NIST – PTB Joint Study of Far Infrared Selected Black Coatings

Leonard Hanssen,[1] Boris Wilthan,[1] Sergey Mekhontsev,[1] Christian Monte,[2] and Jörg Hollandt[2]

[1]National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA,
[2]Physikalisch-Technische Bundesanstalt (PTB), Berlin, Germany

The 11th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2011)

19-23 September 2011, Maui, HI

Introduction

NIST IR Spectrophotometry and Spectroradiometry (Leonard Hanssen):

– IR Optical Properties of Materials (DHR, BRDF, Emittance)	This talk, Poster SBR PO 014
– IR Reflectometry of BB and AR Cavities (DHR with Laser and Thermal Sources)	Poster EAO OR 012
– IR Radiometry (Spectral Radiance and Radiance Temperature)	Talk later today

Background – Related International Comparisons

- **Regular Reflectance and Transmittance**
- **Participants: NPL, NIST**
- **Year: 2000-2001**
- **Spectral Range: 2.5 µm to 18 µm**
- **4 Materials**
- **C.J. Chunnilall, F.J.J. Clarke, M.P. Smart, L.M. Hanssen, S.G. Kaplan, "*NIST-NPL comparison of mid-infrared regular transmittance and reflectance*," Metrologia 40, S55-S59, (2003).**

- **Regular Reflectance and Transmittance**
- **Participants: NIST IR vs. UV-VIS-NIR Scales**
- **Year: 2002**
- **Spectral Range: 1 µm to 2.5 µm**
- **6 Materials**
- **S. G. Kaplan, L. M. Hanssen, E. A. Early, M. E. Nadal and D. Allen, "*Comparison of near-infrared transmittance and reflectance measurements using dispersive and Fourier transform spectrophotometers*," Metrologia 39, 157-164 (2002).**

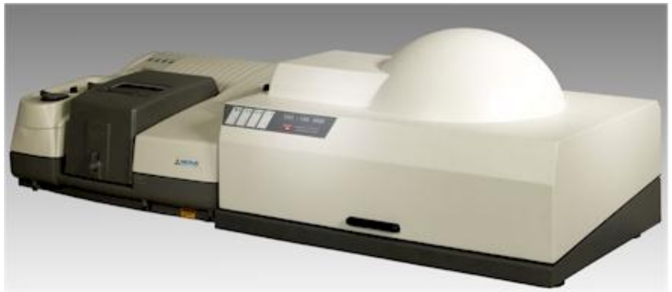
- **Directional-Hemispherical Reflectance**
- **Participants: NRC, NIST**
- **Year: 2006**
- **Spectral Range: 2.5 µm to 18 µm**
- **3 Materials**
- **L.M. Hanssen, N.L. Rowell, "*Comparison of NRC and NIST Infrared Diffuse Reflectance Scales from 2 µm to 18 µm* ," 5th Oxford Conference on Spectrometry, June 26-28, 2006, Teddington, UK (2006).**

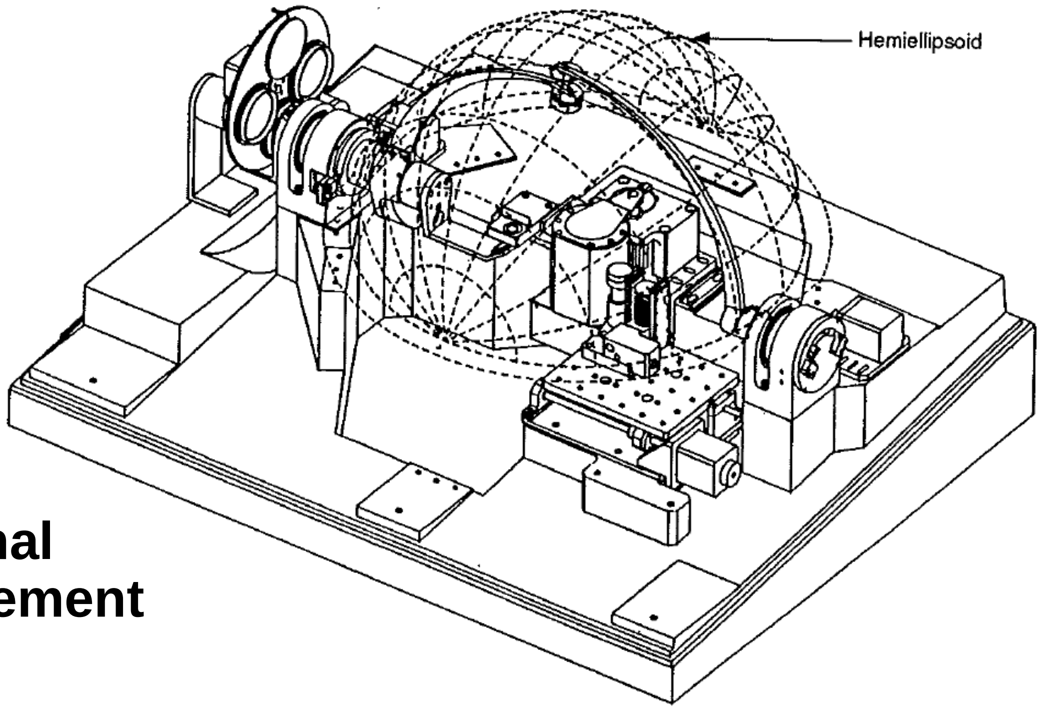
- **Near Normal Absorptance**
- **Participants: NMIJ, NIST**
- **Year: 2004**
- **Spectral Range: 2.5 µm to 10 µm**
- **5 Materials**
- **J. Ishii, L.M. Hanssen, "*Comparison of mid-infrared absorptance scales at NMIJ and NIST*," Proc. 9th NEWRAD, ed. J. Gröbner, Davos, Switzerland, 2005, p. 241-242 (2005).**

- **Near Normal Emittance**
- **Participants: INRIM, LNE, NMIJ, PTB, NIST**
- **Year: 2007-2009**
- **Spectral Range: 2 µm to 14 µm**
- **Temperature Range: 23 ˚ C to 800 ˚ C**
- **3 Materials x 11 Temperatures**
- **L. M. Hanssen, B. Wilthan, C. Monte, J. Hollandt, J. Hameury, J.-R. Filtz, F. Girard, M. Battuelo, J. Ishii, "*Inter-laboratory Comparison of Infrared Emittance Scales*," Book of Abstracts, TEMPMEKO 2010, ed. J. Bojkovski, et. al, Potorož, Slovenia, Vol. B, p. 431 (2010).**

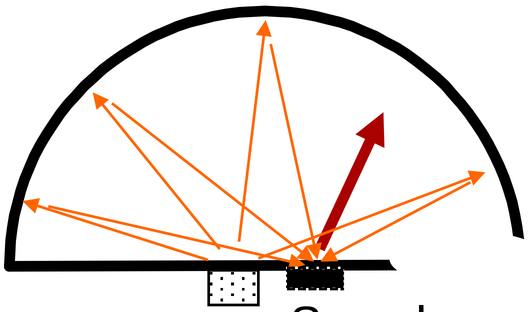
INRIM: Instituto Nazionale di Ricerca Metrologica (Italy)
LNE: Laboratoire National de Métrologieet d'Essais (France)
NMIJ: National Metrology Institute of Japan (Japan)
NPL: National Physical Laboratory (United Kingdom)
NRC: National Research Council (Canada)
PTB: Physikalisch-Technische Bundesanstalt (Germany)

SOC-100 Design and Features





Hemispherical-Directional Reflectance Factor Measurement

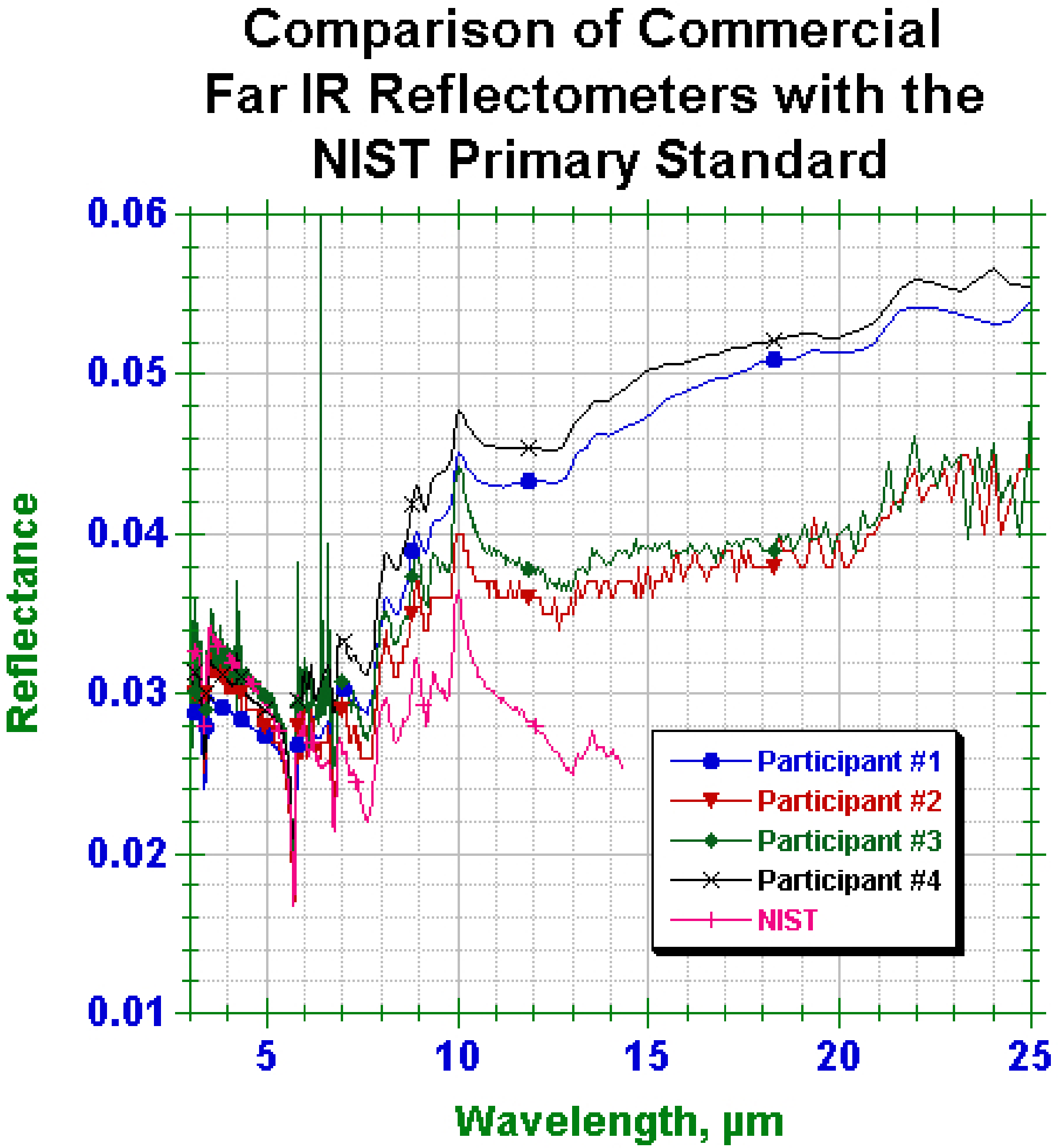


Output To FTIR

$$\frac{V_s}{V_r} = \frac{R_{s,h,d}\Omega_d \rho_m \Phi_i}{\rho_m \Phi_i \Omega_d} = R_{s,h,d}$$

HDR DATA AS A FUNCTION OF	RANGE OF MEASUREMENT
a. Directional Angles θ: 20, 30, 40, 50, 60, 70, 75, 80°	Near-normal, 20 to 80°
b. Azimuthal Angles ϕ	0 to 360°
c. Wavelength	2.0 to 25.0 µm, 2.0 to 45.0 µm,* 2.0 to 200 µm*
d. Beam Polarization	Parallel and Perpendicular
e. Sample Temperature	Room temperature to 500°C w/heated sample holder

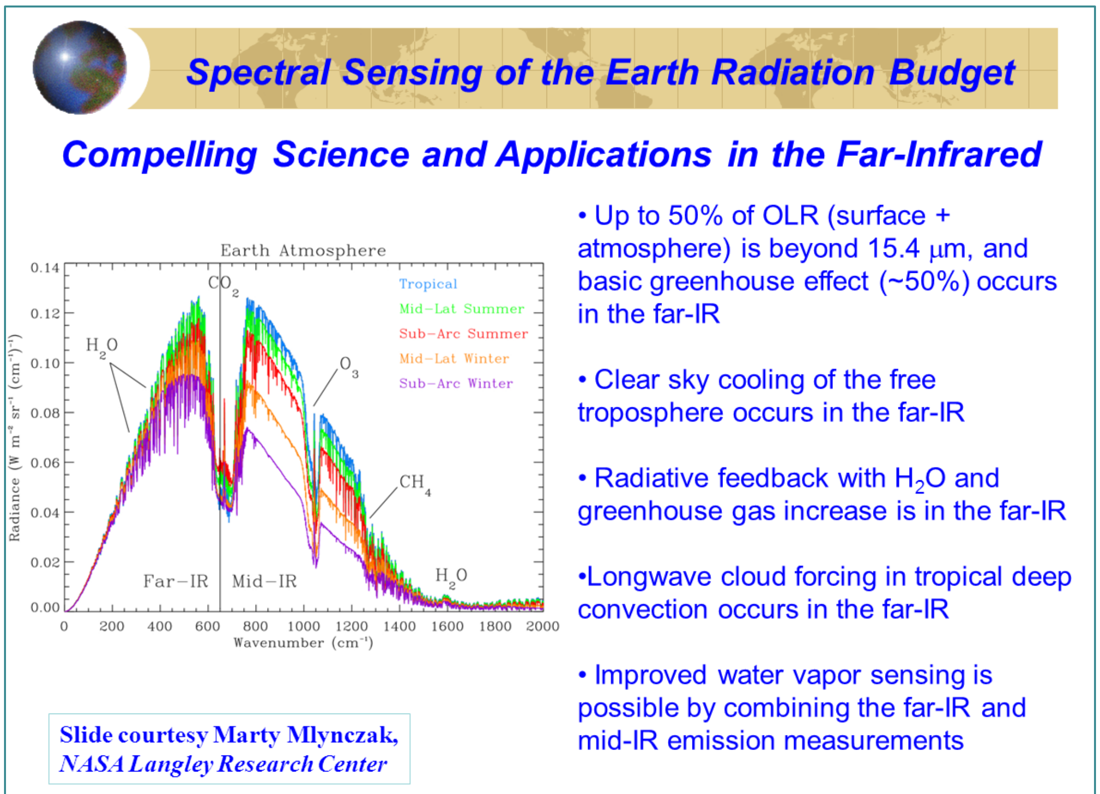
Evidence of Need for FIR Reflectance Standards



Motivation

- Near Term – provide traceability and verified uncertainties for reflectance measurements for Secondary Labs, such as Surface Optics Corp. and AZ Tech Corp., to meet immediate requirements in near-ambient FIR emittance measurements

- Mid-Term - create multiple sources for obtaining critical reflectance and emittance data for instrument optical surfaces to support Remote Sensing Community (NASA / NOAA) and Climate Science



- Long Term – establish well characterized and validated Far IR capabilities at NMI Level

Background – NIST / PTB Cooperation

2009: meeting at PTB Berlin to initiate a cooperative effort on Far IR emittance, Far-IR Cavity absorptance, and Far-IR Spectral Radiance. Actual scope still to be finalized.

NIST / PTB Cooperation Opportunities in the Area of Thermal and Far Infrared Radiometry for Primary Scales Realization and Remote Sensing and Climate Change Science Support

- Far IR Optical Properties of Materials: Emittance, Reflectance and BRDF
  - Use available thermal, laser and synchrotron radiation sources
  - Regular and diffuse blacks for BBs and ACRs
  - Diffuse reflectors for Far IR Integrating Spheres
- IR Optical Properties of Ultra-High Absorptance Targets (Cavities of Thermal and Far IR Sources and Detectors)
  - Goal - at least 5N resolution
  - Traveling Far IR reflectometer for use with variety of FIR sources such as MLS wiggler and lasers)
- Thermal and Far IR Spectral Radiance & Radiance Temperature Scales for Thermo-Vacuum Environment
  - Realize scales
  - Design / build a transfer standard BB
  - Perform comparisons

Establishing Intermediate FIR Emittance Scales for Near –Ambient Targets

	Lab	NIST	PTB	SOC
Measurement Type	Temp., °C	Spectral Range, µm	Spectral Range, µm	Spectral Range, µm
Directional Emittance	200	3 - 100, variable angle	3 - 40, variable angle	
HD Reflectance, Specular/Diffuse Resolved	RT	2 - 14, fixed angle		2 -100, variable angle
	200			

At the time of conception of the study, NASA had immediate requirement in Specular/Diffuse Resolved Hemispherical-Directional Reflectance in Far IR at near-ambient temperatures. Such measurements are supported by the SOC Calibration Lab, which until now has no direct SI traceability. One of outcomes of the study should be establishing indirect traceability for calibration labs.

Properly addressing the issue requires building dedicated primary facilities, such as RBCF (operational at PTB) or CBS3 (may be built at NIST).

Scope

- **Three materials of different types**

  - Specular polished Silicon Carbide, solid, moderately high emittance at long wavelengths, stable at elevated temperatures, used as a transfer standard

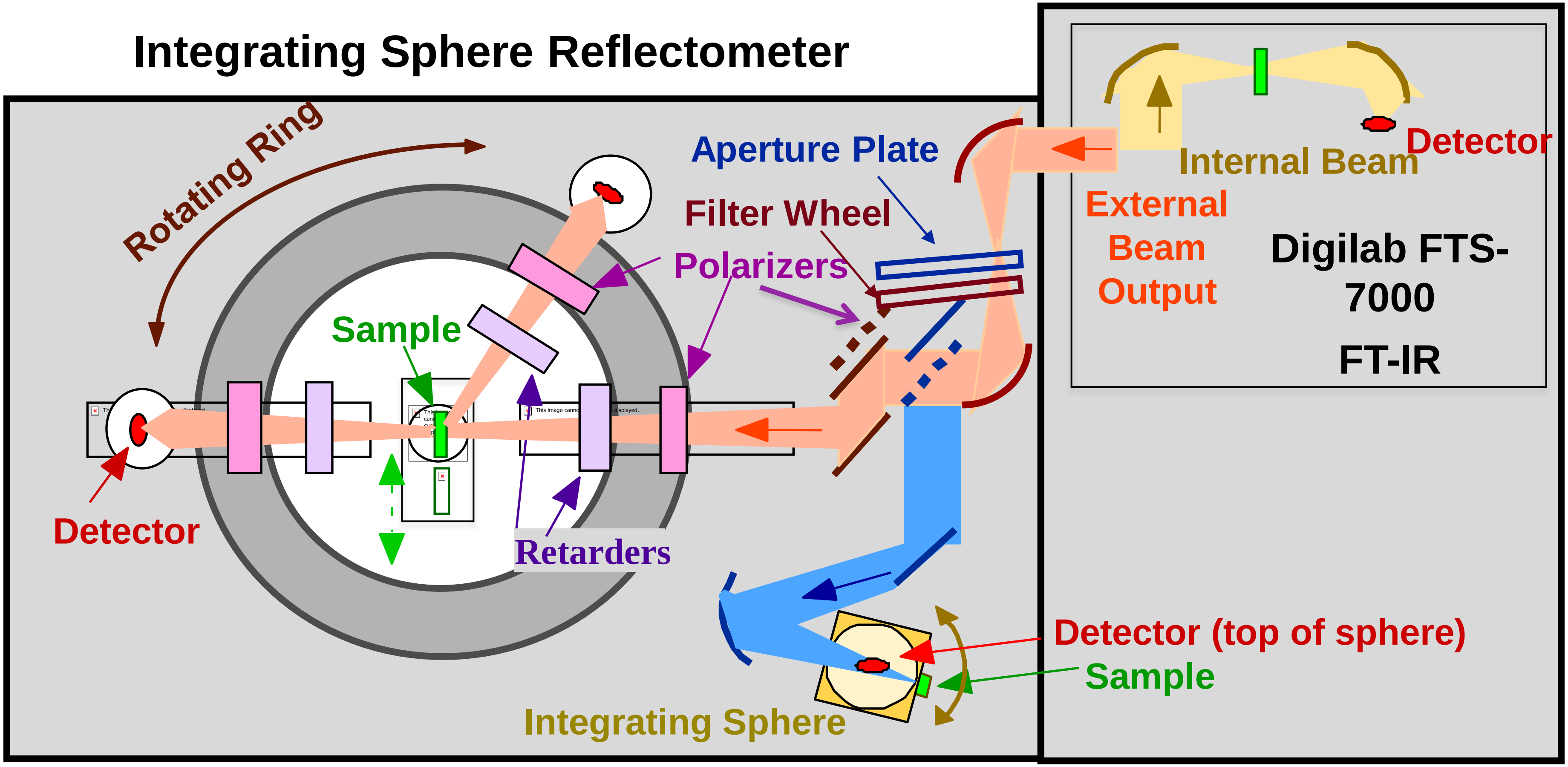
  - Diffuse black paint, Rolls Royce HE-23, stable at elevated temperatures (800 ° C).

  - Specular black paint, PTI PT-401, low reflectance across broad spectral range (2 – 100 µm), may not be best choice for transfer standard but is of interest on it's own

NIST Capabilities: Reflectance / Transmittance

20 ° C to 200 ° C:

Integrating Sphere Reflectometer

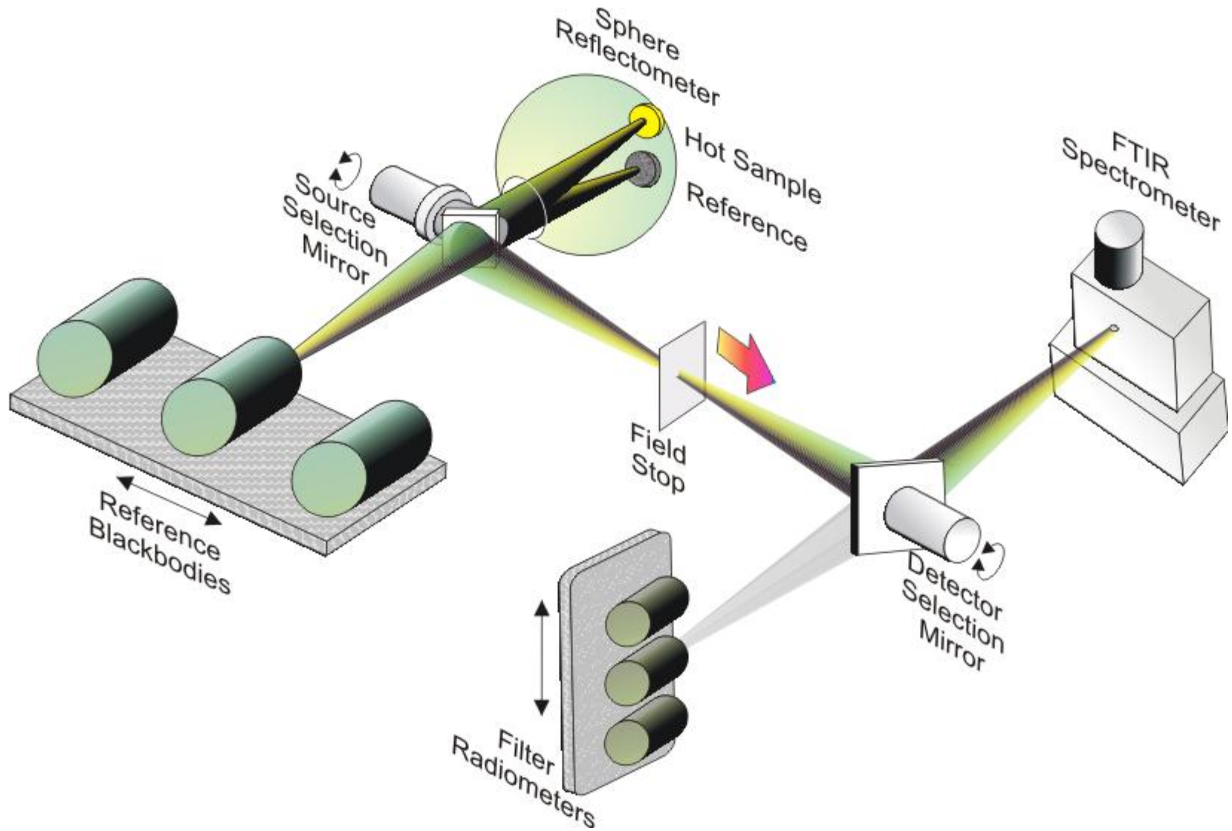


Optical Tables w/ Purged Enclosures

$$\rho(\nu, T_{Sample}) = \frac{V_{Sample}(\nu) - V_{Sample}^{FT\cdot sourceoff}(\nu)}{V_{Sphere}(\nu) - V_{Sphere}^{FT\cdot sourceoff}(\nu)} = 1 - \varepsilon(\nu, T_{Sample})$$

NIST Capabilities: Emittance

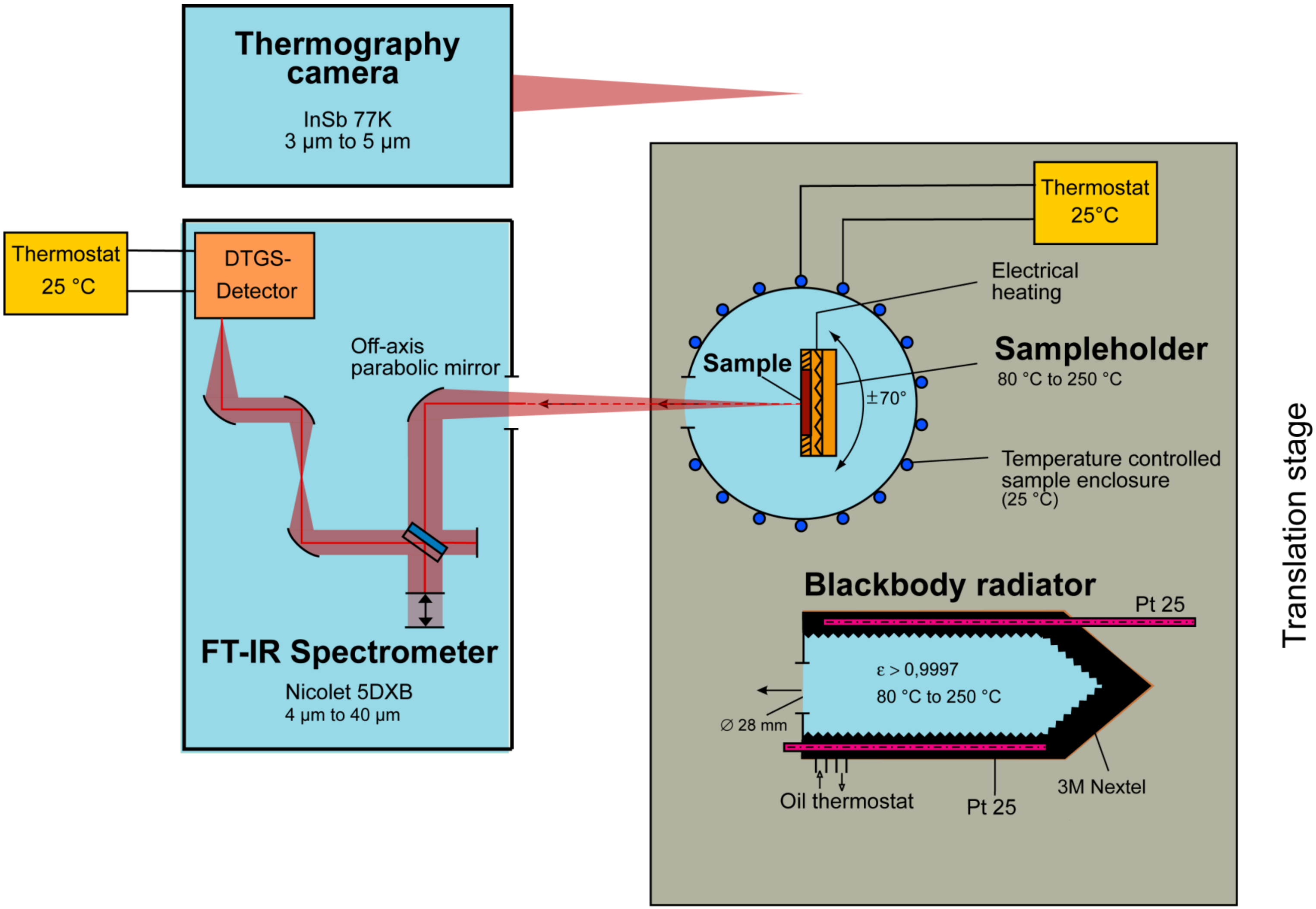
**200 ° C to 900 ° C:
FT-Based Spectral Radiance Comparator (includes Near IR Sphere)**



$$L_{Sample}(\nu, T_{Sample}) = \mathrm{Re}\left[\frac{\left[V_{Sample}(\nu) - V_{BB_{Cold}}(\nu)\right]}{\left[V_{BB_{Hot}}(\nu) - V_{BB_{Cold}}(\nu)\right]}\right]\left[L_{BB_{Hot}}(\nu) - L_{BB_{Cold}}(\nu)\right] + L_{BB_{Hot}}(\nu)$$

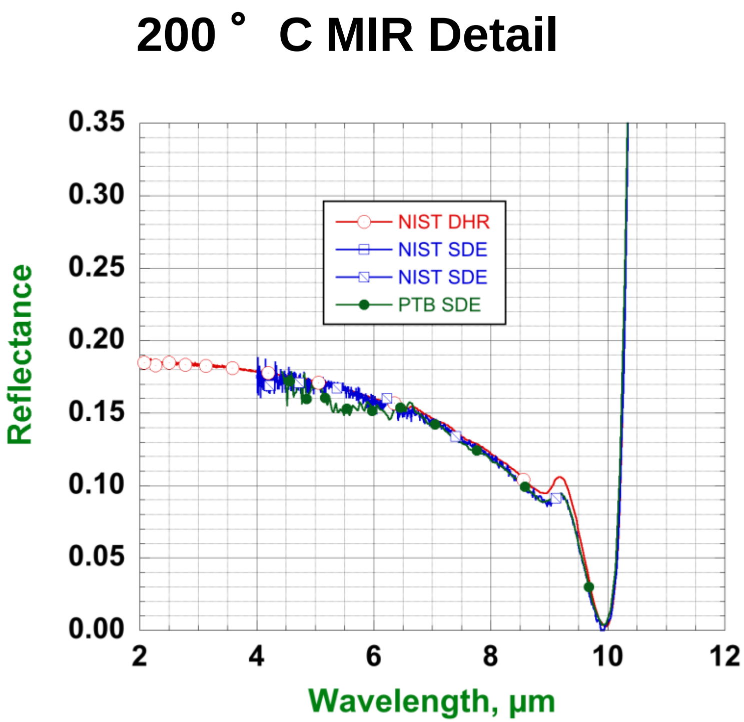
$$\text{and} \quad L_{Sample}(\nu, T_{Sample}) = \varepsilon_{Sample}(\nu, T_{Sample}) \cdot B(\nu, T_{Sample}) + \left[1 - \varepsilon_{Sample}(\nu, T_{Sample})\right] \cdot B(\nu, T_{Ambient})$$

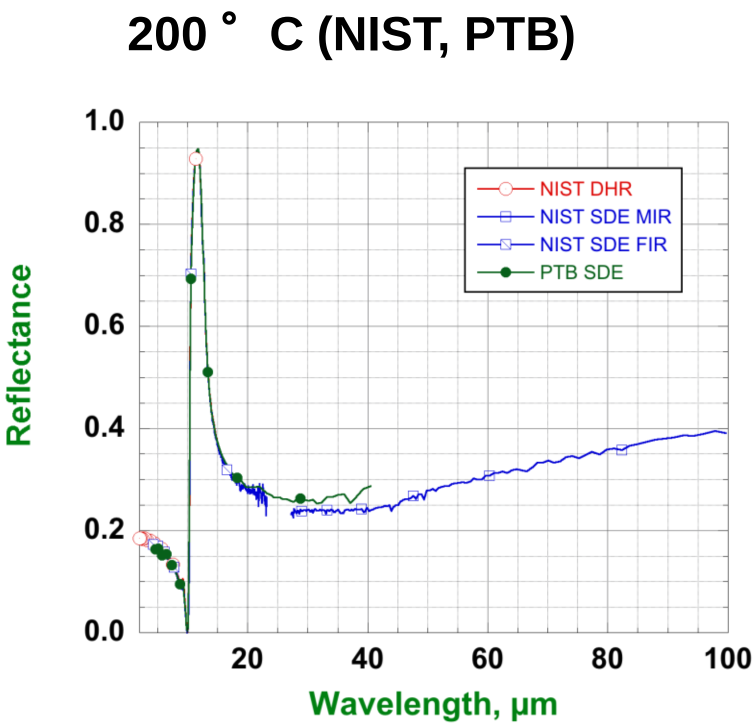
PTB Emittance System



$$\varepsilon_{\mathrm{Sample}} = \frac{Q\cdot\left(L_{\mathrm{Planck}}\left(T_{\mathrm{BB}}\right) - \varepsilon_{\mathrm{Detector}} L_{\mathrm{Planck}}\left(T_{\mathrm{Detector}}\right)\right) + \varepsilon_{\mathrm{Detector}} L_{\mathrm{Planck}}\left(T_{\mathrm{Detector}}\right) - \varepsilon_{\mathrm{Env.}} L_{\mathrm{Planck}}\left(T_{\mathrm{Env.}}\right)}{L_{\mathrm{Planck}}\left(T_{\mathrm{Sample}}\right) - \varepsilon_{\mathrm{Env.}} L_{\mathrm{Planck}}\left(T_{\mathrm{Env.}}\right)}$$

Silicon Carbide Sample Results

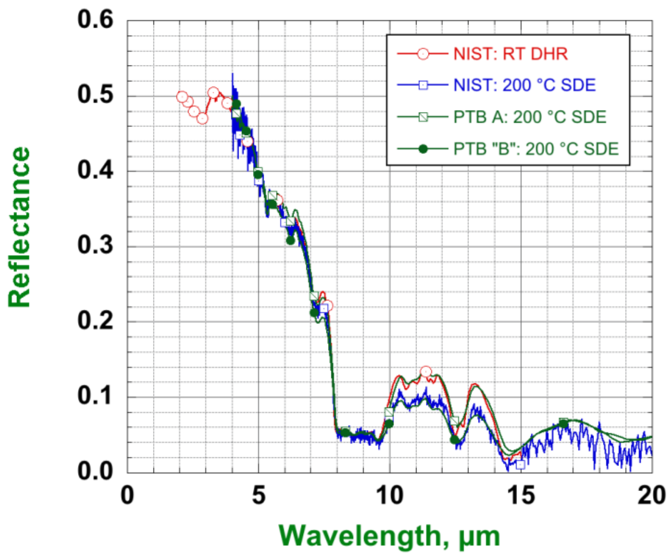




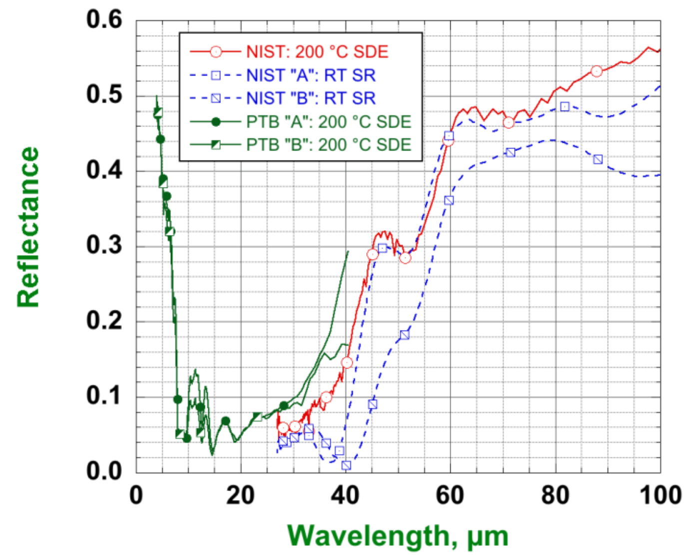
- Agreement very good at for λ > 25 µm, differences to maximum of 5% at 100 µm.

HE-23 Rolls Royce (Diffuse) Paint Results

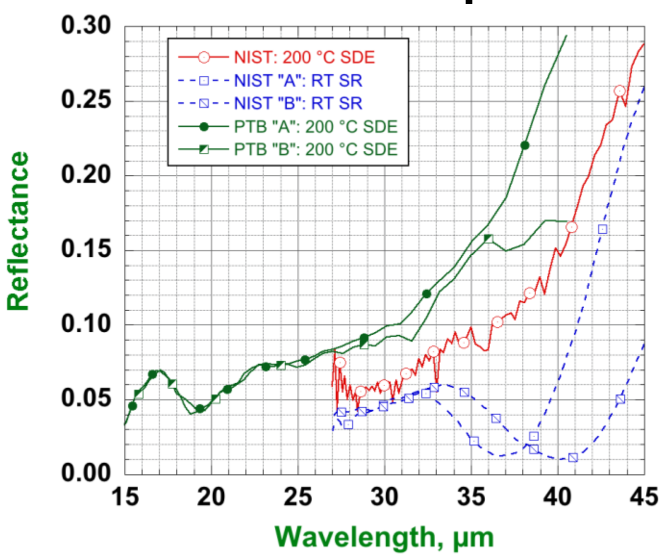
Detail: 2 – 20 µm



Full Range 2 – 100 µm



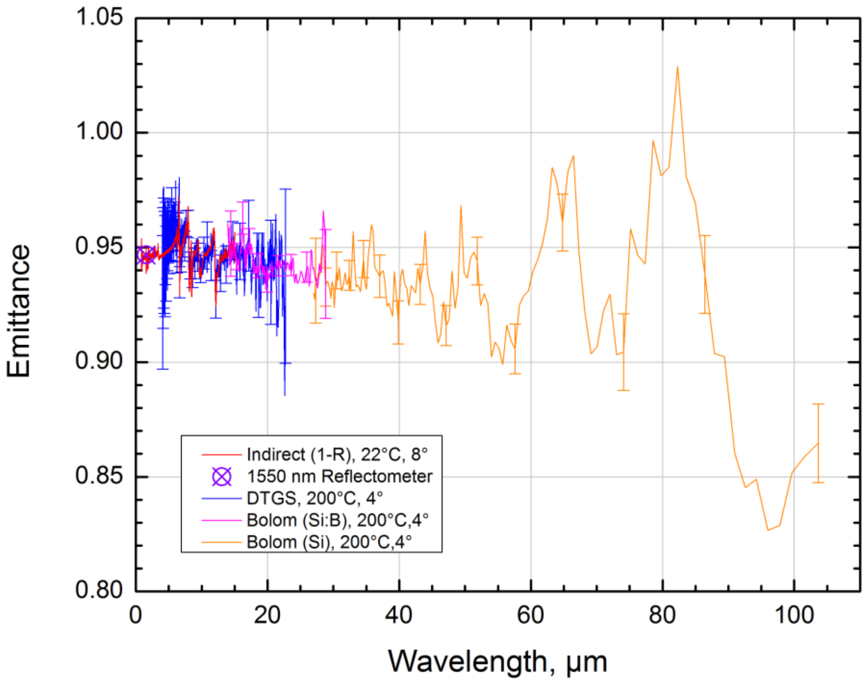
Detail: 15 – 40 µm



- Many of the differences seen can be attributed to sample variation. Temperature dependence is minimal.
- Samples become specular in FIR, as shown by SR results.
- Differences greater than anticipated uncertainties seen in shorter wavelength range.

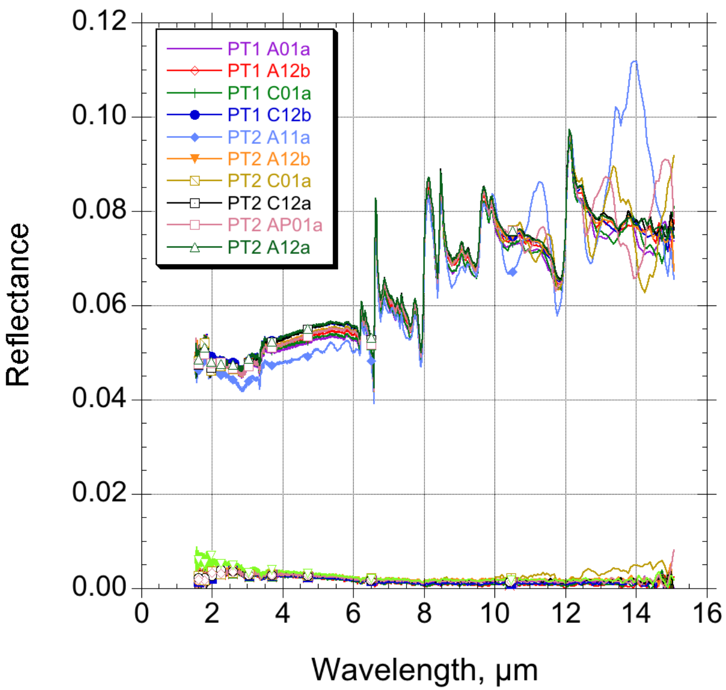
PT-401 (Specular) Paint Results

NIST 3 Detector Continuity



Specular / Diffuse Breakdown

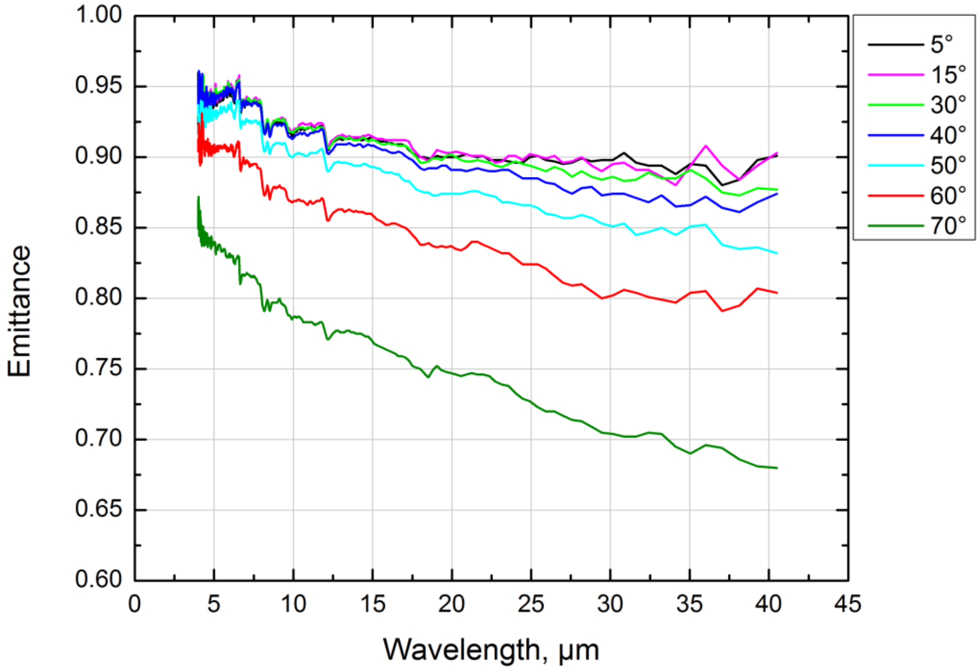
In Thermal IR, NIST data



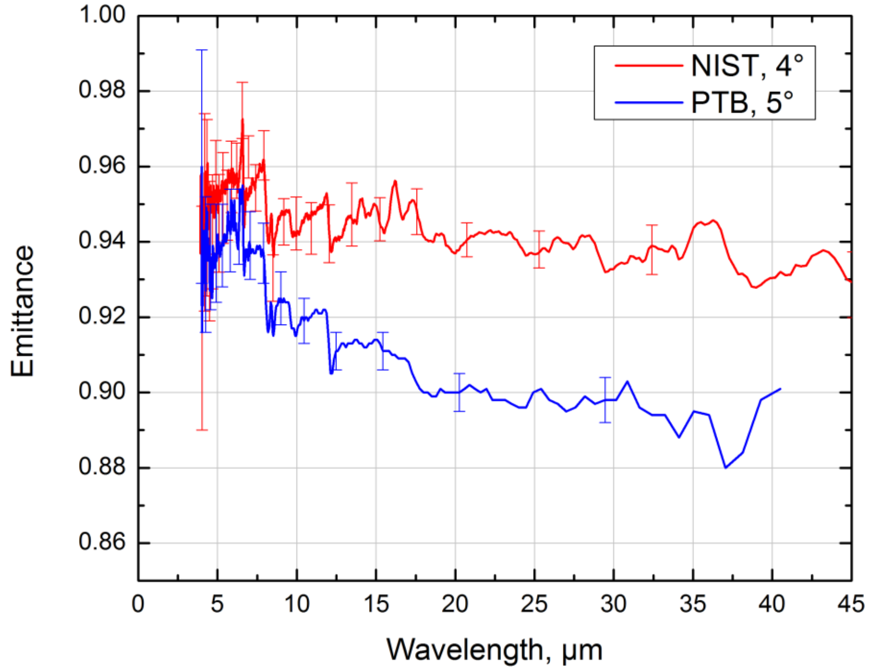
- Right plot shows very low diffuse component of PT-401, which is being studied as potential specular black paint for BB and ACR to replace a discontinued coating.
- PT-401 can be conditioned for low outgassing and has flight heritage. NIST performs thermal conductivity measurements as well.

PT-401 (Specular) Paint Results - Continued

Far IR – Angle Dependence (PTB data)



NIST / PTB SDE Composite



- PT-401 being studied as potential specular black paint replacement for discontinued coating.
- Differences in the right plot may be attributed to the paint thickness variation (different samples were studied)

Conclusions and Future Plans – Far IR Emittance

- Initial results are reasonable, but challenge to sort out differences remains.
- Both labs have active internal projects to further improve respective capabilities
- Candidate specular black paint standard (PT401) shows promise (low overall and very low diffuse reflectance) for FIR
- A new batch of PT401 samples will be prepared for full evaluation
- Near-future improvements (PTB Emittance Facility upgrade with new Vertex 80 FTS and new emittance capabilities of RBCF, and BIB and Boron doped Si detectors at NIST) will further enhance both partners capabilities in the area

Path to reflectance standards / emittance calibrations to 100 µm is started

Conclusions and Future Plans - Collaboration

- Far IR Optical Properties of Materials: Emittance, Reflectance and BRDF
  - ***In Progress, Successful Start***
- Far IR Optical Properties of Ultra-High Absorptance Targets (Cavities of Blackbodies and Absolute Radiometers)
  - ***Being Discussed***
- Thermal and Far IR Spectral Radiance & Radiance Temperature Scales for Thermo-Vacuum Environment
  - ***Plans are not specific (budgetary constraints on the NIST and NASA side), will re-assess later***

Thank You