NASTER Workshop

Calibration

NASA LaRC

July 10 & 11, 2003

Topics

- Expected NASTER calibration performance
- Requirements flow-down to NASTER Blackbodies
- NAST/S-HIS Blackbody Subsystem proposed for NASTER
- NAST & S-HIS Calibration Performance Review

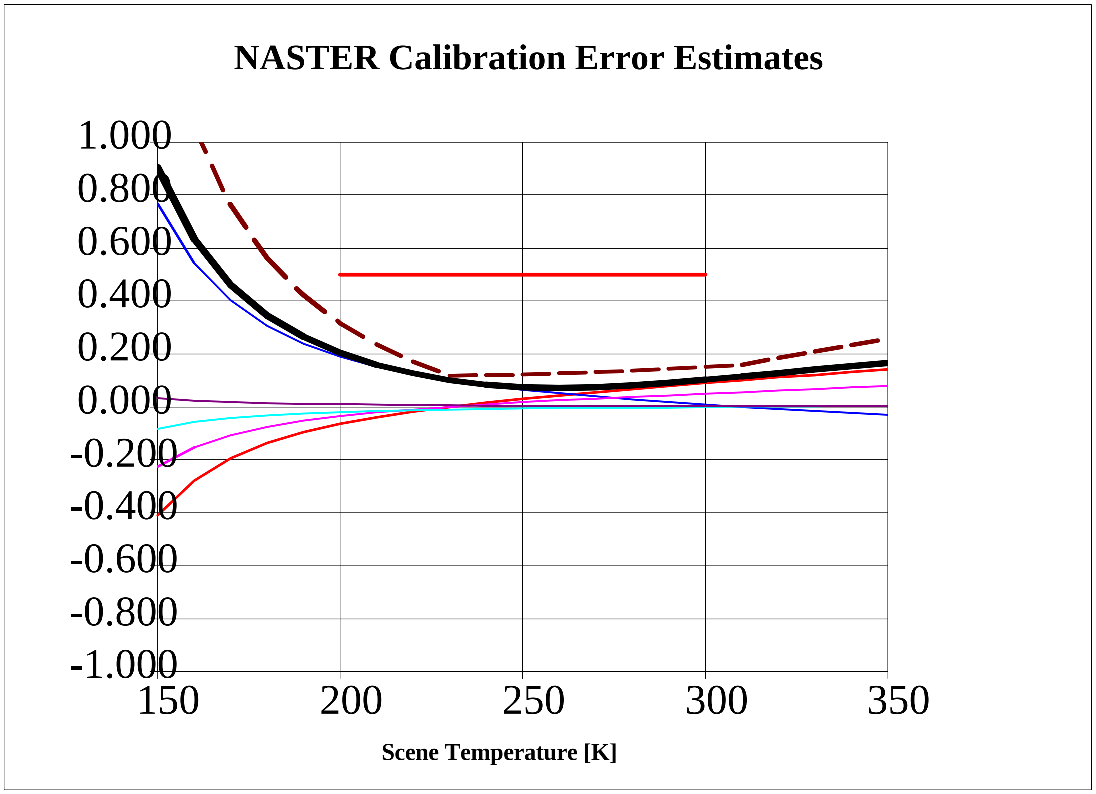
Expected NASTER Calibration Performance

NASTER Instrument Calibration Relationship

$$N = (B_H - B_A)\mathrm{Re}\left(\frac{C_S - C_A}{C_H - C_A}\right) + B_A$$

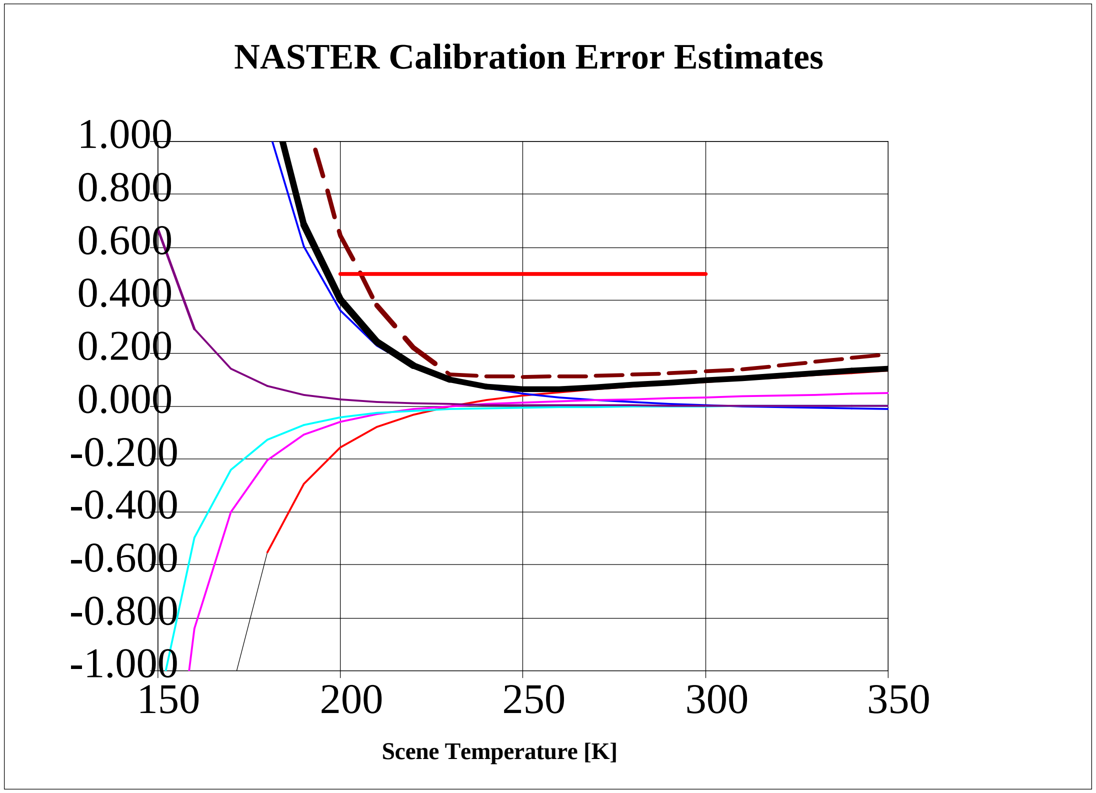
- N is the calibrated spectral radiance
- B_H is the effective Planck emission for the hot blackbody
- B_A is the effective Planck emission for the ambient blackbody
- C_S is the complex spectrum for the sky view
- C_H is the complex spectrum for the hot blackbody view
- C_A is the complex spectrum for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

Expected Calibration Errors at 770 cm^{-1}



Input Parameters			**Uncertainties**		
wn	**770**	Wavenumber, [cm-1]			
Thbb	**310**	Temp. of Hot Blackbody, [K]	^{2}Thbb	**0.1**	[K]
Tcbb	**230**	Temp. of Cold Blackbody, [K]	^{2}Tcbb	**0.1**	[K]
Tstr	**240**	Temp. of Structure Reflecting into BB's, [K]	^{2}Tstr	**5**	[K]
Ehbb	**0.999**	Emissivity of HBB, [-]	^{2}Ehbb	**0.001**	[-]
Ecbb	**0.999**	Emissivity of CBB, [-]	^{2}Ehbb	**0.001**	[-]

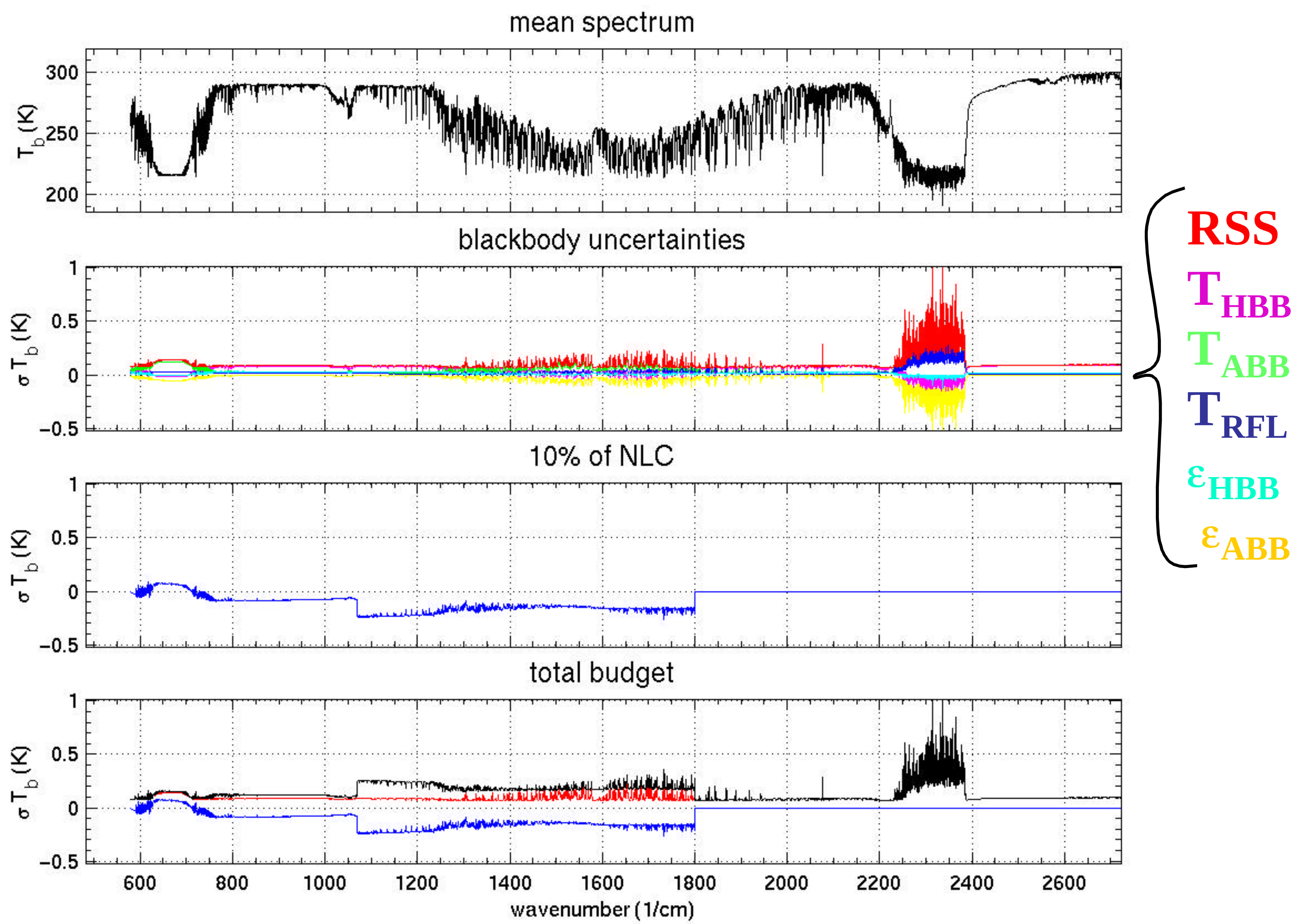
Expected Calibration Errors at 1600 cm^{-1}



Input Parameters			**Uncertainties**		
wn	1600	Wavenumber, [cm-1]			
Thbb	310	Temp. of Hot Blackbody, [K]	^{2}Thbb	0.1	[K]
Tcbb	230	Temp. of Cold Blackbody, [K]	^{2}Tcbb	0.1	[K]
Tstr	240	Temp. of Structure Reflecting into BB's, [K]	^{2}Tstr	5	[K]
Ehbb	0.999	Emissivity of HBB, [-]	^{2}Ehbb	0.001	[-]
Ecbb	0.999	Emissivity of CBB, [-]	^{2}Ehbb	0.001	[-]

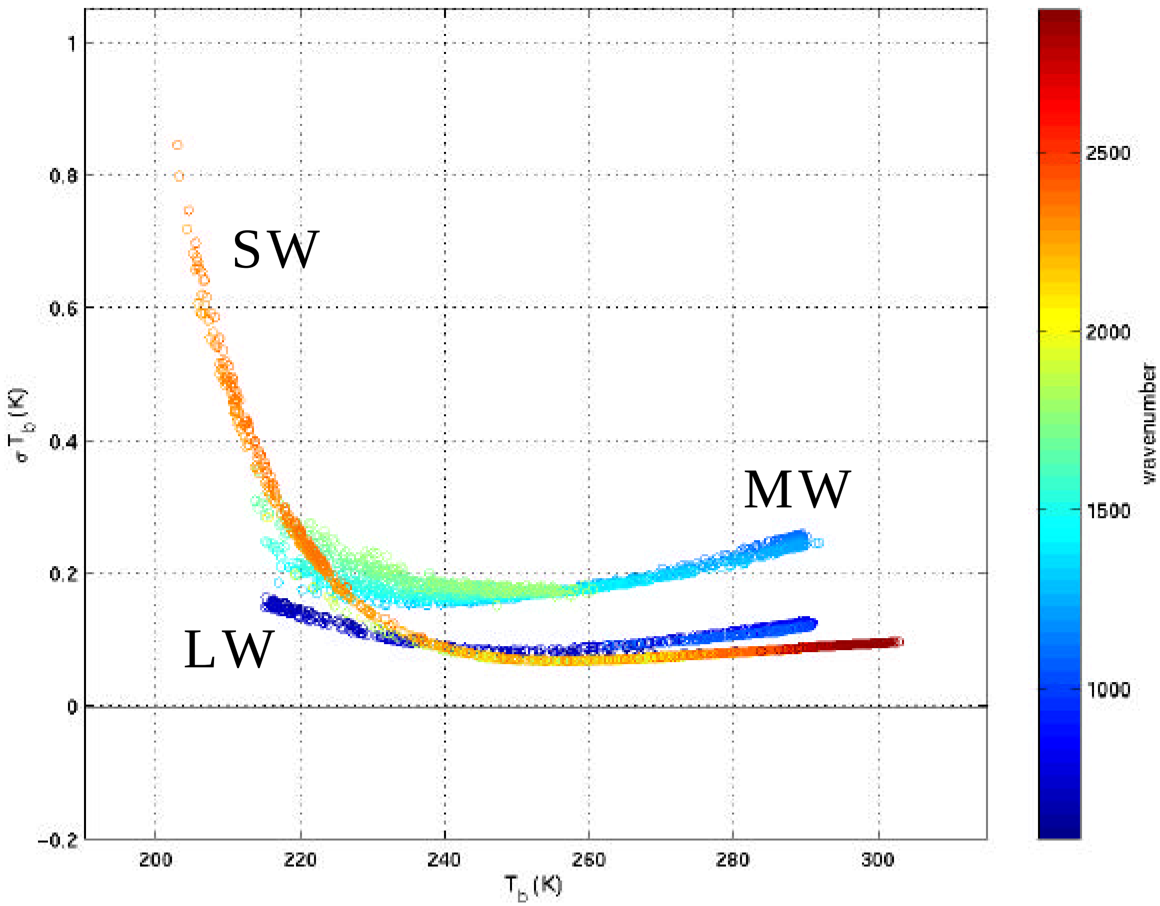
Scanning-HIS Radiometric Calibration Budget for 11/16 case

T_{ABB} = 227K, T_{HBB} = 310K



NASTER Expected Performance

T_{ABB} = 227K, T_{HBB} = 310K



Requirements Flow-down to NASTER Blackbodies

NASTER Blackbody Requirements (TBR)

The blackbody system requirements are (TBR):

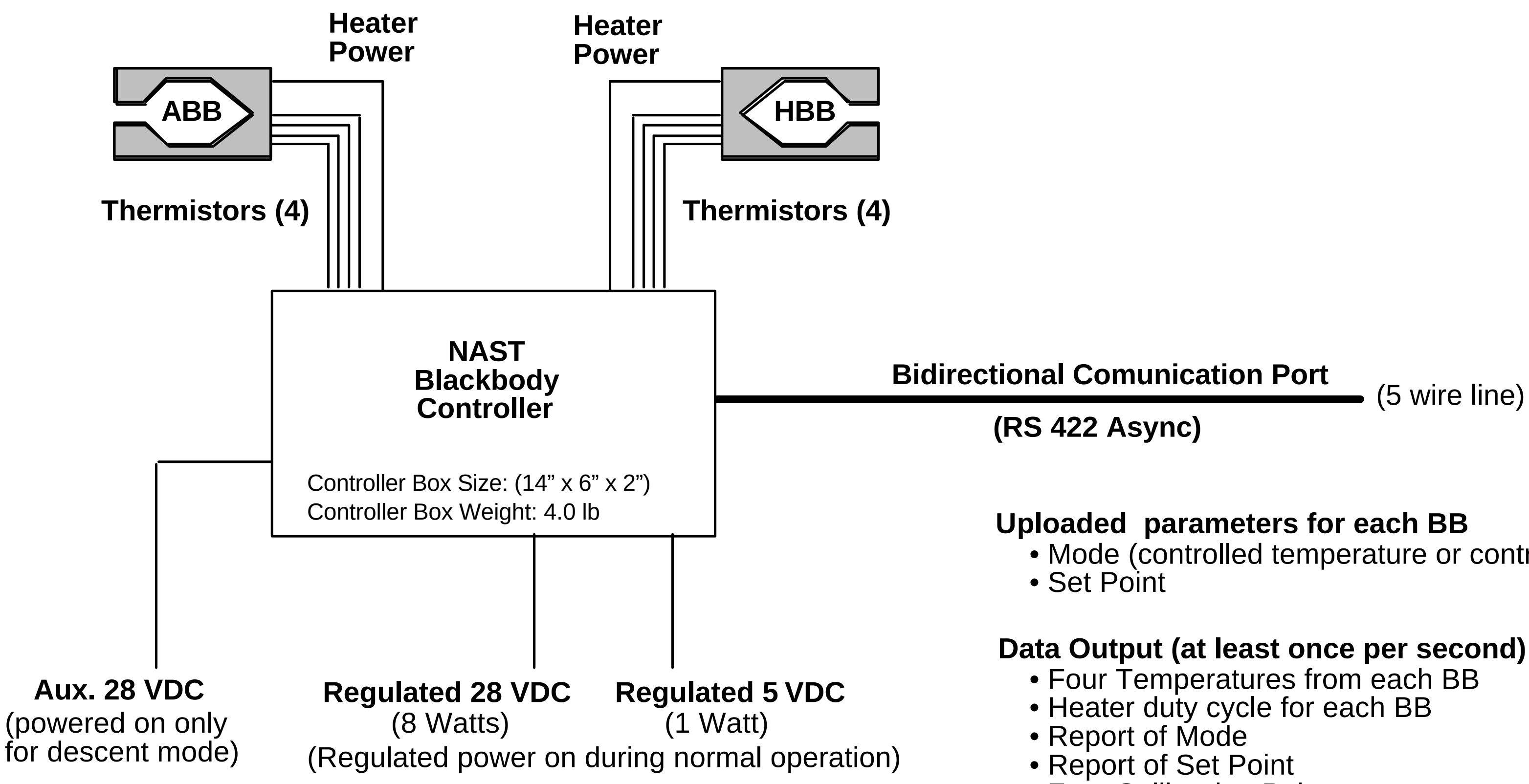
• Temperature knowledge:	±0.1 K
• Emissivity:	better than 0.999
• Emissivity knowledge:	better than ±0.1%
• Temperature gradient :	knowledge within 0.1 K

NASTER Instrument imposed requirements and allocations (TBR):

• BB Aperture:	2.54 cm
• BB Envelope	8.0 cm Dia. X 14 cm long
• BB Operating Temperature:	220 to 330 K
• Mass (2 BB's and Controller):	< 5.0 lb
• Power (2 BB's and Controller):	< 10.0 W

NAST/S-HIS Blackbody System Proposed for NASTER

Blackbody Subsystem Block Diagram



Uploaded parameters for each BB

- Mode (controlled temperature or controlled power)
- Set Point

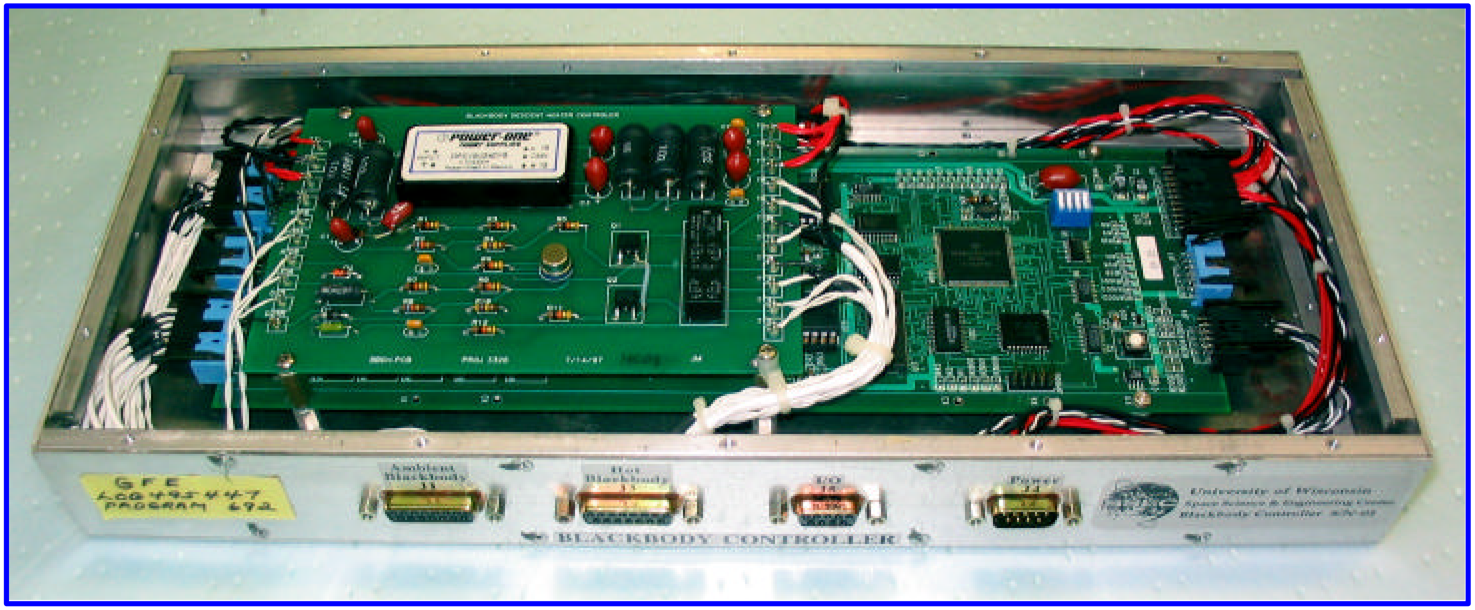
Data Output (at least once per second) *

- Four Temperatures from each BB
- Heater duty cycle for each BB
- Report of Mode
- Report of Set Point
- Four Calibration Points

*The Blackbody Controller can be programmed to allow for automatic updating or it can be used as a polled device. The update period is programmable.

System includes two blackbodies and a controller

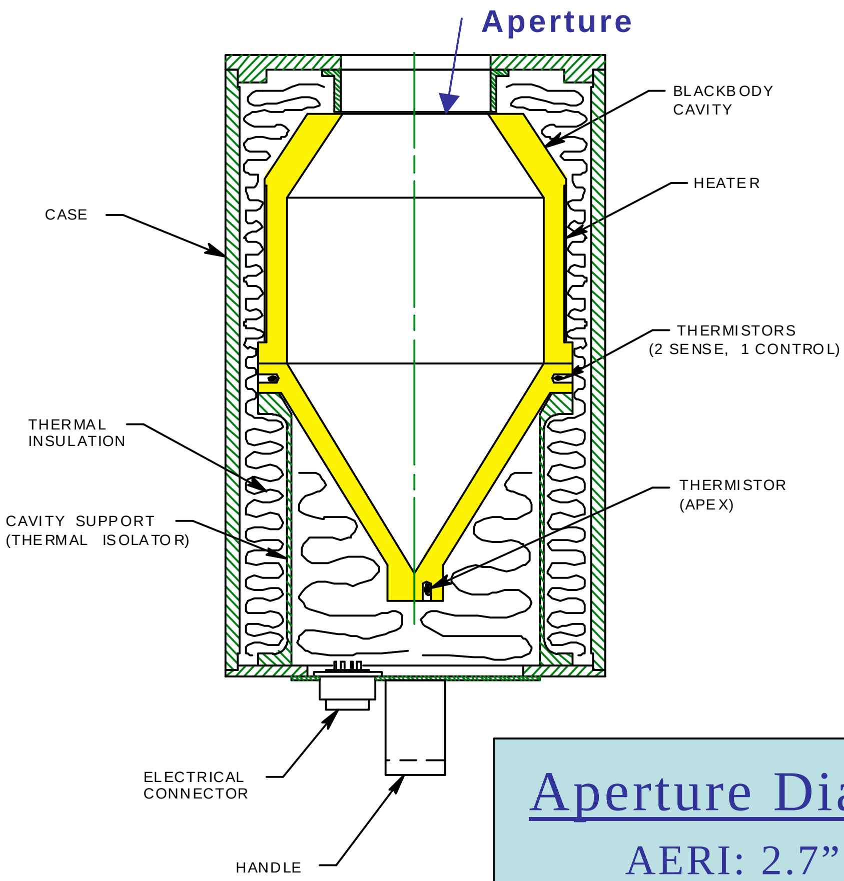
S-HIS/NAST Blackbody Controller

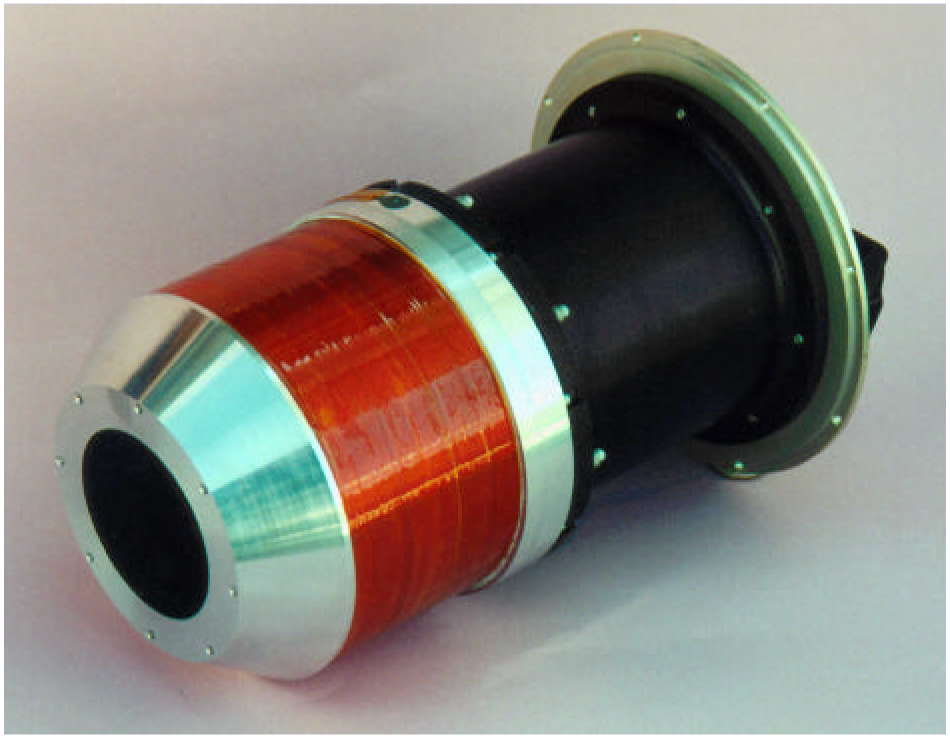


Size: 6" x 14" x 1.75"
Weight: <3.0 lb
Power: <2.0 W (not inc. BB htr.)

Blackbody Geometry

AERI, NAST, S-HIS, GIFTS, & Proposed NASTER





<u>Aperture Diameters</u>

AERI: 2.7”

S-HIS: 1.6”

NAST: 1.0”

Blackbody
Top Level Design Choices

- **Cavity Approach**
  - Provides high emissivity (cavity factor near 100)
  - 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
  - Provides a hardy surface

- **Thermistor Temperature Sensors**
  - Very Stable (0.01 K drift after 100 months at 70 K)
  - Easy to couple thermally to blackbody cavity
  - Reasonably rugged

Summary of Blackbody Temperature Error Contributions

TEMPERATURE (errors in degrees K)

		± peak error		(RSS)
• **Calibration System Errors**				
• Temperature Transfer Standard (Guildline)		0.030		
• Blackbody Controller (resistance measurement)		0.010		
	RSS ±	0.032	±	0.032
• **Thermistor Temperature Calibration**		± peak error		
• Calibration Temperature Gradient Uncertainty		0.020		
• Calibration Coefficient Fit Error		0.003		
• Long Term Stability		0.060		
	RSS ±	0.063	±	0.063
• **Cavity Temperature Non-uniformity Correction Uncertainty**		± peak error		
• Azumuthal Gradients Due to Free Convection				
• Longitudinal Gradients Due Primarily to Conduction				
• Radial Gradients Due to Conduction, Convection, and Radiation		0.040		
• Paint Gradient		0.030		
	RSS ±	0.050	±	0.050
• **Effective Radiometric Temperature Weighting Factor Uncertainty**		± peak error		
• Monte Carlo Ray Trace Model Uncertainty in Determining Teff	RSS ±	0.030	±	0.030
			Total Error ± (RSS)	0.092

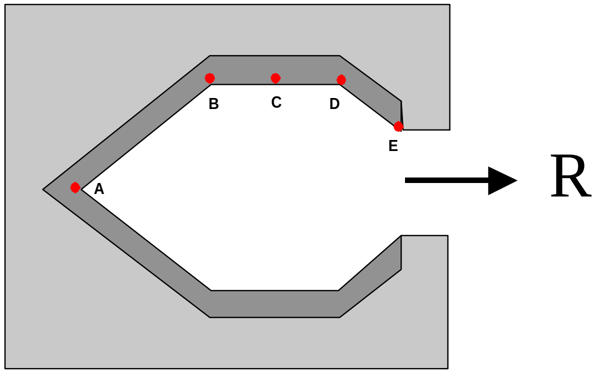
BB Emissivity

- Emissivity better than 0.999
- Emissivity knowledge: better than 0.001

$R = e * B(T_{eff}) + (1\text{-}e)*B(T_{refl})$

$T_{eff} = w_1 * T_A + w_2 * T_B$

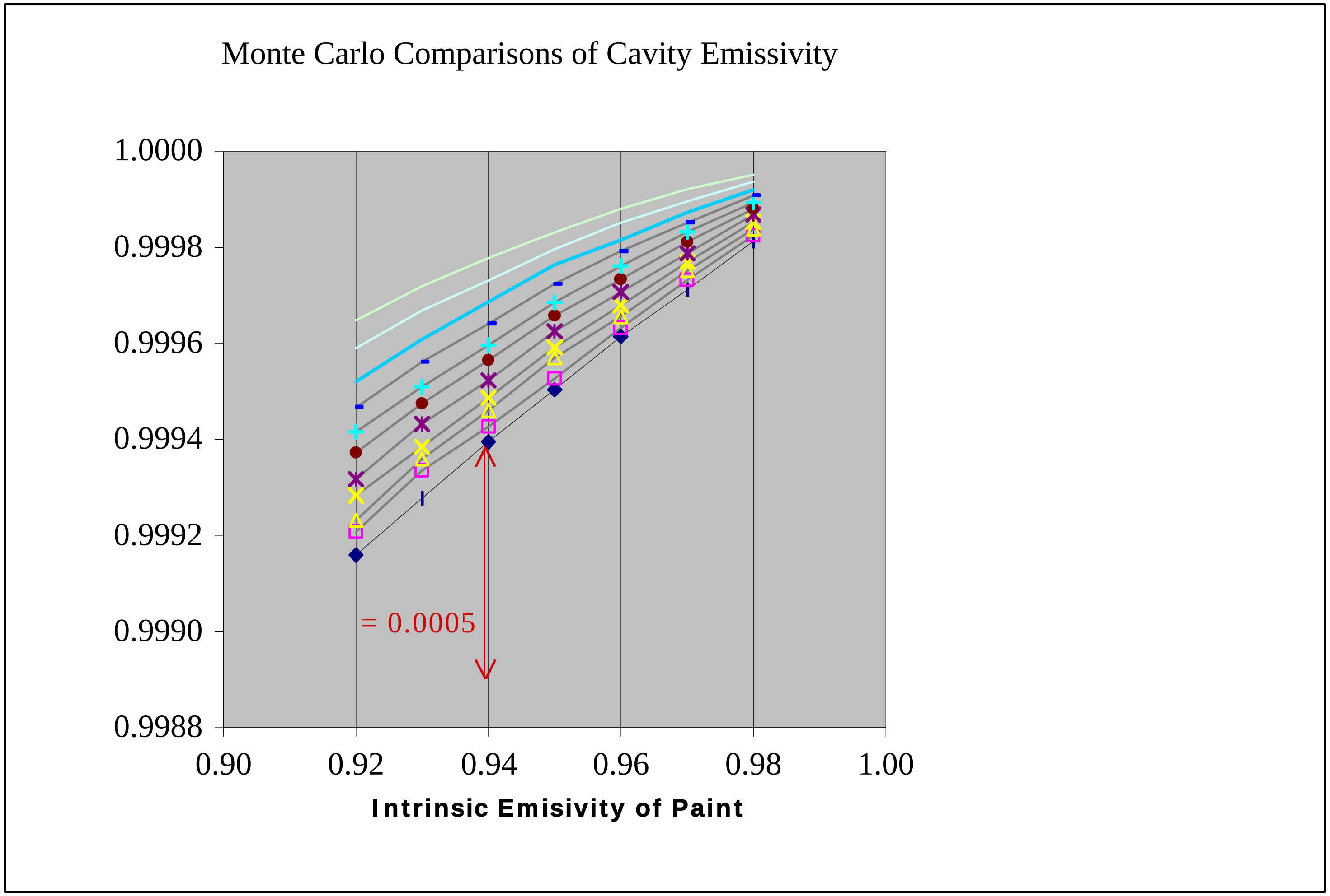
B(T) = Planck radiance at T



e, w1, and w2 are computed using a Monte Carlo based cavity model.

Paint Emissivity vs Thickness

Monte Carlo Comparisons



Summary of Emissivity Error Contributions

EMISSIVITY (errors in cavity emissivity)

{Ep=0.94, ^{2}Ep=0.0024 (2σ), f=100 }

	± peak error	(RSS)
• **Paint Witness Sample Measurement** (4% (2σ) of the reflectivity of the paint)	± 0.000036	± 0.000036
• **Paint Application Variation**	± 0.000060	± 0.000060
• **Cavity Factor Uncertainty**	± 0.000400	± 0.000400
• **Long Term Stability**	± 0.000180	± 0.000180
	Total Error ± (RSS)	0.000444

Ec=1-(1-Ep)/f

^{2}Ec=(1/f)^{2}Ep

$$Ec=1-(1-Ep)/f$$

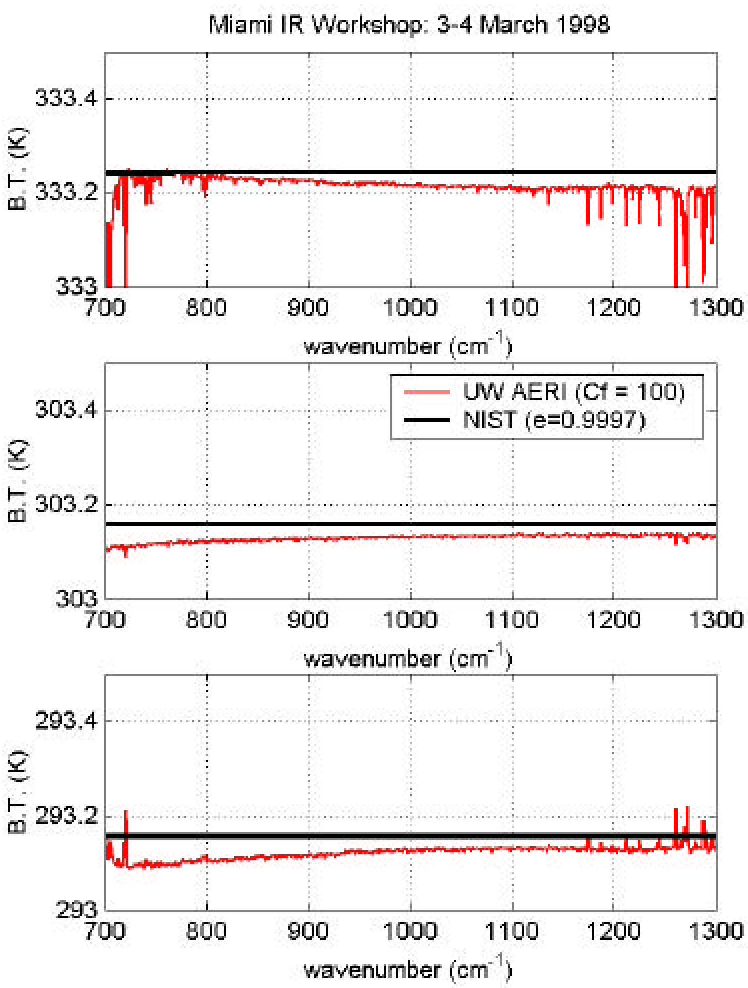
$$Ec=(1/f)\quad Ep$$

NAST & S-HIS Calibration Performance Review

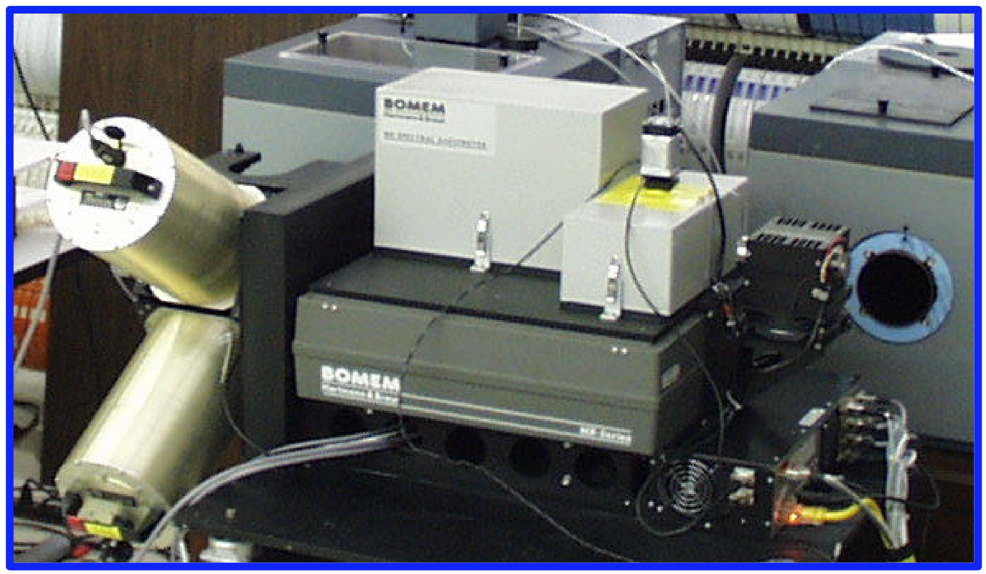
Blackbody Subsystem Heritage

- AERI (groundbased), S-HIS and NAST (aircraft) FTIR Instruments have demonstrated Radiometric Performance with accuracies better than the 1 K required for atmospheric remote sensing.
- These programs have successfully demonstrated a common methodology that integrates instrument Calibration Models and on-board blackbody Calibration Techniques using NIST traceable standards.

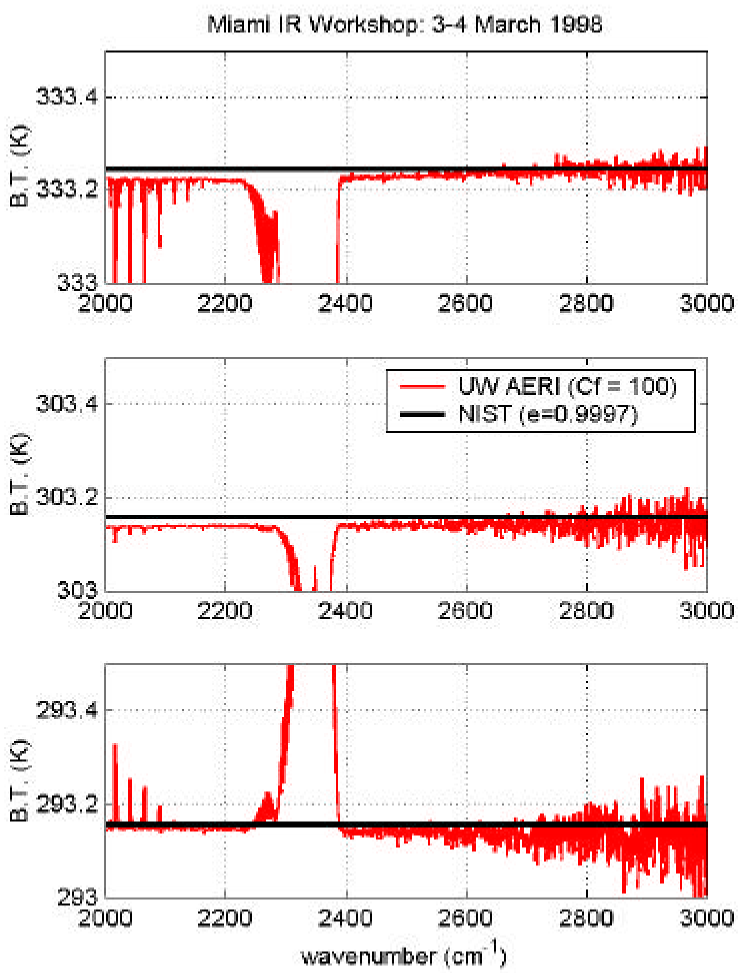
AERI / NIST Blackbody Intercomparison-LW



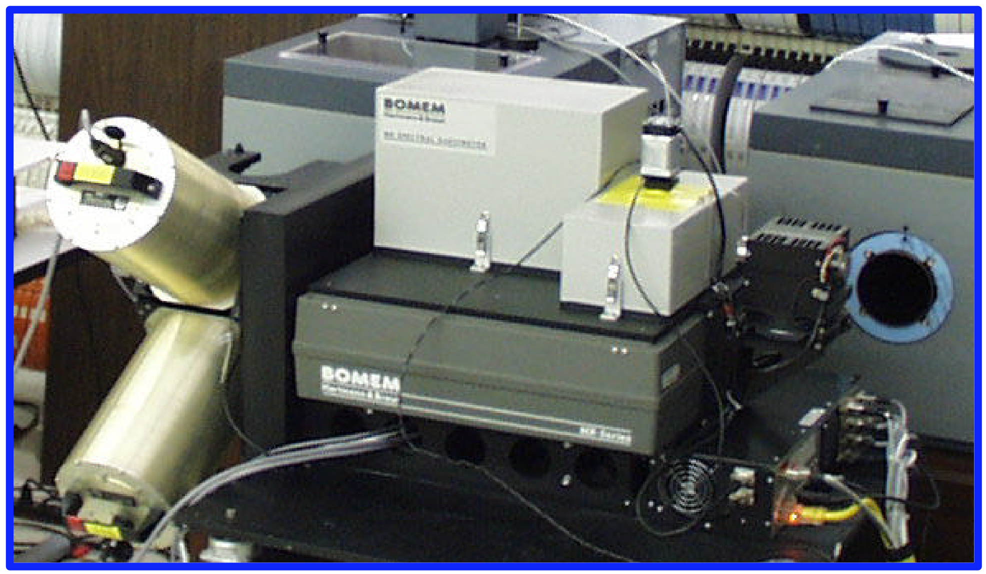
@ 333K, Max Error <0.035K
@ 303K, Max Error <0.050K
@ 293K, Max Error <0.065K



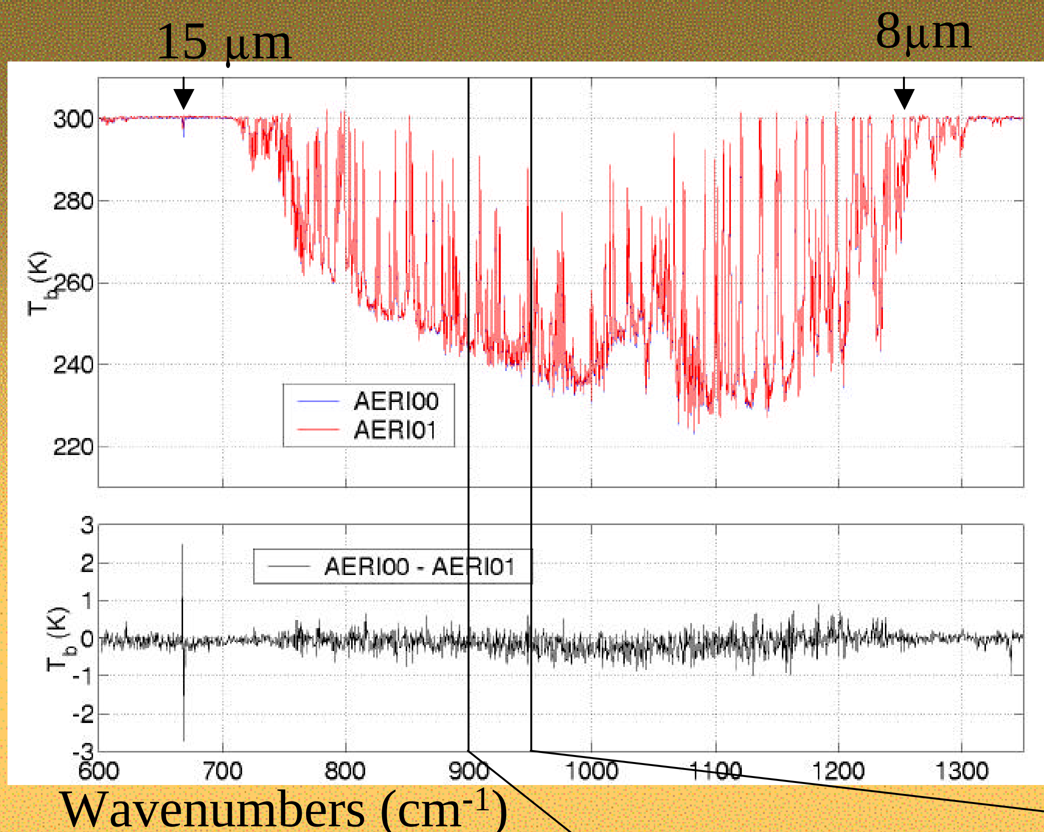
AERI / NIST Blackbody Intercomparison-SW

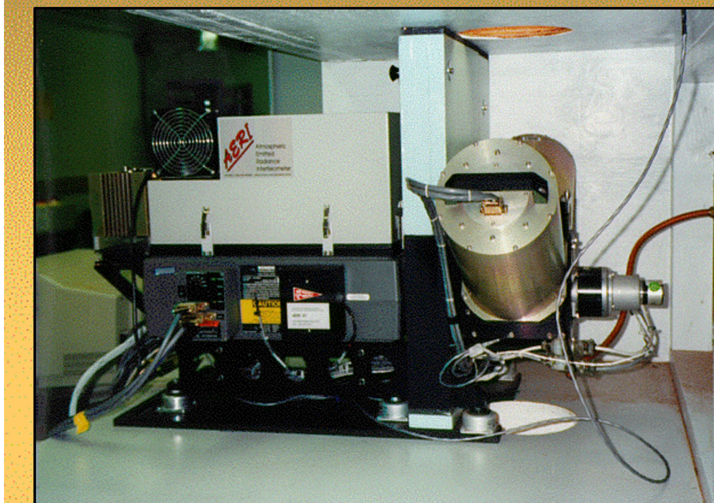


@ 333K, Max Error <0.030K
@ 303K, Max Error <0.030K
@ 293K, Max Error <0.015K

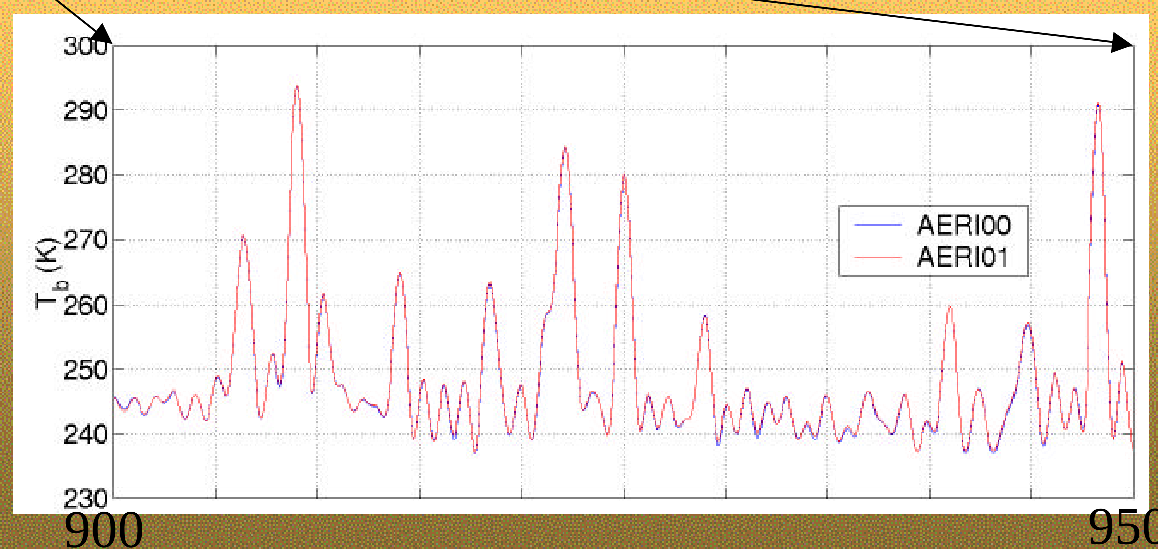


AERI Spectra





Brightness Temp Overlay of 2 Observations



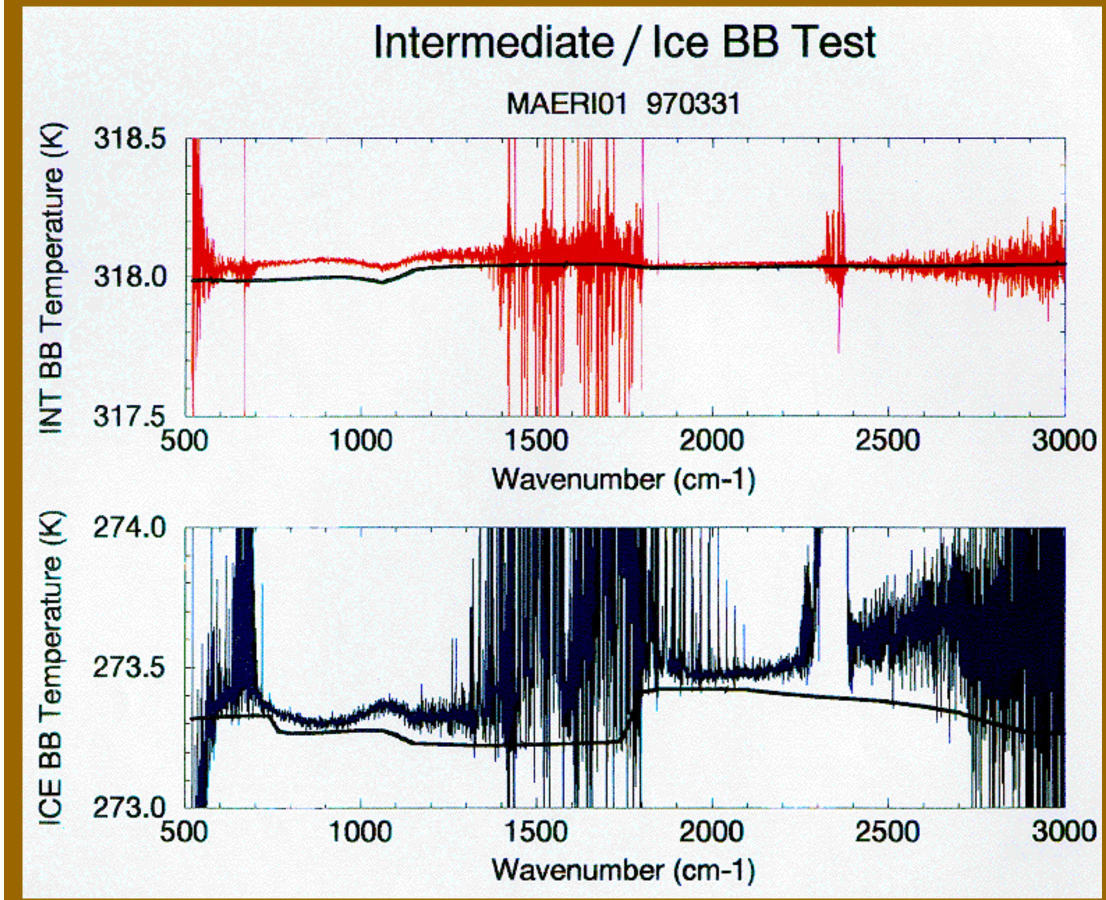
Back-up

Monte Carlo Comparisons

= 0.0005

Typical AERI Instrument End-to-end Radiometric Lab Validation

Intermediate BB

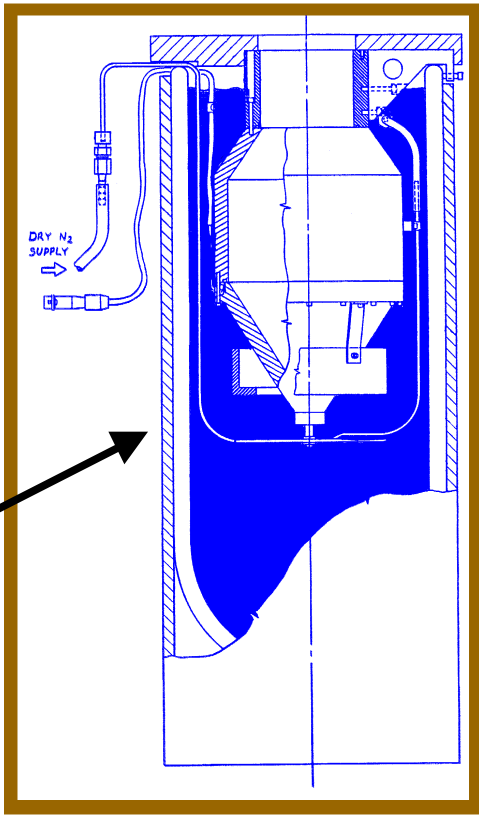


Ice BB

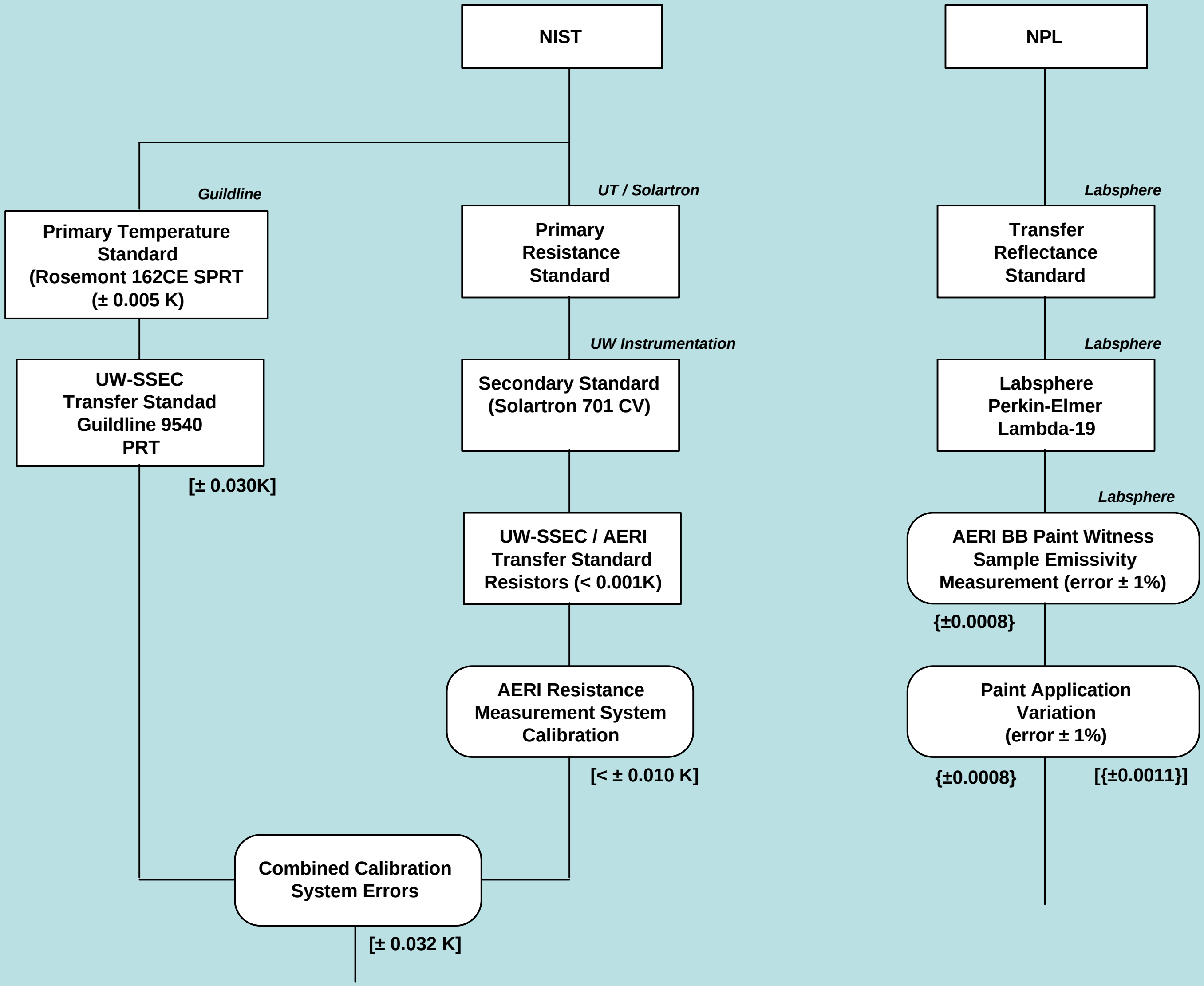
AERI Instrument End-to-end Radiometric Calibration Configuration

AERI Intermediate Temperature Blackbody in Sky view

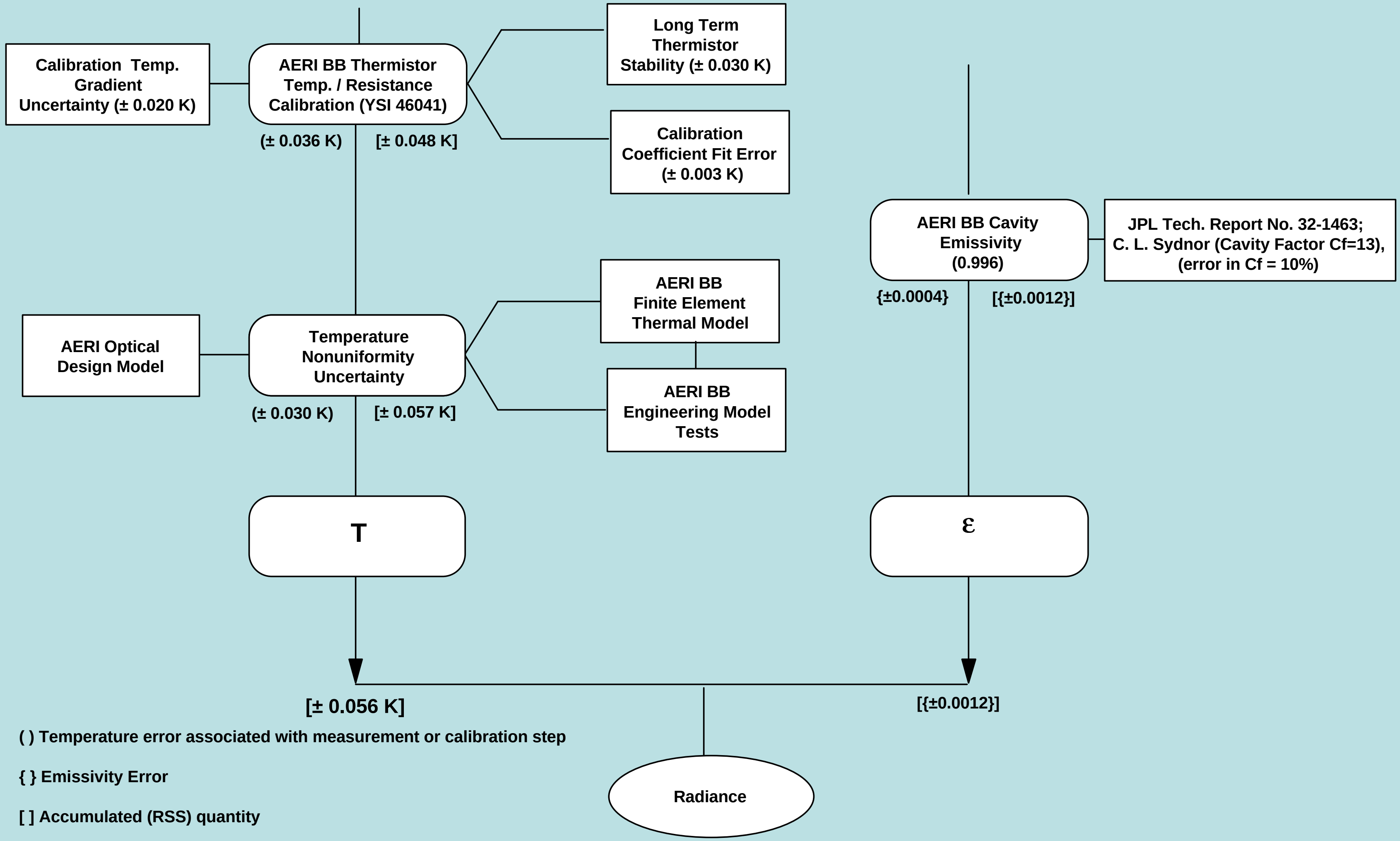
AERI Ice Blackbody in Down View



Blackbody Traceability and Error Budget



Blackbody Traceability and Error Budget



( ) Temperature error associated with measurement or calibration step

{ } Emissivity Error

[ ] Accumulated (RSS) quantity

Impact of Various ABB Temperatures

Important to have ABB well coupled to Ambient Temperature

Impact of Various ABB Temperatures

Important to have ABB well coupled to Ambient Temperature