Spectral correction of photodetectors for LED products

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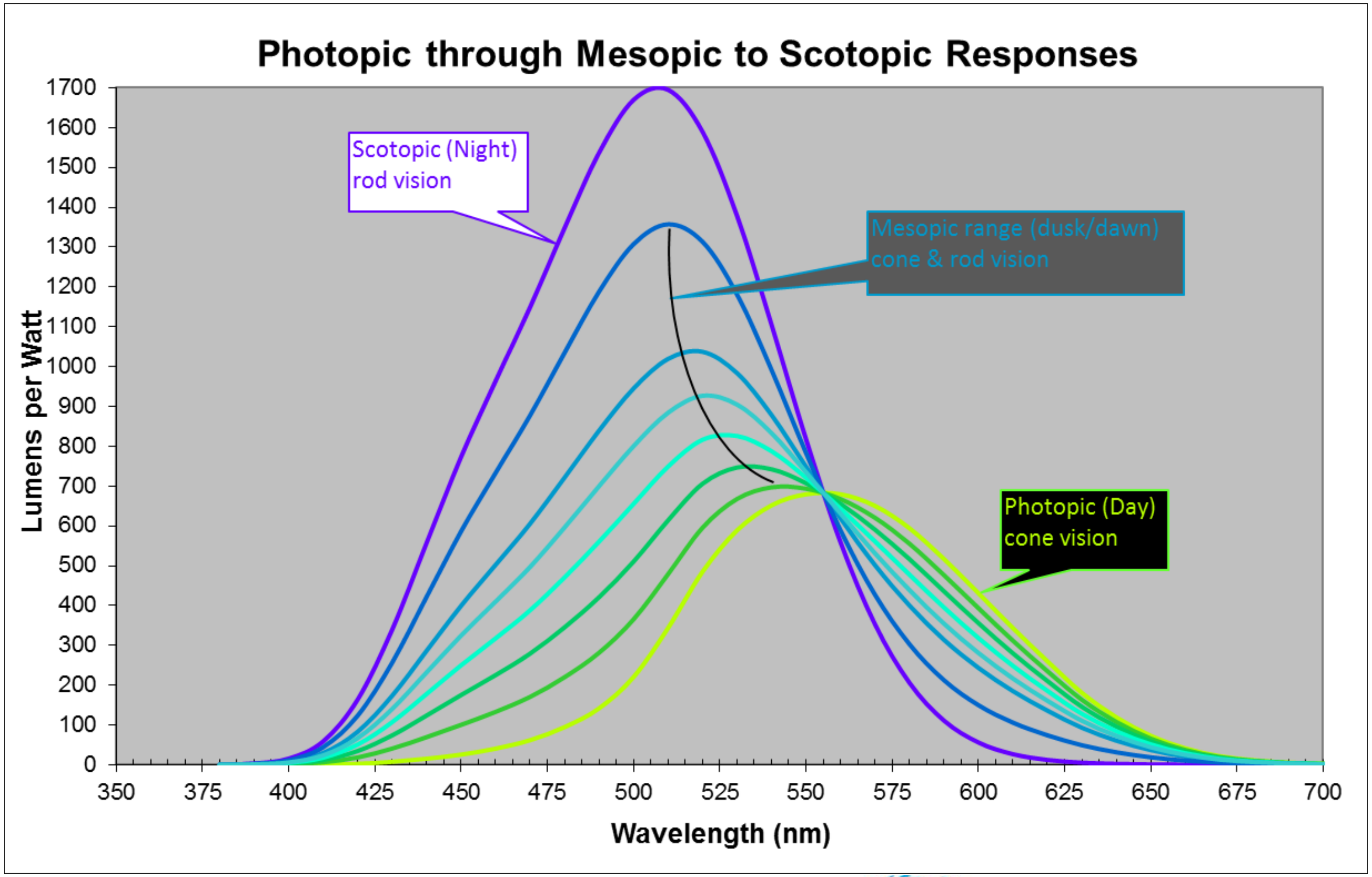
Introduction

- Measurement of light requires a detector which has the same spectral response as the human eye under typical lighting conditions
- “Daytime” visual conditions – photopic vision
- “Dawn/dusk” visual conditions – mesopic vision
- “Night-time” visual conditions– scotopic vision

Varying Visual Response



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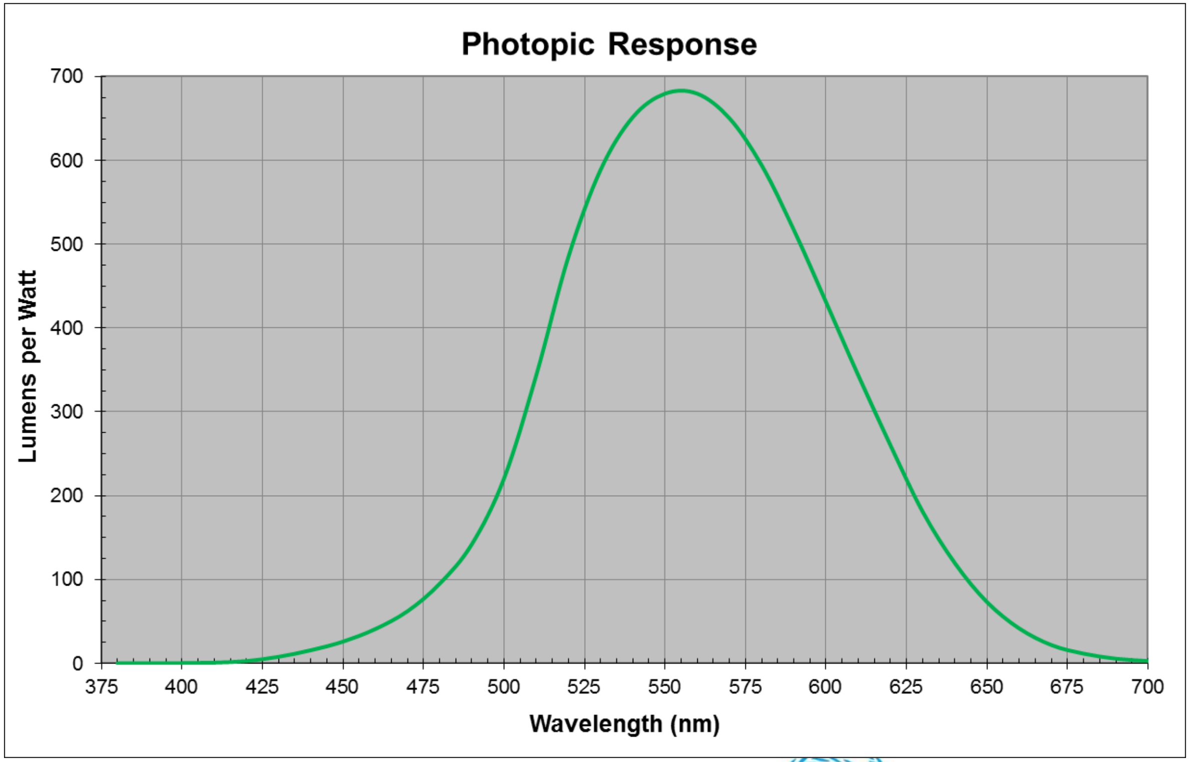
General Photometry

- General photometry based on photopic applications therefore detector requires a photopic spectral response (ie photodetector).



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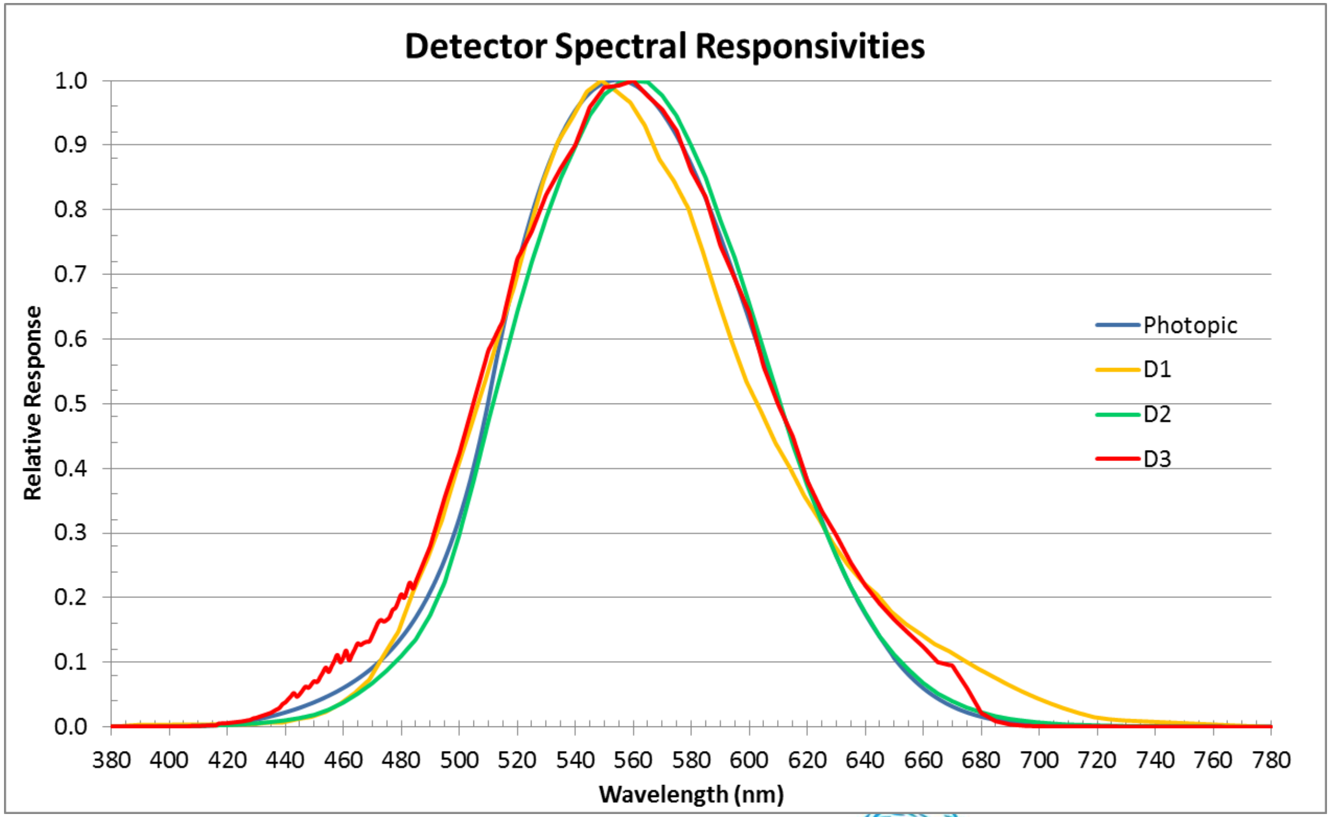
Photodetectors

- Photodetectors do not have the perfect photopic response



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How do we characterise this difference?

- Defined as the deviation of relative spectral responsivity from the $V(\lambda)$ function, f'_1

$$f'_1 = \frac{\int_0^\infty |s(\lambda)_{rel} - V(\lambda)| \; \mathrm{d}\lambda}{\int_0^\infty V(\lambda) \; \mathrm{d}\lambda} \times 100\%$$

$$= 0.93584 \int_0^\infty |s(\lambda)_{rel} - V(\lambda)| \; \mathrm{d}\lambda \;\; \%$$

- Where $s(\lambda)_{rel}$ is the normalised relative spectral responsivity of the detector

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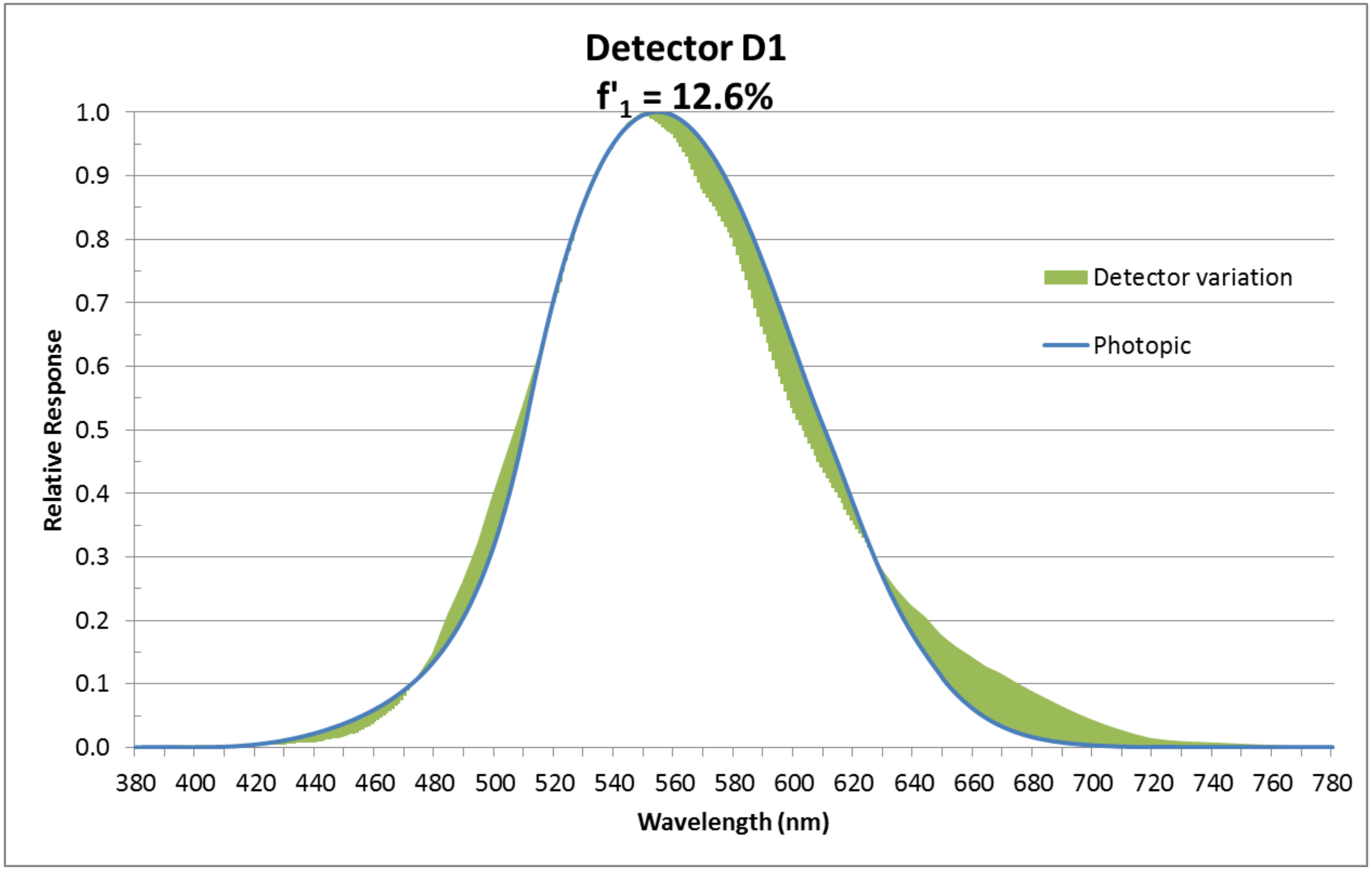
Example: Detector 1



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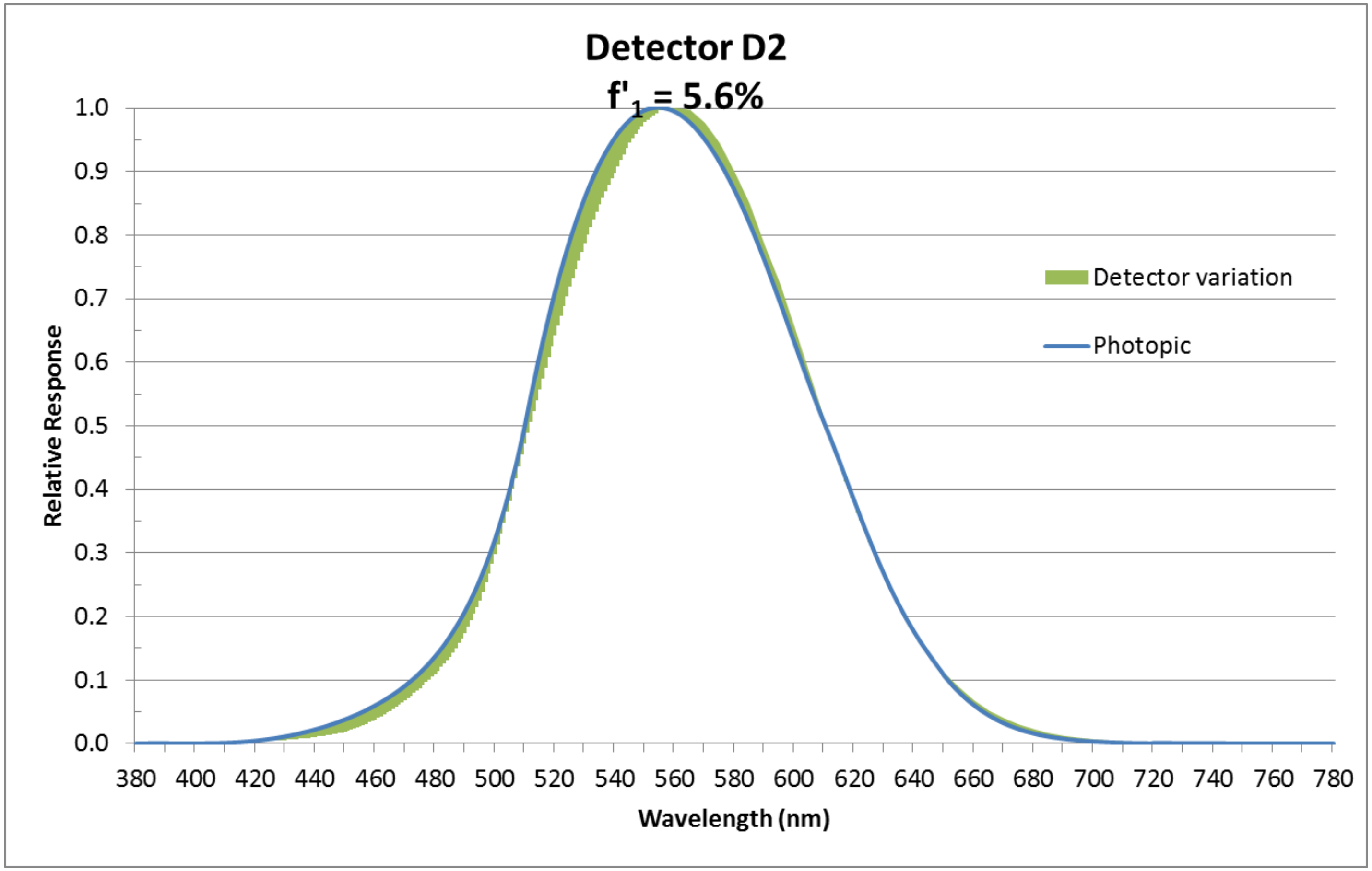
Example: Detector 2



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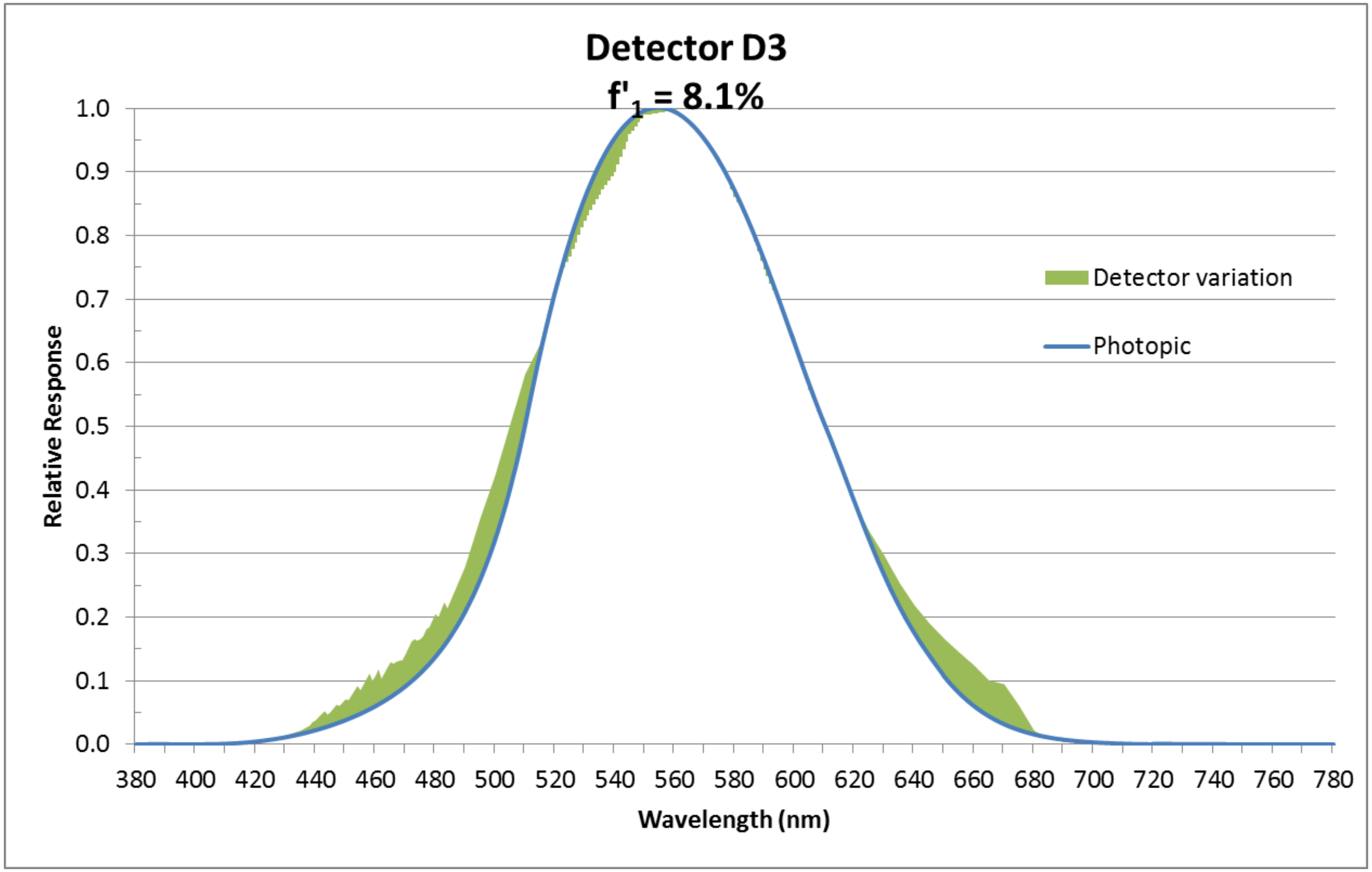
Example: Detector 3



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What effect does this have on measurements?

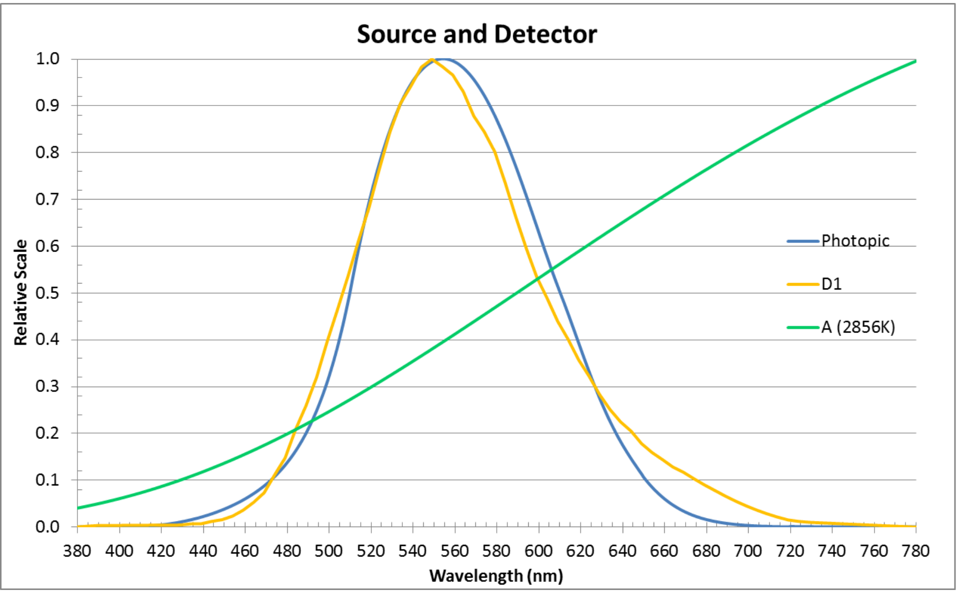
- Compare the measured result to calculated photopic result:

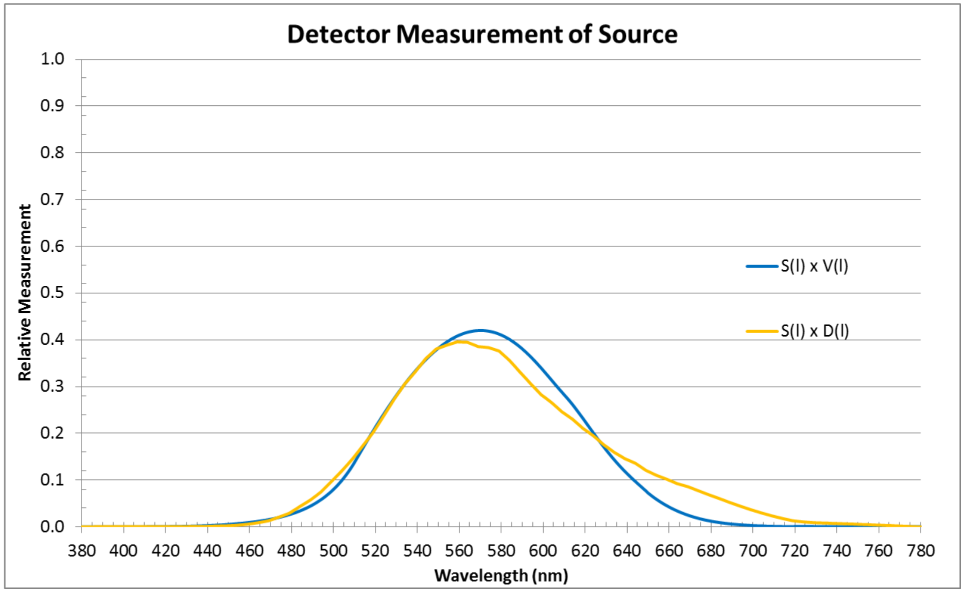
$$Detector\ Measurement = \int_0^{\infty} S(\lambda)_{rel} \times D(\lambda)_{rel}\ \mathrm{d}\lambda$$

$$Photopic\ result = \int_0^{\infty} S(\lambda)_{rel} \times V(\lambda)_{rel}\ \mathrm{d}\lambda$$

$$Relative\ measurement\ result = \frac{Detector\ measurement}{Photopic\ calculation}$$

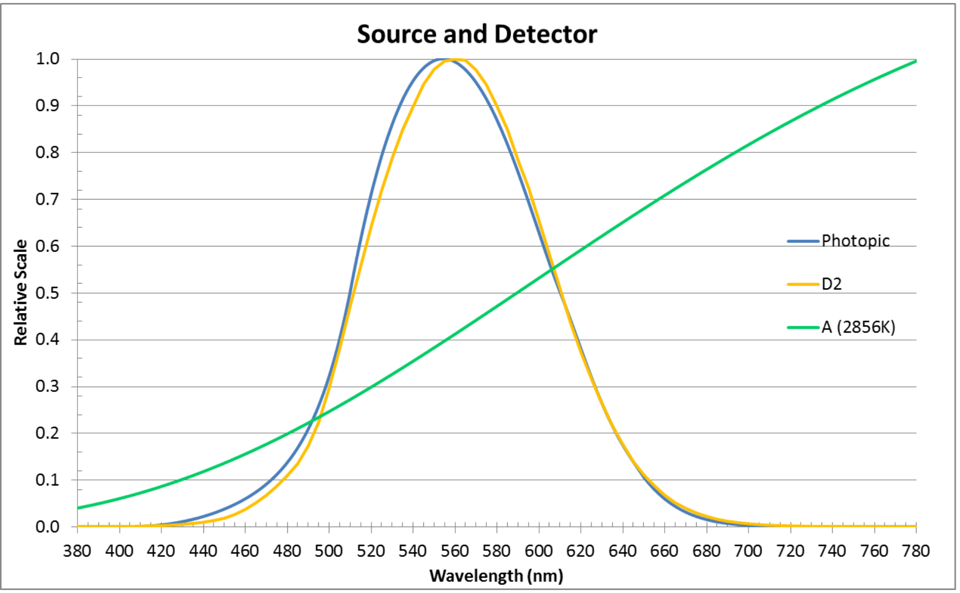
Example: Incandescent Source A & Detector 1

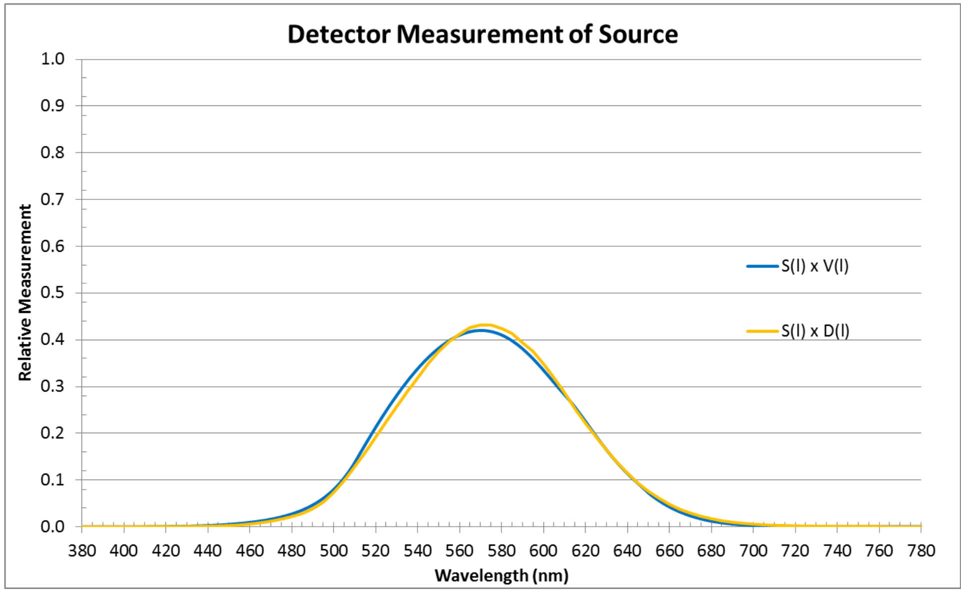




- Relative measurement result = 104.0%

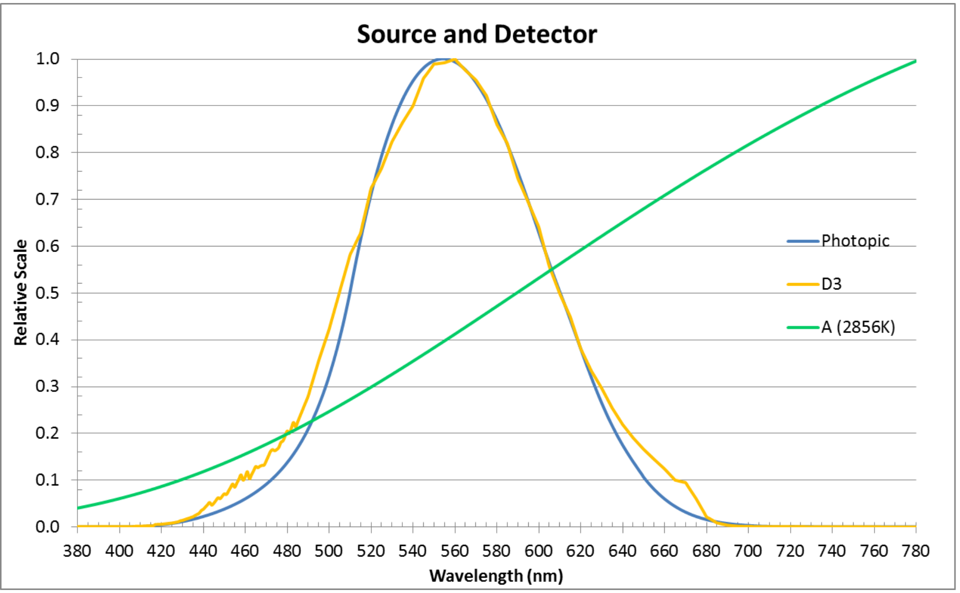
Example: Incandescent Source A & Detector 2

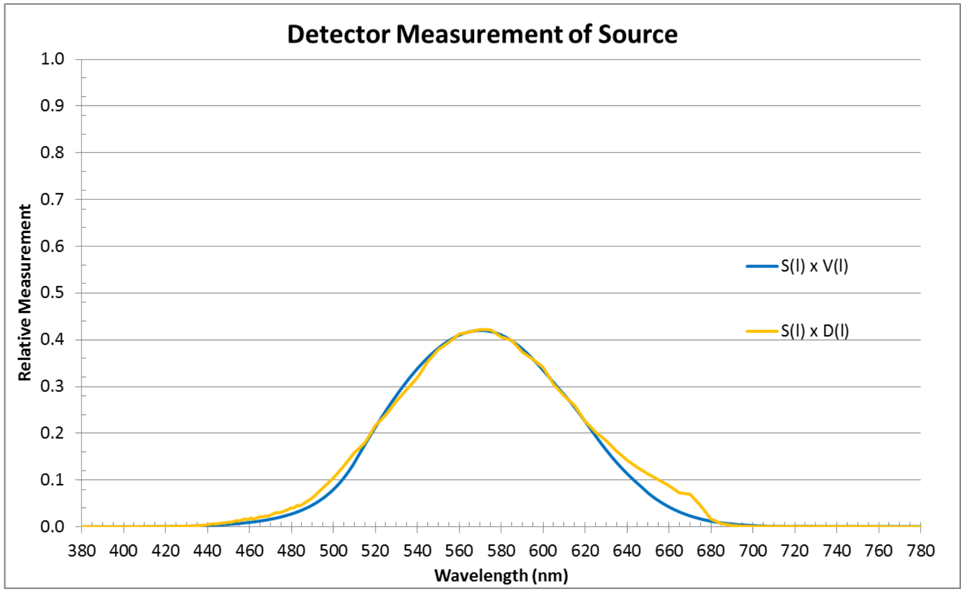




- Relative measurement result = 99.5%

Example: Incandescent Source A & Detector 3





- Relative measurement result = 105.4%

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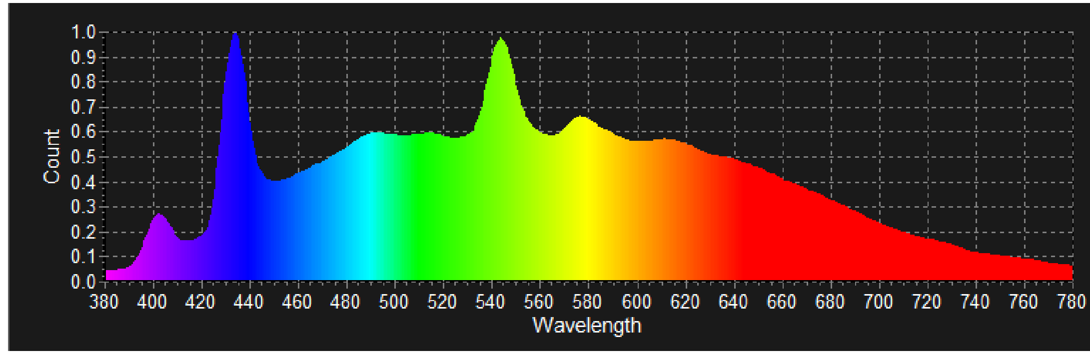
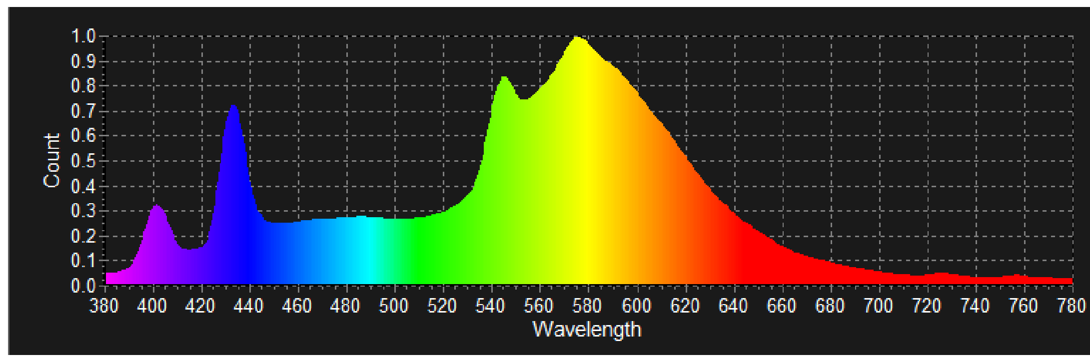
Example: Linear Fluorescent lamp sources

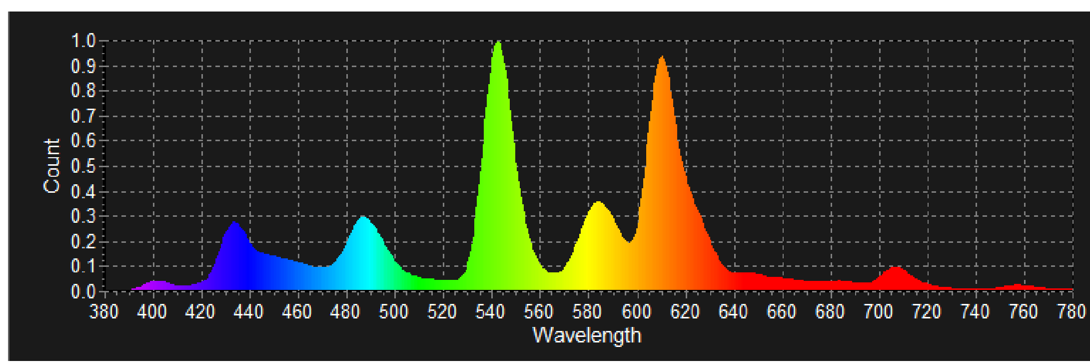
- Halo-phosphor



- Tri-phosphor



- Quad-phosphor



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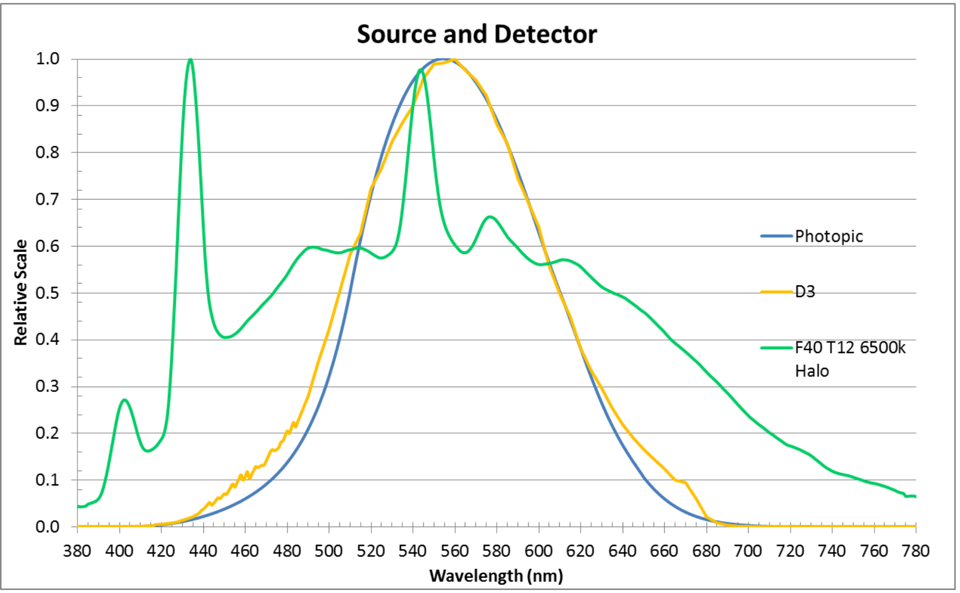
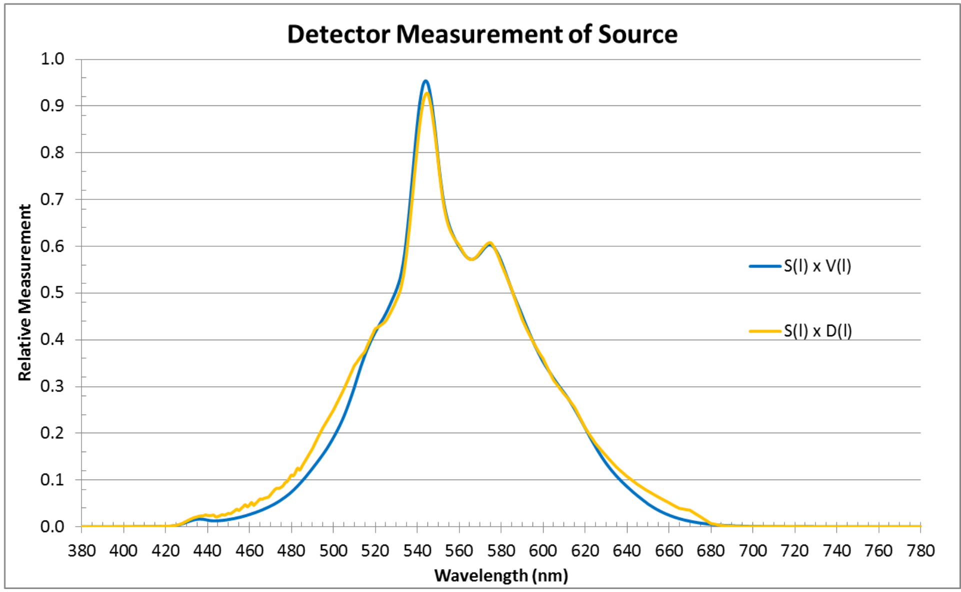
Eg: Fluorescent Source (halo) & Detector 3





- Relative measurement result = 104.3%

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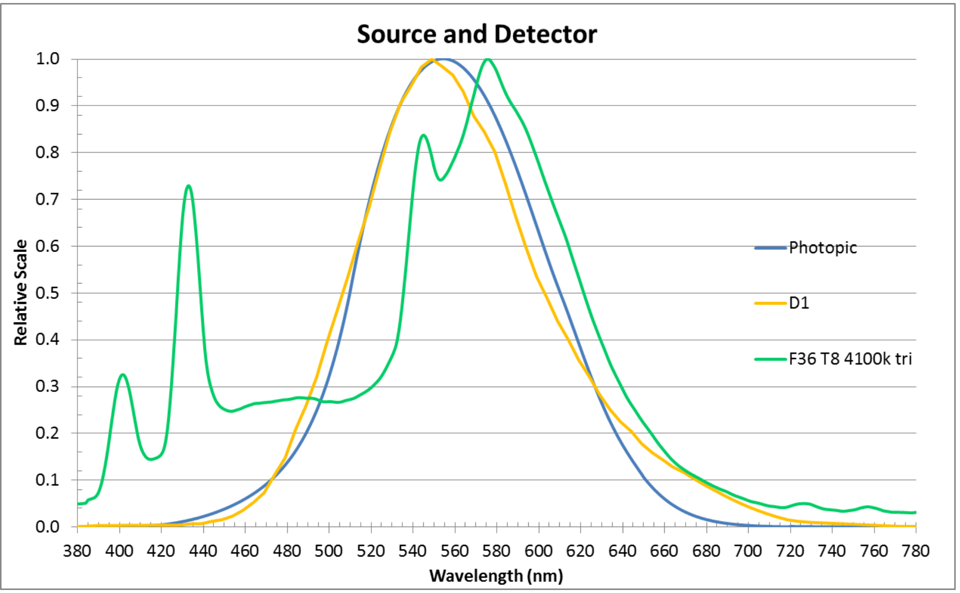
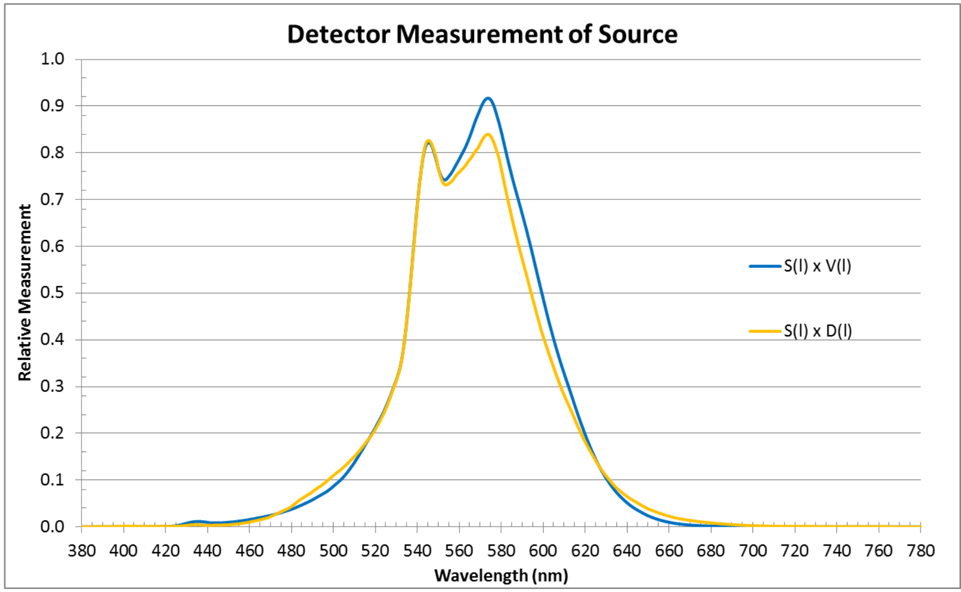
Example: Fluorescent Source (tri) & Detector 1





- Relative measurement result = 95.4%

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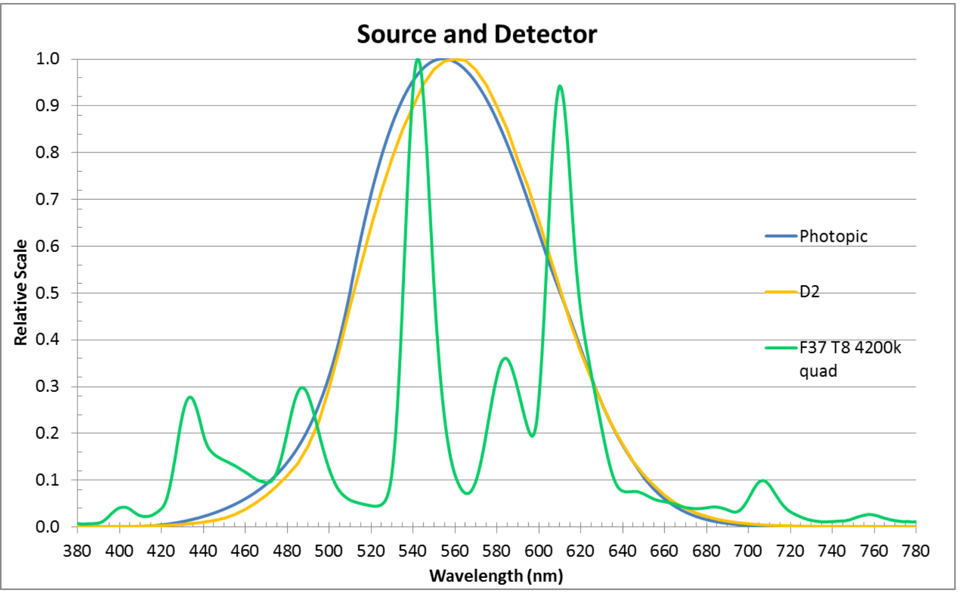
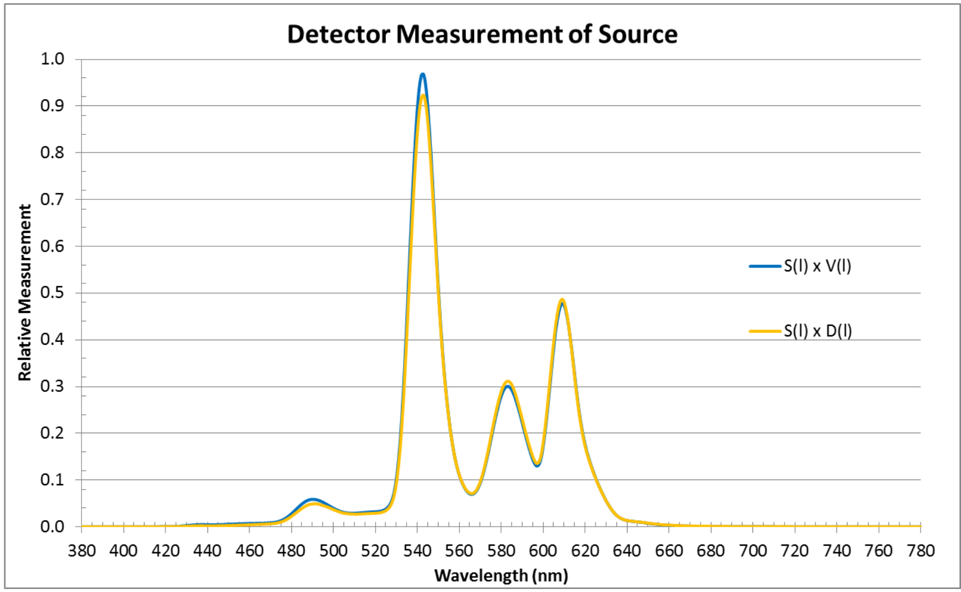
Example: Fluorescent Source (quad) & Detector 2





- Relative measurement result = 97.9%

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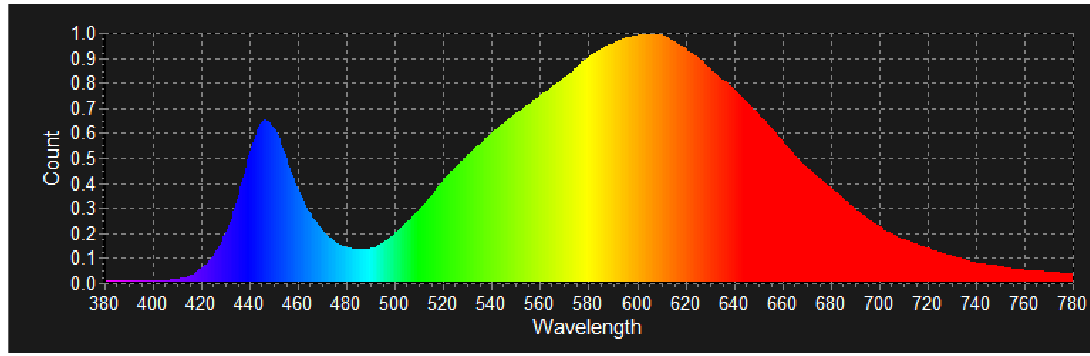
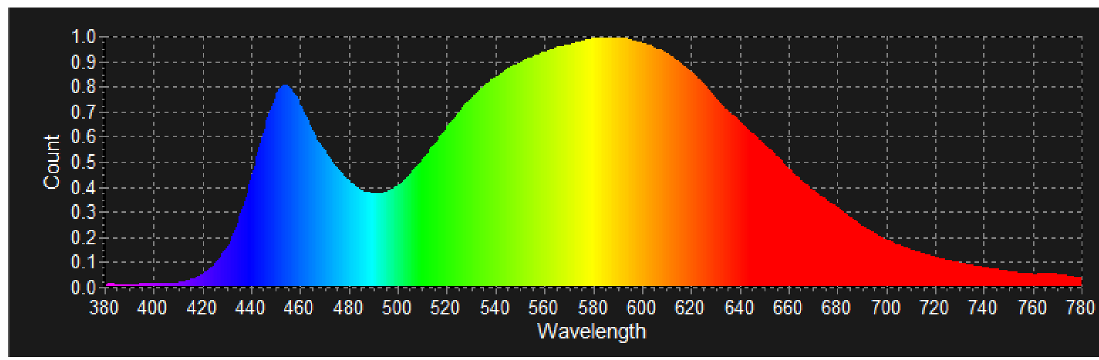
White LED sources

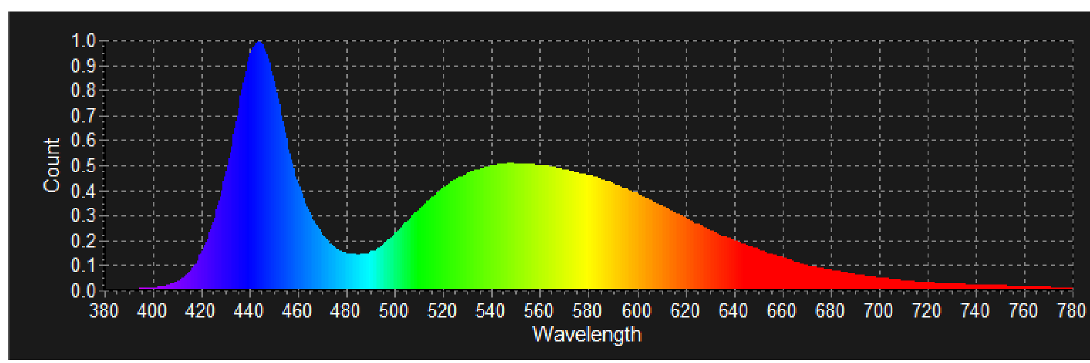
- CCT: 2700k



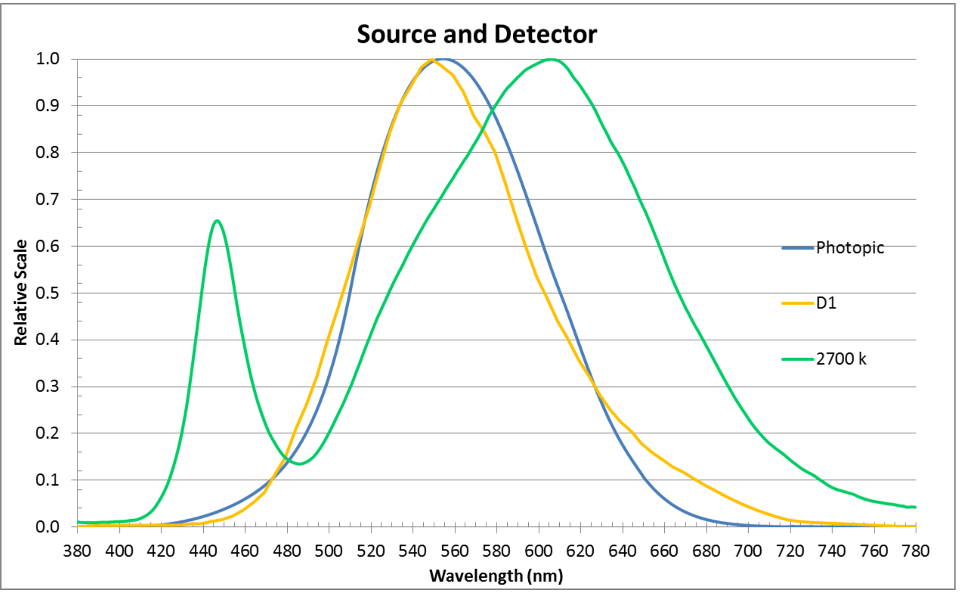
- CCT: 4000k

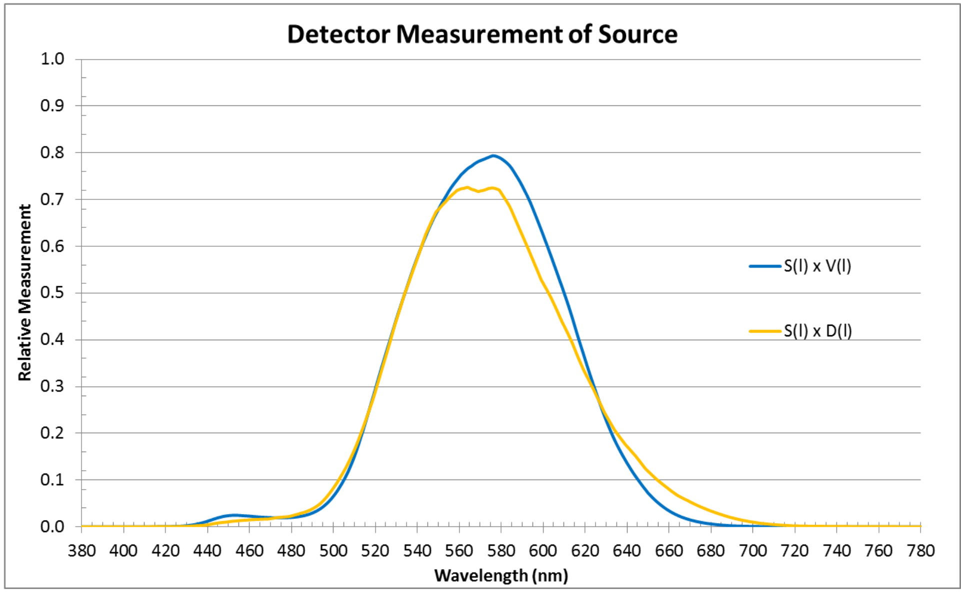


- CCT: 6500k



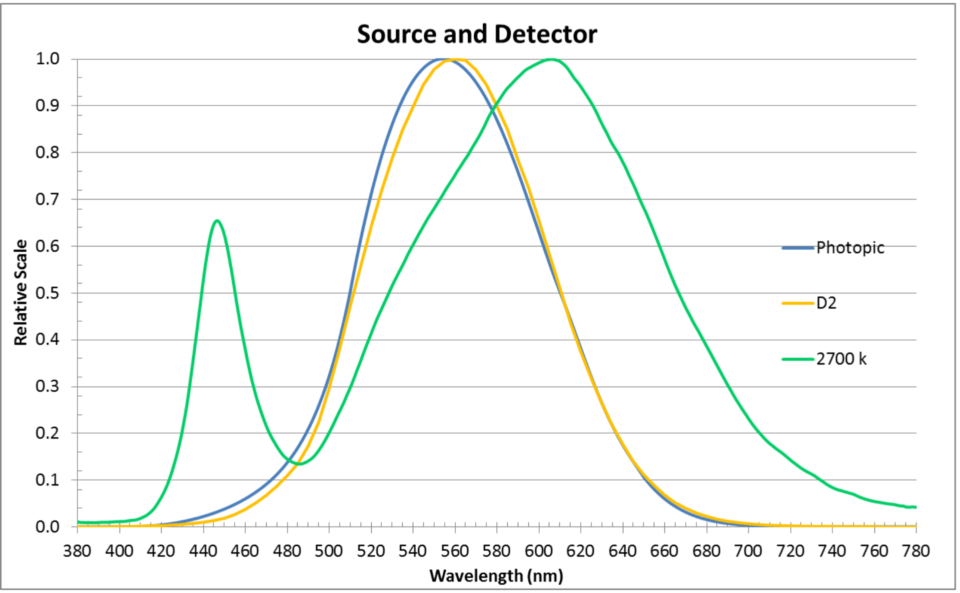
Example: LED Source (2700k) & Detector 1

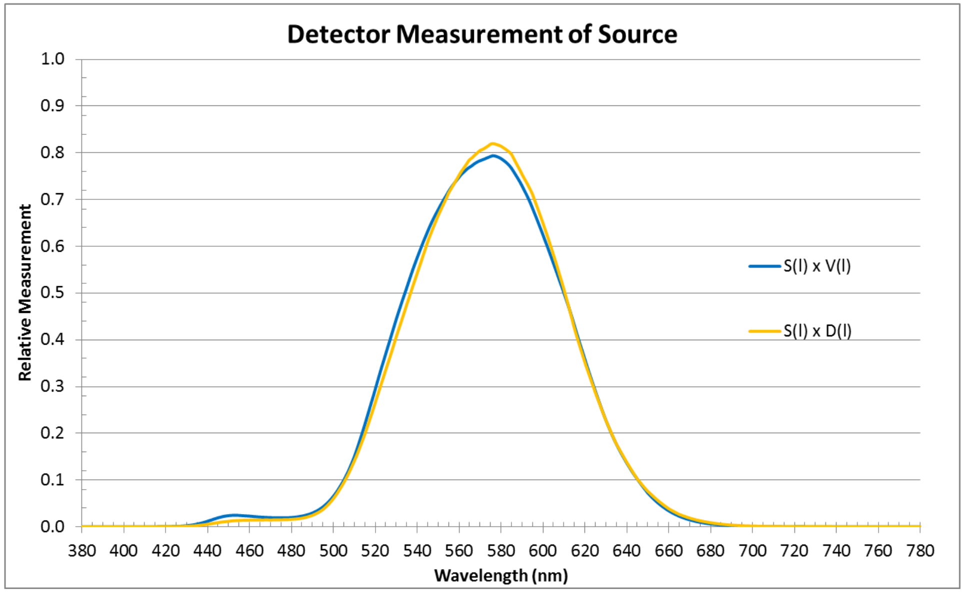




- Relative measurement result = 96.9%

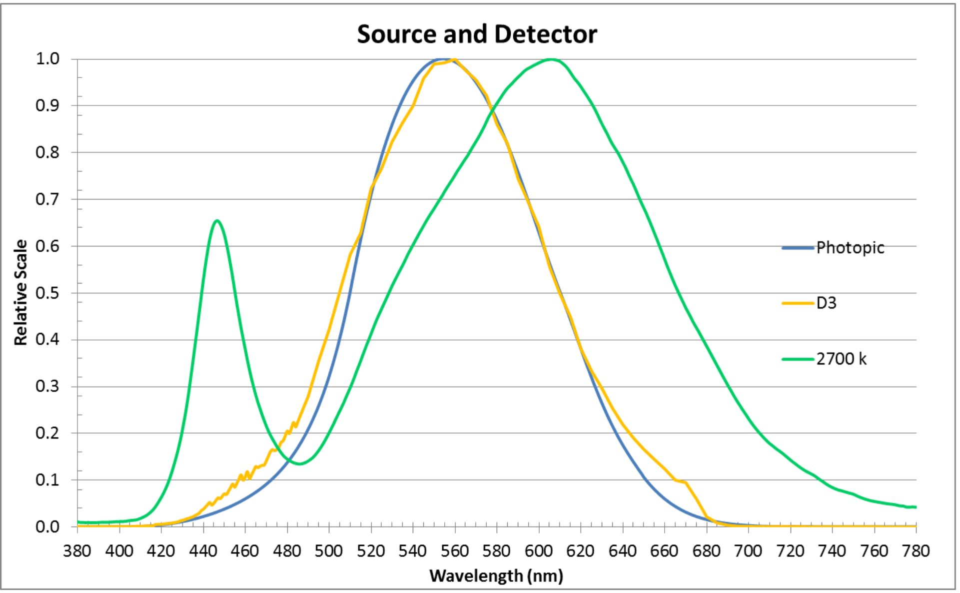
Example: LED Source (2700k) & Detector 2

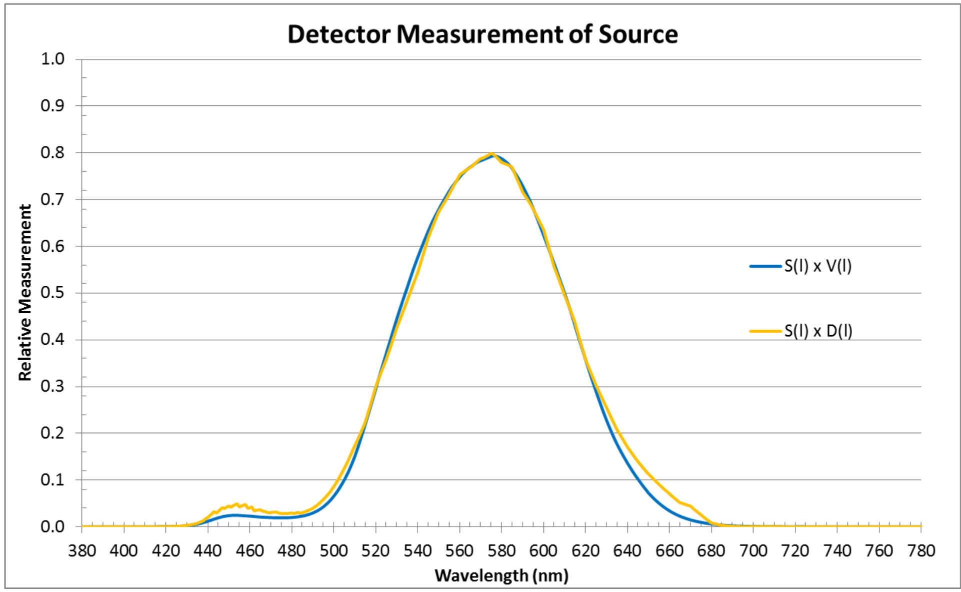




- Relative measurement result = 99.4%

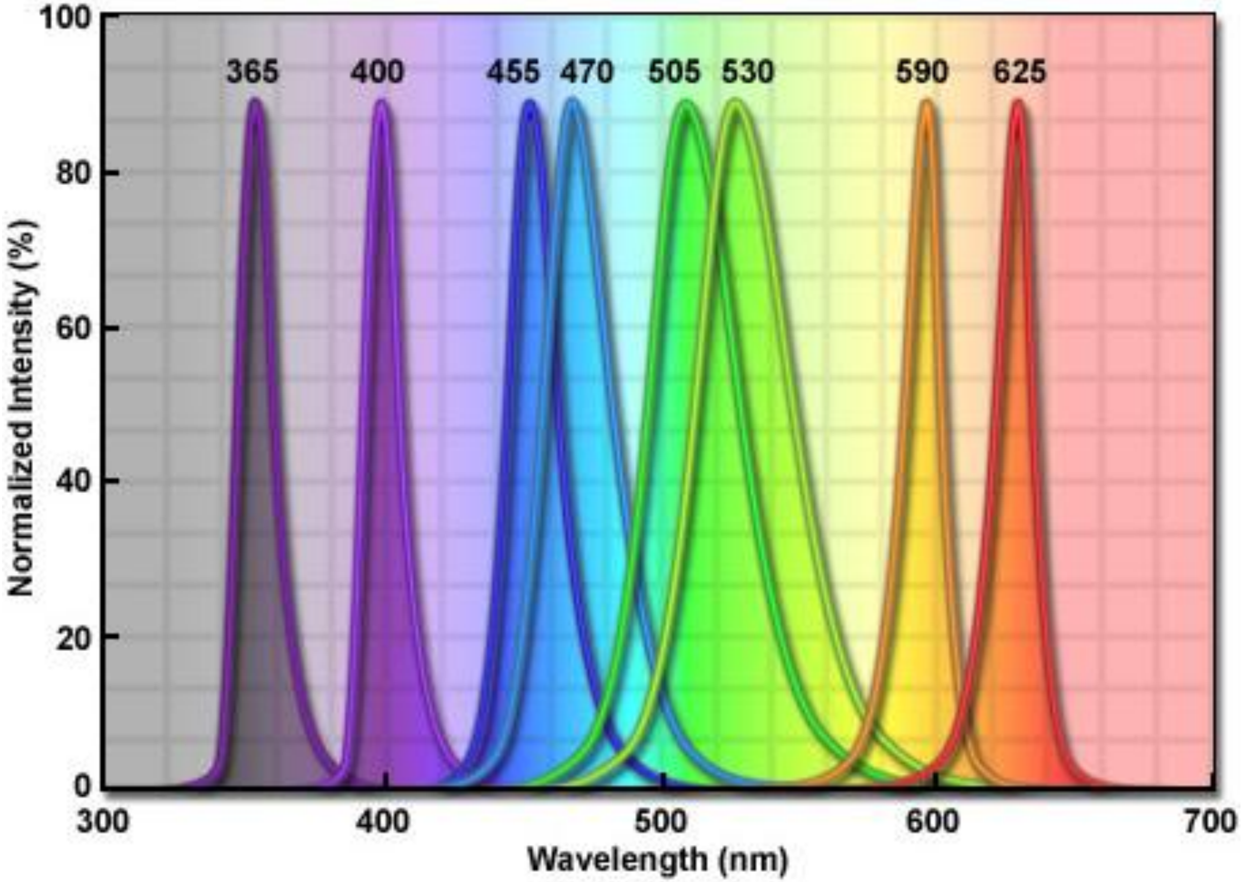
Example: LED Source (2700k) & Detector 3



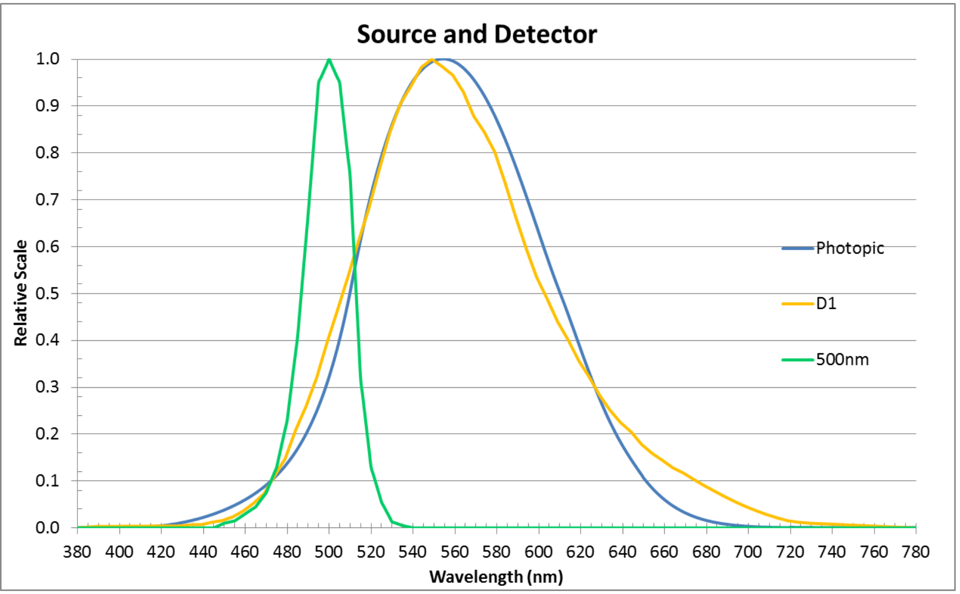


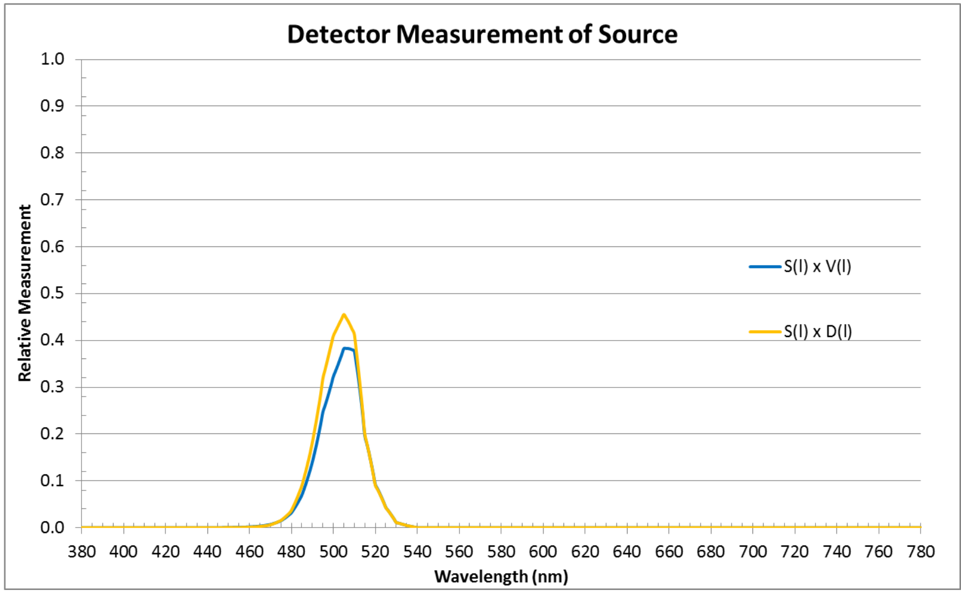
- Relative measurement result = 103.1%

Monochromatic LED Sources



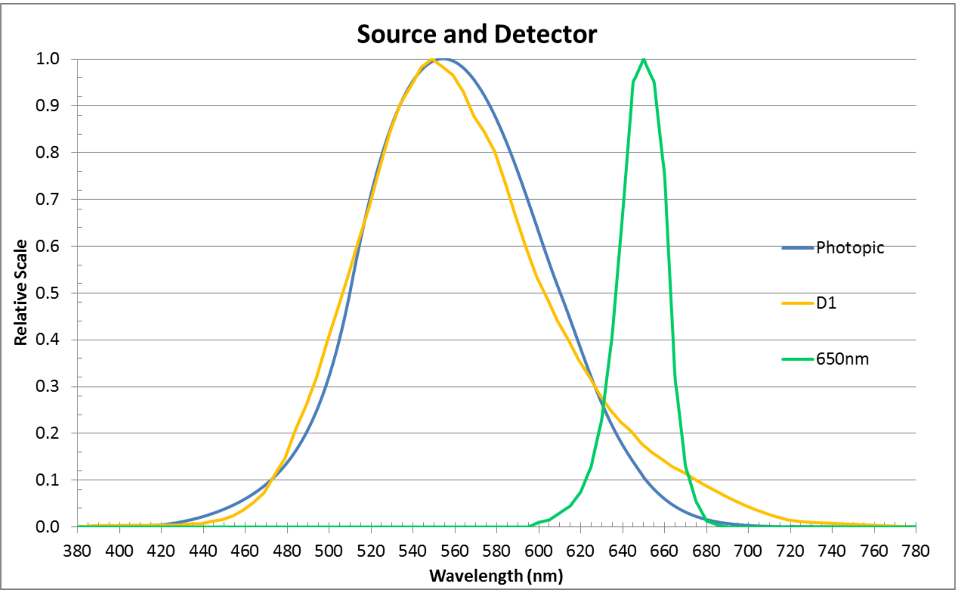
Example: LED Source (500nm) & Detector 1

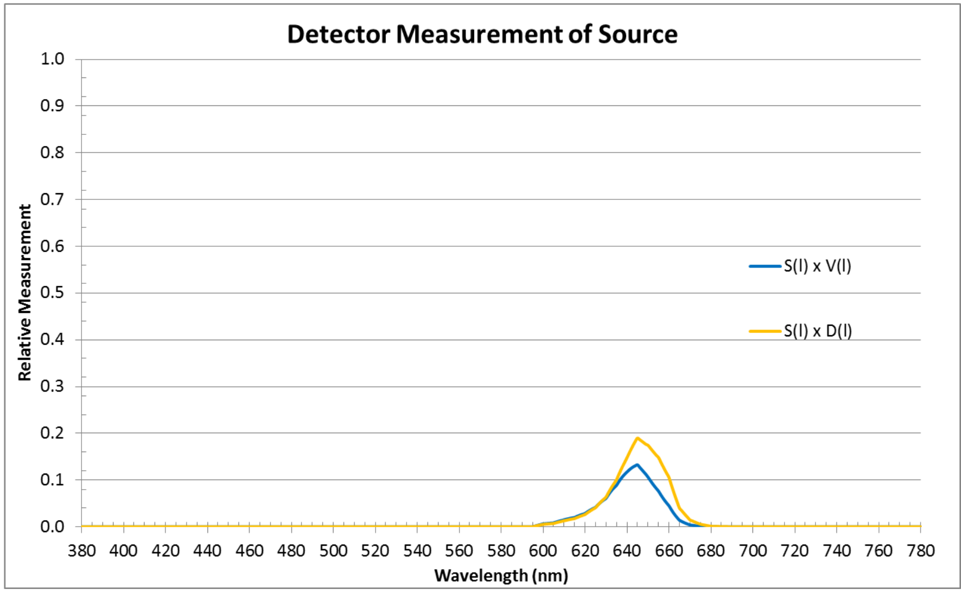




- Relative measurement result = 116.9%

Example: LED Source (500nm) & Detector 1





- Relative measurement result = 143.4%

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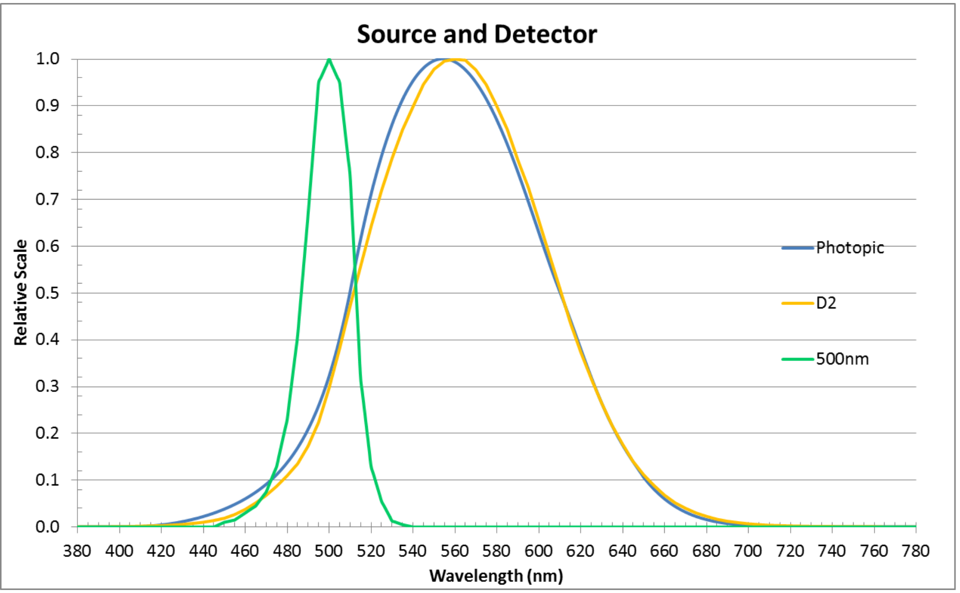
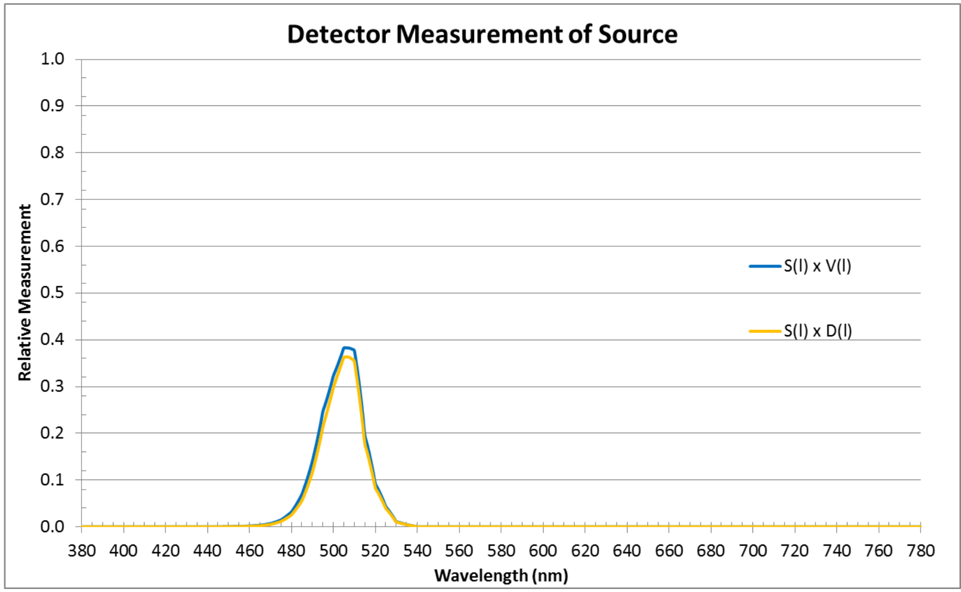
Example: LED Source (500nm) & Detector 2





- Relative measurement result = 90.6%

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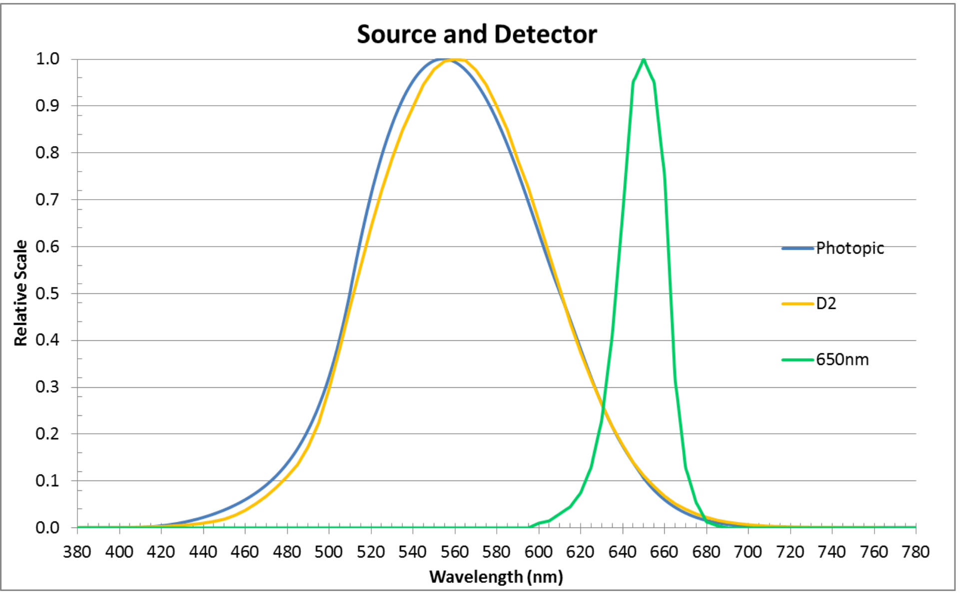
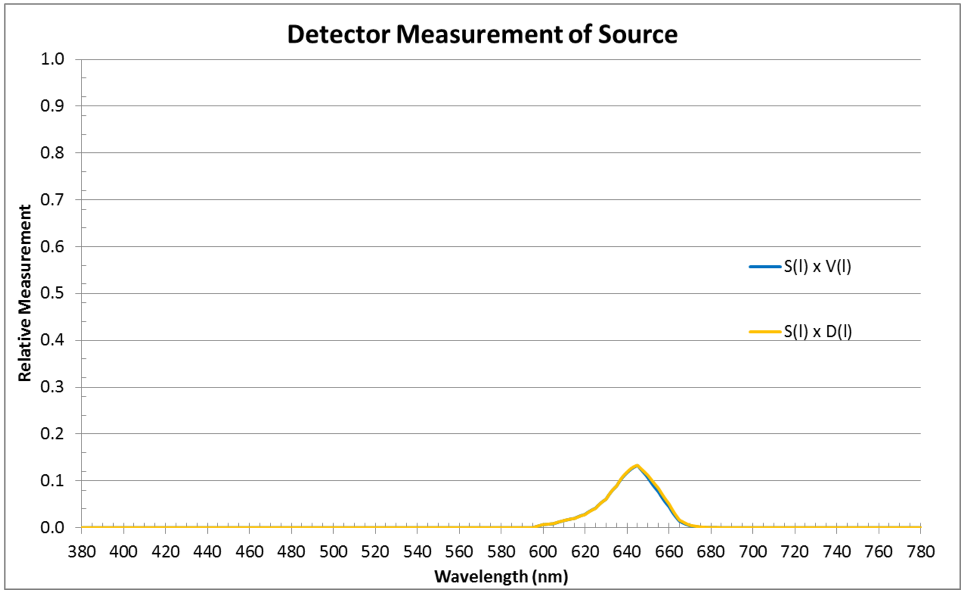
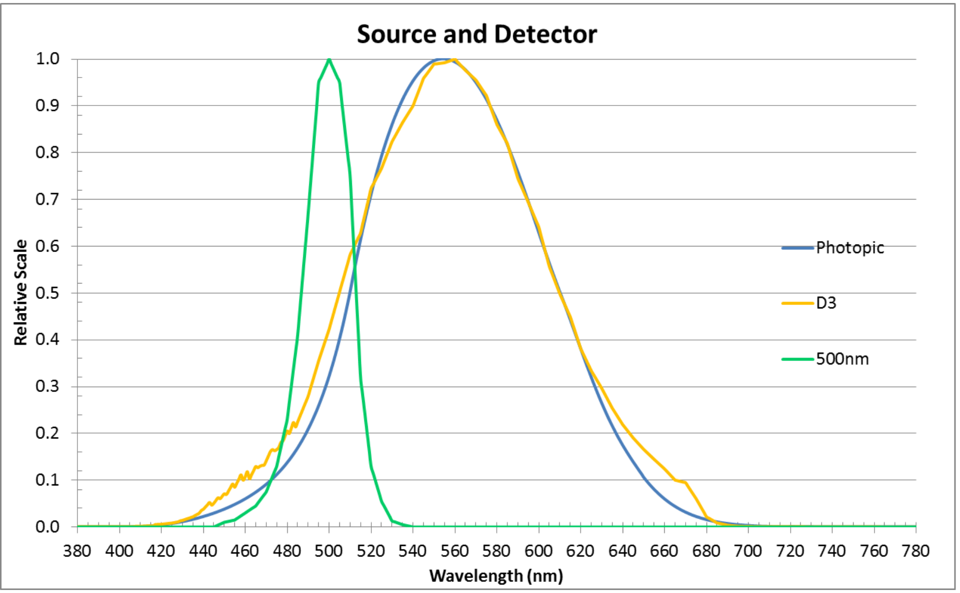
Example: LED Source (500nm) & Detector 2

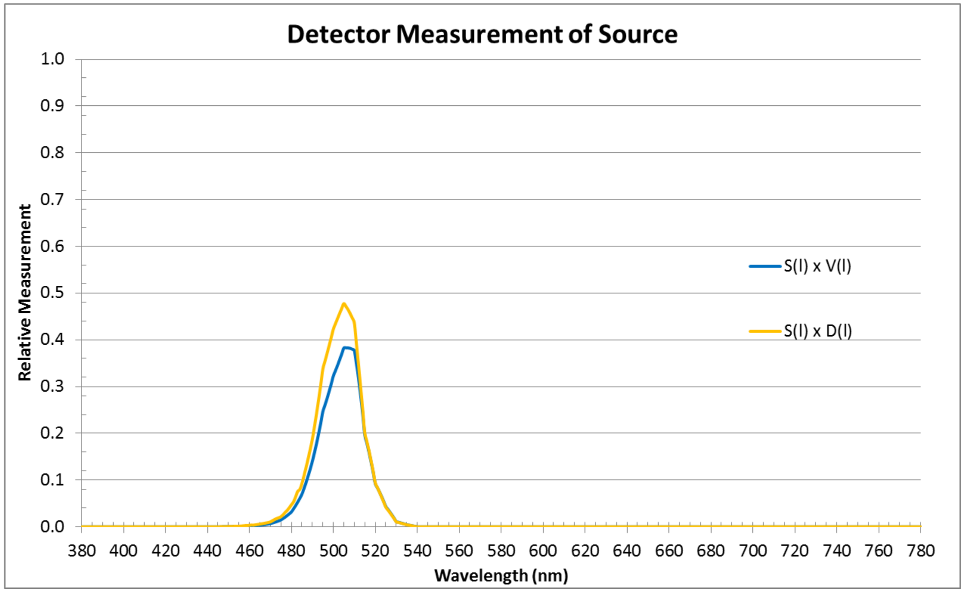




- Relative measurement result = 103.3%

Example: LED Source (500nm) & Detector 3





- Relative measurement result = 122.9%

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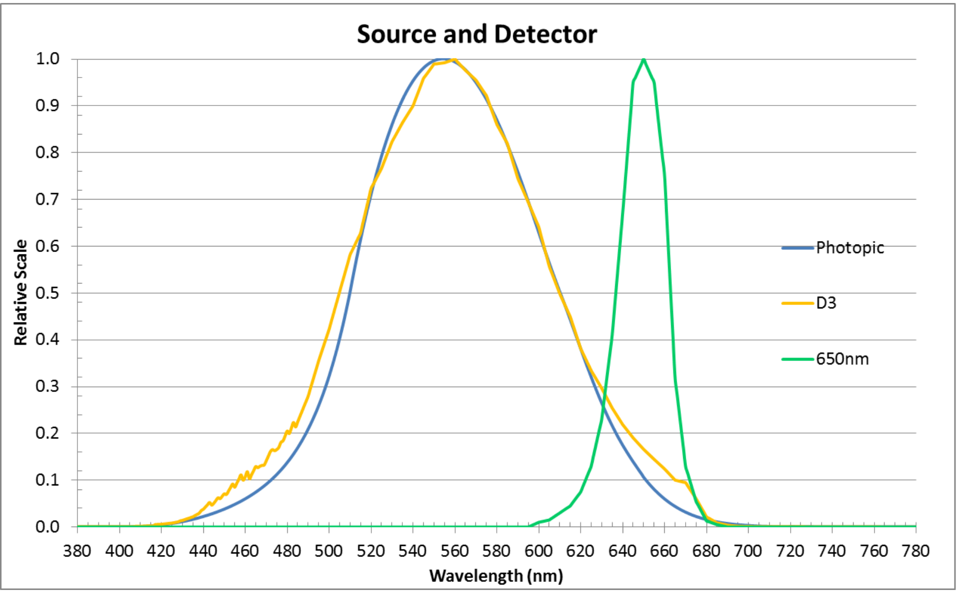
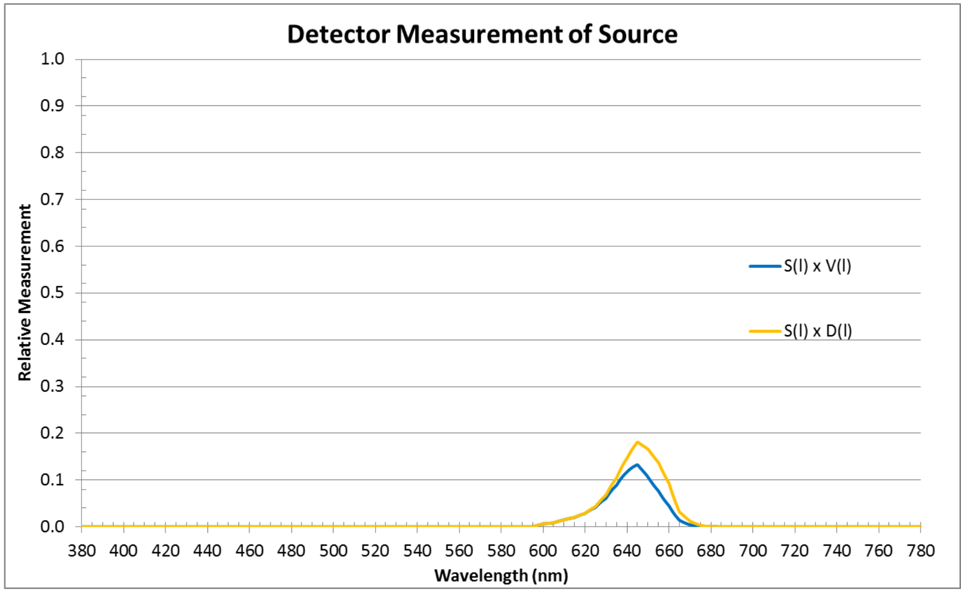
Example: LED Source (500nm) & Detector 3





- Relative measurement result = 138.9%

But you calibrate your detector against a Standard Reference Lamp!

- This Reference lamp is typically a Source A incandescent lamp
- So all test lamps which are incandescent will not require a calibration factor (due to having the same spectrum)

Detector	Correction for Reference Lamp: A (2856K)	Correction for Test Lamps: A (2856K)
D1	104.0%	104.0%
D2	99.5%	99.5%
D3	105.4%	105.4%

What about lamp types different to the Standard Reference Lamp!

- Non incandescent lamps will require a correction factor due to the different spectra of the reference lamp and test lamp.
- This is due to the mismatch of the relative spectral responsivity of the detector to the V(λ) function
- Examples of mismatch errors for detector/lamp combinations

Detector	Inc A 2856 K	Inc D 6500 K	Fluoro Halo 6500 K	Fluoro Tri 4100 K	Fluoro Quad 4200 K	White LED 2700 K	White LED 4000 K	White LED 6500 K	Mono LED 500nm	Mono LED 620nm
D1	0.0%	-3.2%	-4.5%	-9.0%	-8.0%	-7.2%	-7.0%	-7.8%	11.1%	27.5%
D2	0.0%	-2.4%	-2.1%	-0.2%	-1.6%	-0.1%	-1.1%	-2.2%	-9.8%	3.7%
D3	0.0%	0.4%	-1.1%	-3.5%	-4.4%	-2.2%	-2.1%	-2.3%	14.2%	24.1%

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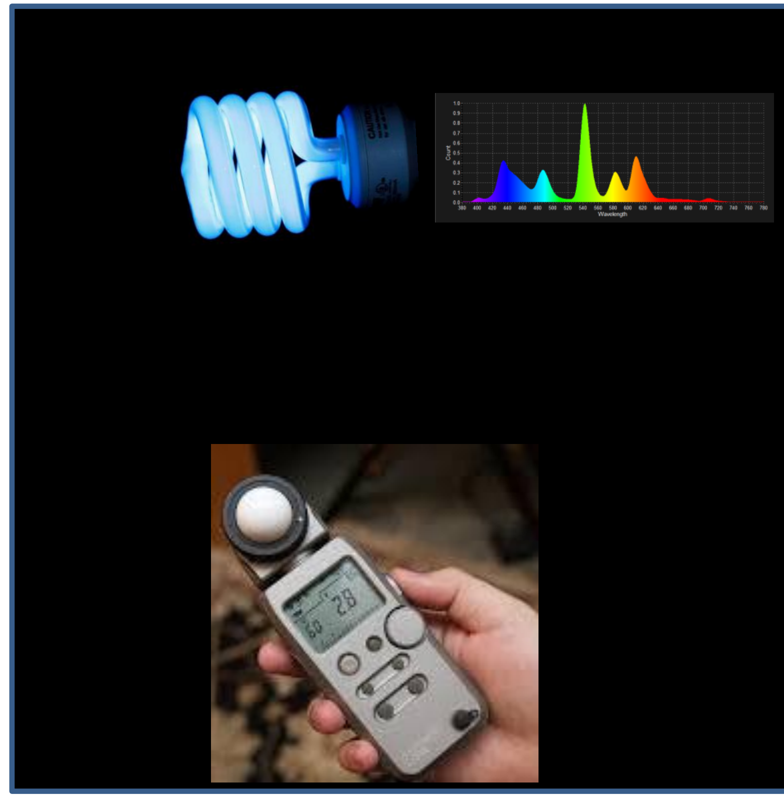
Correcting Measurements for Spectral Mismatch Errors

Calibration with incandescent (Source A)



Measurement of CFL

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Correcting Field Measurements

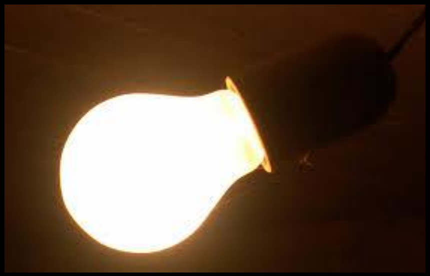
$$E = \frac{1}{F^*} \times E(Z)_{meas}$$

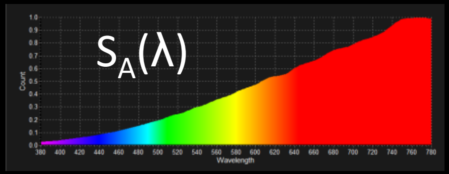
Where

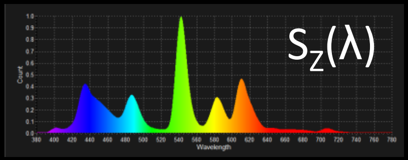
- E is the correct value of the measurement
- $E(Z)_{meas}$ is the measurement value obtained from the photometer, D, measuring test lamp, Z
- F^* is the spectral mismatch correction factor for the [photometer – test lamp] combination

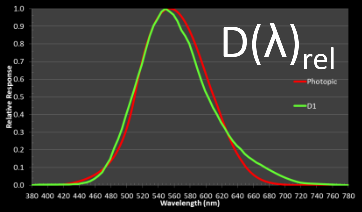
  (ie correction for a particular photometer D(λ) when measuring a particular light source Z(λ)).

What is needed to Calculate Spectral Mismatch Errors









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Determining Spectral Mismatch Errors

Need:

1. Spectral power distribution of the reference lamp used to calibrate the detector: $S_A(\lambda)$
2. Relative spectral responsivity of the detector: $D(\lambda)_{rel}$
3. Spectral power distribution of the test lamp: $S_Z(\lambda)$

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Calculate correction factor of a known photometer for a known light source

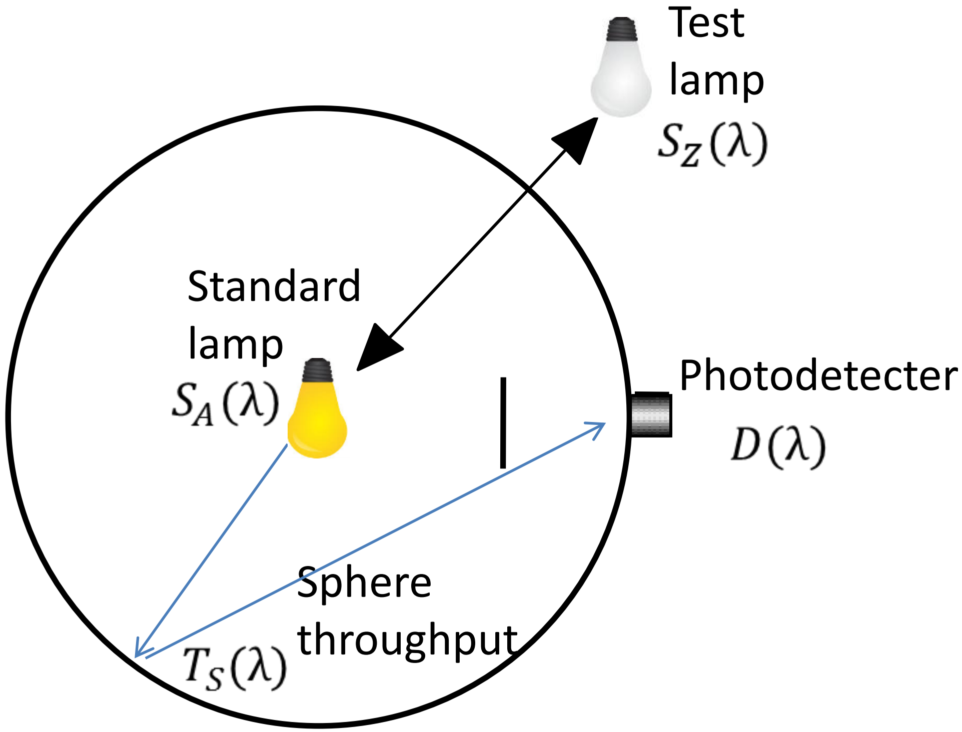
- This is a calculated correction factor based on

$$F^* = \frac{\int_0^\infty S_A(\lambda) \times V(\lambda)\ \mathrm{d}\lambda}{\int_0^\infty S_A(\lambda) \times D(\lambda)_{rel}\ \mathrm{d}\lambda} \times \frac{\int_0^\infty S_Z(\lambda) \times D(\lambda)_{rel}\ \mathrm{d}\lambda}{\int_0^\infty S_Z(\lambda) \times V(\lambda)\ \mathrm{d}\lambda}$$

$$F^* = \frac{Calc\ photopic\colon\ Ref\ A}{Calc\ photometer\colon\ Ref\ A} \times \frac{Calc\ photometer\colon test\ lamp}{Calc\ photopic\colon\ test\ lamp}$$

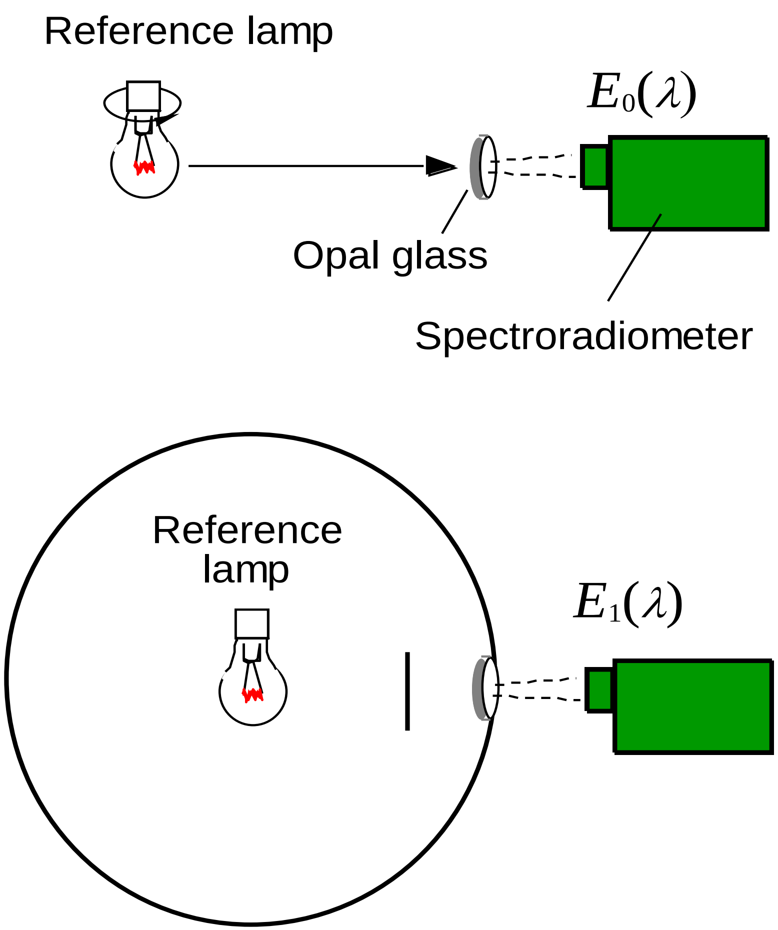
Calculating correction factors for a sphere - photometer system

- Using integrating sphere the lamp's spectral output is modified by the integrating sphere's spectral throughput before light reaches the photodetector



- Common elements are the sphere and photodetector
- Either need separate spectral responsivities [$D(\lambda)$ & $T_S(\lambda)$ or combined $R_S(\lambda)$]

Measuring the Throughput of the Sphere



Relative spectral throughput of the sphere :

$$T_S(\lambda) = c\, E_1(\lambda) \,/\, E_0(\lambda)$$

(c : normalization factor)

Calculate measurement system spectral mismatch for a known light source

- This is a calculated correction factor based on

$$F^* = \frac{\int_0^\infty S_A(\lambda) \times V(\lambda)\ \mathrm{d}\lambda}{\int_0^\infty S_A(\lambda) \times R_S(\lambda)\ \mathrm{d}\lambda} \times \frac{\int_0^\infty S_Z(\lambda) \times R_S(\lambda)\ \mathrm{d}\lambda}{\int_0^\infty S_Z(\lambda) \times V(\lambda)\ \mathrm{d}\lambda}$$

- Where

$$R_S(\lambda) = T_S(\lambda) \times D(\lambda)_{rel}$$

is the spectral responsivity of the measurement system

Determining Spectral Mismatch Errors for

Need:

1. Spectral power distribution of the reference lamp (Ref A) used to calibrate the detector: $S_A(\lambda)$

2. Spectral power distribution of the test lamp: $S_Z(\lambda)$

3. Relative spectral responsivity of the detector: $D(\lambda)_{rel}$ and

4. Spectral power throughput of the sphere: $T_S(\lambda)$

3. Or Relative spectral responsivity of the measurement system: $R_S(\lambda)_{rel}$

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Correcting Test Measurements

$$E = \frac{1}{F^*} \times E(Z)_{meas}$$

Where

- E is the correct value of the measurement
- $E(Z)_{meas}$ is the measurement value obtained from the measurement system, R, measuring test lamp, Z
- F^* is the spectral mismatch correction factor for the [measurement system – test lamp] combination

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CIE S025 Guidance on Measurement with a Sphere-Photometer

- A sphere-photometer shall be calibrated with a total luminous flux standard traceable to the SI. It is desirable that the standard lamp has spectral distribution similar to that of the test lamp.

That is: $S_A(\lambda) \approx S_Z(\lambda)$

- A sphere-photometer shall have a total relative spectral responsivity (sphere plus photometer) that matches the photopic function *V*(λ).

That is: $D(\lambda)_{rel} \times T_S(\lambda)_{rel} = V(\lambda)_{rel}$

Sphere-Photometer Spectral Mismatch - CIE S025 requirement

CIE S025 - Specific requirement: The general $V(\lambda)$ mismatch index (f_1') of the total relative spectral responsivity (sphere plus photometer) shall be 3 % or less.

If achieved ($f_1' \leq 3\ \%$), spectral mismatch correction is:

- not required for measurement of white light LED devices, although highly recommended.
- required for LED devices emitting coloured light (e.g. red, green or blue single colour LED modules).

If not achieved ($f_1' > 3\ \%$) spectral mismatch correction is,

- permitted if applied for each test lamp measured.

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Estimated sphere-photometer spectral mismatch correction for white LED

If spectral mismatch correction is not made (when $f_1' \leq 3\ \%$), the uncertainty contribution from estimated spectral mismatch errors shall be evaluated, either based on the relative spectral responsivity data of the system, or if it is not available, based on the value from the following graphs, based on the test results of greater than 100 each of LED lamps and photometers.

Alternatively the f_1' of a photometer that is required to satisfy a maximum Spectral mismatch correction factor can be determined.

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Estimated sphere-photometer spectral mismatch correction for white LED

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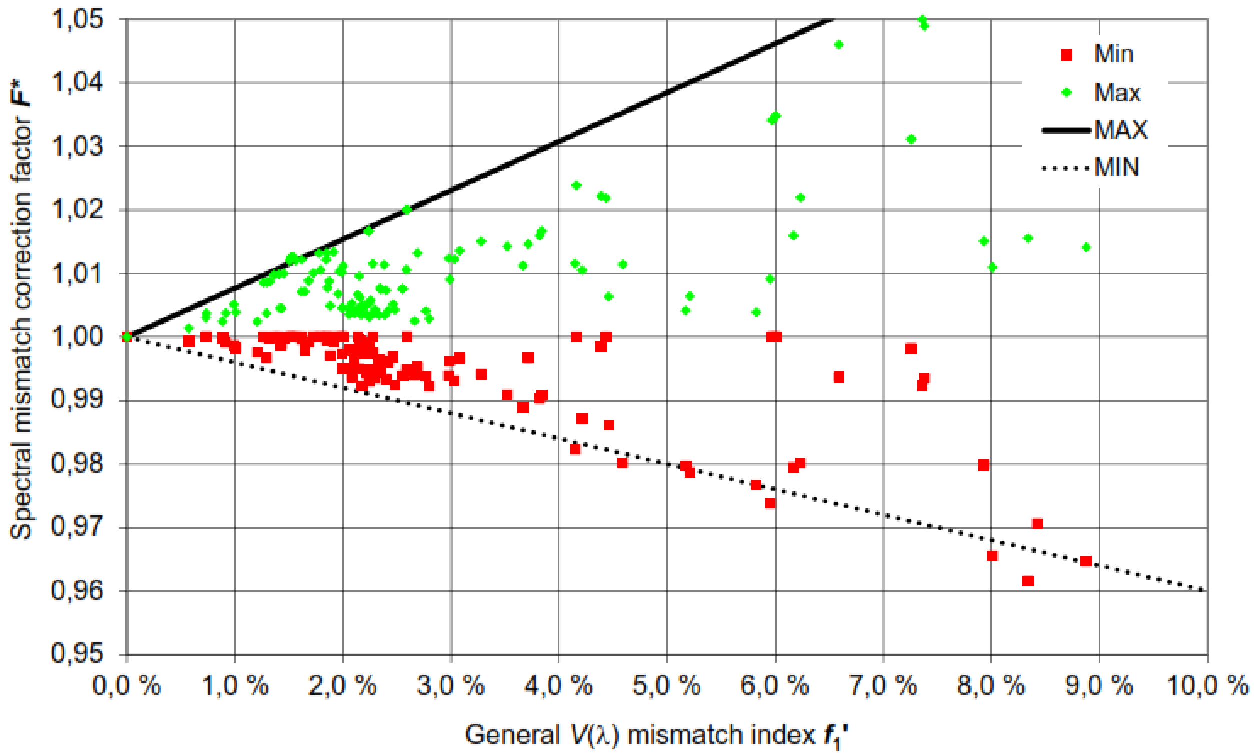

Figure C.4 – Spectral mismatch correction factors (SMCF) for phosphor-type white LEDs and different f_1' values of photometers

National Lighting Test Centre China

Estimated sphere-photometer spectral mismatch correction for RGB LED

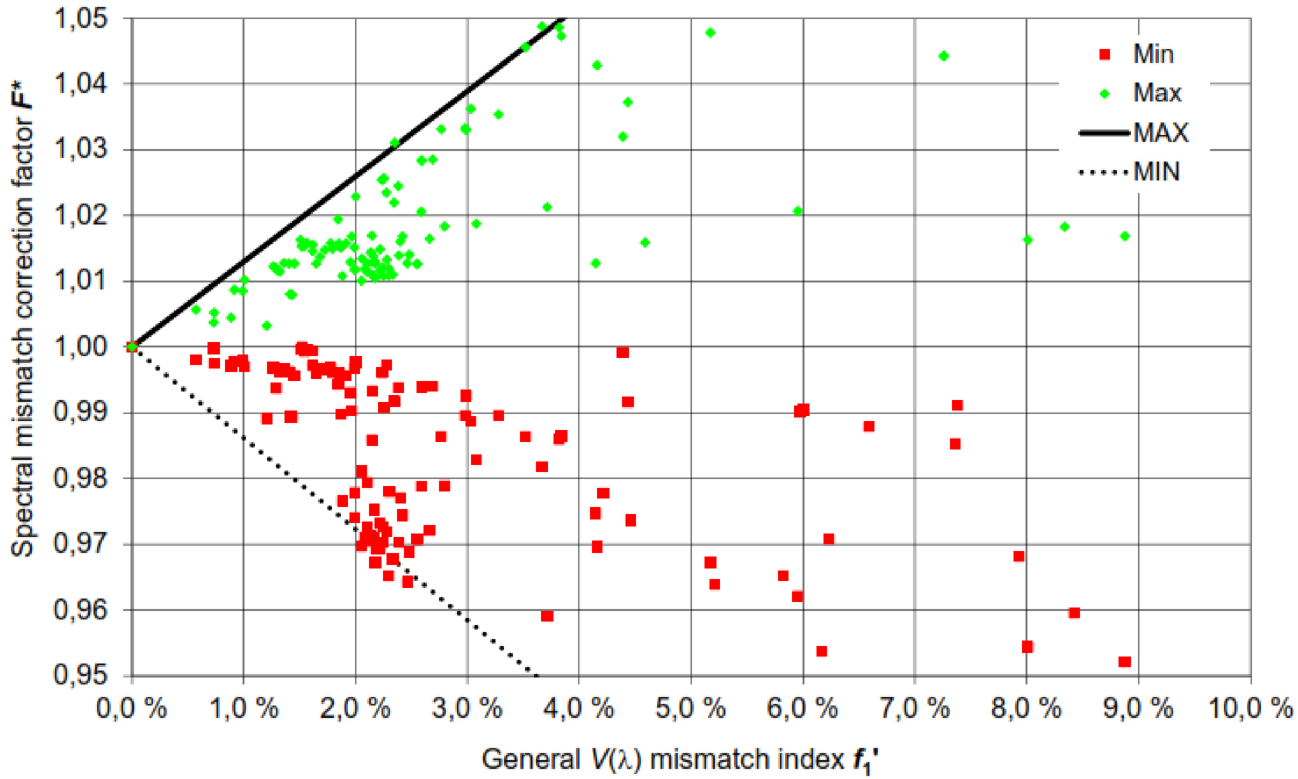

Figure C.5 – Spectral mismatch correction factors (SMCF) for RGB type white LEDs and different f_1' values of photometers

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Questions

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