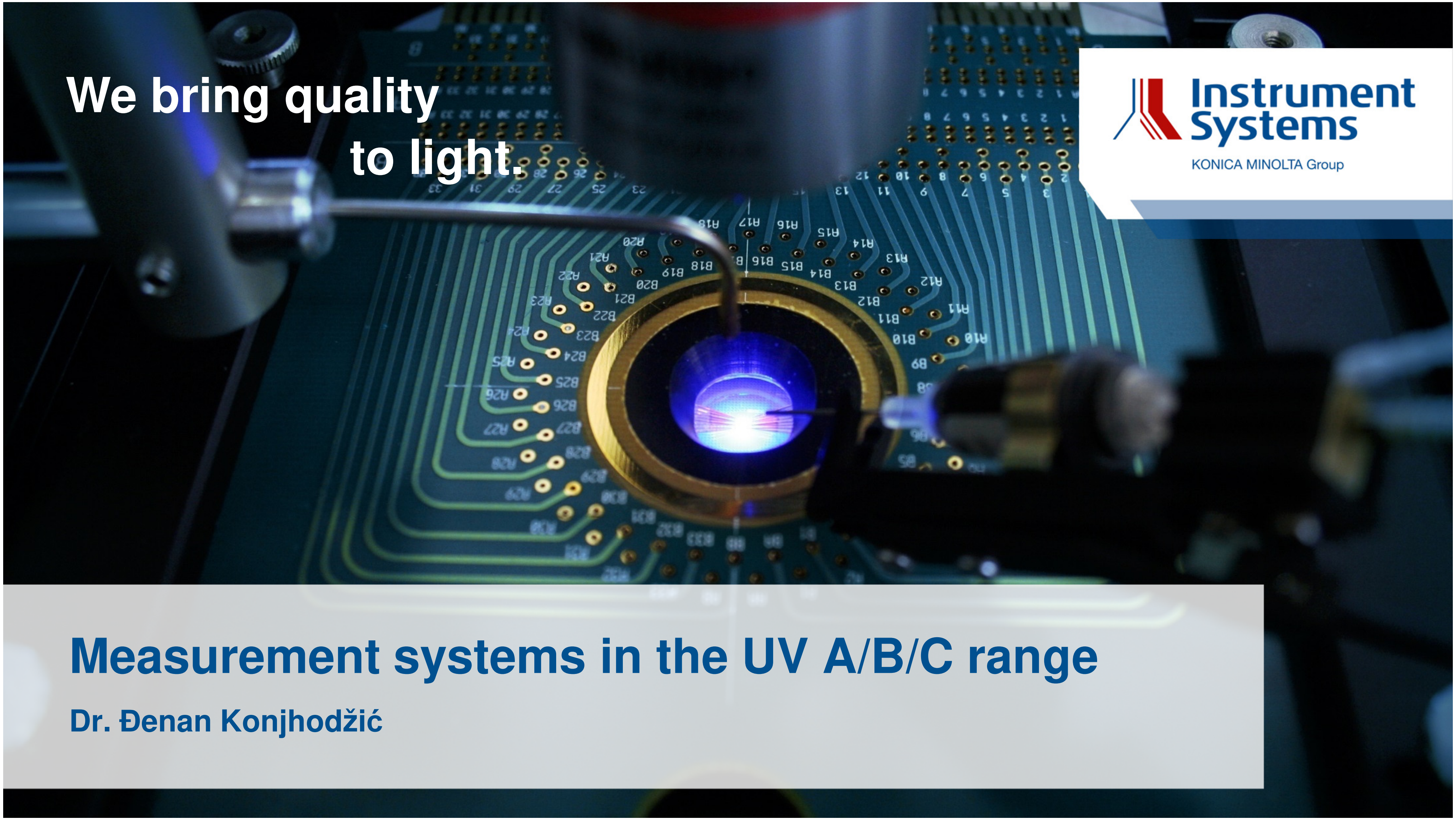


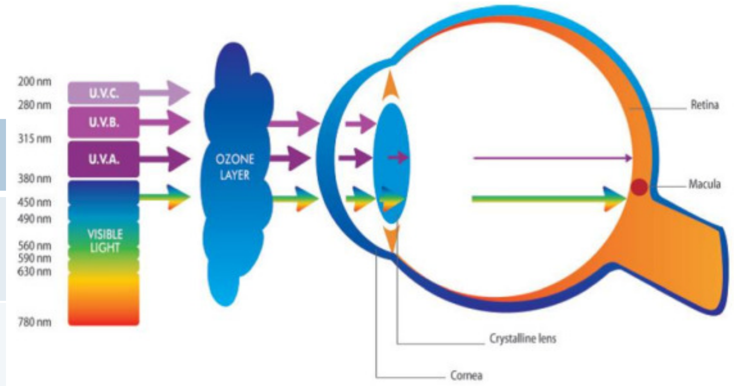
Measurement systems in the UV A/B/C range

Dr. Đenan Konjhodžić

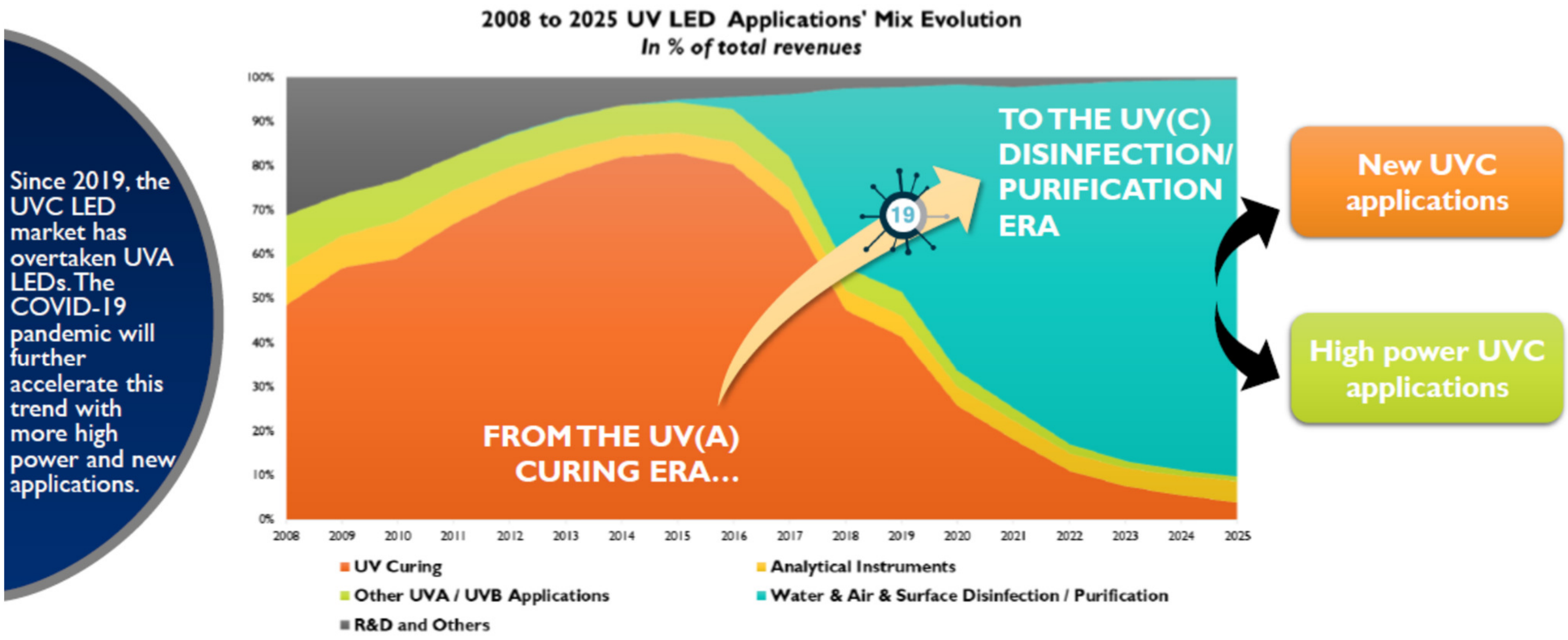
UV-Radiation

- Wavelength range 10 – 380/400 nm
- Classification according to ISO standard ISO-21348:

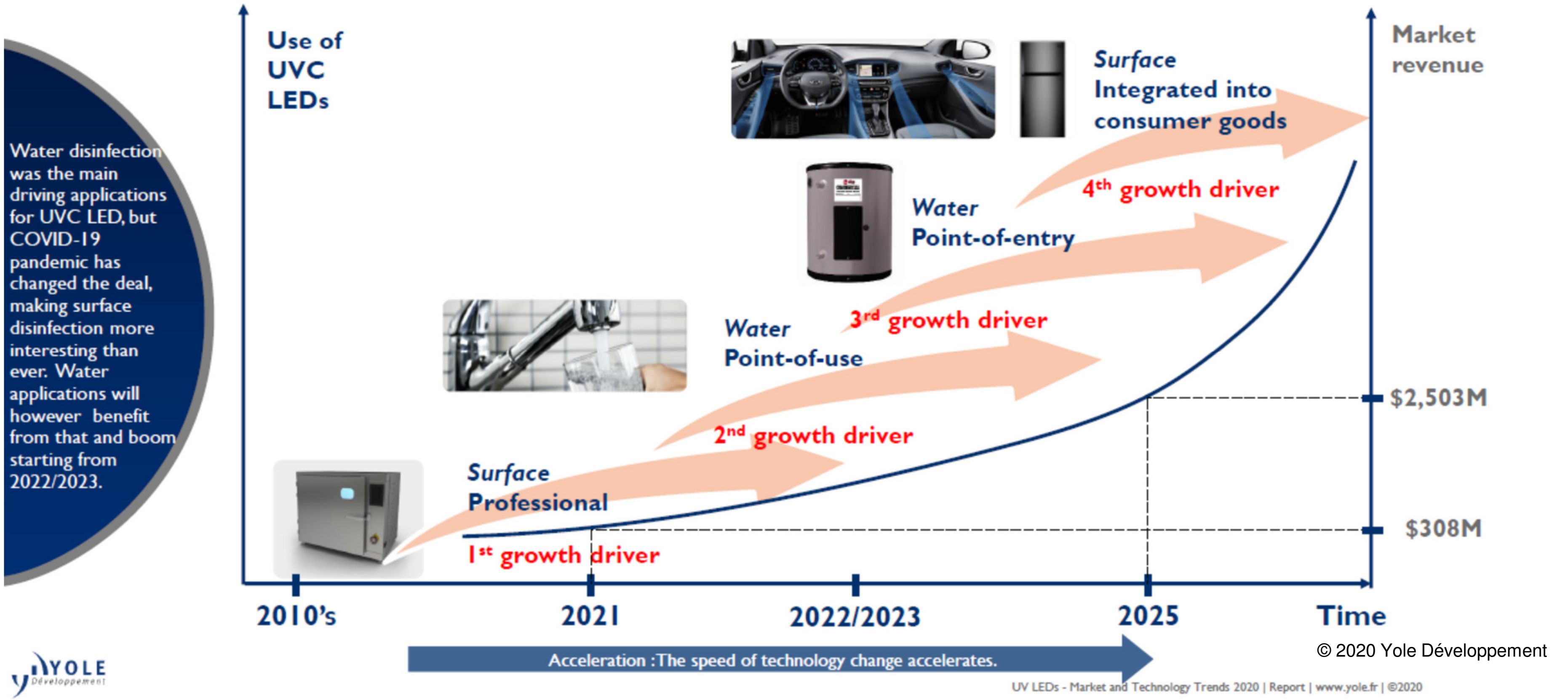
	Wavelength	Typical application
UV-A	315 - 400 nm	UV curing, UV ink printing e.g. 365 nm, 395 nm
UV-B	280 - 315 nm	Skin treatment e.g. 310 nm
UV-C	100 - 280 nm	Water and air disinfection, also Corona-Virus e.g. 254 nm, 265 nm
Vacuum UV	10 - 200 nm	Strongly absorbed by atmospheric oxygen



UV LED Market - Overview



UVC Market Growth Drivers

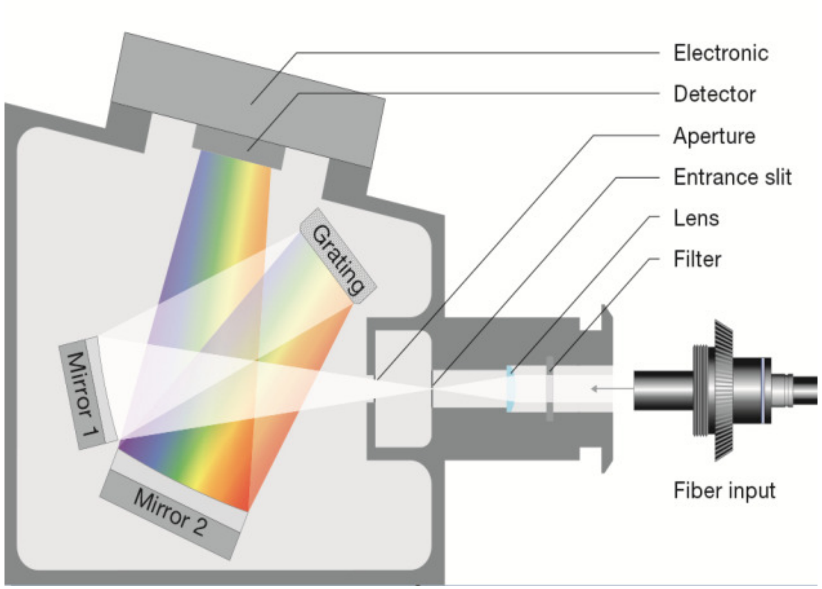


Complete Measurement Solutions for UV

- Radiometers are limited to the very narrow wavelength range
- Recommended:
  Array-spectroradiometer e.g. 200-830 nm
- Stray light correction
- Probes for irradiance measurements (depending on cosine correction)
- PTFE integrating spheres for radiant flux (size 50, 75, 100, 150 or 250 mm)
- Auxiliary light source for UV and VIS
  e.g. combination deuterium & halogen
- UV LED calibration standards
- PTB traceable calibrations

Array-Spectroradiometer

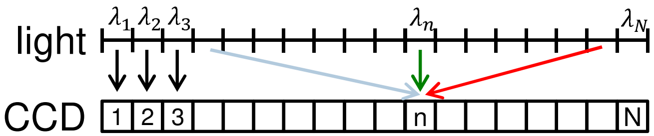
- CCD array captures entire spectrum simultaneously
- No moving parts → robust design
- Measurement time down to 4 ms
- Back-thinned CCD array:
  - high sensitivity for fast testing
  - high sensitivity in blue and UV
  - highest dynamic range

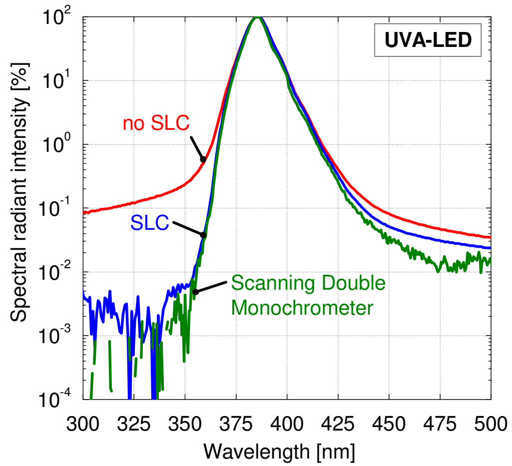


Crossed-Czerny-Turner geometry

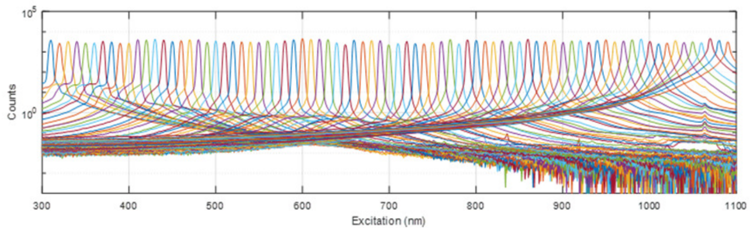
Stray Light Correction

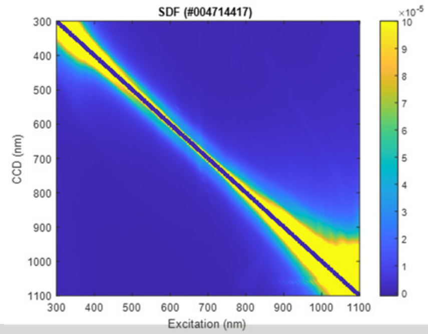
- Particular element of the array detector registers radiation from a different spectral region than the designated one



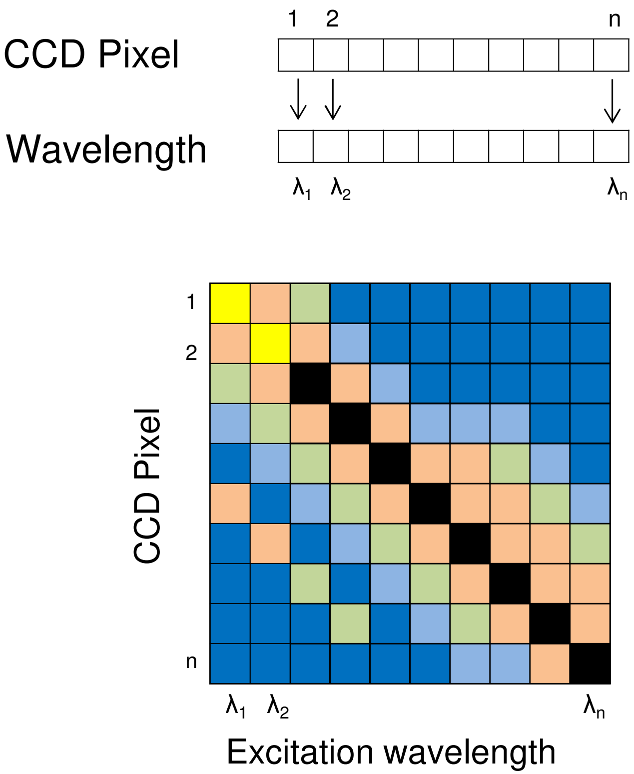


- Stray light correction with OPO tunable laser (NIST method)

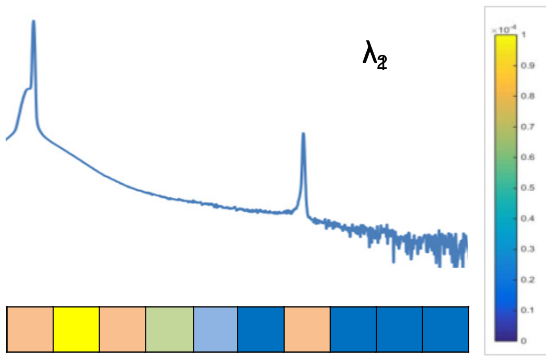




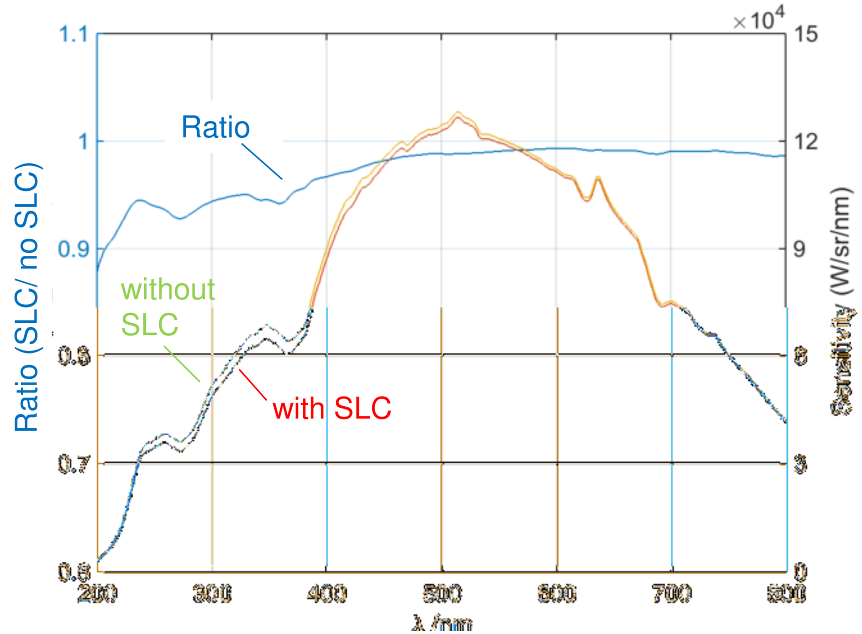
Creation of a Stray Light Matrix



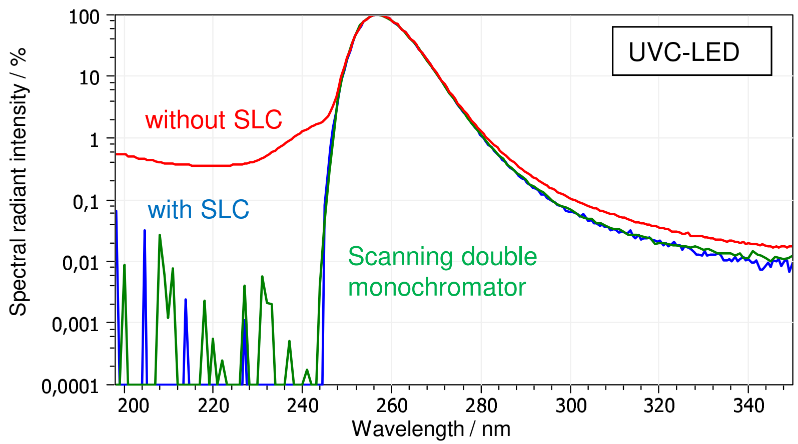
Spectrum of one laser line



Stray Light Correction in Calibration

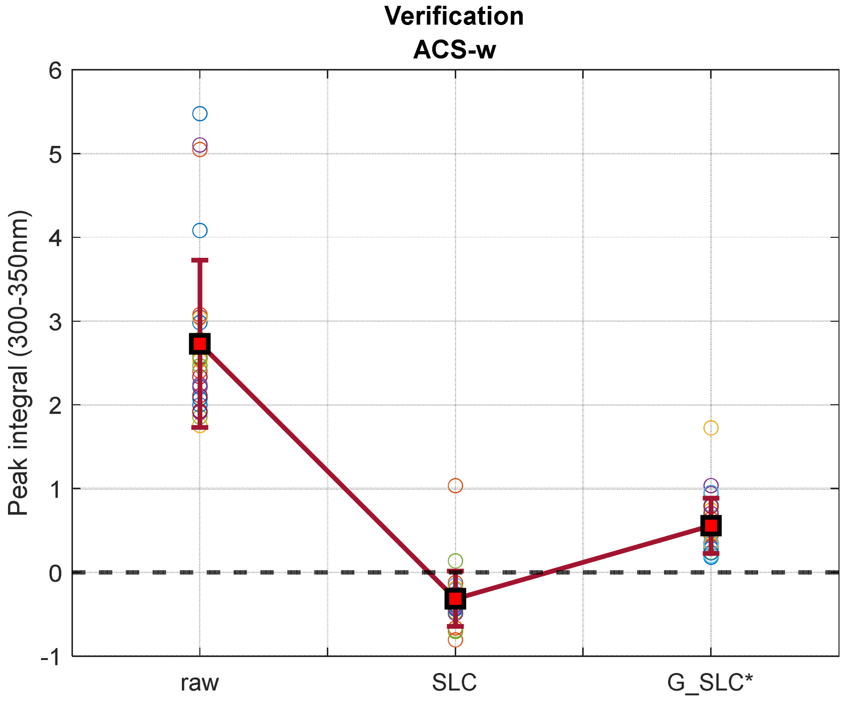


- Relationship of sensitivity curves with and without stray light correction after calibration shows a stray light portion of up to 10% in the UV range (<400 nm)
- Stray light free sensitivity has a direct effect on the absolute precision



Simplified Stray Light Correction (S-SLC)

- Creation of a generic stay light matrix on the basis of existing full SL matrices for one spectroradiometer type
- Two fast additional device specific measurements with edge filtered halogen lamp and laser
- Software tool for automated generation of device specific but simplified SLC
- Verification measurement
- Only 2% and 5% of raw signal remain uncorrected in UV and NIR region, respectively



Calibration of the System

- Wavelength calibration with HgAr line lamp
- Spectral with deuterium and halogen lamp
- No absolute LED standard up to now

- Probes for irradiance measurements (depending on cosine correction)

$$E_e = \frac{d\Phi_e}{dA}$$

[W/m²]

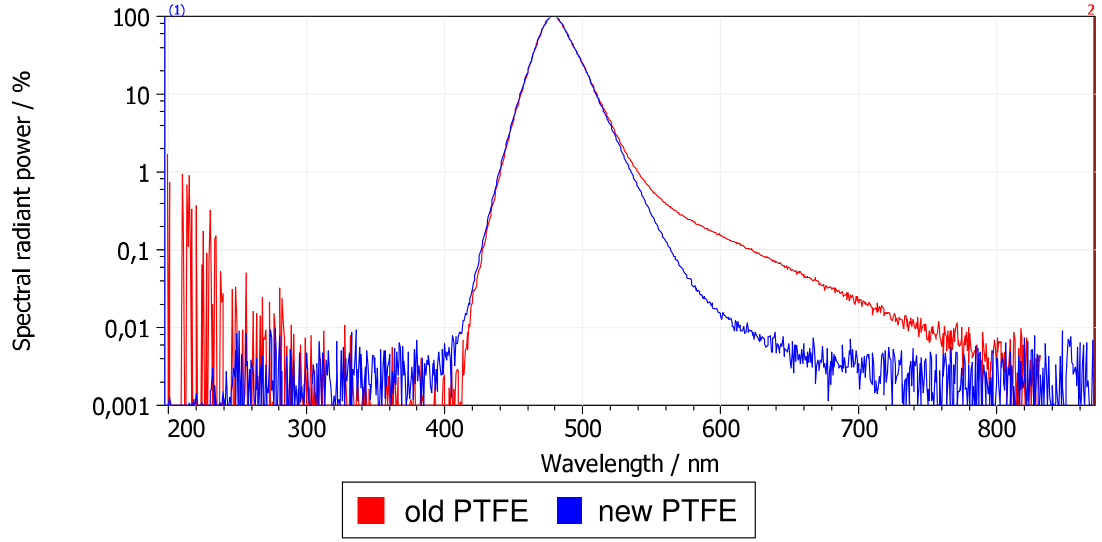
- PTFE integrating spheres for radiant flux (size 50, 75, 100, 150 or 250 mm)

$$\Phi_e$$

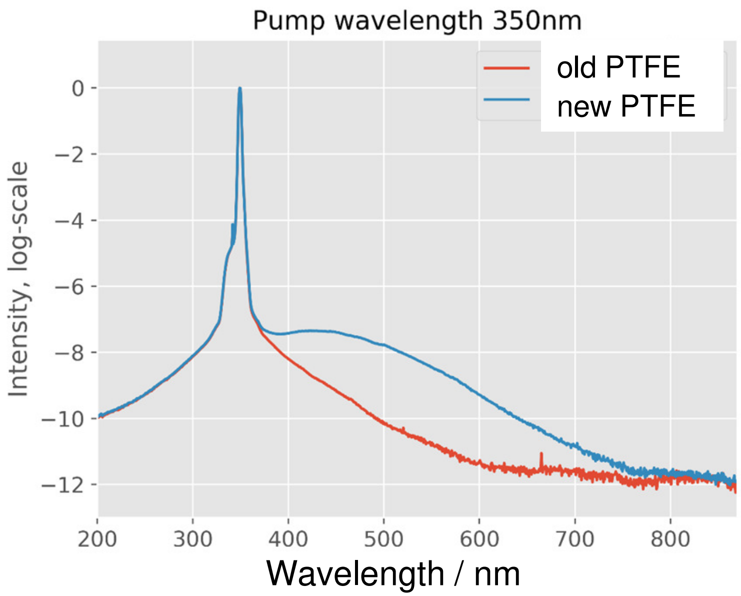
[W]

Fluorescence of Integrating Spheres

- Blue LED measurement shows a portion of the fluorescence on the right flank

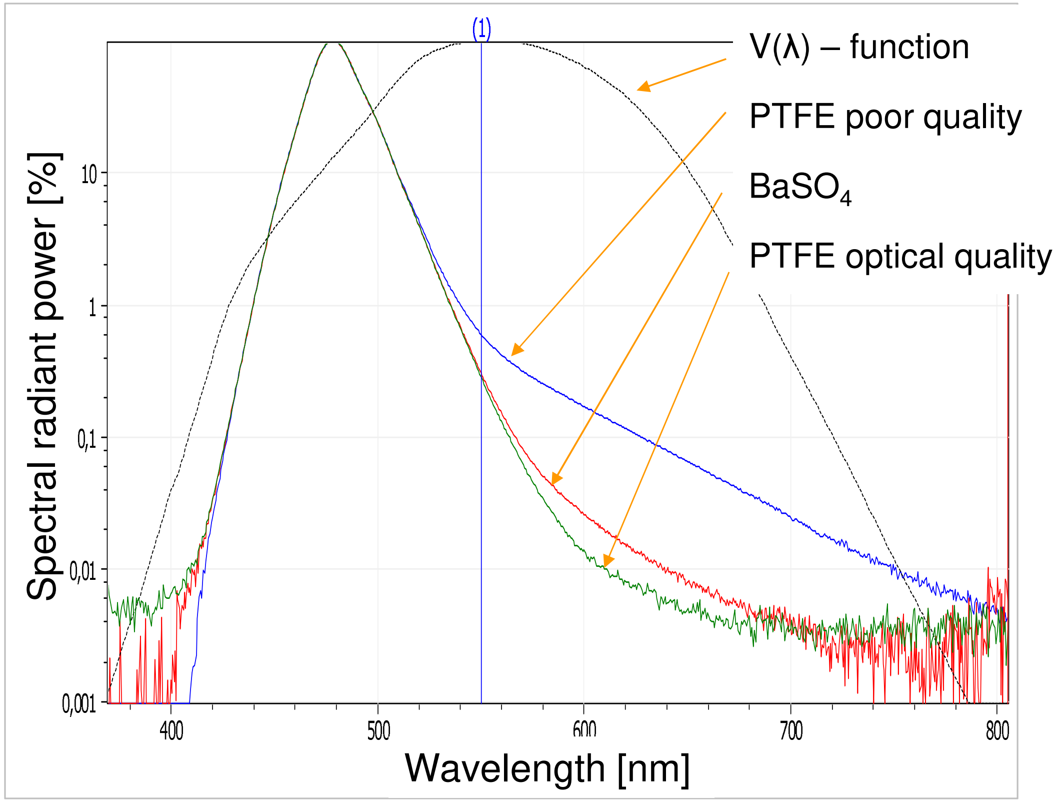


- Laser variations 210-360 nm



- Much lower fluorescence of the new PTFE material with optical quality

Fluorescence Verification With a Blue LED

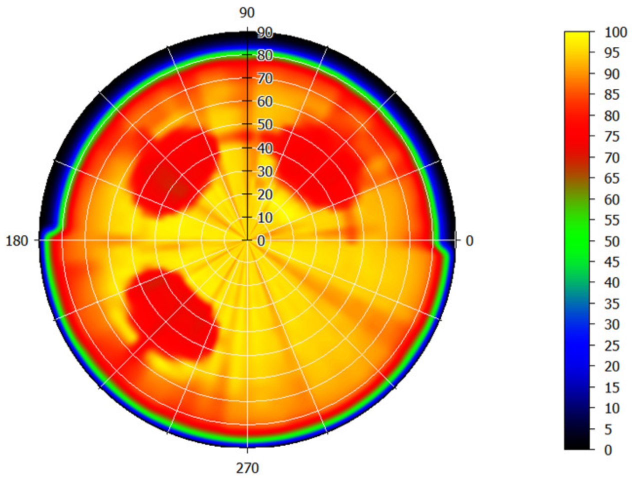


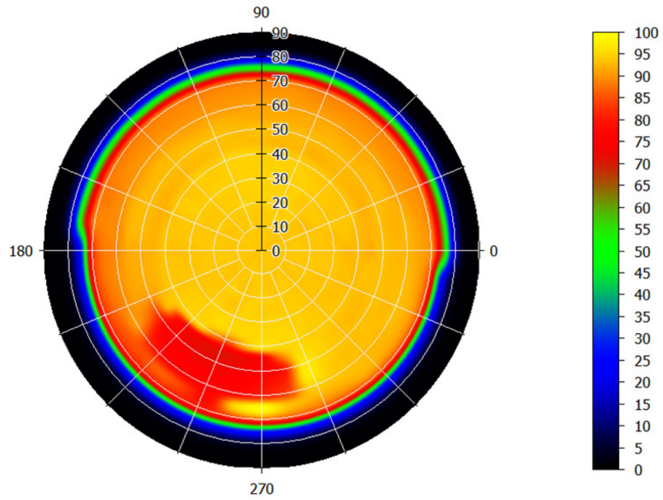
- By weighting the spectrum with the eye sensitivity curve V (λ), the higher right flank of the blue LED spectrum has a major influence on the calculation of the color coordinates, especially for green.

Green LED	Δx	Δy	ΔΦ
optical PTFE	ref.	ref.	ref.
$BaSO_4$	0.0002	0.0006	
poor PTFE	0.0037	0.0051	6.5%

Design of the Integrating Spheres

- Bad position of the ports
- Improved design





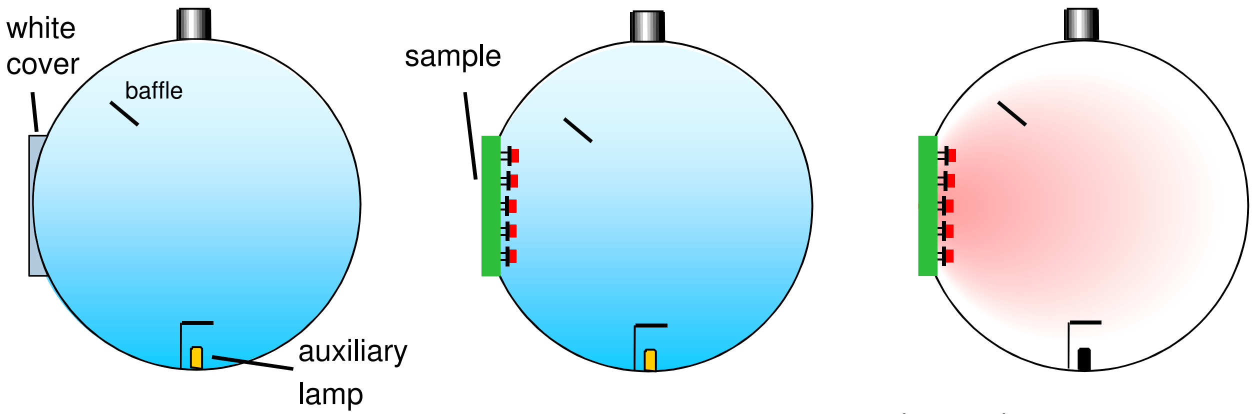
- Positioning of all ports on one sphere side away from equator improves accuracy
- Black surface in order to minimize reflexions
- Increased mechanical and temperature stability up to 150 °C

Self-absorption Correction

Step1:
- Measure auxiliary lamp
- Use white cover instead of sample
- Auxiliary lamp is on

Step2:
- Measure auxiliary lamp
- Sample is inside sphere
- Auxiliary lamp is on
- Sample is off

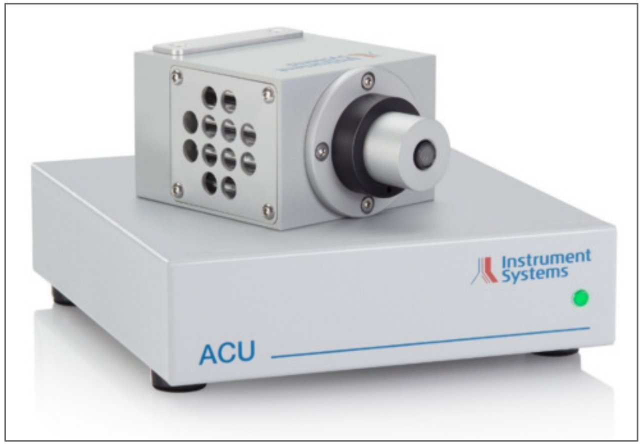
Step3:
- Measure sphere with sample
- Auxiliary lamp is off
- Sample is on

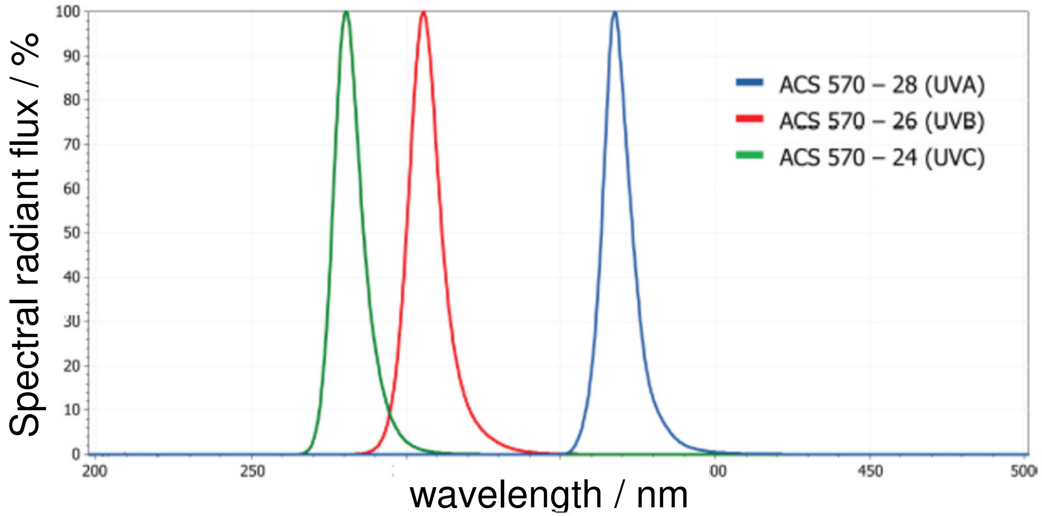


$$\text{True spectrum} = \text{spectrum(step3)} \times \frac{\text{spectrum(step1)}}{\text{spectrum(step2)}}$$

- Combined light source for self-absorption correction in UV (deuterium) and VIS (halogen)

UV LED Calibration Standards



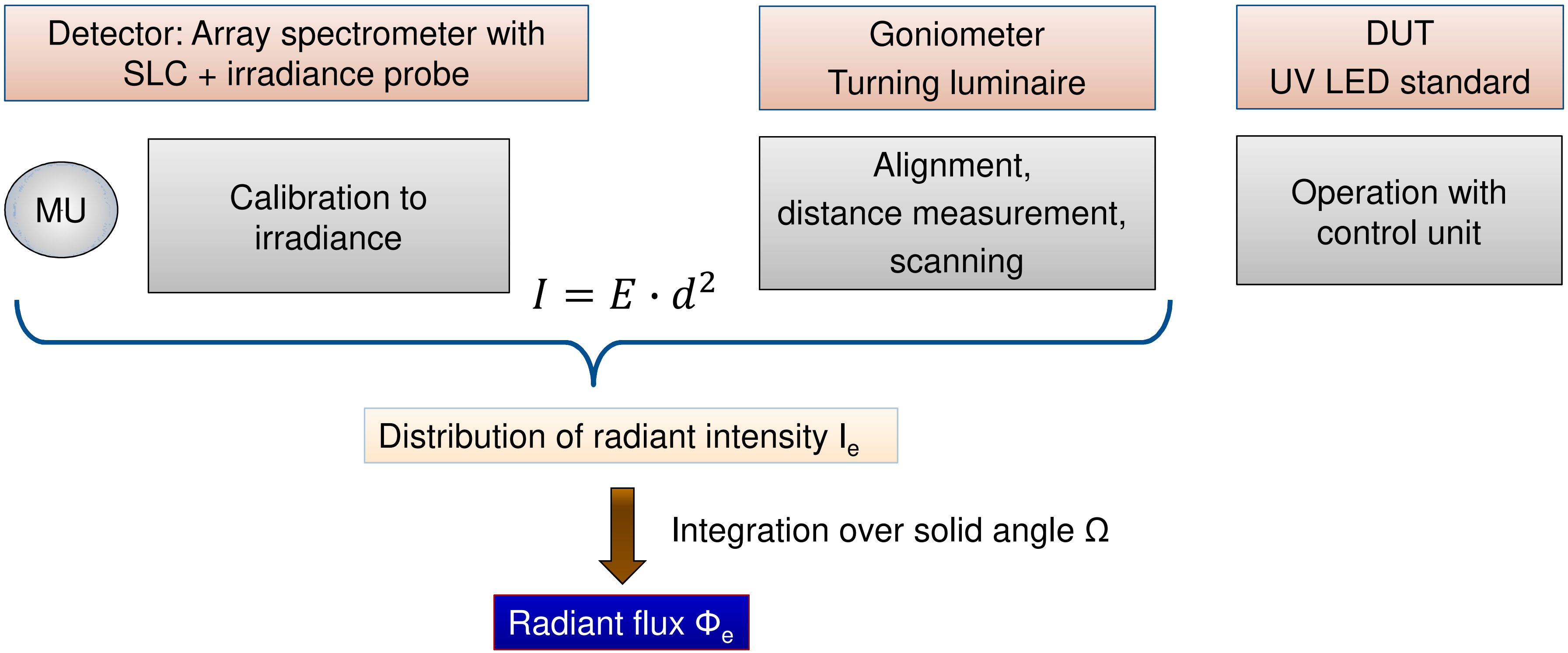


ACS 570 UV calibration standard	ACS-570-24	ACS-570-26	ACS-570-28
Typical irradiance @ 300 mm distance [mW/m²]	180 – 200	280 – 300	670 – 690
Typical radiant flux [mW]	40 – 60	65 – 70	54 – 56
Expanded measurement uncertainty (k=2)	4.5 %	3.5 %	2 %
Typical peak wavelength	278 nm ± 3 nm	306 nm ± 3 nm	367 nm ± 3 nm

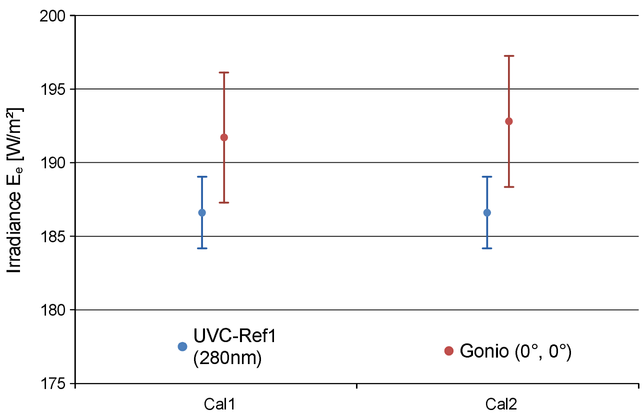
Challenges for the UV Calibration Standards

- Required for audit and absolute calibration of integrating spheres to the radiant flux in the UV range.
- National labs, such as PTB and NIST, provide no radiant flux calibrations for UVB and UVC so far.
- We realized traceable calibration to radiant flux using a goniospectroradiometer and a probe calibrated to spectral irradiance in UV.
- Instrument Systems is the first company to provide LED calibration standards for radiant flux in the UVB and UVC range.

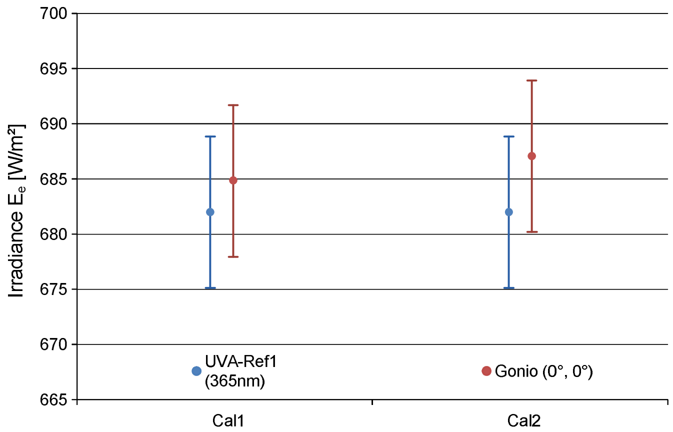
Calibration Concept



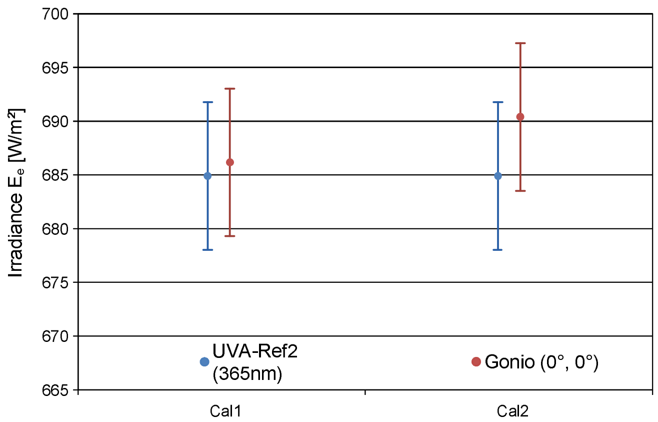
Irradiance Comparison with PTB



UVC (ACS-570-24)



Ref1: UVA ACS-570-28 (1))



Ref2: UVA (ACS-570-28 (2))

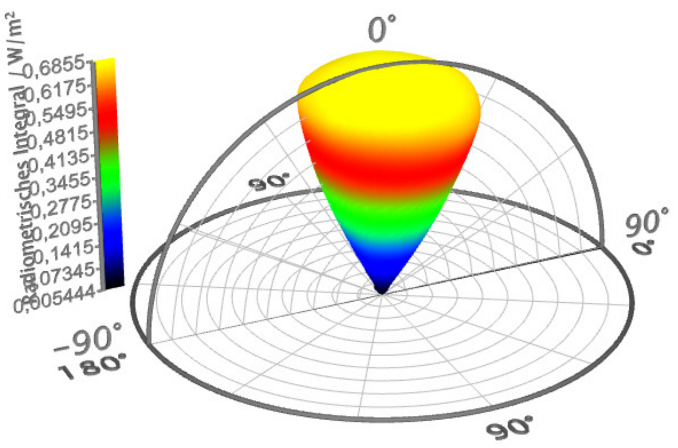
CAL 1 = absolute & spectral with 1000W FEL + spectral extended with deuterium lamp

CAL 2 = absolute & spectral with deuterium lamp + spectral extended with 1000W FEL

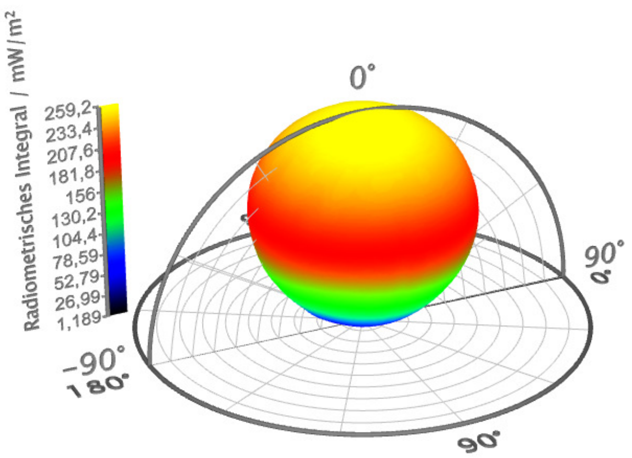
→ CAL-1 is better procedure

Goniometric Measurements

- Radiant intensity distribution UVA



- Radiant intensity distribution UVB & UVC



Radiant flux for UVA:
Ref1 = 51.7 mW (PTB value = 51.9 mW)
Ref2 = 52.7 mW (PTB value = 52.9 mW)

Procedure very well suitable also for UVB & UVC

Concept for Measurement Uncertainties

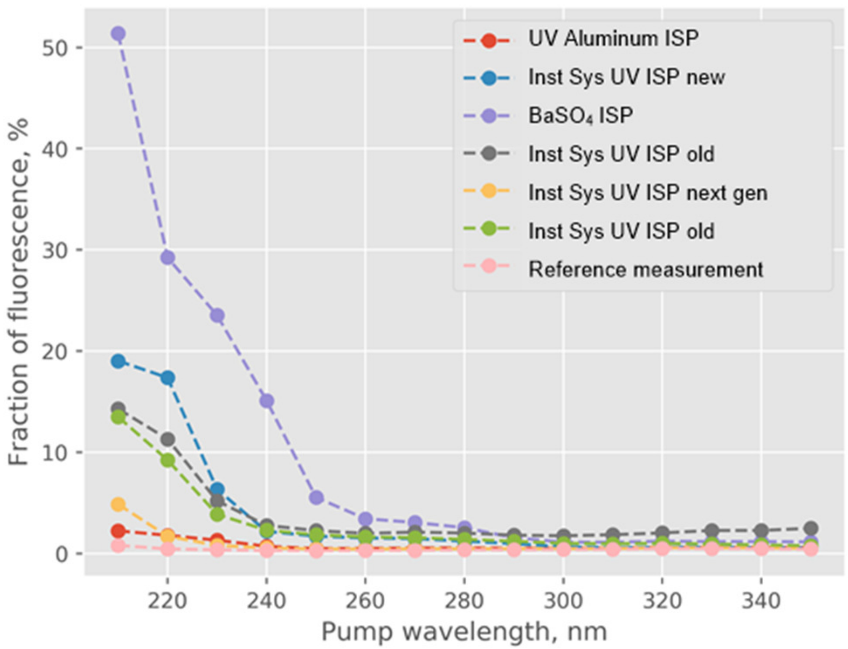
Calibration to irradiance	**Monte Carlo** Stray light matrix, external stray light, bandpass matrix, wavelength uncertainty, temperature variation, reference lamp uncertainty, reference lamp aging, CCD noise, reference lamp distance, reference lamp alignment, power supply, linearity, EOP-COS adaptation,…
Alignment, distance measurement, scanning	**Standard GUM calculation** Distance, alignment of the optical axis, alignment of the test sample in transverse direction, angle scanning, goniometer uncertainties,…
DUT operation with a special controller	**Measurement data** DUT stability

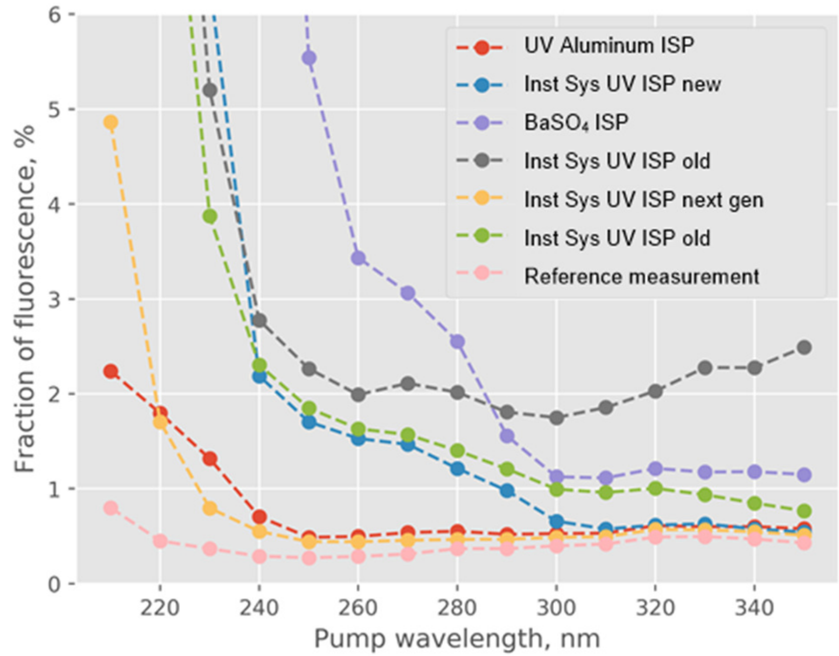
ACS	$U_{k=2}(F_e)$ (%)
365 nm	2.0
305 nm	3.5
285 nm	4.5
250 nm	6.5

DUT
Measurement uncertainties for radiant flux

Outlook

- Completely new manufacturing procedure for practically fluorescence-free PTFE spheres even below 250 nm





Conclusions

- Stray light corrected spectroradiometers with various coupling optics are best suitable measurement systems for entire UV range.
- PTFE integrating spheres should provide low fluorescence and a self-absorption correction with a deuterium/halogen lamp is recommended.
- UV LED calibration standards can be used for verification and monitoring of irradiance or radiant flux and absolute calibration, if necessary.

THANK YOU

for your attention!