is < 0.004*

Aeroglaze Z306 Diffusity vs. Angle



Paint diffusity for Aeroglaze Z306 estimated from published values (Persky, Rev. Sci. Instrum., 1999).

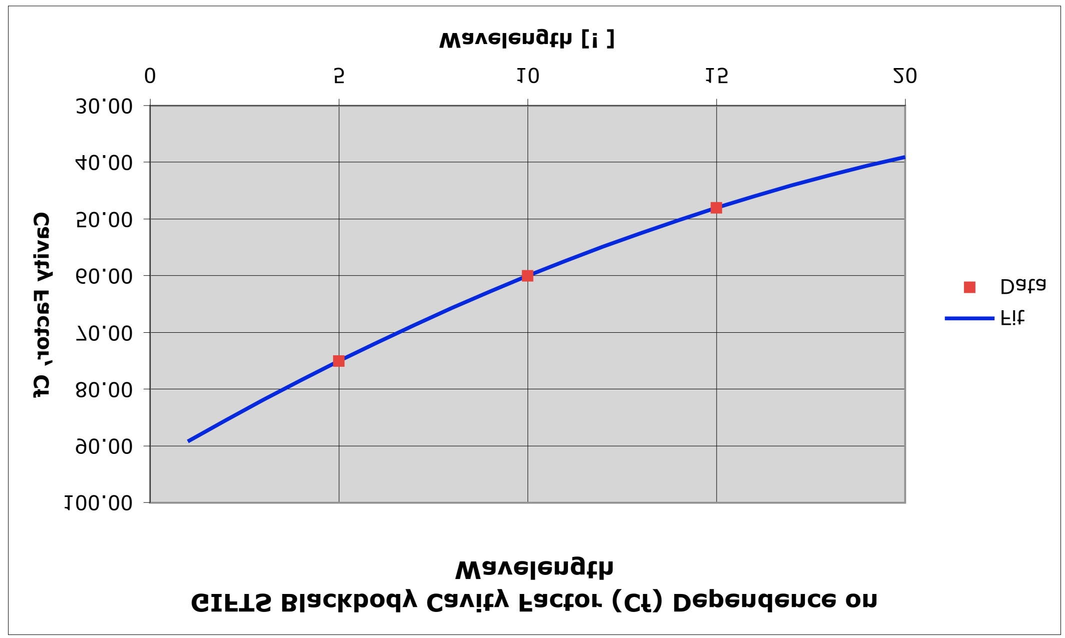
Isothermal Cavity Emissivity (Aeroglaze Z306)



$$C_f = (1-E^{-1}_{paint})/(1-E^{-1}_{cavity})$$

The Monte Carlo results can be summarized using a "cavity factor" which is a convenient parameterization of the relation between paint and cavity emissivity.

Quadratic Fit of Cavity Factor vs Wavelength



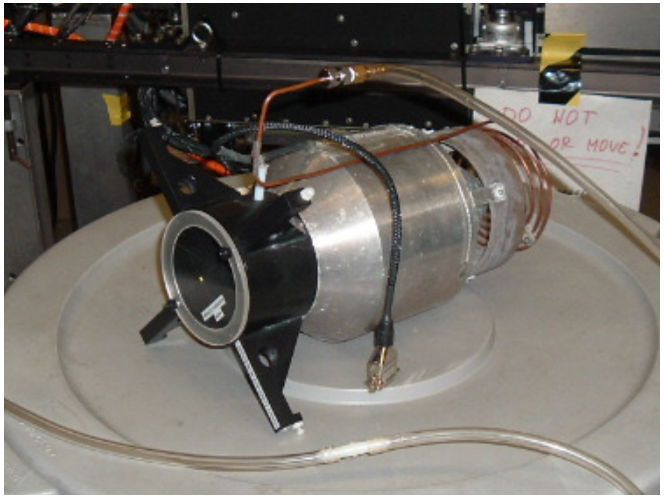
S-HIS Blackbody Cavity Isothermal Emissivity

Paint emissivity (Ep) is the measured S-HIS Blackbody Witness Sample data, and cavity factor (Cf) is the quadratic fit of the Monte Carlo Cf vs Wavelength model results.

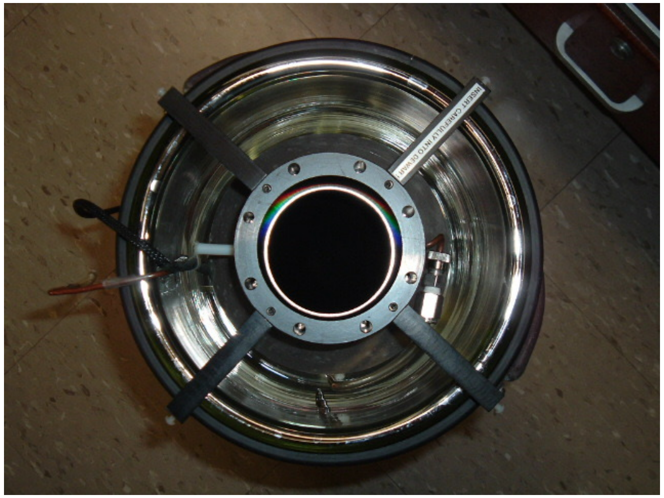
End-to-End Verifications & Checks

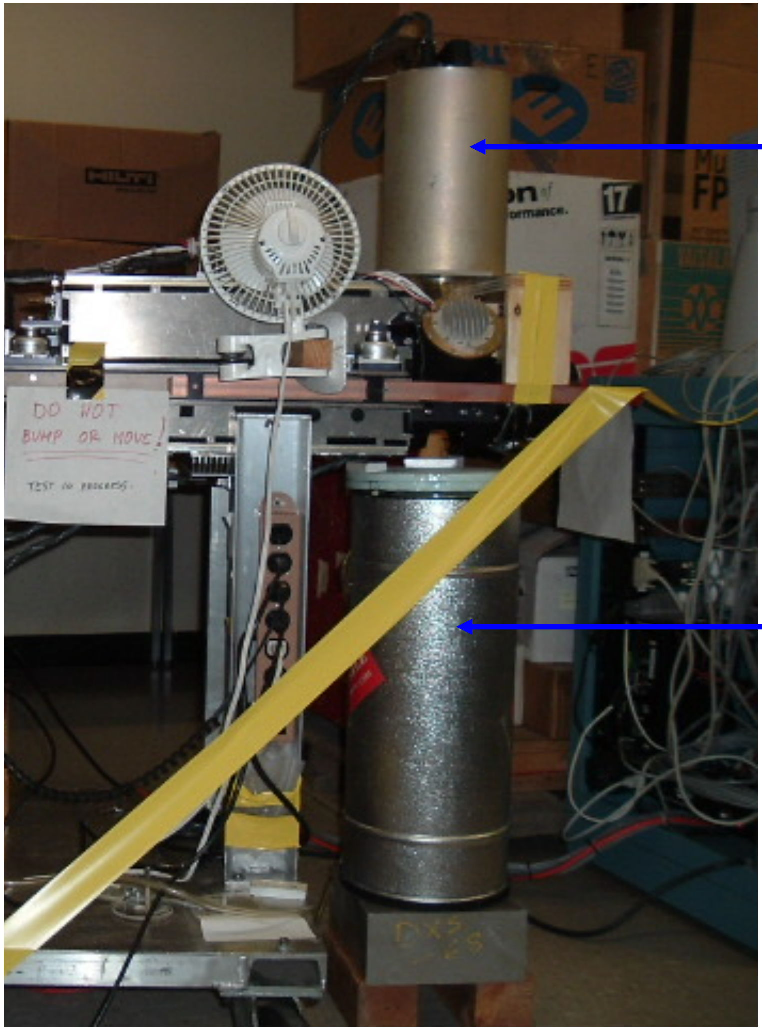
UW Pre-Mission Cal. Verification

UW Ice BB



BB In Ice Slurry



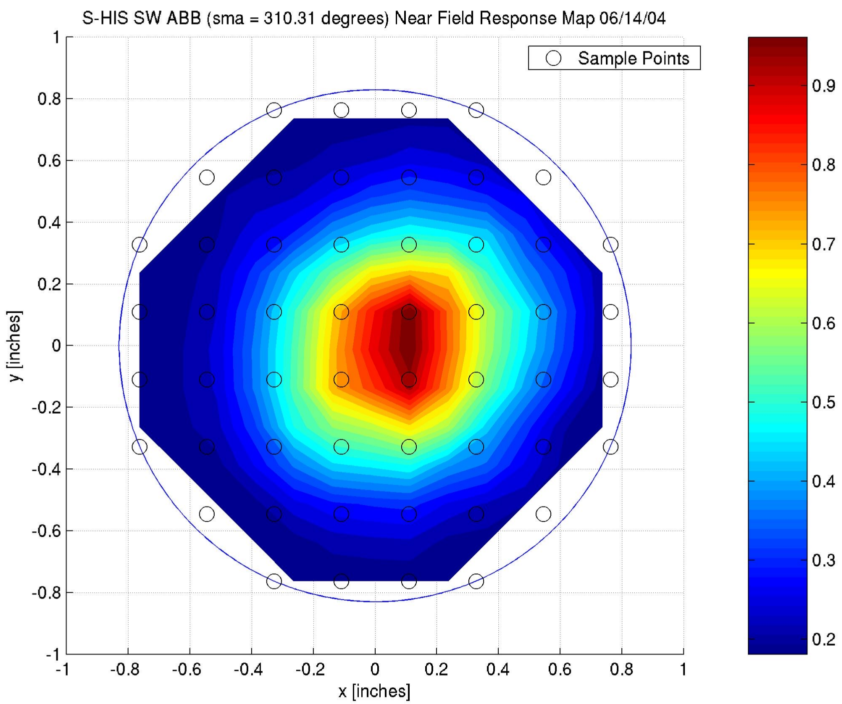


318K AERI BB

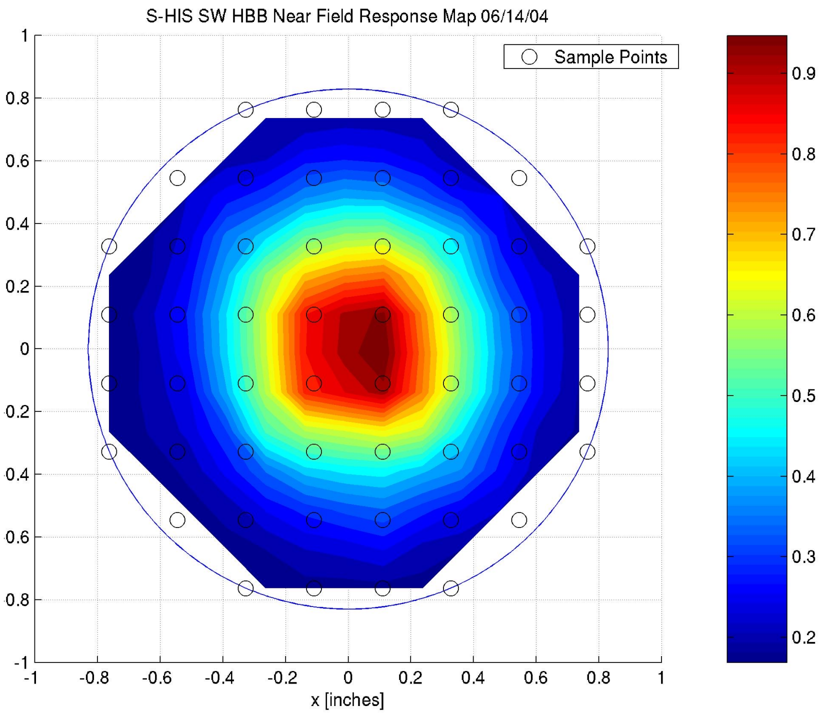
273 K AERI BB

UW Pre-Mission Cal. Verification

- Check alignment of on-board and external BBs.

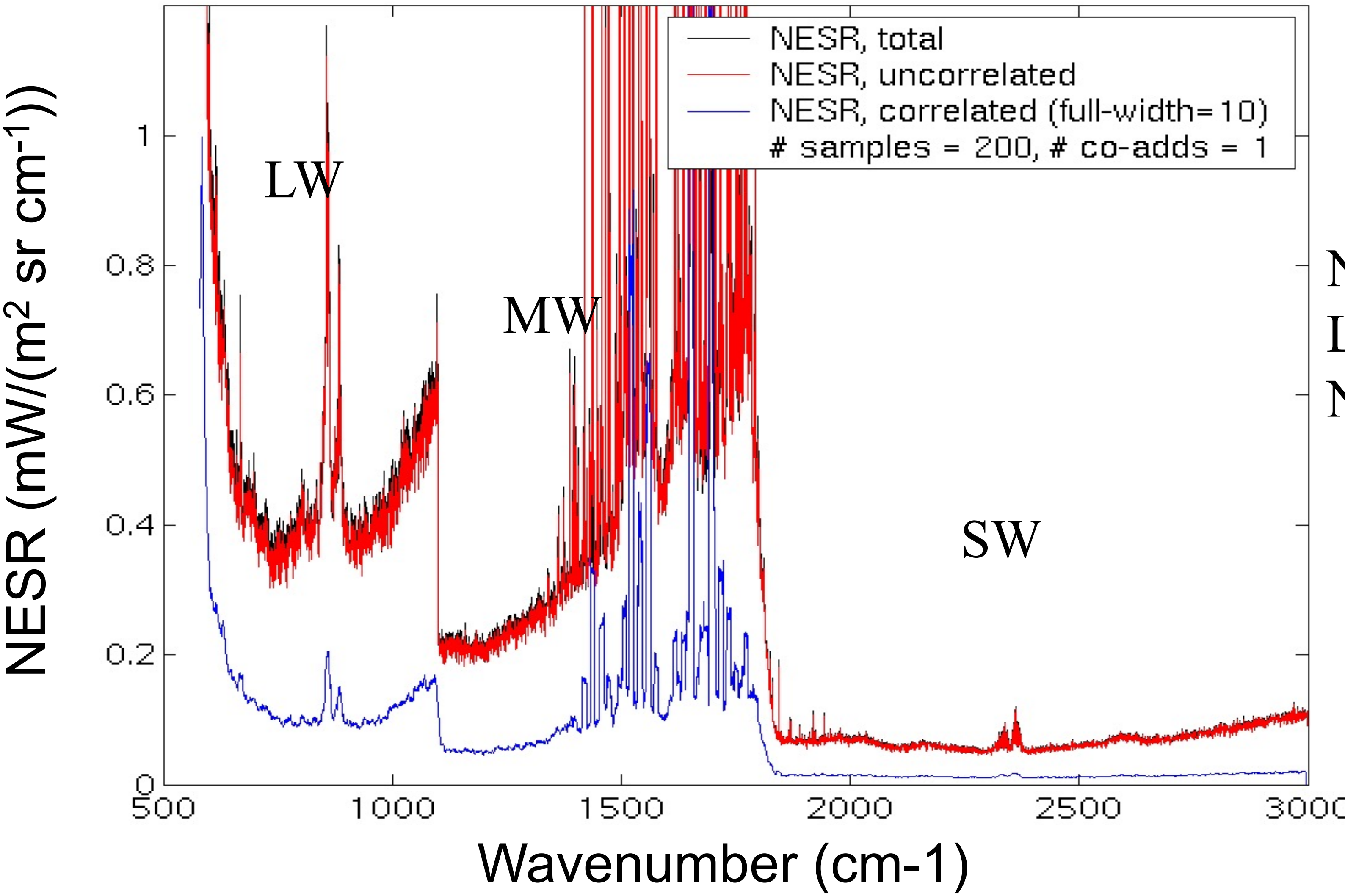


Cold BB Position



Hot BB Position

UW Pre-Mission Cal. Verification

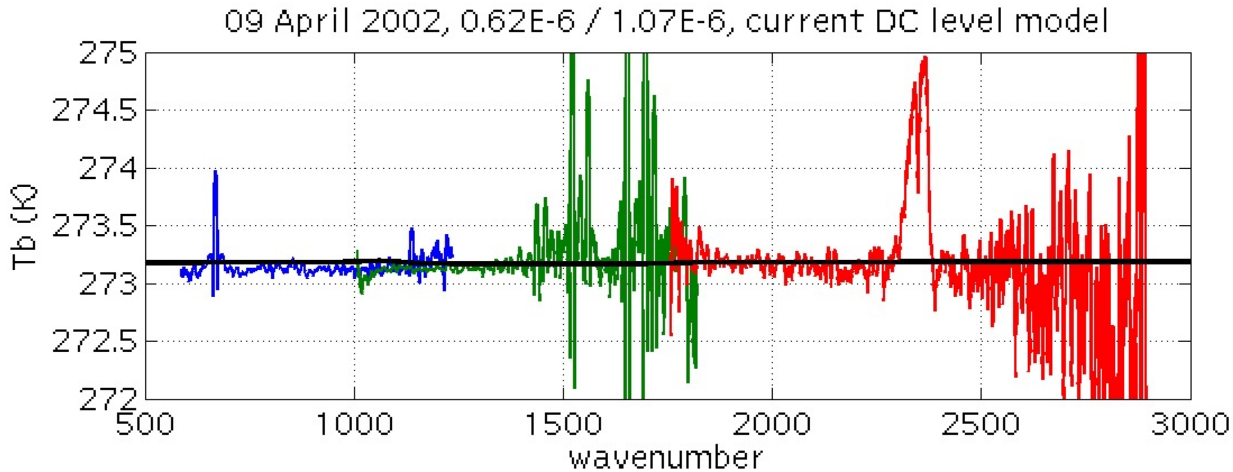


Noise Levels Nominal

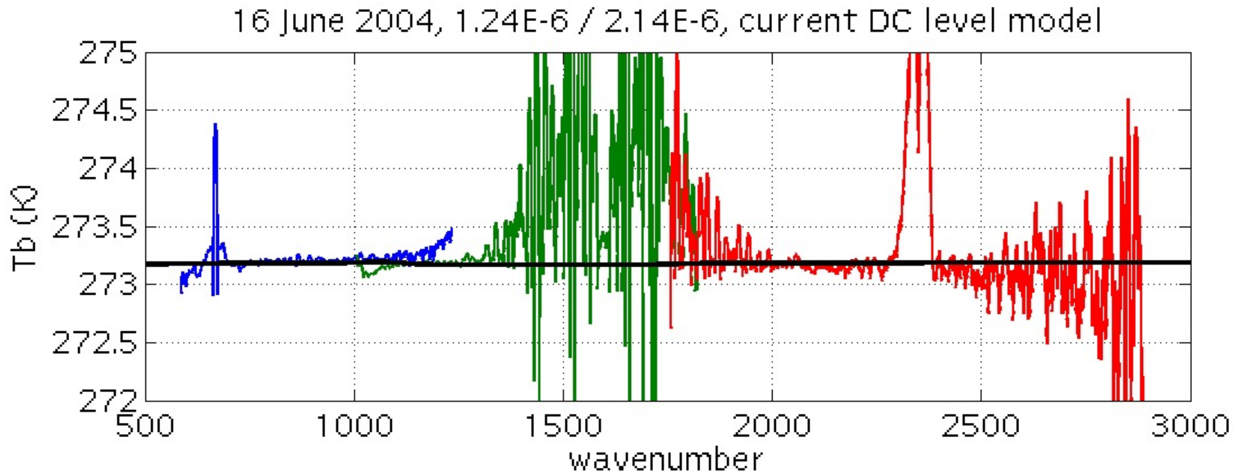
LW & MW Nonlinearity Refinement:

- **Excellent agreement in Linear SW band (< 0.1 K).**
- **Used Ice BB data to determine a_2 nonlin coefficient for LW & MW**

09 April 2002 case
preamp gains = X
CdTe IFG window
LW a2 = 0.5*1.24E-6
MW a2 = 0.5*2.14E-6



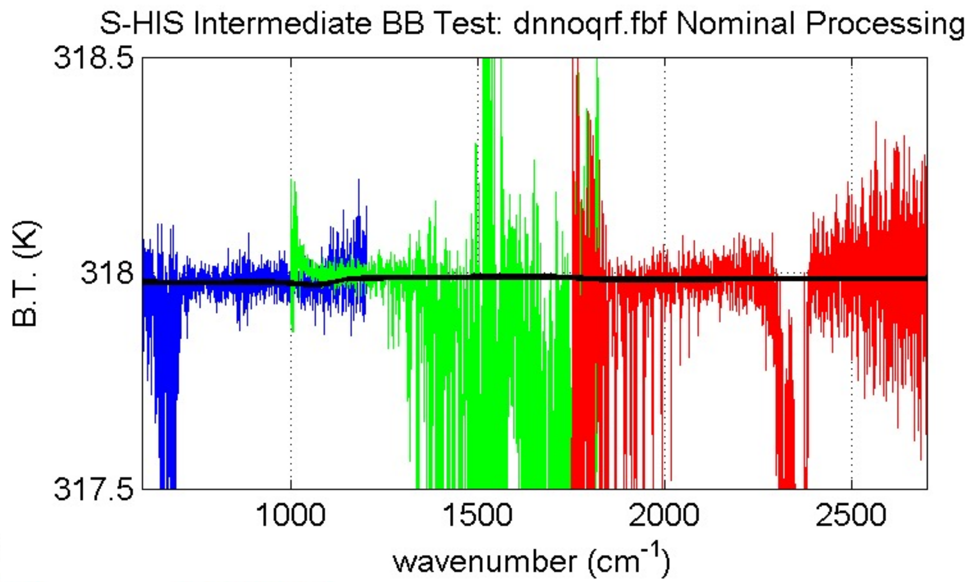
16 June 2004 case
preamp gains = X/2
ZnSe IFG window
LW a2 = 1.24E-6
MW a2 = 2.14E-6

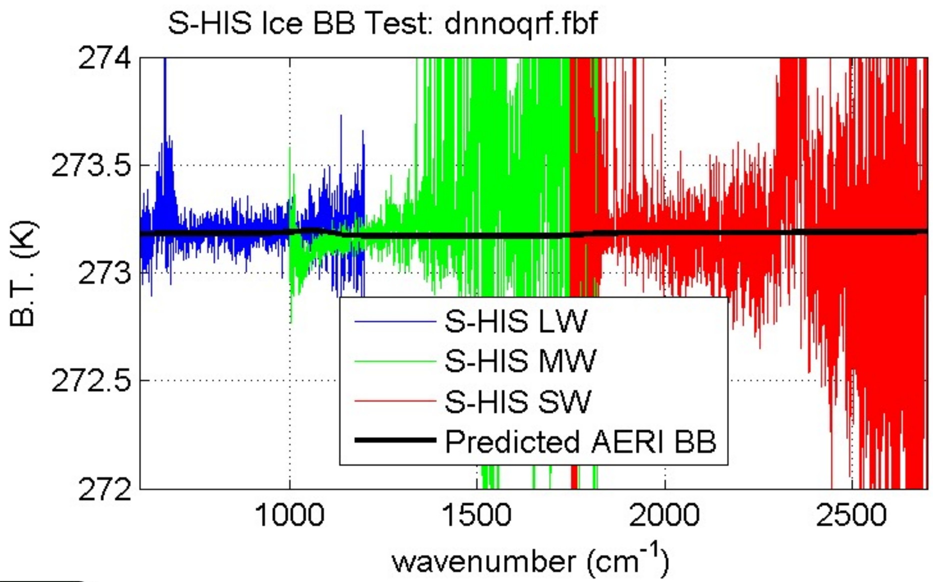


25 point smoother applied to displayed spectra
NLC squared terms not included

UW Pre-Mission Cal. Verification

Intermediate Temperature BB Test (318.0 K)

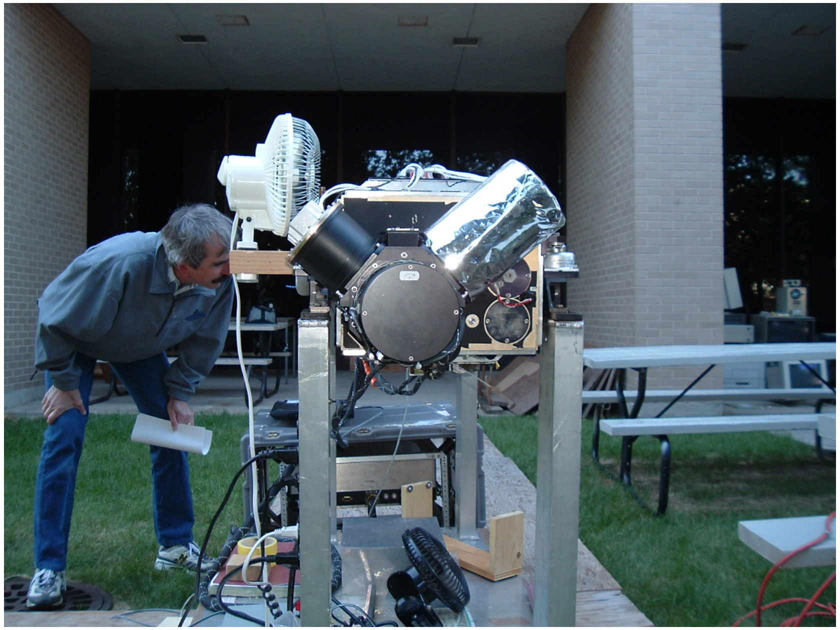




UW Ice Temperature BB test (273.15 K)

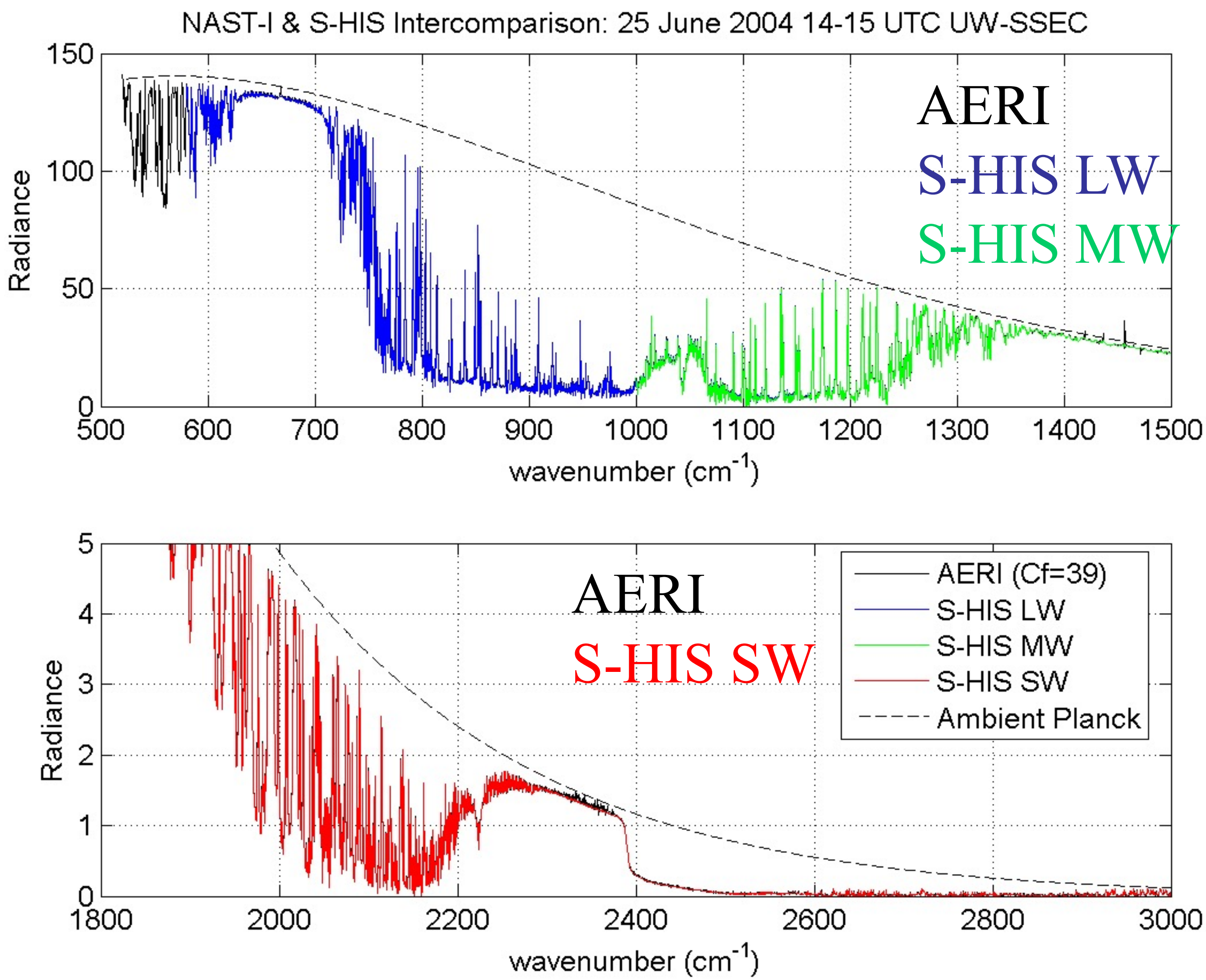
(16 June 2004, UW-SSEC)

UW Pre-Mission Cal. Verification



- A groundbased uplooking comparison was performed between the Scanning-HIS and the UW Atmospheric Emitted Radiance Interferometer (AERI) built for the U.S. DOE ARM program.
- Excellent agreement was obtained showing that S-HIS (on the ground) has an absolute accuracy consistent with the AERI systems.

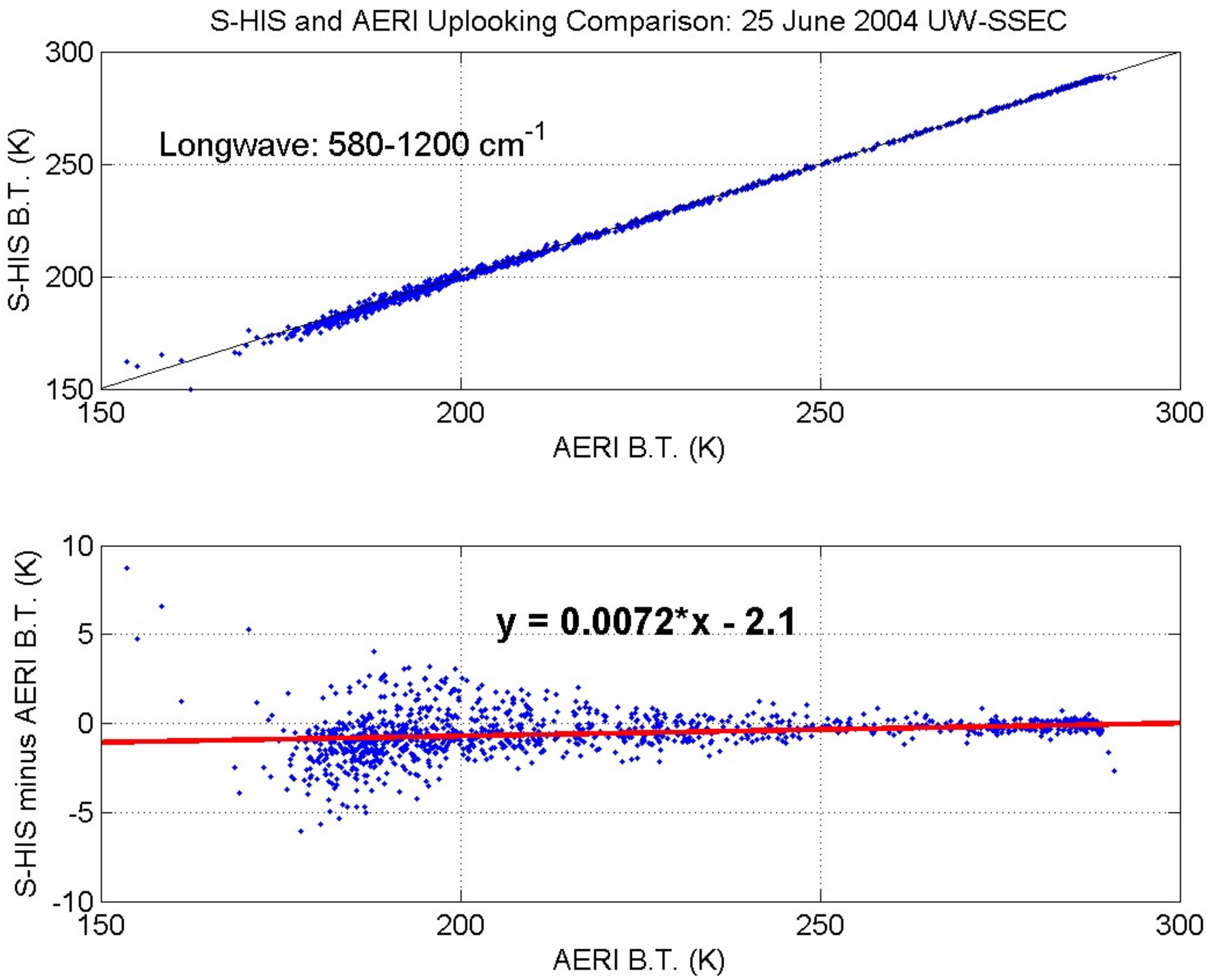
UW Pre-Mission Cal. Verification



Uplooking **AERI** data And Uplooking **S-HIS** data Show Excellent Agreement!

Consistent With Expected Calibration Reproducibility.

UW Pre-Mission Cal. Verification

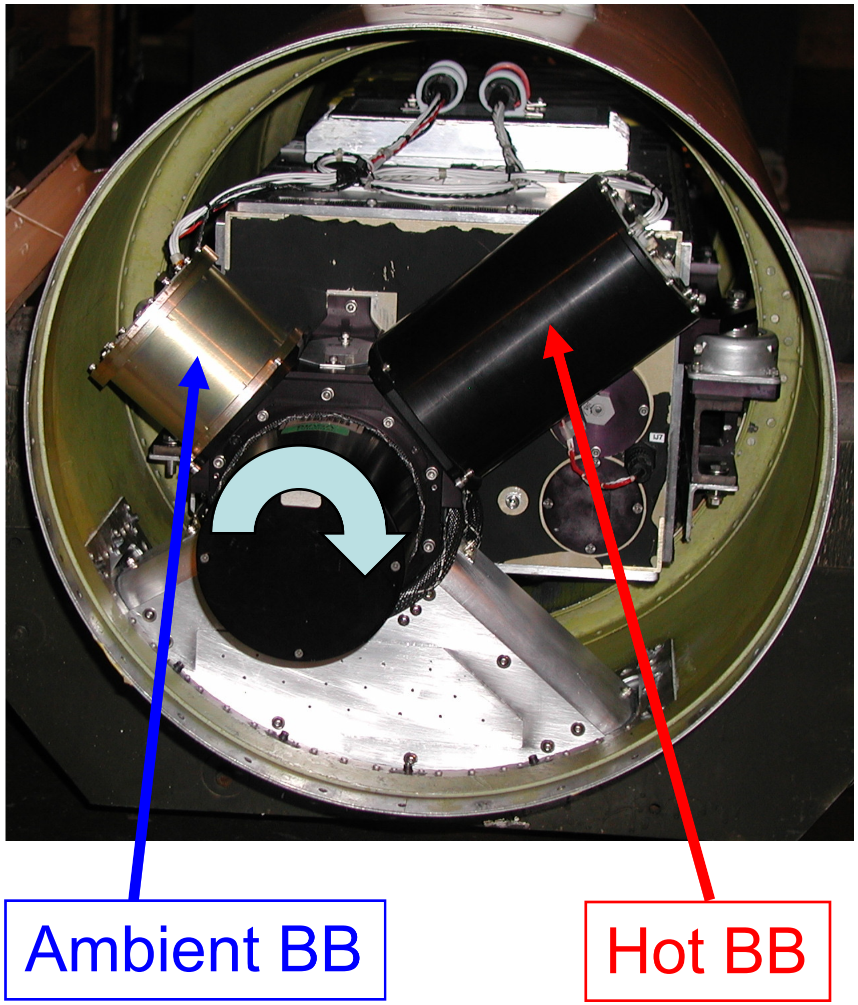


Observed Tb Agreement Better than 1% over the Range of Atmospheric Conditions Encountered (175 – 290 K)

In-flight Calibration Checks

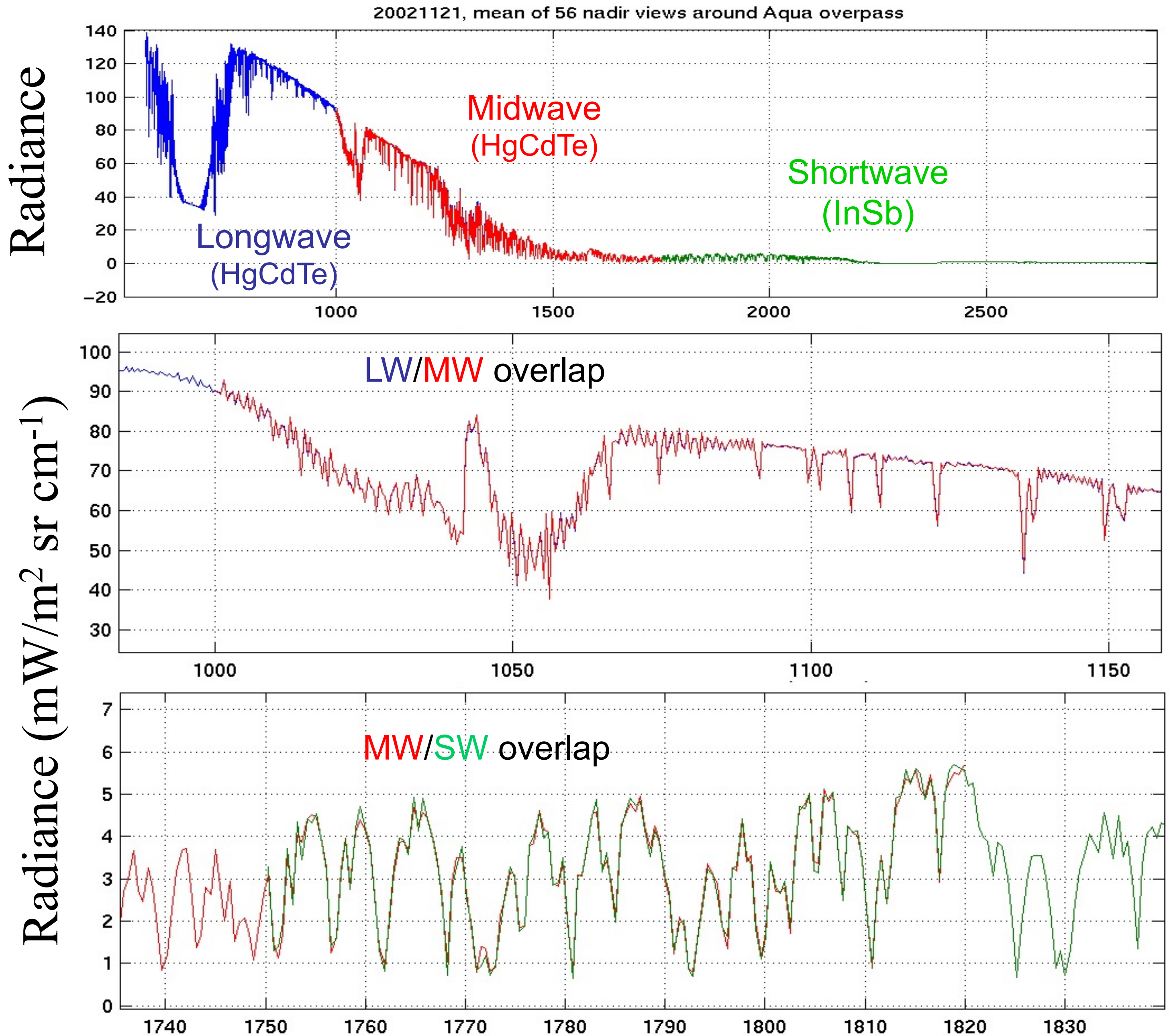
- **Hot and Cold onboard BBs viewed every x-track scan (12 sec).**
- **LW/MW and MW/SW bands overlap in spectral coverage.**
- **Uplooking calibrated radiance at altitude should be non-negative.**

In-flight Check: Calibrated BB views



- Hot and Cold onboard BBs are viewed about every 12 seconds during the flight.
- The on-board BB views are used in a two point calibration to characterize instrument offset and gain changes during the flight.
- Individual on-board blackbody views are calibrated to check calibration reproducibility and to provide a measure of data quality (NESR, mirror tilt, phase).

In-Flight Check: Band Overlap

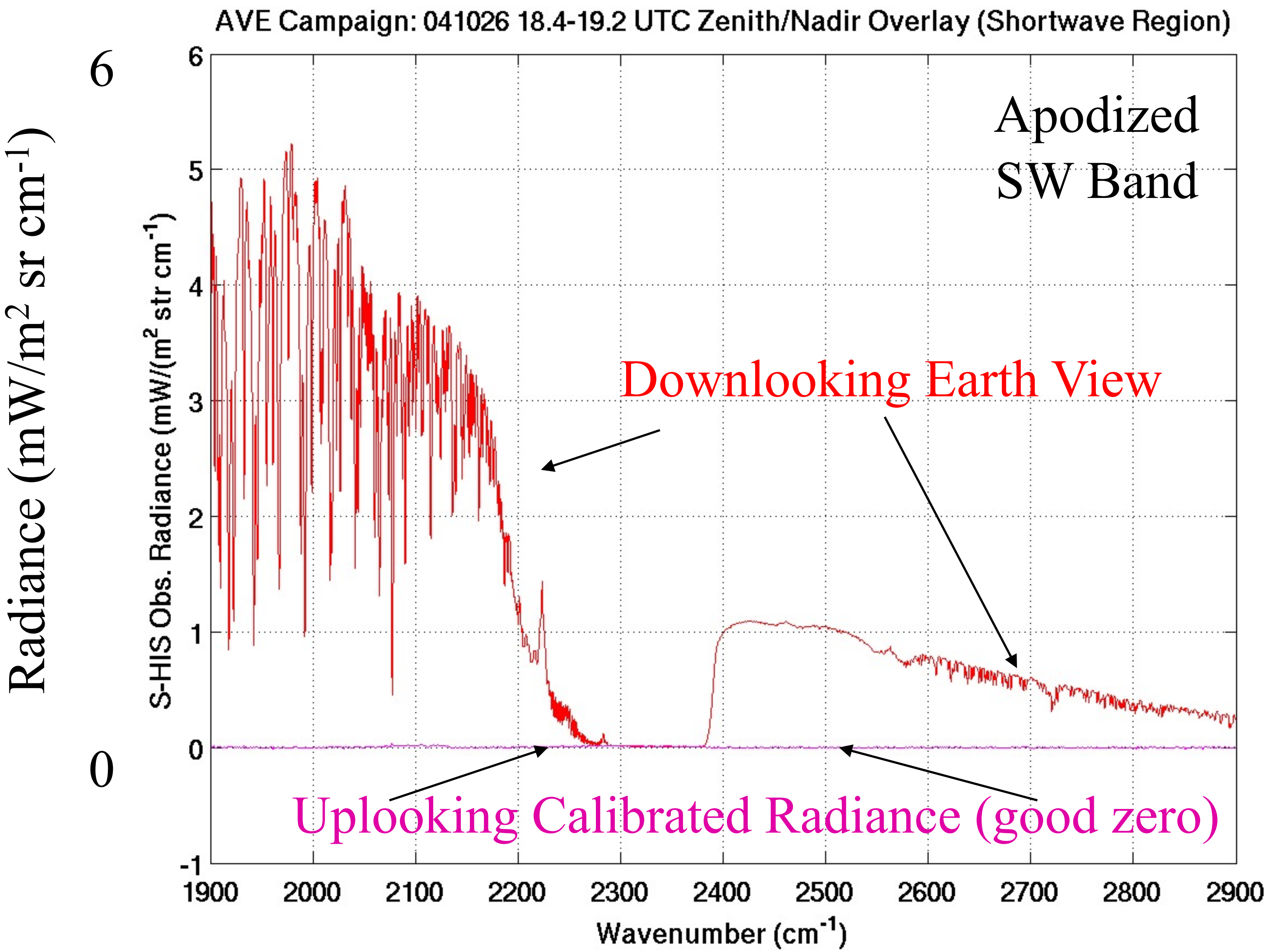


LW & MW Require Nonlinear Correction

LW/MW Band Overlap (< 0.1 K)

MW/SW Band Overlap (noisy)

In-flight Check: View to Cold Scenes

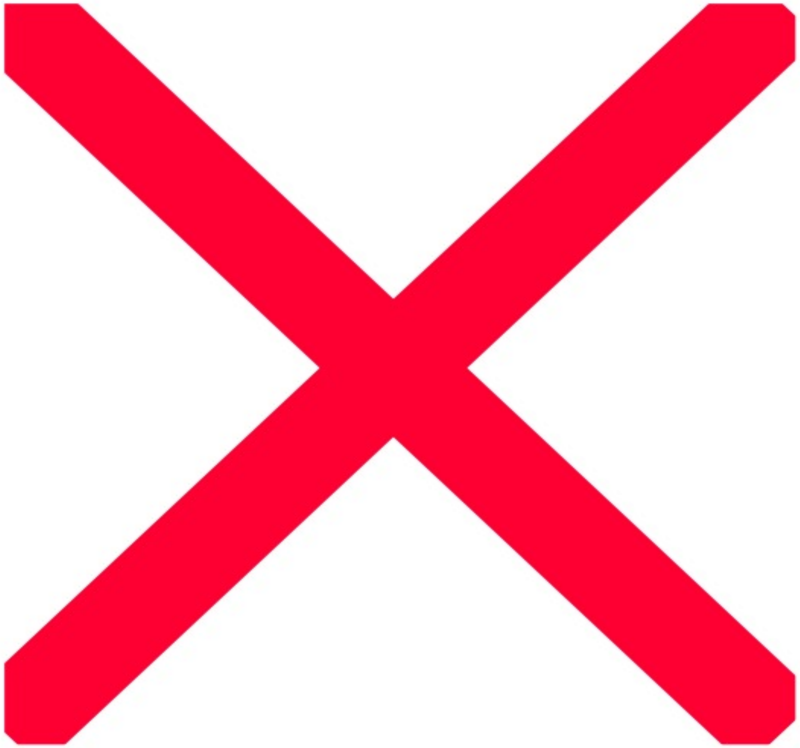


Apodized Radiance Should Be Non-Negative.

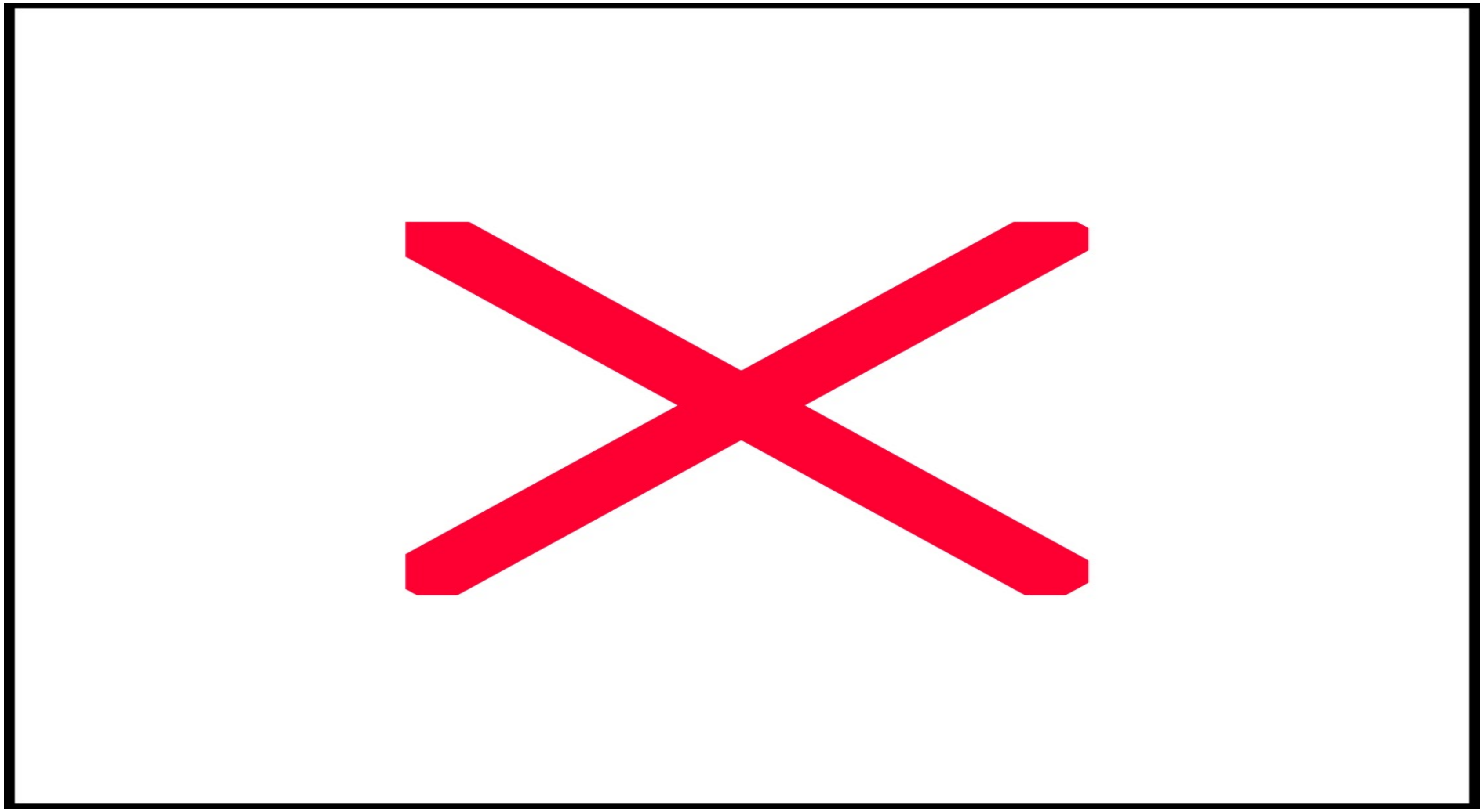
Plans For Comparison With NIST TXR

S-HIS / TXR Side-by-side Comparison Both Viewing AERI Blackbody

Tests will be conducted in a Temperature Chamber at flight temperatures



S-HIS / TXR Side-by-side Comparison Both Viewing AERI Blackbody



TXR/S-HIS CHAMBER ARRANGEMENT