Dependence of Bidirectional Instrument Performance on Sample BRDF Properties

David R. Wyble

CORM/ISCC Joint Conference
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July 31 - August 1, 2017

Why this is hard

image credit: Coatings World

image credit: KonicaMinolta

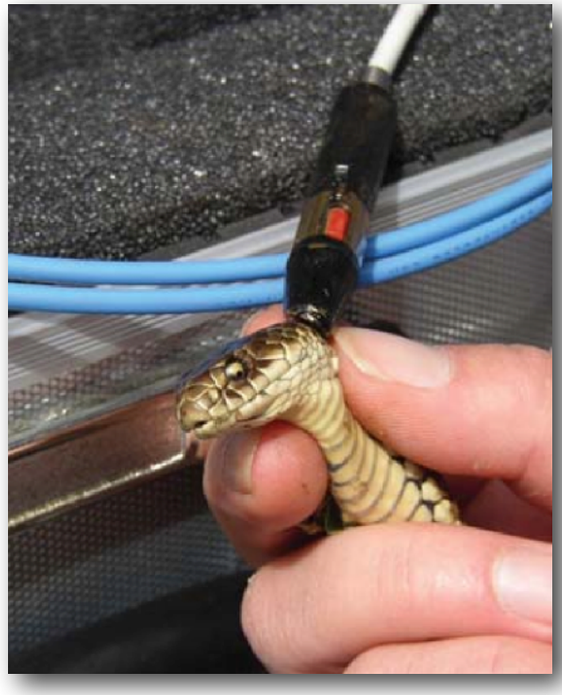


image credit : Ted Rohn

image credit: X-Rite

image credit: BYK gardner

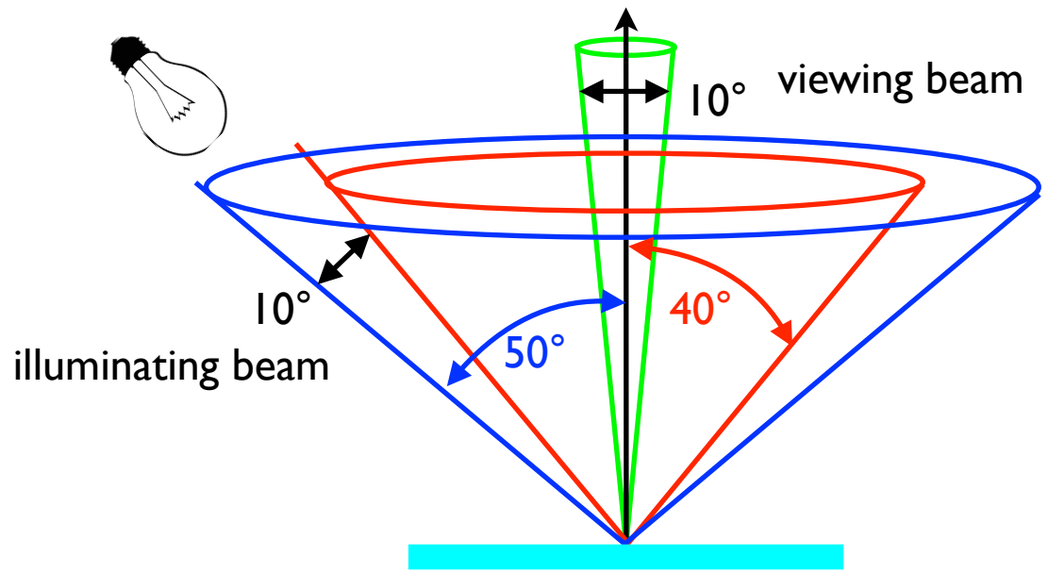
Before we begin…a disclaimer

"I have read your paper and observe that you have discovered some well-known facts about metrology."

Dr Danny Rich

Upon reviewing a paper that he felt was not quite novel enough

Bidirectional Geometry (45:0, 0:45)



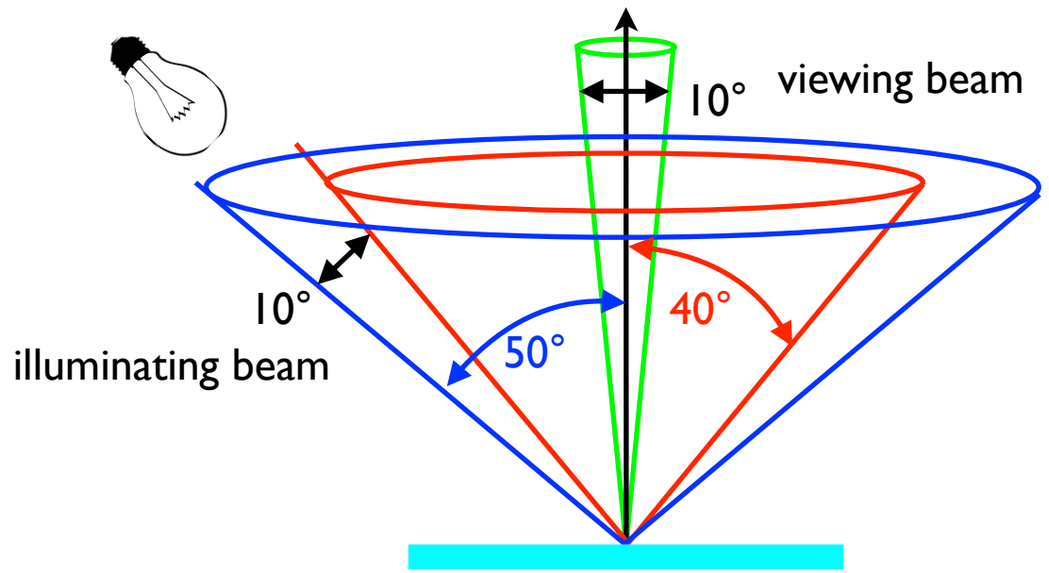
CIE 45°:0°a geometry shown.
Similar definitions are allowed for
0°:45°a geometry

From CIE 15.2004: Colorimetry

5.2.7 Forty-five degree annular / normal geometry (45°a:0°)

It is recommended that the sampling aperture be irradiated uniformly from all directions between two right circular cones with their axes on the normal to the sampling aperture and apices at the centre of the sampling aperture, the smaller cone having a half angle of 40° and the larger 50°. It is recommended that the receiver uniformly collects and evaluates all radiation reflected within a cone with its axis on the normal to the sampling aperture, apex at the centre of the sampling aperture, and a half angle of 5°. If this illuminating geometry is approximated by the use of a number of light sources in a ring or a number of fibre bundles illuminated by a single source and terminated in a ring, one gets the circumferential/normal geometry (45°c:0°). The above angular specifications should also hold for this geometry. These angular specifications affect measured values and may be standardized in the future.

Bidirectional Geometry (45:0, 0:45)



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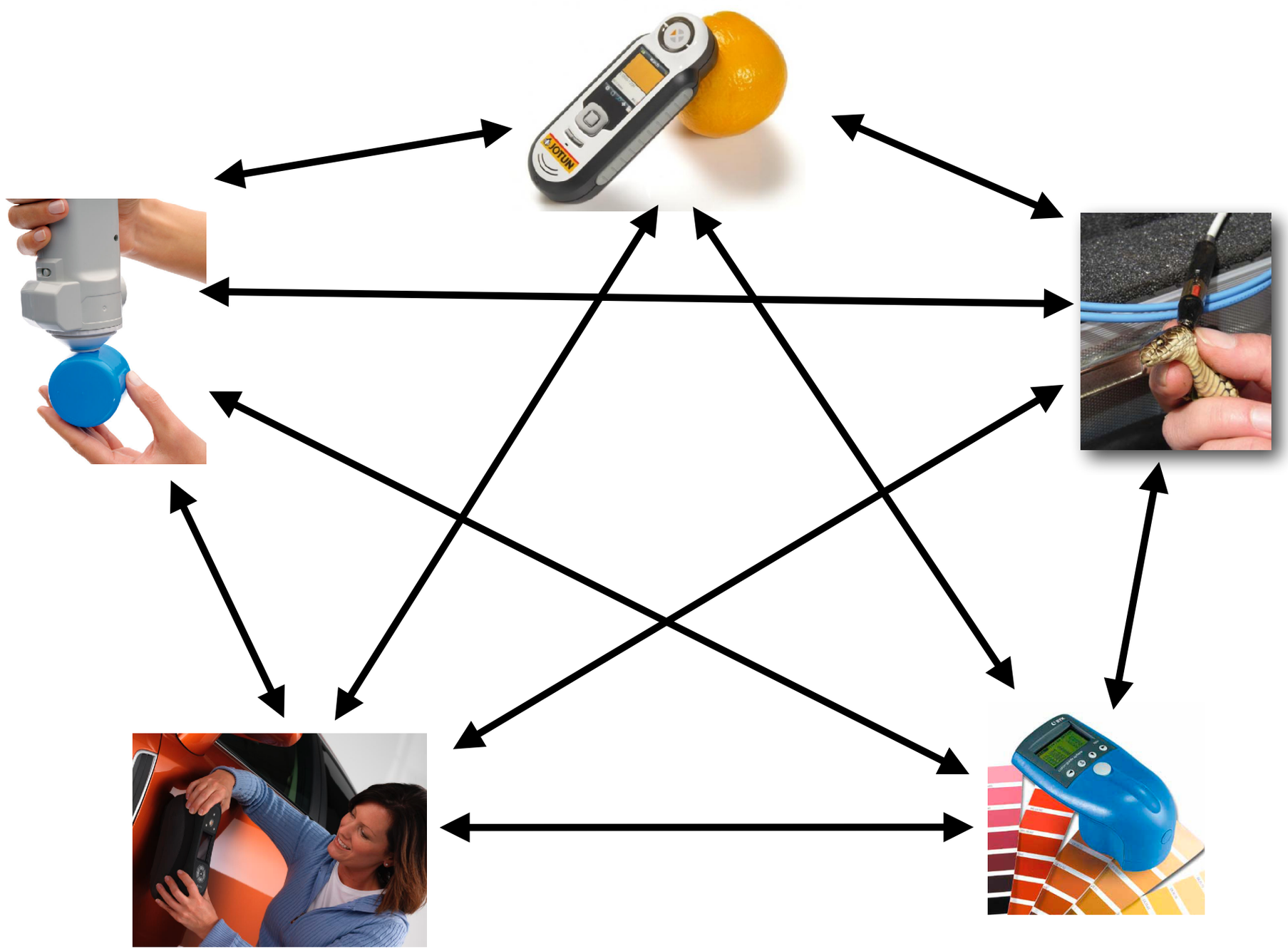
Experiment



Instruments

Code	Source	Aperture	Accuracy	Repeatability
A	tungsten	25 mm	0.30	0.10
B	xenon	16 mm	0.40†	0.10
C	xenon	16 mm	0.40†	0.10
D	xenon	11 mm	0.25†	0.05
E	LED	3 mm	0.30†	0.05

† Inter-instrument Agreement

Hint: none of these are pictured in this presentation

Instruments

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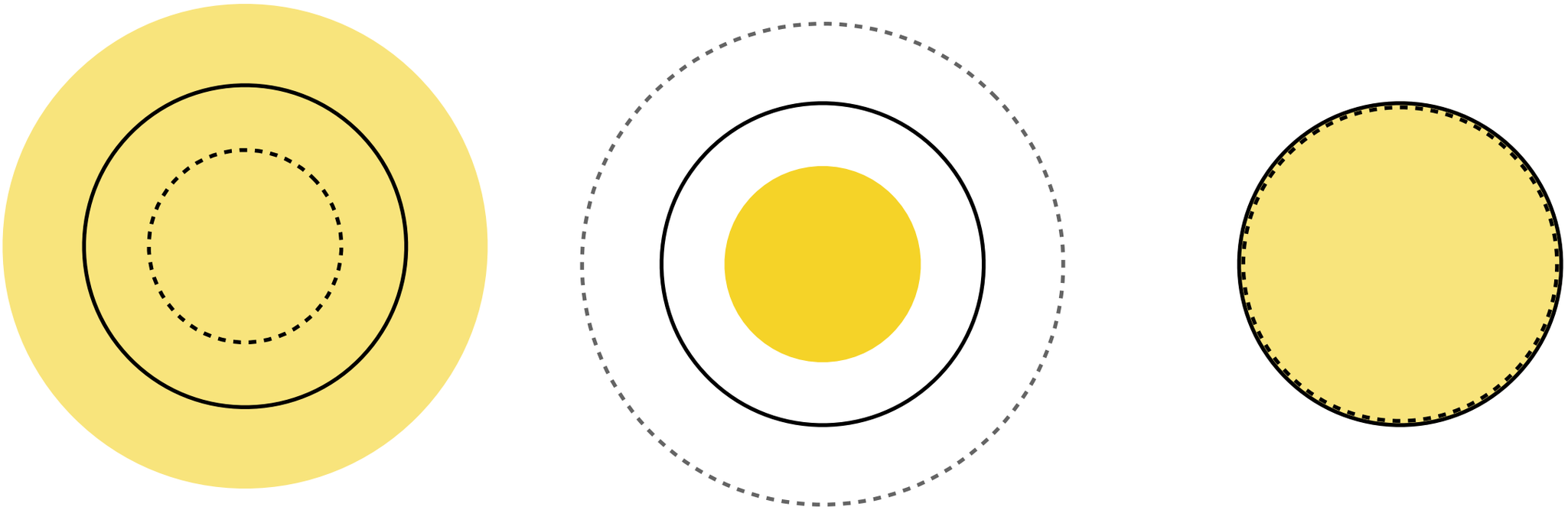
Illumination beam?

Detection beam?

Instruments



Overfill

Underfill

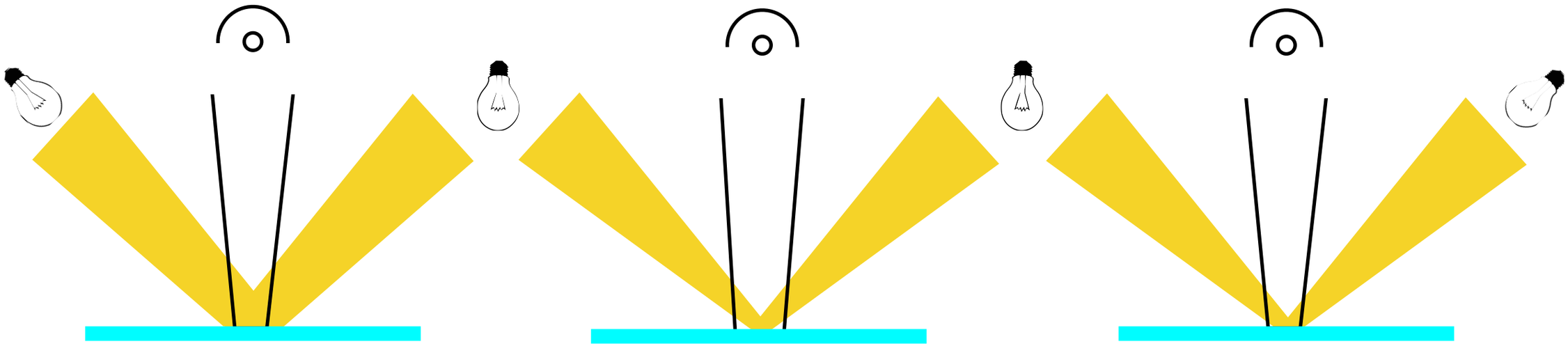
Match?

Illumination beam

Detection beam

Aperture

Instruments



Overfill

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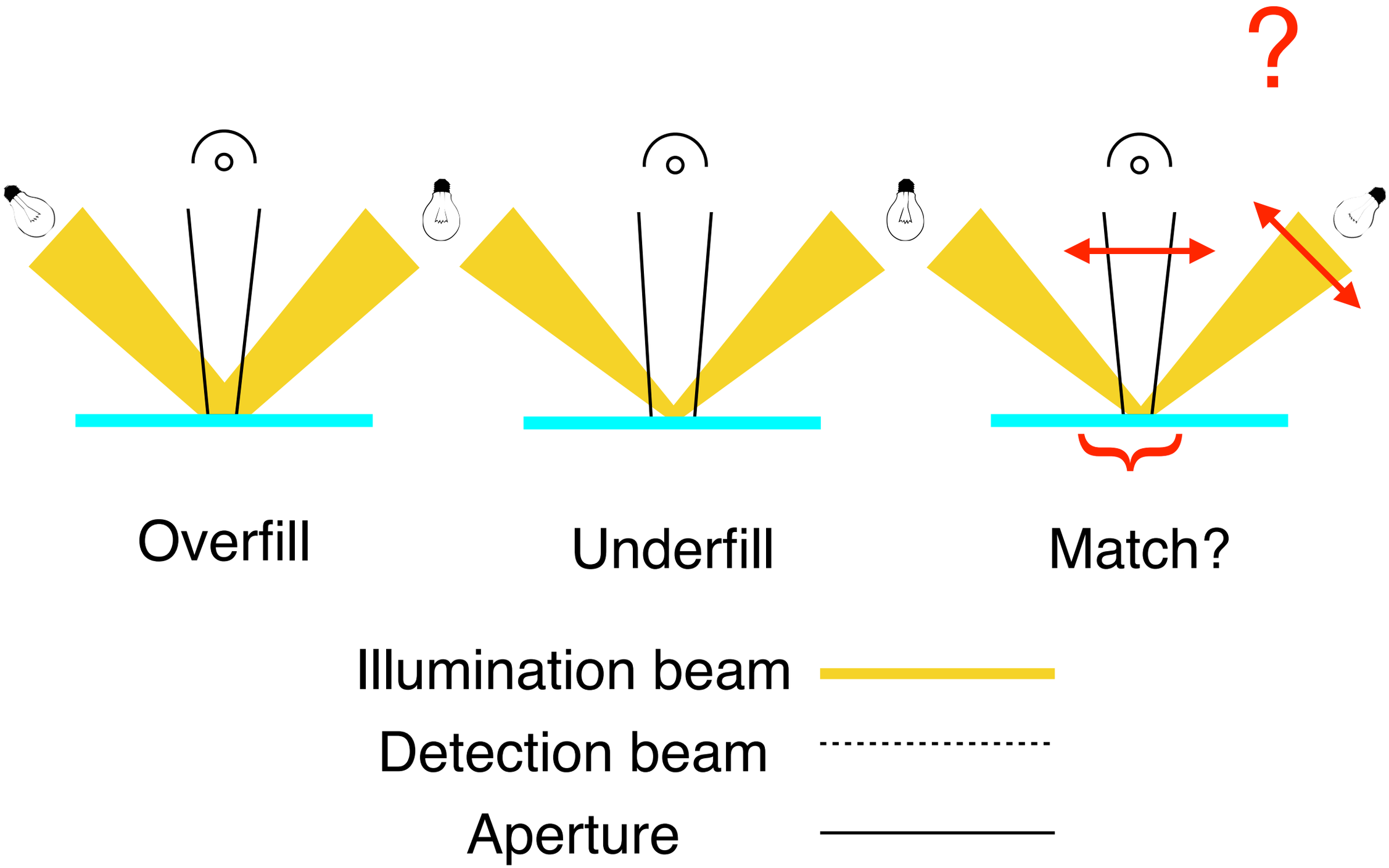
Match?

Illumination beam

Detection beam

Aperture

Instruments



Experiment: Measurement Specifics

- Instruments were all standardized immediately prior to each measurement suite.
- Samples were measured three times, with replacement, and averaged.
- Approximately 90° rotation between each measurement.
- Spectra were reported from 380-720nm, sampled every 10nm.
- Colorimetric data were calculated using CIE D65 and the 1964 10° standard observer.
- For consistency, external software was used for the CIELAB calculations, based on the spectra reported by the instruments.
- Color difference was calculated using CIE ΔE_{94}.

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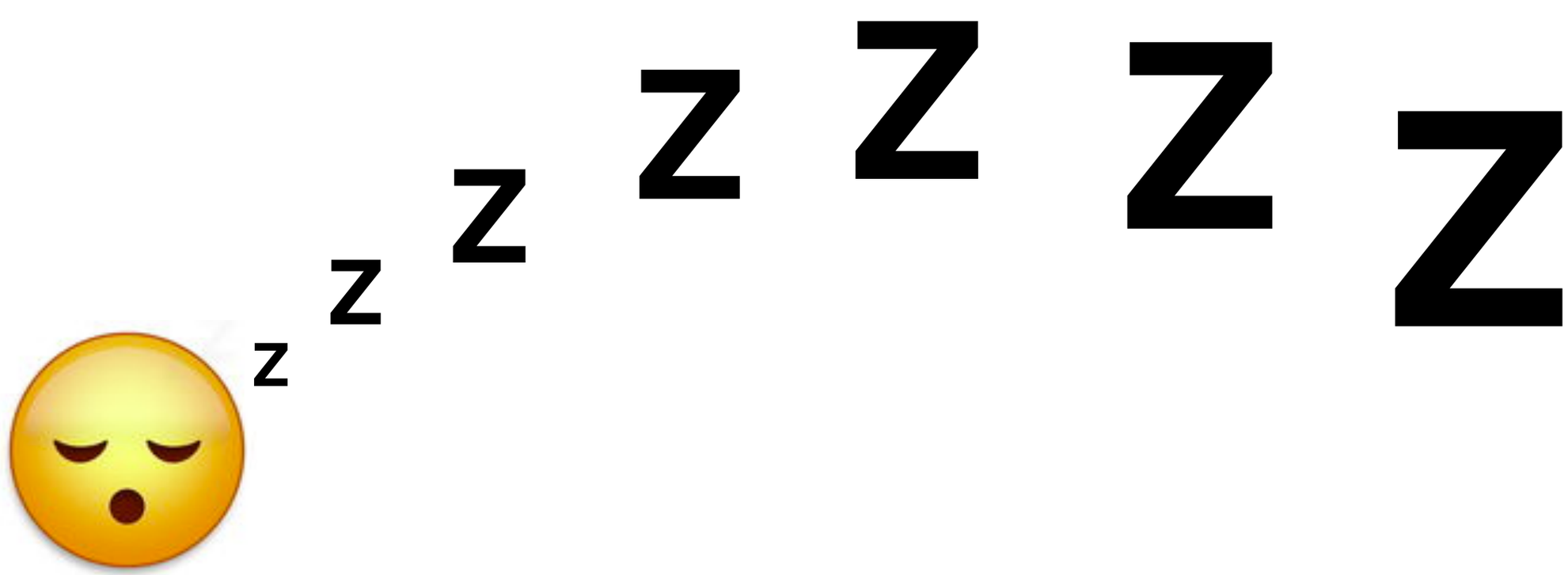
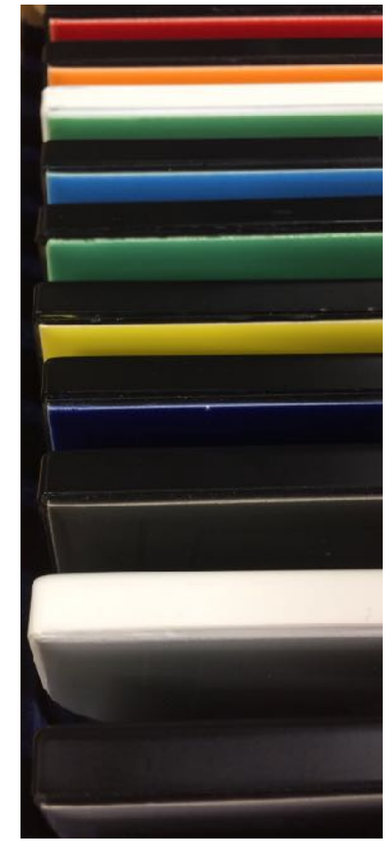


Experiment: Samples

Wool

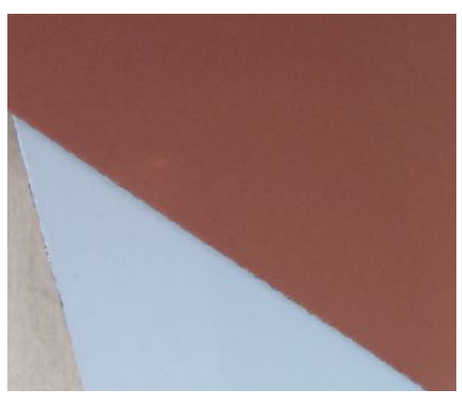
Carpet

Enamel paint



Ceramic

Colored acrylic



Paint under acetate

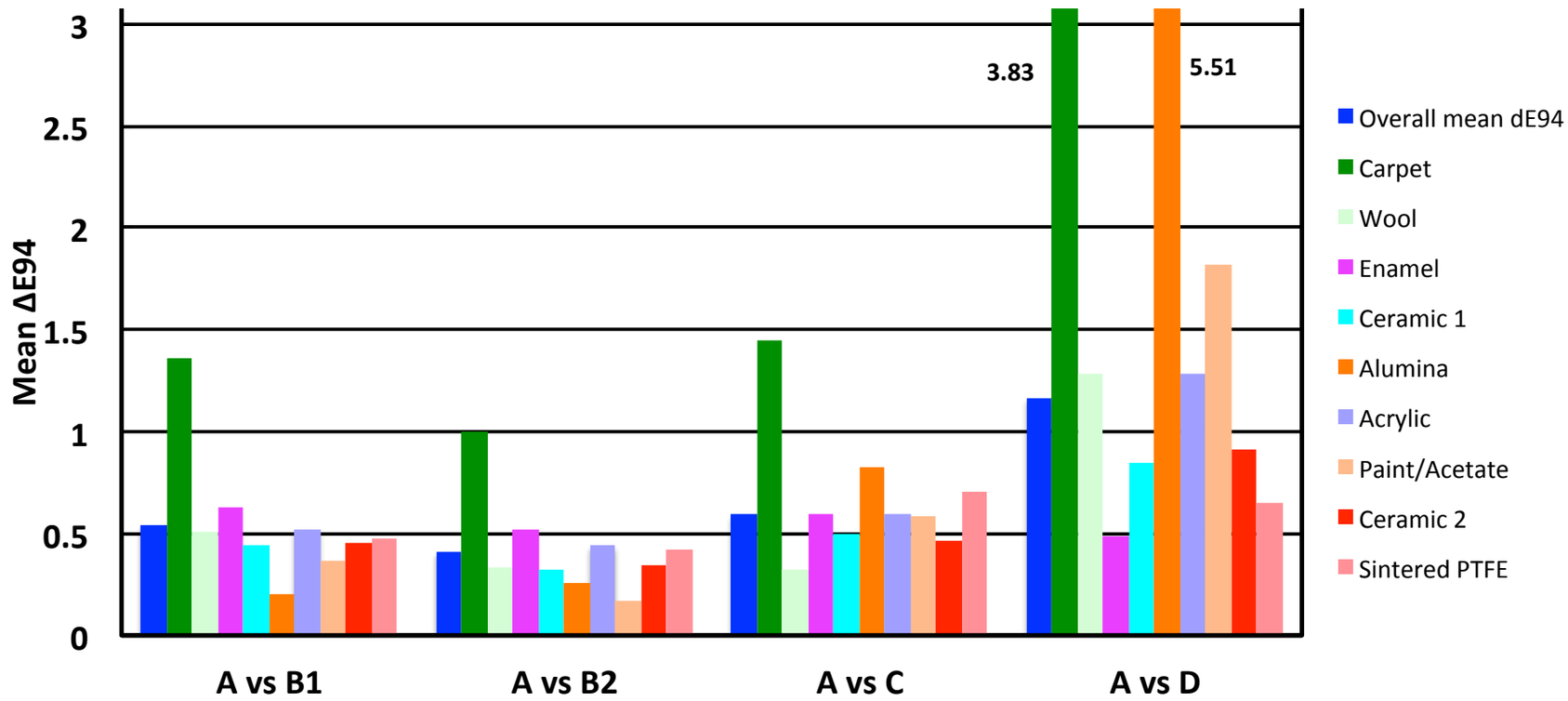
Sintered PTFE

Experiment: Samples

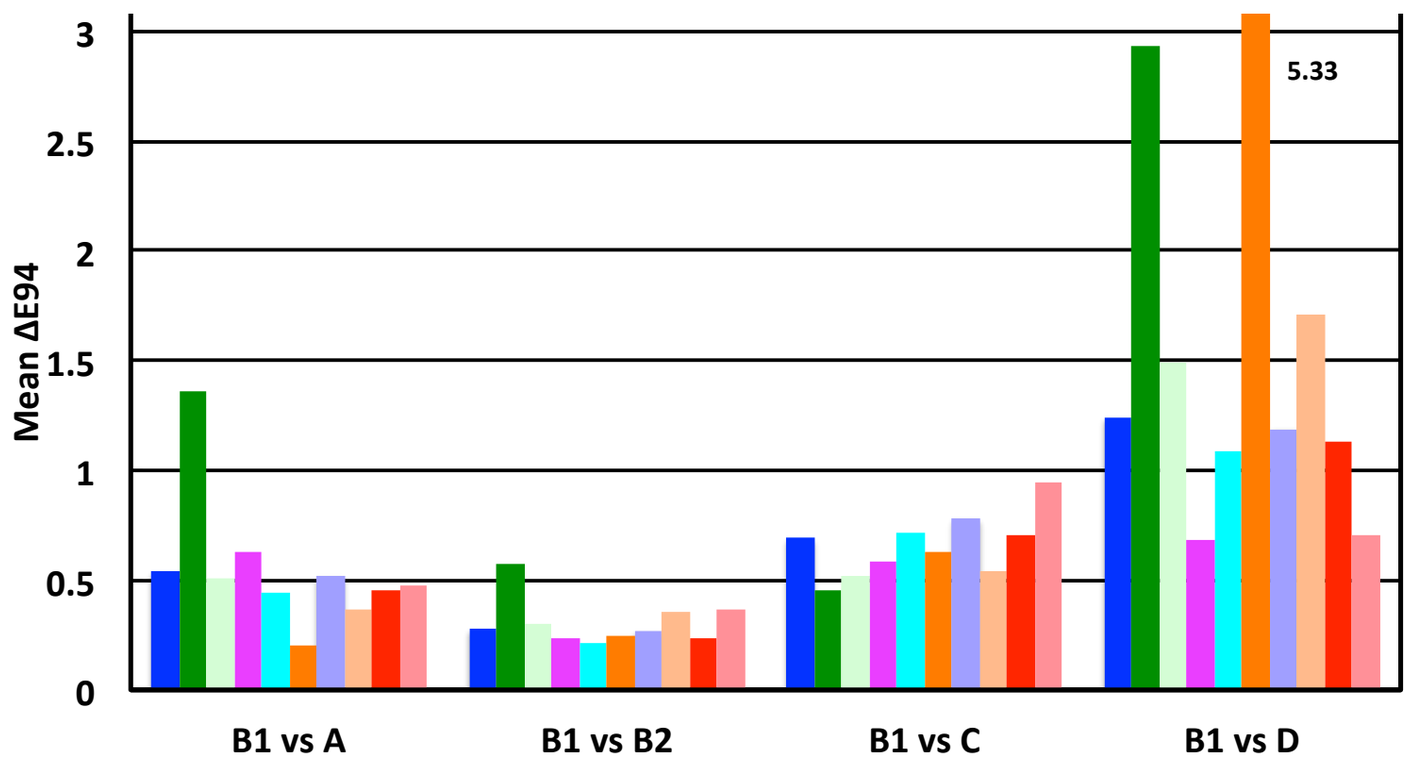
Sample type	Number of samples
carpet	3
wool	5
enamel	8
CERAM	12
Alumina white	1
FTS Acrylic	5
Acetate over paint	2
Mount Baker ceramic	8
Sintered PTFE	8
Total	**52**

Experiment: Colorimetric Results

A

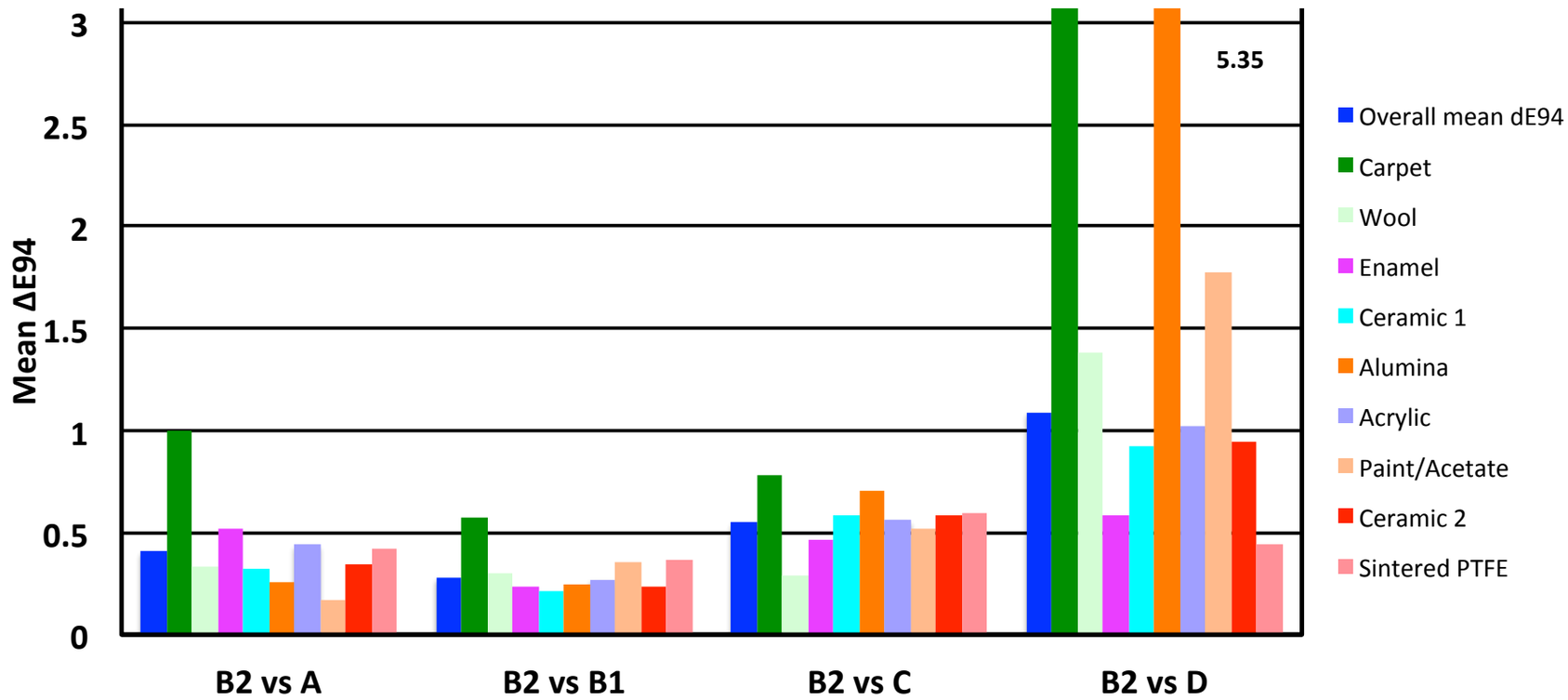


B1

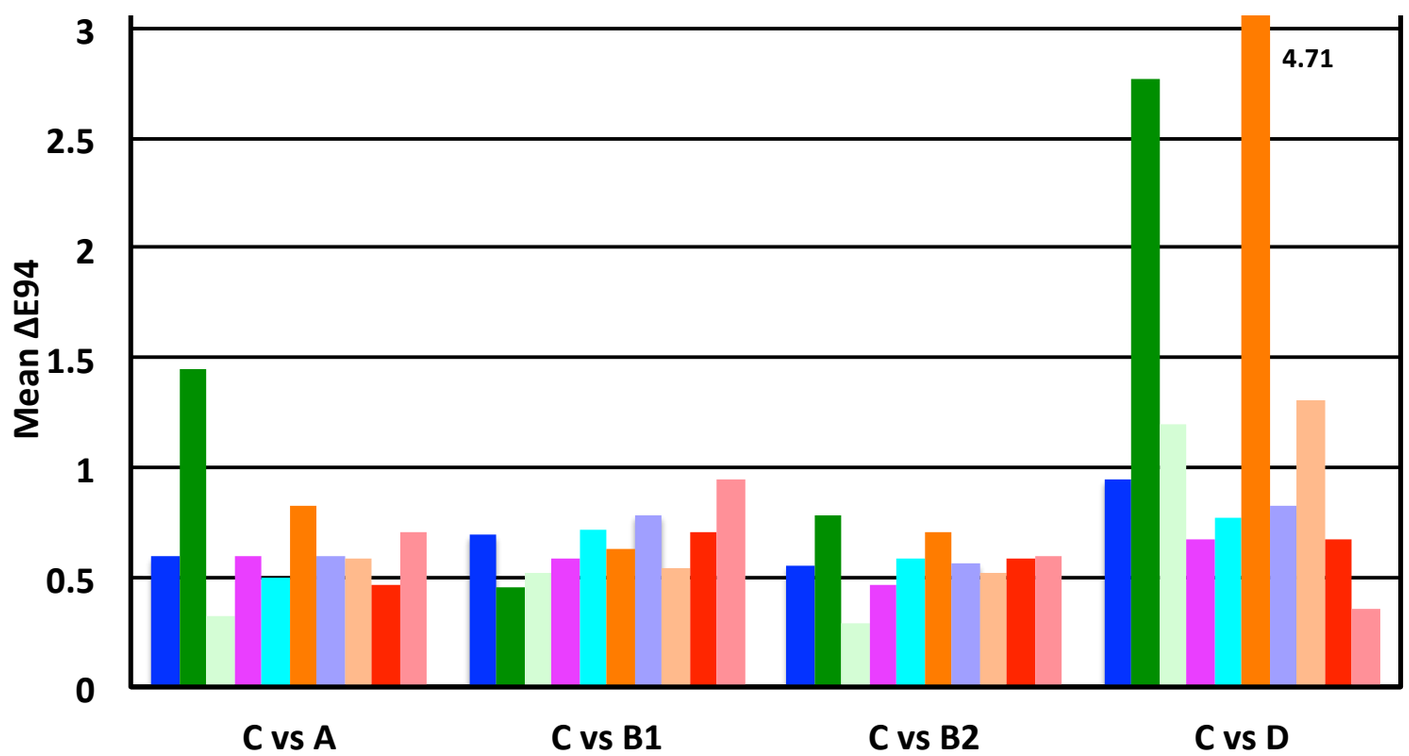


Experiment: Colorimetric Results

B2

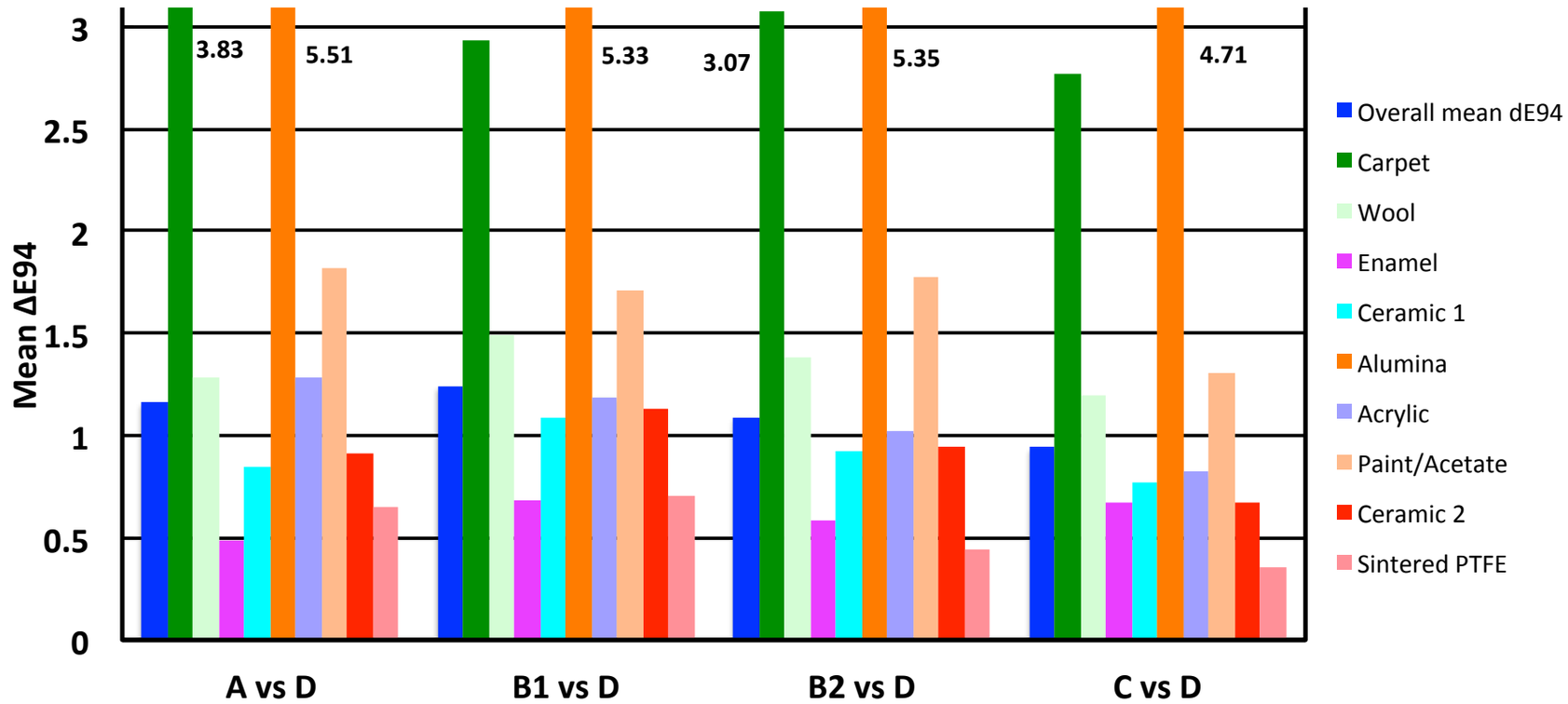


C



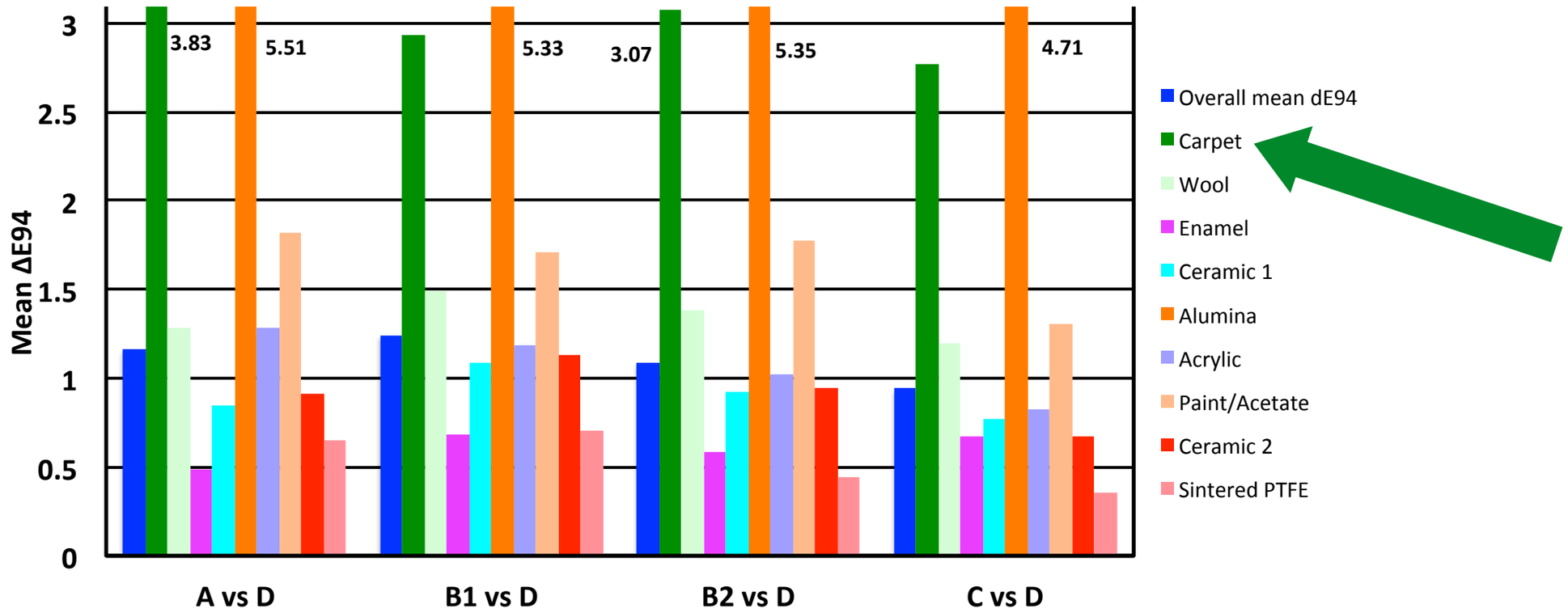
Experiment: Colorimetric Results

D



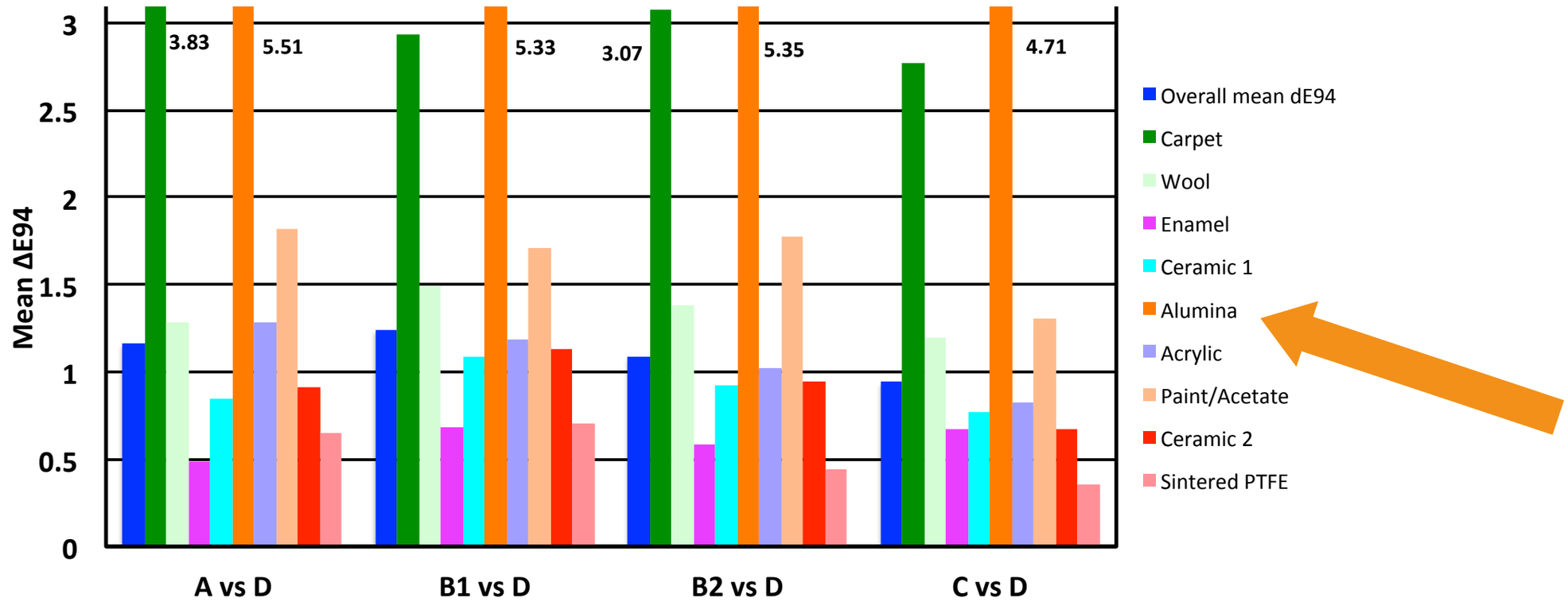
Experiment: Colorimetric Results

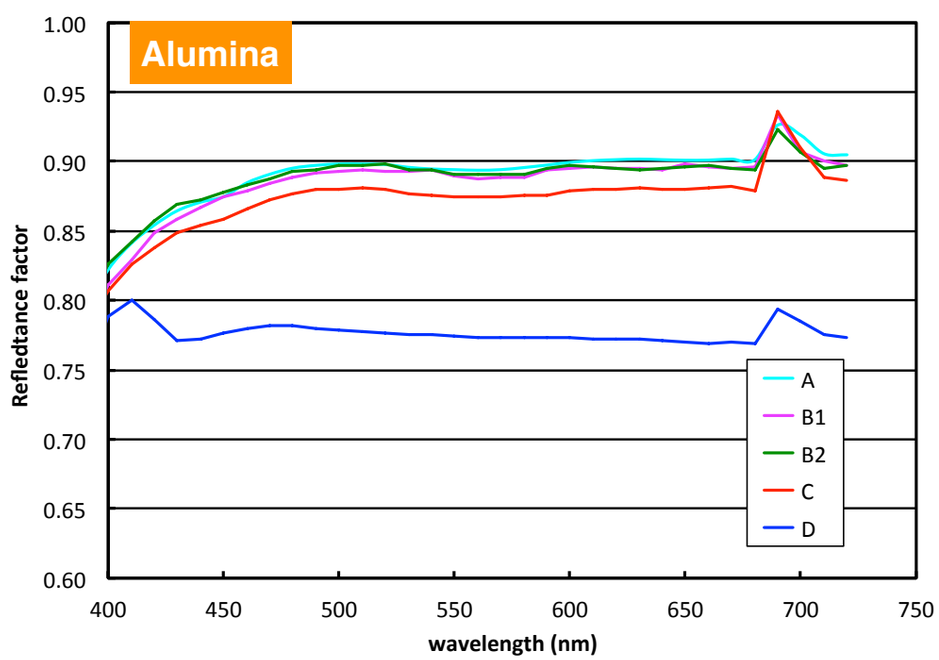
D



Experiment: Colorimetric Results

D





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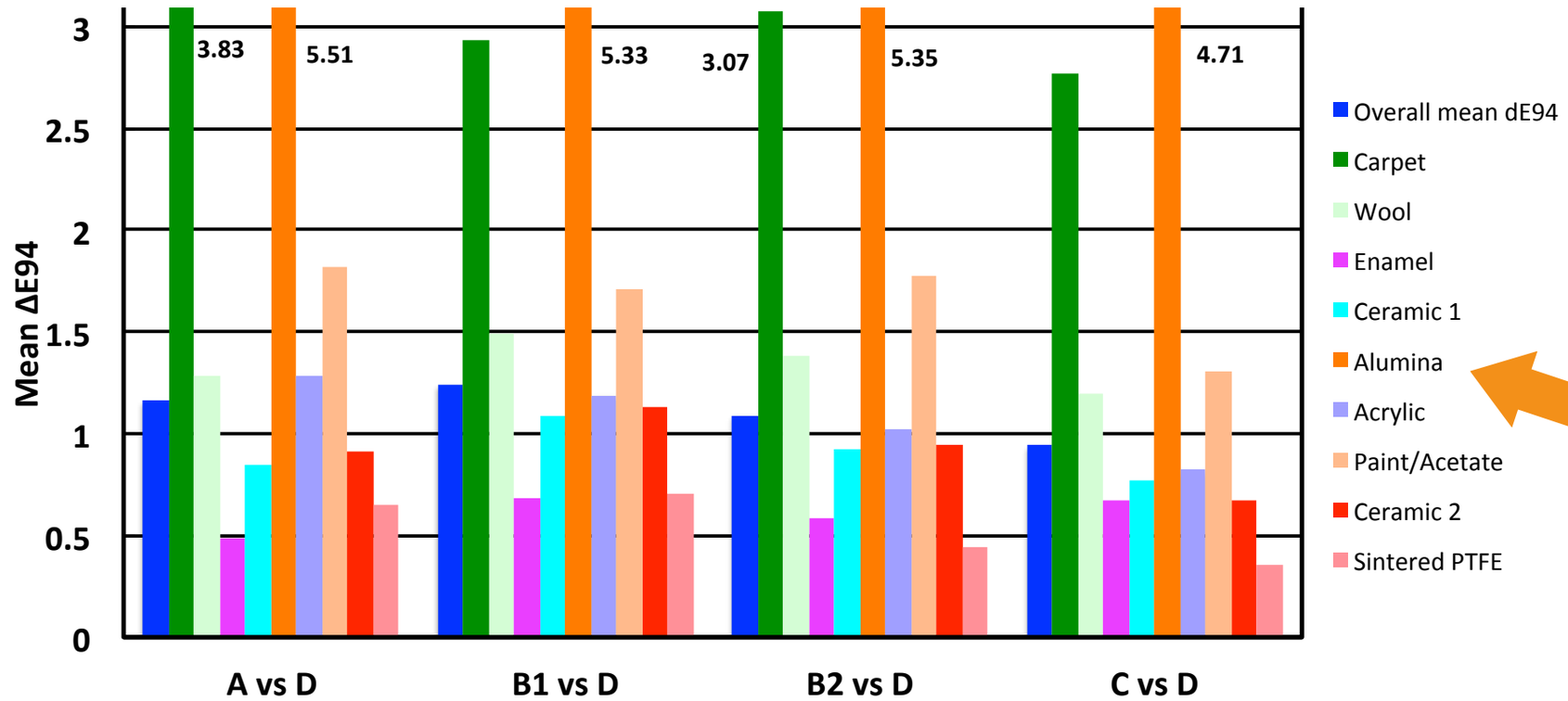
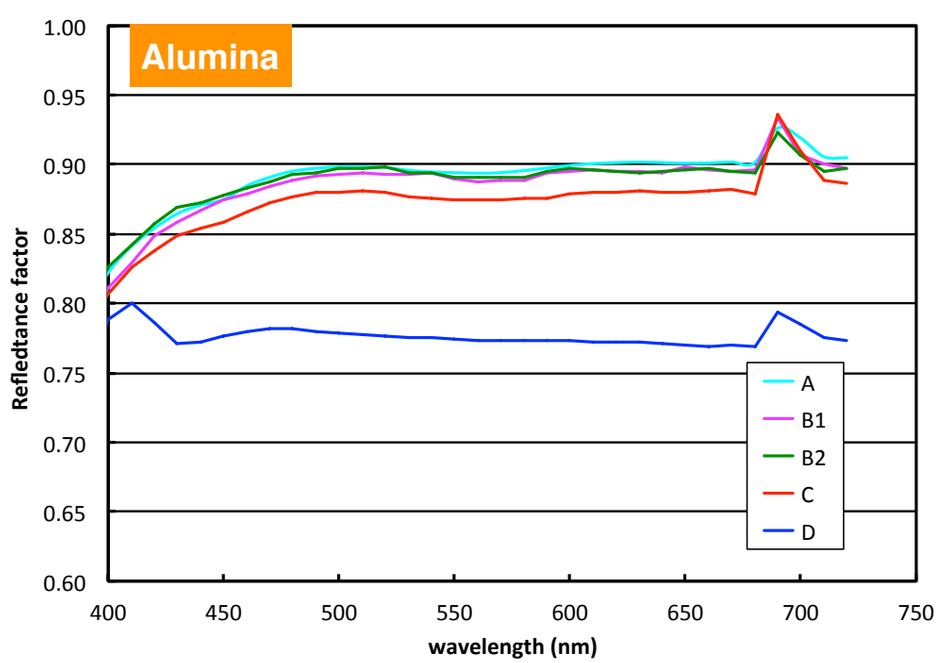
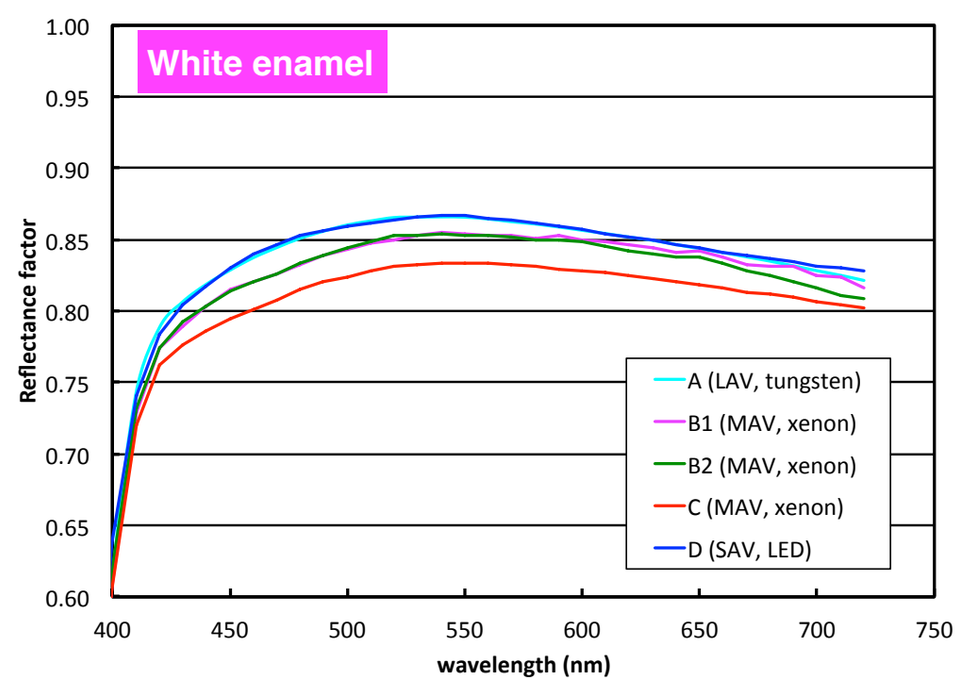
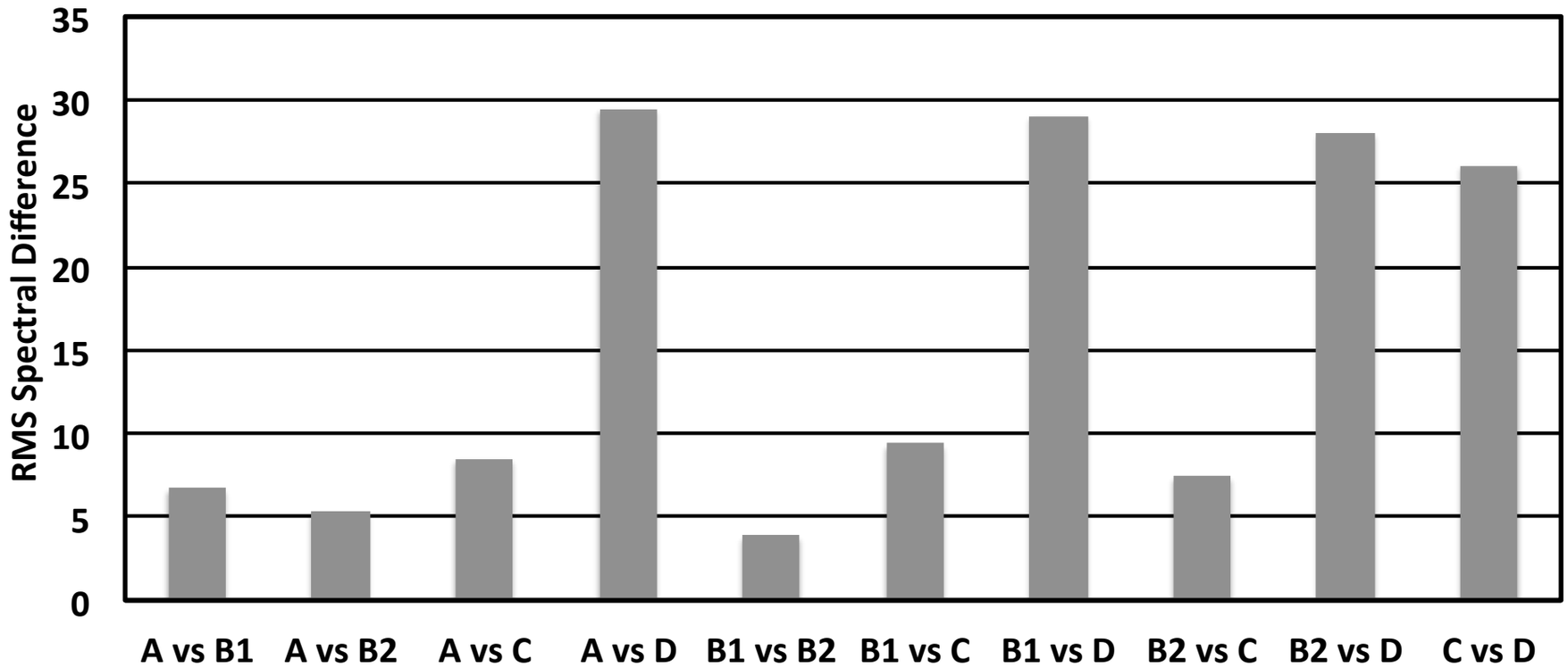






Experiment: Spectral Results

Spectral RMS



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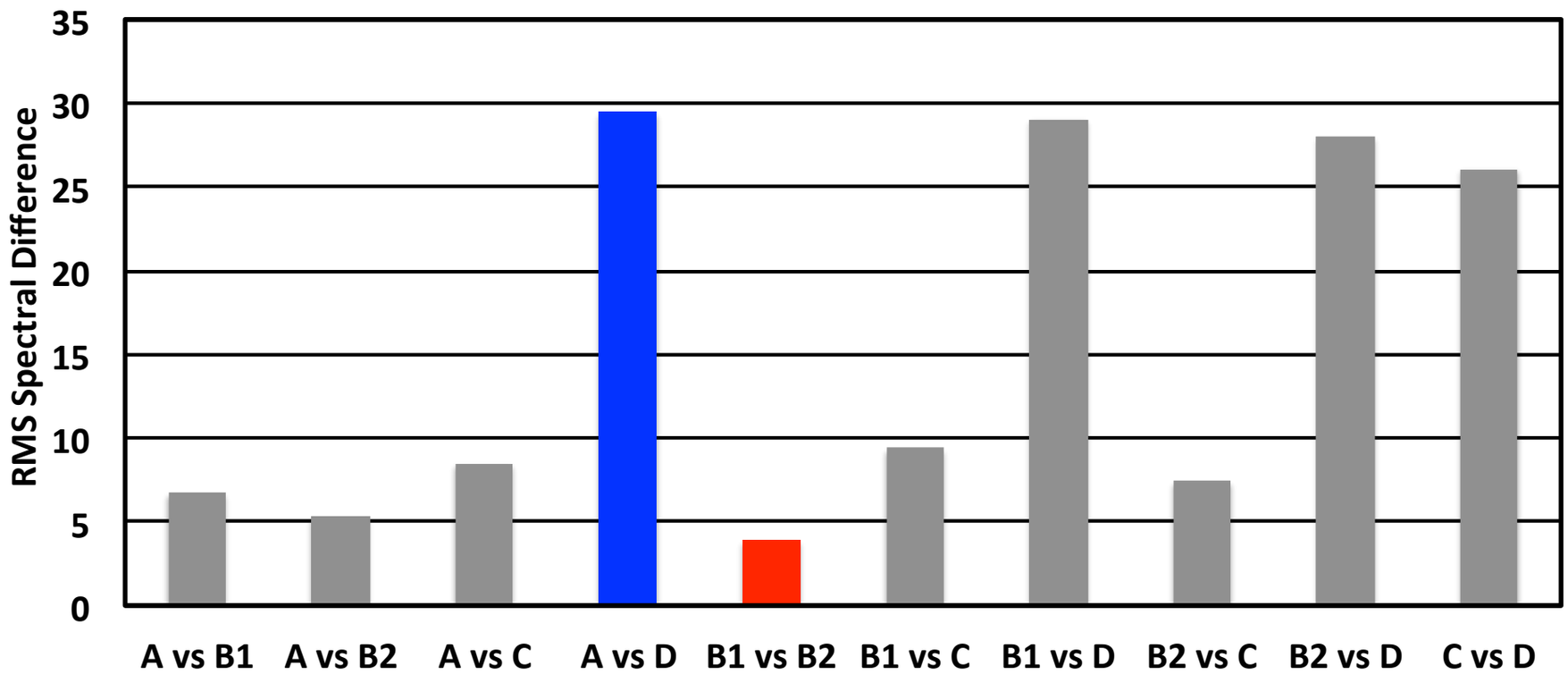
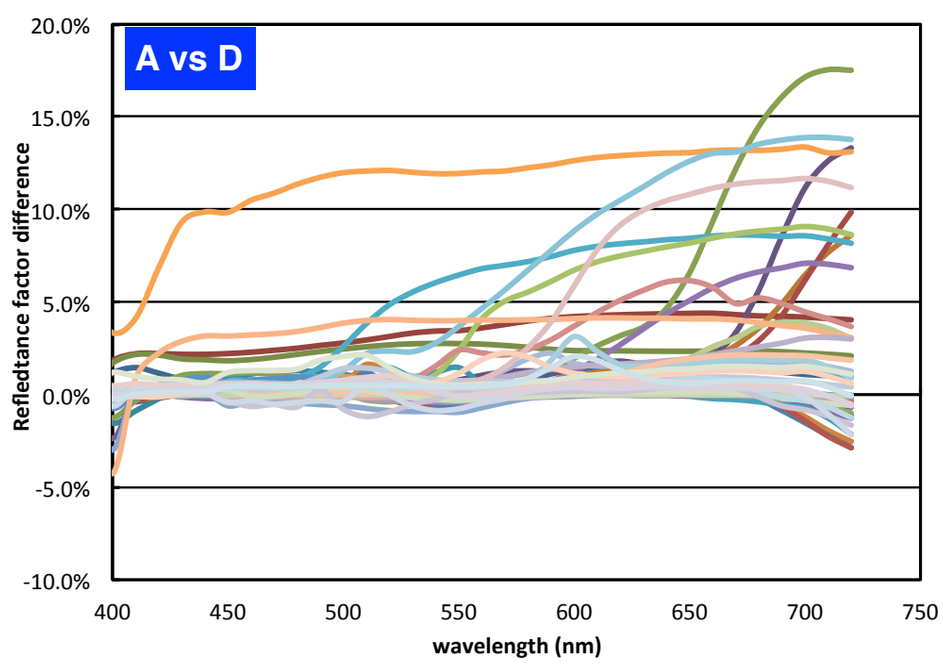
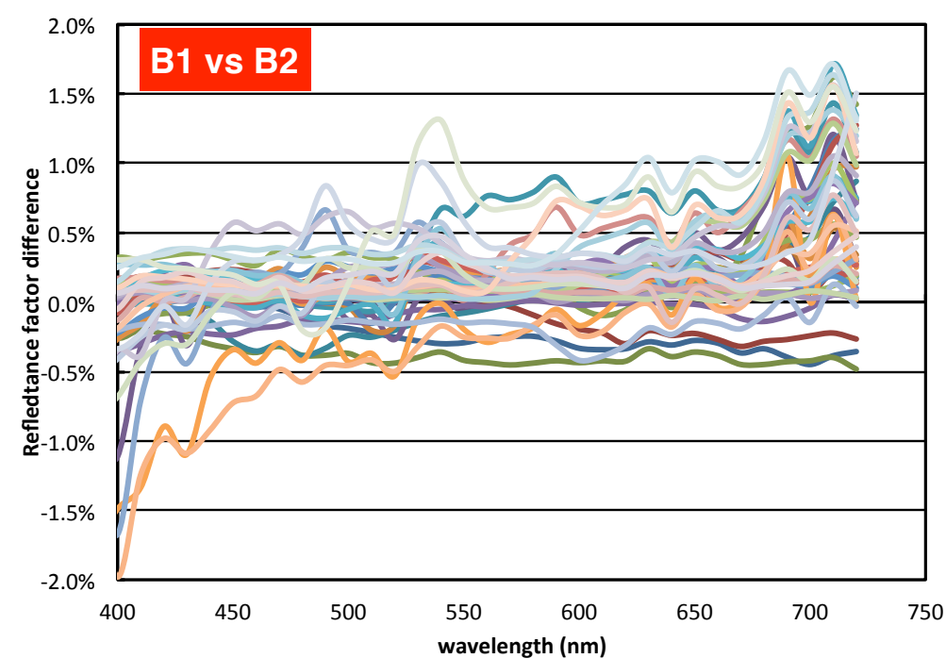
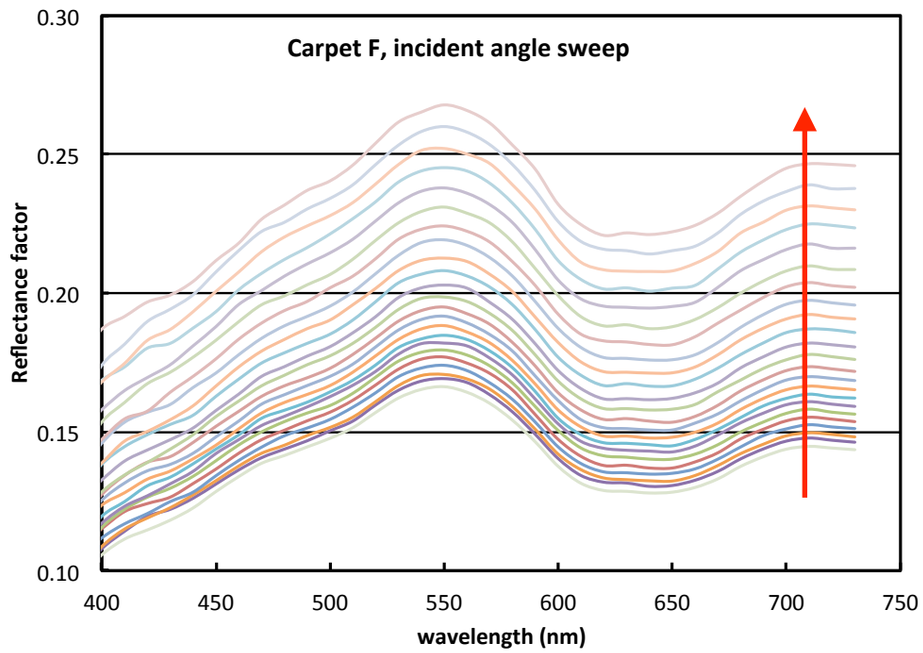
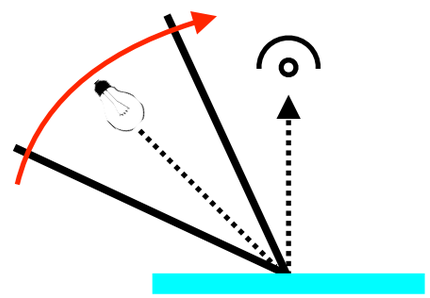


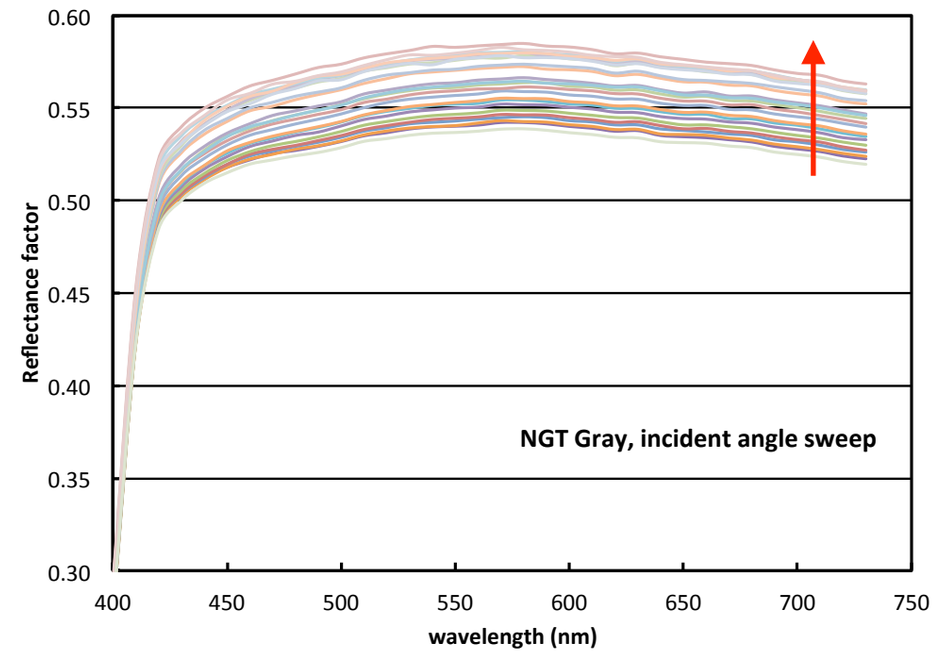


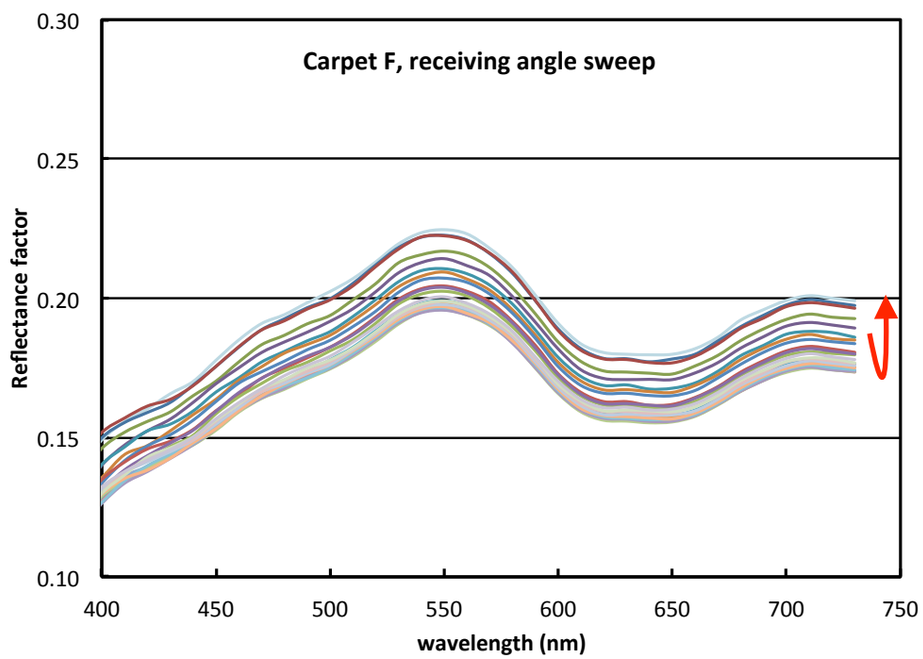


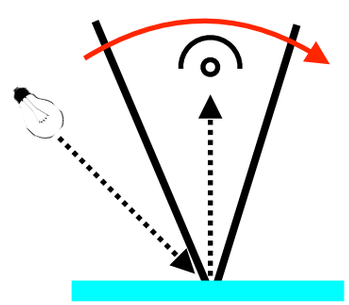
Experiment: BRDF Spectral Data

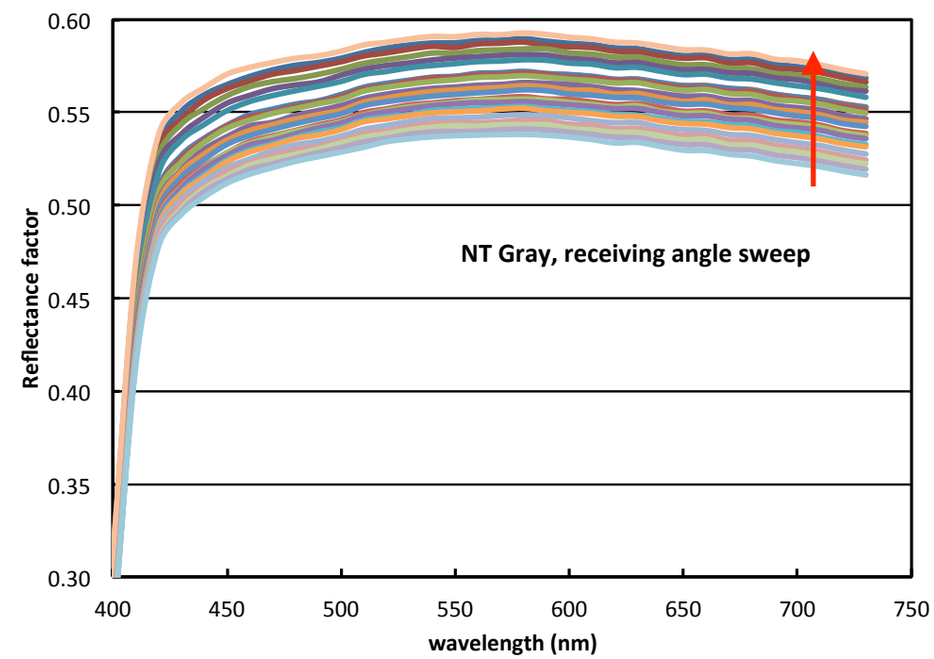




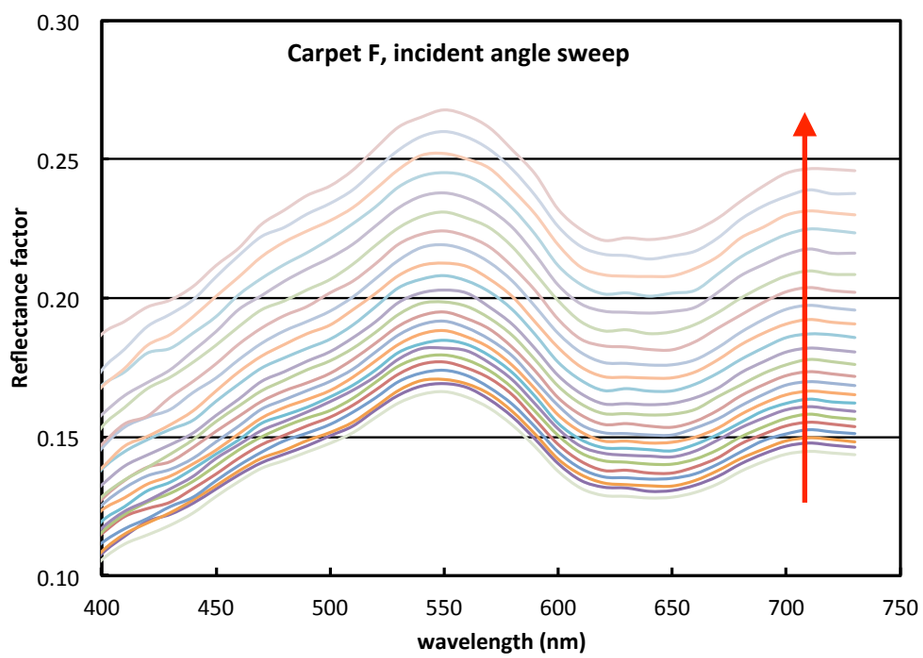


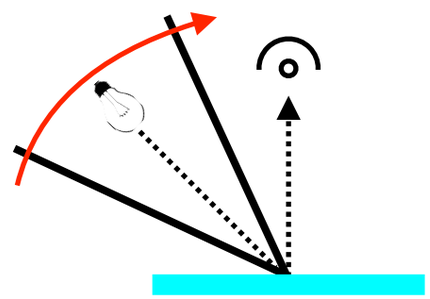


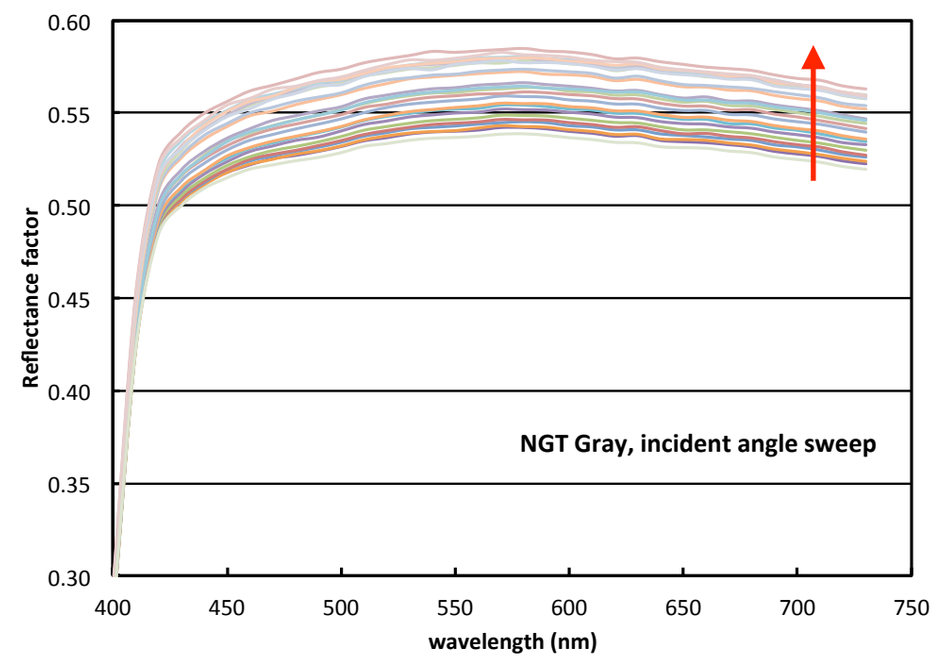




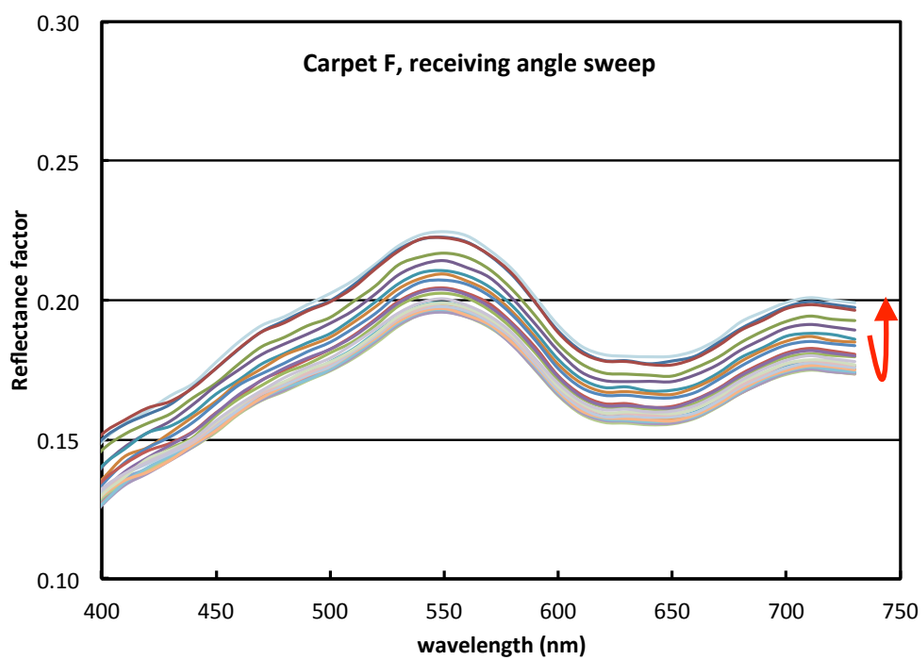
Experiment: BRDF Spectral Data

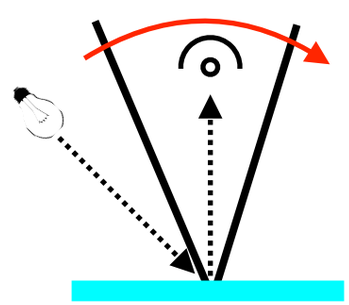


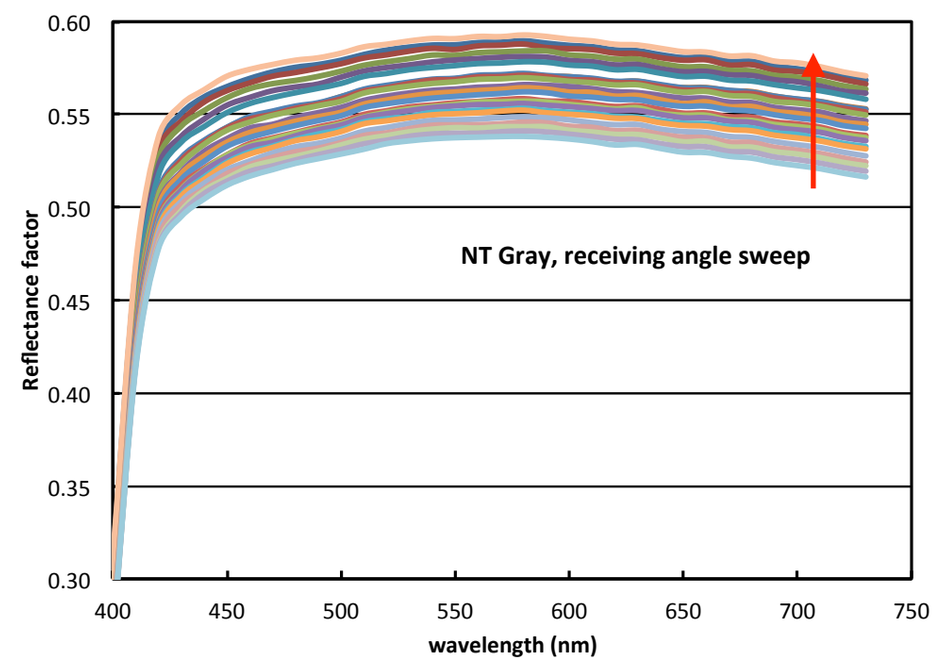




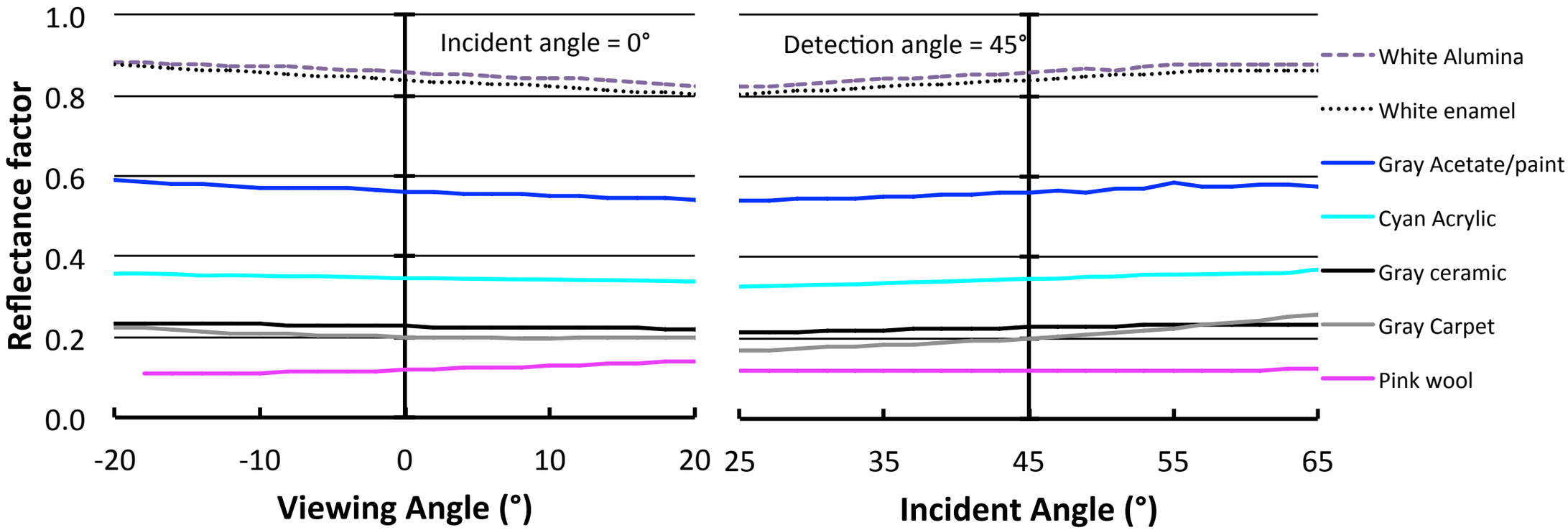
"in plane" only

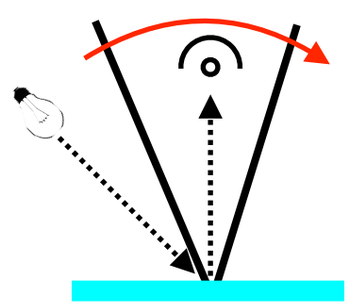


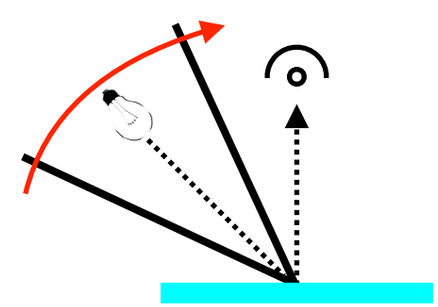




Experiment: BRDF 550nm Data

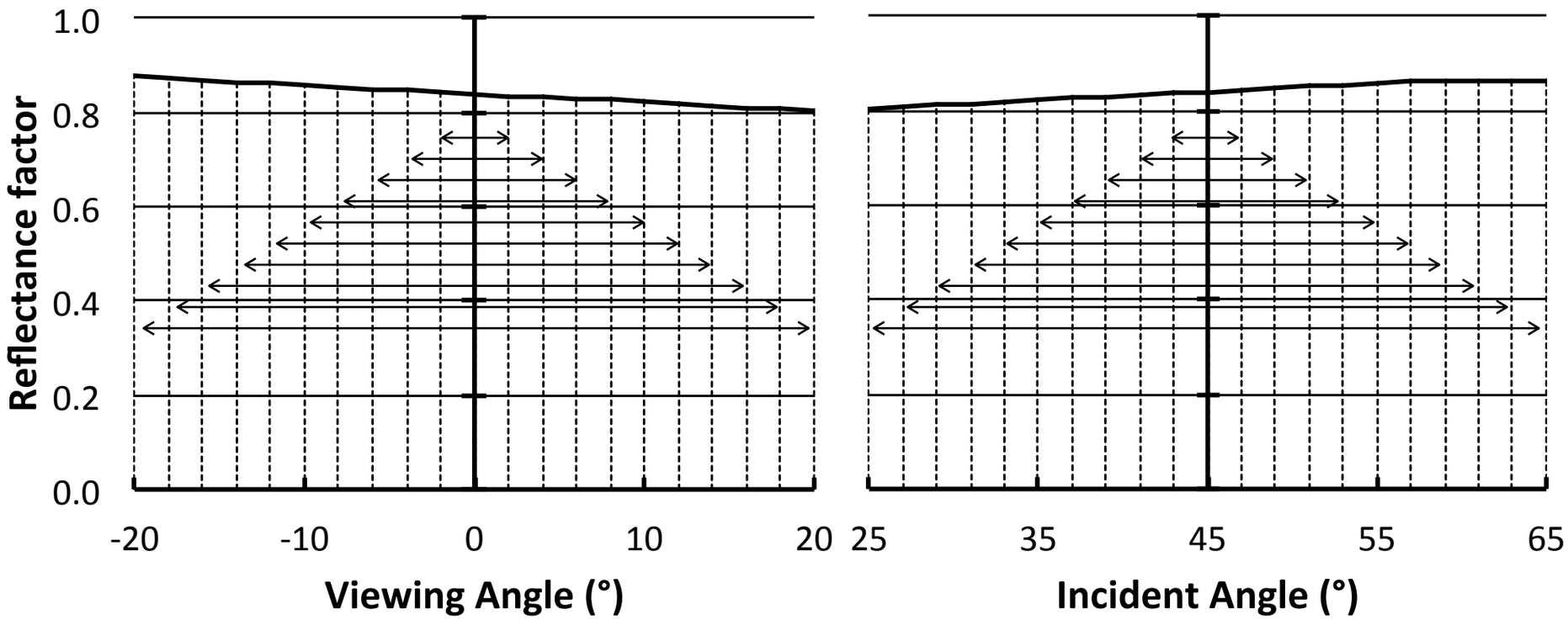






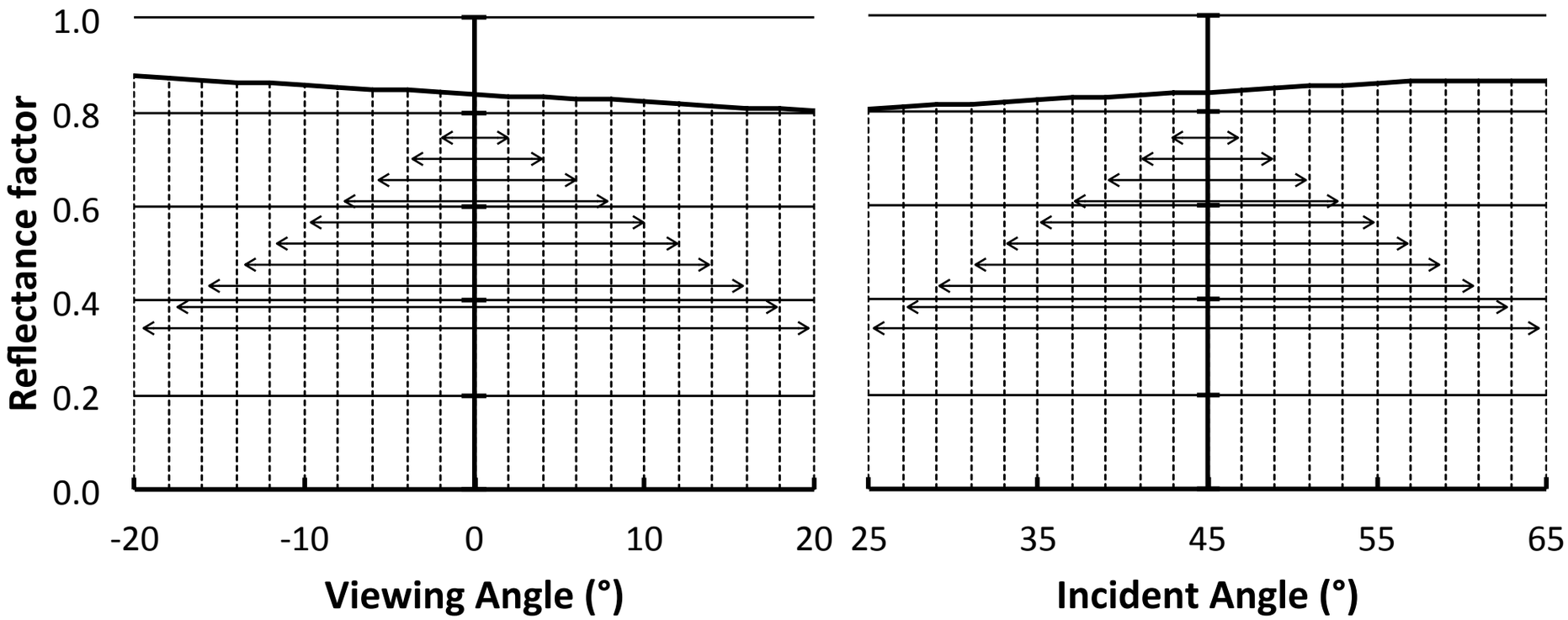
They are all nearly linear.

Experiment: BRDF 550nm Data



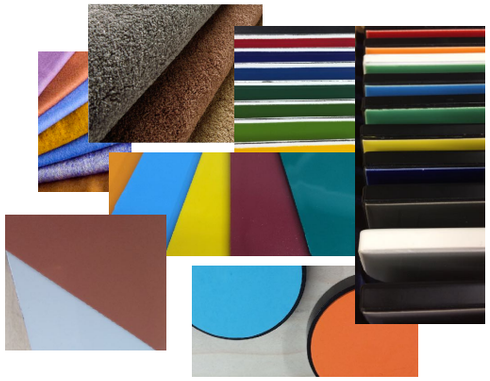
Average across each centered angular band.

Experiment: BRDF 550nm Data



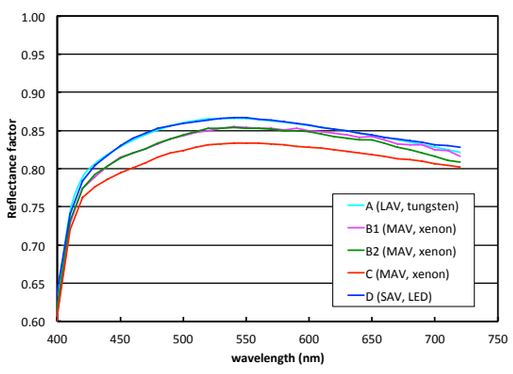
The averages across each centered band are essentially identical for sample. This is equivalent to linearity assuming they cross the 0° or 45° at their mean levels.

Summary



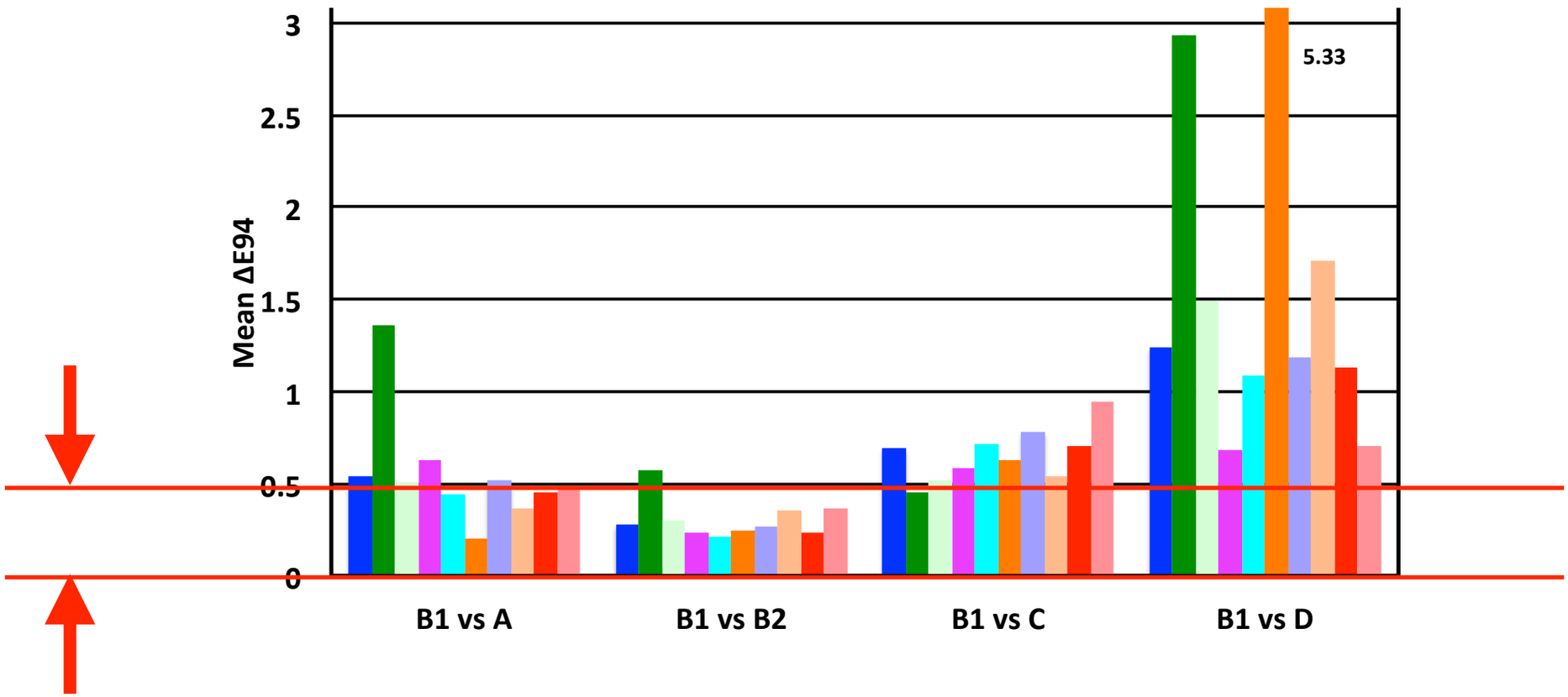
A set of samples were selected for a range of surface texture and color uniformity properties.

A set of 45:0 spectrophotometers were selected to represent a range of aperture sizes and light sources.



The set of samples were measured on the set of spectrophotometers.

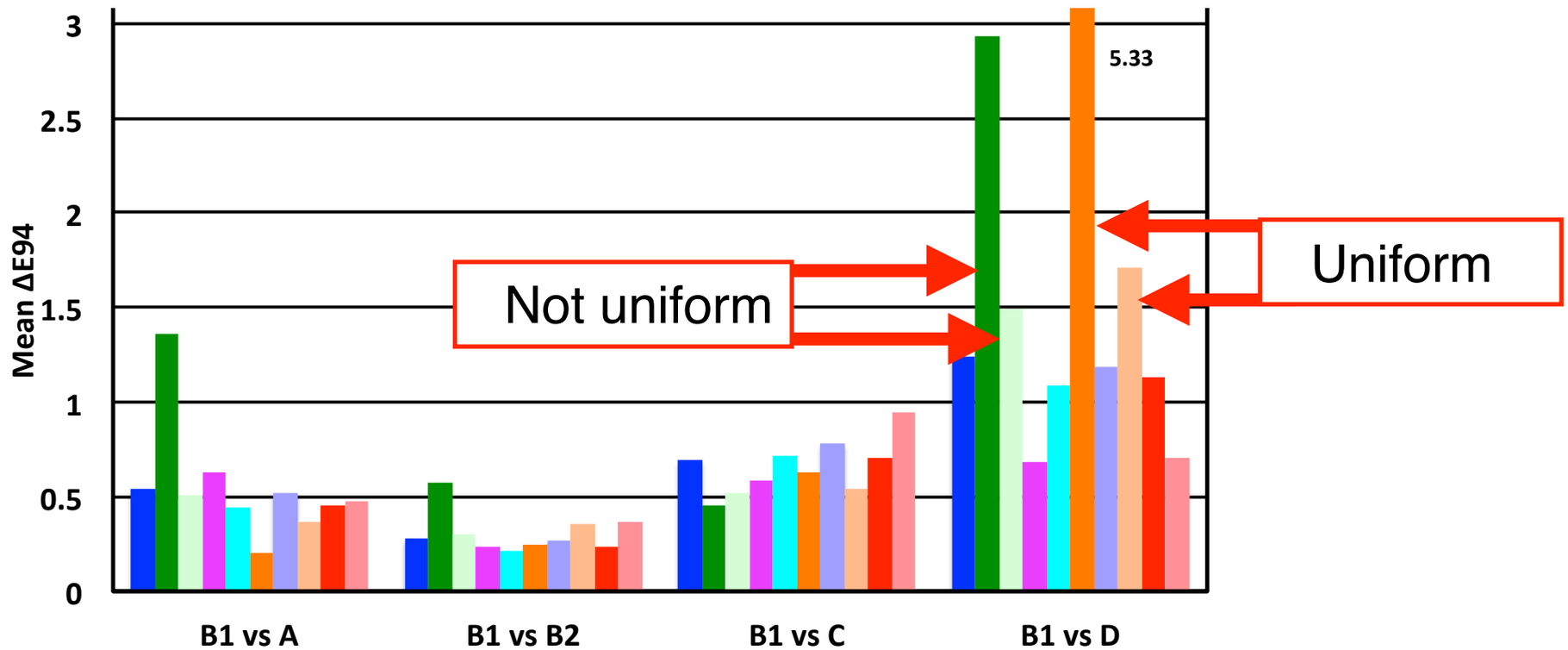
Summary



With the exception of instrument D (the smallest aperture) all instrument correlated quite well across the range of samples.

Most of these are reasonable for inter-model agreement.

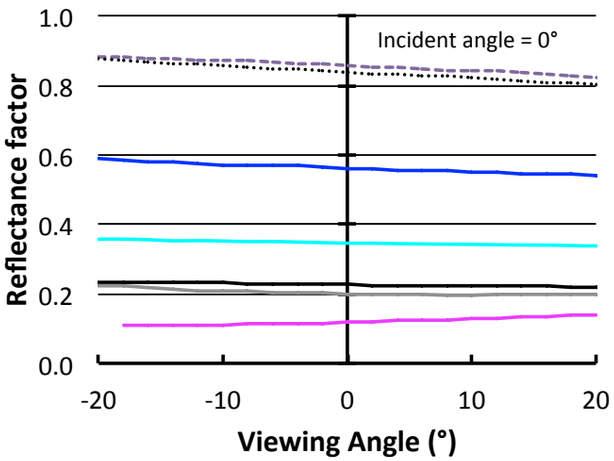
Summary



Some, but not all, of the large differences seen in instrument D can be explained by nonuniform samples.

Summary

In-plane BRDF data were captured, but they did not have any features that would help explain the differences between the instruments.



Even for the wide range of sample surface properties, the BRDF measurements across the interesting regions of 45:0 angular space do not show any variation.

We will not claim that there are no sample that would show such features across these small angular ranges. At the very least they would need to be very carefully prepared.

More likely, the variation between the instrument are due to other geometric and calibration differences, such as traceability differences or aperture size.

Thank you

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