Metrology for Solid State Lighting

EURAMET European Association of National Metrology Institutes

EMRP-ENG05 Stakeholder Meeting

Traceable spectral measurements

Armin Sperling

Physikalisch-Technische Bundesanstalt

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Traceable spectral measurements

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contributing partners

PTB

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VSL Dutch Metrology Institute

Physikalisch-Technische Bundesanstalt

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Outline

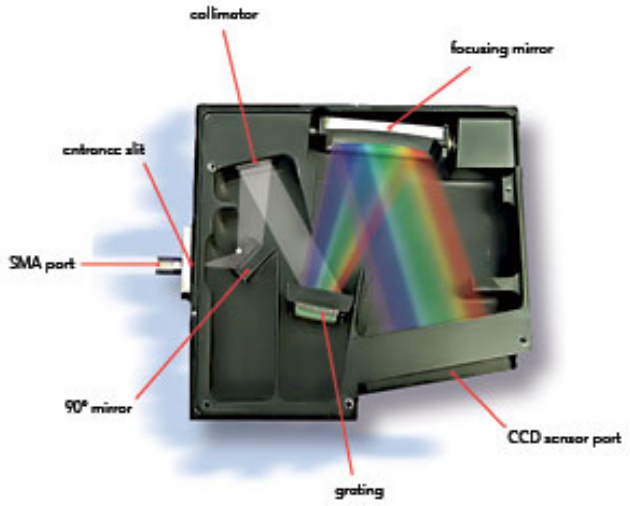
- Goals of the task
- Background
- Stray light and band-pass correction
- Fluorescence in spheres
- Guidelines

Goals

- The aim of this Task was to develop and implement methods for traceable spectral characterisation of SSL source by:
  - Development of mathematical models and methods for combined band-pass and stray-light correction for propagation and reduction of uncertainties when integrated quantities are determined using spectroradiometers
  - Characterisation and correction of fluorescence effects in integrating spheres when used with SSL products
  - Validation of procedures for band-pass and stray-light corrections and a Guideline on the calibration of spectroradiometer

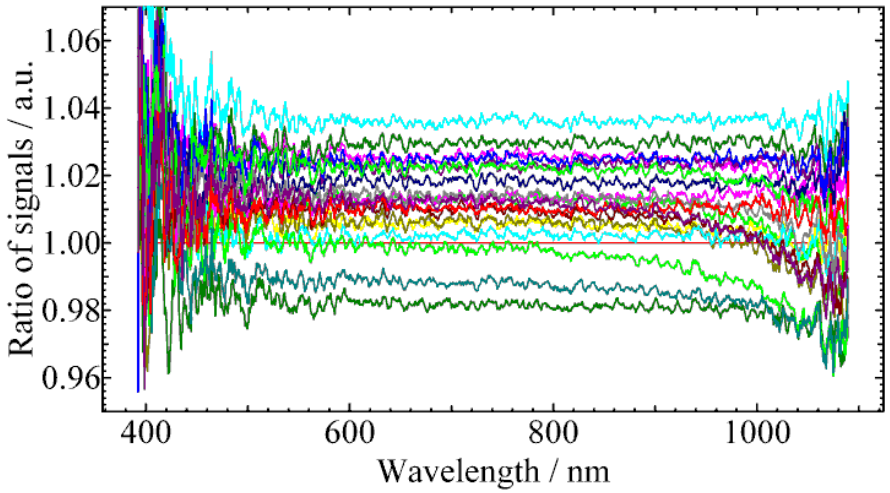
Background

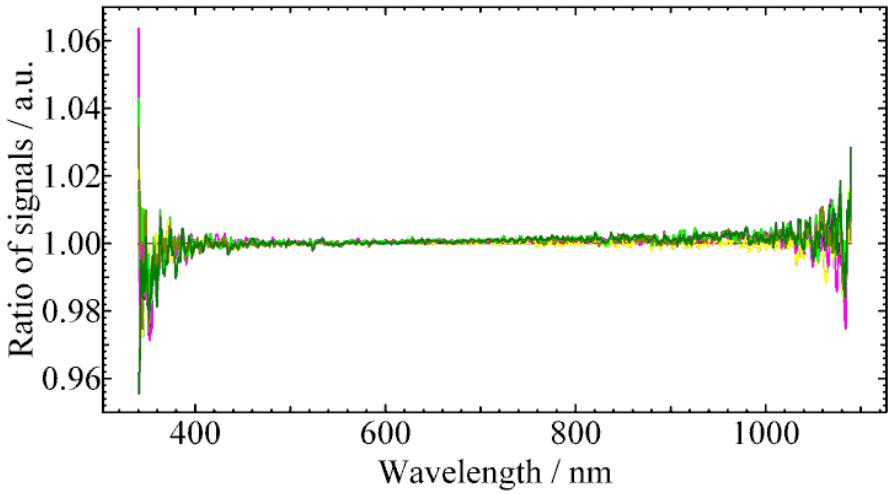
- Photometry and colorimetry of light originated from SSL sources requires spectral measurements.
  - The spectral mismatch of classical photometers can only be determined when the spectral distribution of the source is known.
  - The chromaticity coordinates of white, but also of coloured LEDs have to be determined with very high resolution (and lowest uncertainty)
  - In many cases measurements are carried out with array spectroradiometers because of their versatility, but are they suited for traceable measurements
  - Spectral measurements may be performed, to directly determine absolute photometric or colorimetric quantities or to determine relative spectral distributions



Background

- An array spectroradiometer used for reliable photometric measurement has to fulfil a set of requirement regarding its stability
  - The fibre entrance optic has to be stable enough and reproducible

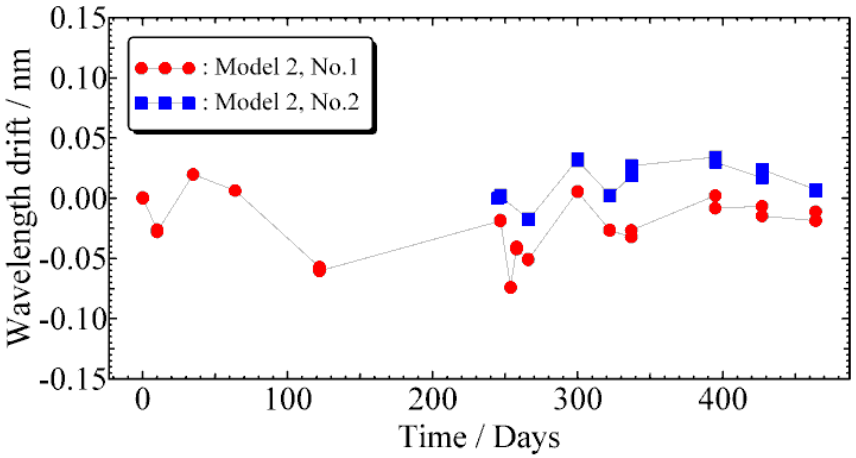


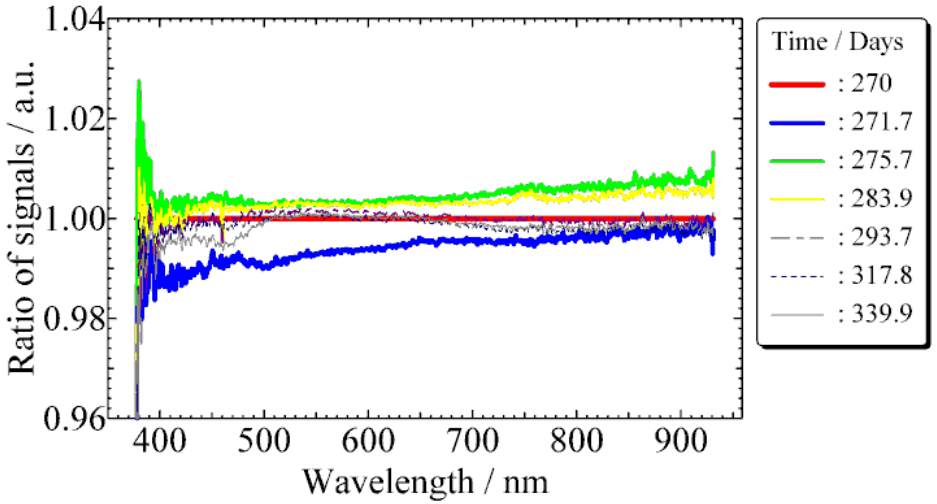


Difference in reproducibility of two array spectroradiometers fitted with SMA- type (left) and FC-type (right) connectors. The connectors were removed from the spectroradiometer adapters and refitted again before every consecutive measurement.

Background

- An array spectroradiometer used for reliable photometric measurement has to fulfil a set of requirements regarding its stability
  - The instrument itself has to be stable enough and reproducible





Stability of two (lower price) array spectroradiometers of the same type with respect to wavelength scale at a nominal wavelength of 450 nm (left) and amplitude, immediately after a 40 h lasting exposure to the relative air humidity of > 95 %.

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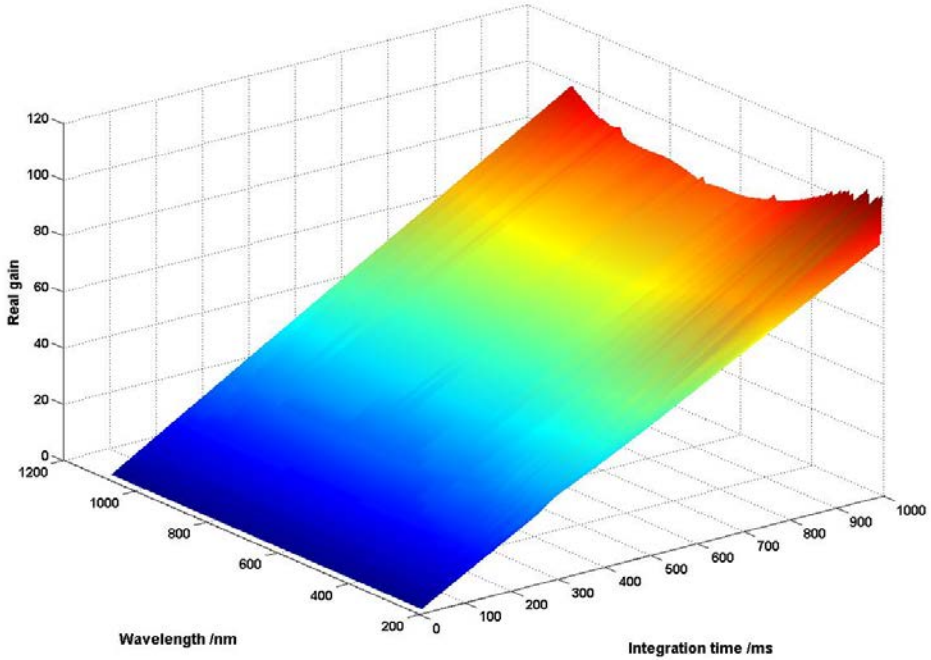
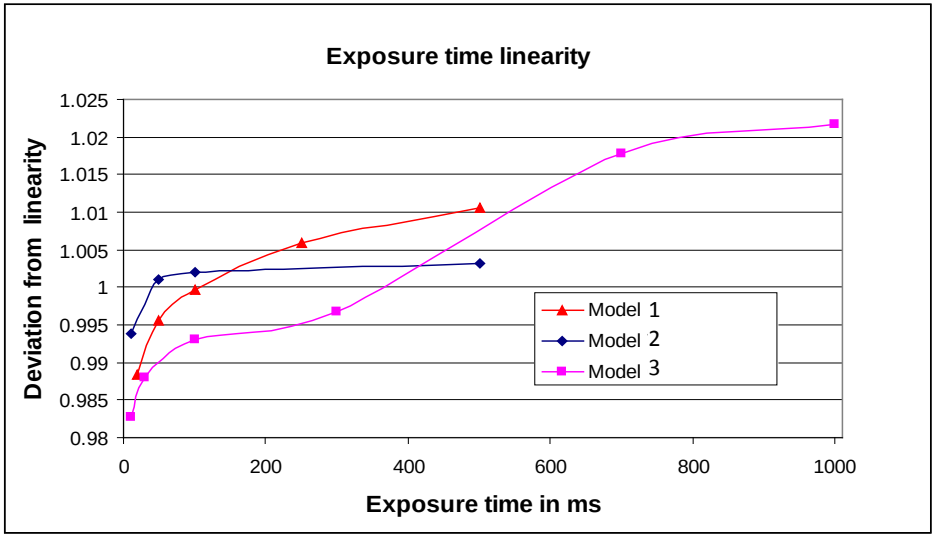
Background

- But an array spectroradiometer used for reliable photometric measurements has also to fulfil a set of requirements regarding linearity

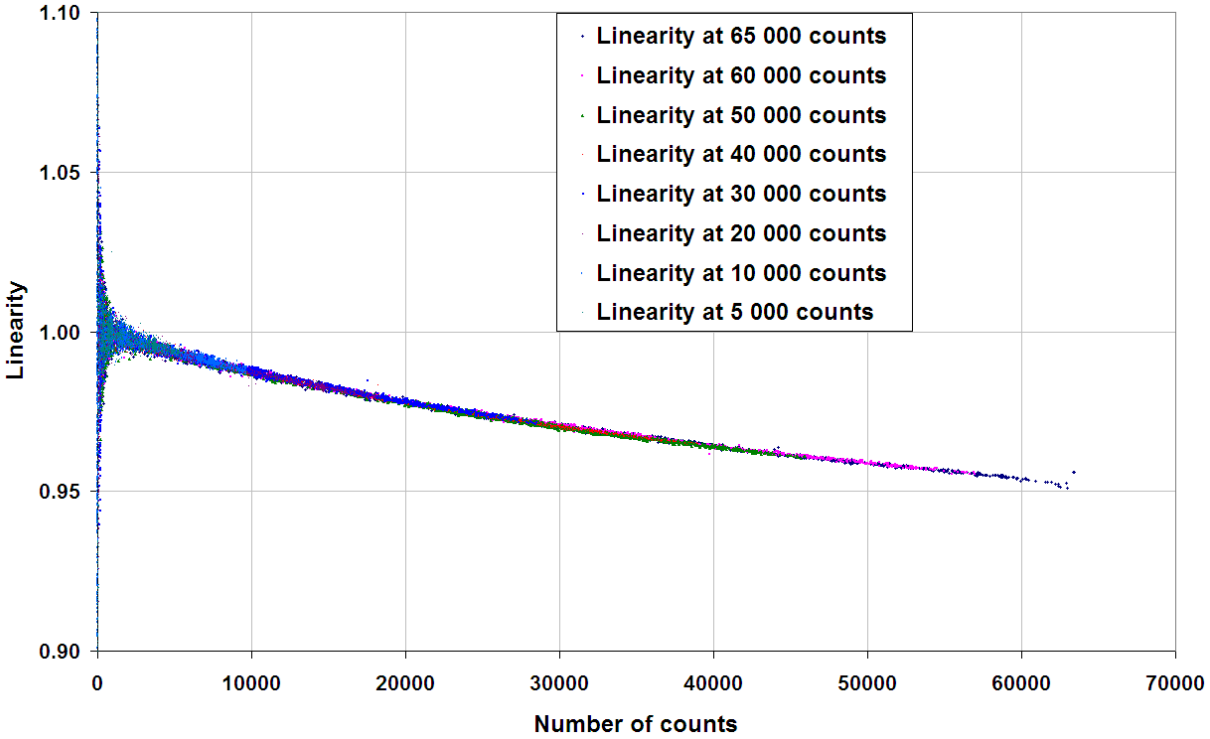




Linearity at different integration (exposure) times.

Background

- But an array spectroradiometer used for reliable photometric measurements has also to fulfil a set of requirements regarding linearity

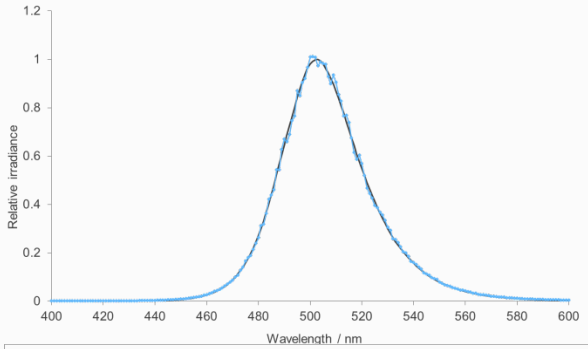


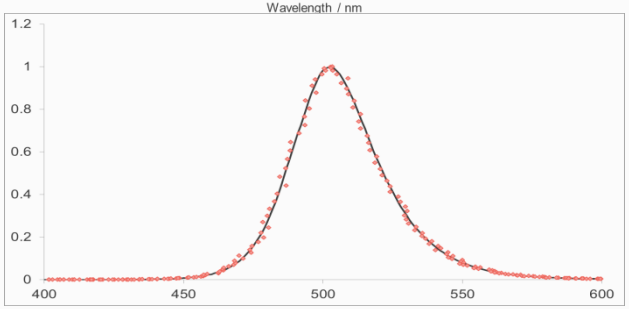
Linearity at different input signal using the double aperture technique. Each colour represents a different source radiant power (and the different dots in that colour represent different pixels).

Stray light and Band-pass correction

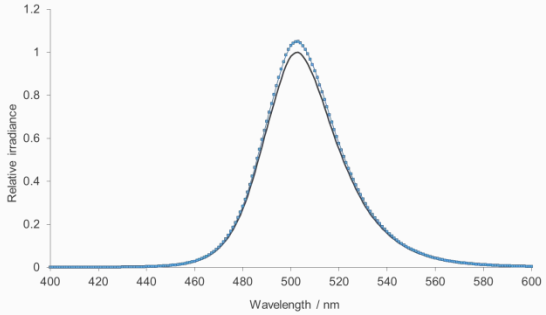
- The combined uncertainty of spectroradiometers can always be separated in random (typ A) and systematic (type B) components.
  - Systematic components like stray-light and band-pass can be however partly reduced.

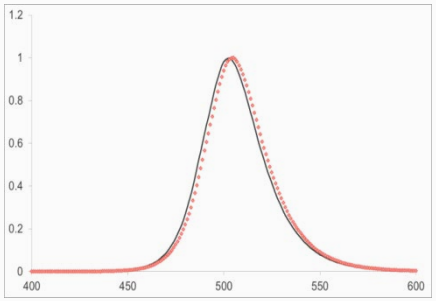
Random





Systematic



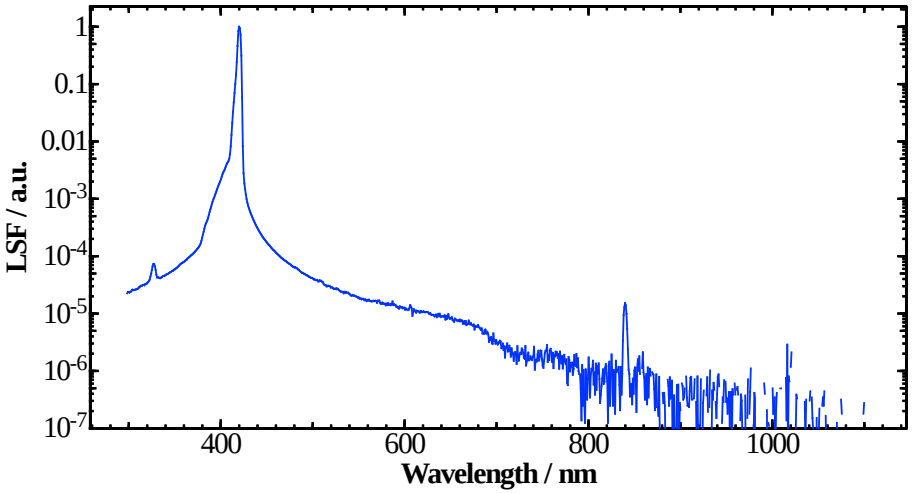


In the ‘y-axis’

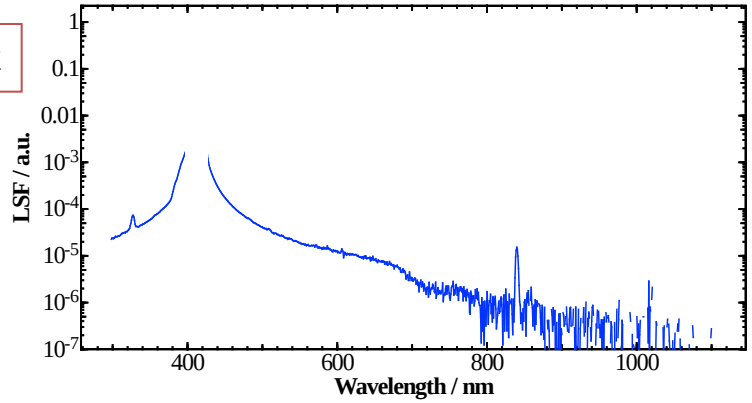
In the ‘x-axis’ (wavelength)

Stray light and Band-pass correction

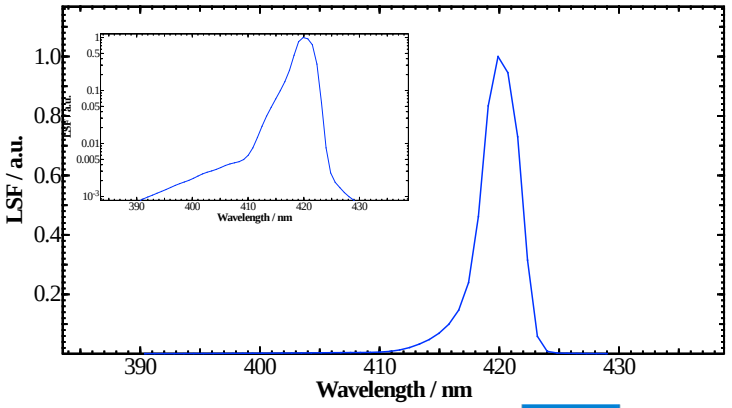
- Existing correction techniques typically deal separately with either the band-pass or the stray light correction



Stray light



Bandpass



- ***Where is the border between the band-pass and near-field stray light?***

Stray light and Band-pass correction

- The influence of stray light is often underestimated

  - consider a spectrally flat source across the spectral region from 300 nm to 800 nm.
  - assume an instrumental bandwidth of $\delta\lambda$=1 nm
  - consider an instrument with stray light suppression of 10^{-5} (many low cost array spectroradiometers are much worse)

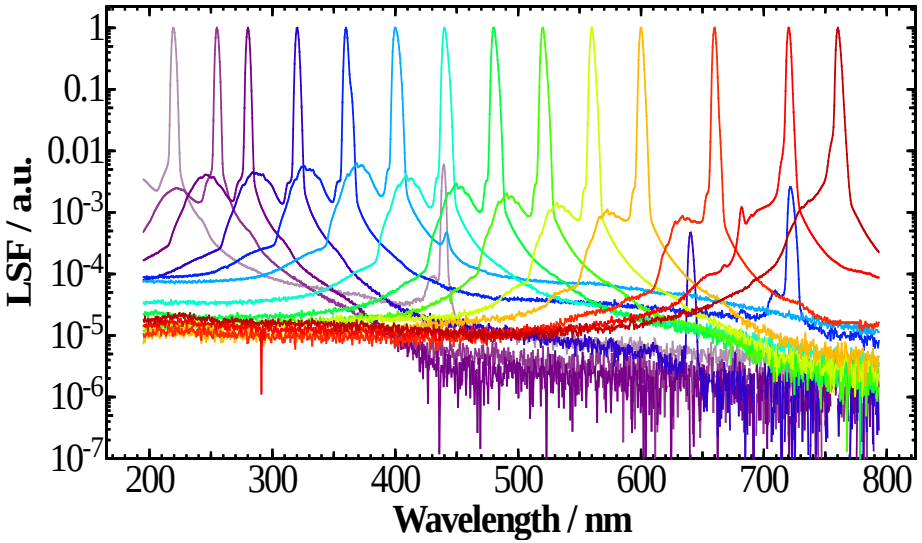
Stray light contribution at every single data point

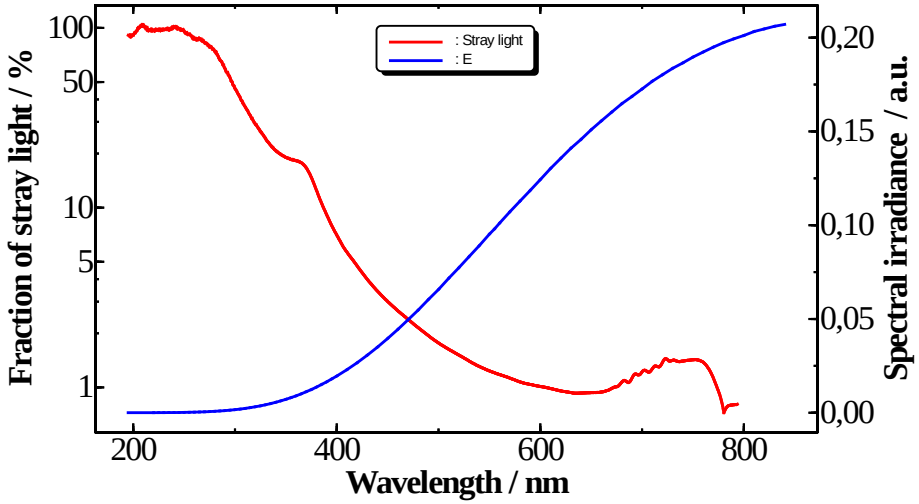
$$S = \sum_{300}^{800} 10^{-5} \times \delta\lambda = 5 \times 10^{-3}$$

  - this yields to a systematic indication error which only does not matter, if your the source to be measured is identical to your calibration source.

Stray light and Band-pass correction

- The influence of stray light is often underestimated





Line spread function (LSF) of an array spectroradiometer at different excitation wavelengths (left) and a fraction of stray light caused signal in the measurement data of a quartz-tungsten-halogen lamp (right).

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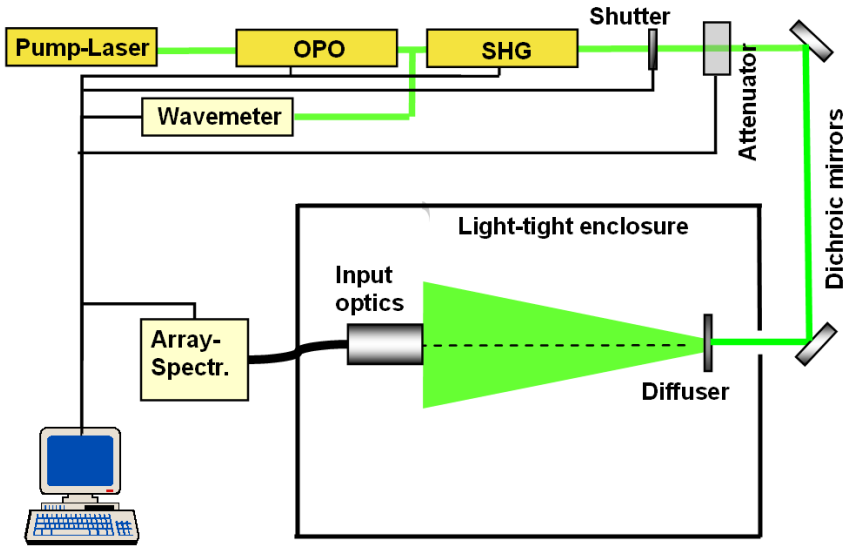
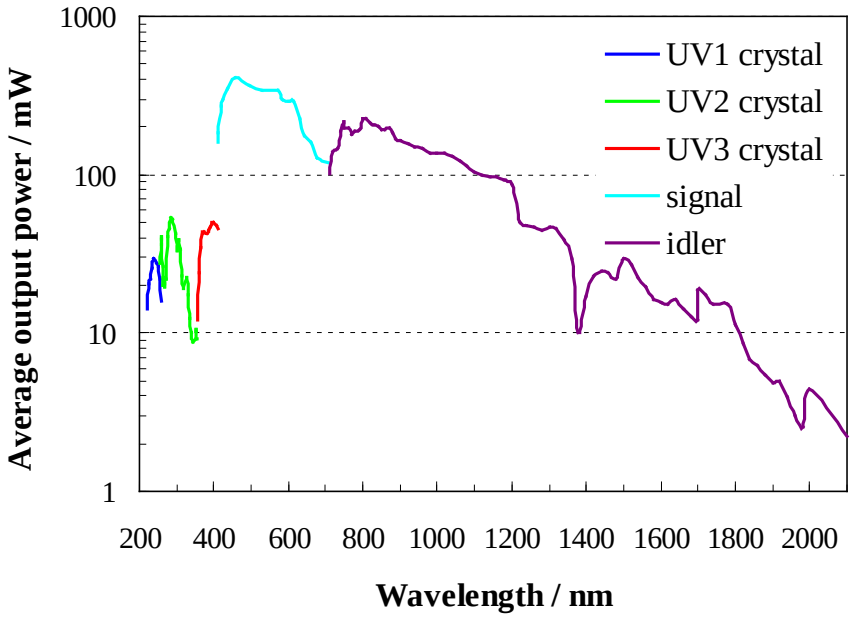
Stray light and Band-pass correction

- A possible setup for the charcterisation of LSF using pulsed lasers and OPOs



OPO, optical parametric oscillator
SHG, second harmonic generator

- easy to handle
- pulsed operation (20 Hz, 5 ns)
- automatic change of wavelength



* S. Nevas, M. Lindemann, A. Sperling, A. Teuber, R. Maass, "Colorimetry of LEDs with Array Spectroradiometers", *MAPAN - Journal of Metrology Society of India* **24**, 153-162 (2009).

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Straylight and Bandpass correction

- The Basic idea for correction

Instrument Matrix

Measured Spectrum

$$\mathbf{X} = \mathbf{A}\mathbf{Y}$$

Source spectrum

$$\mathbf{Y} = \mathbf{A}^{-1}\mathbf{X}$$

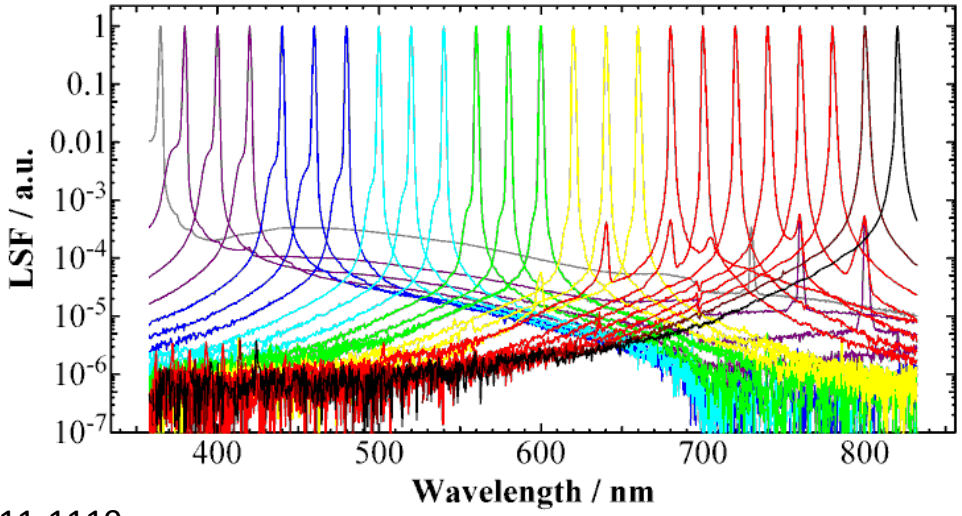
Regularisation procedure:

In band signal of LSF is set to zero

$$\mathbf{Y} = \mathbf{C}_{corr}\mathbf{X}$$

Y. Zong et al
Applied Optics **45**(**6**) 1111-1119

Typical series of line spread functions of array spectroradiometer

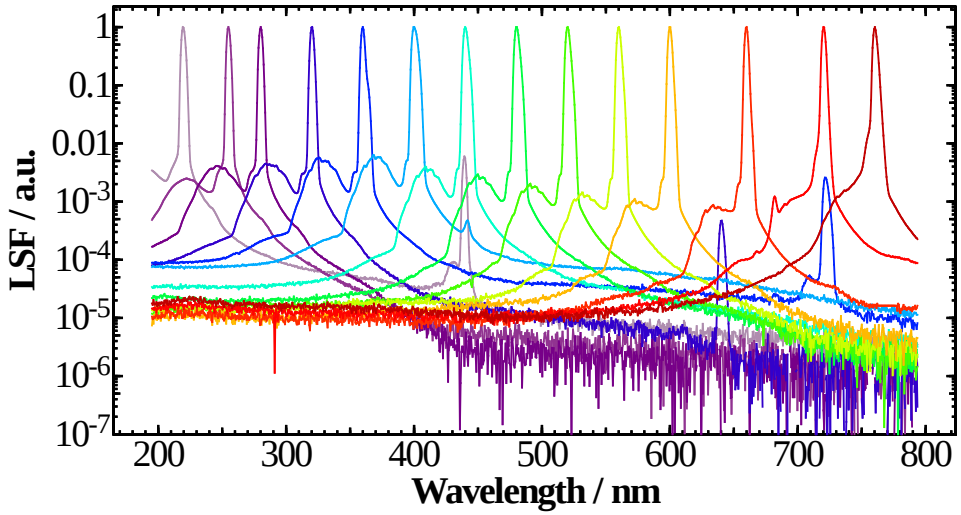


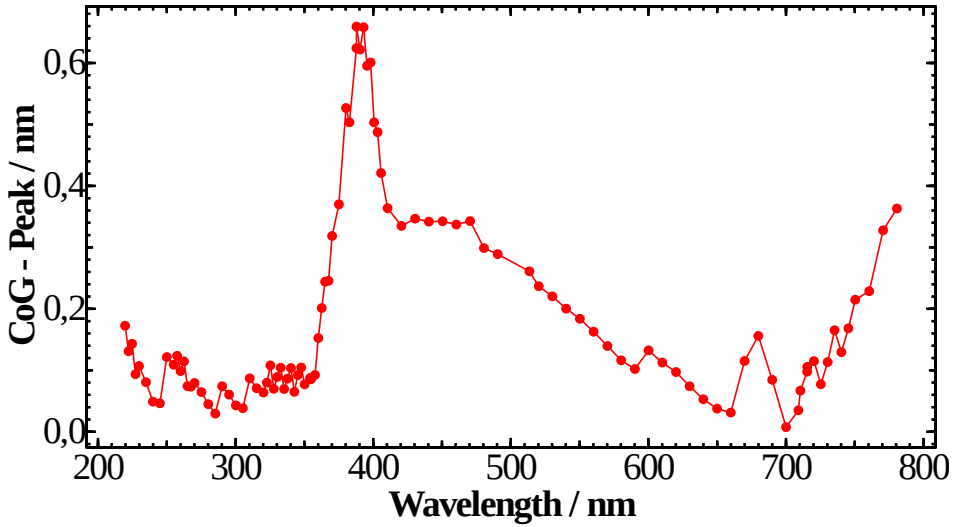
C_{corr} – spectral correction matrix

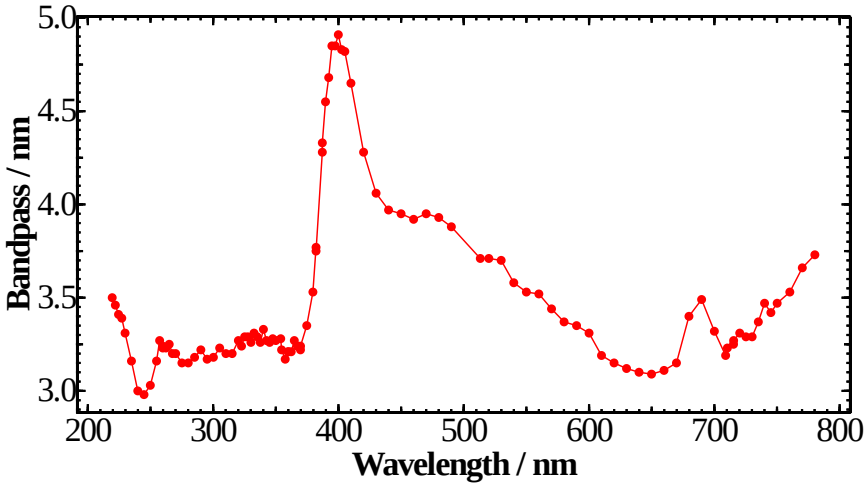
only stray light correction

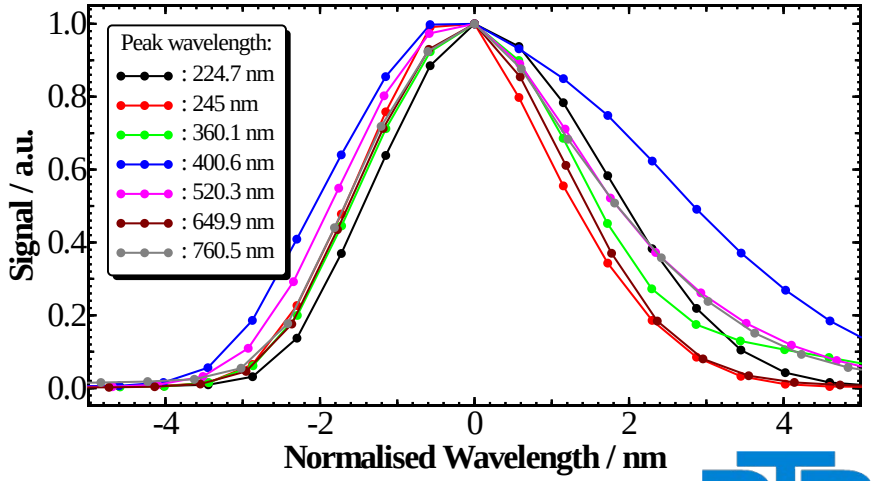
Straylight and Bandpass correction

- The role of band pass



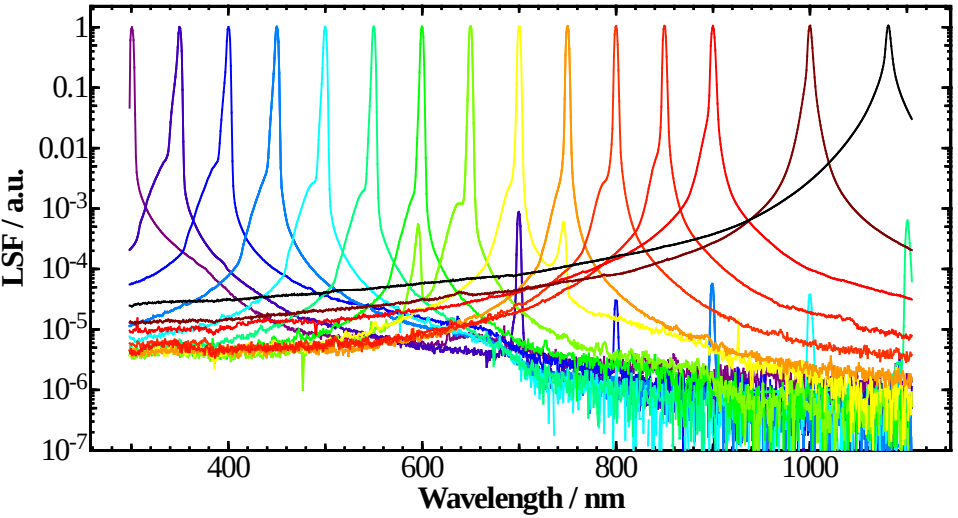


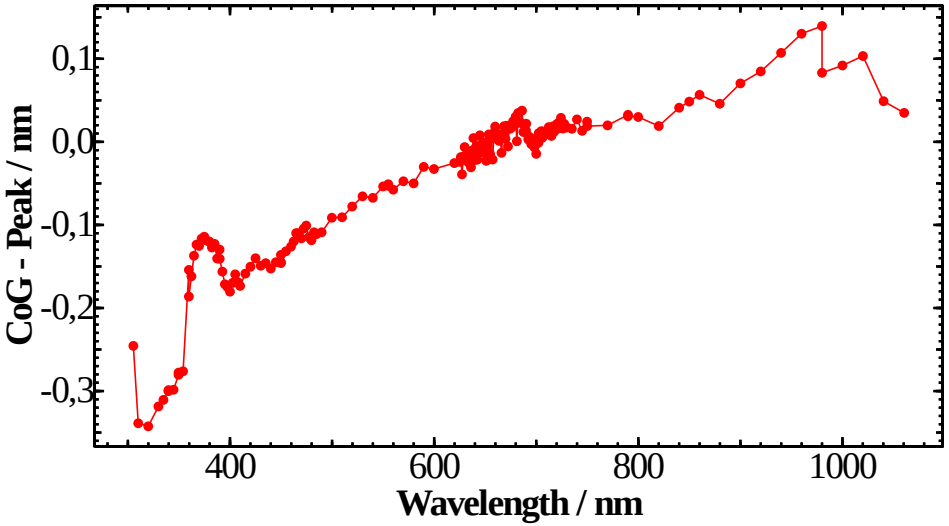


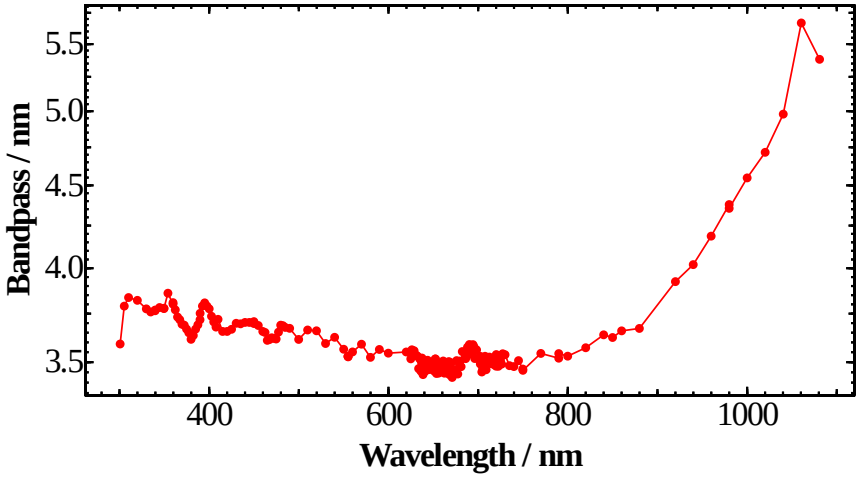


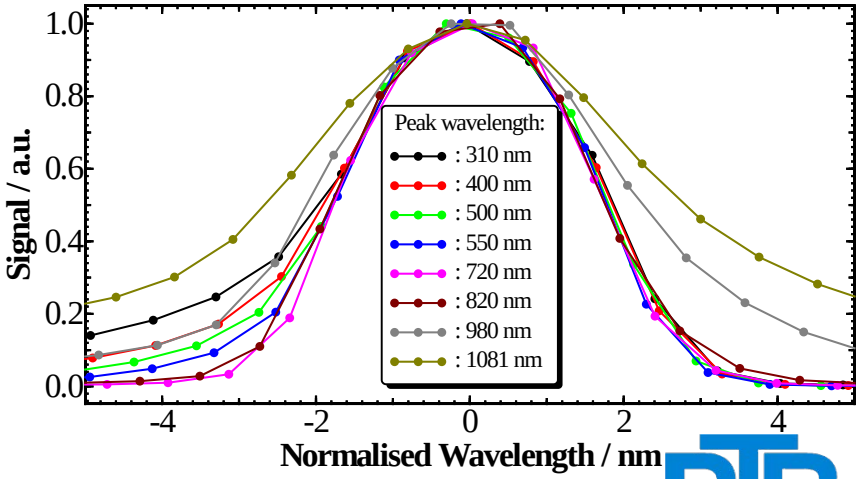
Straylight and Bandpass correction

- The role of band pass









Straylight and Bandpass correction

- The Basic idea for correction

Instrument Matrix

Measured Spectrum

$$\mathbf{X} = \mathbf{A}\mathbf{Y}$$

Source spectrum

$$\mathbf{Y} = \mathbf{A}^{-1}\mathbf{X}$$

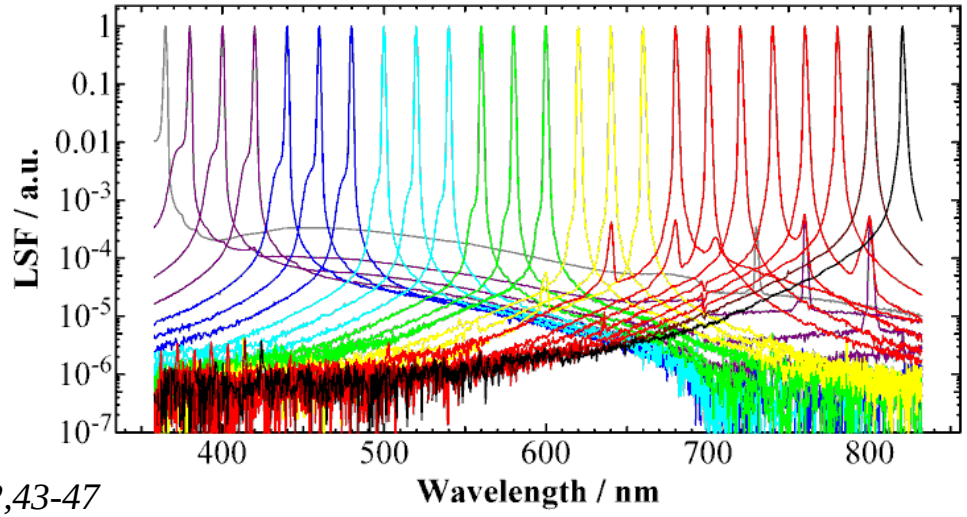
Regularisation procedure:

Thikonov regularisation

Nevas et al
Metrologia 49 (2012),2,43-47

$$\mathbf{Y}_{\alpha} = \underbrace{\left(\mathbf{A}^{\mathrm{T}}\mathbf{A} + \alpha^{2}\mathbf{I}\right)^{-1}\mathbf{A}^{\mathrm{T}}}_{\mathbf{C}_{corr}}\mathbf{X}$$

Typical series of line spread functions of array spectroradiometer



α – regularization parameter
$\mathbf{I}$ – identity matrix
$\mathbf{C}_{corr}$ – spectral correction matrix

stray light and band-pass correction possible

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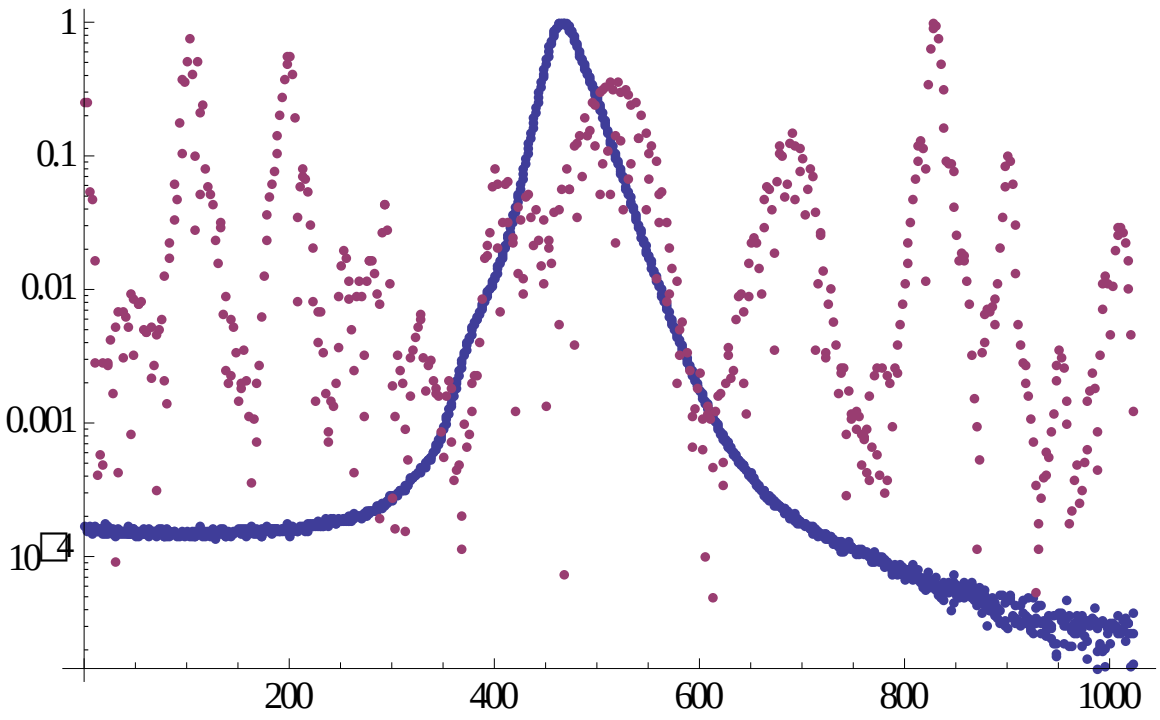
Straylight and Bandpass correction

- How do we choose α?
- LED measurement data before and after the correction:

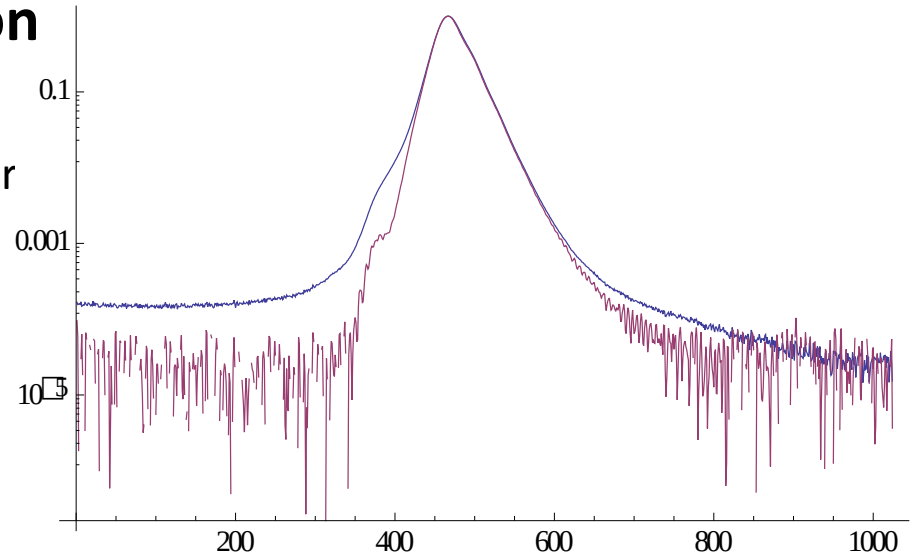
$\alpha = 0$:

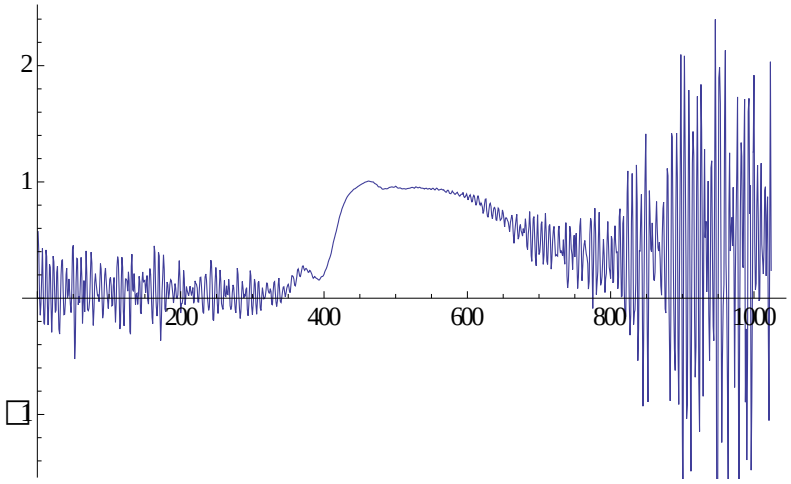


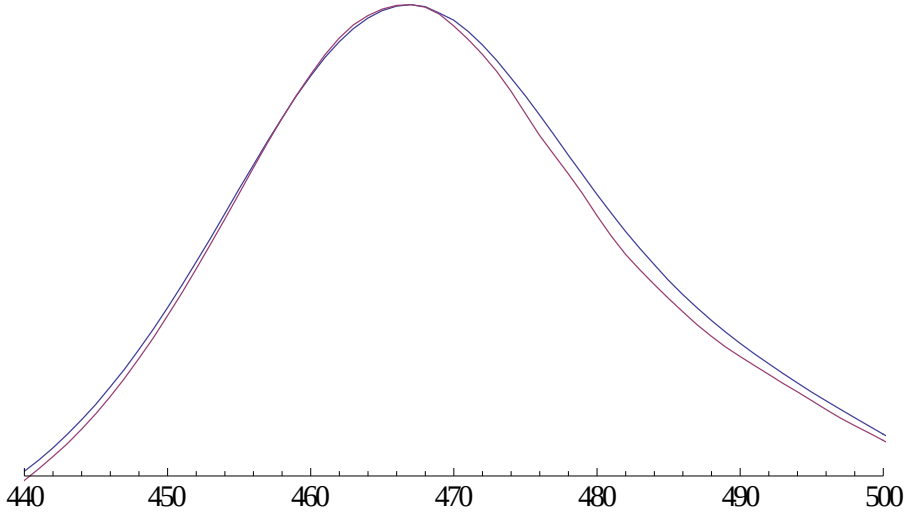
Straylight and Bandpass correction

- How do we choose α?
- LED measurement data before and after

α = 0.1:



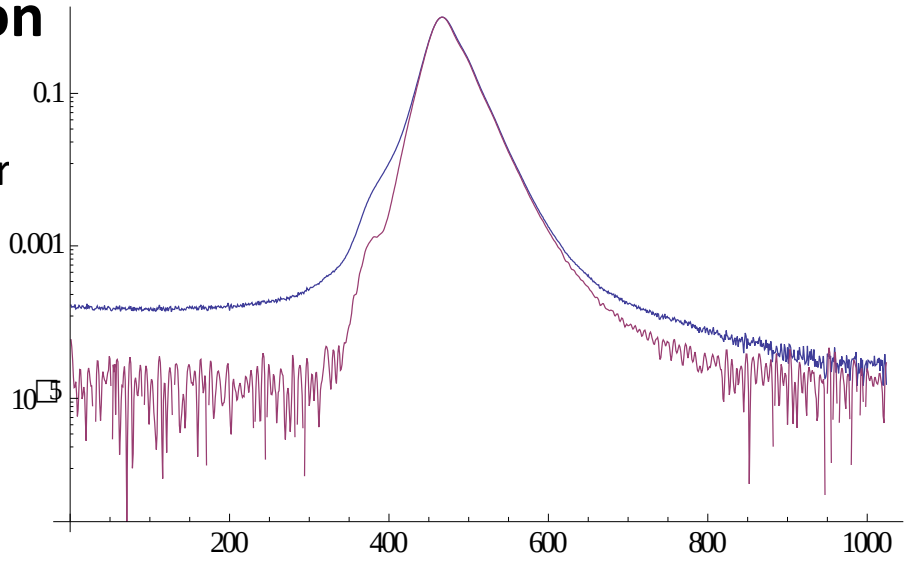


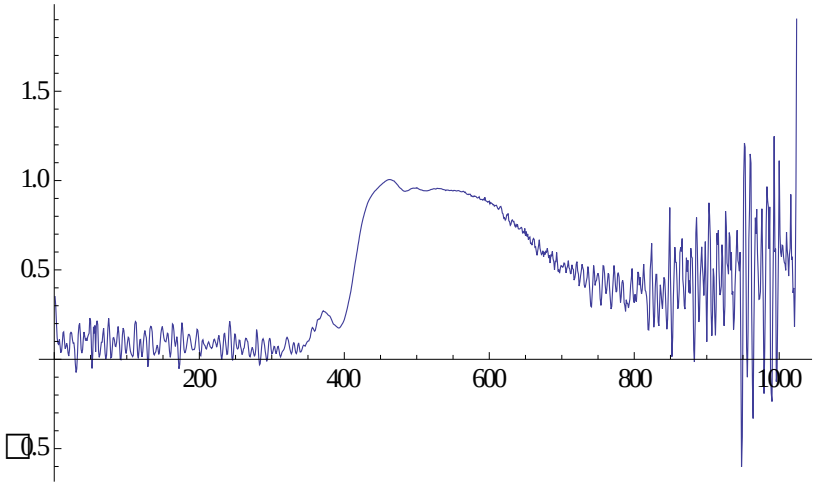


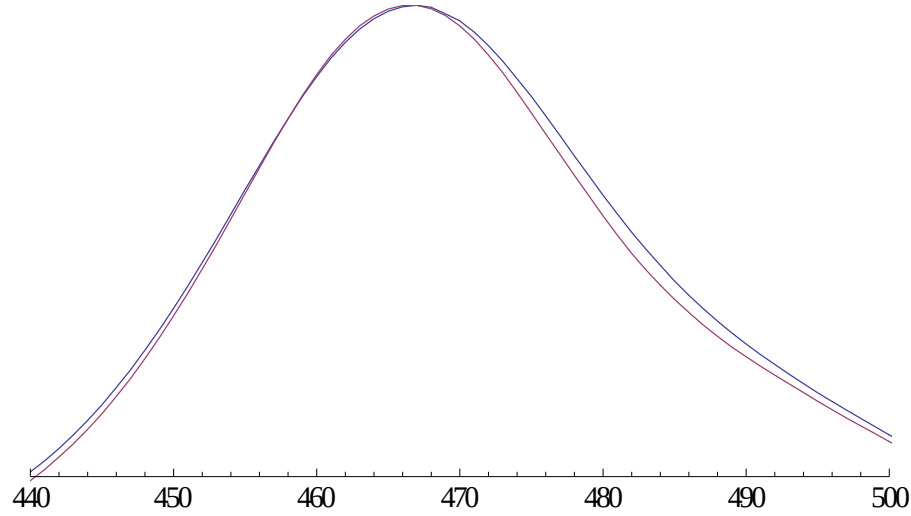
Straylight and Bandpass correction

- How do we choose α?
- LED measurement data before and after

α = 1:



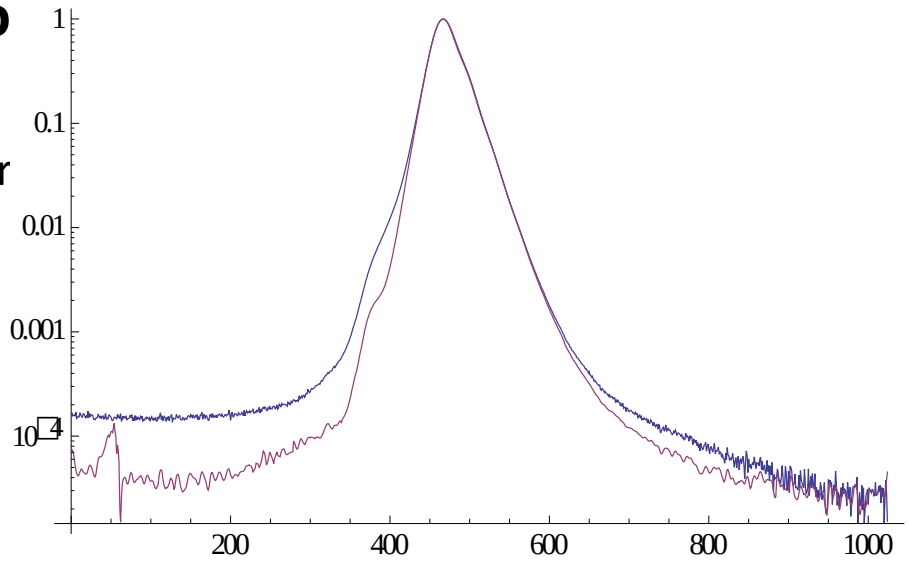


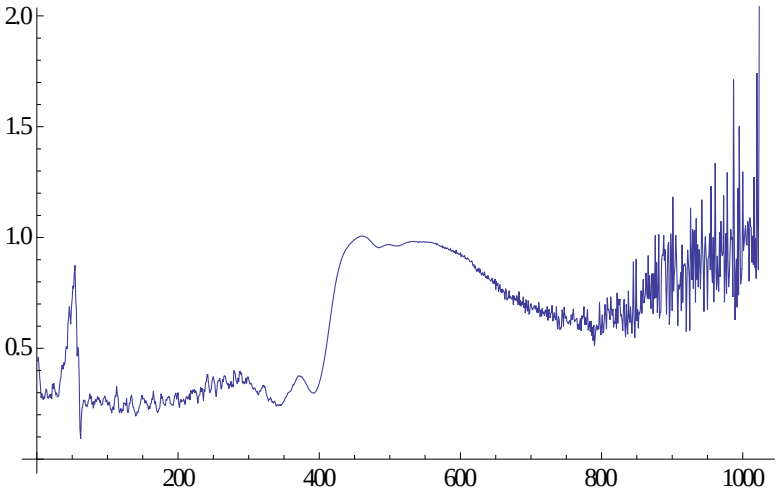


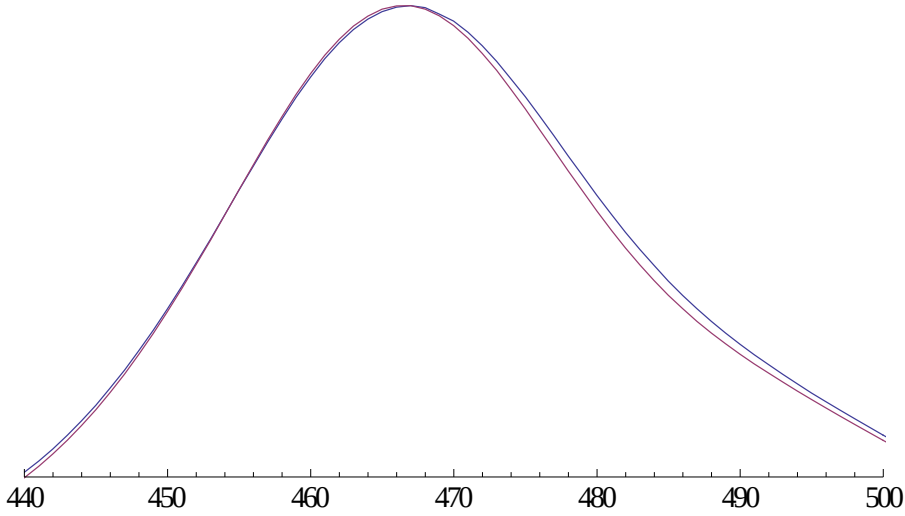
Straylight and Bandpass correctio

- How do we choose α?
- LED measurement data before and after

α = 10:

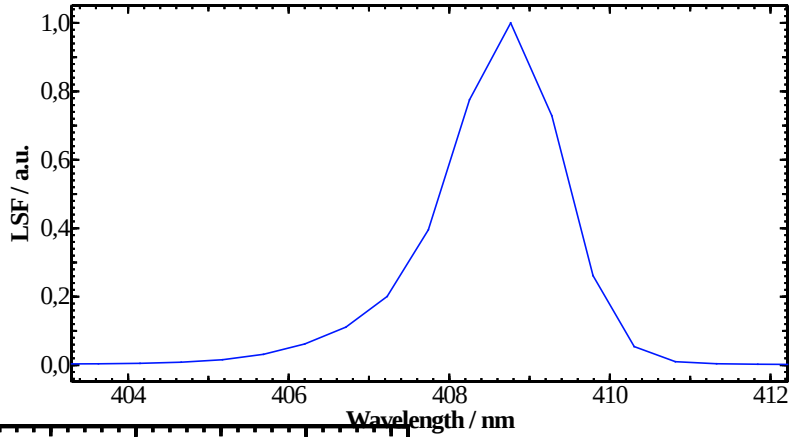


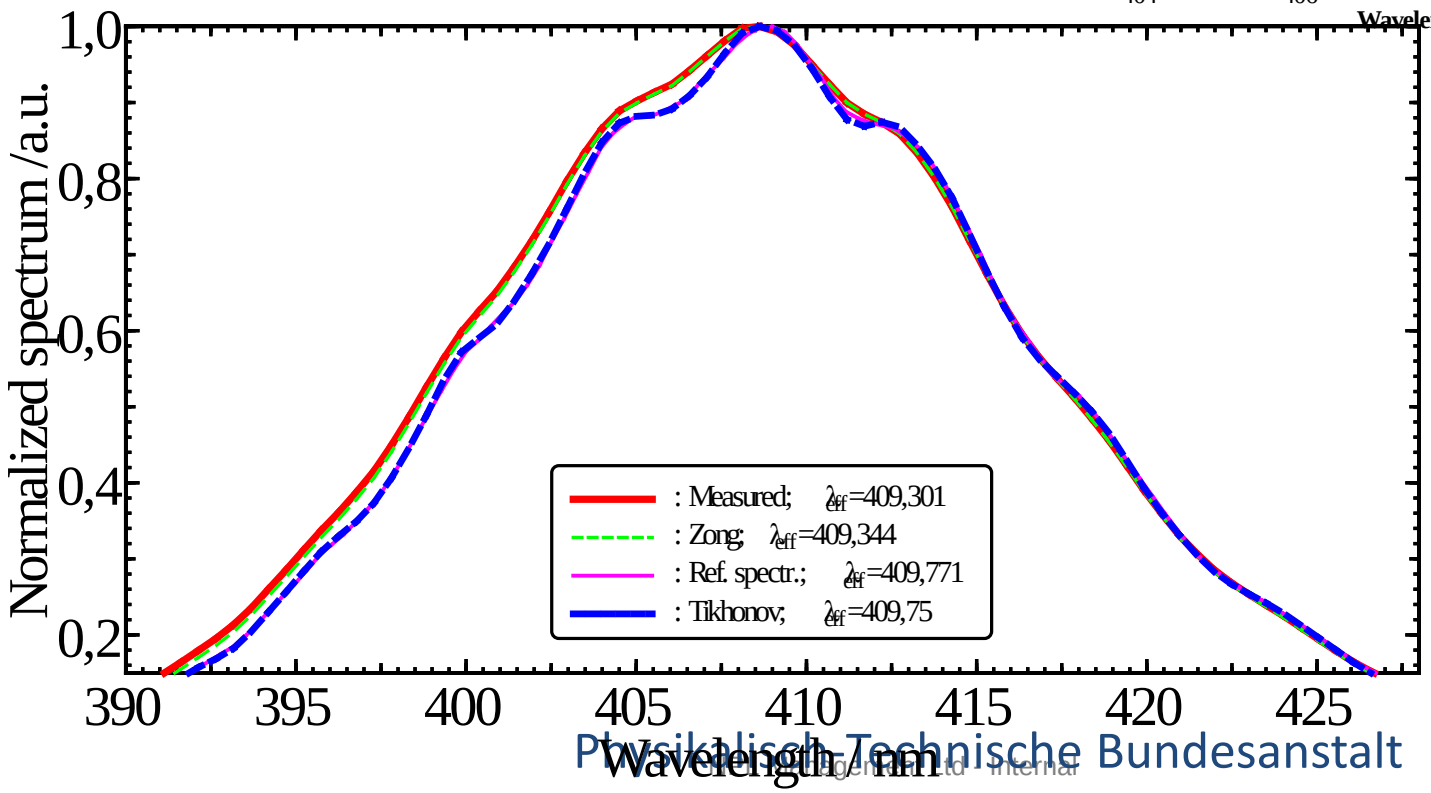




Straylight and Bandpass correction

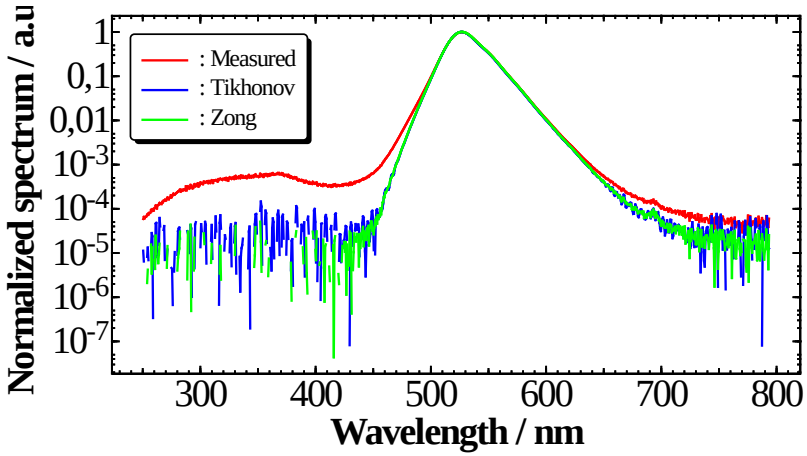
- Applied corrections for Bandpass

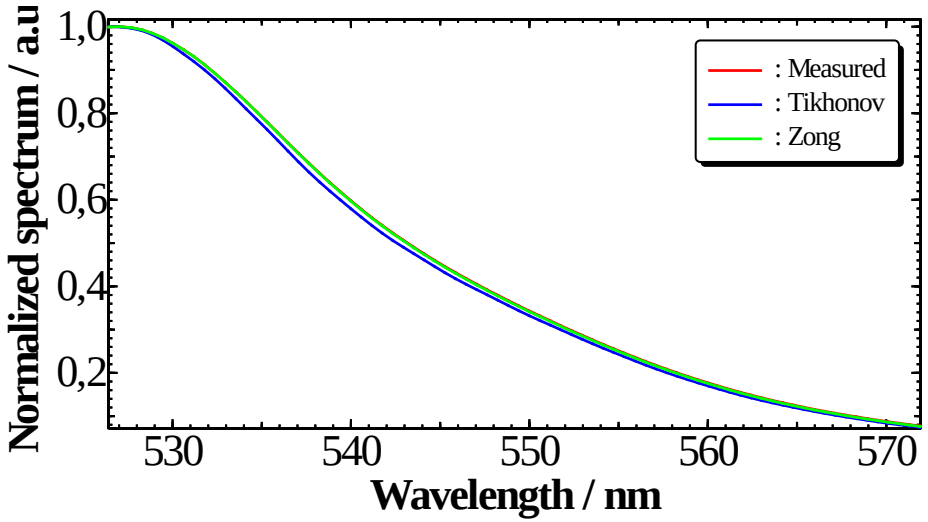




Straylight and Bandpass correction

- One result for a green LED

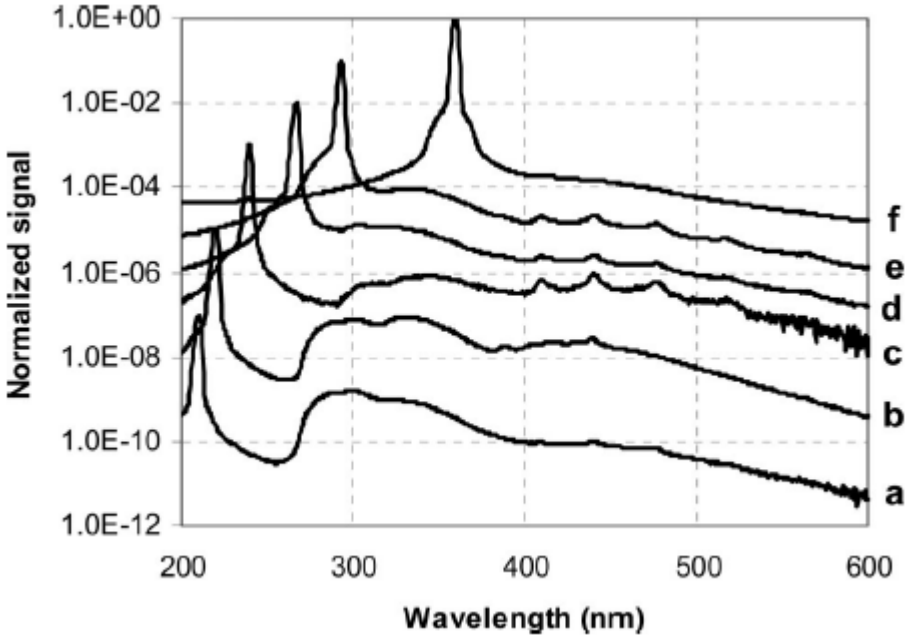




Data	FWHM, nm	$x,\Delta x$	$x,\Delta y$
Measured	29.25	0.2055	0.7355
Tikhonov	-0.68	-0.0012	0.0047
Zong	-0.13	0.0002	0.0037

Fluorescence in spheres

- Many test setups for LEDs are using integrating spheres as input optic
  - Fluorscence, as with stray light, may cause incalculable results if not characterised



Guidelines

o Prepared of Guidelines

- to describing the possible influencing components on spectral measurement
- describing the principles for calibration of spectroradiometers
- describing how to deal with stray light issues and possible correction procedures
- describing how to deal with band-pass issues and possible correction procedures
- describing how to deal with fluorescence effects
- describing the influence of correlation if integrated quantities are calculated from a set of spectral data out of a spectroradiometer
- Proposal of how to deal with such correlated data

Metrology for Solid State Lighting

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Special Thanks go to:

Emma Woolliams
Saulius Nevas
Edgar Vuelban
Gerd Wübbeler

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