Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

LUMINOUS INTENSITY LED STANDARD LAMP LIS-A

EMPIR PhotoLED – Stakeholder Meeting

DTU Fotonik, Roskilde, DK, 28 August 2019

T. Gerloff, L. Kallenbach, J. Ledig, C. Schrader, A. Sperling, T. Pulli, J. Askola, M. Šmid, P. Kliment, A. Pons, A. Ferrero, P. Gál, G. Brida, P. Blattner, F. Stuker, M. Schneider, T. Dönsberg and T. Poikonen

PhotoLED Research Project

EMPIR 15SIB07 PhotoLED
Future Photometry Based on Solid-State Lighting Products

1 September 2016 – 31 August 2019

PhotoLED approach towards LED reference

Proposal of a reference spectrum for detector calibrations with improved properties for most LED measurements

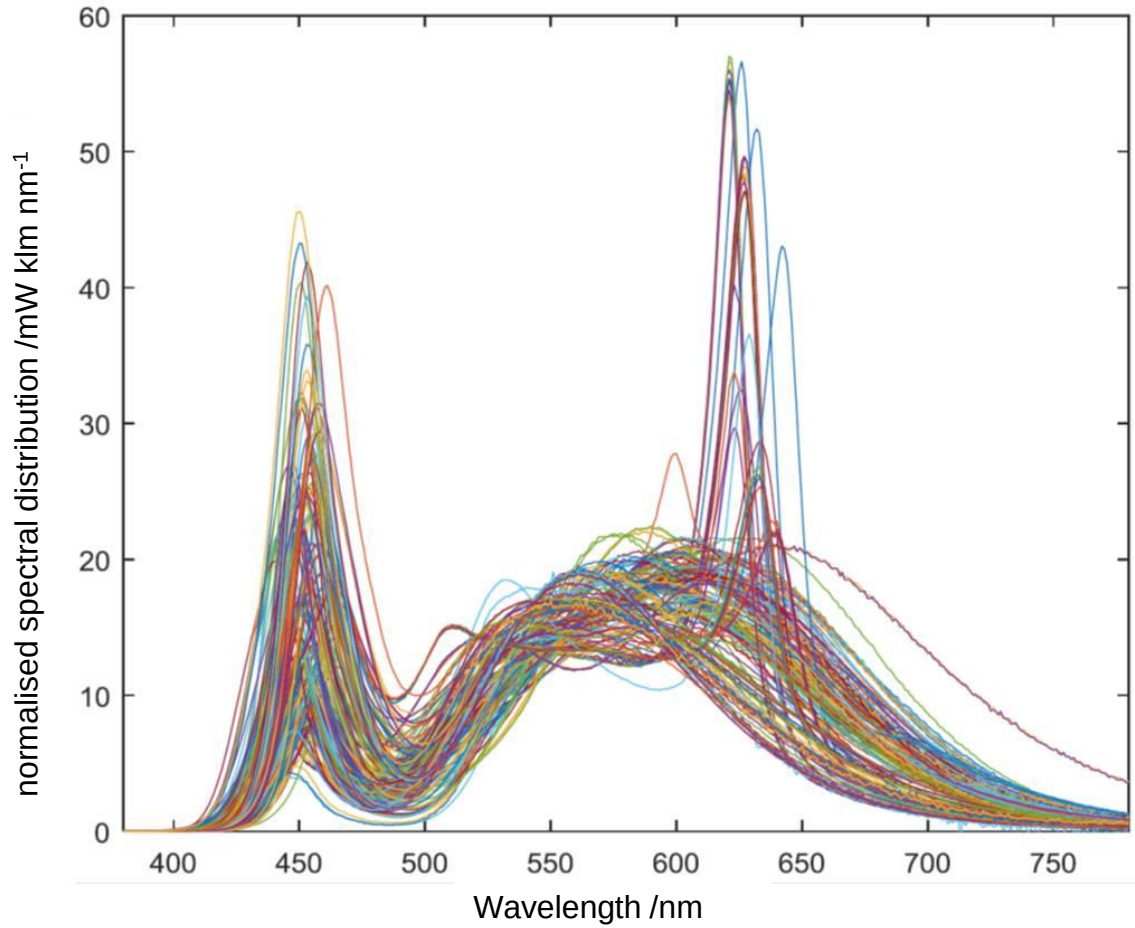
- Define a reference spectrum for LED light sources
- Development and construction of LED reference light sources
- Checking the suitability of the new LED reference light sources
- Calibration of photometers with LED reference light sources
- NMI luminous intensity comparison with LED reference light sources

Definition of a reference spectrum for LEDs

Goal: representative of as many LED spectra as possible

- 1516 LED products

KOKKA, A. et al, 2018, *Development of white LED illuminants for colorimetry and recommendation of white LED reference spectrum for photometry*. Metrologia. 55. 526-534



First results

CIE 2017 October 20-28 Jeju, Korea
Smarter Lighting for Better Life

EMPIR EURAMET
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

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DETERMINATION OF ILLUMINANTS REPRESENTING TYPICAL WHITE LIGHT EMITTING DIODES SOURCES

UNIVERSITÉ DE LYON
ENTPE L'école de l'aménagement durable des territoires
PhOto LED

Sophie JOST
Building and civil engineering Lab
Researcher
Light and Lighting quality
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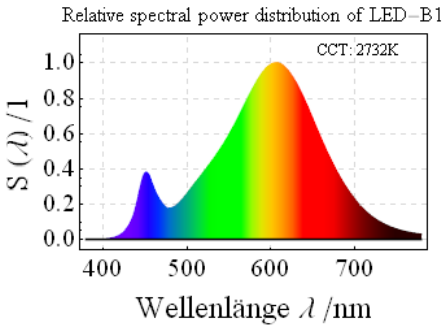
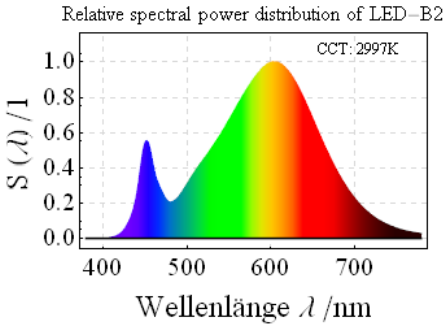
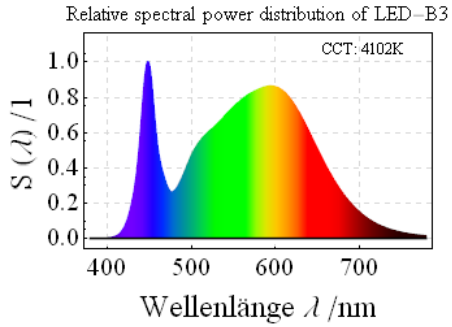
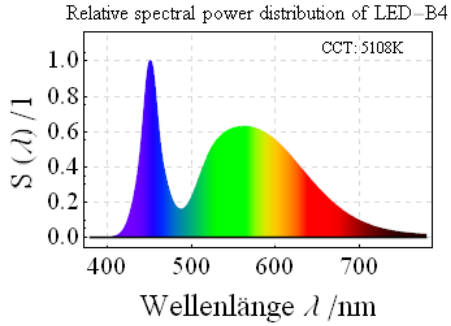
Colorimetry, 4th ed. (CIE 015:2018)

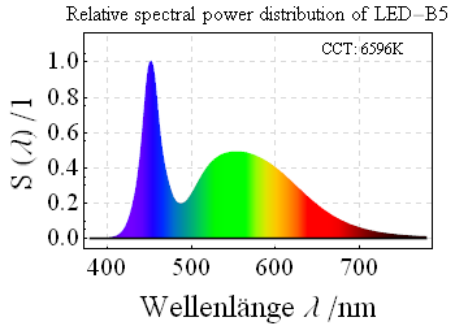
Phosphor-type LEDs



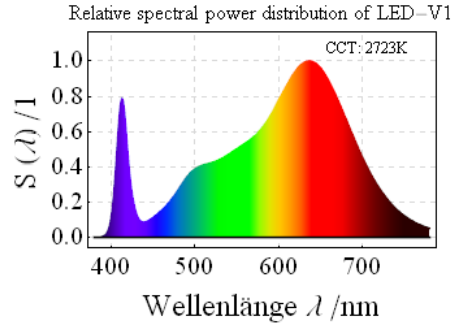


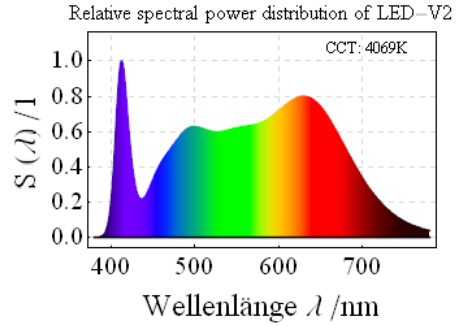




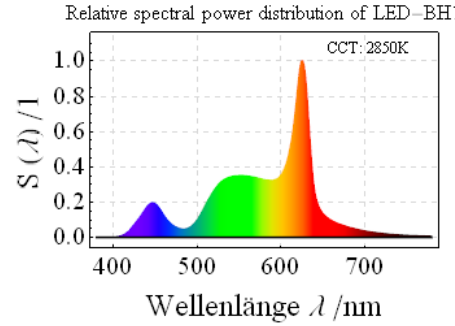


Violet-pumped phosphor-type LEDs

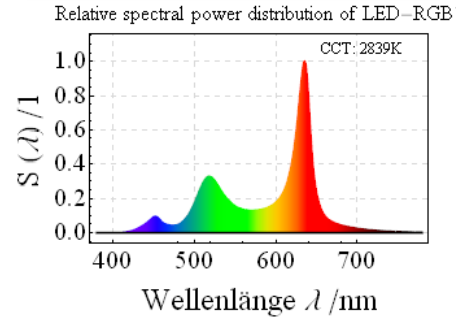




Hybrid-type LED

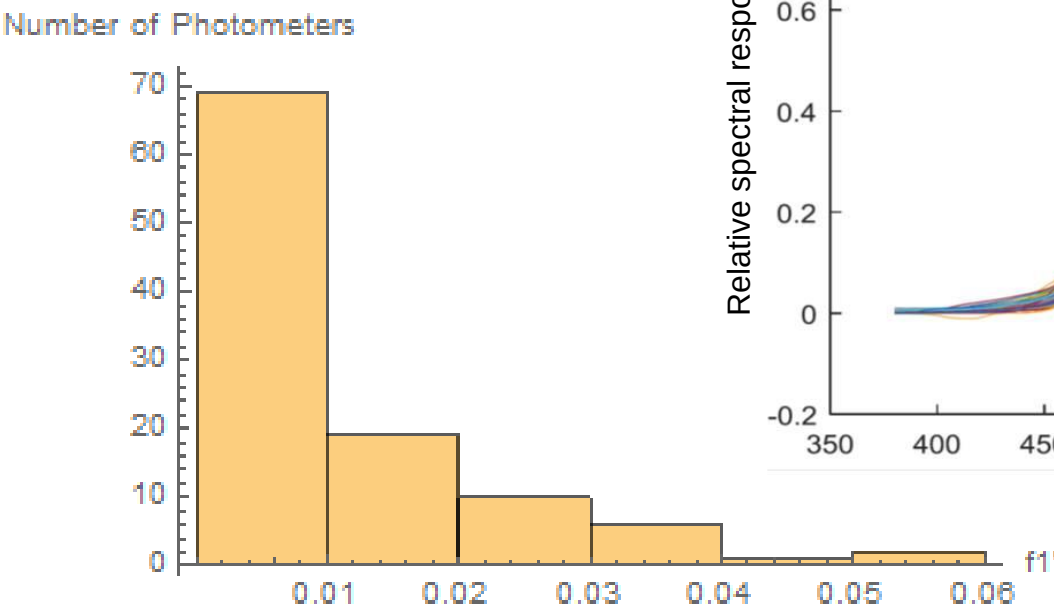


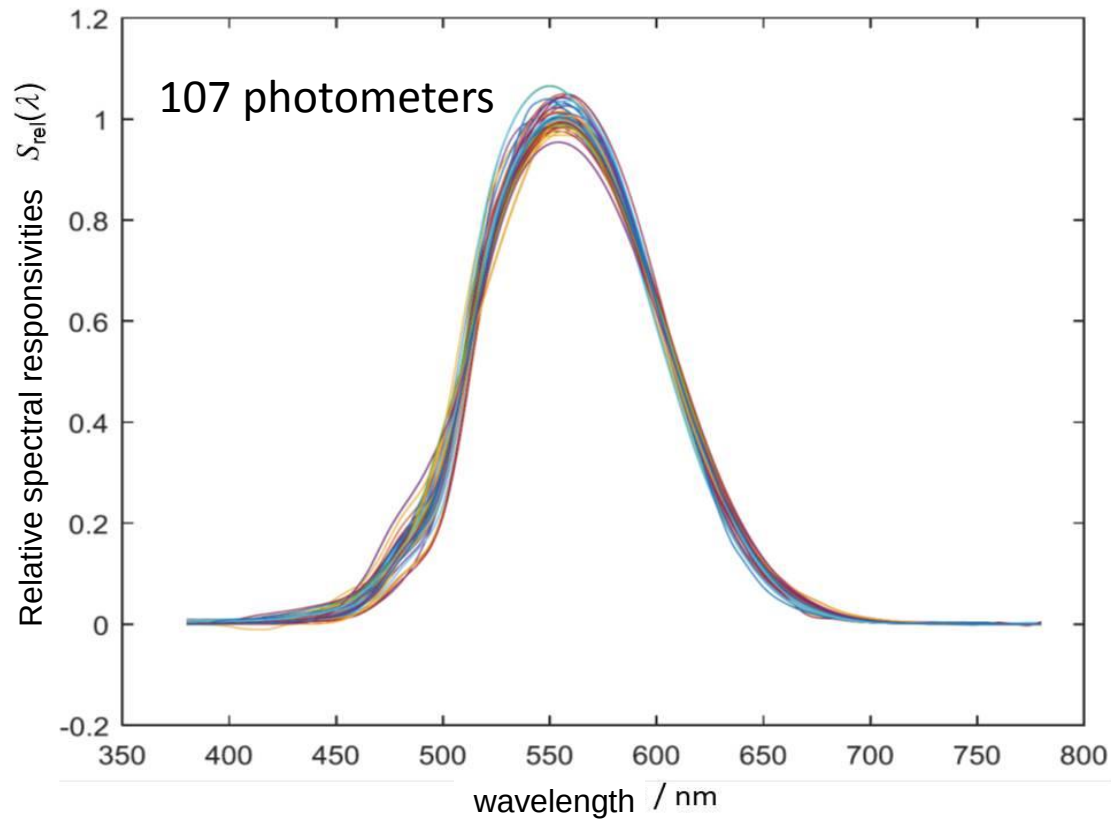
RGB-type LED



Spectral mismatch correction factor (SMCF)

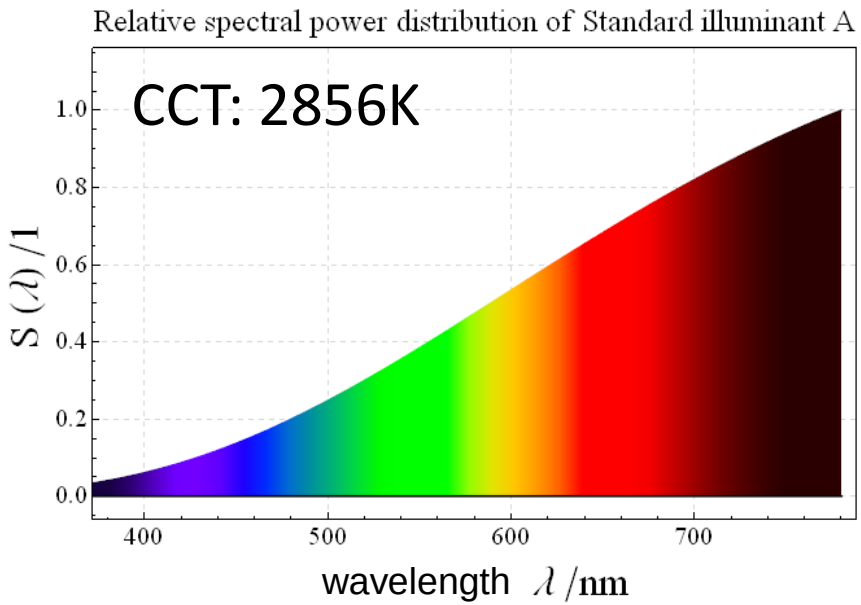
$$spectral\ mismatch\ correction\ factor = \frac{\int V(\lambda)\, S_{\mathrm{lamp}}(\lambda)\mathrm{d}\lambda}{\int \boldsymbol{s}_{\mathbf{rel}}(\boldsymbol{\lambda})\, S_{\mathrm{lamp}}(\lambda)\mathrm{d}\lambda} \Bigg/ \frac{\int V(\lambda)\, P(\lambda, T_{\mathrm{A}})\mathrm{d}\lambda}{\int \boldsymbol{s}_{\mathbf{rel}}(\boldsymbol{\lambda})\, P(\lambda, T_{\mathrm{A}})\mathrm{d}\lambda}$$





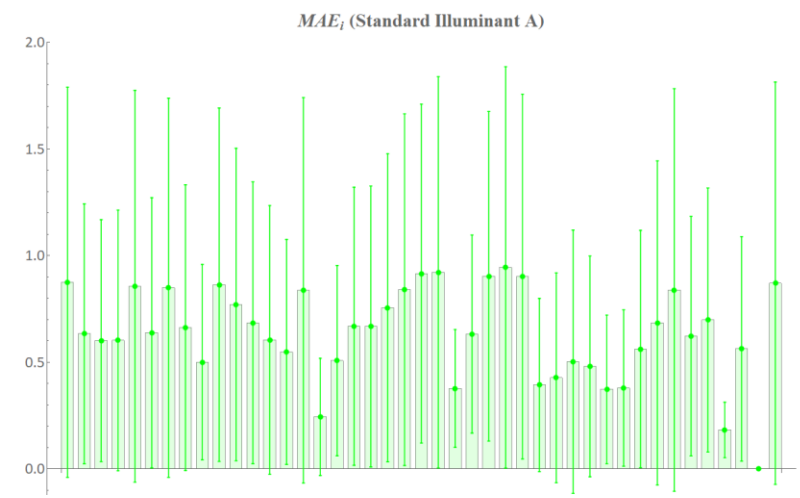
SMCF for different calibration spectra

Standard Illuminant A



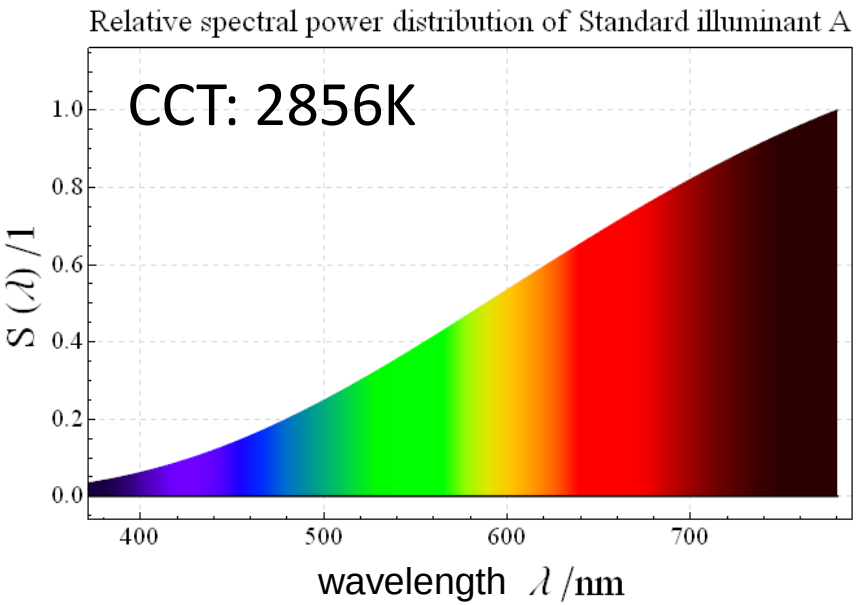
$$\frac{\int V(\lambda)\, S_{lamp}(\lambda)\mathrm{d}\lambda}{\int s_{rel}(\lambda)\, S_{lamp}(\lambda)\mathrm{d}\lambda} \Bigg/ \frac{\int V(\lambda)\, \boldsymbol{S(\lambda, T_A)}\mathrm{d}\lambda}{\int s_{rel}(\lambda)\, \boldsymbol{S(\lambda, T_A)}\mathrm{d}\lambda}$$

$$MAE_i = \frac{\sum_{j=1}^{N=107} \left| SMCF_j - 1 \right|}{N} \cdot 100\%$$



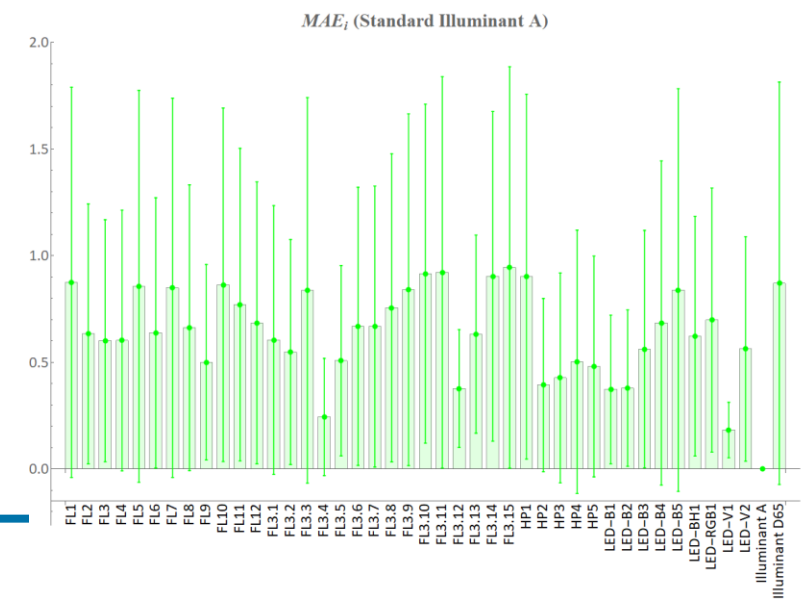
MAEi for Standard Illuminant A

Standard Illuminant A



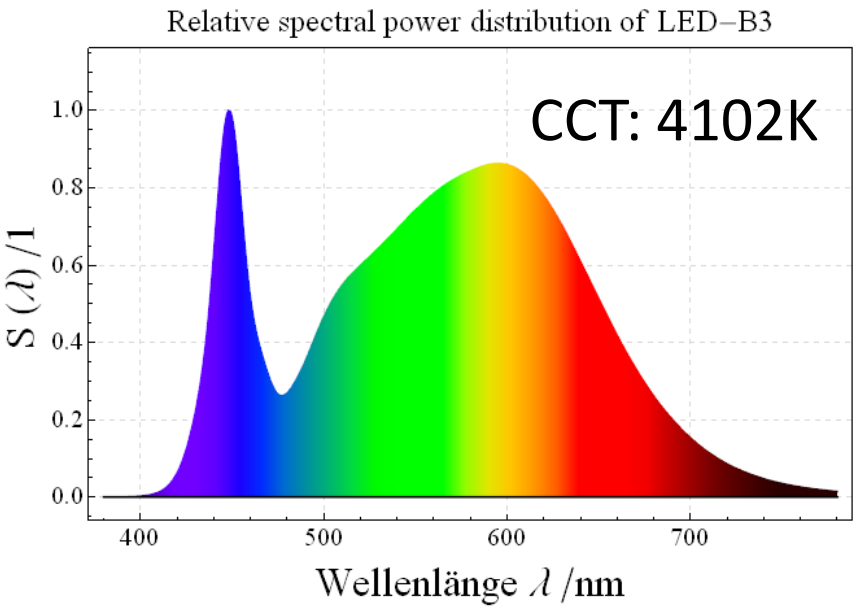
$$\frac{\int V(\lambda)\, S_{lamp}(\lambda)\mathrm{d}\lambda}{\int \boldsymbol{s}_{rel}(\boldsymbol{\lambda})\, S_{lamp}(\lambda)\mathrm{d}\lambda} \Bigg/ \frac{\int V(\lambda)\, \boldsymbol{P}(\boldsymbol{\lambda}, \boldsymbol{T_A})\mathrm{d}\lambda}{\int \boldsymbol{s}_{rel}(\boldsymbol{\lambda})\, \boldsymbol{P}(\boldsymbol{\lambda}, \boldsymbol{T_A})\mathrm{d}\lambda}$$

$$MAE_i = \frac{\sum_{j=1}^{N=107} \left| SMCF_j - 1 \right|}{N} \cdot 100\%$$



SMCF for different calibration spectra

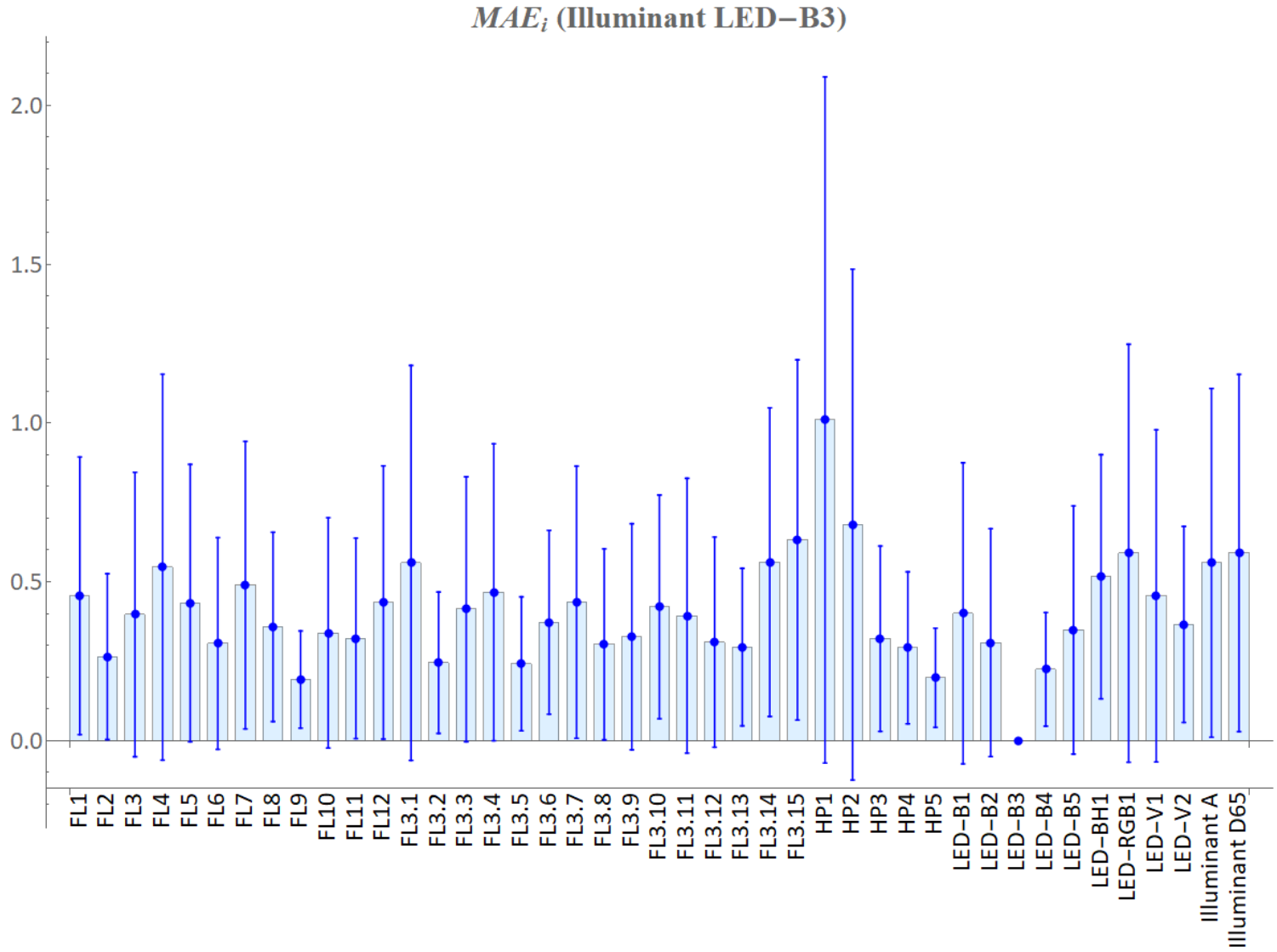
Illuminant LED-B3



$$\frac{\int V(\lambda)\, S_{lamp}(\lambda)\mathrm{d}\lambda}{\int s_{rel}(\lambda)\, S_{lamp}(\lambda)\mathrm{d}\lambda} \Bigg/ \frac{\int V(\lambda)\, \boldsymbol{S(\lambda, LED)}\mathrm{d}\lambda}{\int s_{rel}(\lambda)\, \boldsymbol{S(\lambda, LED)}\mathrm{d}\lambda}$$

$$MAE_i = \frac{\sum_{j=1}^{N=107} \left| SMCF_j - 1 \right|}{N} \cdot 100\%$$

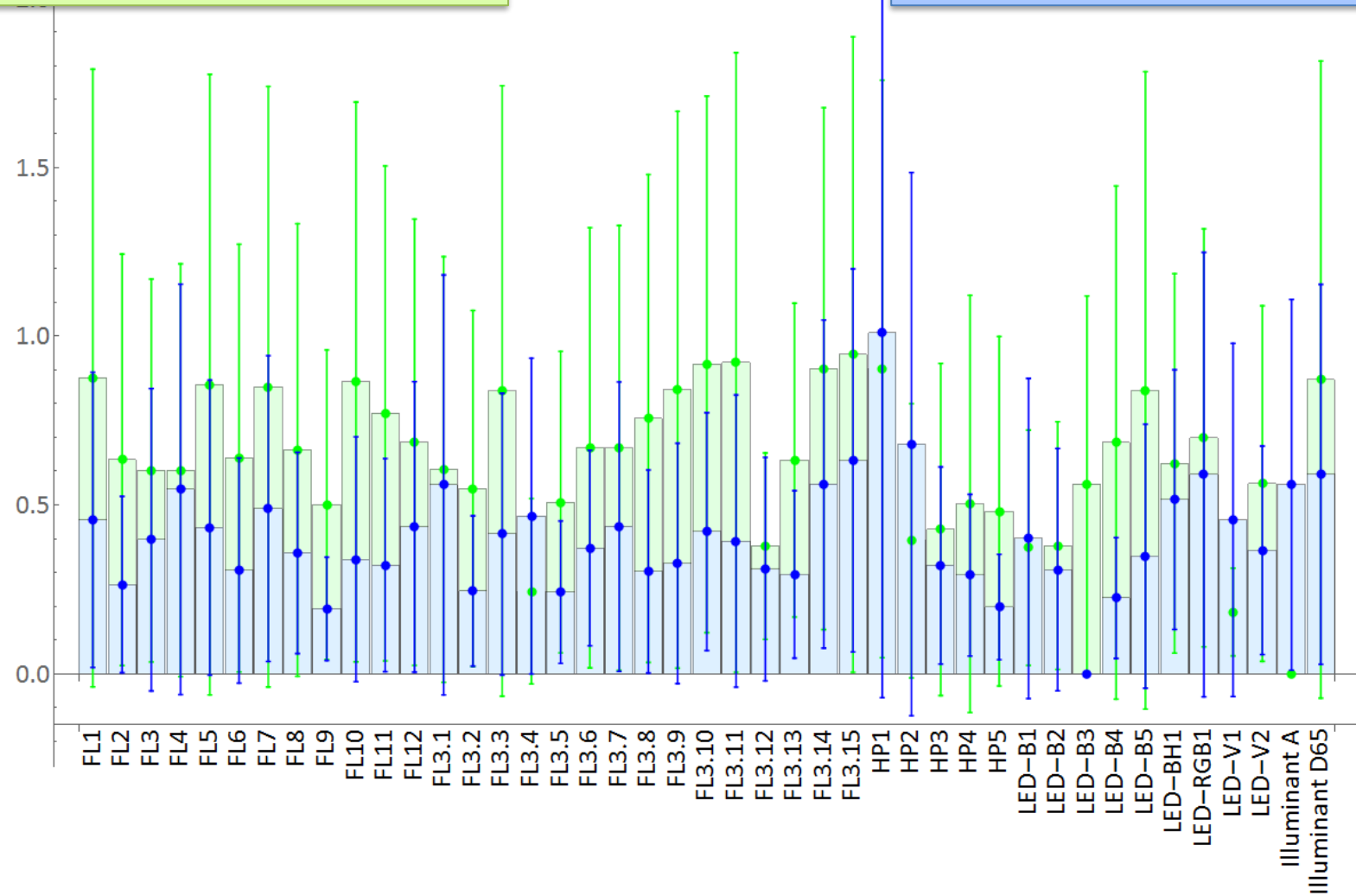
MAEi for Illuminant LED-B3



MAEi for different calibration spectra

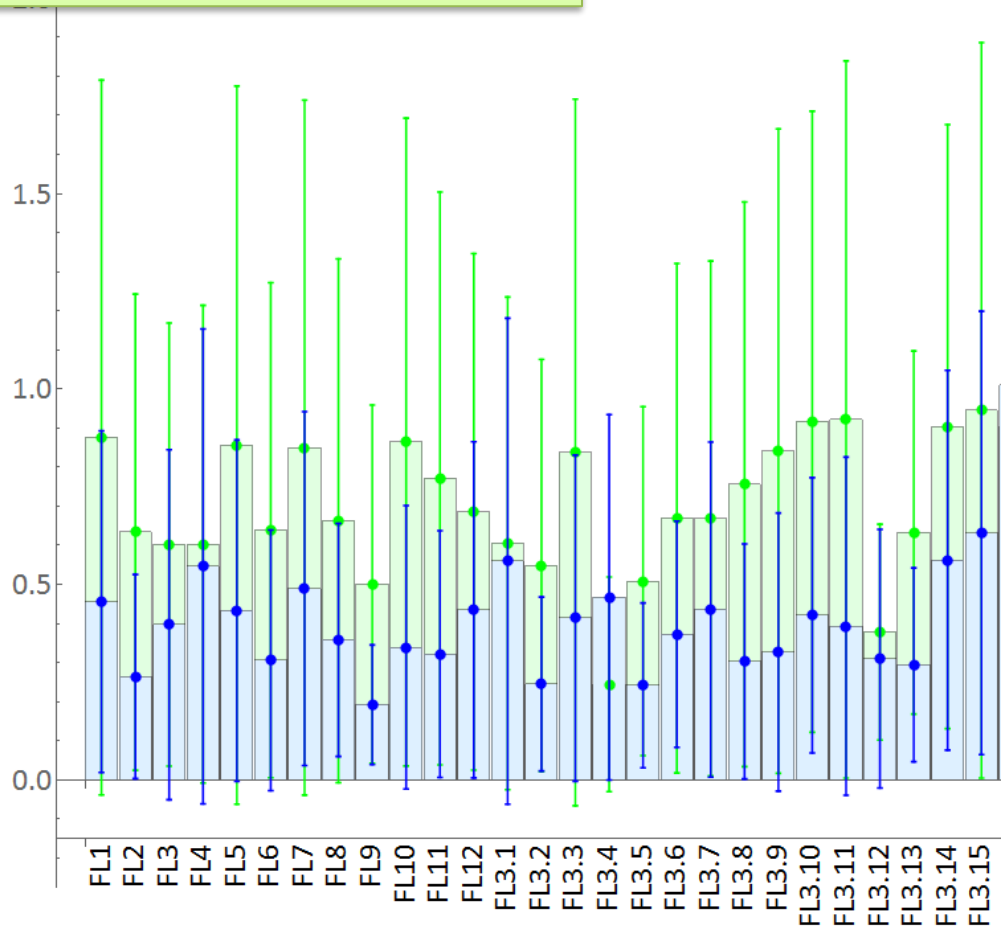
Standard illuminant A

Illuminant LED-B3

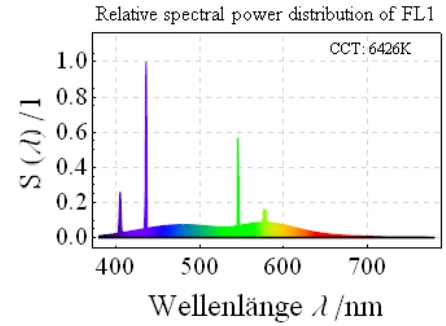


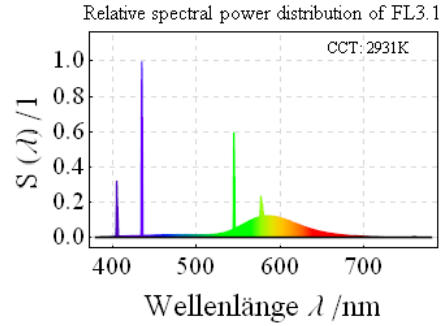
SMCF for different calibration spectra

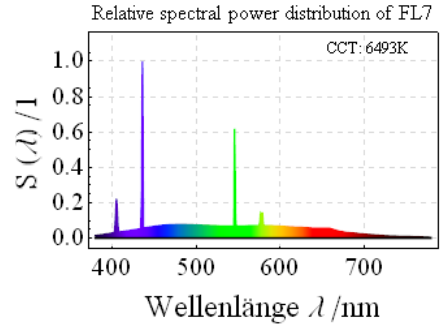
Standard illuminant A



Illuminant LED-B3



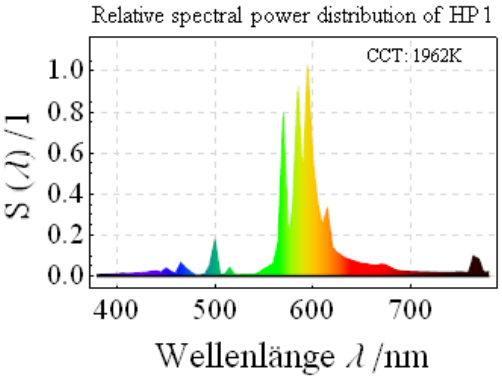


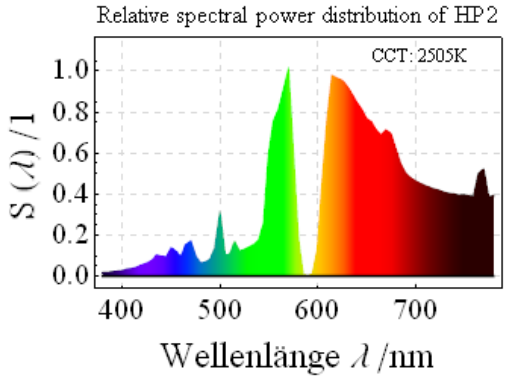


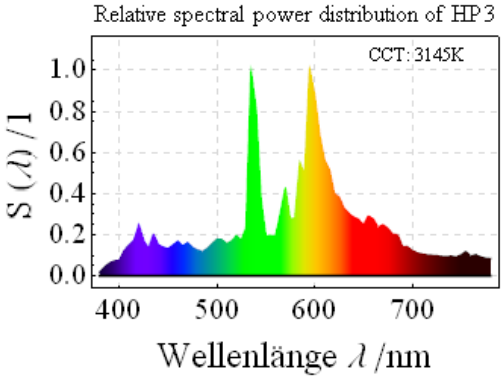
SMCF for different calibration spectra

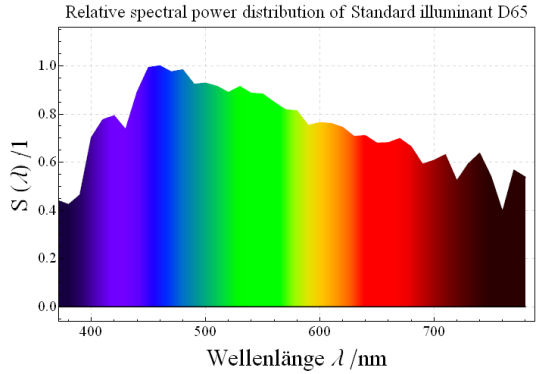
Standard illuminant A

HP1: Standard high pressure sodium lamp
HP2: Colour enhanced high pressure sodium lamp

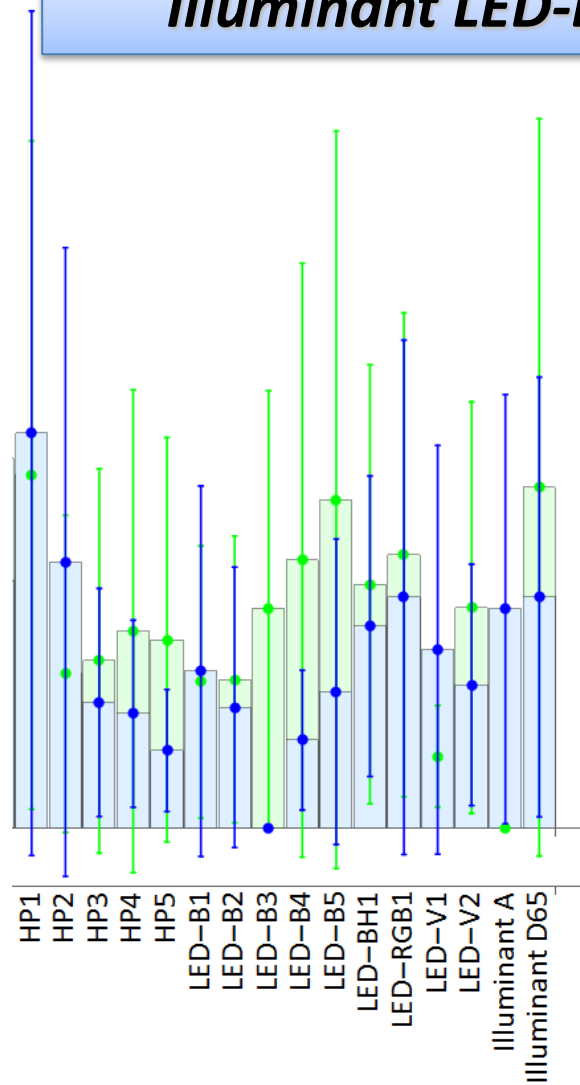








Illuminant LED-B3



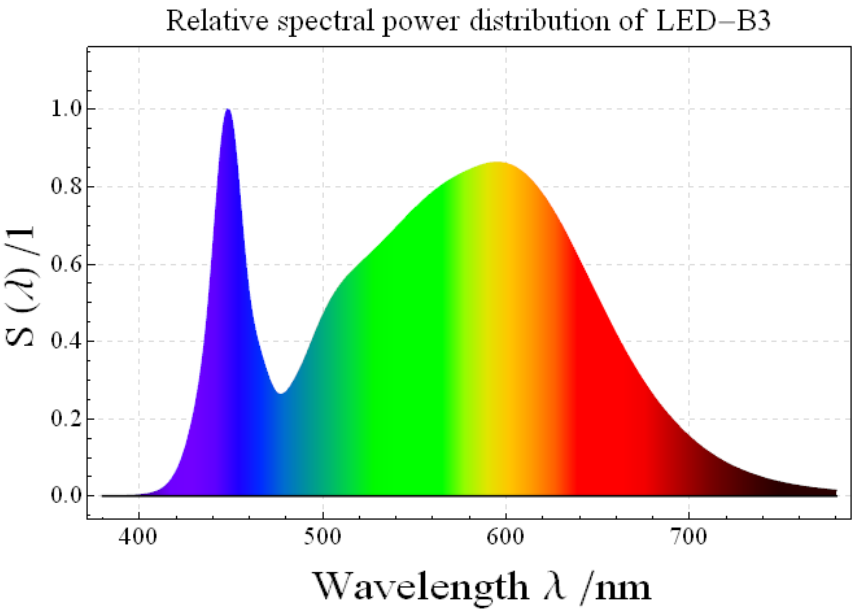
Luminous Intensity Standard type A (LIS-A)

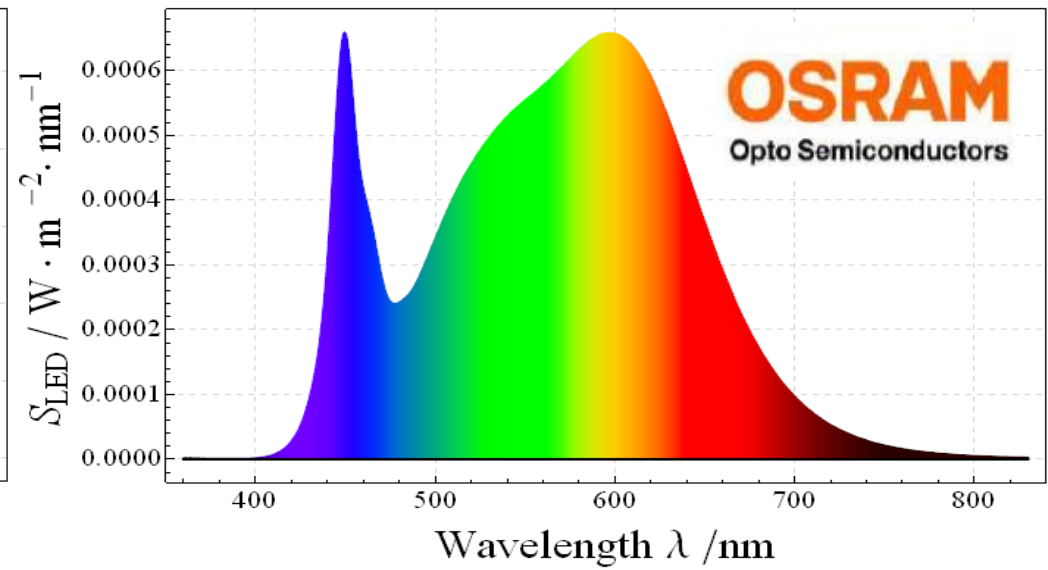
- 25 LEDs
- Light output area similar to WI 41/G
- Internal temperature controller
- Lamp current appr. 65 mA (DC)
- Lamp voltage appr. 75 V
- Lamp power appr. 5 W
- Spectral distribution similar to proposed LED reference spectrum
- Luminous intensity appr. 245 cd, similar to WI 41/G

Comparison of Illuminant LED-B3 and LIS-A

Illuminant LED-B3

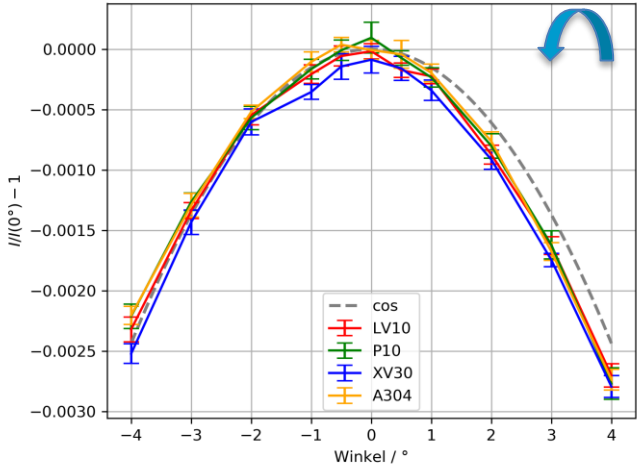
LIS-A



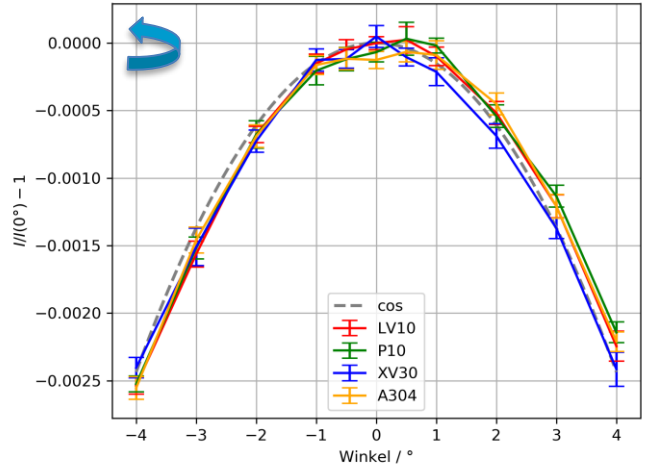


Quantity	Illuminant LED-B3	LIS-A	Difference
CCT	4102 K	4020 K	82 K
Blue peak WL	448 nm	450 nm	2 nm
Phosphor peak WL	595 nm	597 nm	2 nm
Blue peak / phosphor peak	1.12	1.00	0.12

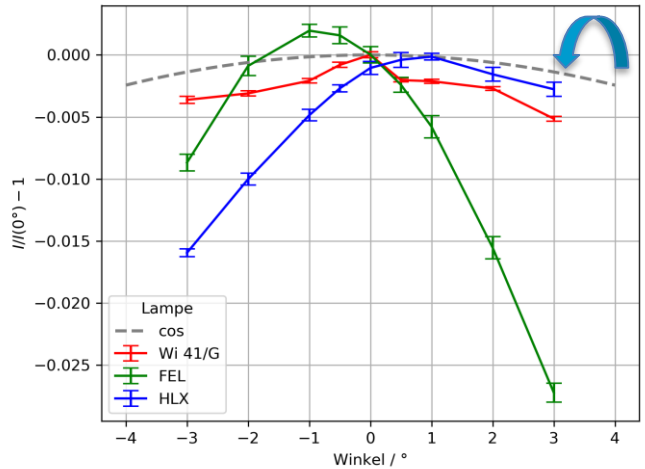
LIS-A geometrical alignment behaviour



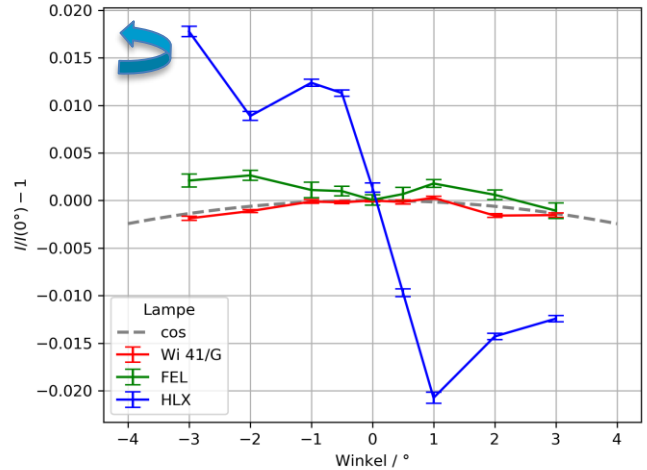
LED standard, rotation arround horizontal axis



LED standard, rotation arround vertical axis

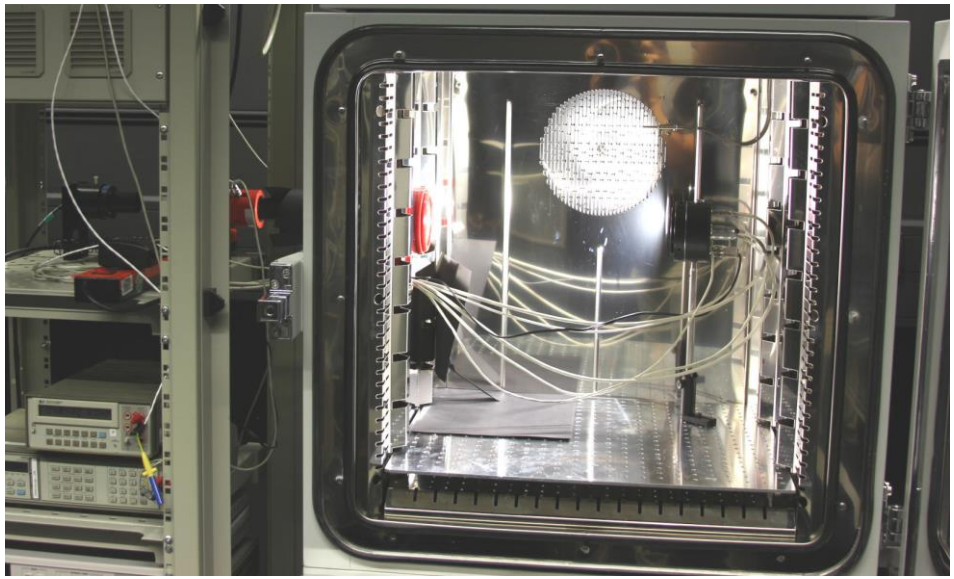


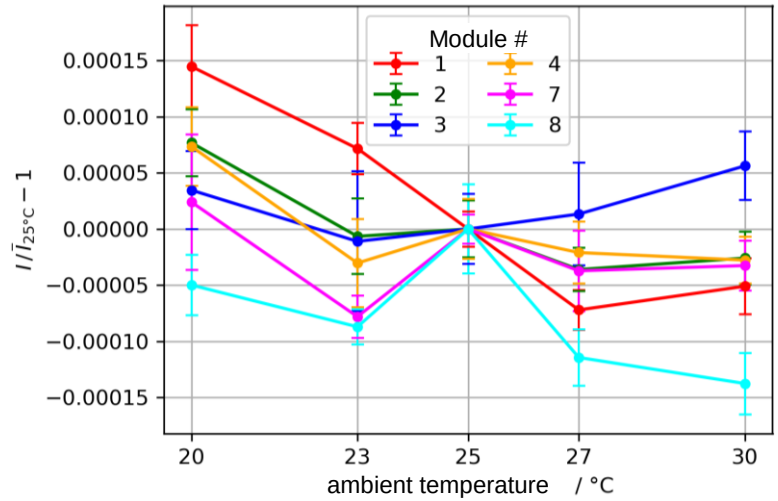
incandescent lamps, rotation arround horizontal axis

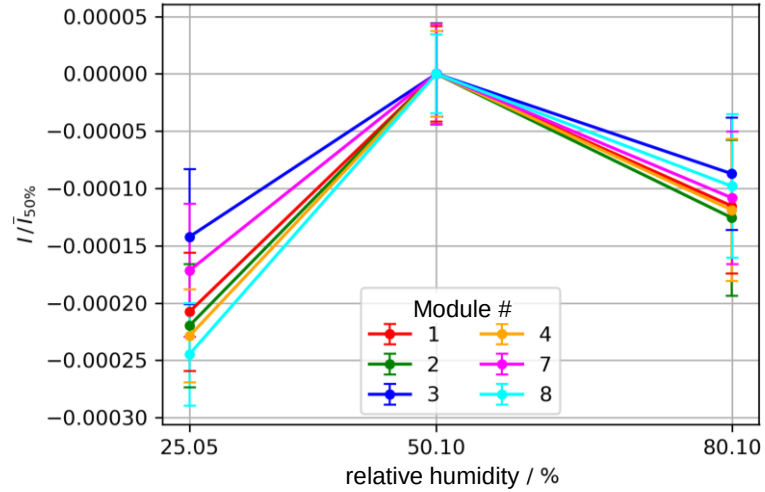


incandescent lamps, rotation arround vertical axis

LIS-A ambient climate behaviour





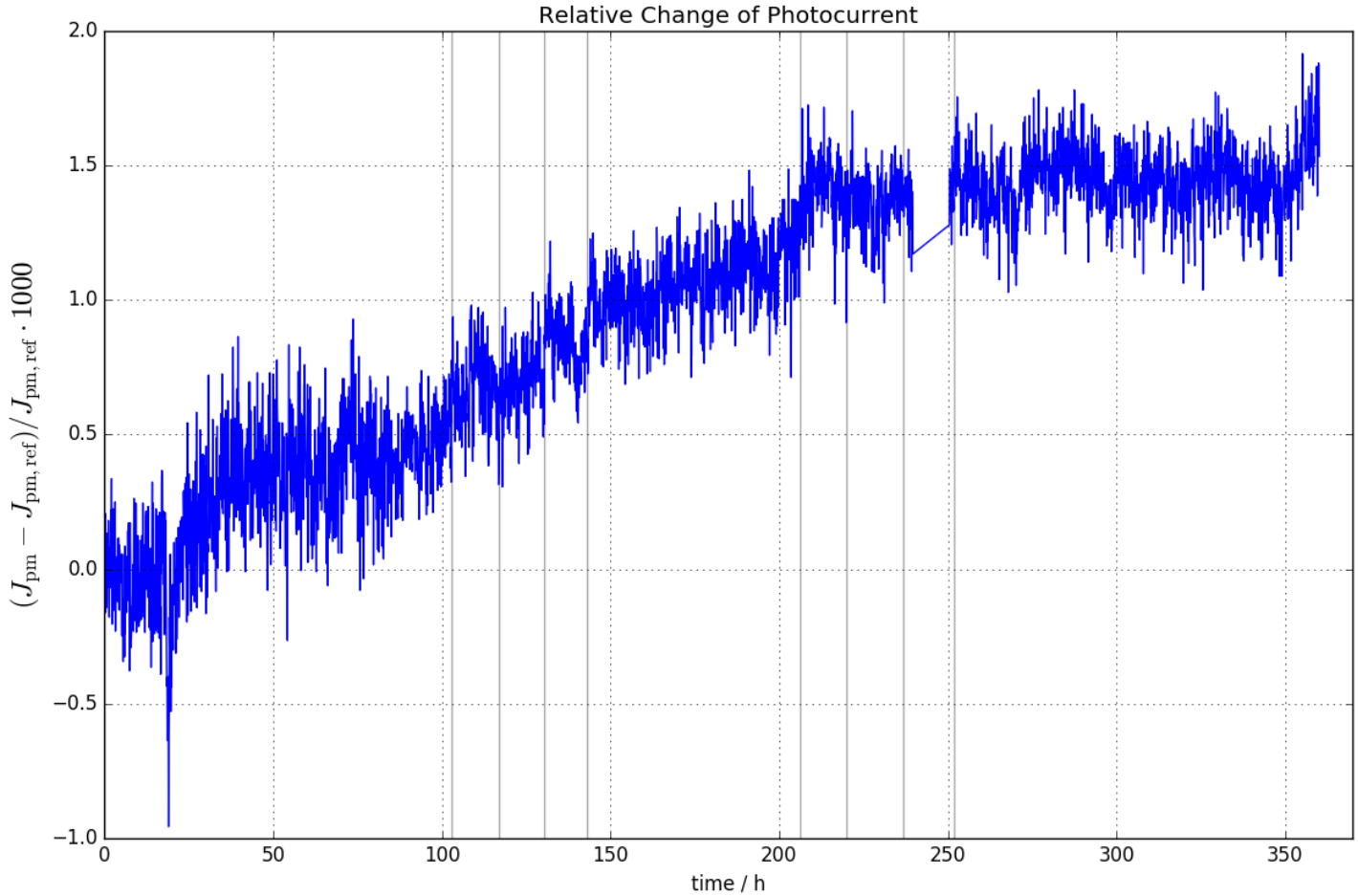


Operation in climate chamber

→ no systematic temperature dependency <1.5·10^{-4}

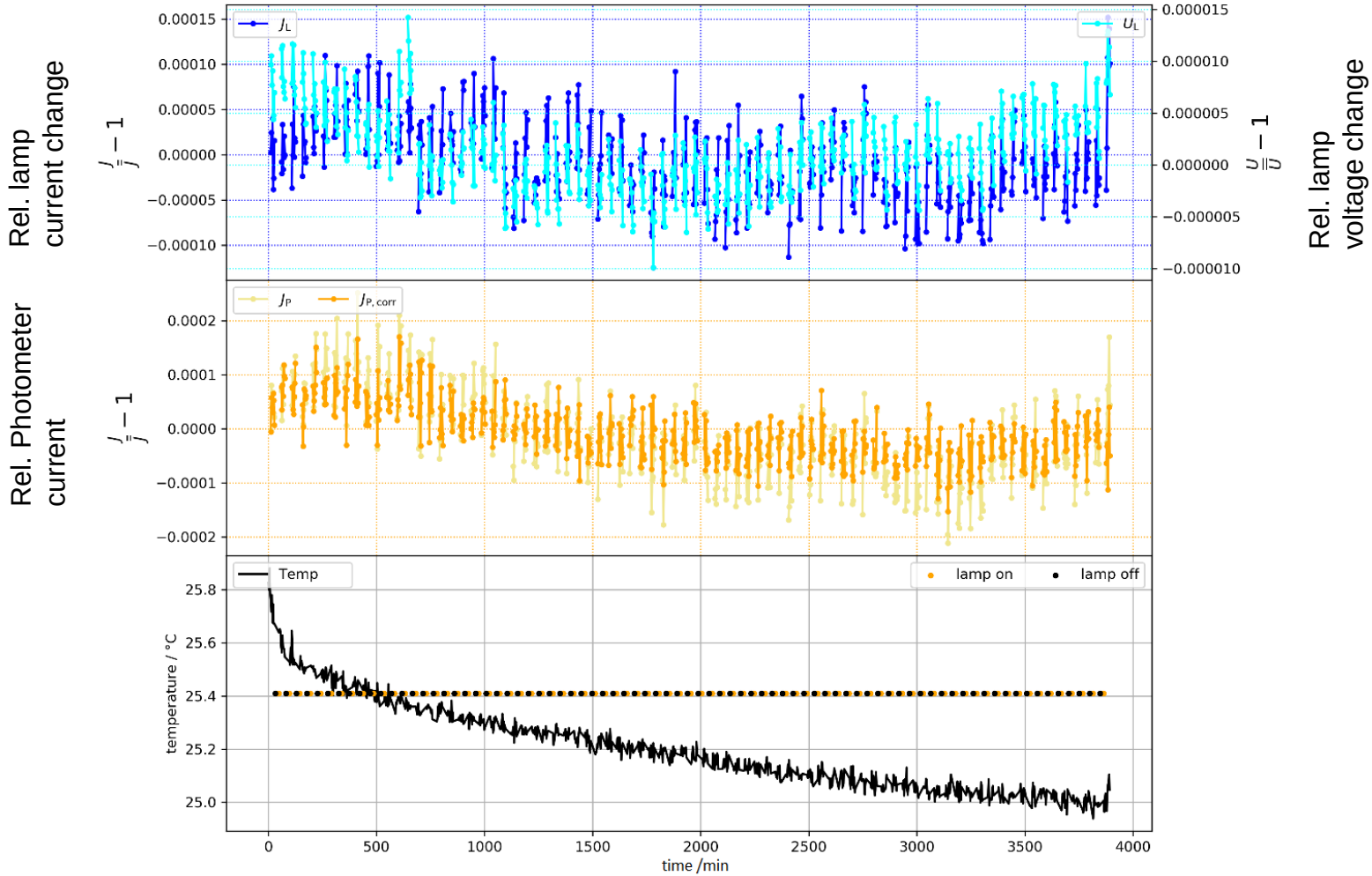
→ Neglectable dependence on humidity

LIS-A seasoning



Mean change in the light intensity of the modules is significantly lower than 0.1% for the last 100 hours of seasoning

LIS-A repeatability



- 65 hours cyclic operation: 30 min on-state, 15 min off-state
- 10 min warm up for each cycle (removed from graph)

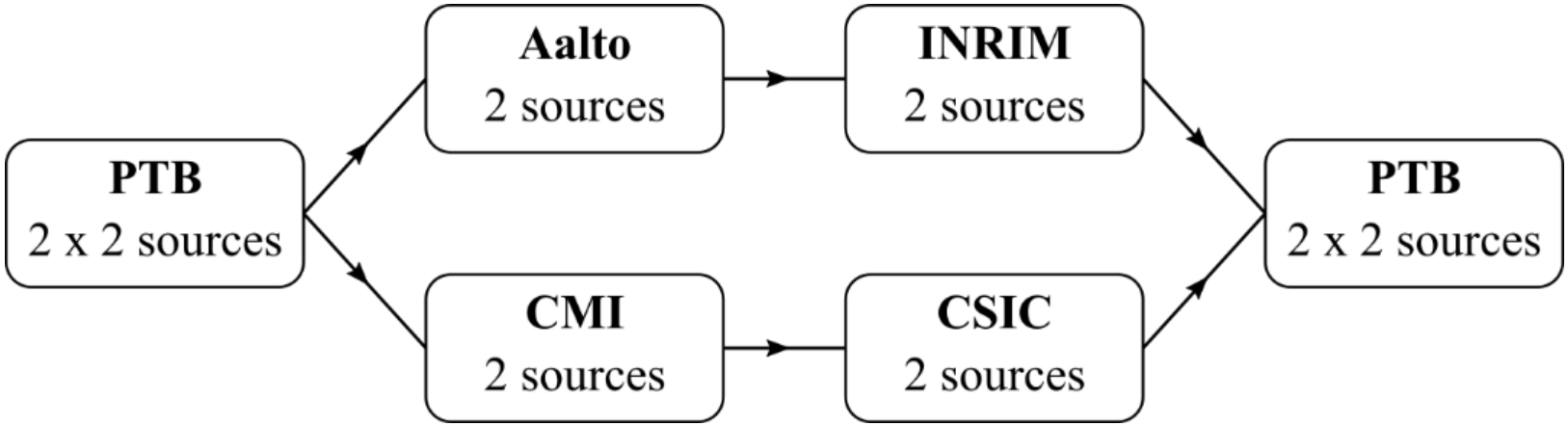
LIS-A luminous intensity uncertainties

$$ILED = c_{Spectral}\, c_{StrayLight}\, c_{Alignment}\, c_{AmbTemp}\, distance^2 \left(\frac{J_{LED}}{J_{LED0}}\right)^{-\alpha} \left(\frac{U_{LED}}{U_{LED0}}\right)^{-\beta} \frac{f_{AmpLight} - f_{AmpDark}}{w_f\, R_g\, s_v}$$

DESCRIPTION	UNIT	SYMBOL	VALUE	UNCERTAINTY (IN)	DOF	SENSITIVITY	UNCERTAINTY	REL. UNCERTAINTY
LED Nominal Current	A	J_{LED0}	0.065	0	∞	2779.39	0.	0.
LED Nominal Voltage	V	U_{LED0}	70.653	0	∞	10.2626	0.	0.
Exponent LED Voltage Corr.	1	β	2.97	0.09	19	0.00314445	0.000283	1.15919×10^{-6}
Photo Current Amplifier Dark	Hz	$f_{AmpDark}$	1574.02	3.14804	49	-0.00150284	-0.00473101	-0.0000193786
Exponent LED Current Corr.	1	α	0.74	0.05	19	-0.172363	-0.00861813	-0.0000353006
Corr. Ambient Temperature	1	$c_{AmbTemp}$	1	0.00005	19	244.135	0.0122068	0.00005
LED Current	A	J_{LED}	0.0650459	6.50459×10^{-6}	49	-2777.43	-0.018066	-0.000074
Amplification Photo Current Amplifier	Ω	R_g	2.99954×10^{6}	299.954	99	-0.0000813909	-0.0244135	-0.0001
Photo Current Amplifier	Hz	$f_{AmpLight}$	164023	32.8046	49	0.00150284	0.0493002	0.000201938
LED Voltage	V	U_{LED}	70.6521	0.00706521	49	-10.2627	-0.0725082	-0.000297
UF/converter conversion factor	$\frac{Hz}{V}$	w_f	50078.3	15.0235	49	-0.00487507	-0.0732406	-0.0003
Corr. Factor for Straylight	1	$c_{StrayLight}$	0.9995	0.0005	39	244.257	0.122129	0.00050025
Distance	m	distance	2.50001	0.001	49	195.307	0.195307	0.000799997
Corr. f. LED Alignment	1	$c_{Alignment}$	1	0.0008	19	244.135	0.195308	0.0008
Corr. Factor f. Spec. Mismatch Photom.	1	$c_{Spectral}$	1.0009	0.00137	49	243.916	0.334165	0.00136877
Luminous Responsivity Photometer	$\frac{A}{lx}$	s_v	2.7684×10^{-8}	6.921×10^{-11}	∞	-8.81864×10^{9}	-0.610338	-0.0025
Result: Luminous Intensity	**cd**	**I_{LED}**	**244.135**	**-**	**945**	**-**	**0.767857**	**0.00314521**

DESCRIPTION	UNIT	SYMBOL	VALUE	k	CONFIDENCELEVEL	EXPAND. UNCERTAINTY	REL. EXPAND. UNCERTAINTY
Result: Luminous Intensity	**cd**	**I_{LED}**	**244.135**	**2.025**	**0.9545**	**1.55491**	**0.00636905**

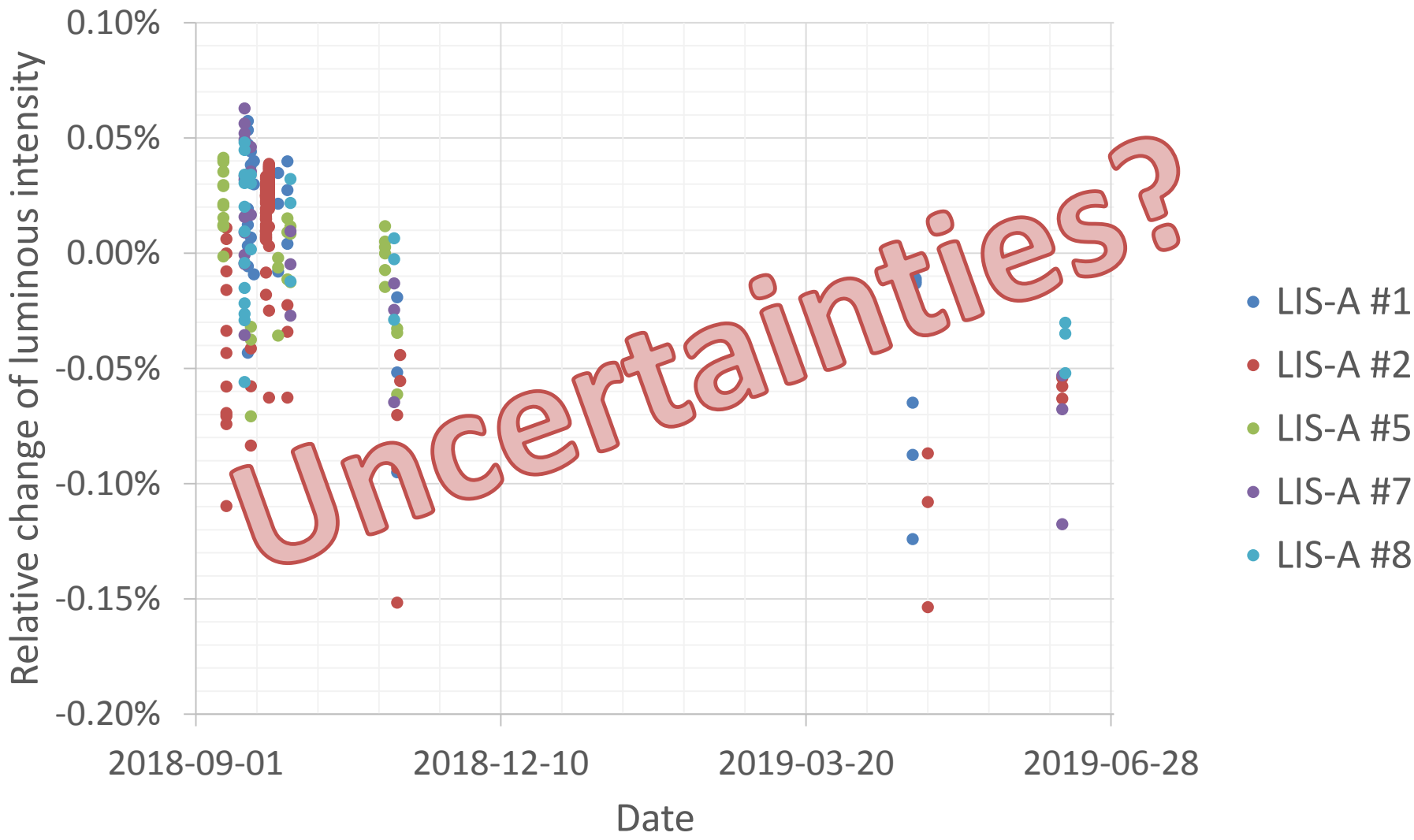
Luminous intensity comparison (5 NMIs)



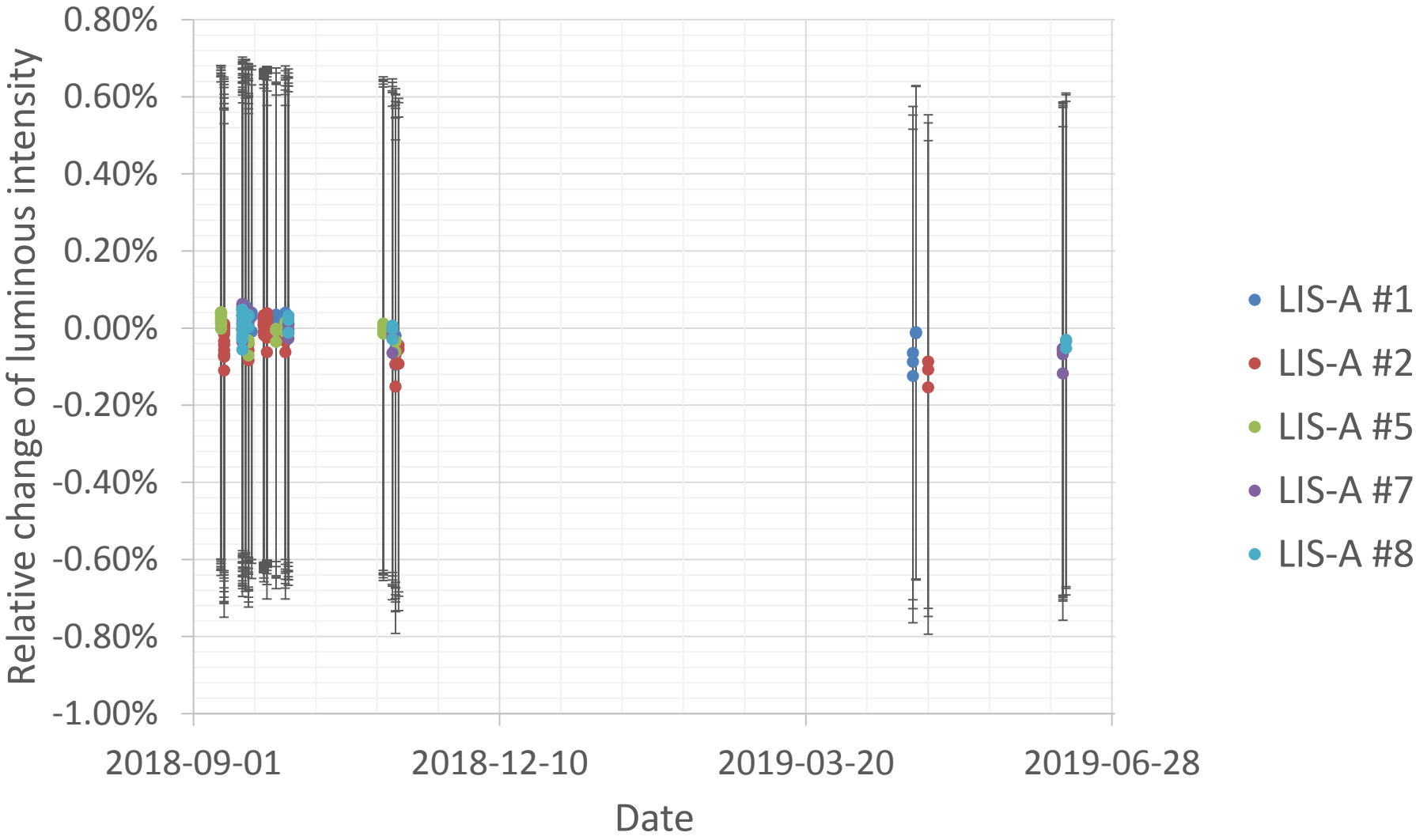
Status of the comparison

- All measurements are finished.
- Data analysis is ongoing.

Preliminary results of PTB

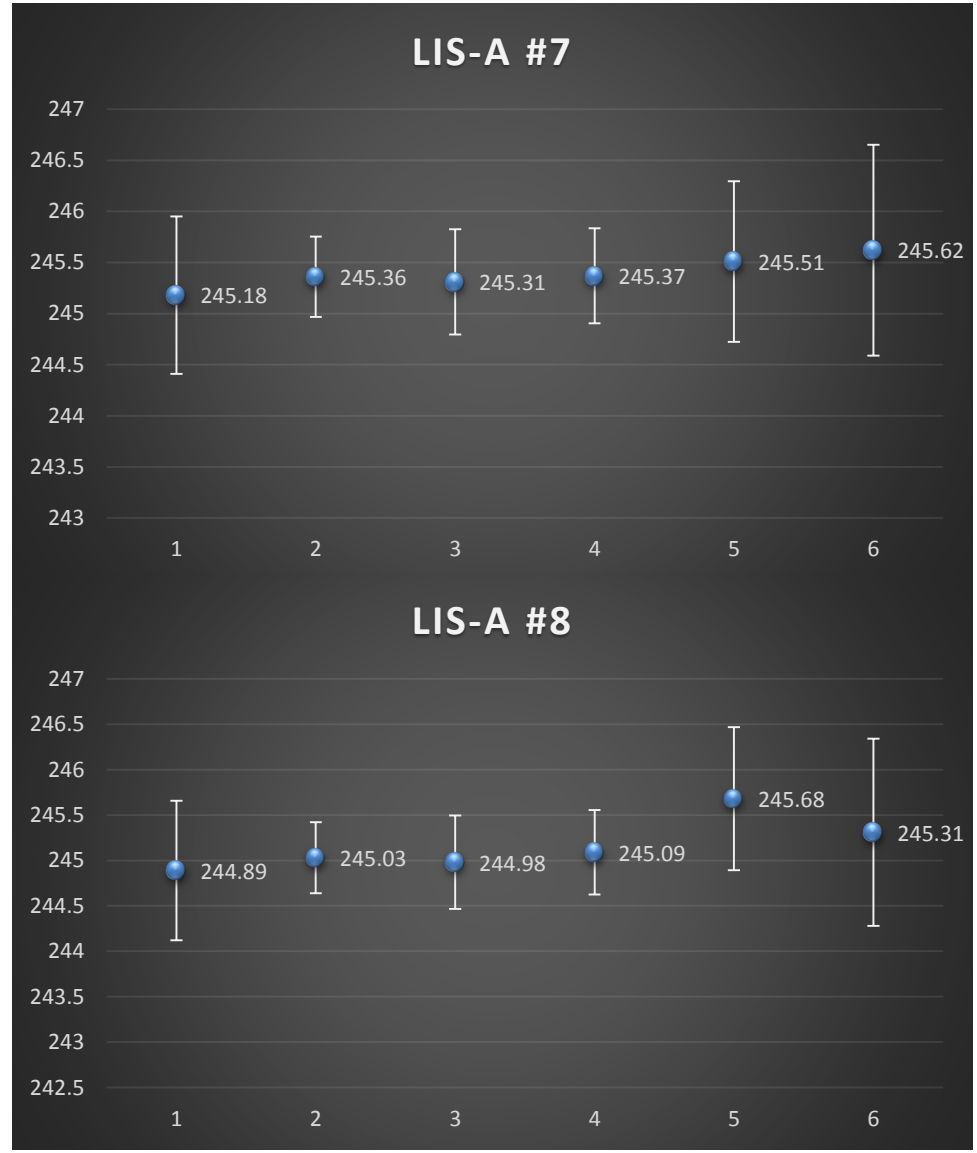


Preliminary results of PTB



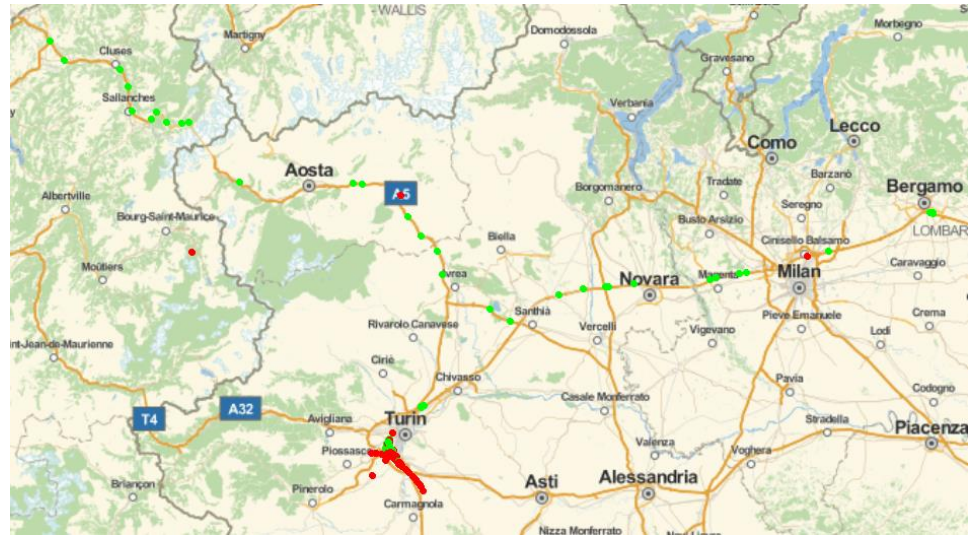
Preliminary results of the comparsion

- Preliminary results of several NMIs with different detector-types (Photometer, Trap, PQED).
- Standard uncertainties (k=1) are shown.



Transportation

- The artefacts were sent around with courier services.
- Several times the shock sensors with GPS measured accelerations of more than 20G!
- No indication that the properties of the LIS-A artefacts were affected.



Making LIS-A commercially available

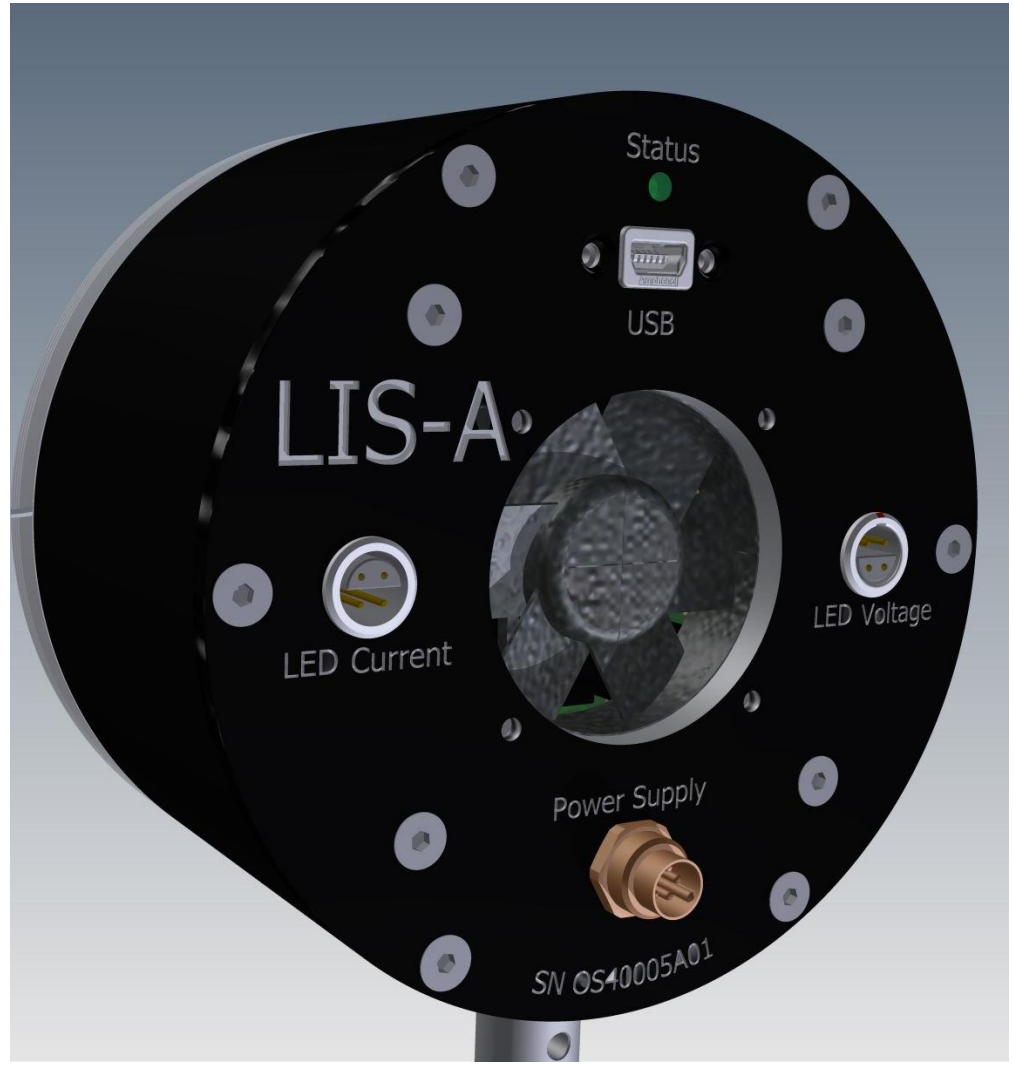
- PTB employees plan a spin-off for making LIS-A commercially available.
- Approval is expected soon.

- For details contact **info@luminous-intensity.de**
- Or visit www.luminous-intensity.de

New revision

Slightly improved design:

- 24 LEDs in 2 el. circuits
- Max Voltage < 40V per circuit
- Luminous Intensity: ~240 cd



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