Results of a Nationwide Inter-Laboratory Comparison of Infrared Reflectance

L. M. Hanssen, B. Wilthan

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Outline

I. Background

II. Intercomparision Details

III. Sample & Calibration Description

IV. Calibration & Comparison Results

V. Conclusions

EO-IR Calibration and Characterization Workshop, 7-9 March 2006

"Presenters from government, industry and academia will discuss the importance and potential of a united effort to improve and standardize measurements and data formats within the EO/IR community. Participants will benefit from presentations on current calibration and characterization activities and lessons learned, while also taking part in focused breakout sessions that will address specific issues of interest to the community. The breakout sessions will foster open discussion and provide participants with the opportunity to share ideas and explore possibilities, as well as contribute to the development of a roadmap based on broad community input."

Outcome of Workshop Discussion Sessions:

Priority of Highest Interest as expressed by the Workshop Participants:

Round Robin of near-normal diffuse & specular reflectance amongst DoD & Contractor Labs/Ranges to be conducted by NIST.

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Intercomparison Structure

- NIST is Pilot Lab - organizes and coordinates intercomparison
- Process: "Star" Intercomparison approach
  - One sample set for each participant, NIST measures all samples - evaluates uniformity between samples
  - Measurement sequence: NIST-Participant-NIST
  - Advantage:
    - shorter time overall, especially for large group
    - Less risk due to sample accident
  - Disadvantage:
    - sample-sample variability, although characterized
    - more work for Pilot lab
- **Results compiled/analyzed by NIST**
  - Results communicated to all participants
  - Participants information listed, but data not identified (use 1,2,3, …)

Final Participant List

	IR Round Robin Participants		
#	Company/Agency	Contact	State
1	Air Force Research Lab 2	Bill Lynn	Ohio
2	Arnold Engineering Development Center	Dustin Crider	Tennessee
3	Boeing 1	Daniel Northem	Missouri
4	Boeing 2	Myrna Guhit	California
5	Boeing 3	Steve Wicken	Washington
6	CACI MTL Systems, Inc.	David J. Kelch	Ohio
7	General Electric	Joseph Sparks	Ohio
8	Lockheed Martin 1	Mei Graham	Texas
9	Lockheed Martin 2	Sarah Mieding	California
10	MIT Lincoln Labs	Merle Persky	Massachussetts
11	Naitonal Research Council	Nelson Rowell	Ontario, Canada
12	Northrop Grumman 1	Steven Chu	New York
13	NWSC Carderock	Bill Yeager	Maryland
14	Optical Data Associates	Michael Jacobson	Arizona
15	Pratt and Whitney	John Borla	Connecticut
16	Raytheon, El Segundo	Vijay Murgai	California
17	Sandia National Labs	Robert Ellis	New Mexico
18	SRI International	Jeffrey Voss	California
19	Surface Optics Corp.	Martin Szsecznіak	California
20	The Aerospace Corp.	Chung-tse Chu	California
21	USGS	Jim Crowley	Virginia

Participant Survey Results

Survey Responses: 20/25 received

Spectrometer Type: all **FT**, except 1 x broad band; several second instruments, 1 x monochromator, 1 x filter

DHR system: 5 x **integrating sphere**, 6 x **SOC-100**, 16 x unspecified

Spectral Range: **2 µm - 14 µm**; 2 x 2.5 µm, 2 x 12 µm

Spectral Resolution: **8 cm^{-1}**; 5 x 16 cm^{-1}, 6 x 8 cm^{-1}, 5 x 4 cm^{-1}, 2 x ≤ 2 cm^{-1}

Sample Size Acceptable: 18 x **1 inch** dia., 6 x **2 inch** dia., 2 unknown

Geometry: “near normal” incidence angle: **8° - 20°**

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Intercomparison Transfer Standard Sample Set

5 samples in set:
diffuse - hi, med, low; specular - hi, med
(51 mm dia. set shown)

Intercomparison Transfer Standard Sample Set - Details

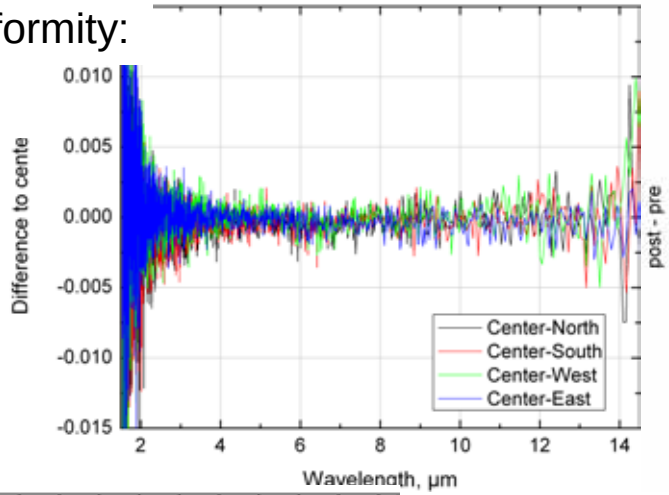
- **Specular standards:**
  - High (SA): Electroplated Gold Mirror on polished copper substrate
  - Medium (SD): Polished High Density Silicon Carbide
  - {Low (SC): Z-302 paint on brass substrate: problems with paint thickness and diffuse component in semitransparent region – dropped from comparison}
- **Diffuse standards:**
  - High (DA): Electroplated Gold on Nickel on arc-sprayed aluminum on machined brass substrate
  - Medium (DD): Krylon Silver Paint on arc-sprayed aluminum on machined brass substrate {replaced initial "DB" set due large sample to sample variability}
  - Low (DC): Nextel Black Paint on machined brass substrate

Sample Characterisation

Gold Mirror, Silicon Carbide - Details

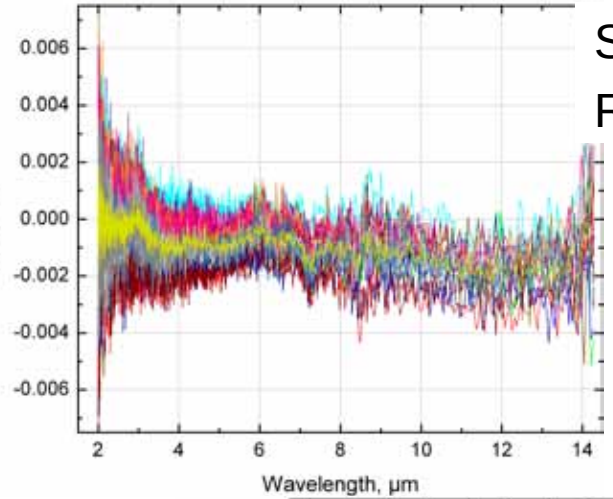
Spatial Uniformity:

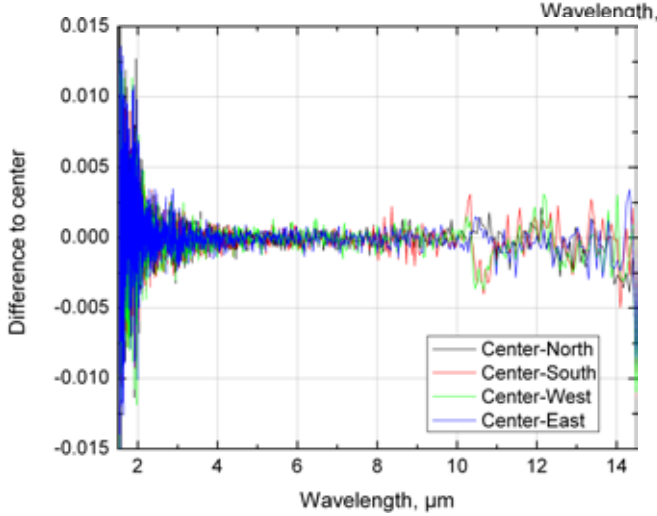
Gold Mirror



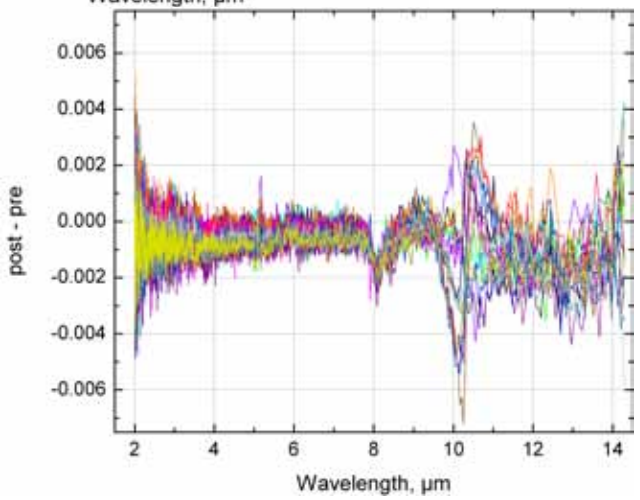
Stability/

Repeatability:



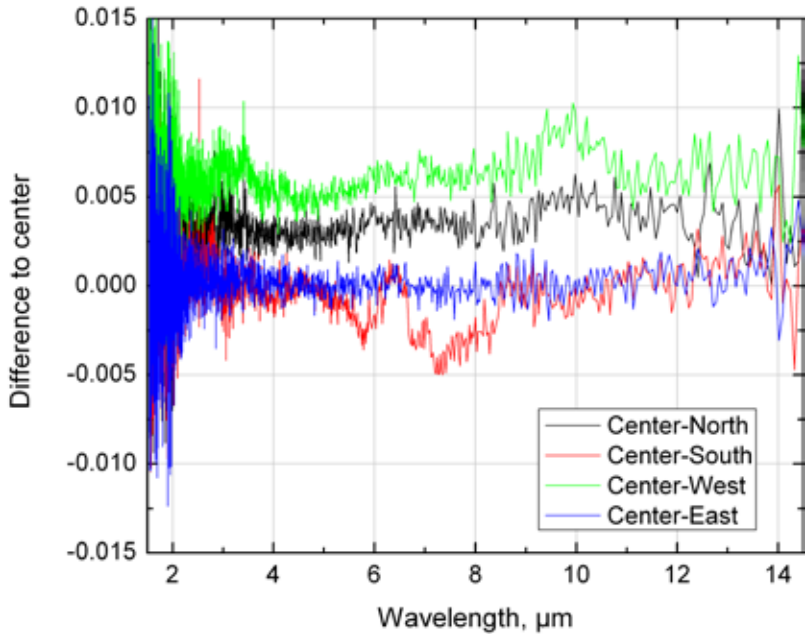


Silicon Carbide

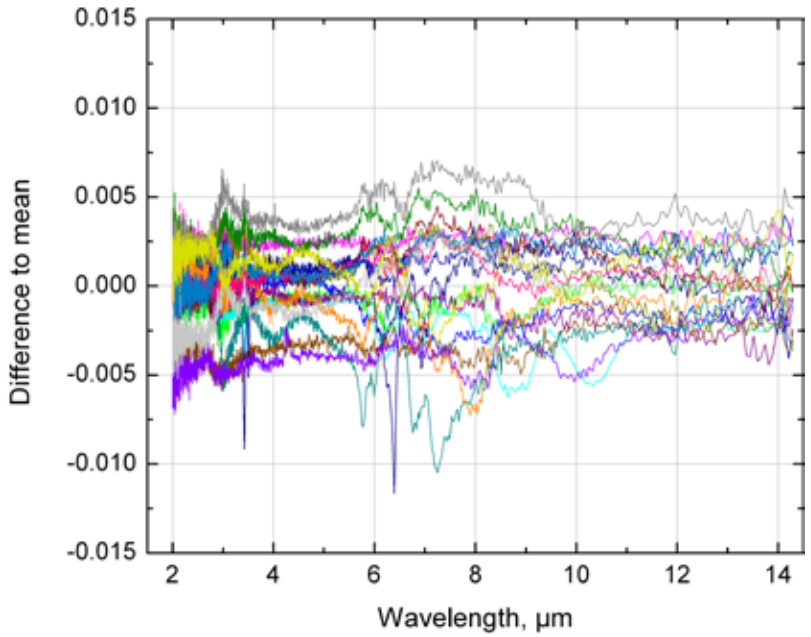


Sample Characterisation

Rough Gold - Details



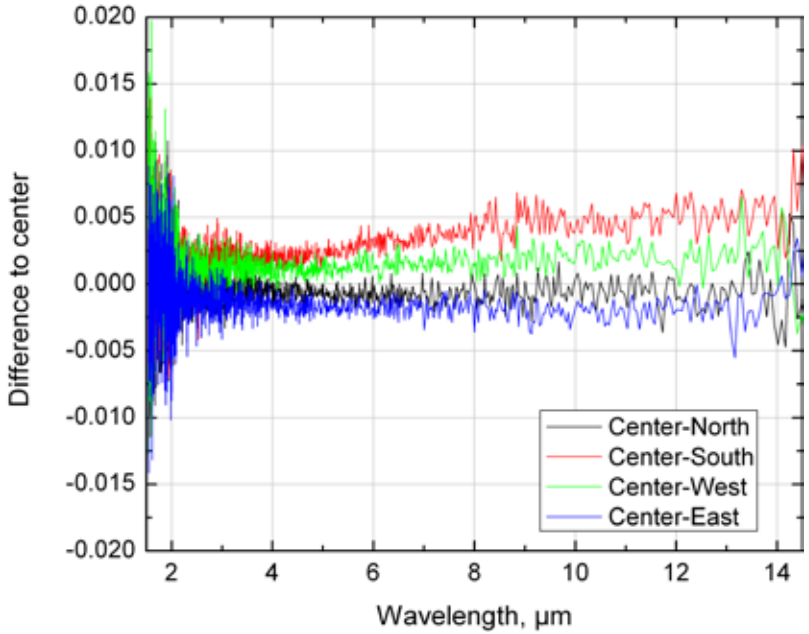
Spatial Uniformity of one sample.



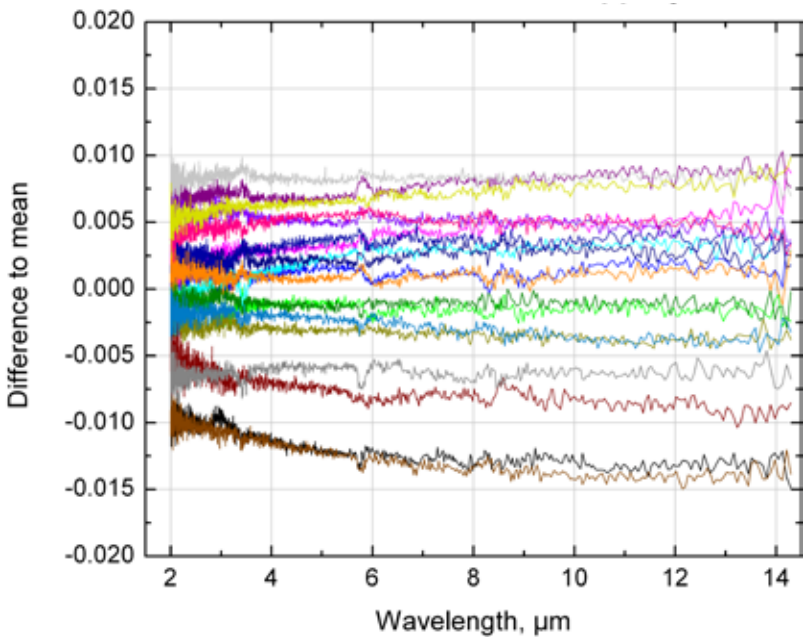
Variability of the sample set.

Sample Characterisation

Krylon Silver Paint - Details



Spatial Uniformity of one sample.



Variability of the sample set.

Intercomparison Specifics

- Quantity: near-normal infrared spectral reflectance of opaque standard samples
- Measurement geometry: for 3 diffuse standards - directional-hemispherical (DHR) or hemispherical-directional (HDRF); for 2 specular standards - collect specular reflection
- Incident angle: $q \leq 15°$ (20° for one participant)
- Spectral range: 2 to 14 µm (can vary for some participants)
- Sample set (5): specular: high, medium w/ structure; diffuse high, medium (paint) reflectance, low (paint) reflectance
- Sample size: 1 and 2 inch diameter (3 to 5 mm thick)
- Data submission: preformatted spreadsheet, data at 4 cm^{-1} intervals

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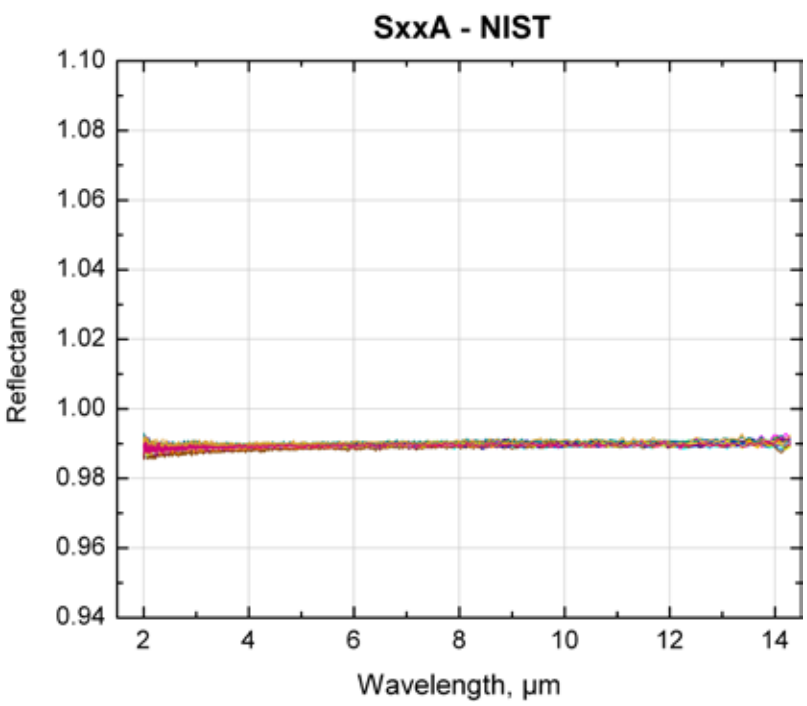
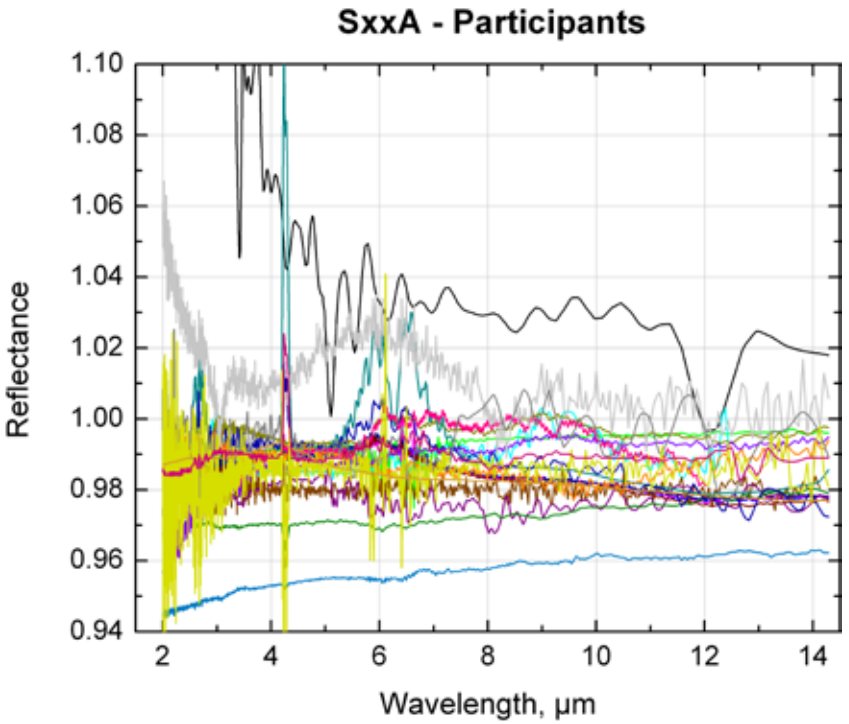
SxxA – Gold Mirror Samples I

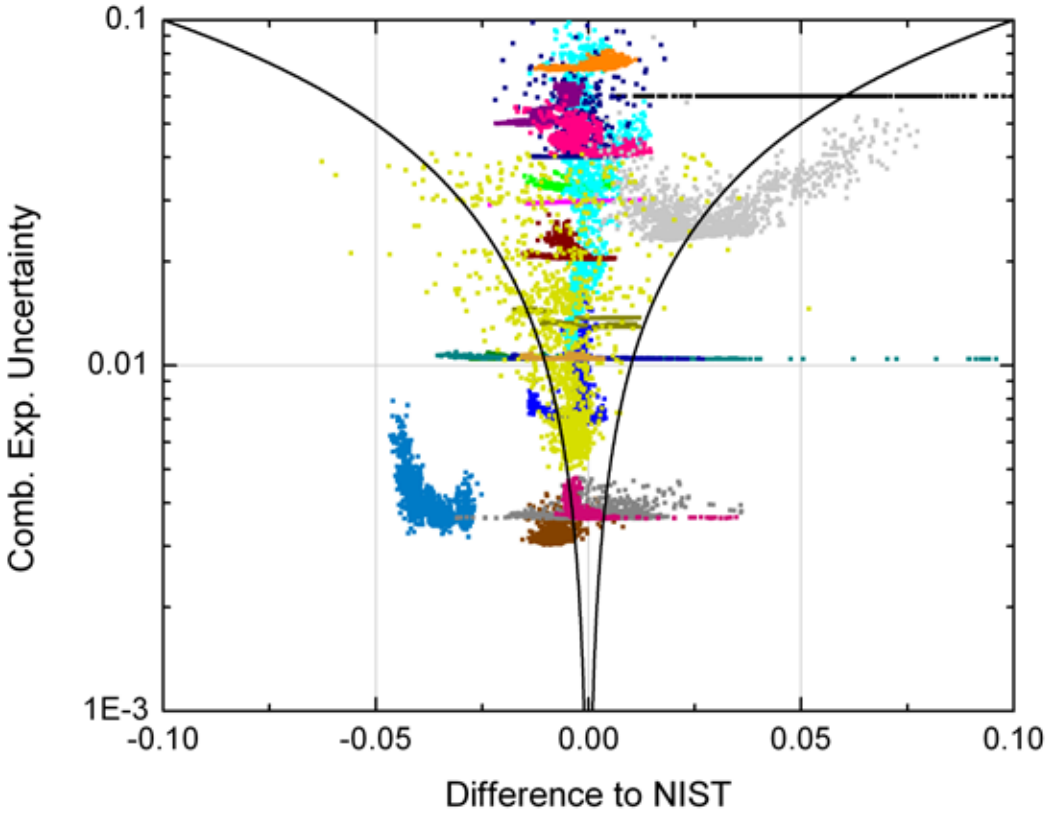




21 Curves overlaid in each plot

NIST data are mean of before and after measurements

SxxA – Gold Mirror Samples II



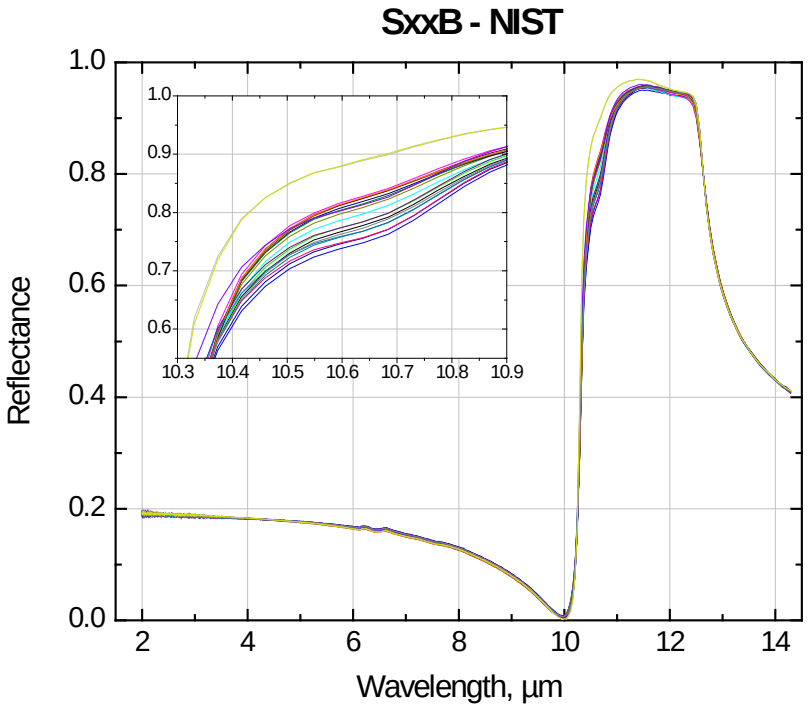
Comparison of Combined Uncertainty with Difference to NIST

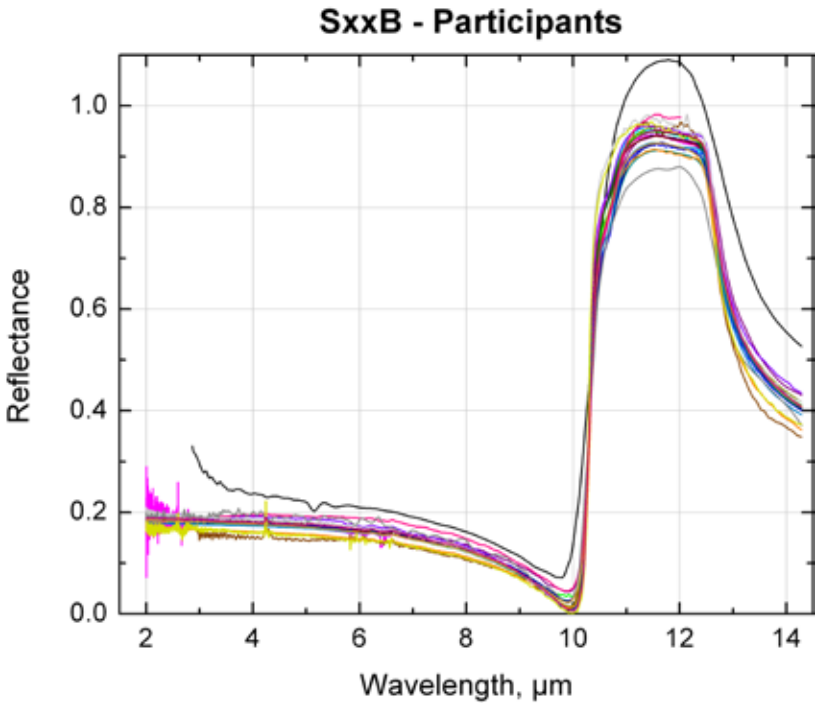
Individual results are consistent with claimed uncertainties if points lie within black curves

Combined Expanded Uncertainties = $\sqrt{U(NIST)^2 + U(Sample)^2 + U(Participant)^2}$

Some uncertainties underestimated; some uncertainties overestimated

SxxB – Silicon Carbide Samples I

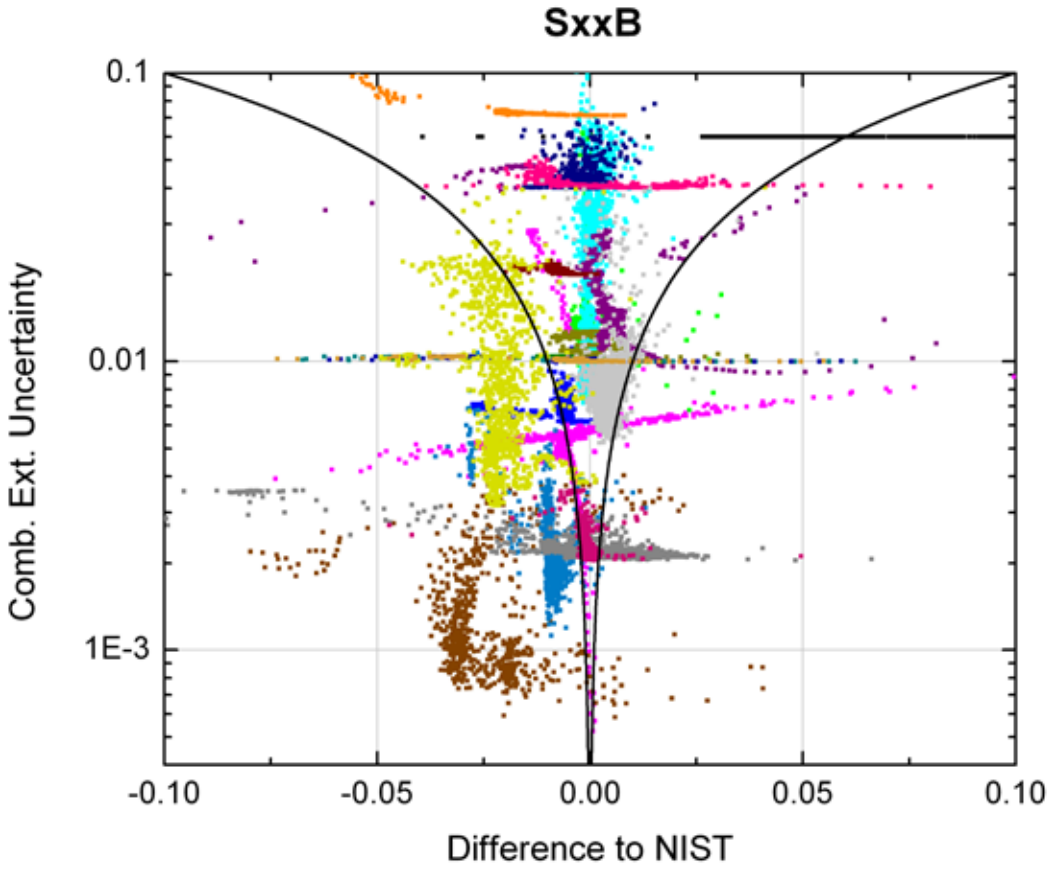




Minor sample to sample variability

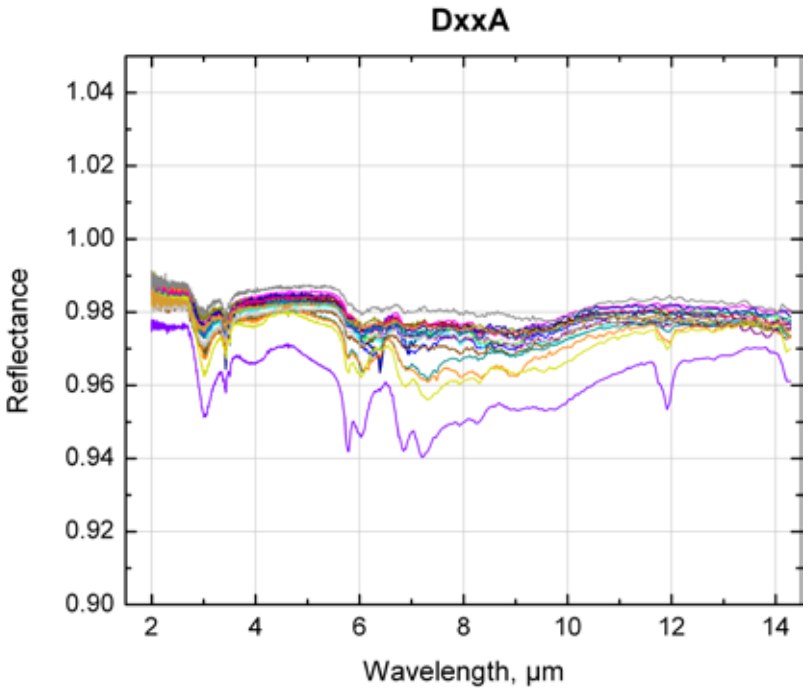
Near complete coverage of reflectance range 0 to 1

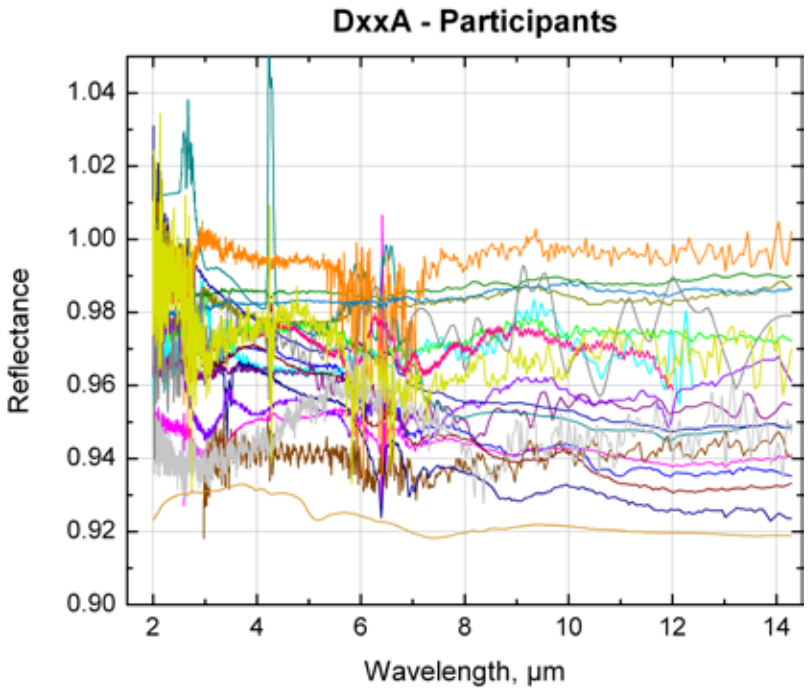
SxxB – Silicon Carbide Samples II



Significant differences seen between NIST & a number of participants results

DxxA – Rough Gold Samples I

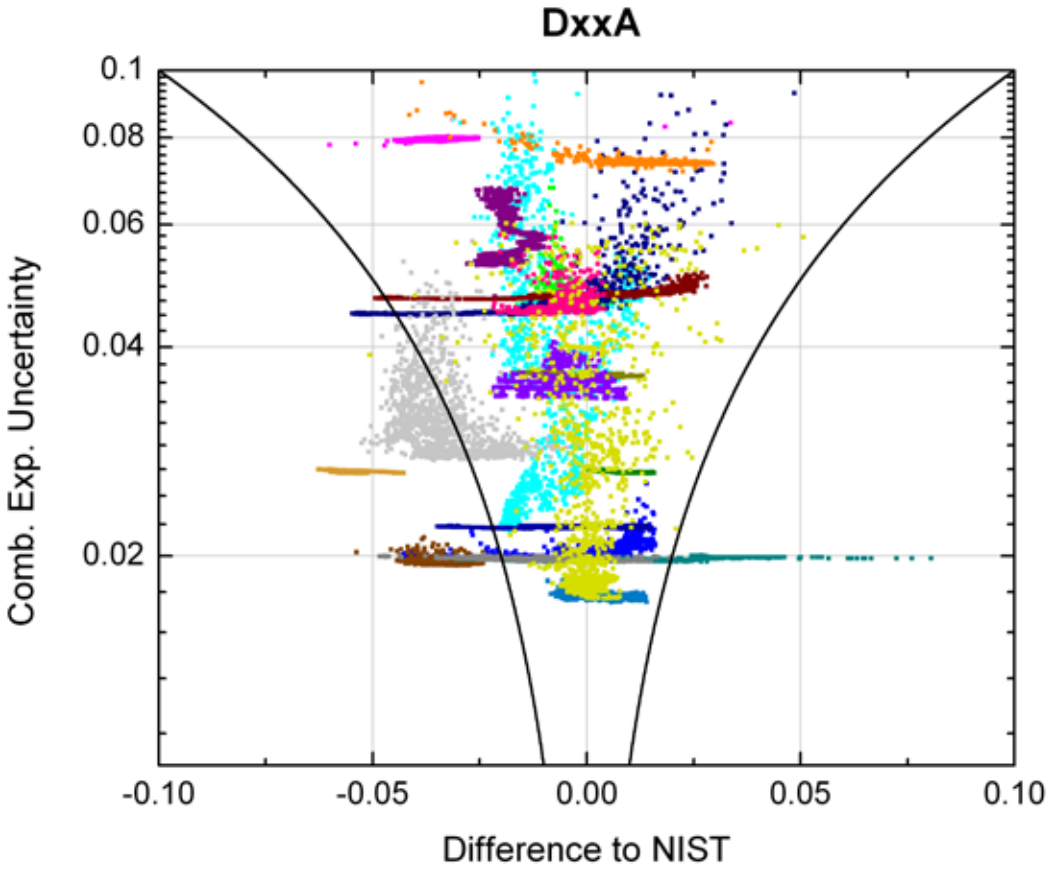




Some change in reflectance seen in a few samples, one poor in particular

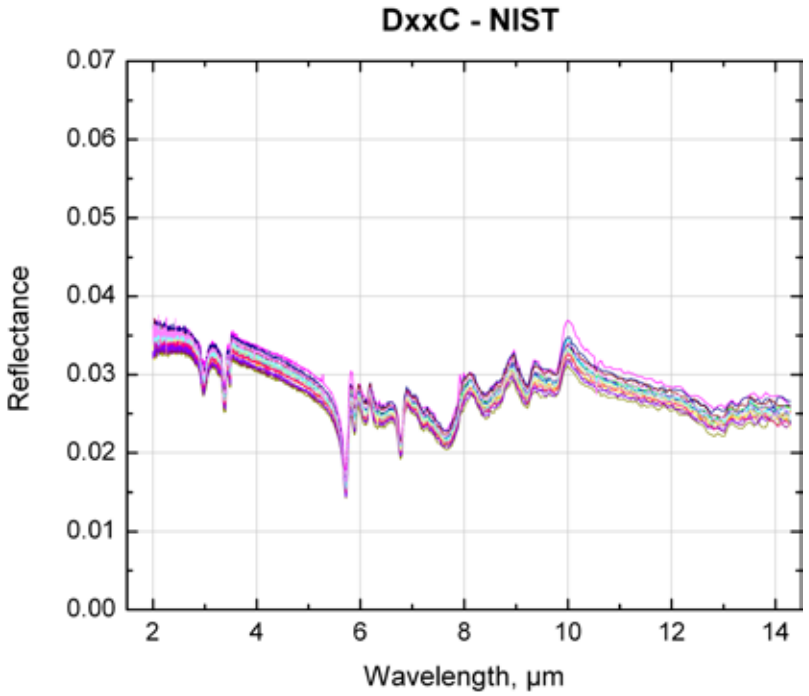
Monitoring of samples will continue to examine long term stability

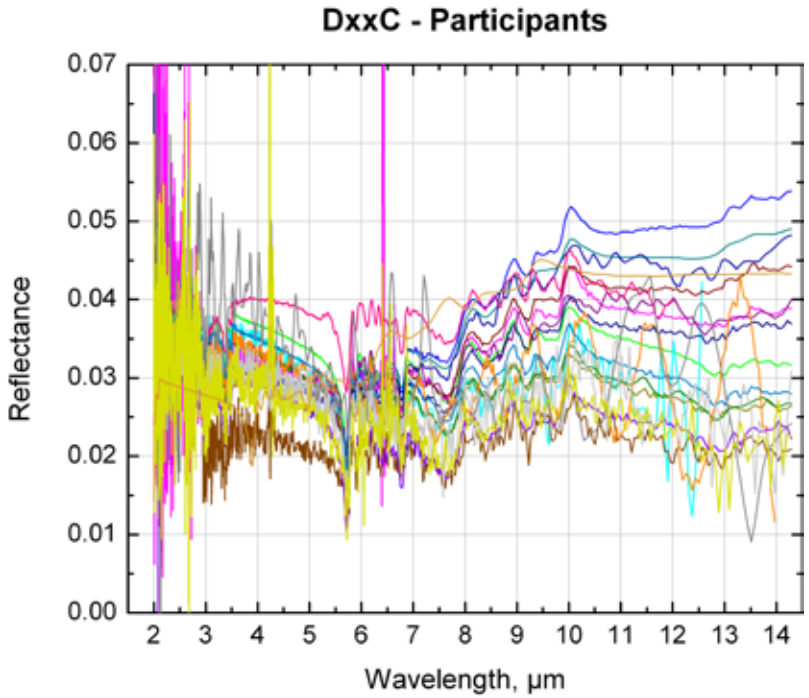
DxxA – Rough Gold Samples II



Most (but not all) results within combined uncertainties

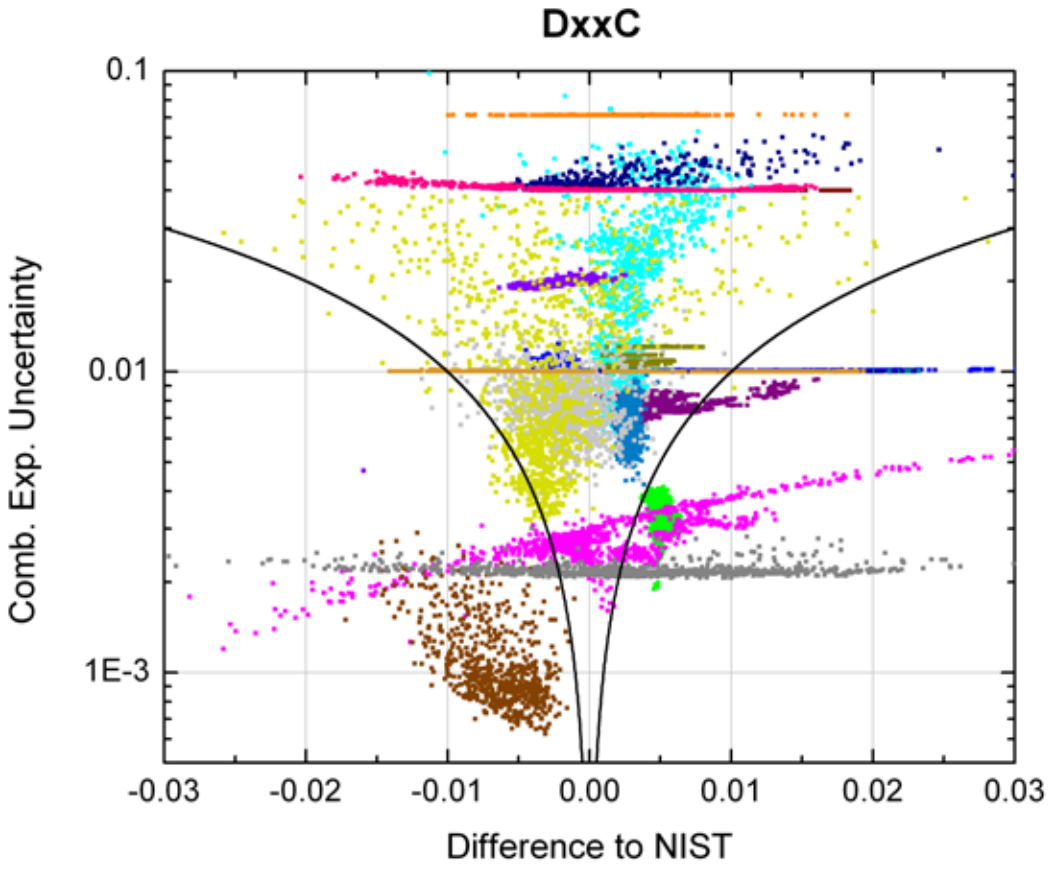
DxxC – Nextel Black Paint Samples I





Large relative variability in participants results

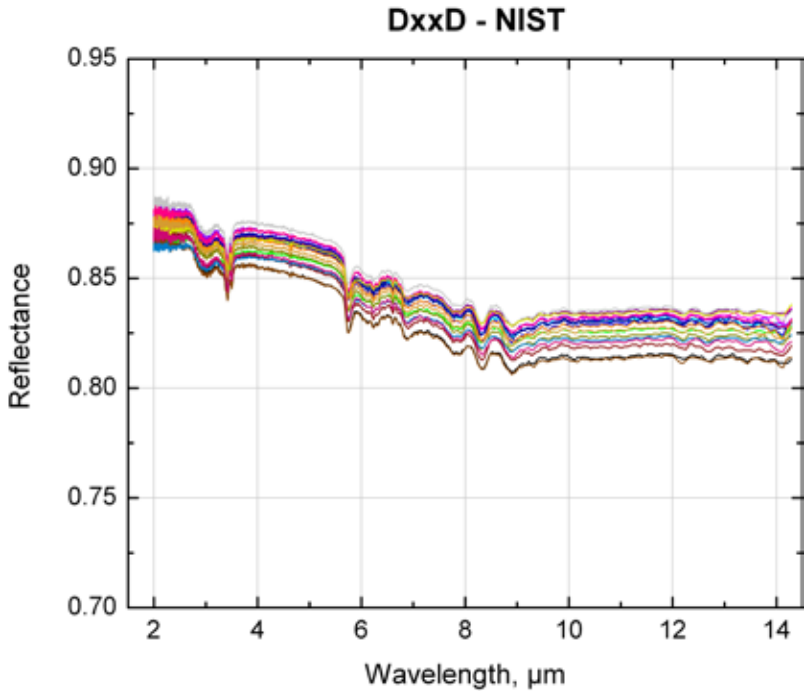
DxxC – Nextel Black Paint Samples II

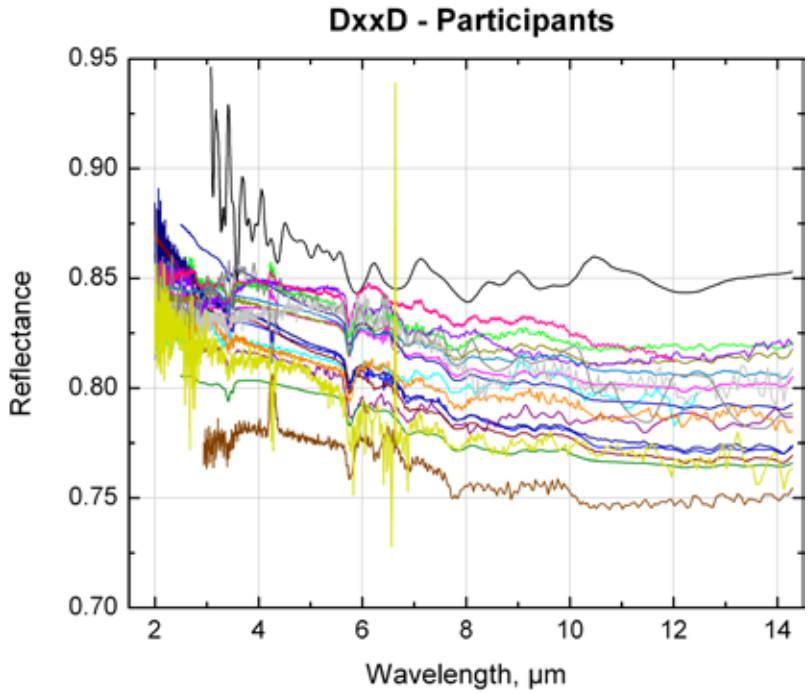


Large range of uncertainties from participants.

Some points outside curves due to failure to include noise component in uncertainty calculation

DxxD – Krylon Silver Paint Samples I



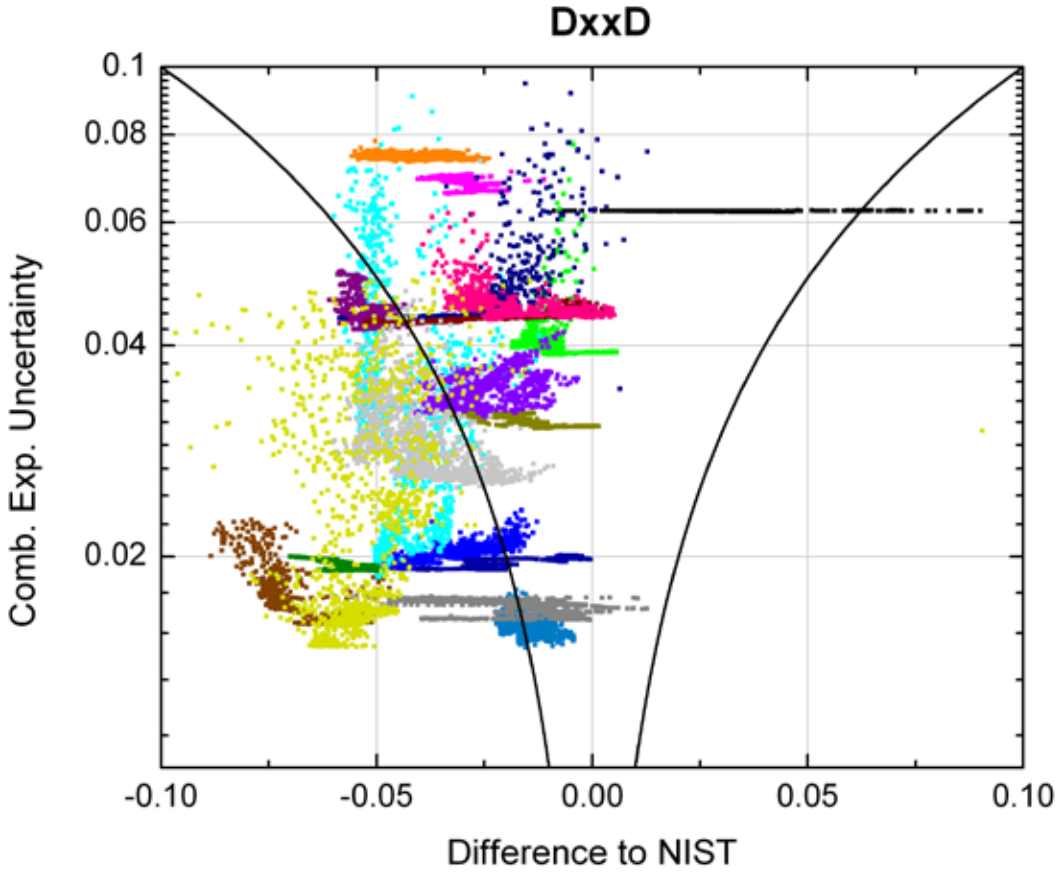


Somewhat larger sample to sample variation

Generally lower values for participants

Not surprising (see followings slides) but clear indication of inherent large(r) uncertainties for diffuse sample measurements

DxxD – Krylon Silver Paint Samples II



Clear “shift” between most participants and NIST

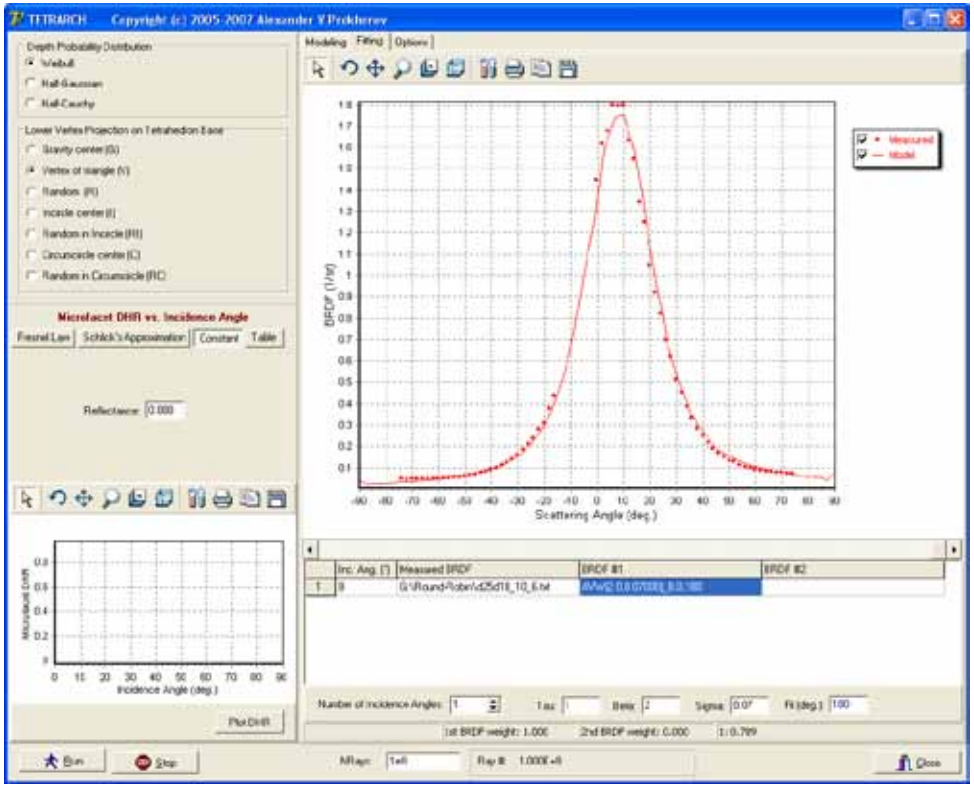
Not revealed in preliminary comparison plot shown last year

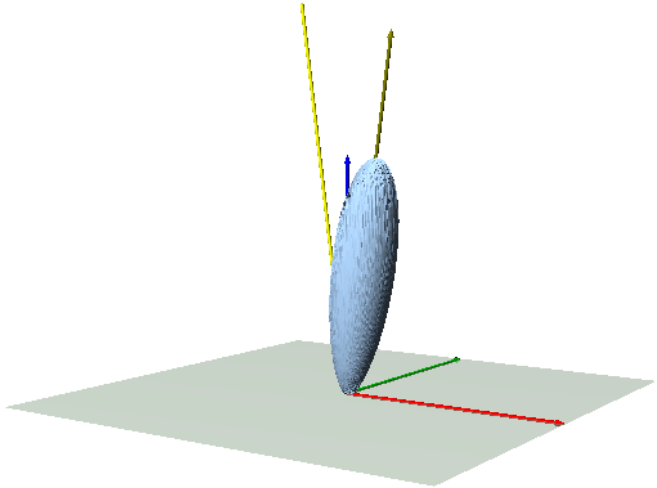
Result of correction applied to NIST data, but unlikely to participant’s data

NIST method for Absolute Diffuse Reflectance

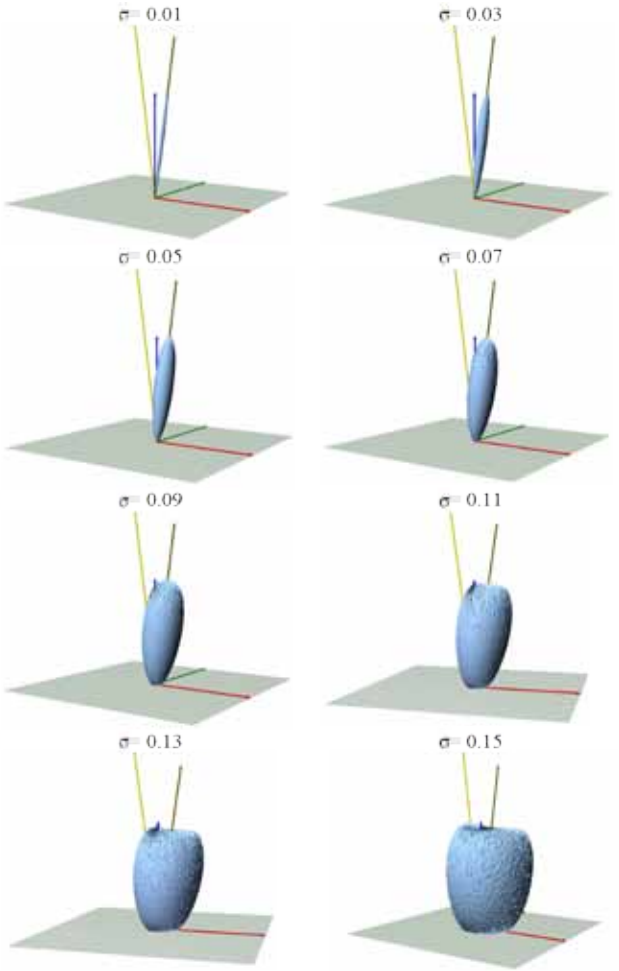
- Basic sample / reference measurement results supplemented with sphere response uniformity (map) characterization and sample BRDF information
- Standard calibration measurements use correction curve determined for Lambertian scattering – uncertainty budget includes possible deviations
- Specialized calibrations (e.g. for IR reflectance intercomparison) include BRDF measurements – and reduced uncertainties
- Specifically, In-plane BRDFs measured at 1.55 µm and 10.6 µm
  - Interactive program used to fit combination of BRDF to measured data
  - 3D BRDF data are generated from fit using Monte Carlo program
  - 3D BRDF data are folded with integrating sphere uniformity map data to generate spectral correction curves for 1.55 µm and 10.6µm
  - Spectral corrections curves are interpolated to obtain final correction curves

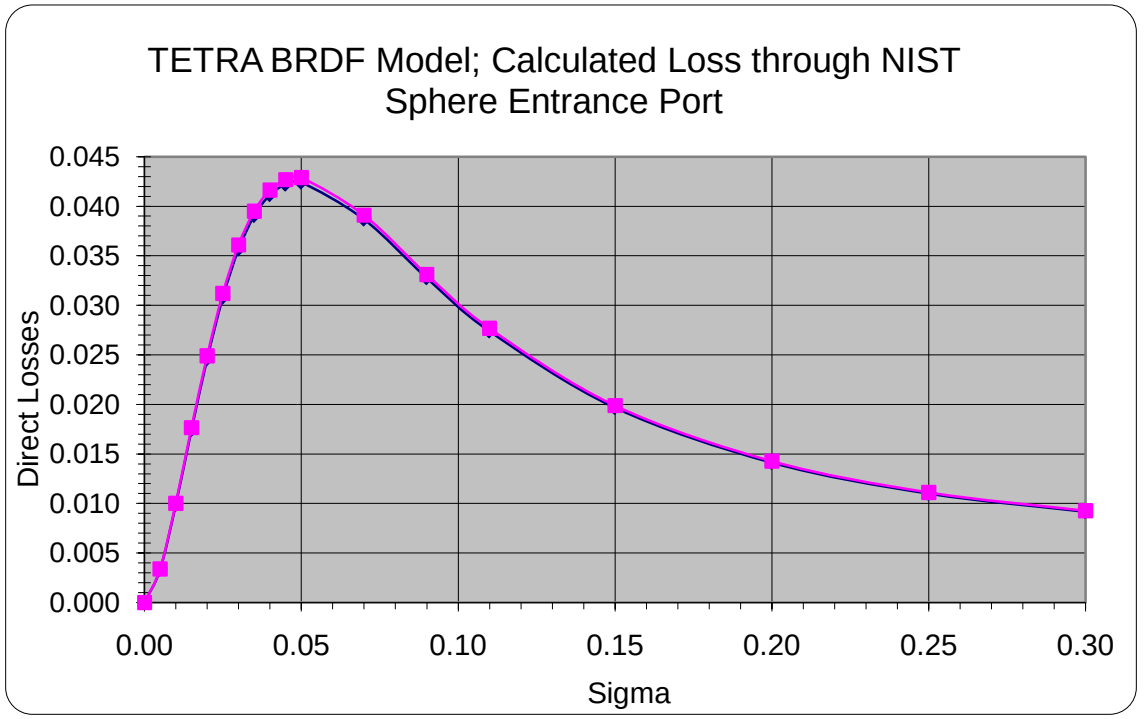
DxxD – Krylon Silver Paint BRDF





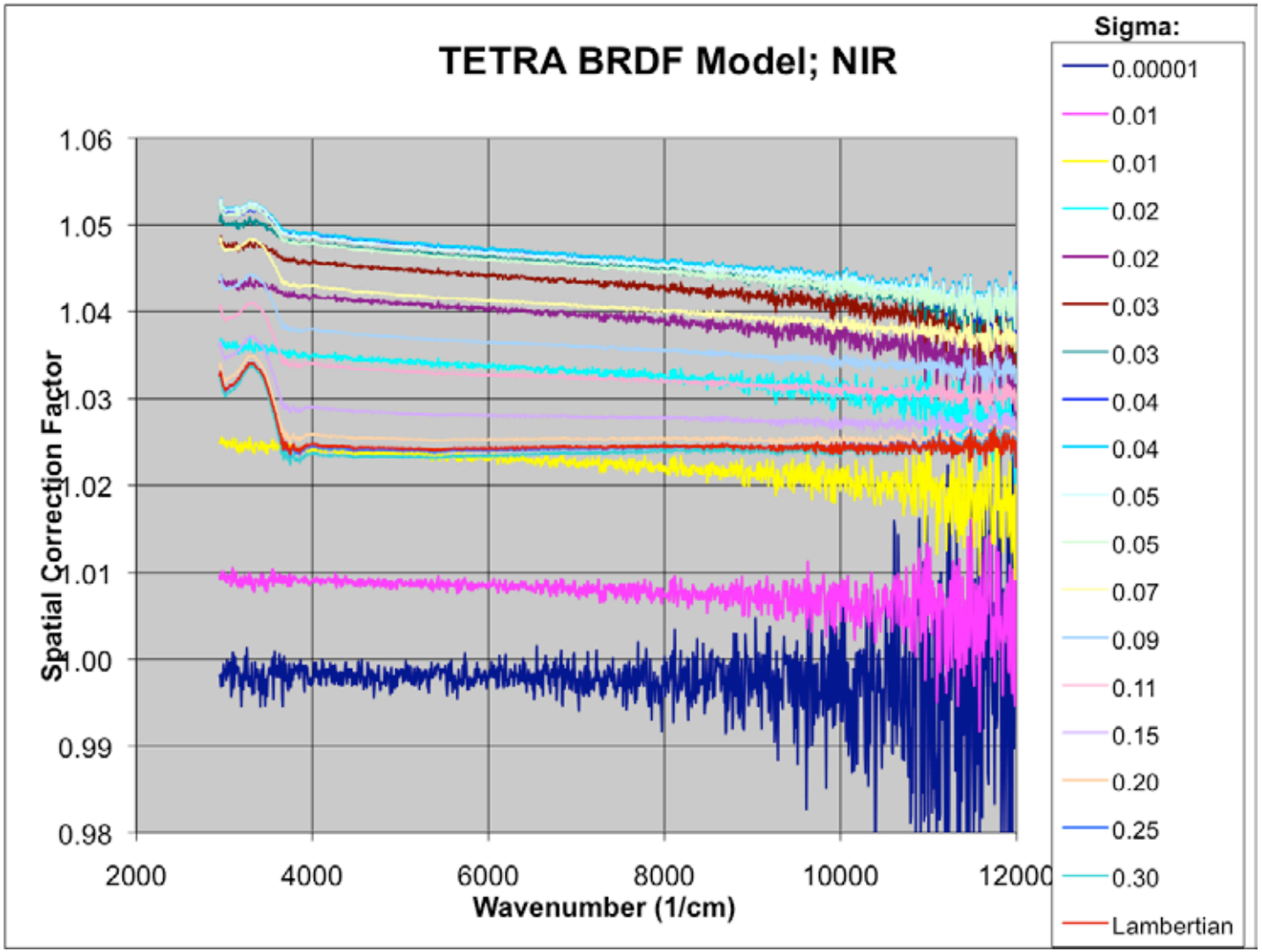
Dependence of Port Loss on BRDF Example





- TETRA procedural model developed to account for multiple surface reflection effects
- Maximum port loss > 4% vs. Lambertian case 1%
- Results used for uncertainty estimate & data correction

Correction Curves for Range of BRDFs



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Conclusions and Future Directions

- Ø Nationwide IR Reflectance Intercomparison successfully completed
- Ø Results reveal general lack of realistic uncertainty values (both under- and over-estimated)
- Ø Inherent design of measurement instruments (incl. port loss) can limit ultimate accuracy
- Ø Use of calibrated samples/standards can reduce error and uncertainties – standard sets transferred to about 40% of participants (purchase/support)
- Ø NIST capabilities expansion: variable angle & grazing incidence DHR, and extended wavelength range > 50 µm
- Ø Presentation of Results at EO-IR Workshop, CALCON and SPIE San Diego, Publication in progress
- Ø NIST capabilities expansion: variable angle. Potential future Intercomparisons: Variable angle R, BRDF

Validation of the Infrared Spectral Radiance Scales Realized at NIST Spectral Emittance and Infrared Radiometry Facilities

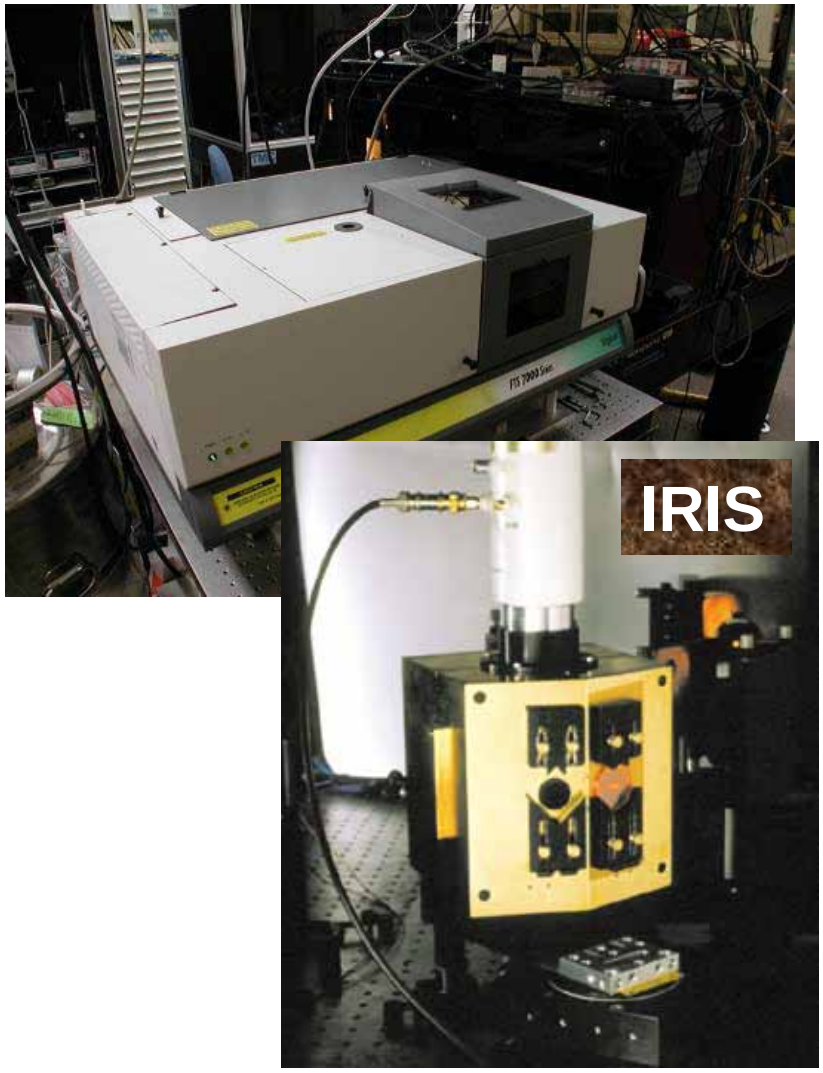
Thank You

L. M. Hanssen, B. Wilthan

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Backup Slides

FTIR w/ Infrared Reference Integrating Sphere



Specifications

- l range: 1.0 – 14(18) µm
- 6 inch diameter
- gold-electroplated plasma-sprayed metal coating
- MCT detector w/ non-imaging concentrator optics; high efficiency
- baffling in sphere
- 8° incidence angle
- T range: 20 – 200 °C

Capabilities

- Reflectance, Transmittance & Absorptance
- absolute & relative specular R, T & A
- absolute & relative diffuse R, T & A
- uncertainties (2s):
  - specular: ≤ 0.3%
  - diffuse: 1.5 - 3%
  - larger for angle dependent structure
- can measure R of transmissive samples
- can sort out scatter from total R & T