Emitted and Reflected Radiance Calibration of two Large Area Cavity Blackbodies Using the NIST TXR

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Outline

- Test objectives and flow chart
- Test configuration and equipment overviews
- Radiance as a function of position and angle
- Emissivity as a function of position and angle
- Modeled emissivity
- Summary

Test Objectives

- **NIST traceable radiance, radiance temperature and effective temperature calibration of two Large Area Blackbodies (LABBs) using the Thermal Transfer Radiometer (TXR) at 5 and 10 μm over LABBs operational temperature range**
- **Emissivity measurements of both LABBs with the TXR at 5 and 10 μm**
- **Radiance and emissivity uniformity measurements over the LABB viewing configurations**
- **All measurements performed in an ambient temperature thermal vacuum chamber**

Perform Emitted Radiance Tests with TXR

- Test each LABB individually
- LABB not under test set to < 90 K
- FLIR data acquired for each LABB temperature and during temperature transitions

→

Perform Reflected Radiance (Emissivity) Measurements with TXR

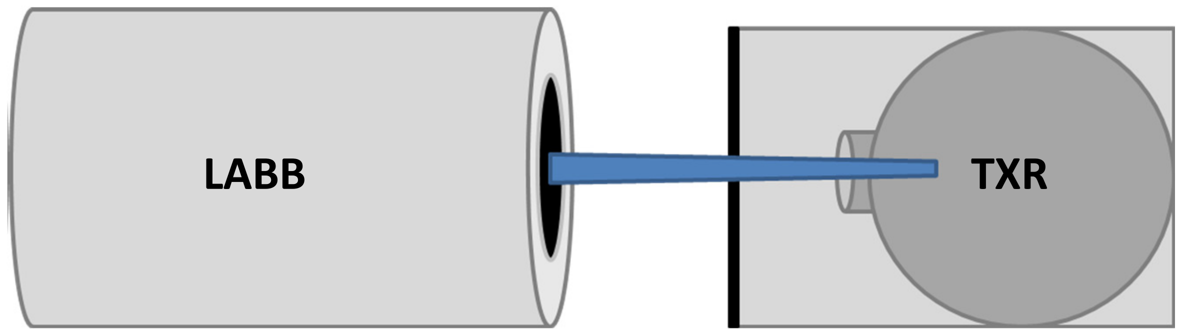
- Each LABB set to < 90 K
- Variable Temperature Scene Plate Temperature varied
- Linear and angular rotation scans

→

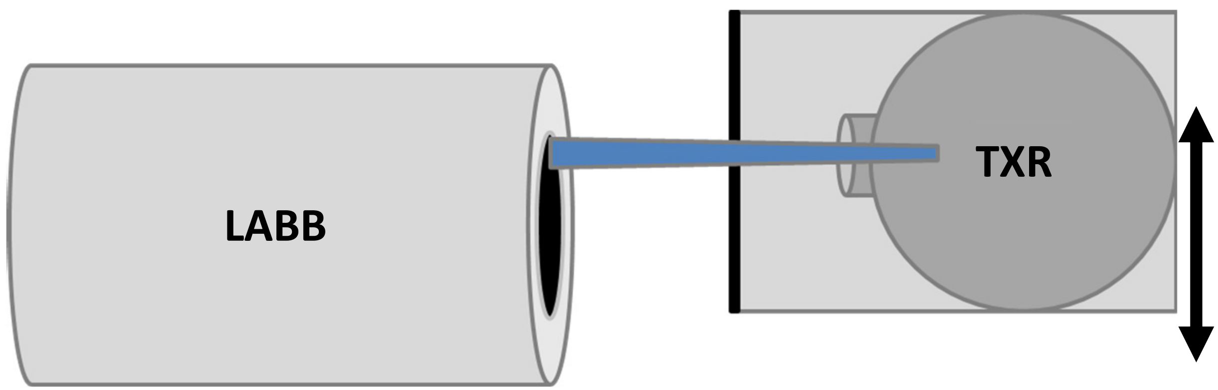
Repeat Emitted Radiance Tests for all temperatures

- Center of aperture
- No angular rotation
- LABB not under test set to < 90 K
- FLIR data acquired for each LABB temperature

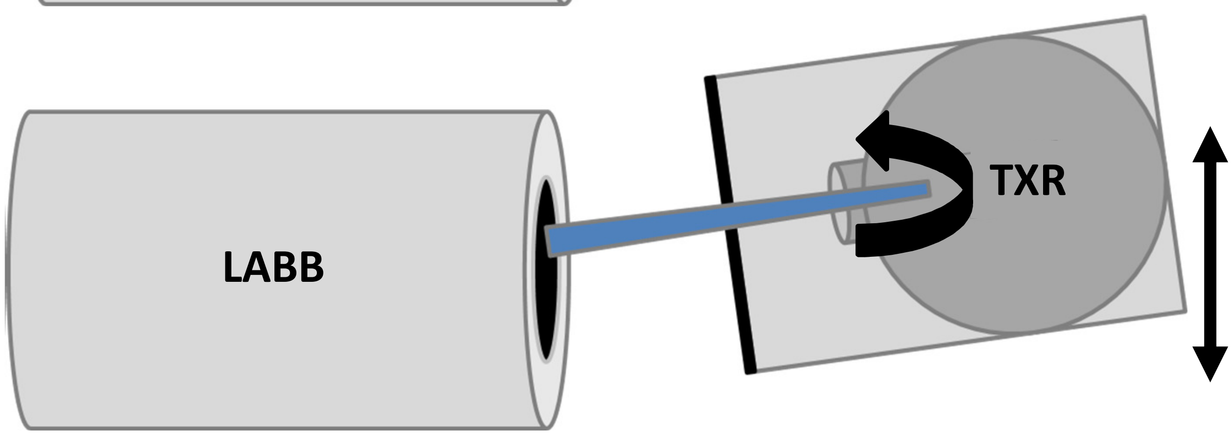
The TXR was Scanned in Linear and Angular Position Relative to the LABB Aperture



TXR centered on LABB Aperture

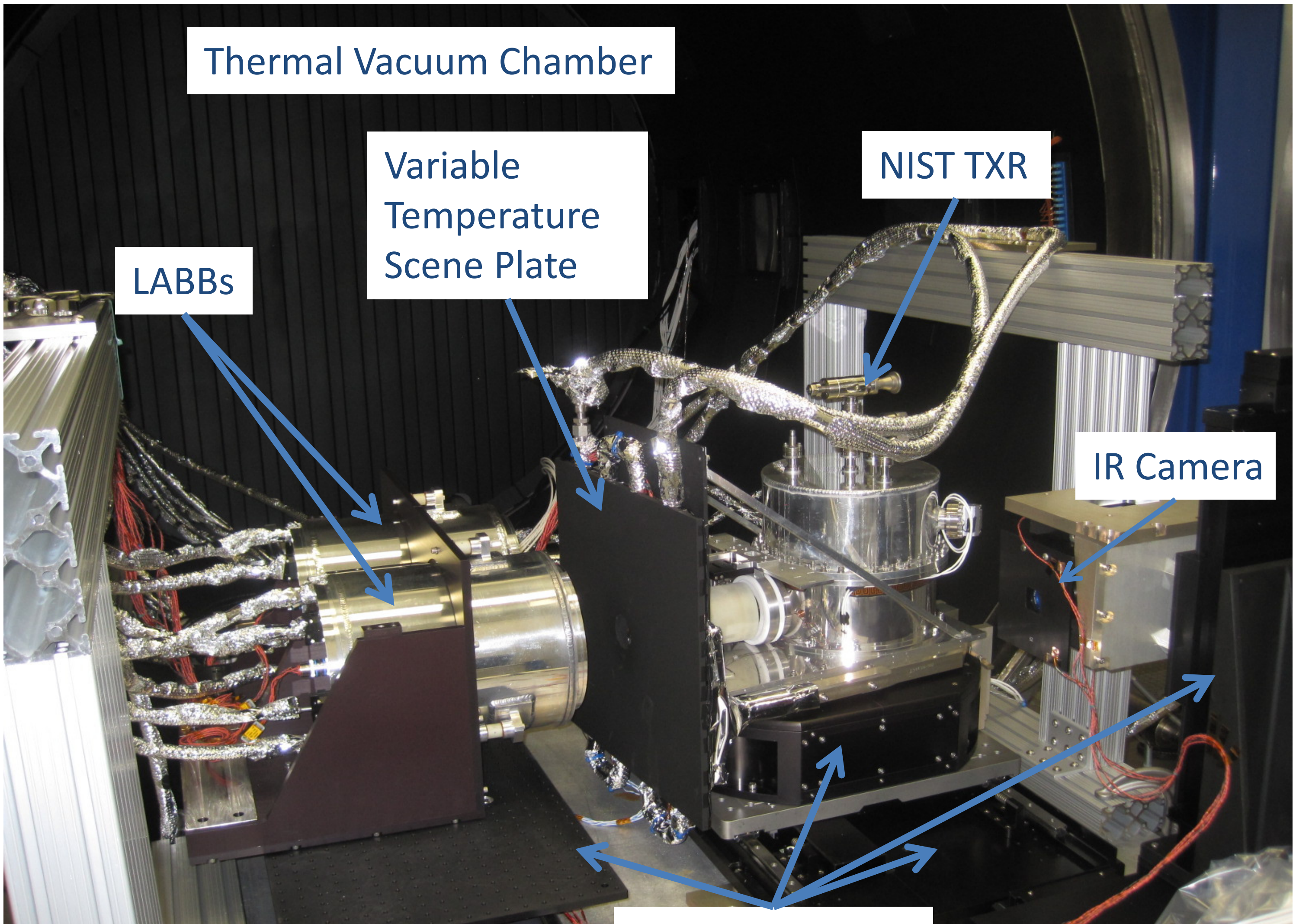


TXR linearly translated ± 50.8 along the LABB aperture diameter



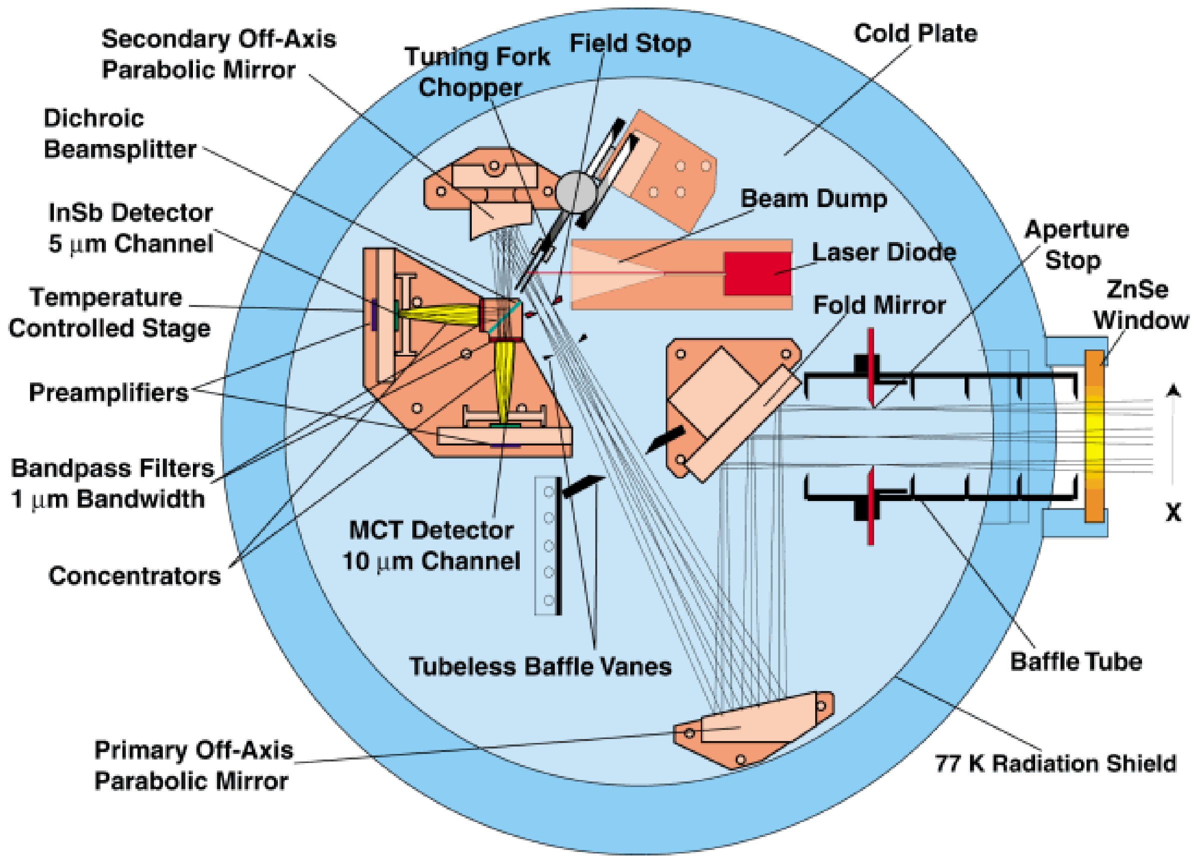
TXR linearly translated up to ± 50.8 along the LABB aperture diameter and rotated up to ± 4°

Radiance and Emissivity Measurements Made in Ambient Temperature Thermal Vacuum Chamber



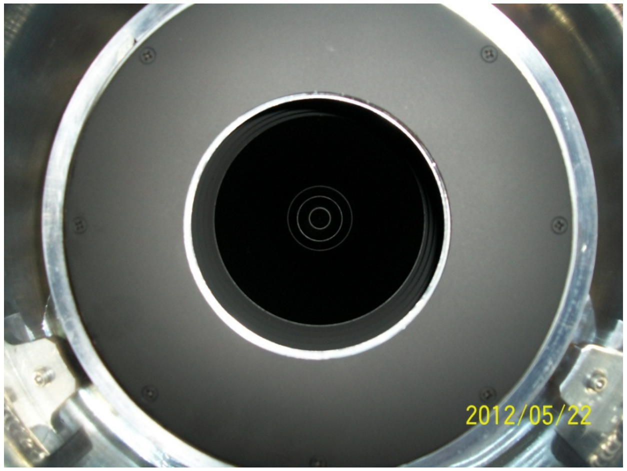
NIST Thermal Infrared Transfer Radiometer (TXR) Used to Establish NIST Traceable Radiance Calibration and Emissivity at Various Sites for > 10 Years

- Portable radiometer with 2 channels
  - 10 µm center wavelength with 1 µm bandwidth and MCT detector
  - 5 µm center wavelength with 1 µm and InSb detector
- Reflective optics, chopper and filters in LN2 cryostat
- Laser diode used for alignment
- Blackbody check source (not shown) rotates in front of ZnSe window to maintain TXR responsivity
- TXR Scene Plate baffle around optic axis 29.6 cm from entrance aperture (not shown)



BATC LABB Physical Description

- **Two LABBs that are used in an ambient thermal vacuum chamber**
- **Both LABBs have an LN2 shroud and the cones can be actively cooled by LN2**
- **Consist of a LN2 cooled aperture, fore shield and an emitting cone**



	LABB 1	LABB 2
Operational Temperature Range	<90 K to 350 K	< 90 K to 450 K
Calibration Temperature Range	235 K – 350 K	250 K – 450 K
Aperture Size	127 mm	127 mm
Viewing Configuration	F/6.4	F/6.4
Cavity Geometry	Inverted cone	Cone
Coating	Specular black paint	Specular black paint

LABB Data from Commercial FLIR 6700 IR Camera is Used for Characterization

- Commercial Off-the Shelf IR camera modified for TVAC use
  - F/2.3, 25 mm aperture lens
  - 3-5 µm spectral band width
  - Low NEdT (< 25 mK)
  - InSb FPA cooled to 70 K
  - External thermal control
- FLIR images of the LABBs…

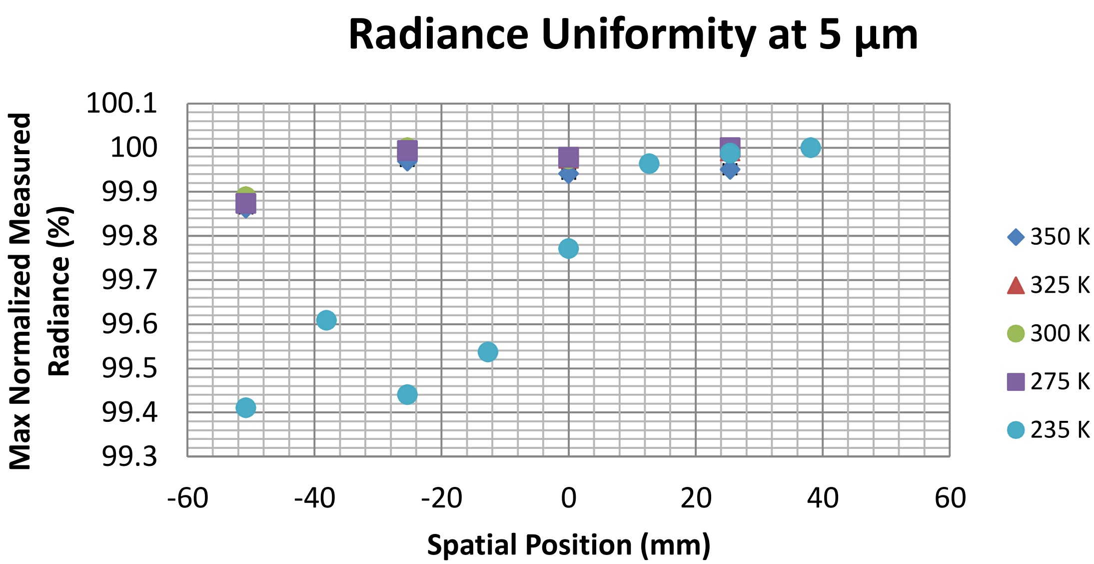
  …used to look for any structure

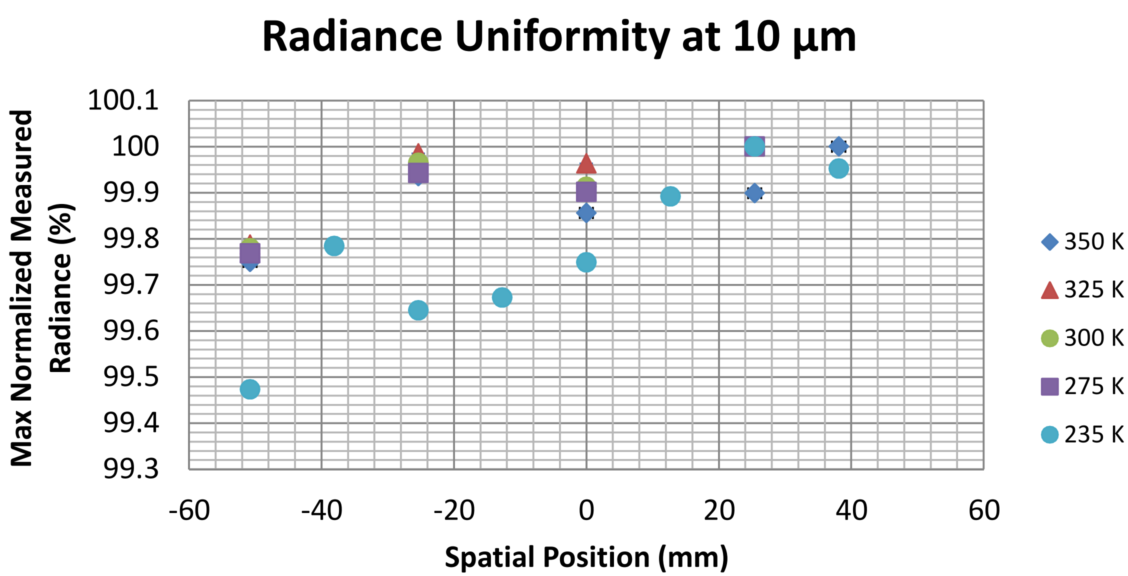
  …used to characterize the FLIR with the LABBs as a calibration source

Radiance, Radiance Temperature and Effective Temperature

- The LABBs were calibrated for radiance, radiance temperature and effective temperature over their entire operational temperature range
  - 235 – 350 for LABB 1
  - 250 – 450 for LABB 2
- Required extra calibrations of the NIST TXR for the extended upper temperature range
- Thermal optical mechanical design to control environment background enabling low uncertainty measurements in an ambient temperature thermal vacuum chamber
  - Design of test incorporated multi-level scattering stray light analysis results
- Measured total effective temperature standard uncertainties < 0.1 K over temperature range meet our requirements

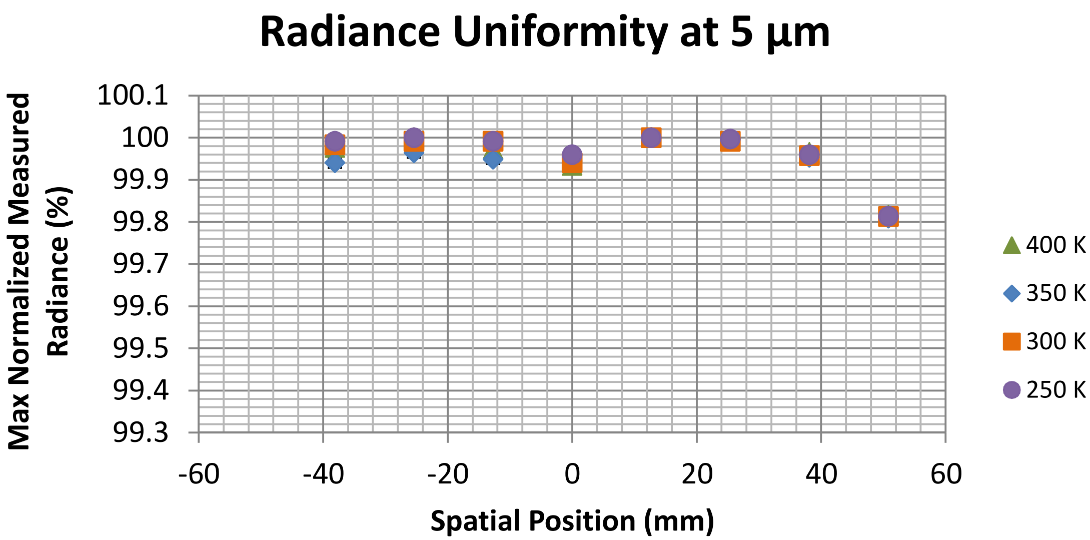
Radiance Uniformity as a Function of Position was Measured for Each LABB

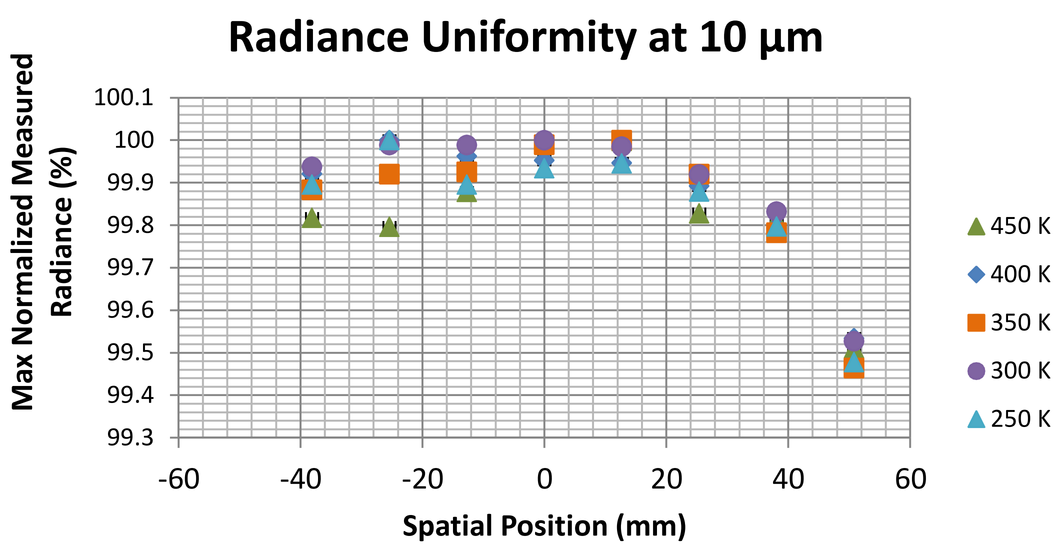




- Radiance uniformity is not temperature dependent
  - With the exception of LABB 1 at 235 K
- Radiance uniformity was measured in both TXR channels has similar shape
- The measurement uncertainty is < 0.15%
- The values at 50.8 mm for LABB1 are clipping the edge of the LABB aperture and are not plotted

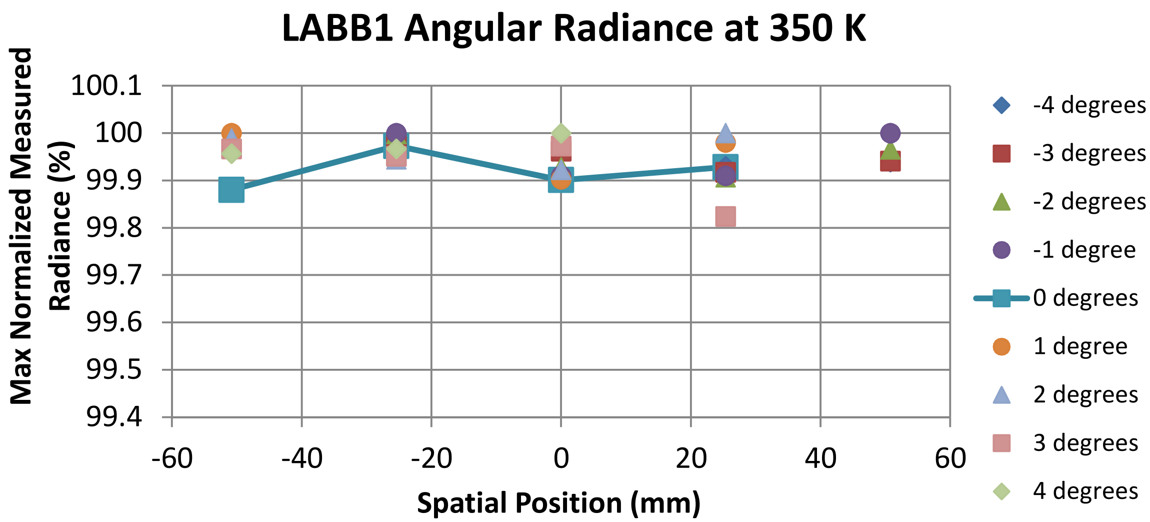
Radiance Uniformity as a Function of Position for LABB 2

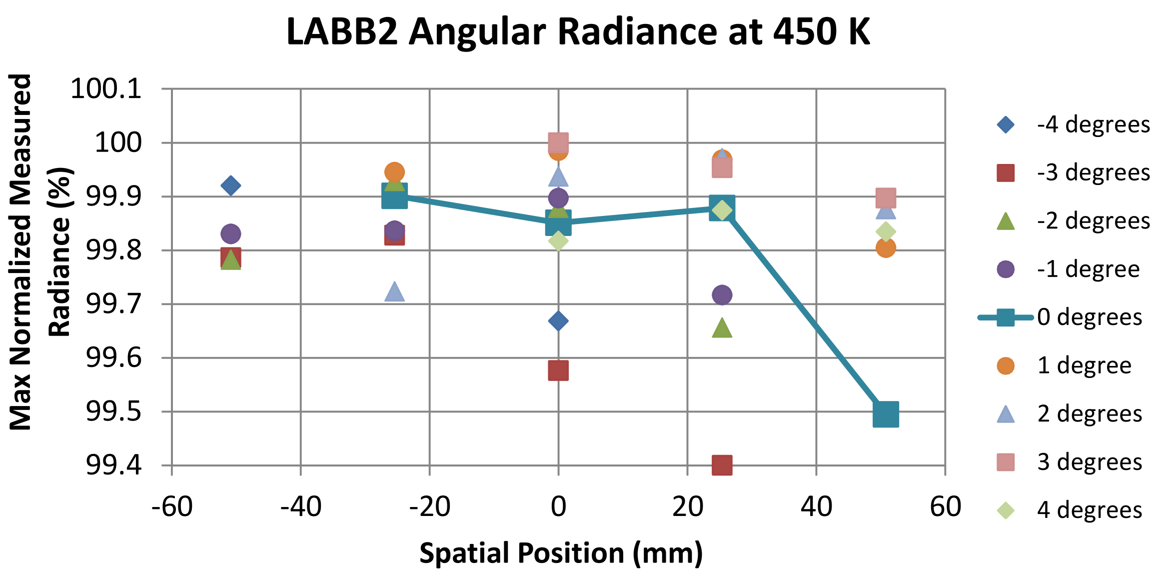




- Radiance uniformity is not temperature dependent
- Radiance uniformity was measured in both TXR channels
  - 10 µm channel shows more non-uniformity
- The measurement uncertainty is < 0.15%
- The values at -50.8 mm for LABB2 are clipping the edge of the LABB aperture and are not plotted

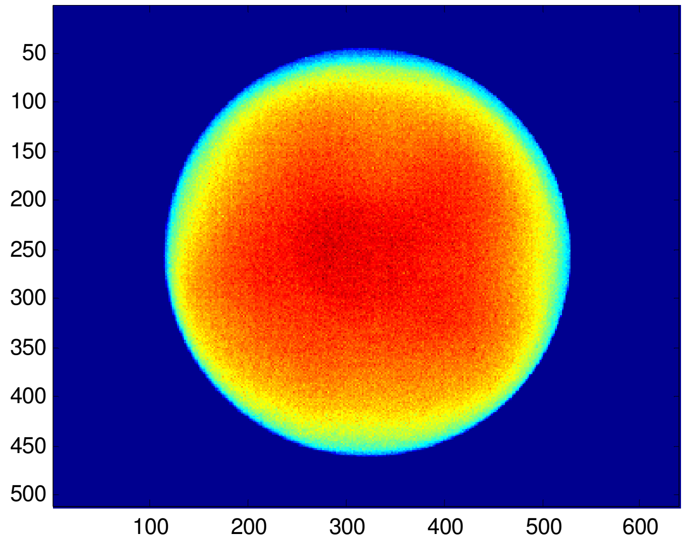
Radiance as a Function of Angle and Position Measured for Each LABB at 1 Temperature



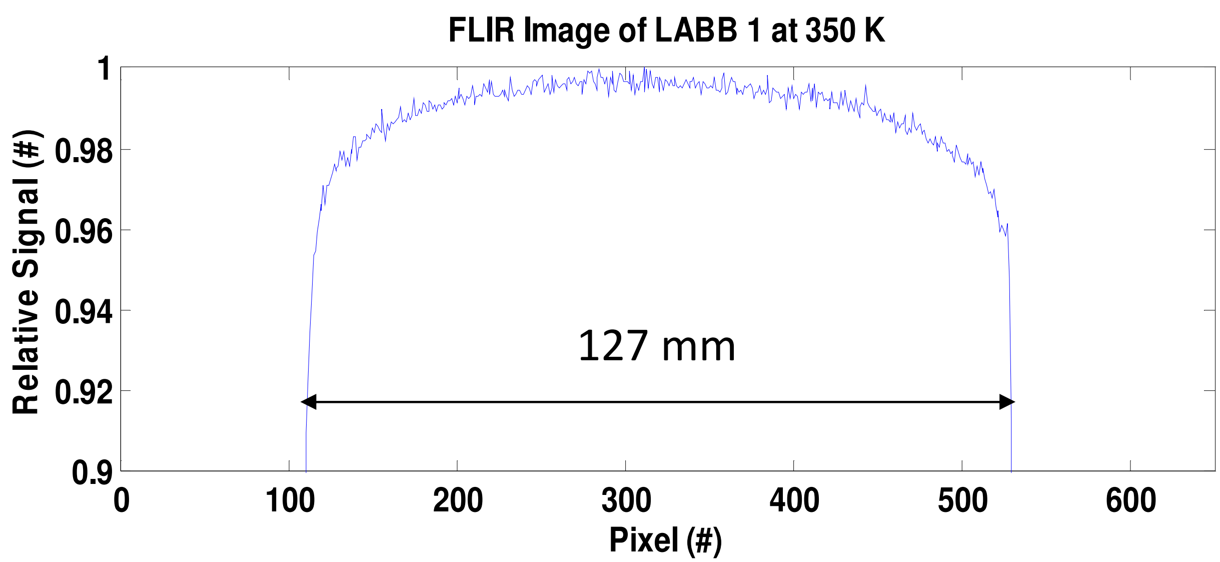


- LABBs are designed for a 4.5° acceptance angle
- Each LABB was measured at the maximum operational temperature

IR Images of the LABBs Used as Monitor



- FLIR imaging configuration has a larger footprint and a different FOV
- Images are useful trending tools



Emissivity as a Function of Linear Position and Angle

- TXR measures radiance reflected out of the LABBs
  - — Radiance source is the variable temperature scene plate
  - — Variable temperature scene plate temperature is set to 5 different temperatures
  - — LABBs are set to < 90 K
- Measurement equation:

$$L_i = \underbrace{\varepsilon_{LABBi} L_{LABBi}(T_c)}_{\text{LABB emitted radiance}} + \underbrace{L_{Ki}}_{\text{Background radiance}} + \underbrace{(1 - \varepsilon_{LABBi})\varepsilon_{VTSPi} F_{VTSP,LABB} L_{VTSPi}(T_{VTSP})}_{\substack{\text{Radiance reflected from LABB} \\ \text{F is a geometric configuration factor}}}$$

- Data collected at 0 angle at the center of the LABB aperture is “standard” and analyzed by NIST
  - — Including an uncertainty analysis
- Data collected at other linear positions and angles was analyzed by BATC
  - — Engineering data to evaluate Lambertian qualities of LABBs
  - — Requires a different configuration factor for each angle and position
- Geometric configuration factor calculated for each TXR position
  - — Configuration factor of > 0.8 determined by two methods: multi-level stray light analysis and 3-D numeric integration

Linear and Angular Scan Measured Emissivity for LABB 1

- **NIST standard uncertainty (k=1) for measured emissivity is 0.0002 at 5 µm and 10 µm**
- **Emissivity over the operational aperture has a pattern which is under investigation**

5 µm

	Linear Position (mm)				
Angular setting (degrees)	-50.8	-25.4	0	25.4	50.8
-4				0.9934	
-3					
-2					
-1					0.9882
0			0.9994	0.9995	0.9994
1	0.9836				
2			0.9994	0.9994	0.9995
3					
4		0.9889		0.9994	0.9994

10 µm

	Linear Position (mm)				
Angular setting (degrees)	-2	-1	0	1	2
-4				0.9981	
-3					
-2					
-1					0.9972
0			0.9981	0.9988	0.9996
1	0.9947				
2			0.9987	0.9981	0.9988
3					
4		0.9953		0.9987	0.9981

Linear and Angular Scan Measured Emissivity for LABB2

- **LABB 2 emissivity is less than LABB 1 but exhibits the same pattern**

5 µm

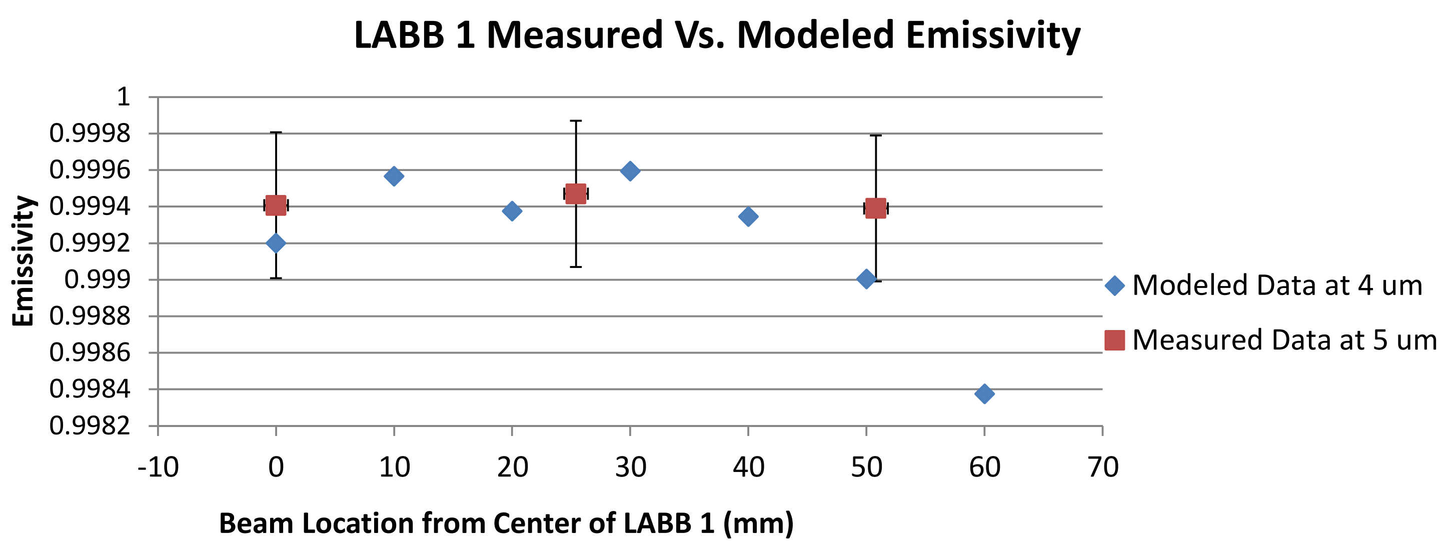
	Linear Position (mm)				
Angular setting (degrees)	-50.8	-25.4	0	25.4	50.8
-4				0.9900	
-3					
-2					
-1					0.9891
0			0.9989	0.9994	0.9991
1	0.9894				
2			0.9994	0.9994	0.9994
3					
4		0.9892		0.9994	0.9990

10 µm

	Linear Position (mm)				
Angular setting (degrees)	-50.8	-25.4	0	25.4	50.8
-4				0.9916	
-3					
-2					
-1					0.9926
0			0.9987	0.9987	0.9984
1	0.9936				
2			0.9990	0.9992	0.9986
3					
4		0.9927		0.9988	0.9987

Modeled Data for Emissivity

- **Multi-level scattering model for both LABBs developed in ASAP and FRED**
  - **Measured BRDF from paint coupons at 3.39 µm and 4 µm**
  - **Measured HDR from paint coupons between 2 – 15 µm**
  - **Apply scaling factor to transition between model at 4 µm and measured data at 5 µm**



Summary

- The NIST TXR was used to evaluate radiance and emissivity non-uniformity at 5 and 10 μm
- The technique to measure spatial and angular radiance and emissivity uniformity is valid and can be correlated to models
- Carefully constructed thermal optical mechanical test geometry enabled good measurements at ambient temperatures in a thermal vacuum environment for both radiance and emissivity
- The FLIR camera performs well in vacuum and is a useful trending tool

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