Method for Quantifying the Spectral Based Error in Luminance Measurements

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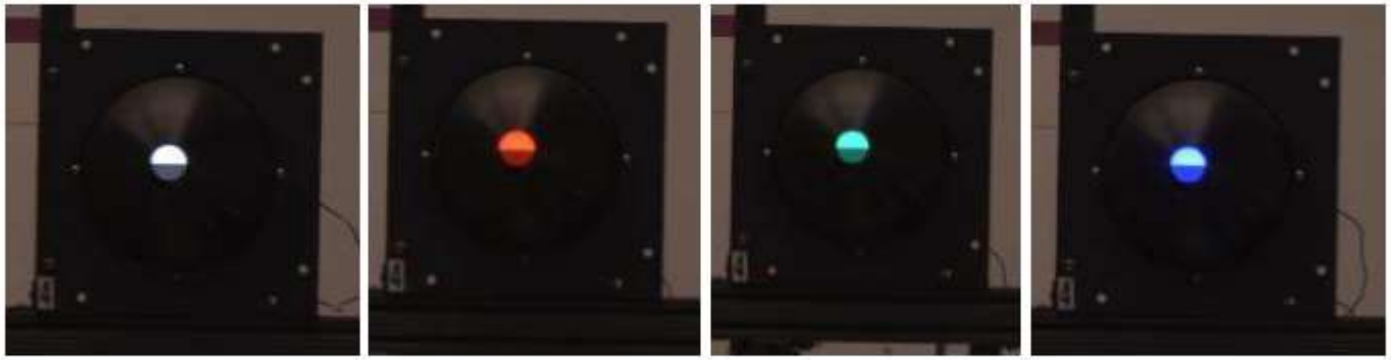
Research Motivation

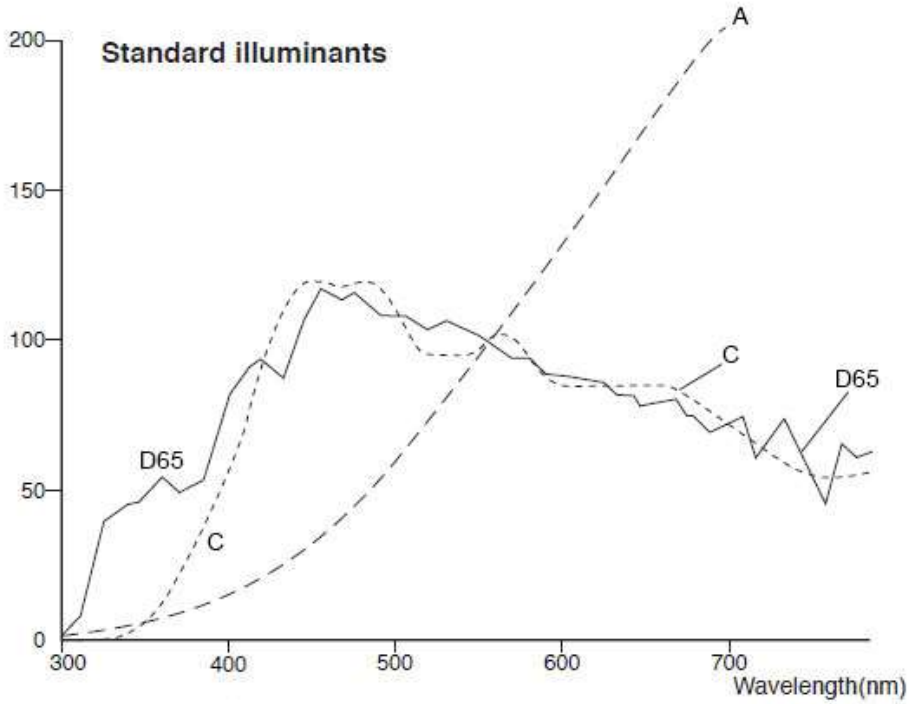
- Accuracy of standard luminance meters throughout the visual spectrum
- HDRI luminance mapping
- Large errors found in HDRI derived luminance of colored light sources



[1]

Light Meter Errors

- Standard illuminance and luminance meters have a **1-pixel responsivity** type sensor, covered by a **V(λ) correction filter**
- Specified meter accuracy is based on **CIE Standard Illuminant A**, 2856 K incandescent
  - Other source types may not have the same accuracy
- CIE Standard Illuminants
  - Average daylight models
  - Typical fluorescent



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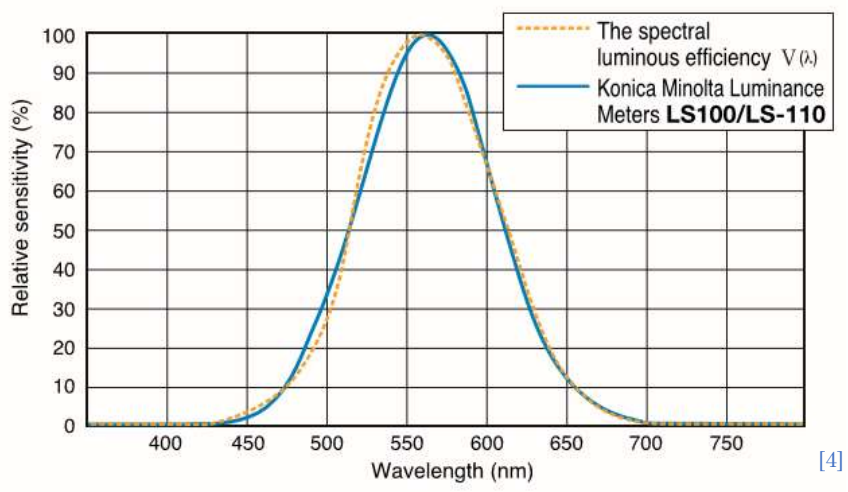
Light Meter Errors

- Standard light meters vs. spectral meters
  - **Light broken up by wavelength** via optical grating or prism
  - Many unique sensor types
  - Photometric conversion via internal software
- Illuminance measurement comparison of standard meter and spectroradiometer under various source types
  - **Up to 31% error for LEDs**
  - 21% error with CFL sources

Equipment: Light Meters

- Konica Minolta **LS-110 luminance meter**
  - 1 sensor pixel type, responsive to 360 – 740 nm
  - V(λ) correction filter over sensor



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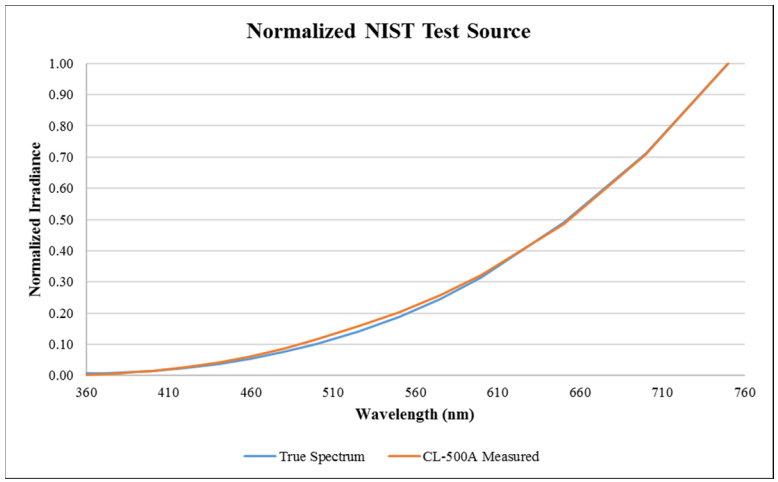
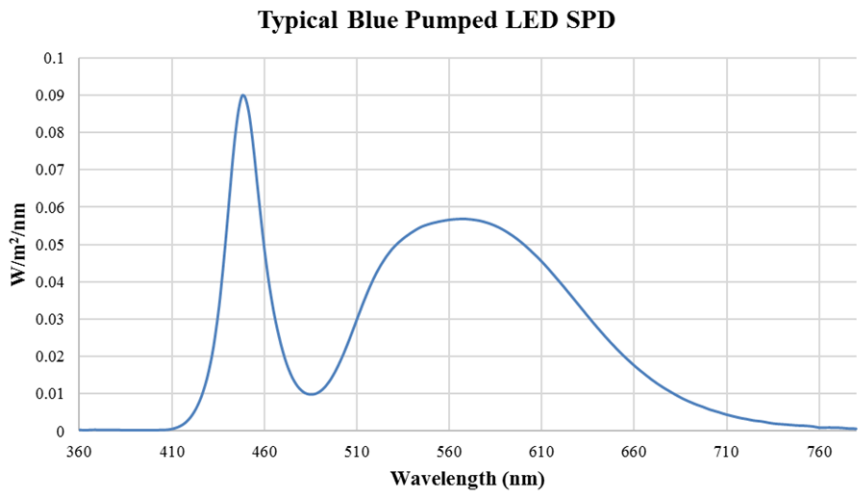
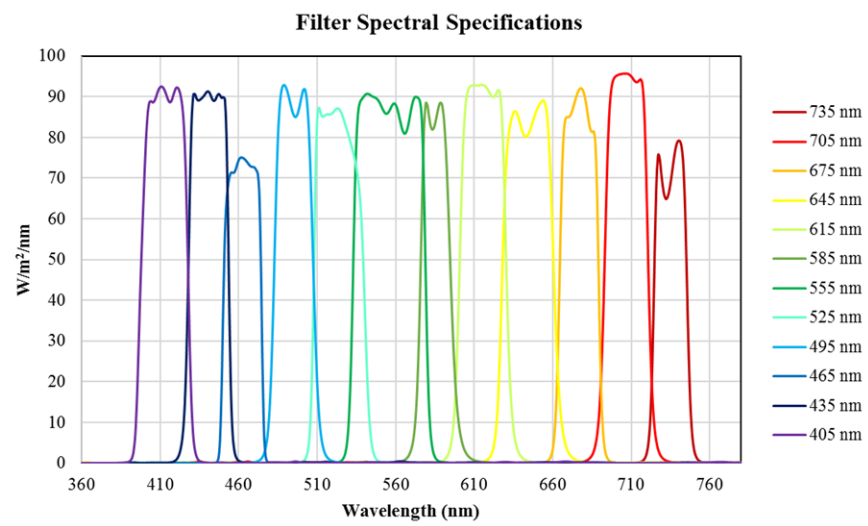
- Konica Minolta **CL-500A illuminance spectrophotometer**
  - 128-pixel sensor
  - NIST light source calibration
  - Within ± 2%



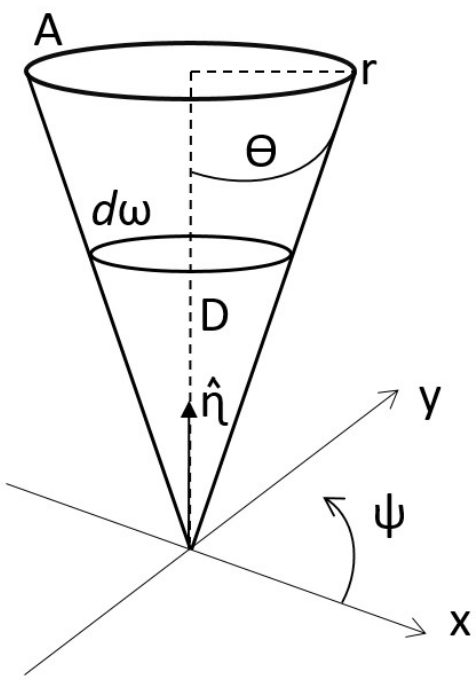
Equipment

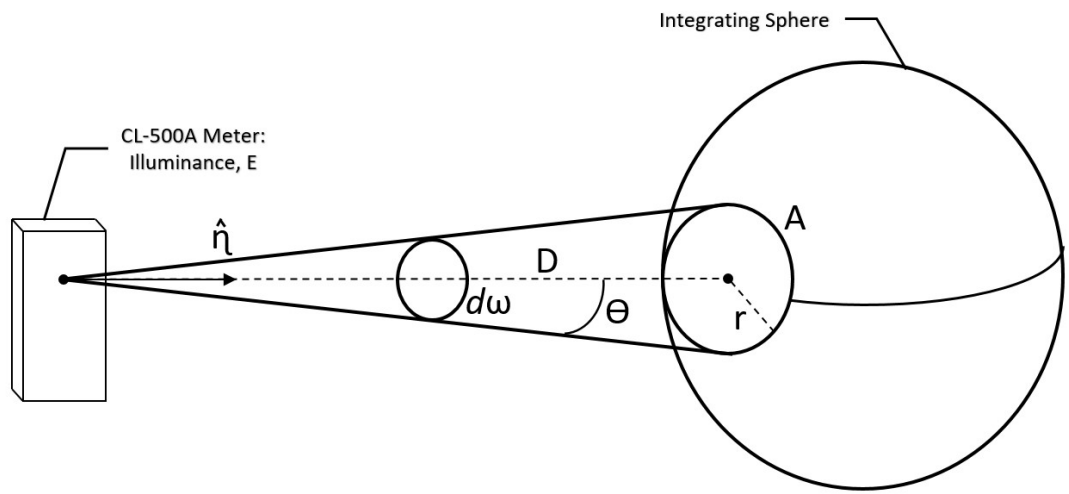
- Integrating sphere
- Broadband LED light source
- Narrow bandwidth filters





Luminance Calculation Methodology



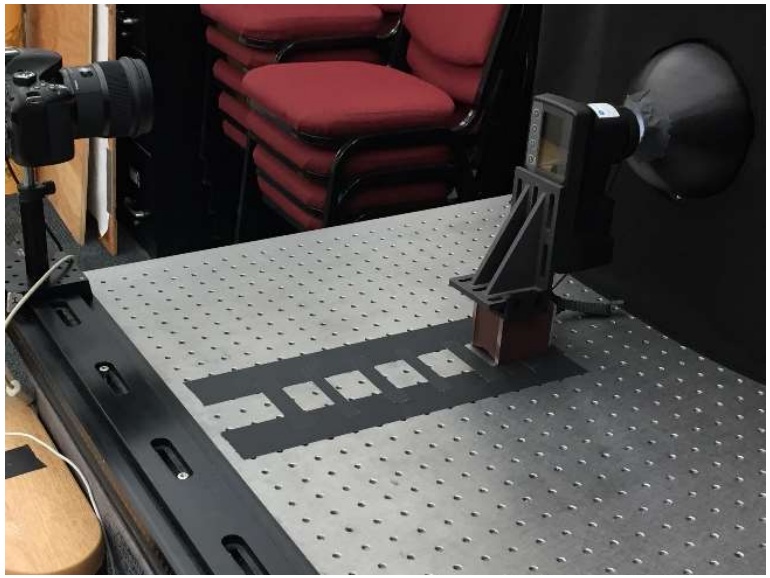


$$L = \frac{E}{\pi sin^2\Theta}$$

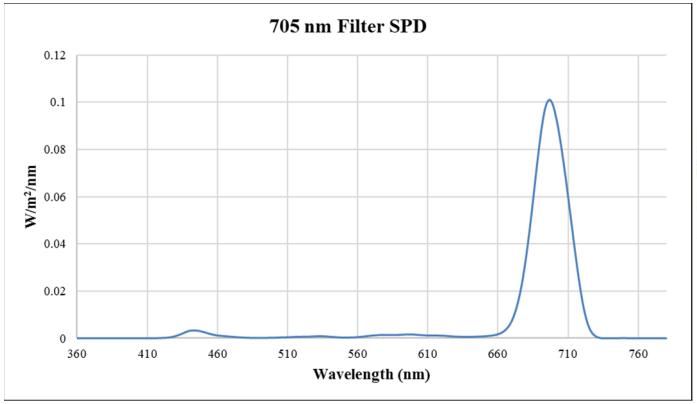
$$\Theta = \tan^{-1}\left(\frac{d}{2D}\right)$$

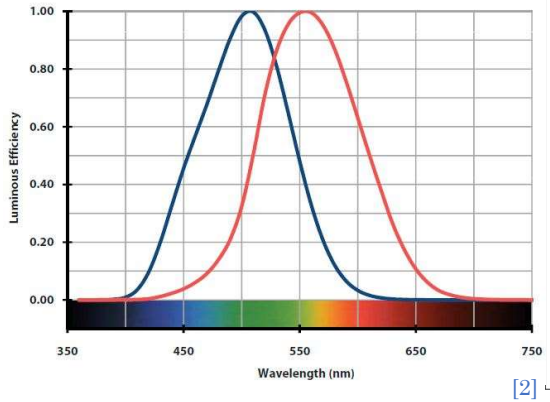
Testing Procedure

- Illuminance and distance measurements at 7 positions
- Luminance measurements of entire source area



Photometric Filter Response





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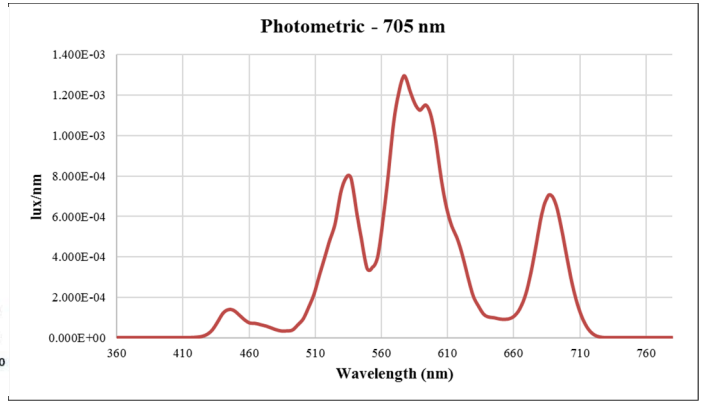
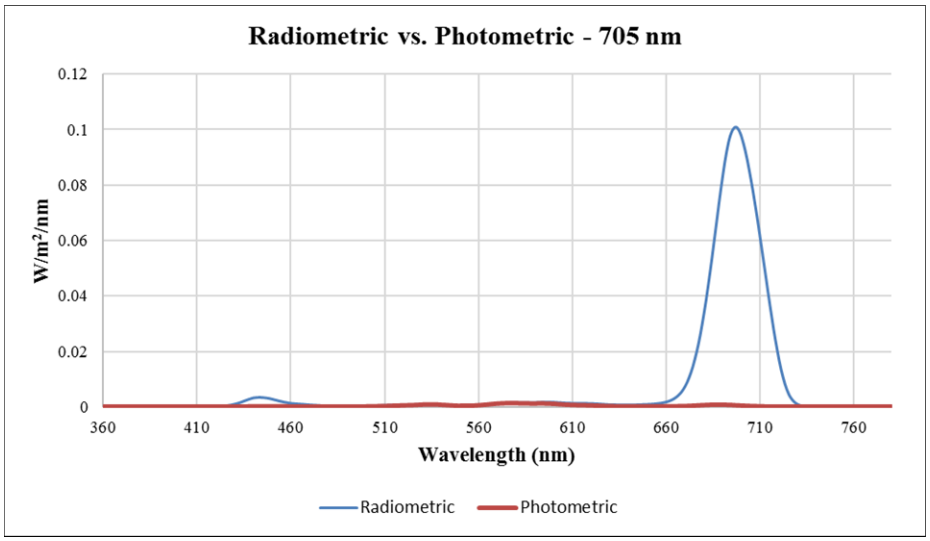
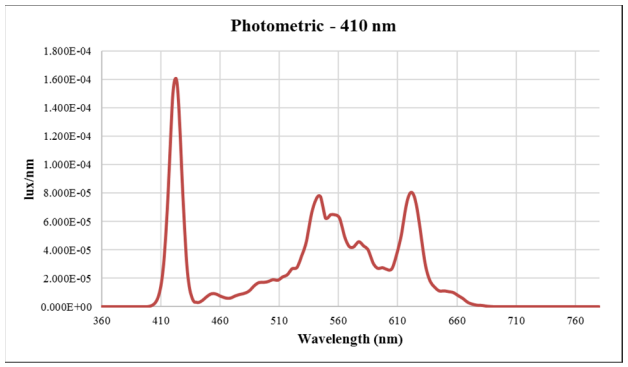
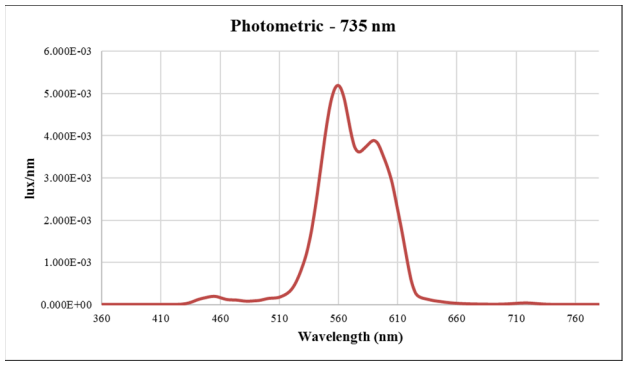


Radiometric → $\phi \equiv 683 \int_0^\infty \phi_{e\lambda}(\lambda) v(\lambda) d\lambda$ → Photometric

Photometric Filter Response



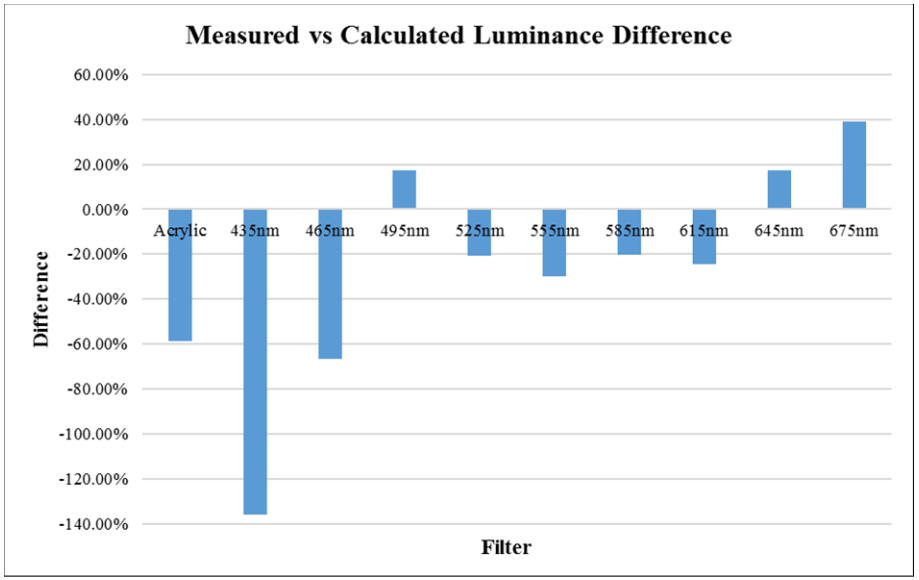


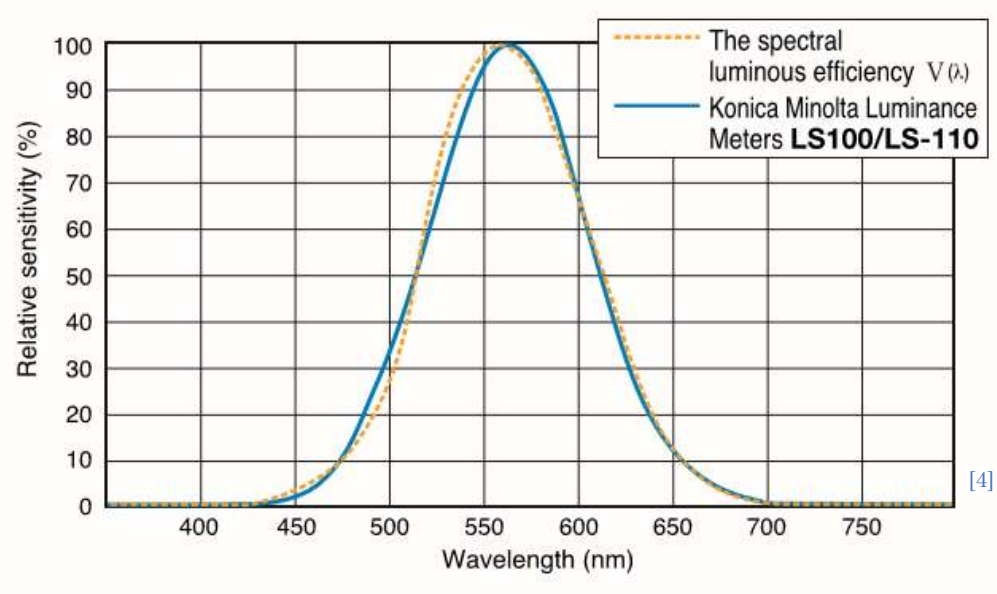


- **3 of 12 filters excluded** from further testing due to photometric response
  - 410 nm, 705 nm and 735 nm

Calculated vs. Measured Luminance

- Positive percentages signify measured L was greater than calculated L





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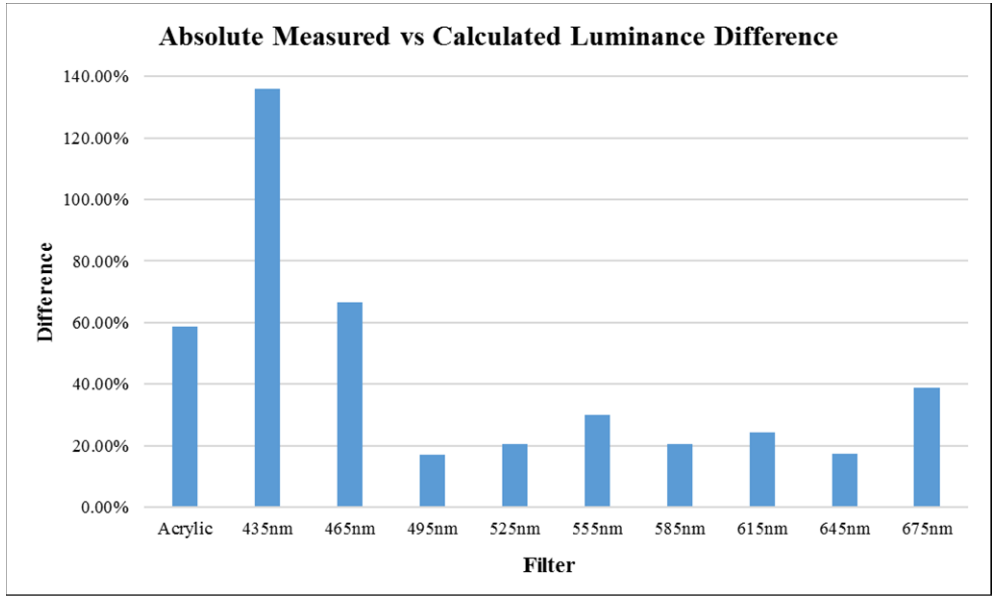
Calculated vs. Measured Luminance

- Color correction factors (CCFs) only improved a few wavelength ranges
- **Largest differences** on **blue** end of spectrum
  - Similar to past luminance studies with standard color cards



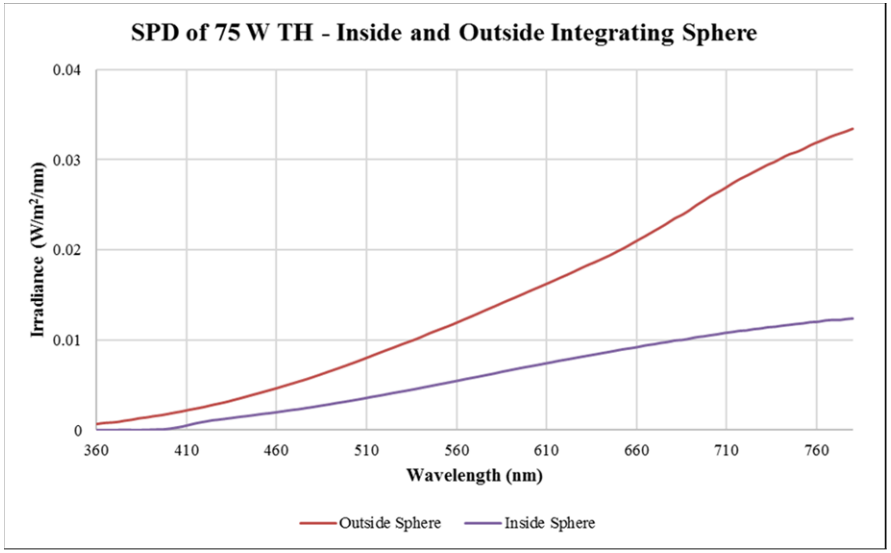
White Light Condition

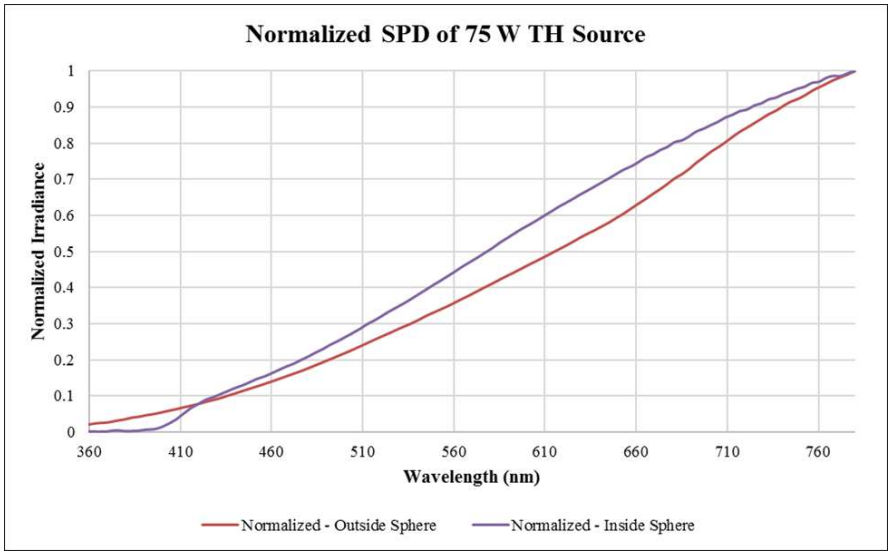
Illuminant	LS-110, Avg. L (cd/m²)	Calculated, Avg. L (cd/m²)	Avg. Difference
50 W TH	5769	6942	-20.3%
75 W TH	8027	9339	-16.3%
LED_1	90950	144426	-58.8%
LED_2	120583	155808	-29.2%
LED_{3A}	101950	124593	-22.2%
LED_{3B}	81173	118703	-46.2%
LED_{3C}	82902	132372	-59.7%
LED_{3D}	98495	133268	-35.3%

- Average TH difference of 18%
- Average LED difference of 42%
- **24% average difference** of broadband LED measurements with LS-110 luminance meter compared to calculated luminance

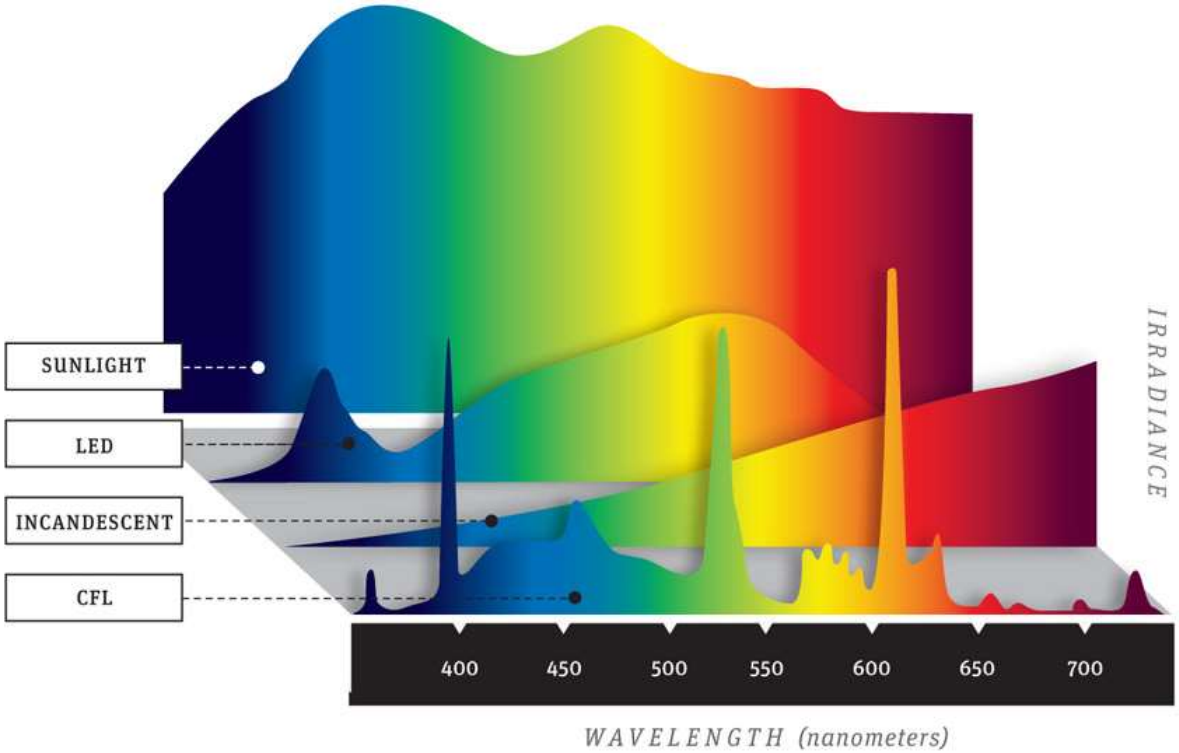
White Light Condition

- Why was the average TH source difference 18% with a CCT of 2815K?
  - Spectral shift due to integrating sphere paint and acrylic





Spectrally Dependent Measurements



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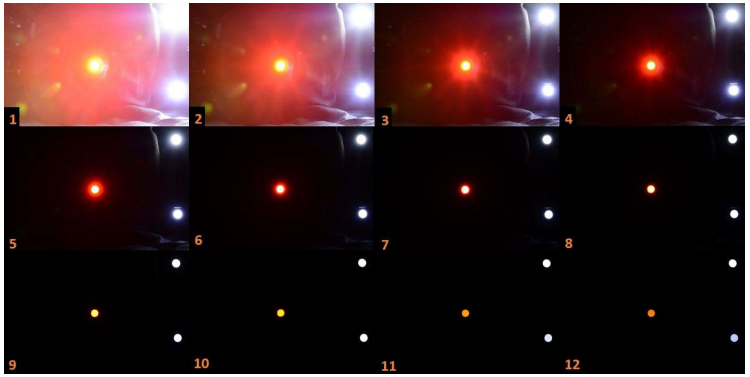
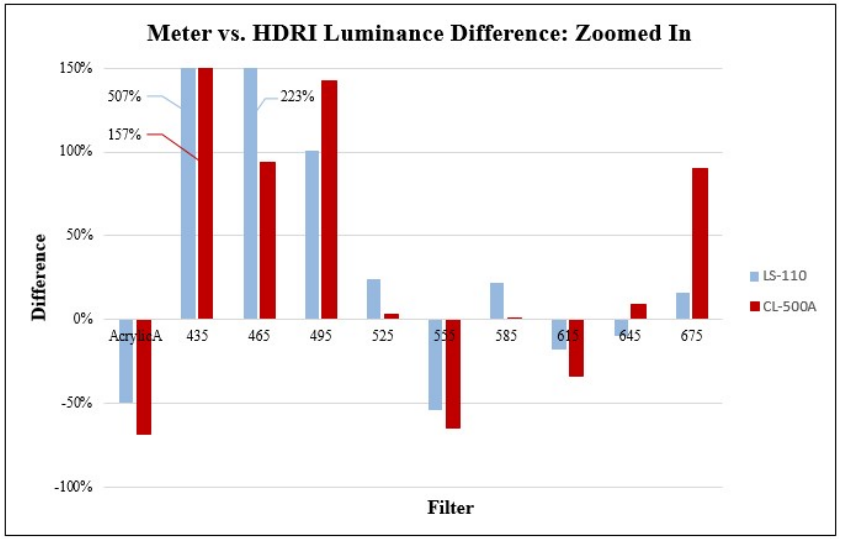
White Light Measurement Errors

- Similar 1-pixel type sensor with V(λ) correction filter for illuminance meters
- Spectrums significantly different than incandescent will result in errors with typical luminance and illuminance meters
  - Daylight
  - Fluorescent
  - LED
  - Metal halide
- Many different white light LED spectrum possibilities
- Meters with spectral capabilities are crucial for measurements of modern lighting technologies

Application of Findings to HDRI

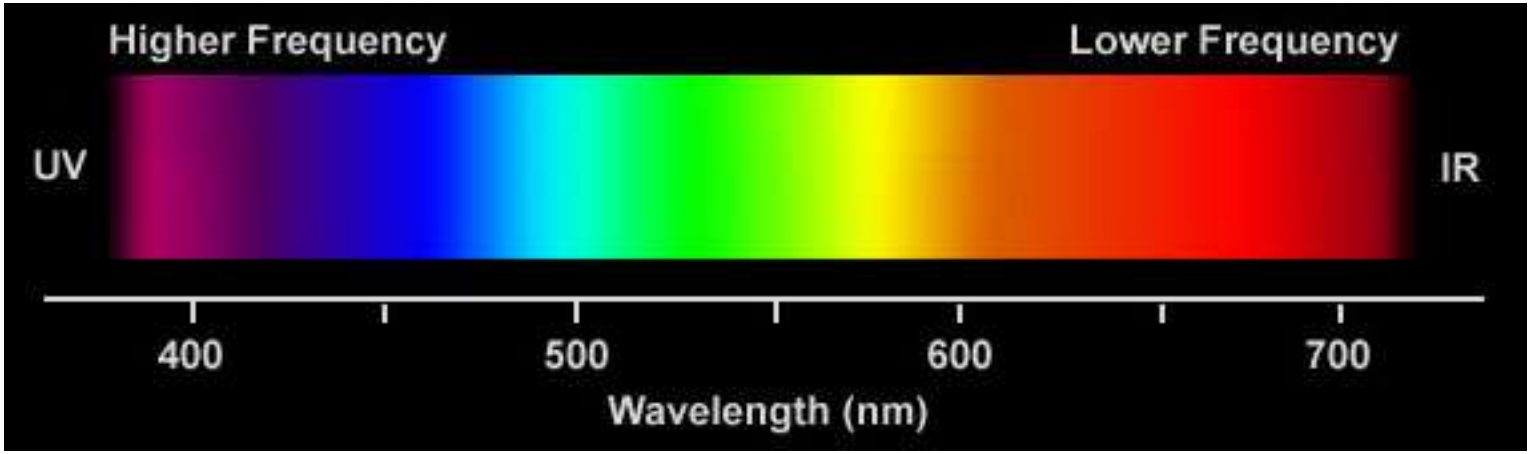
- HDRI taken were calibrated to LS-110 measurements of LED sources
- HDRI luminance calibration must consider source spectrum
- Over 500% difference between LS-110 measurement and HDRI luminance for 435 nm filter





Conclusion

- **Largest luminance meter errors on blue end** of visual spectrum, errors also increase towards red wavelengths
- Industry standard light meters are typically **calibrated to an incandescent source**
- Measurements of sources other than incandescent may have large, **spectrally dependent errors**
  - LED, daylight, fluorescent, metal halide, etc.
- Calculated luminance on average **24% different** than LS-110 measurements for tested LED module
- HDRI luminance mapping should be calibrated using a meter with spectral capabilities in order to derive absolute luminance values


Higher Frequency
Lower Frequency
UV
IR
400
500
600
700
Wavelength (nm)

[6]

Questions?

Image Sources

[1] Stanley, Mio J. *On the development and error analysis of a high dynamic range imaging system for luminance measurements*. s.l. : University of Colorado Boulder, 2016.

[2] Luminous Efficacy. [Online] http://ceae.colorado.edu/~beamer/Images/Luminous%20Efficacy.JPG.

[3] Understanding Standard Illuminants in Color Measurement. *Konica Minolta*. [Online] [Cited: December 11, 2016.] http://sensing.konicaminolta.us/2013/11/understanding-standard-illuminants-in-color-measurement/.

[4] Luminance Meter LS-100 LS-110 Instruction Manual. [Online] http://www.konicaminolta.com/instruments/download/instruction_manual/light/pdf/ls-100-110_instruction_eng.pdf.

[5] Herrman, John. Ultimate Light Bulb Test: Incandescent vs. Compact Fluorescent vs. LED. *Popular Mechanics*. [Online] September 20, 2011. [Cited: December 23, 2016.] http://www.popularmechanics.com/technology/gadgets/reviews/g164/incandescent-vs-compact-fluorescent-vs-led-ultimate-light-bulb-test/?.

[6] Panoscan. http://www.panoscan.com/IR/spectrum1.jpg