

JRP EPM 21NRM01 HiDyn

Support for the standardisation of luminance distribution measurements for assessing glare and obtrusive light using high-dynamic-range imaging systems



Johannes Ledig

August 29th 2025

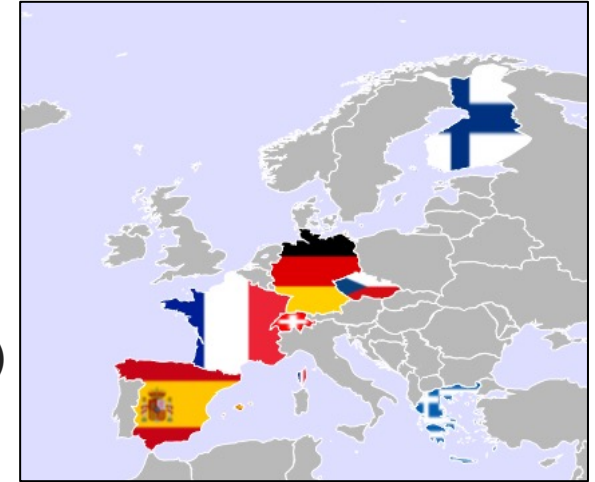
resources of **143.2 PMs** (84.3 internal + 27.5 external + 31.4 unfunded)
941 k€ EU contribution for 7 funded partners (with 35% for universities)
459 k€ national funding for two associated partners (from Switzerland)

Project administrative information

{HiDyn}

Normative Joint Research project EPM 21NRM01 HiDyn:

- Start: **1st October** 2022; Duration: 36 Months
- Consortium: **six NMIs** and **three universities** from seven European countries
- Coordination: PTB, Dr. Johannes Ledig
- Funded in the **Normative Call 2021** of the European Partnership on Metrology (EPM) and Swiss national funding for two associated partners.



Project number: 21NRM01

Project name: Support for the standardisation of luminance distribution measurements for assessing glare and obtrusive light using high-dynamic-range imaging systems

Project acronym: HiDyn

Call: Pre-Co-Normative (2021)

Topic: SRT n08

Type of action: Metrology Partnership Research and Innovation actions

Granting authority: EURAMET e.V

**METROLOGY
PARTNERSHIP**



- Needs
- Consortium and Objectives to be addressed
- Structure of the JRP
- Achievements
- Upcoming Dissemination, Workshops

Acknowledgement: The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

**METROLOGY
PARTNERSHIP**



Disclaimer: Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or Euramet e.V.. Neither the European Union nor the granting authority can be held responsible for them.

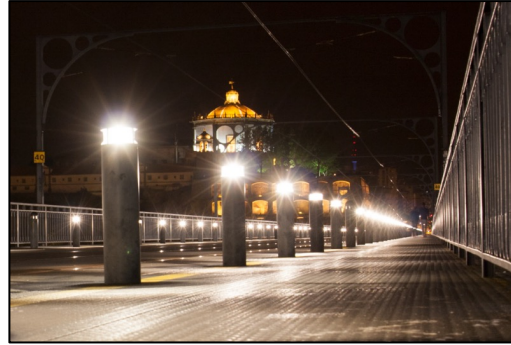


Funded by the
European Union

tasks involving vision in lighting environments with very high luminance contrast



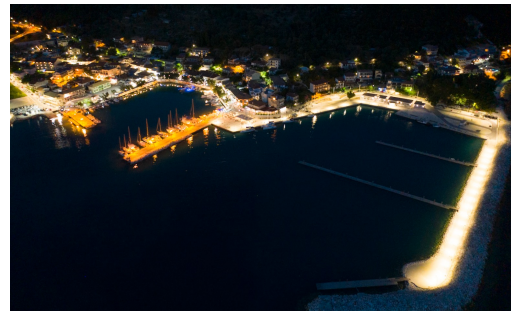
Evaluation of discomfort glare



Increased safety in street lighting



Support for fundamental research



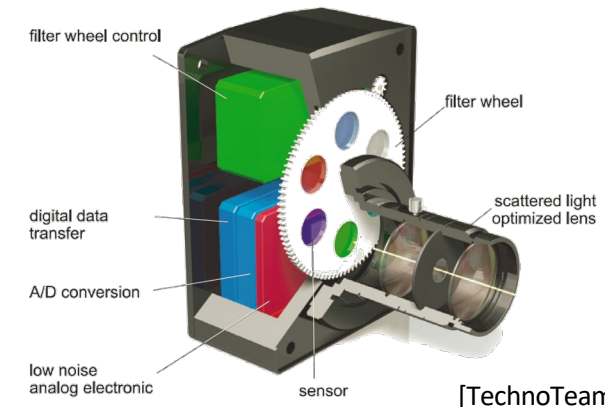
Documenting environmental impact of light pollution

[demonstrating photos by partner ICCS]



Uptake of Outcomes and Impact

- National metrology institutes
- Manufacturers of imaging luminance measurement devices (ILMDs) implementing adjustments
- ILMD operators evaluating glare and obtrusive light (researchers, luminaire designers, assessors)
- Scientific community addressing obtrusive light and glare
- Citizen/communities impacted by obtrusive light, glare and high-contrast luminance scenes



[TechnoTeam]

Main Goal:
to enable the traceability of HDR luminance measurements

Objectives of EPM JRP 21NRM01 HiDyn

{HiDyn}

Main Goal: to enable the traceability of HDR luminance measurements

- Objective 1: To develop luminance standards with high dynamic contrast pattern
- 2: To model and validate HDR luminance measurements
- 3: To develop a harmonised metric for generating traceable HDR-luminance images
- 4: To develop guidelines on the determination of uncertainty budgets
- 5: To contribute to the standards development work

Chief Stakeholder:

International Commission
on Illumination (CIE)



Partners of the European consortium

*internal funded
(Euramet NMIs)*



25 PM



CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

22 PM

le cnam

15.5 PM

*external funded
(universities)*



18.5 PM

*Unfunded
(NMI and university)*



METAS

17 PM



12 PM



Aalto University

10 PM



9 PM

EPFL

14.5 PM

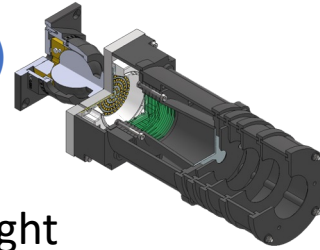


WP1: Characterization of HDR imaging measurement systems for luminance, glare and obtrusive light (CSIC)

Task 1.1: Development of high-contrast-luminance references standard source

Task 1.2: Development of procedures for the characterisation of HDR imaging measurement systems

Task 1.3: Experimental verification of HDR luminance measurements and assessment of glare and obtrusive light

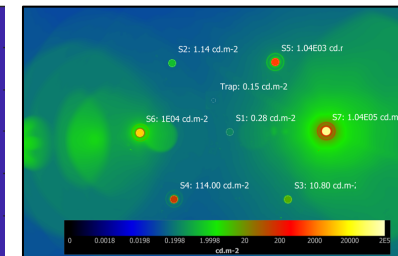
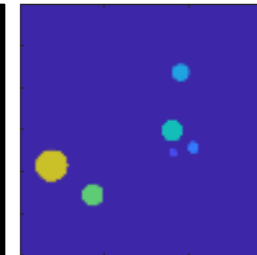
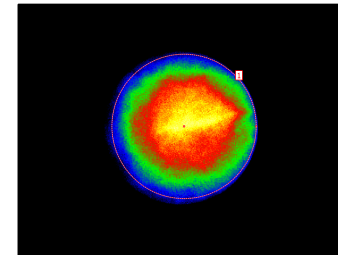


WP2: Algorithm for traceable HDR-luminance imaging (CNAM)

Task 2.1: Development of an HDR algorithm selection method

Task 2.2: Selection of an HDR algorithm

Task 2.3: Implementation of the HDR algorithm into source code



WP3: Uncertainty evaluation of HDR luminance measurements (METAS)

Task 3.1: Development of a model for the uncertainty evaluation of HDR luminance measurements

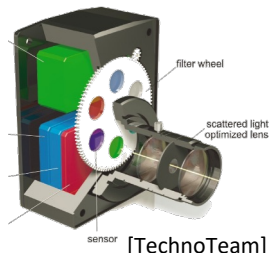
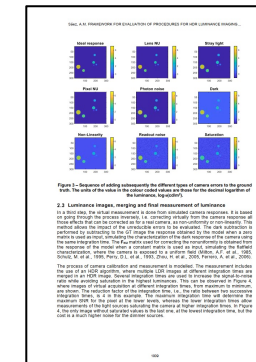
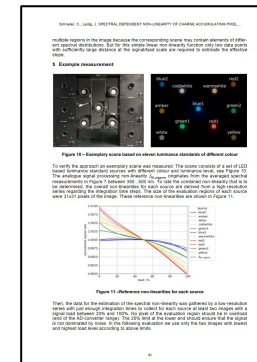
Task 3.2: Development of a model to evaluate the uncertainty of glare and obtrusive light measurements



WP4: Creating impact (PTB)

Project Website: www.hidyn.ptb.de

WP5: Management and coordination (PTB)





International Commission on Illumination
Commission Internationale de l'Éclairage
Internationale Beleuchtungskommission

OP77

SPECTRAL DEPENDENT NON-LINEARITY OF CHARGE ACCUMULATING PIXEL MATRIX SENSORS

Schrader, C., Ledig, J.

DOI 10.25039/x50.2023.OP077

Pages 34–44 from

CIE x050:2023

Proceedings
of the
30th CIE SESSION
Ljubljana, Slovenia, September 15 – 23, 2023
(DOI 10.25039/x50.2023)

The paper has been presented at the 30th CIE Session, Ljubljana, Slovenia, September 15 – 23, 2023. CIE 2023 conference papers were accepted on the basis of double-blind abstract review. The Proceedings papers are published as supplied by the authors.

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International Commission on Illumination
Commission Internationale de l'Éclairage
Internationale Beleuchtungskommission

PO33

FRAMEWORK FOR EVALUATION OF PROCEDURES FOR HDR LUMINANCE IMAGING MEASUREMENTS

Sáez, Á., Ferrero, A., Ledig, J., Schrader, C., Gevaux, L., Dupiau, A., Maltezos, E., Antonopoulos, M., Rezadeh, Y., Bouroussis, C.

DOI 10.25039/x50.2023.PO033

Pages 1004–1013 from

CIE x050:2023

Proceedings
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Schrader, C., Ledig, J. SPECTRAL DEPENDENT NON-LINEARITY OF CHARGE ACCUMULATING PIXEL...

multiple regions in the image because the corresponding scene may contain elements of different spectral distributions. But for this simple linear non-linearity function only two data points with sufficiently large distance at the signal/load scale are required to estimate the effective slope.

5 Example measurement

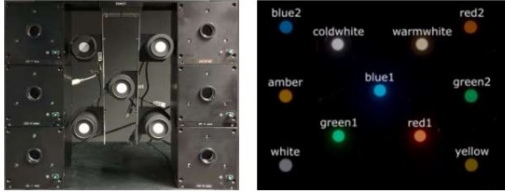


Figure 10 – Exemplary scene based on eleven luminance standards of different colour

To verify the approach an exemplary scene was measured. The scene consists of a set of LED based luminance standard sources with different colour and luminance level, see Figure 10. The analogue signal processing non-linearity $f_{NL,algenc}$ originates from the averaged spectral measurements in Figure 7 between 350...500 nm. To rate the combined non-linearity that is to be determined, the overall non-linearities for each source are derived from a high-resolution series regarding the integration time steps. The size of the evaluation regions of each source were 31x31 pixels of the image. These reference non-linearities are shown in Figure 11.

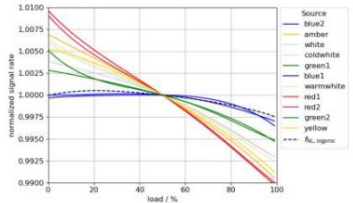


Figure 11 –Reference non-linearities for each source

Then, the data for the estimation of the spectral non-linearity was gathered by a low-resolution series with just enough integration times to collect for each source at least two images with a signal load between 20% and 100%. No pixel of the evaluation region should be in overload (end of the AD-converter range). The 20% limit at the lower end should ensure that the signal is not dominated by noise. In the following evaluation we use only the two images with lowest and highest load level according to above limits.



International Commission on Illumination
Commission Internationale de l'Éclairage
Internationale Beleuchtungskommission

PO33

FRAMEWORK FOR EVALUATION OF PROCEDURES FOR HDR LUMINANCE IMAGING MEASUREMENTS

Sáez, Á., Ferrero, A., Ledig, J., Schrader, C., Gevaux, L., Dupiau, A., Maltezos, E., Antonopoulos, M., Rezadeh, Y., Bouroussis, C.

DOI 10.25039/x50.2023.PO033

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Sáez, A.M. FRAMEWORK FOR EVALUATION OF PROCEDURES FOR HDR LUMINANCE IMAGING...

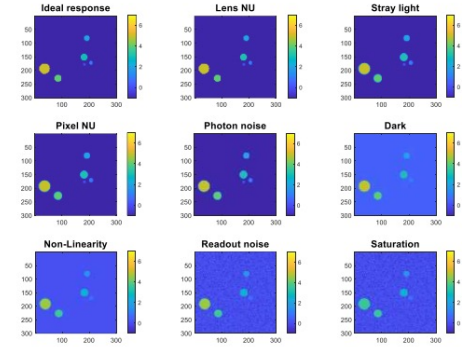


Figure 3 – Sequence of adding subsequently the different types of camera errors to the ground truth. The units of the value in the colour coded values are those for the decimal logarithm of the luminance, $\log_{10}(\text{cd/m}^2)$.

2.3 Luminance images, merging and final measurement of luminance

In a third step, the virtual measurement is done from simulated camera responses. It is based on going through the process inversely, i.e. correcting virtually from the camera response all those effects that can be corrected as for a real camera, as non-uniformity or non-linearity. This method allows the impact of the unreducible errors to be evaluated. The dark subtraction is performed by subtracting to the GT image the response obtained by the model when a zero matrix is used as input, simulating the characterization of the dark response of the camera using the same integration time. The F_{NU} matrix used for correcting the nonuniformity is obtained from the response of the model when a constant matrix is used as input, simulating the flatfield characterization, where the camera is exposed to a uniform field (Milton, A.F. et al., 1985, Schulz, M. et al., 1995, Perry, D.L. et al., 1993, Zhou, H. et al., 2005, Ferrero, A. et al., 2006).

The process of camera calibration and measurement is modelled. The measurement includes the use of an HDR algorithm, where multiple LDR images at different integration times are merged in an HDR image. Several integration times are used to increase the signal-to-noise ratio while avoiding saturation in the highest luminances. This can be observed in Figure 4, where images of virtual acquisition at different integration times, from maximum to minimum, are shown. The reduction factor of the integration time, i.e., the ratio between two successive integration times, is 4 in this example. The maximum integration time will determine the maximum SNR for the pixel at the lower levels, whereas the lower integration times allow measurements of the light sources saturating the camera at higher integration times. In Figure 4, the only image without saturated values is the last one, at the lowest integration time, but the cost is a much higher noise for the dimmer sources.

Achievements: field measurements in M18

Measurement session at the **LED catwalk in Berlin** (street installation for research) during the M18 full consortium meeting
Stable scene with **additional targets** for evaluation: **grey cards**, **light traps**, and three high contrast **luminance sources** (CMI)

Measurement devices: (various configurations of focus, aperture, neutral density filter, lens)

- ILMDs from four partners (TUB, CNAM, METAS, PTB)
- DSLRs from two partners (EPFL, PTB)
- spot luminance meter and flicker meter (PTB)



Photo of the measurement setup on 14.03.2024



HDR luminance image (logarithmic look-up table, luminance values $> 430 \text{ cd/m}^2$ are clipped)

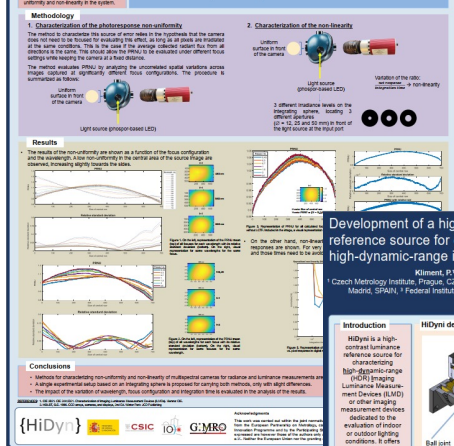


Achievements: CIE Conference 2025

{HiDyn}

Characterization of photoresponse non-uniformity and non-linearity of multispectral cameras for radiance and luminance measurements

Sáez, A.M., Ferrero, A.
Instituto de Óptica "Daza de Vieda", Agencia Estatal Consejo Superior de Investigaciones Científicas, Madrid, SPAIN
Corresponding e-mail address: saez@ioa.csic.es



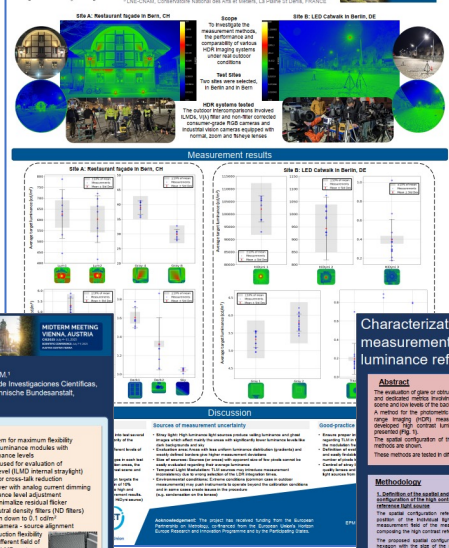
Development of a high contrast luminance reference source for characterization of high-dynamic-range imaging measurement systems

Klement, P.Y., Linduka, P.Y., Chien, B.Y., Ferrero, A., Bouroussis, C.Y., Ledig, J., Smei, M.
Czech Metrology Institute, Prague, CZECH REPUBLIC, * Institute of Optics, Agency Estatal Consejo Superior de Investigaciones Científicas, Madrid, SPAIN, * Federal Institute of Metrology METAS, Bern-Benlen, SWITZERLAND, * Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY
Corresponding e-mail address: klement@iml.cz



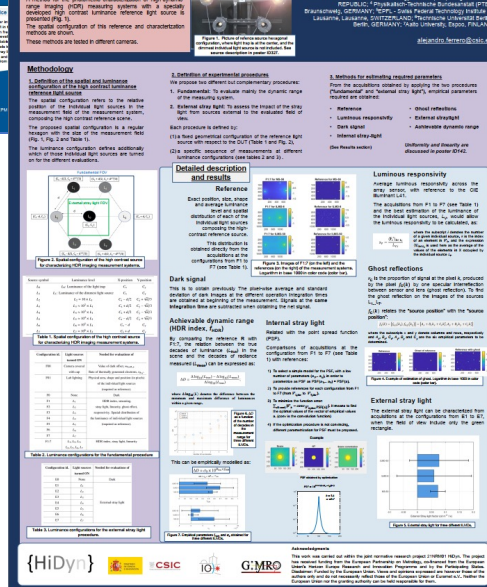
Outdoor Intercomparison of HDR Imaging Luminance Measurement Systems using a High Contrast Luminance Scene

Bouroussis, C.A., Ledig, J., Gensler, L.J., Schneider, C.J.
*Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY, *Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY, *Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY



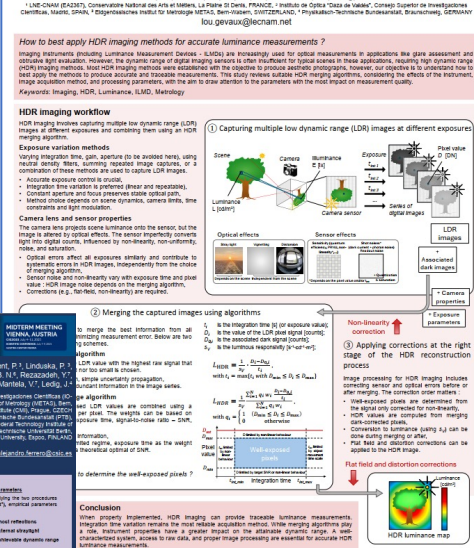
Characterization of high-dynamic-range imaging measurement system by using a high contrast luminance reference source

Ferrero, A., Bouroussis, C.Y., Klement, P.Y., Linduka, P.Y., Smei, M., Rado, B.N., Rado, B.N., Rado, B.N.
Instituto de Óptica "Daza de Vieda", Agencia Estatal Consejo Superior de Investigaciones Científicas, Madrid, SPAIN, * Czech Metrology Institute, Prague, CZECH REPUBLIC, * Federal Institute of Metrology METAS, Bern-Benlen, SWITZERLAND, * Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY, * Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY, * Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY



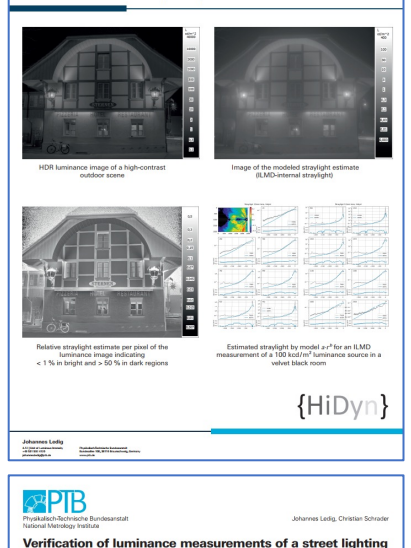
HIGH DYNAMIC RANGE IMAGING METHODS FOR TRACEABLE OPTICAL MEASUREMENTS

Geveux, L., Ferrero, A., Dupiau, A., Bouroussis, C.Y., Ledig, J.
*LNE-CNAM (EAD27), Conservatoire National des Arts et Métiers, La Plaine St Denis, FRANCE, * Institut de Optique "Daza de Vieda", Consejo Superior de Investigaciones Científicas, Madrid, SPAIN, * Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY, * Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY



Estimating the straylight in HDR imaging luminance measurement devices (ILMD)

Johnes, L., Ferrero, A., Dupiau, A., Bouroussis, C.Y., Ledig, J.
*LNE-CNAM (EAD27), Conservatoire National des Arts et Métiers, La Plaine St Denis, FRANCE, * Institut de Optique "Daza de Vieda", Consejo Superior de Investigaciones Científicas, Madrid, SPAIN, * Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY, * Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY



Verification of luminance measurements of a street lighting scene using different configurations of luminance meters

Johnes, L., Ferrero, A., Dupiau, A., Bouroussis, C.Y., Ledig, J.
*LNE-CNAM (EAD27), Conservatoire National des Arts et Métiers, La Plaine St Denis, FRANCE, * Institut de Optique "Daza de Vieda", Consejo Superior de Investigaciones Científicas, Madrid, SPAIN, * Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY, * Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY



Dissemination in relevant technical committees:

Standards Committee / Technical Committee / Working Group	Partners involved
CIE TC 2-62	PTB
CIE TC 2-86	EPFL (chair), CNAM, METAS, PTB
CIE TC 2-95	METAS (chair), PTB
CIE TC 2-96	PTB (chair), CSIC, METAS
CIE TC 3-57	EPFL, TUB
CIE TC 4-xx	TUB (chair)
CIE TC 4-50	TUB / monitoring via NCs
CIE TC 4-58	METAS
CIE TC 8-18	CSIC
CIE JTC 12	CSIC (chair), CNAM, METAS, PTB, CMI
CEN TC-169 – WG11	EPFL
CEN TC-169 – WG7	METAS, PTB
DIN FNL	PTB

Reportership on HDR for CIE Division 2 and new TC proposal:

METAS together with PTB will summarize output from WP1, WP2 and WP3 to a report for the CIE (e.g., in terms of a Reportership on HDR imaging measurements). In the same context, they will prepare a proposal for a new CIE TC on HDR measurements

Deliverable 8: contributions to new or improved international standards development work
(focus on TCs of Division 2 and Division 4 of CIE)

Dissemination to industrial stakeholders

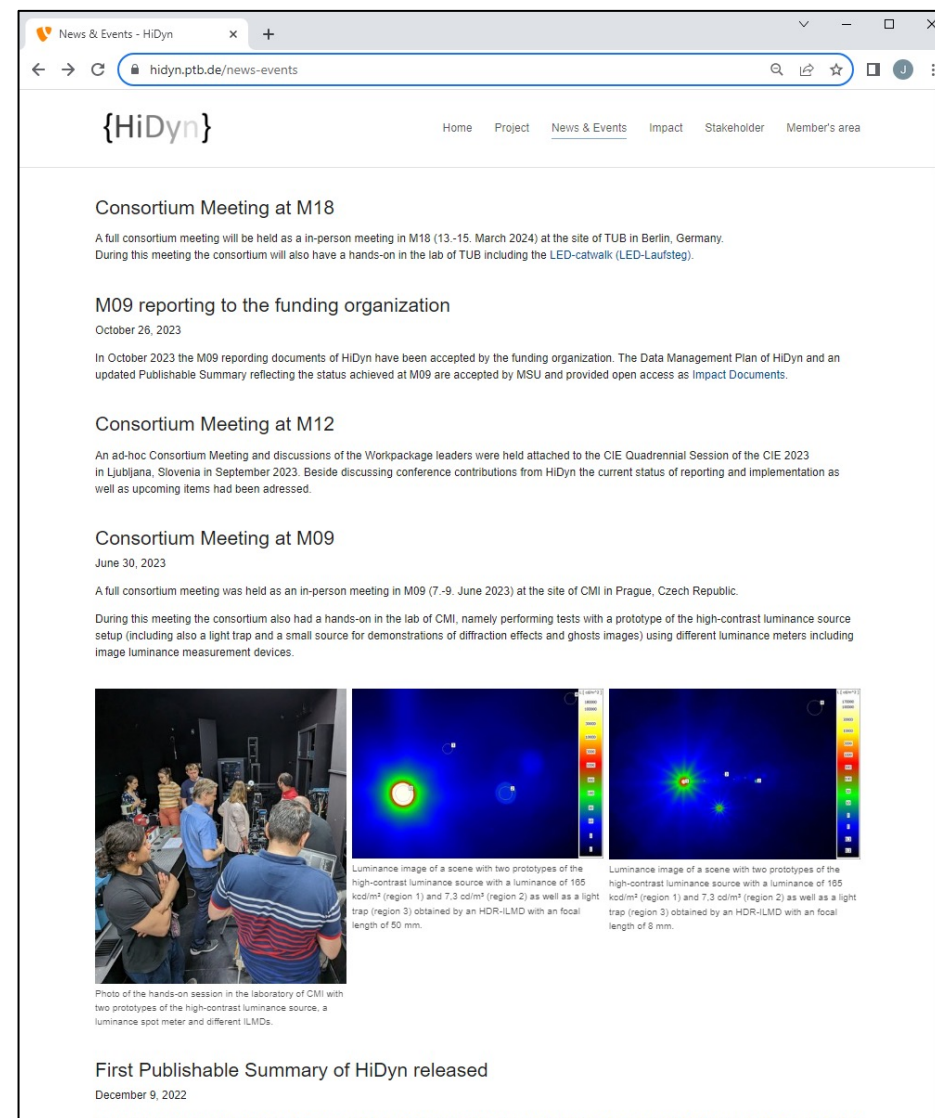
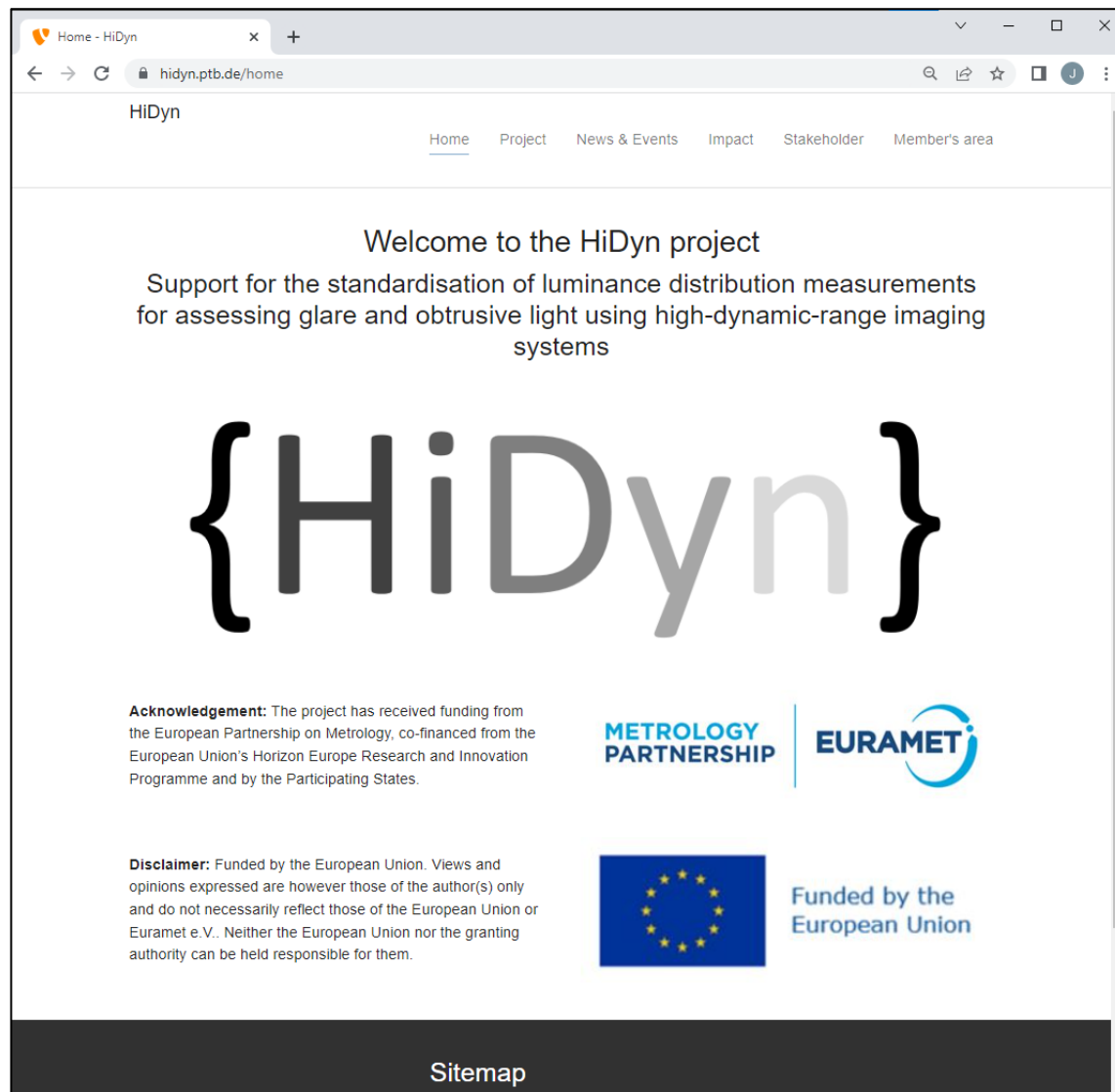
dedicated to prerequisites for traceable instrumentation
→ exhibition booth at the CIE Quadrennial Session 2025, Vienna

Workshop for end users and research institutes

dedicated on an introduction to HDR measurement background, theory on glare and obtrusive light measurements, implementation guidelines on how to scale an HDR luminance image to a traceable spot measurement

Supportive stakeholders

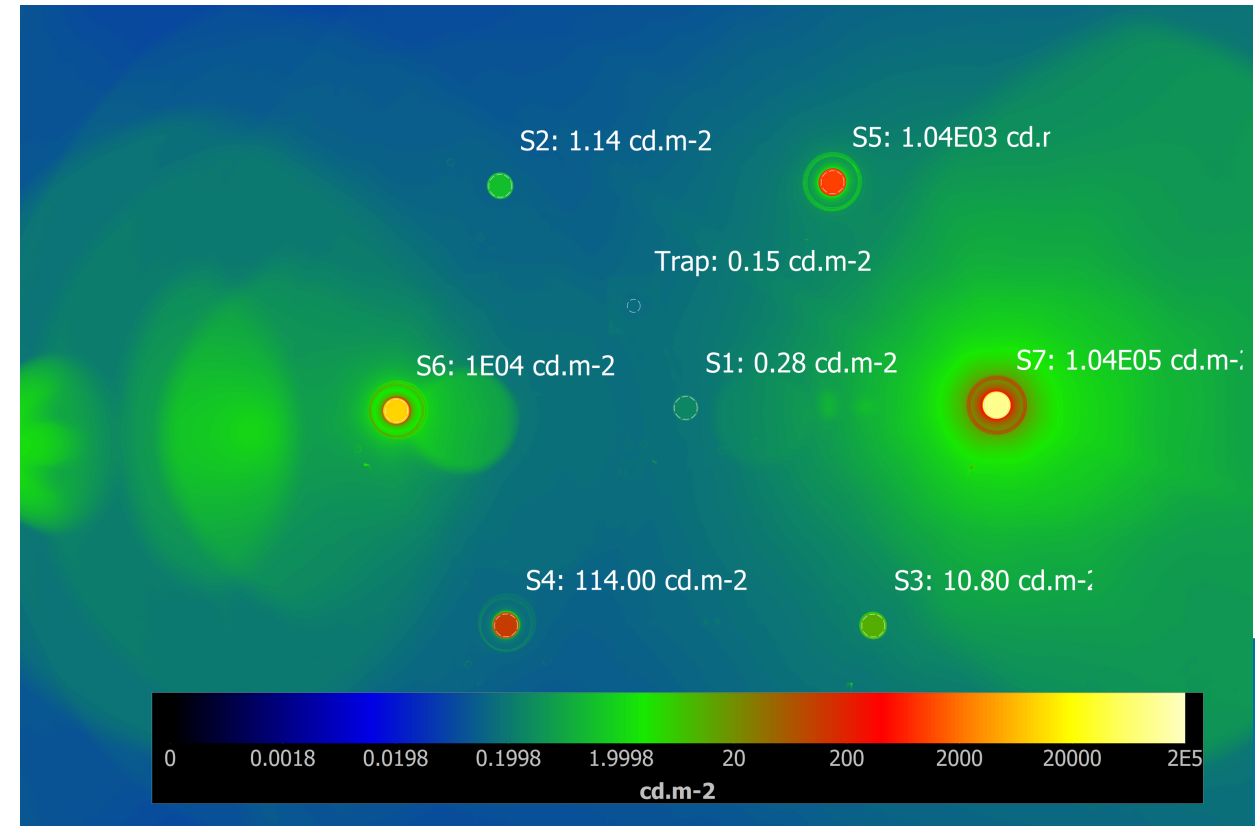




Characterization of imaging devices using reference light sources

Johannes Ledig, Petr Kliment,
Alejandro Ferrero, Christian Schrader,
Sumita Pommerol, Costi Bouroussis

August 28th 2025



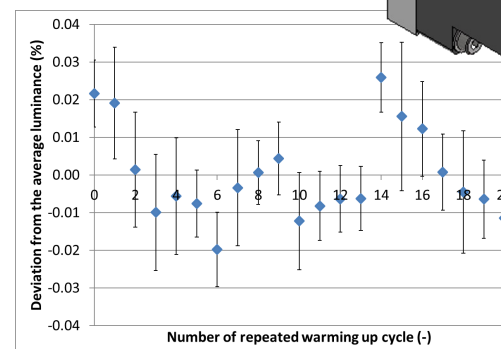
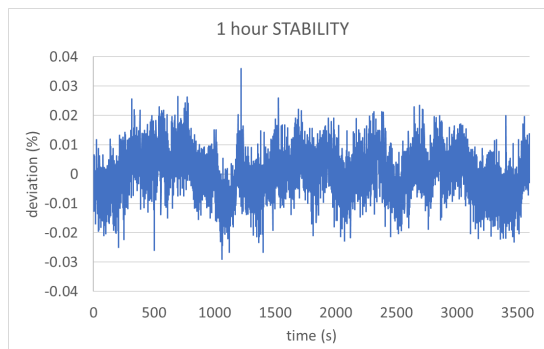
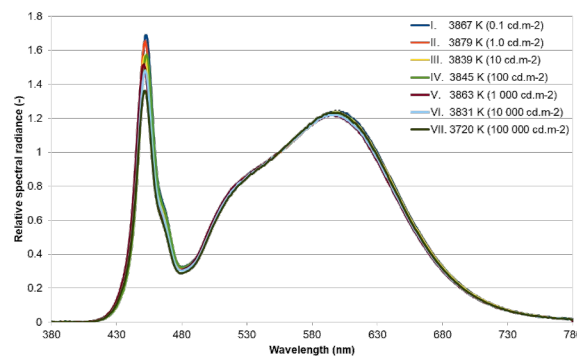
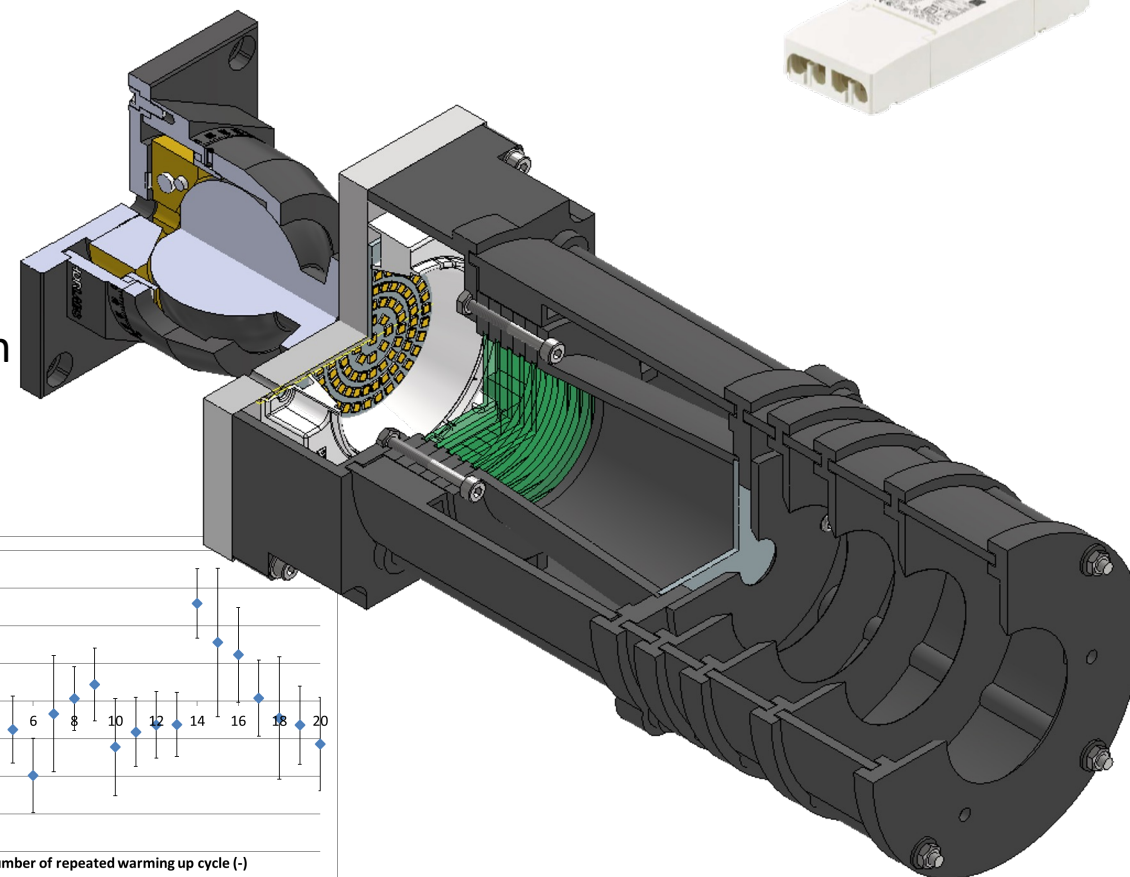
High contrast luminance source: revised prototype

Based on commercially available **off-the-shelf components** and **3D-printing** technology:

- **White LEDs on PCB and diffuser**: Philipps FORTIMO LED DLM FLEX 5000/840 GEN2
LED module diameter of about 60 mm, colour temperature 4000 K, Luminous flux 5000 lm.
- **LED driver** (stabilised current source): XITANIUM 50W WH
AM dimming reduces the current through the LEDs
- **Neutral density filters** (as a stack inside a light mixing chamber)
combined with dimming via a digital parameter of the driver

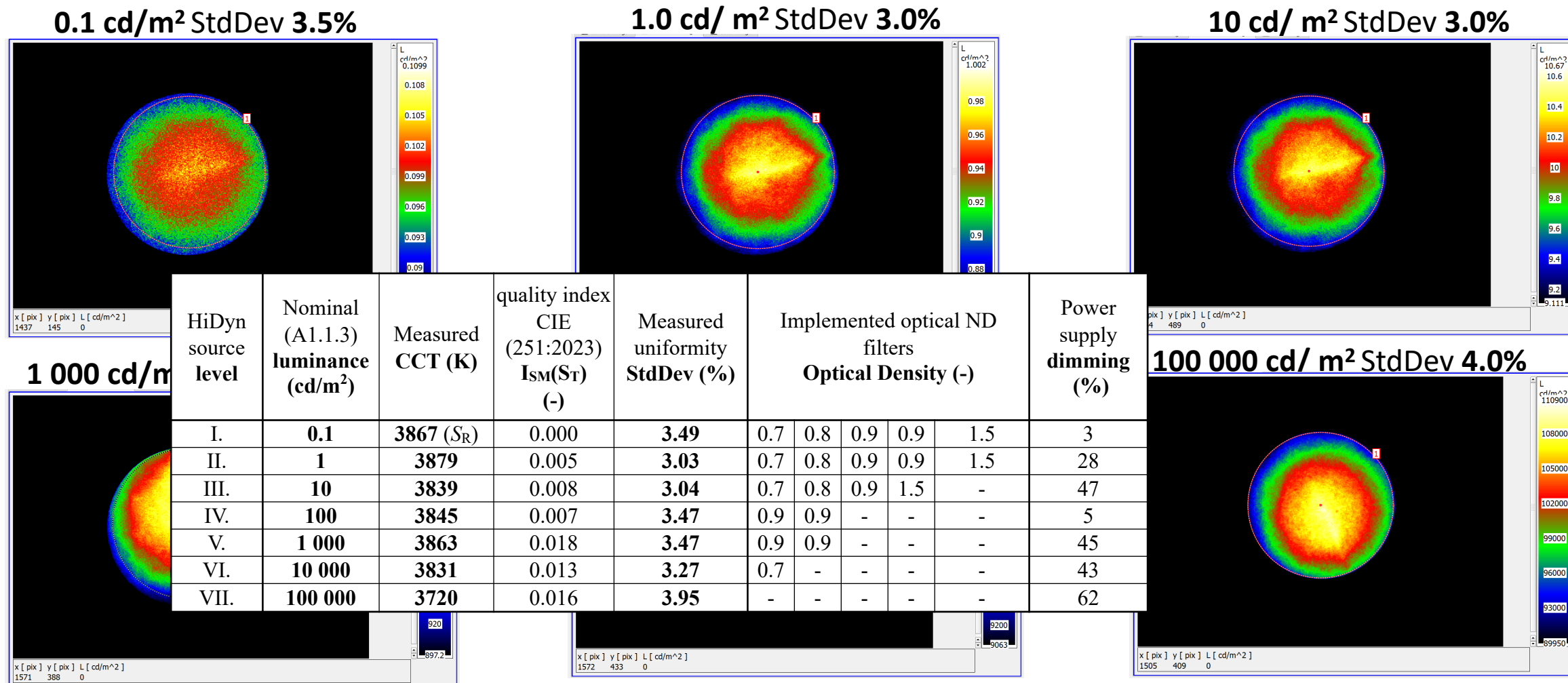
➤ Long term stability: repetitive operation, low drift after stabilization

➤ Prototype: 7 particular sources to cover 6 orders at hand
with luminance values from about 0.1 cd/m² to about 100 kcd/m²



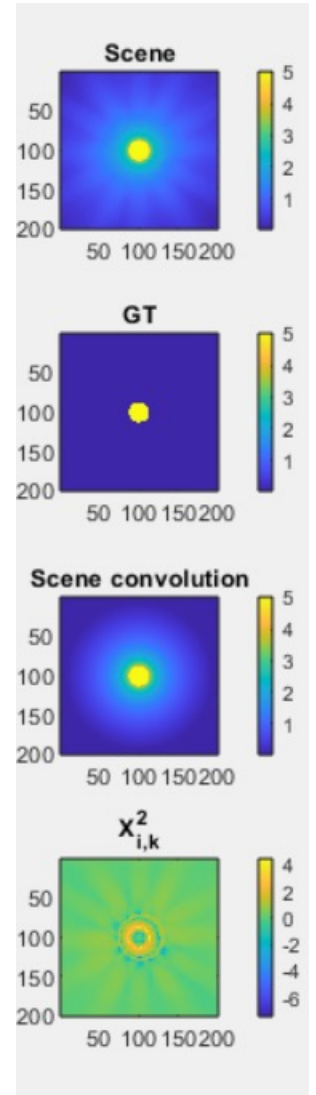
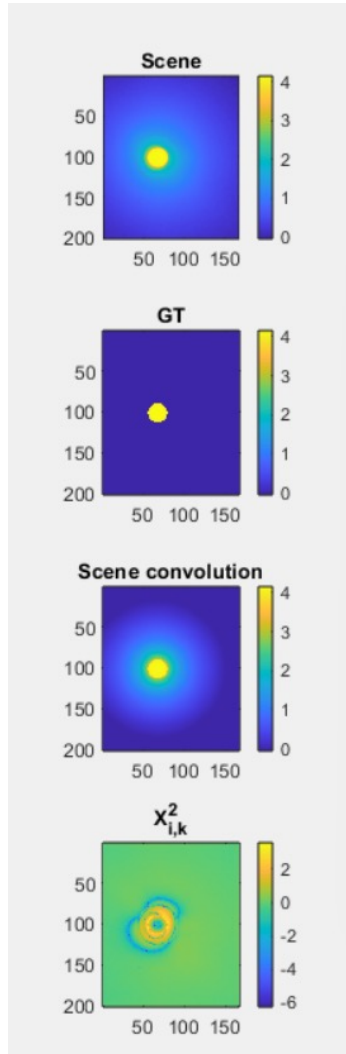
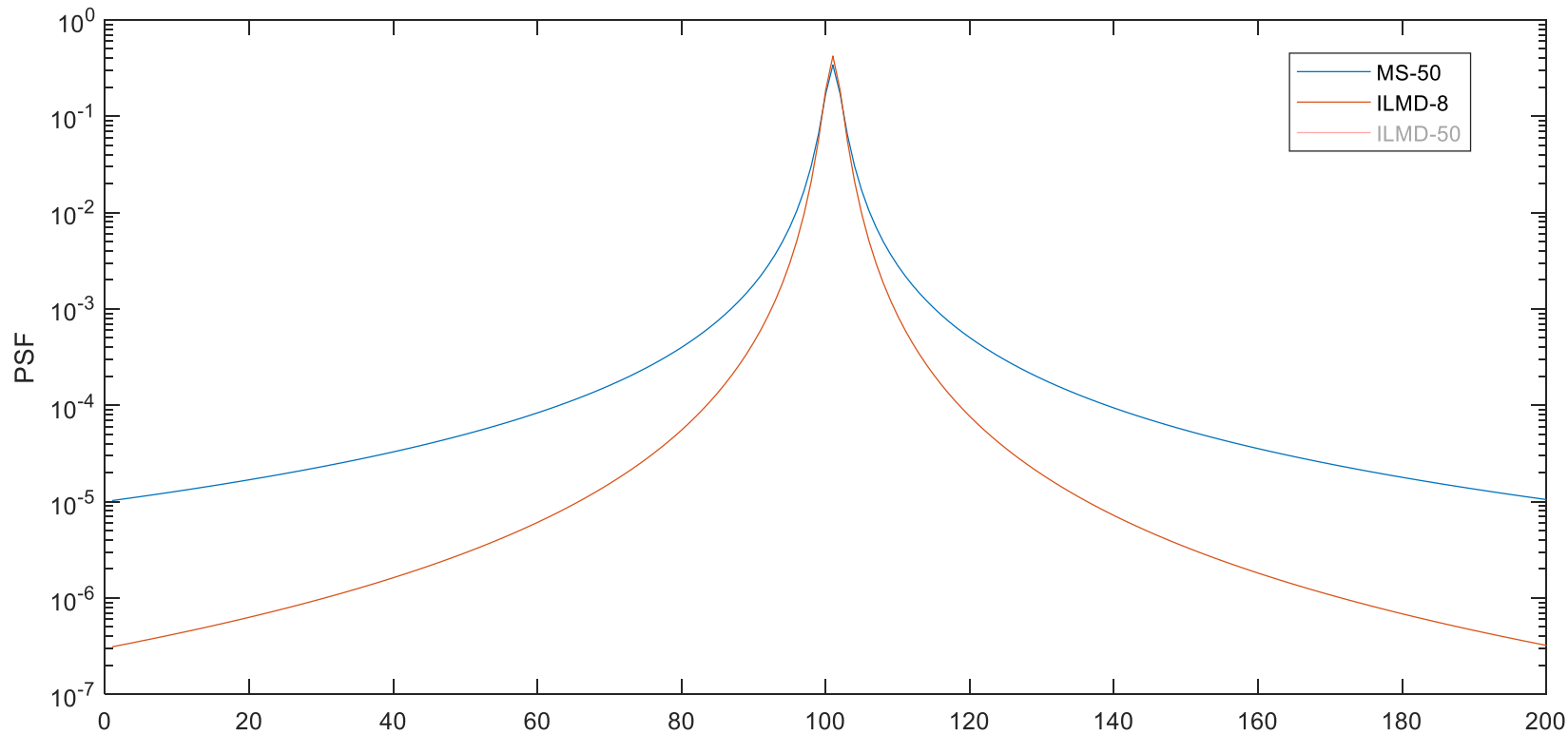
High contrast luminance source: revised prototype

Spatial uniformity (aperture diameter 45 mm, viewed by an ILMD placed normal to the emitting surface)



Point Spread Function (PSF)

for estimating the straylight in measurements close to the light source



Achievements: lab-based measurement session in M18

Characterization of ILMDs and industrial vision cameras using seven prototypes of the revised high contrast luminance source in a measurement session at the lab of [CMI in Prague](#) on 05.-07.03.2024 together with partners [CSIC](#) and [METAS](#).

Using various arrangement of sources and ILMD configurations (lenses, aperture)

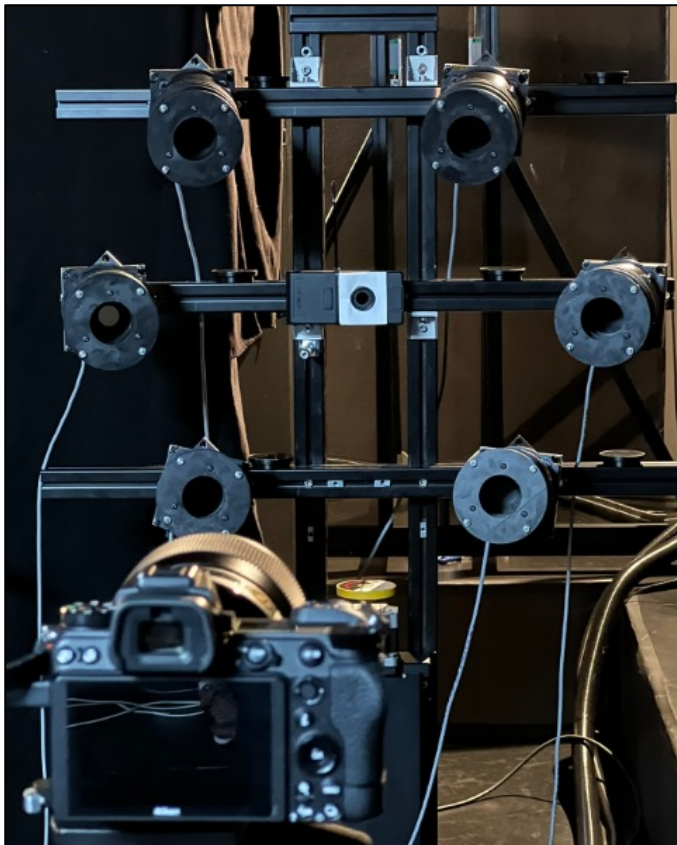
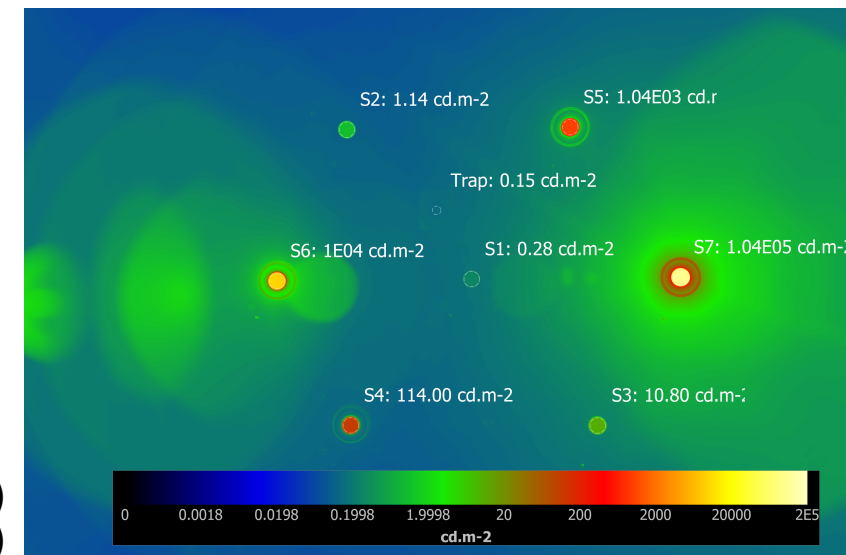
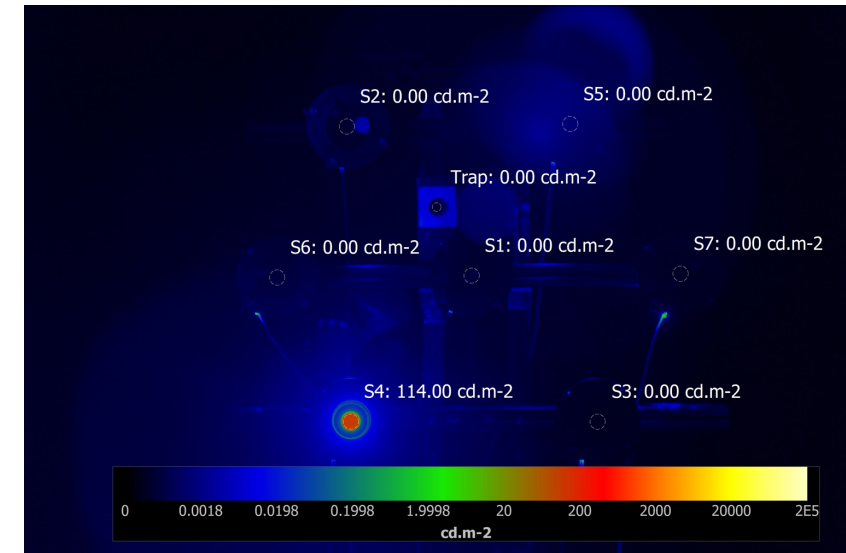


Photo of the setup at [CMI](#), with room illumination



LDR luminance image with all luminance sources lit

HDR luminance image with one source lit (top)
and with all sources lit (bottom)





21NRM01 HiDyn
{HiDyn}

D1: Report describing the design, development and technical specification of a type of high-contrast-luminance reference standard (covering at least 6 orders of magnitude), including the determination of luminance with an expanded uncertainty no larger than 1 % for the brightest source and no larger than 2 % for the dimmest one

Organisation name of the lead participant for the deliverable: CSIC

Due date of the deliverable: 31 March 2025

Actual submission date of the deliverable:

DOI:

Confidentiality Status: PU - Public, fully open (remember to deposit public deliverables in a trusted repository)

Deliverable Cover Sheet

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

European Partnership

Cofunded by the European Union

METROLOGY PARTNERSHIP



The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

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4.9 Manual how-to assembly the module

The 3D model of one of the assembled Hidyni module is shown in Figure 11. The construction of each of the 7 modules is very similar. A particular module is assembled from the components listed in the appropriate tables see the section 4.8. In the following, How-to assembly the module manual is provided based on the several steps.

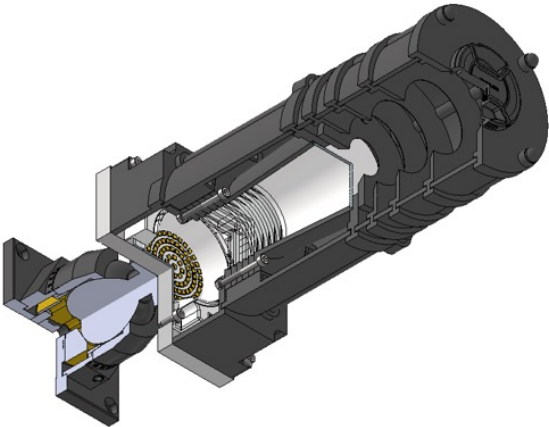


Figure 11: rendering of the 3D model of one assembled Hidyni module with cover cap

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Step 8

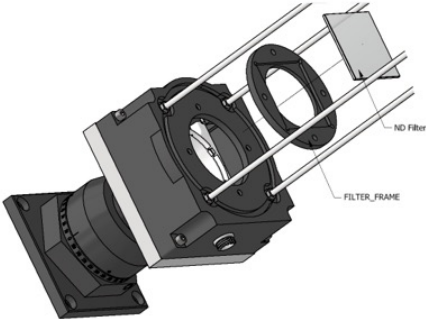


Figure 19: rendering of assembling Step 8

Table 21 Parts for Step 8

Parts Description	Qty.
FILTER_FRAME	5
ND_Filter	5

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High contrast luminance source: replicated at METAS

Design guide (internal draft, used by METAS)

- Bill of Materials, 3D printed parts (STL-files)
- Assembly manual; minor modifications @METAS

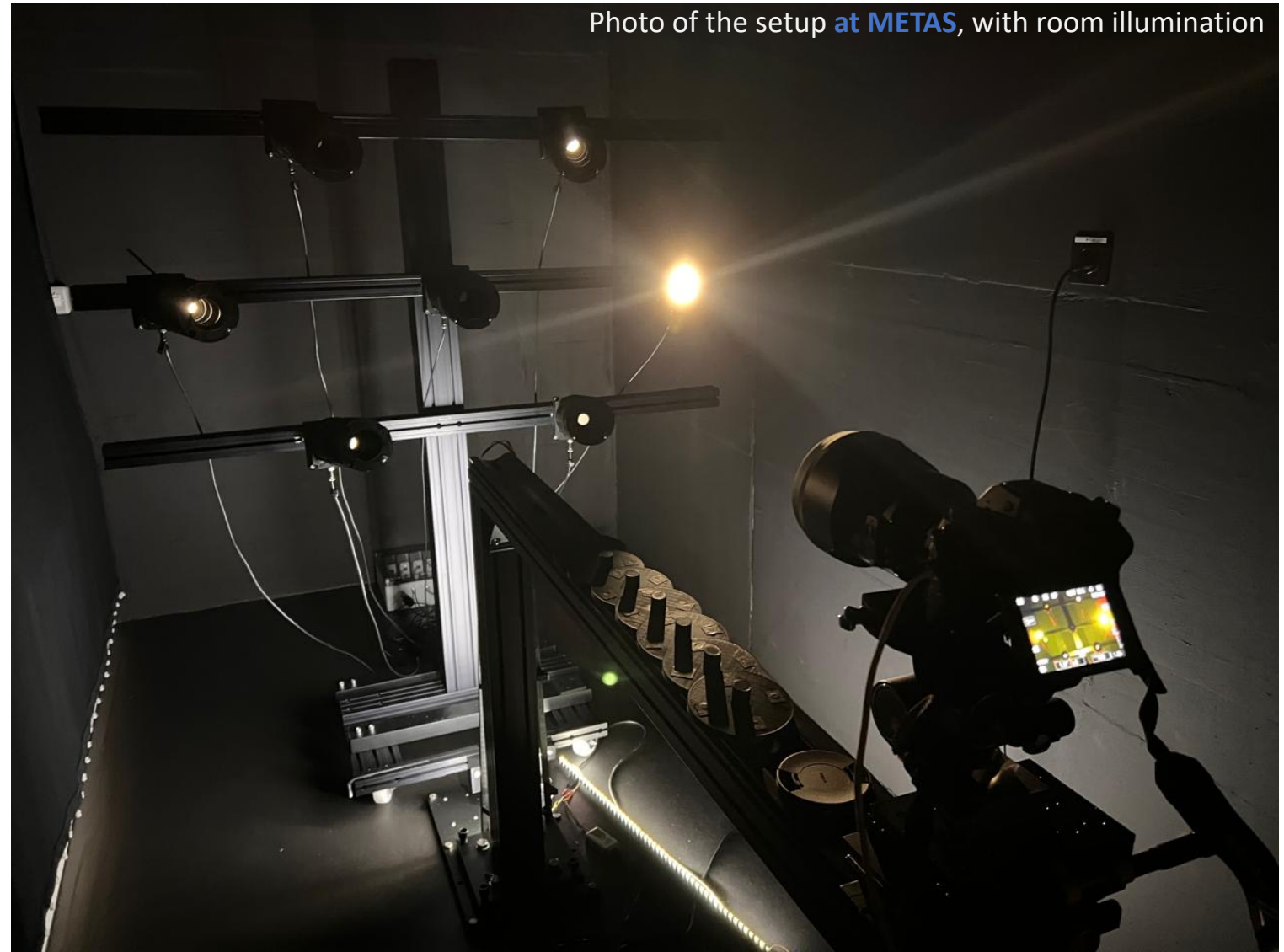
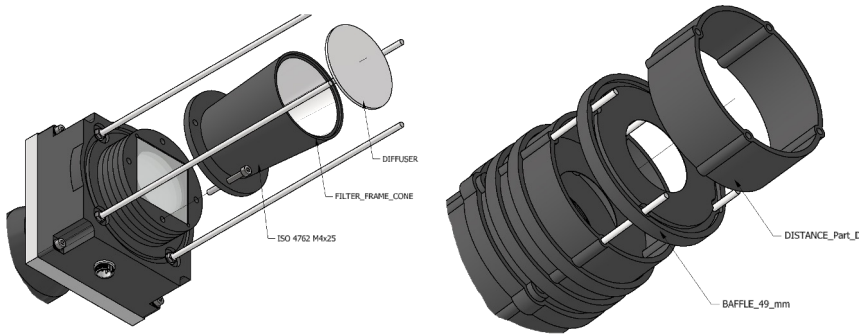
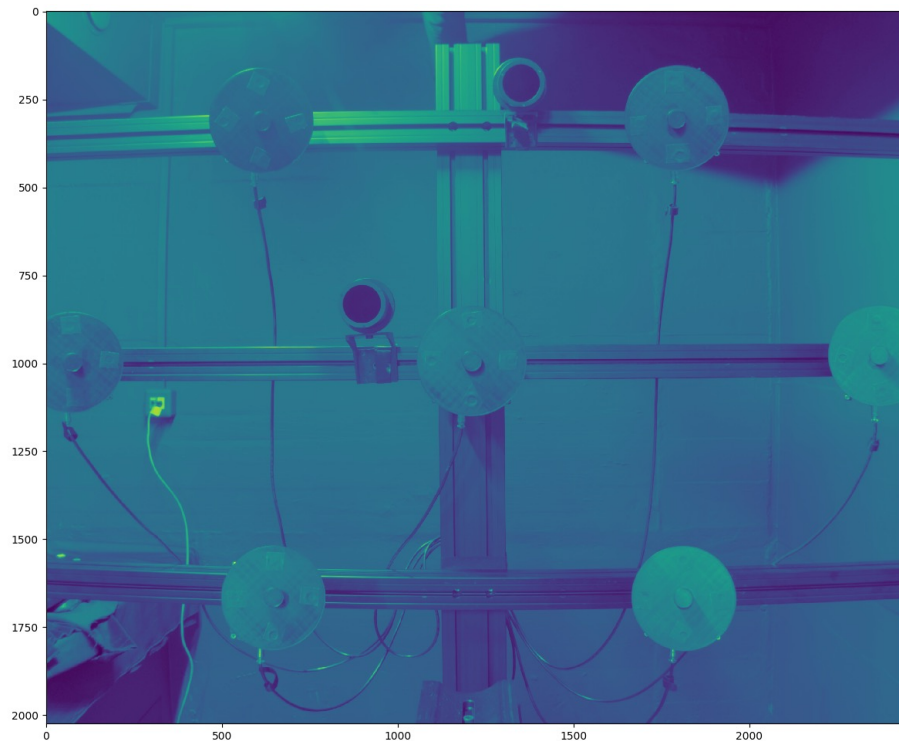
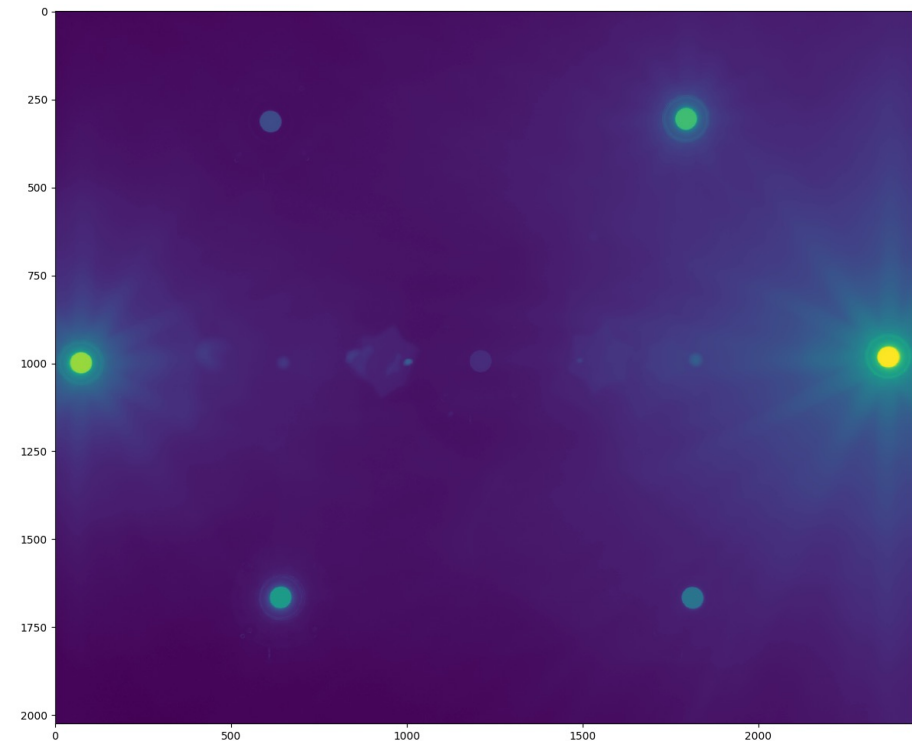


Photo of the setup at METAS, with room illumination

- measurement uncertainty for ILMD-based HDR measurements for glare assessment
- “HiDyni”-reference source dedicated for characterization of ILMDs (seven LED-based luminance sources and a light trap)



False colour luminance image with room illumination and each of the seven HiDyni sources blanked out by a cover

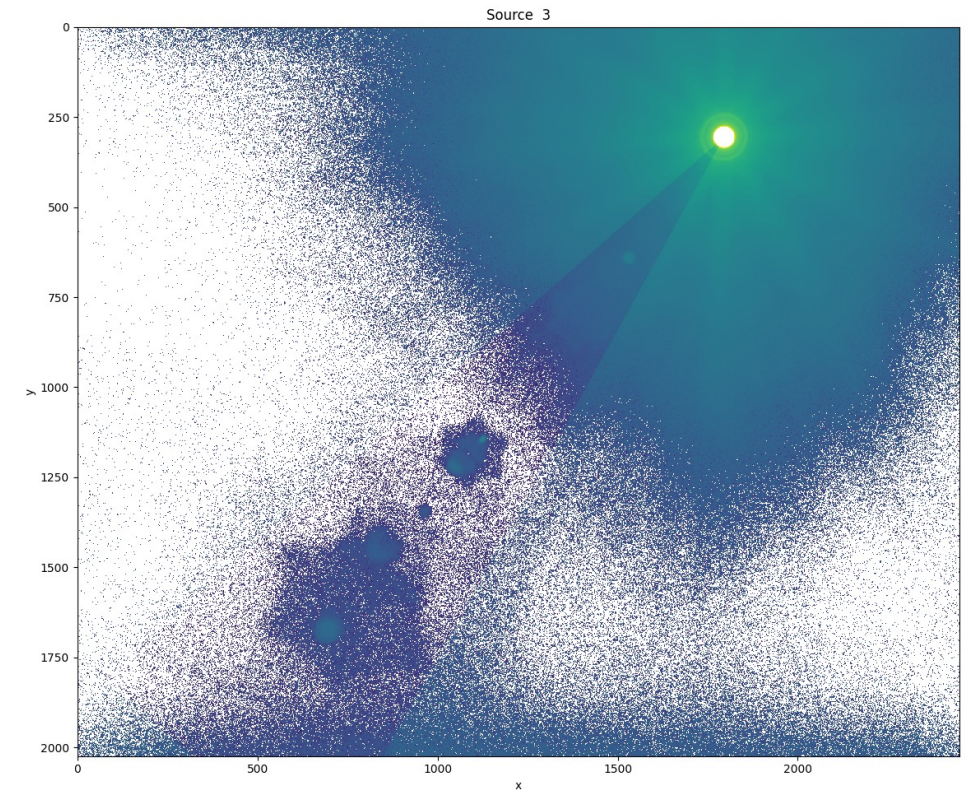
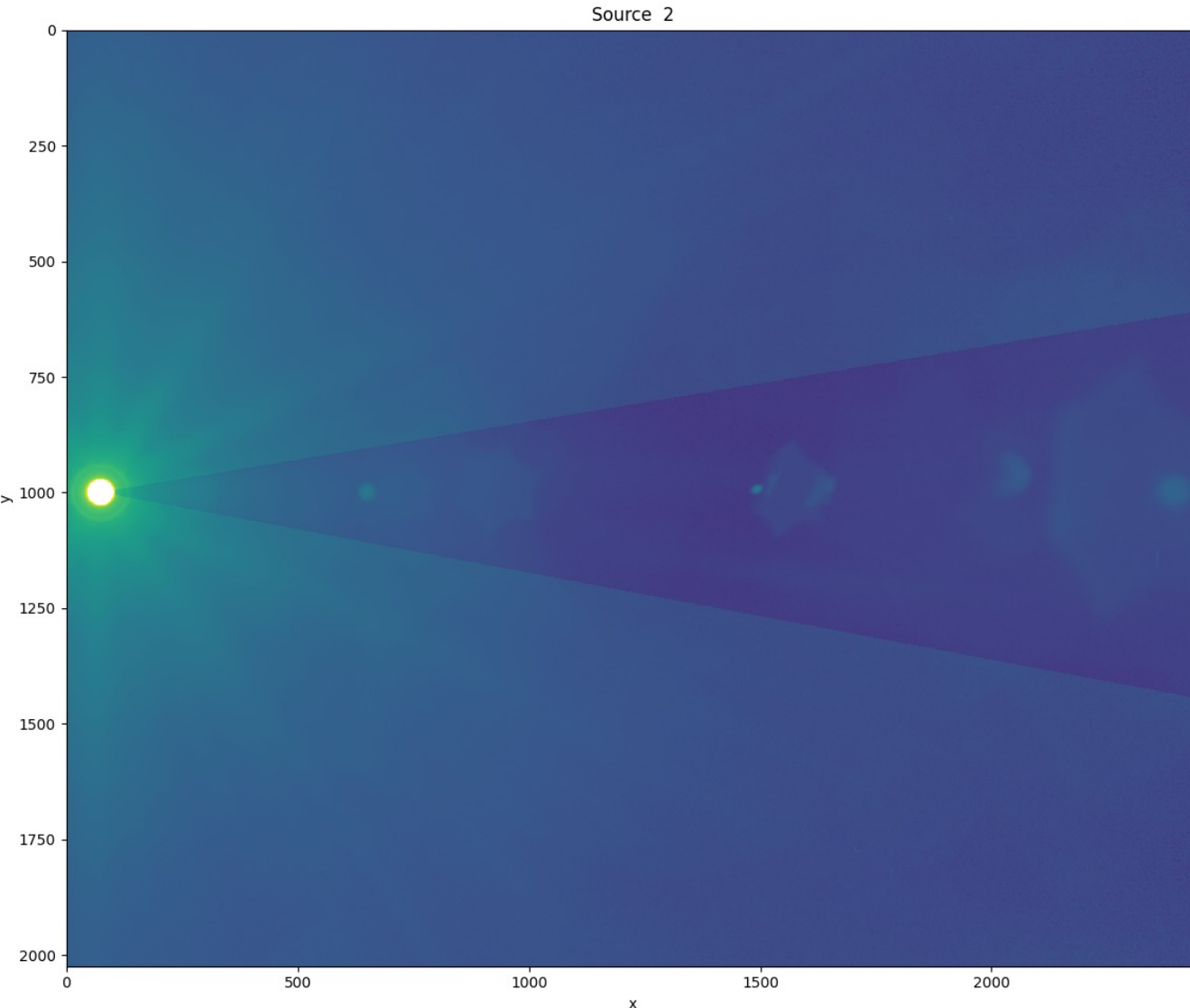


False colour luminance image with all seven sources open and lit, demonstrating straylight and ghosts

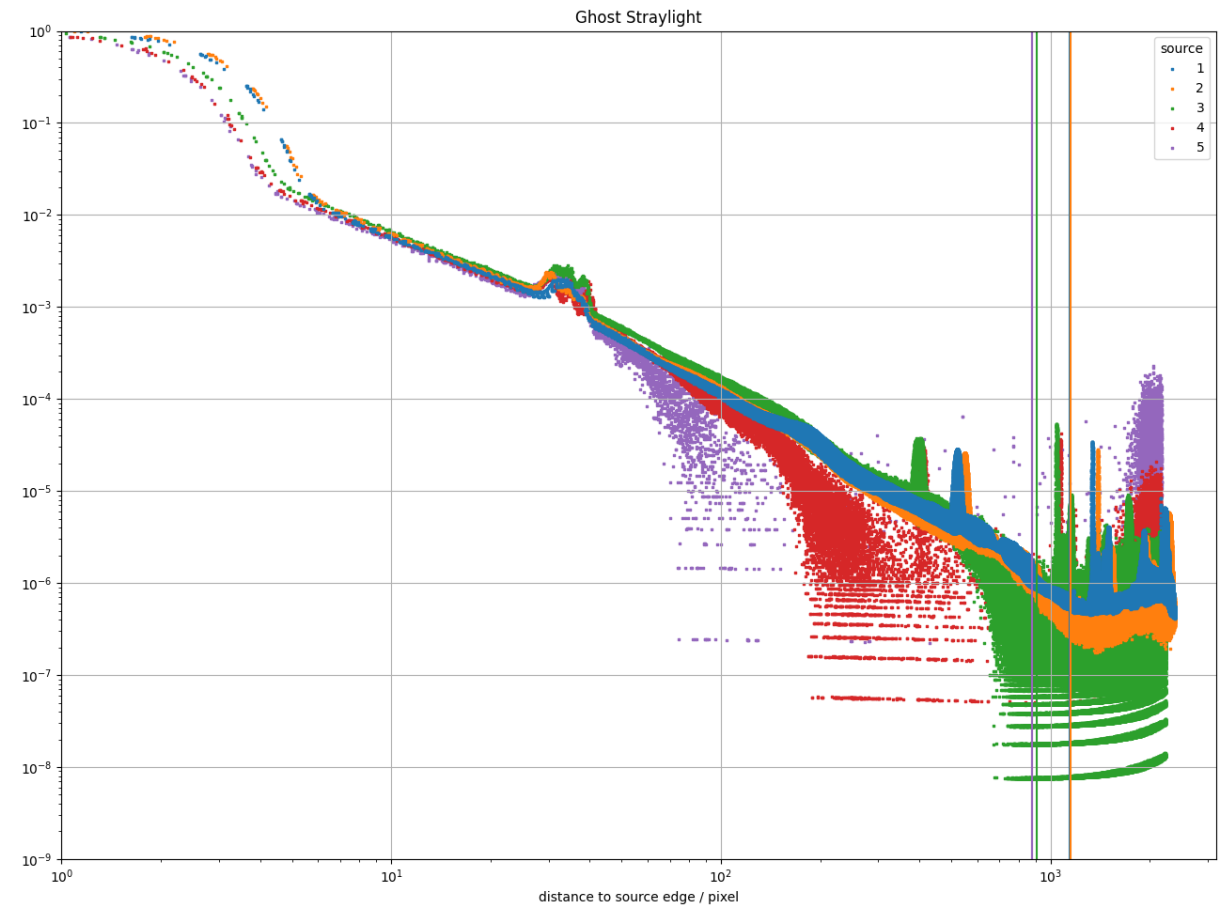
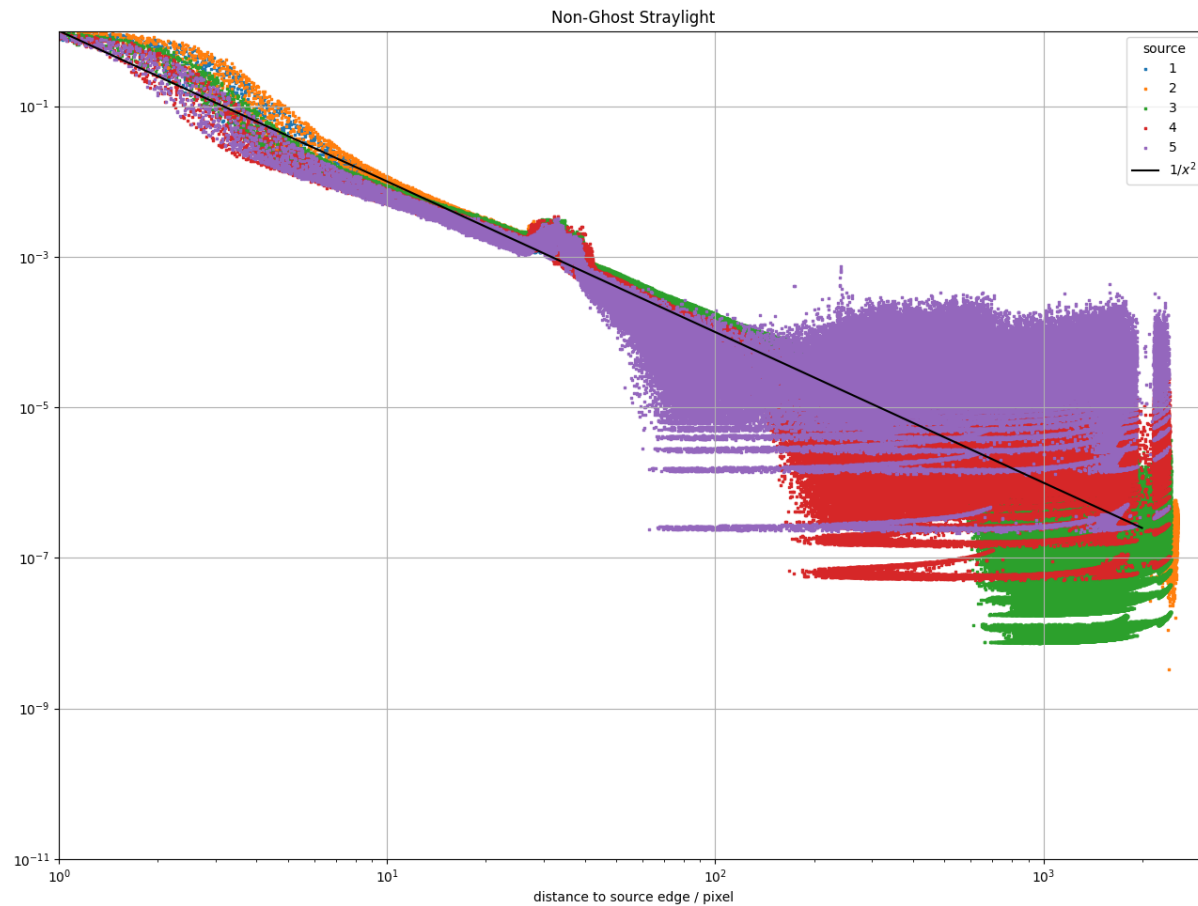
How to estimate straylight? First steps...

{HiDyn}

- use single-source HDR images
- determine ghost corridor (dark triangle)
→ mask out most of the ghosts
- background considered as ideal black!



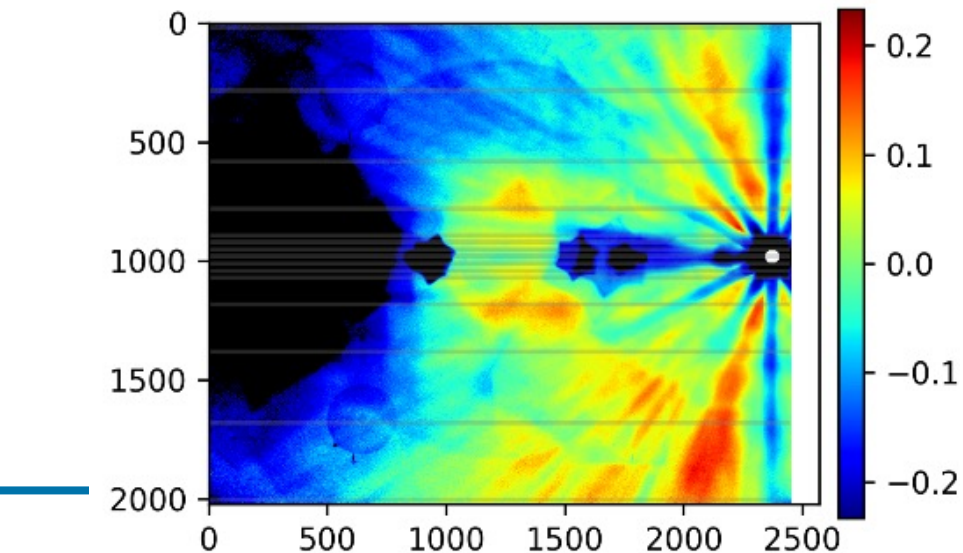
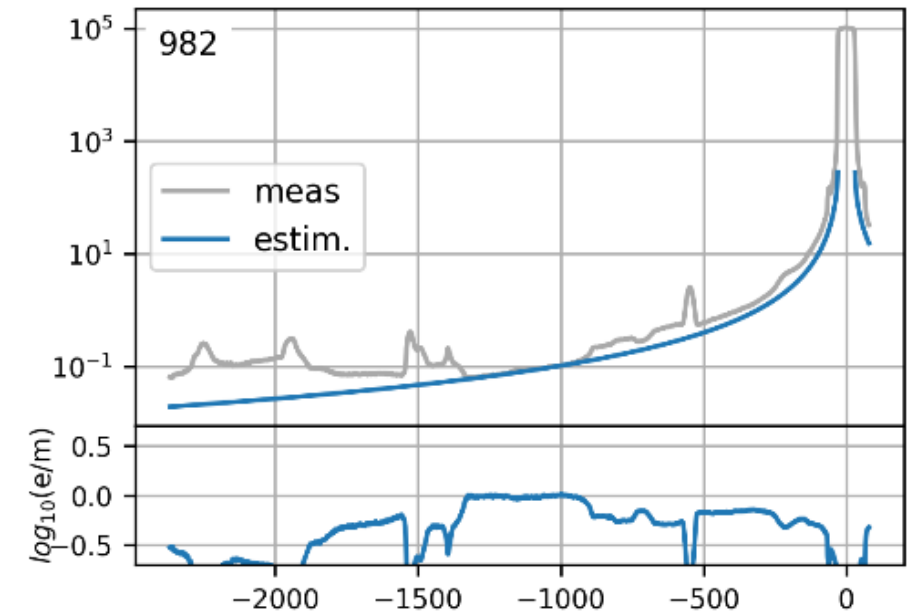
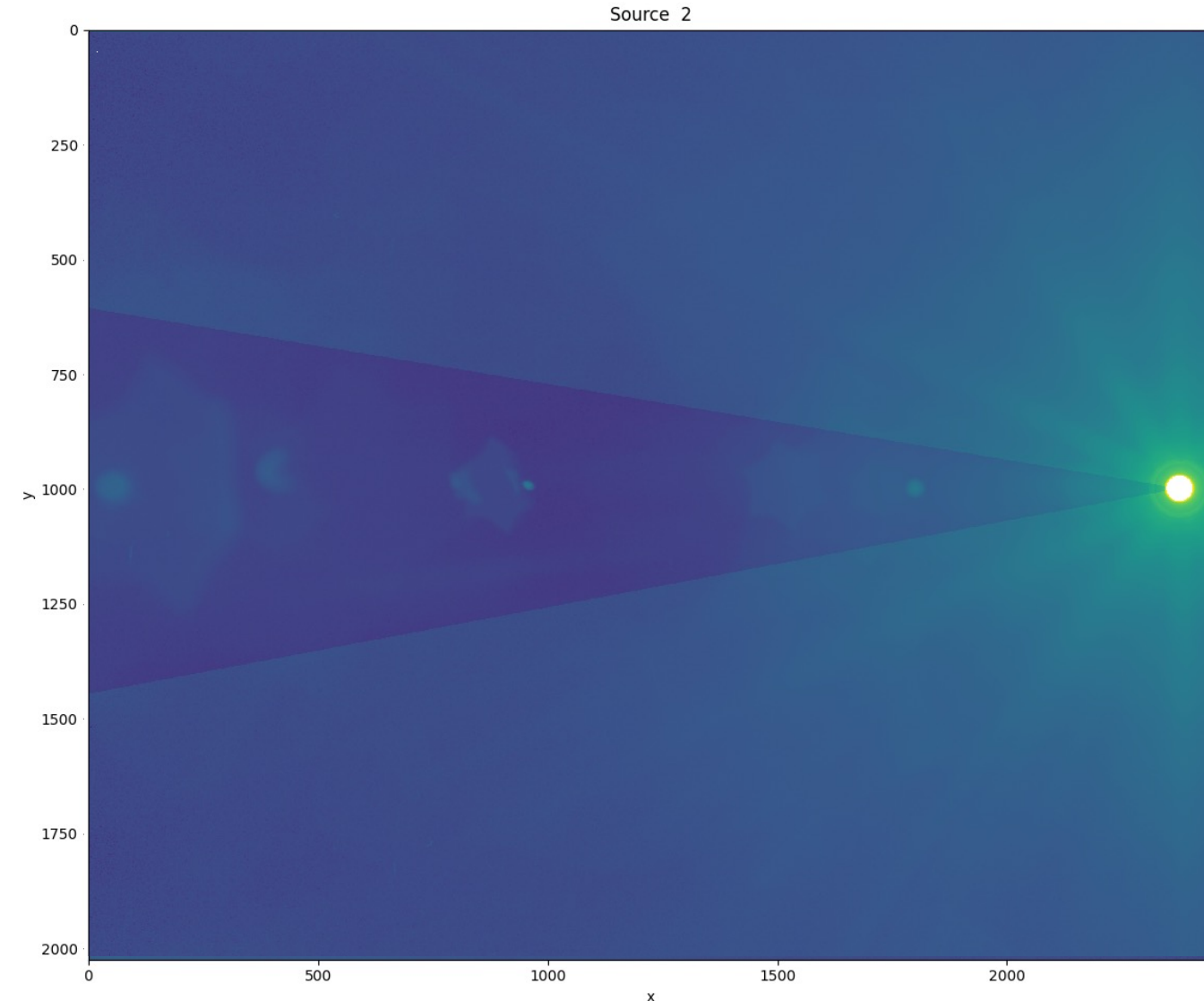
First results...



- with loglog-scaling mostly linear (if sufficient signal and not near source)
→ power function, not exponential! Can be modelled by $a \cdot r^b$

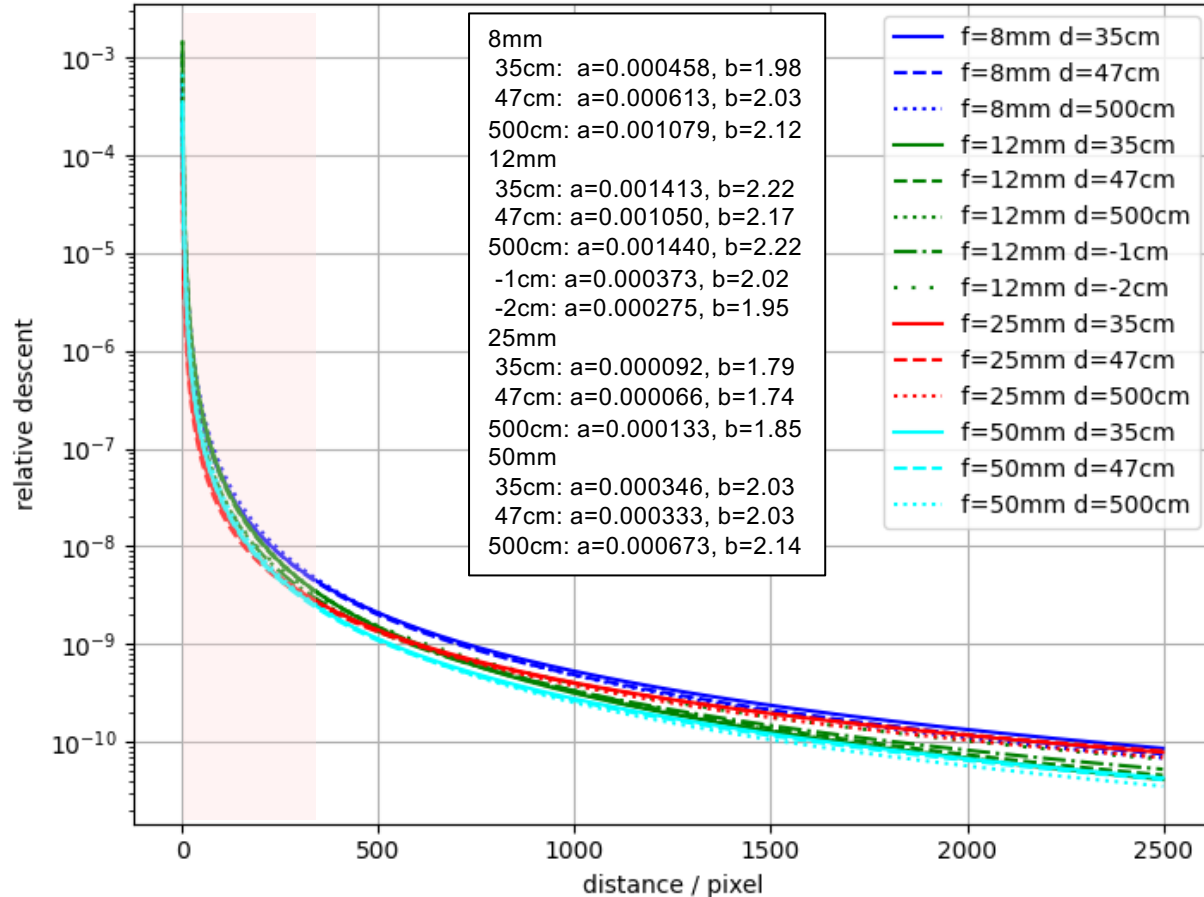
Straylight estimate by $a \cdot r^b$

{HiDyⁿ}

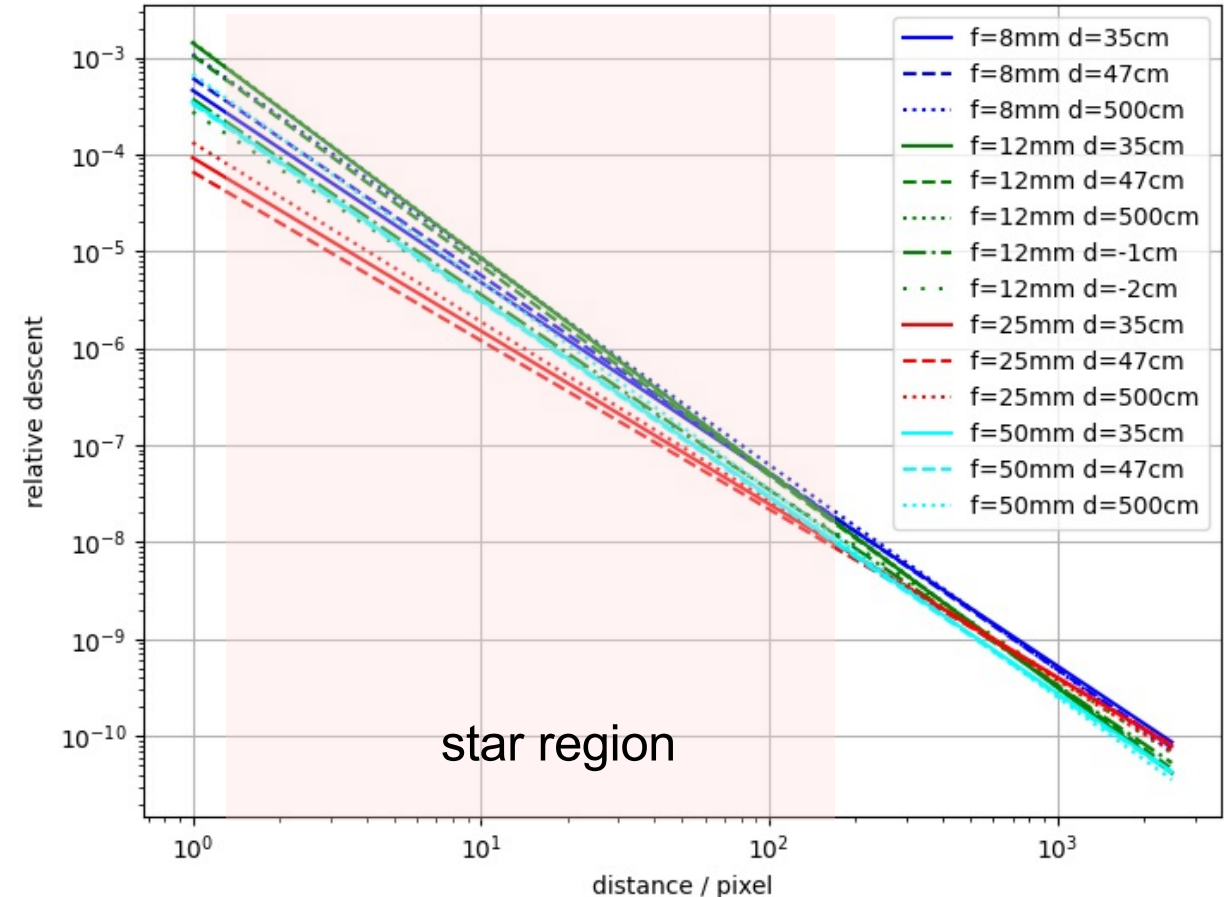


Spread of straylight-parameters for ILMD lenses {HiDyn}

log



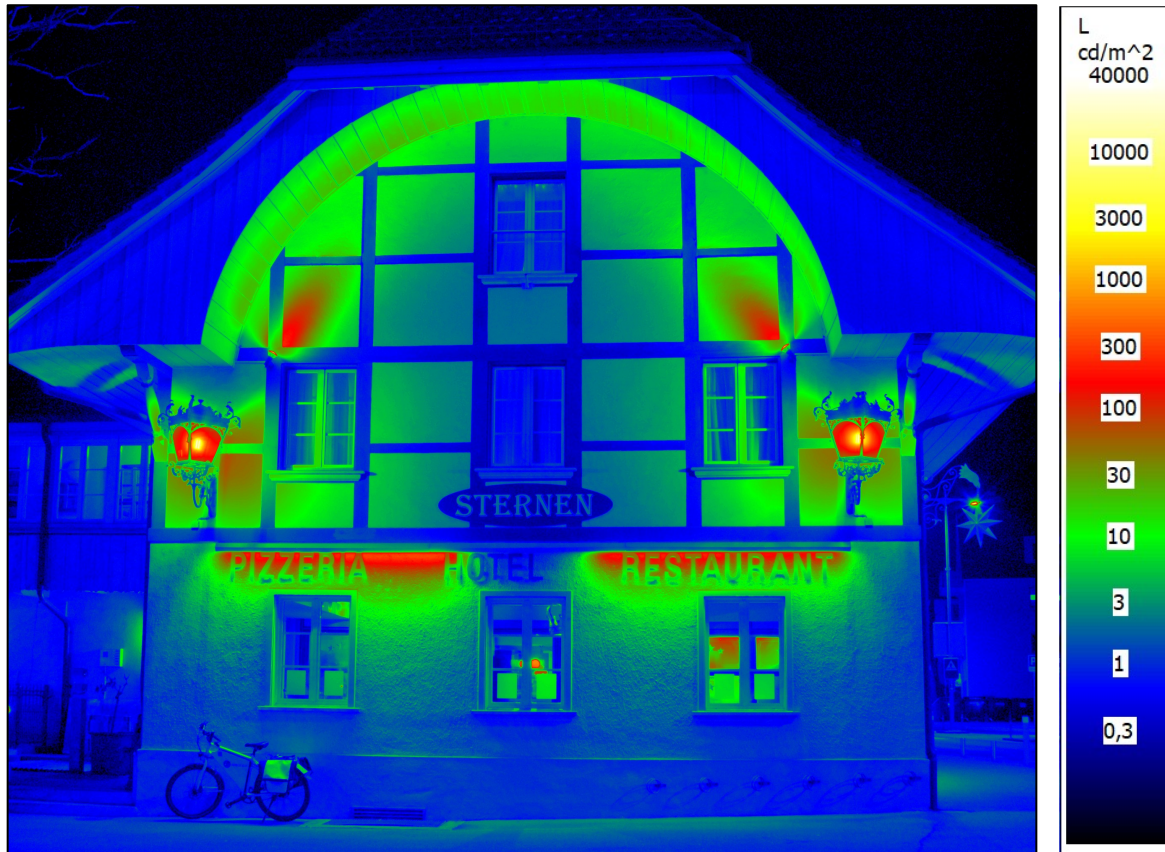
loglog



- small variation of parameters between lenses
- variation caused by focus distance even smaller

Straylight estimate in field measurements

{HiDyn}



HDR luminance image of a high-contrast outdoor scene

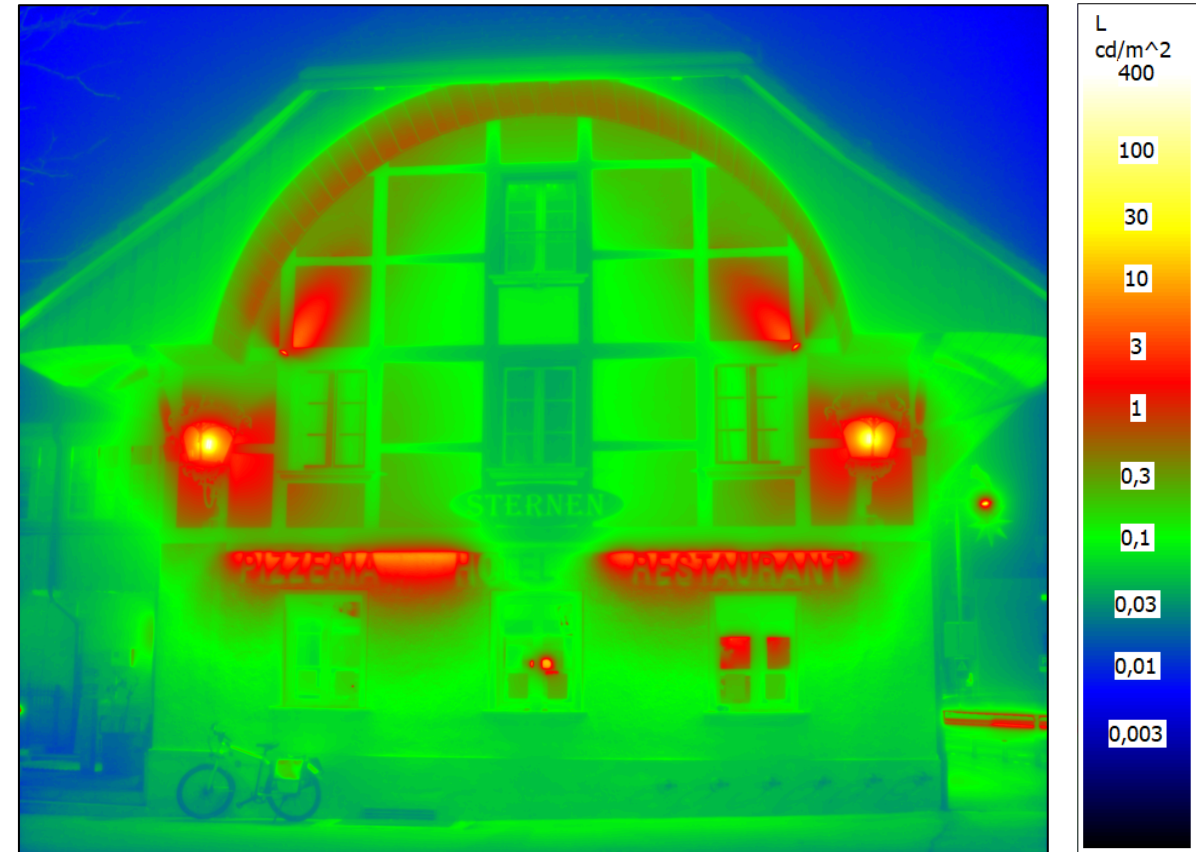
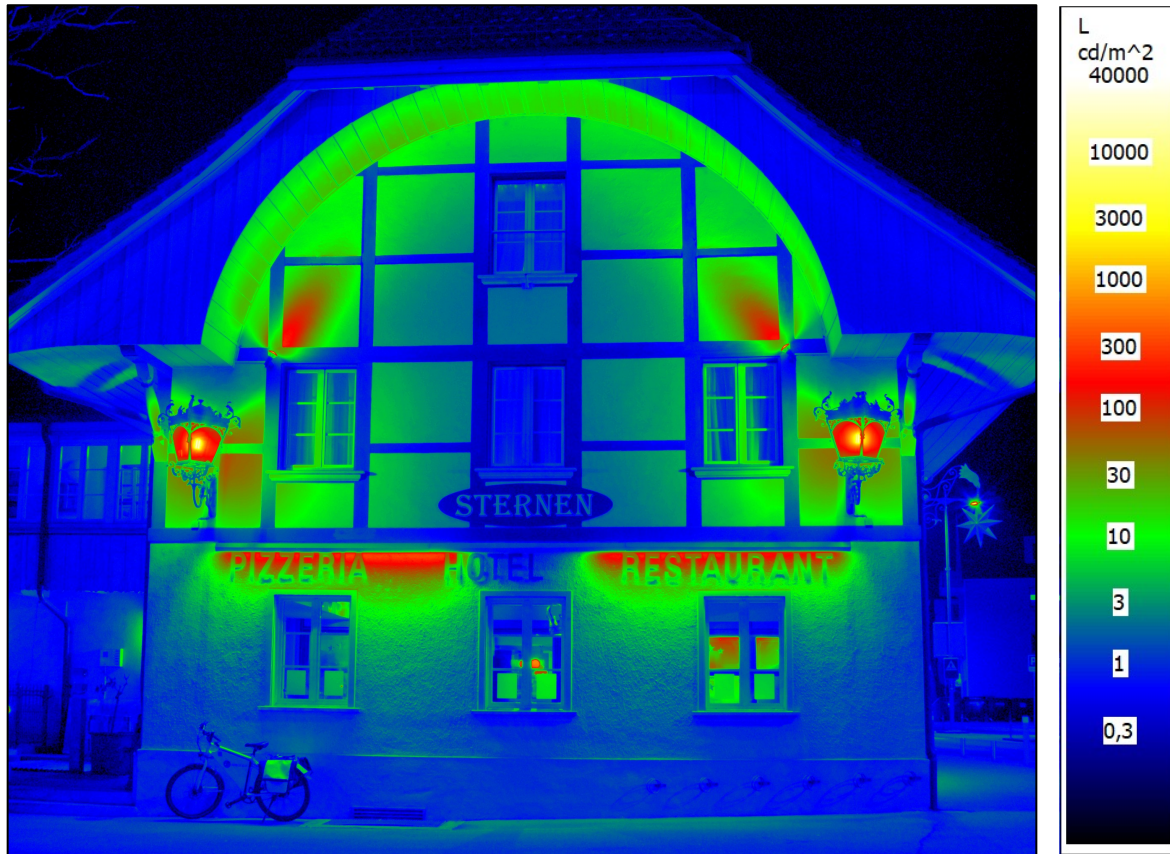
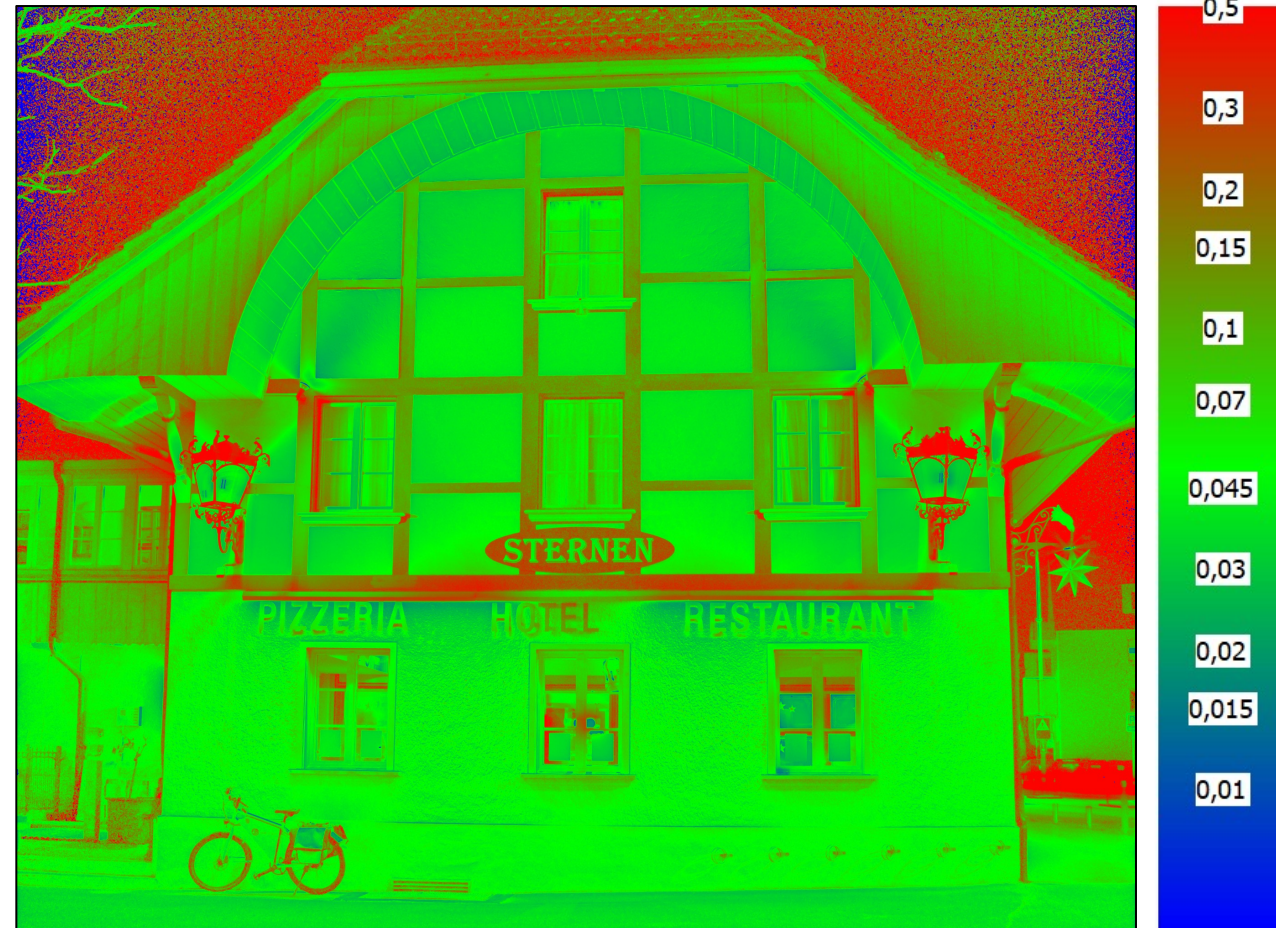


Image of the modeled straylight estimate
(ILMD-internal straylight)

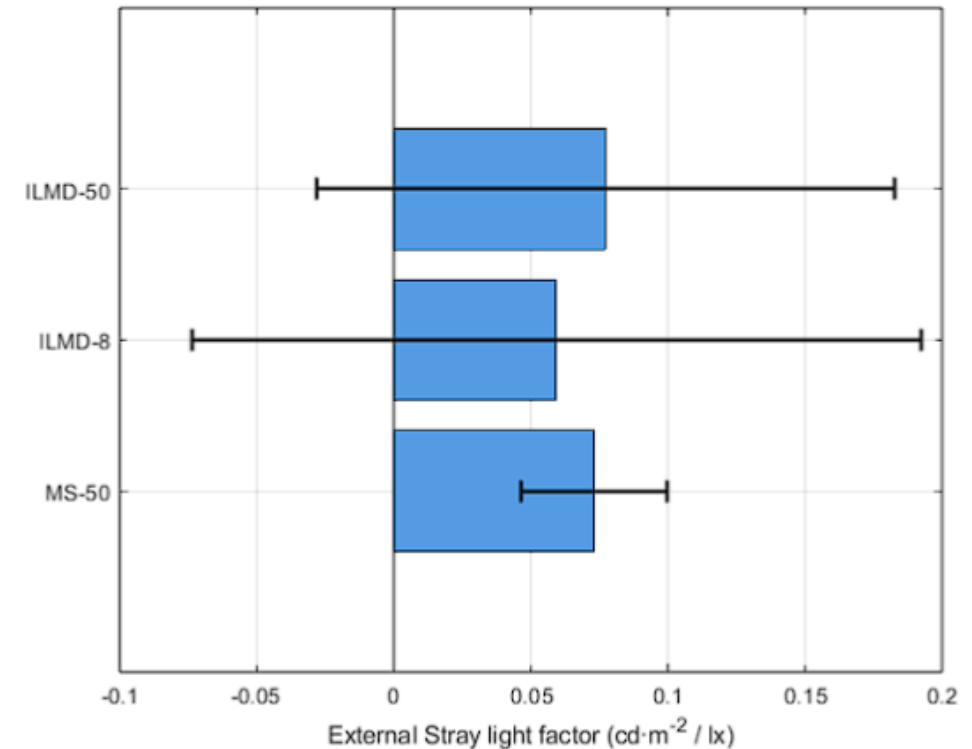
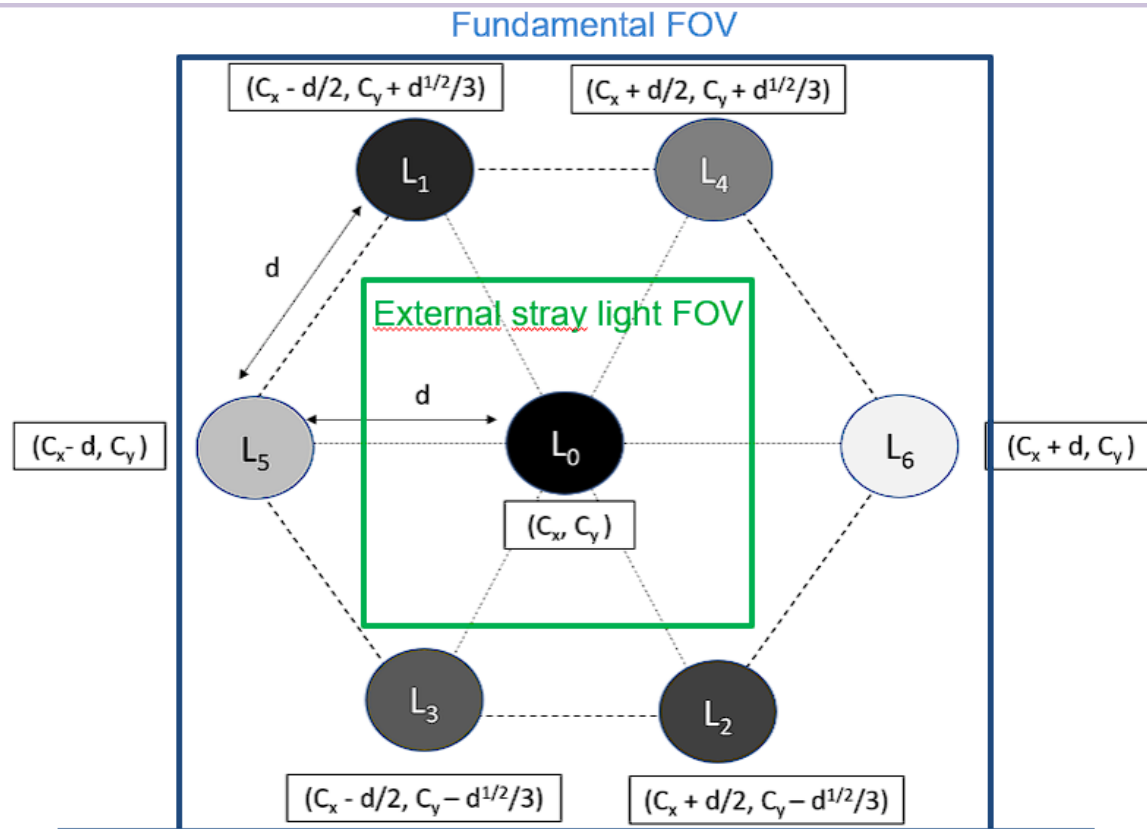
Straylight estimate in field measurements {HiDyn}



Relative straylight estimate image
indicating < 1 % in bright and > 50 % in dark regions



Example for straylight from outside image {HiDyn}



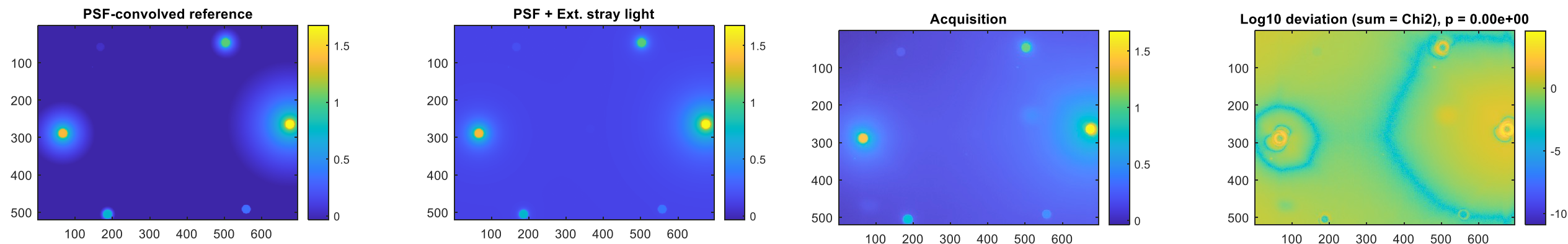
Example for straylight from outside image

{HiD_{yn}}

Characterization of effects
(internal and external stray light, ...)
using individual sources, while others
are **OFF**



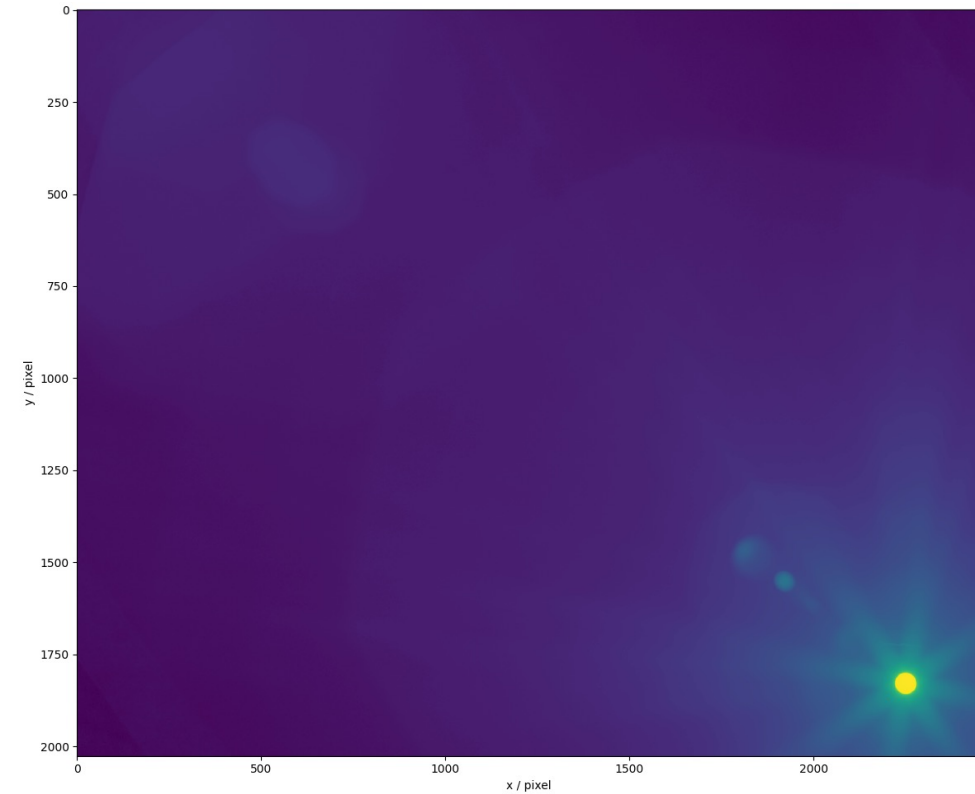
Verification
with all sources **ON**
at the same time





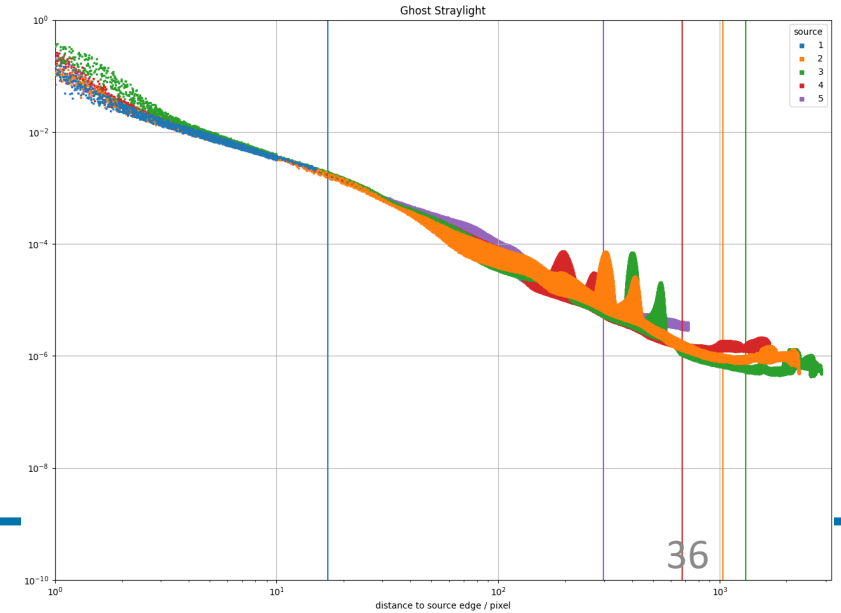
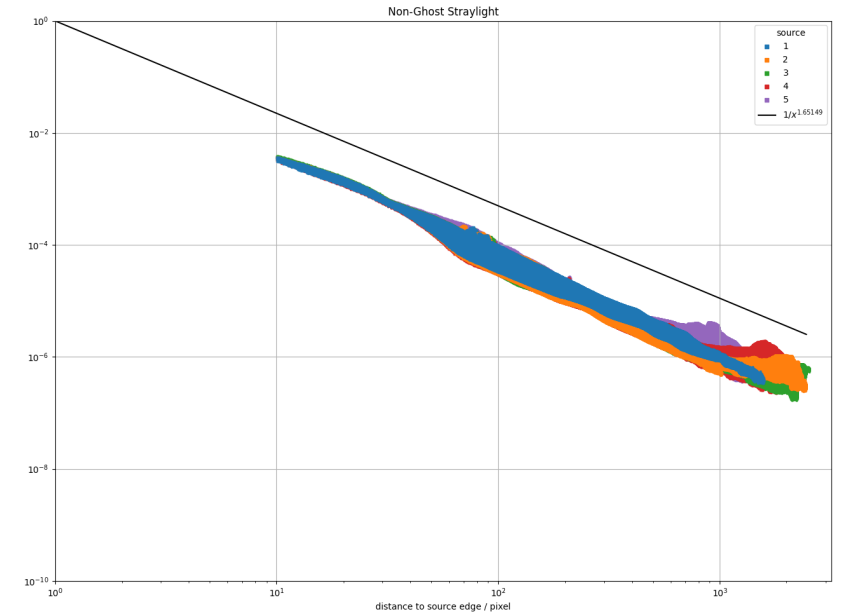
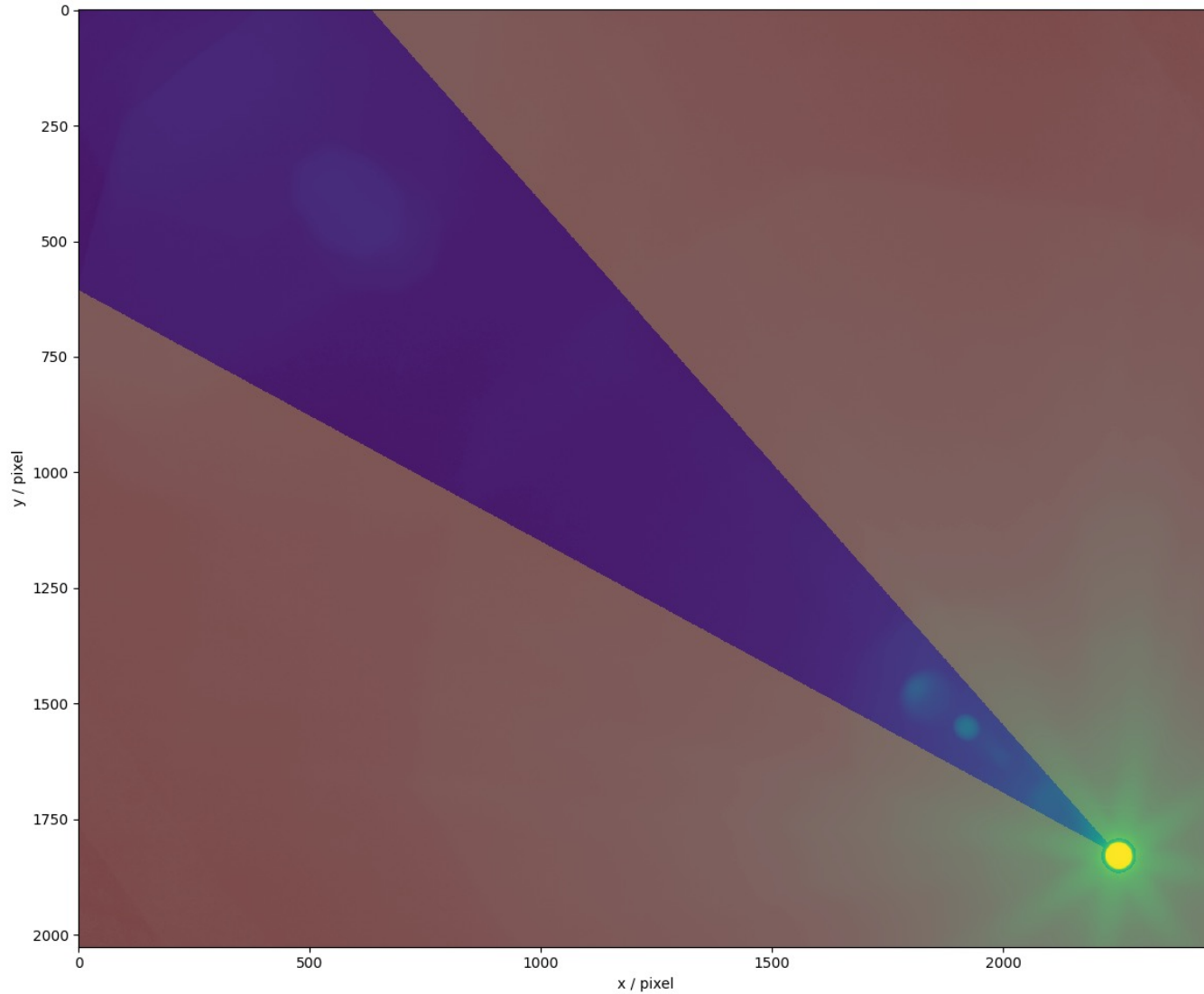
White dark room with black curtain

{HiDyn}



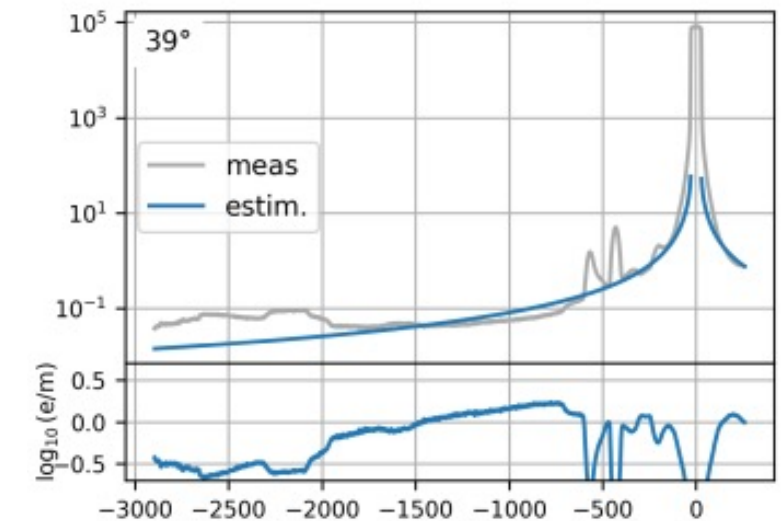
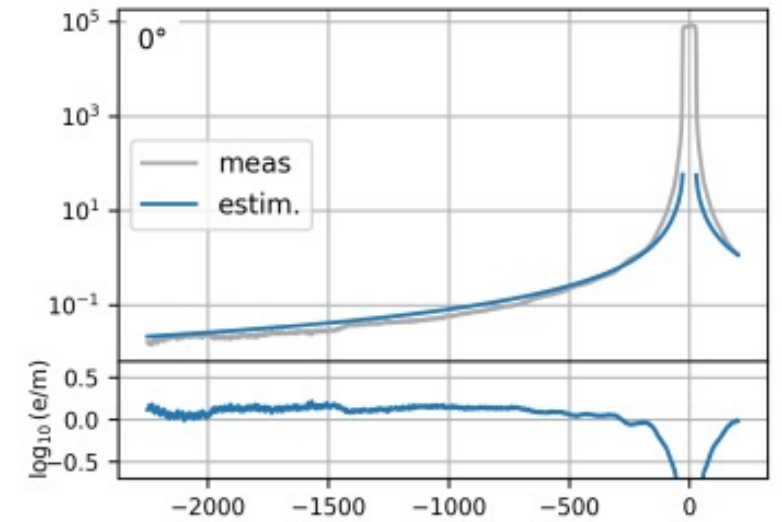
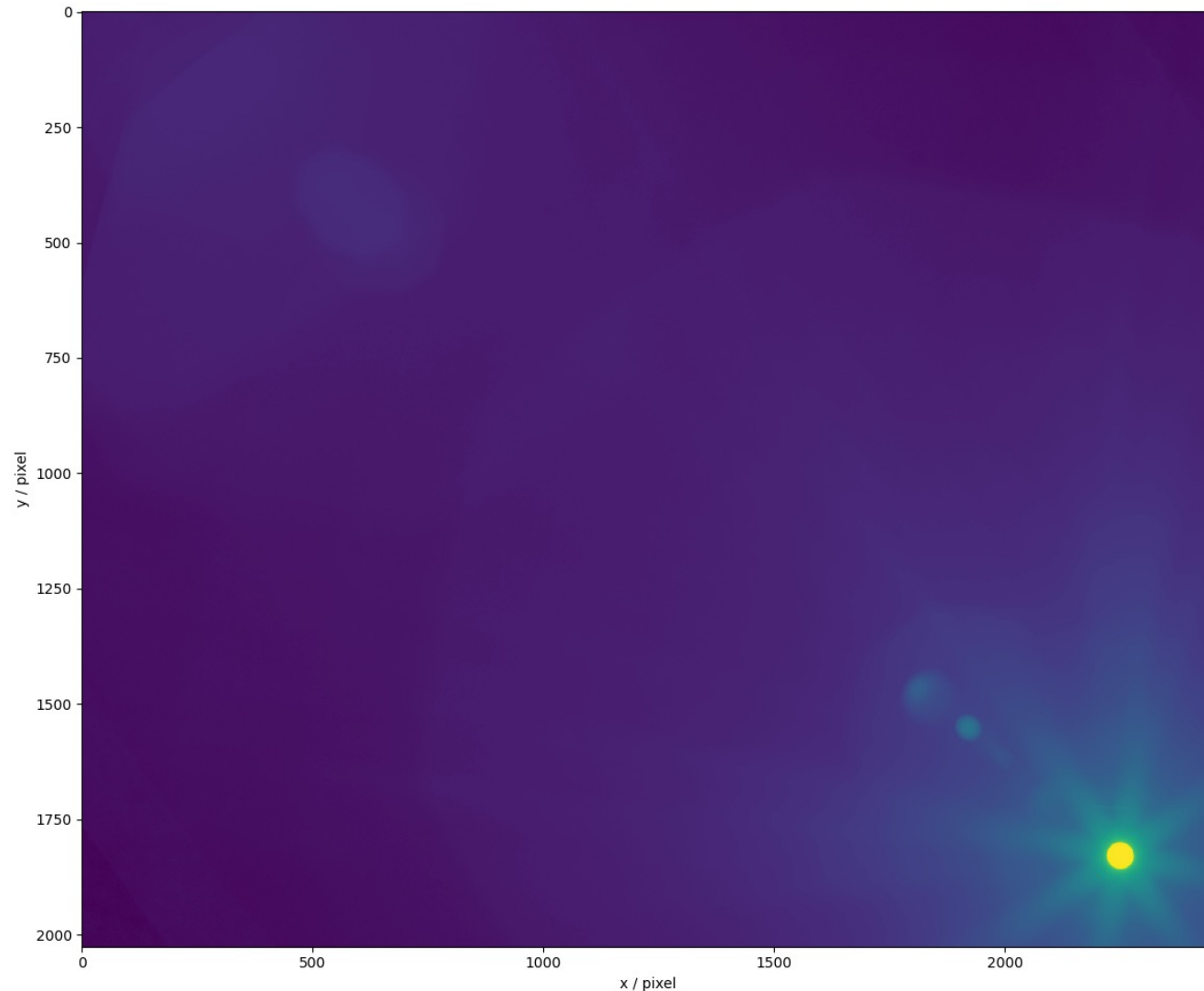
White dark room with black curtain

{HiDyn}



White dark room with black curtain

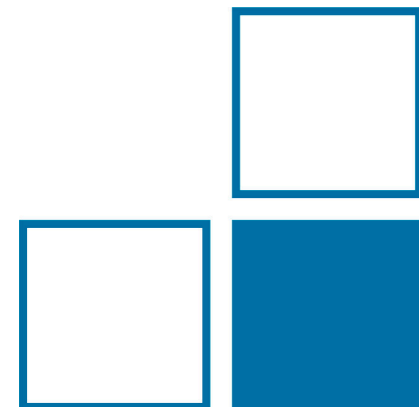
{HiD_{yn}}



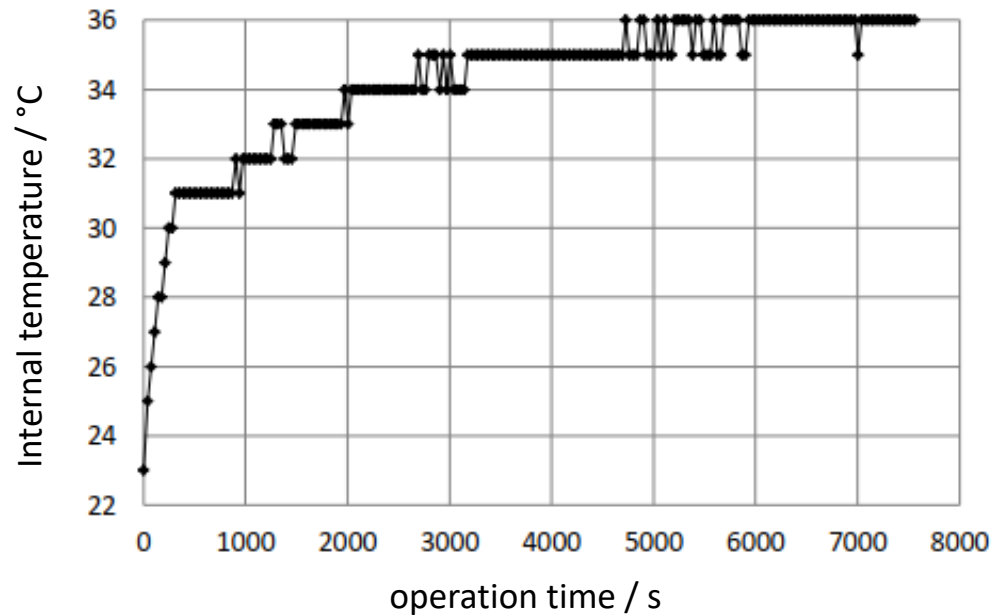
Checklist of ILMD configuration

To avoid significant errors which cannot be covered by uncertainties

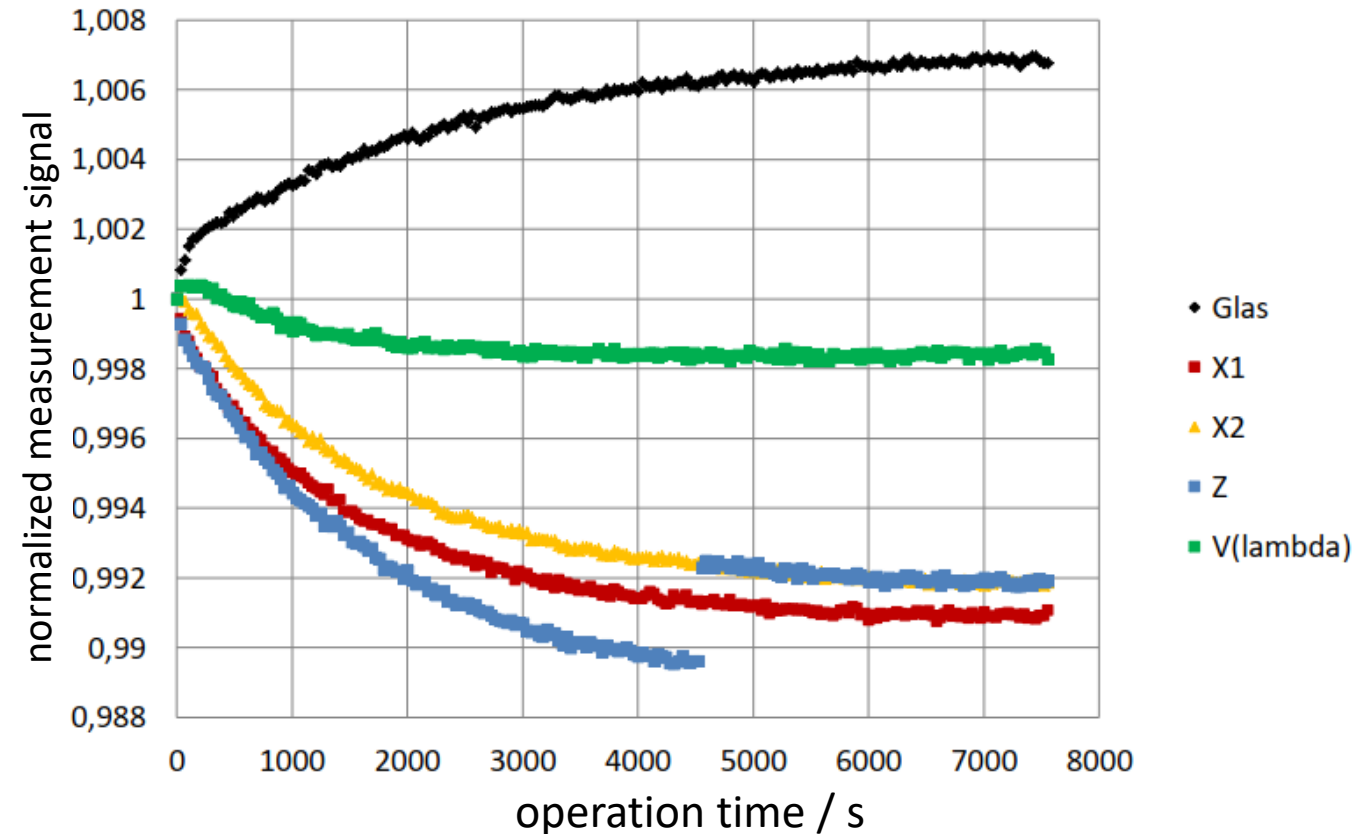
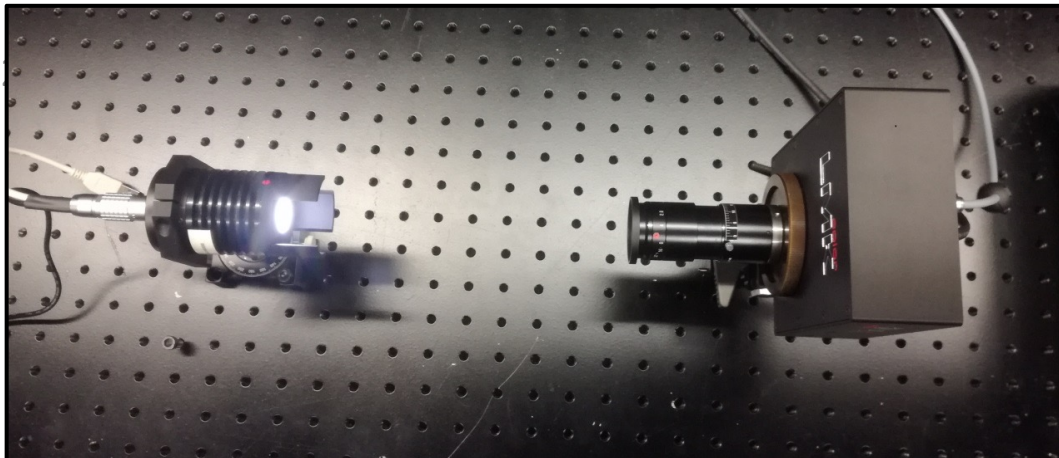
Johannes Ledig, Christian Schrader, Fabien Eloi



ILMD Temperatur characteristic after power on

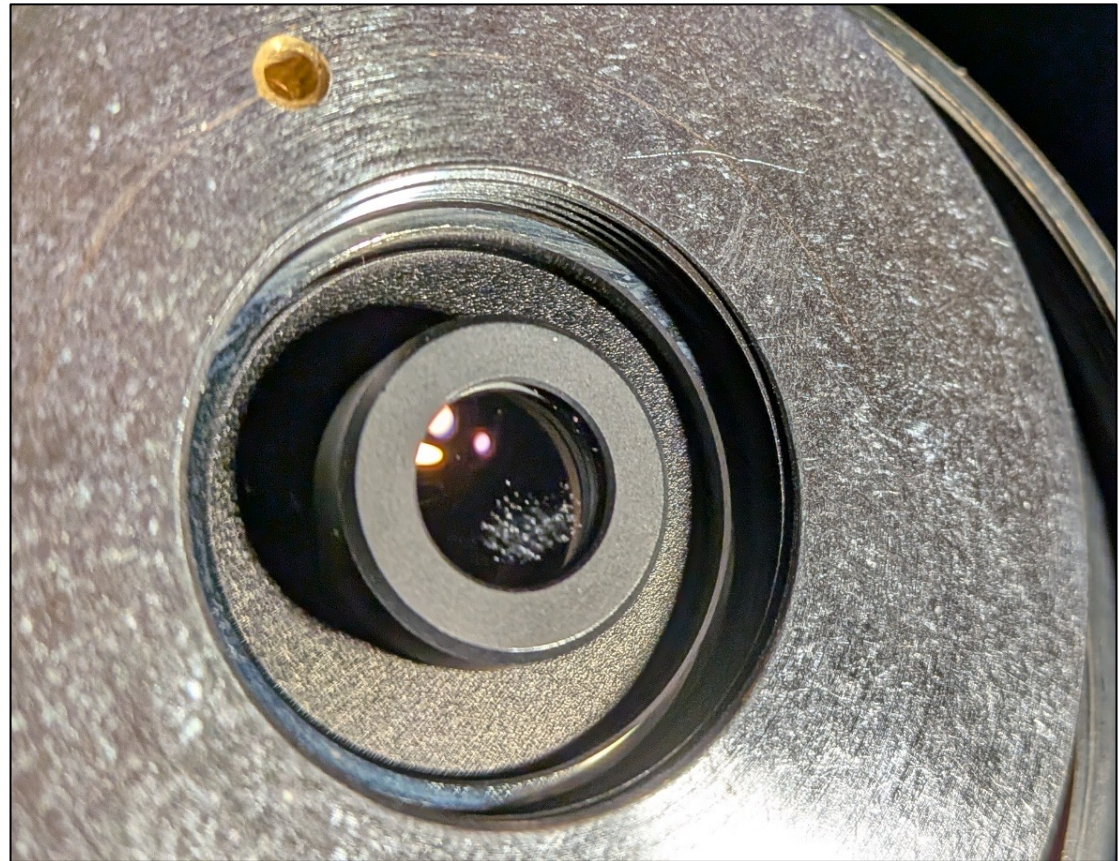
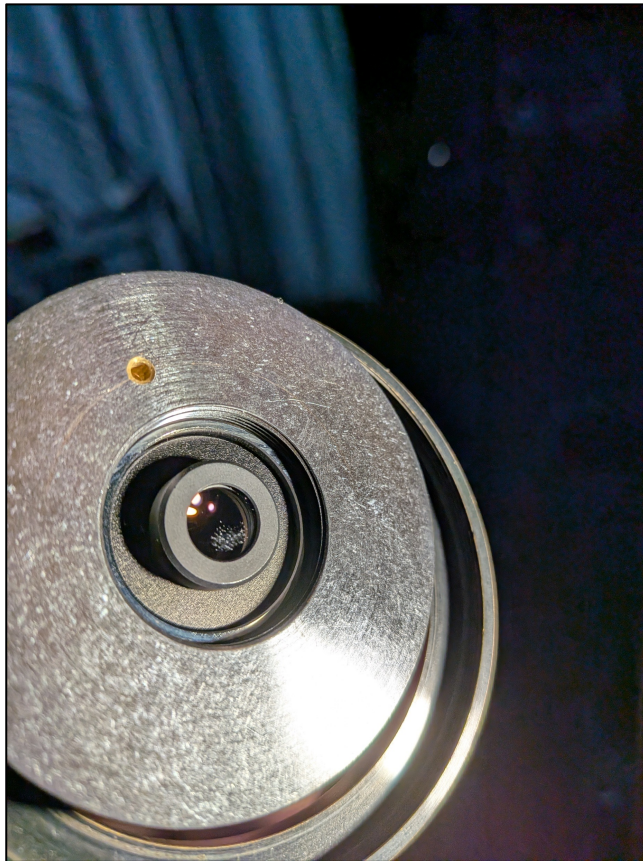


TechnoTeam LMK 98-4 color:
self heating by about 14°C



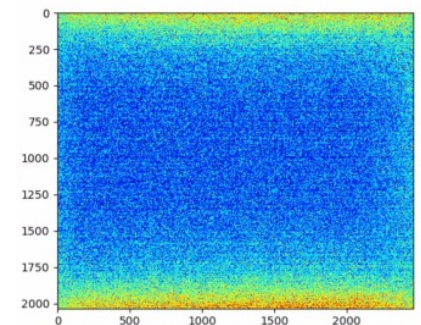
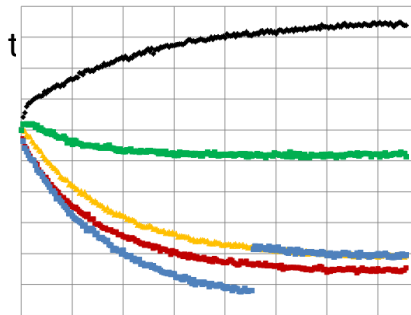
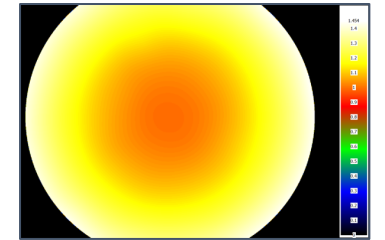
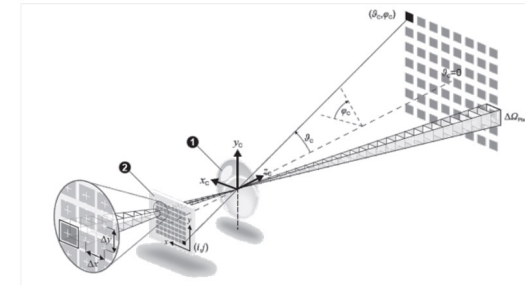
aspects that should be ensured

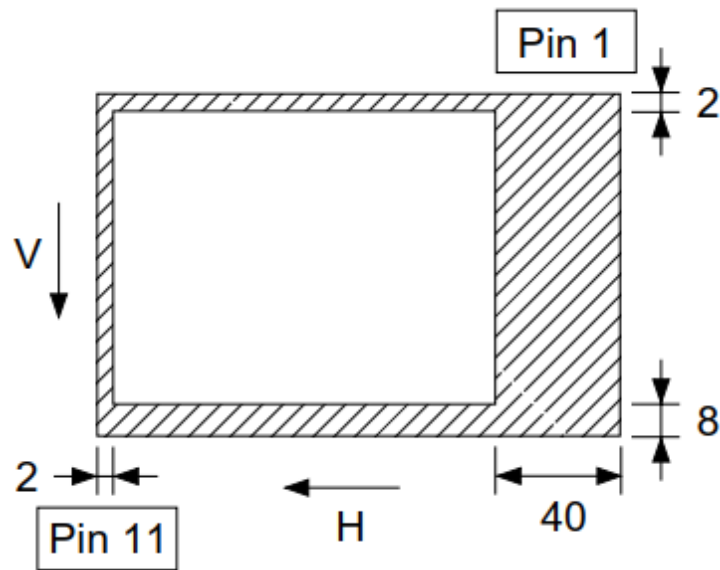
- Good **state** of device components
correct assembly and professional handling, i.e. clean and not damaged,
documentation of usage and relevant aspects of storage/transport,
(consider using clean room gloves when handling optical surfaces and blow dust away by N₂ or oil free air)



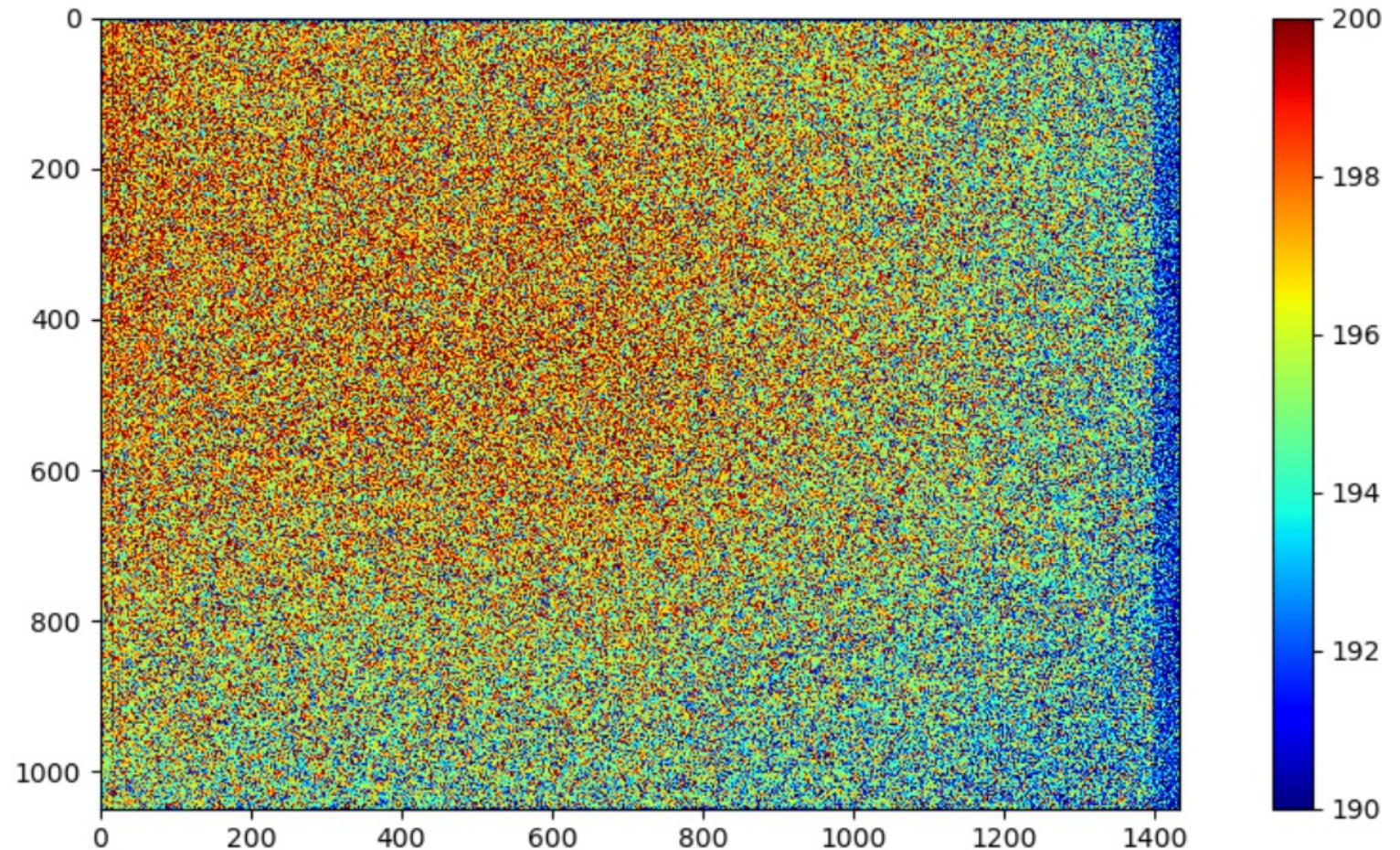
PTB aspects that should be ensured

- Good **state** of device components
correct assembly and professional handling, i.e. clean and not damaged,
documentation of usage and relevant aspects of storage/transport,
(consider using clean room gloves when handling optical surfaces and blow dust away by N₂ or oil free air)
- Selection of an adequate **objective lens** (aperture, focal length and zoom)
resulting in a field of view that is fitting to the application, i.e. a focal length as large as possible.
- Selection of an adequate **neutral density filter** (c.f. integration time)
to avoid extremely short integration times where the timing uncertainty gets relevant
- to avoid/reduce effects of Temporal Light Modulation (TLM)
- Setting of utilized optical components into the **control software**
i.e. type and serial number of the objective lens, neutral density filter.
(this is relevant also for relative measurements inside the image, it might reset to default after start-up)
- **Adjustment data** loaded into the control software
(configuration file, calibration file for internal corrections, user defined corrections) belonging to t
(consider **aging** and replacement/**maintenance** of components since the characterization)
- Stabilized **internal temperature** for all components
i.e. ILMD in operation (powered up and initialized, i.e. **imaging loop**) for more than one hour
- **Dark signal** correction inside the control software
belonging to the operation mode (i.e. binning, smoothing, integration time)
and aging state (pixel characteristic might change)



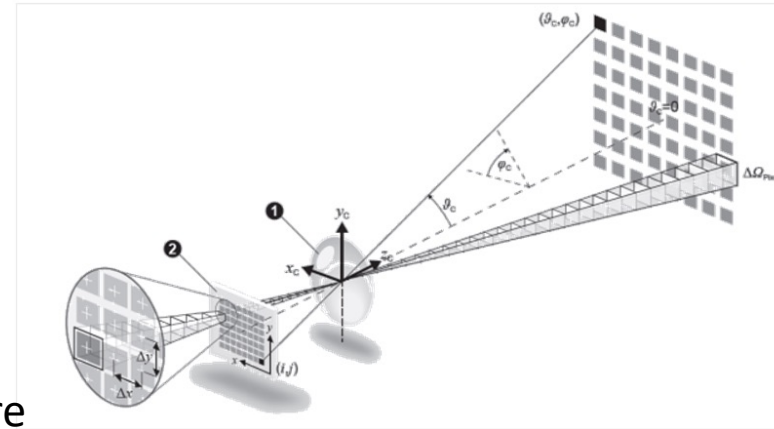


**Optical black position
(Top View)**



- Zoom value of the objective lens
- Aperture value of the objective lens
- Neutral density filter
- Focus value of the objective lens

measurement plane in focus,
focus setting or focus distance provided to the control software



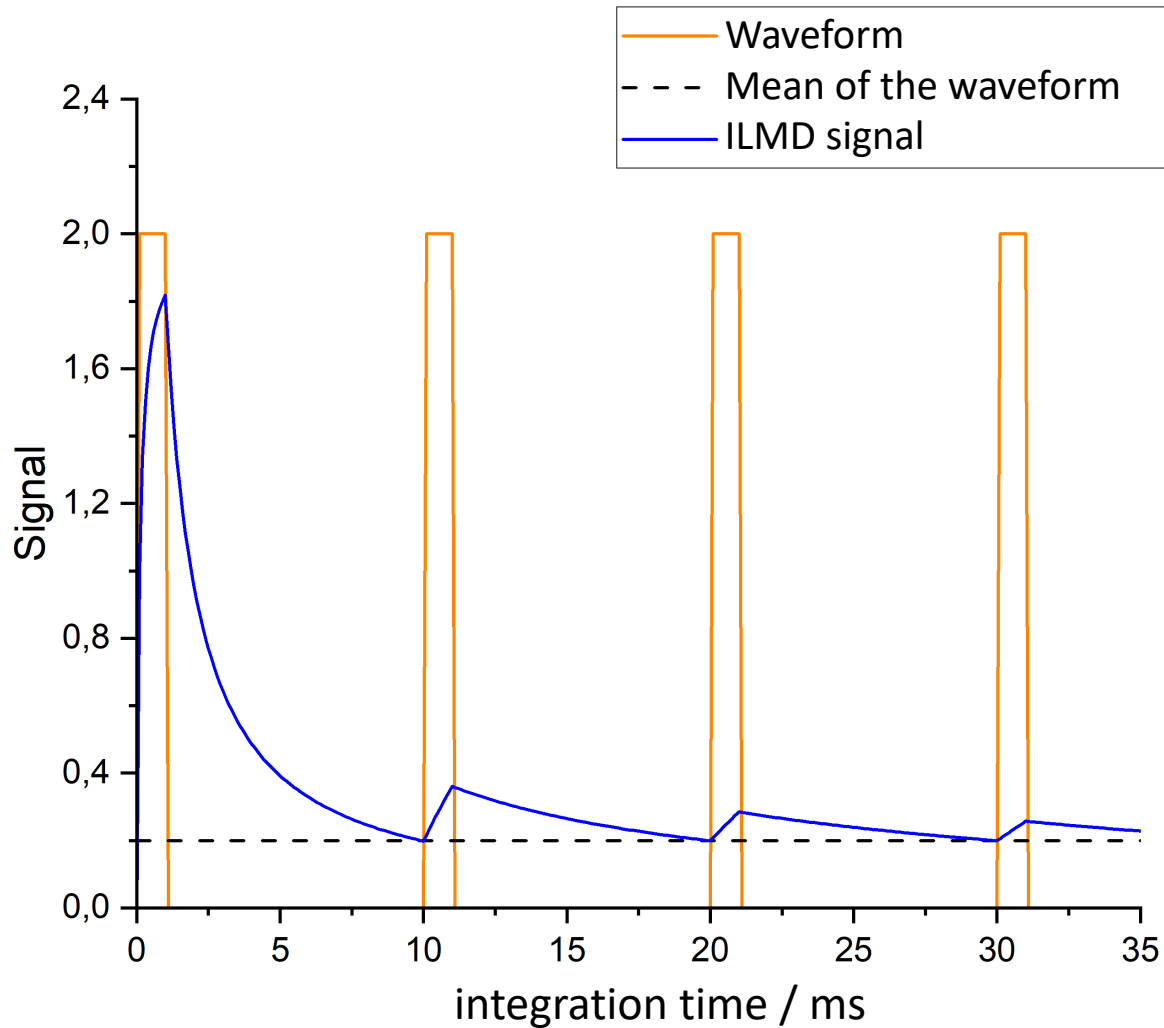
- Integration time

sufficiently long to reach a signal level well above the **detection limit**
but within the dynamic range and to **avoid** sensor-internal timing issues in the **μs -domain**,
integration time should be an integer multiple of the **temporal light modulation** period;
avoid blooming as this in general also affects the result from all other pixel) by using an appropriate ND-filter
(and setting this inside the control software, c.f. neutral density filter).

- Region of interest:

is each evaluation region **many pixels in size** and **homogeneous**?
consider smoothing parameters (i.e. averaging or median filtering)

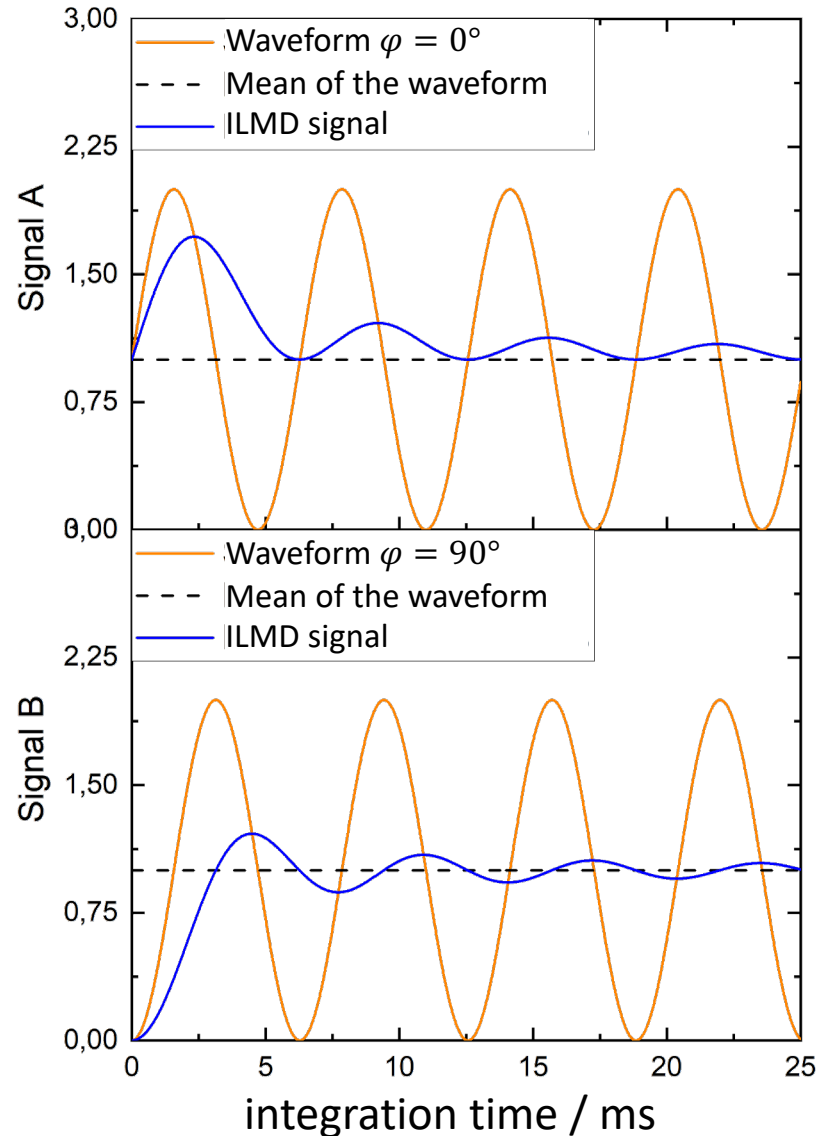
Temporal modulated light: PWM example {HiDyn}



- Small deviation from the integer multiple of the modulation period
→ results in a huge uncertainty

Periods	Error for +2ms
>3	≈+25 % (-7%...+25%)
>5	≈16 % (-4%...+16%)
>20	≈4 % (-1%...+4%)

Temporal modulated light: phase shift



Periods	Error
3,5	$\approx 10 \%$
5,5	$\approx 6 \%$
20,5	$\approx 1,5 \%$

Periods	Error
>3	$\approx 5 \%$
>5	$\approx 3 \%$
>20	$\approx 0,8 \%$

- Error depends on the waveform (e.g. larger for PWM than for a sinus)
- Error depends on the phase shift regarding the waveform and t_{int}
- Measurement signal vs. integration time oscillates around the mean value
- Uncertainty need to consider the alignment to the waveform phase (triggering might hide the effect in repetitions but does not cancel it out)

- [illegible]

The following article is hosted by PTB.

DOI: 10.7795/530.20240206A

Good Practice Guide for setting up an uncertainty budget for the measurement of luminance distributions including correlation of the 2D datasets

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¹Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin, Germany

²TechnoTeam Bildverarbeitung GmbH, Ilmenau, Germany

³Instrument Systems Optische Messtechnik GmbH, München, Germany

⁴Laboratoire National de métrologie et d'Essai (LNE), Paris, France

⁵TÜBİTAK UME, National Metrology Institute of Türkiye, Kocaeli, Türkiye

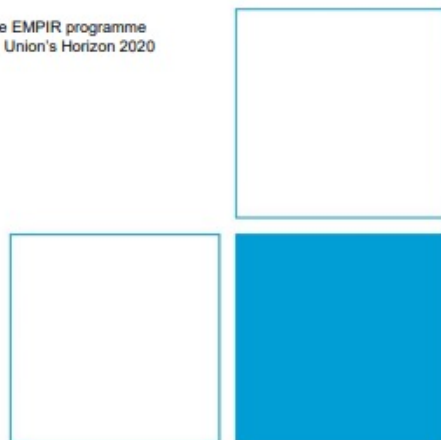
⁶Instituto Português da Qualidade, Caparica, Portugal

⁷candelTEC S.L., Valencia, Spain

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Available at:

<https://doi.org/10.7795/530.20240206A>



13 Appendix I: Checklist for the ILMD configuration

To avoid significant errors which cannot be covered by uncertainties it is necessary to use a configuration that is suitable for the application. Namely the following aspects should be ensured:

Good state of device components

- correct assembly and professional handling, i.e. clean and not damaged
- documentation of usage and relevant aspects of storage/transport
- consider using clean room gloves when handling optical surfaces and blow dust away by N₂ or oil free air

Selection of an adequate objective lens

- focal length → resulting in a measurement field that is fitting to the application, i.e. a focal length as large as possible.

Selection of an adequate neutral-density filter

- to avoid extremely short integration times where the timing uncertainty gets relevant
- to avoid/reduce effects of Temporal Light Modulation (TLM)

Setting of utilized optical components into the control software

- i.e. type and serial number of the objective lens, neutral density filter. This is relevant also for relative measurements inside the image, it might reset to default after start-up.

Adjustment data loaded into the control software

- configuration file, calibration file for internal corrections, user defined corrections belonging to the actual condition (consider aging and replacement/maintenance of components since the characterization)

Stabilized internal temperature for all components

- i.e. ILMD in operation (powered up and initialized, i.e. imaging loop) for more than one hour

Dark signal correction inside the control software

- belonging to the operation mode (i.e. binning, smoothing, integration time) and aging state (pixel characteristic might change)

Parameter values inside the control software correspond to hardware setting

- **Zoom** value of the objective lens
- **Aperture** value of the objective lens
- **Focus** value of the objective lens (measurement plane in focus, focus setting or focus distance provided to the control software)
- **Integration time**
 - sufficiently long to reach a signal level well above the detection limit but within the dynamic range and to avoid sensor-internal timing issues in the μ s-domain
 - integration time should be an integer multiple of the temporal light modulation period
 - avoid blooming as this in general also affects the result from all other pixel) by using an appropriate neutral-density filter (and setting this inside the control software, c.f. neutral density filter).