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Spectral stray light correction of array spectroradiometers: Implications for UV metrology



Steven Brown, Yuqin Zong, Keith Lykke
Optical Technology Division

Joannie Chin, W. Eric Byrd, Li Piin Sung
Building and Fire Research Laboratory

APMP PR-S1 COMPARISON ON IRRADIANCE RESPONSIVITY OF UVA DETECTORS

Gan XU, Xuebo HUANG, Yuanjie LIU

National Metrology Centre
Standards, Productivity and Innovation Board
(SPRING Singapore)
E-mail: huang_xuebo@spring.gov.sg



1. Introduction

- UVA broadband radiometers widely used in various applications
- Calibration discrepancies: >30%
- Lack of an international accepted standard for calibration
- The aim of this comparison is to assess the equivalence of standards and techniques used in the calibration of irradiance responsivity of UVA detectors among the participating laboratories.

Problems in filter-radiometer-based UV meters

- Poor match between a UV meter's spectral responsivity and a defined weighting function.
 - Out-of-band responsivity
 - Fluorescence error
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-
- Low cost, portable array spectrometers are commercially available now.
 - A simple, practical stray-light-correction technique is available now, which can reduce the stray light errors more than one order.

Example 1: UV LED measurements for total radiant flux using a stray-light & fluorescence corrected sphere-spectroradiometer system

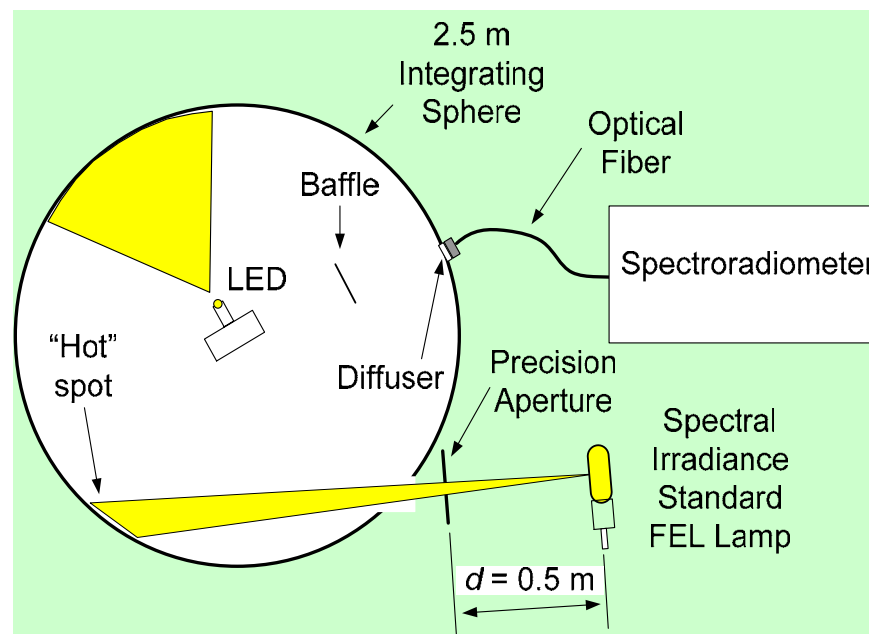
$$\Phi_{\text{ext}}(\lambda) = A \cdot E_{\text{ext}}(\lambda)$$

$$\Phi_{\text{LED}} = k_{\text{corr}} \int_{\lambda} \Phi_{\text{ext}}(\lambda) \frac{i_{\text{LED}}(\lambda)}{i_{\text{ext}}(\lambda)} d\lambda$$

$$k_{\text{corr}} = k_E \cdot k_{\text{angle}} \cdot k_{\text{spatial}}$$

- 1) 2.5 m integrating sphere, BaSO₄
- 2) CCD array spectroradiometer

- Bandpass: ~ 3 nm.
- Stray light: ~ 10⁻⁴.
- Resolution: 15 bits.
- CCD array: 1024.
- Linearity: ~ 2 %.

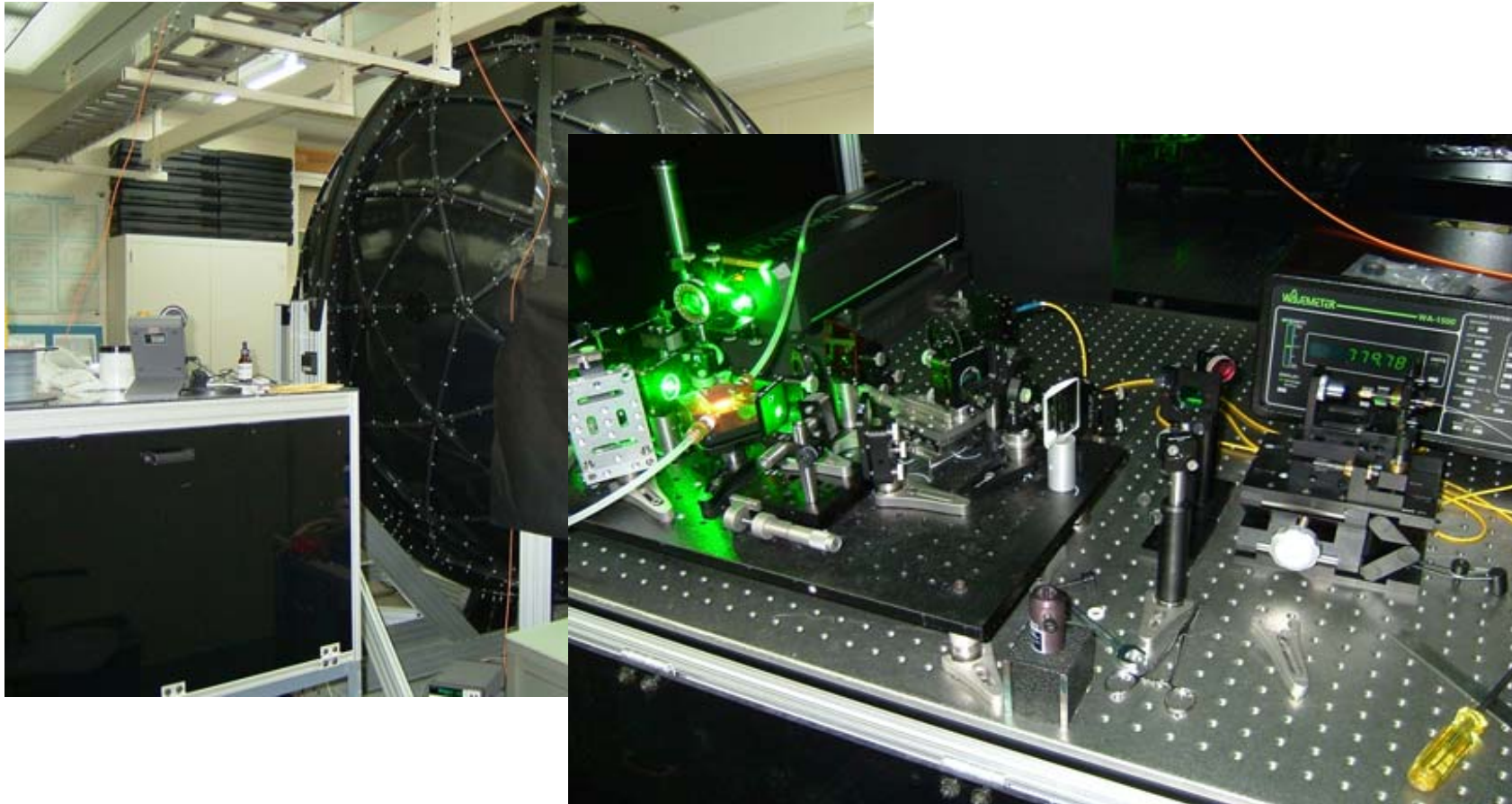


→
 $y_{\text{test}}(\lambda)$,
 $y_{\text{ref}}(\lambda)$

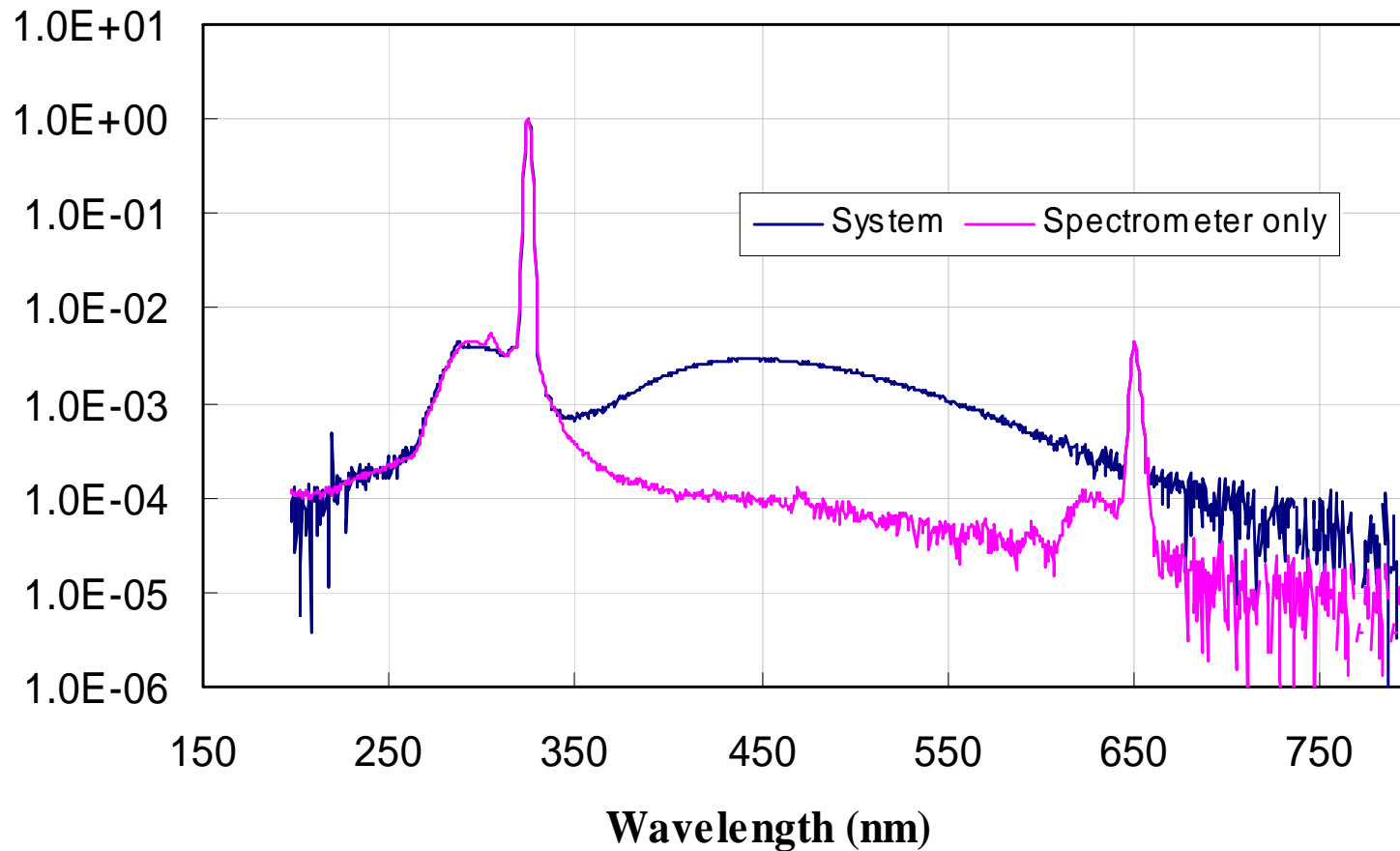
$\Phi_{\text{ext}}(\lambda)$ – spectral flux of the external reference beam
 Φ_{LED} – total radiant flux of the LED
 k_{corr} – overall correction factor
 k_E – correction factor for irradiance nonuniformity
 k_{angle} – correction factor for incident angle dependence
 k_{spatial} – correction factor for sphere spatial nonuniformity

System characterization using tunable laser sources

- Traveling SIRCUS (360 nm-450 nm).

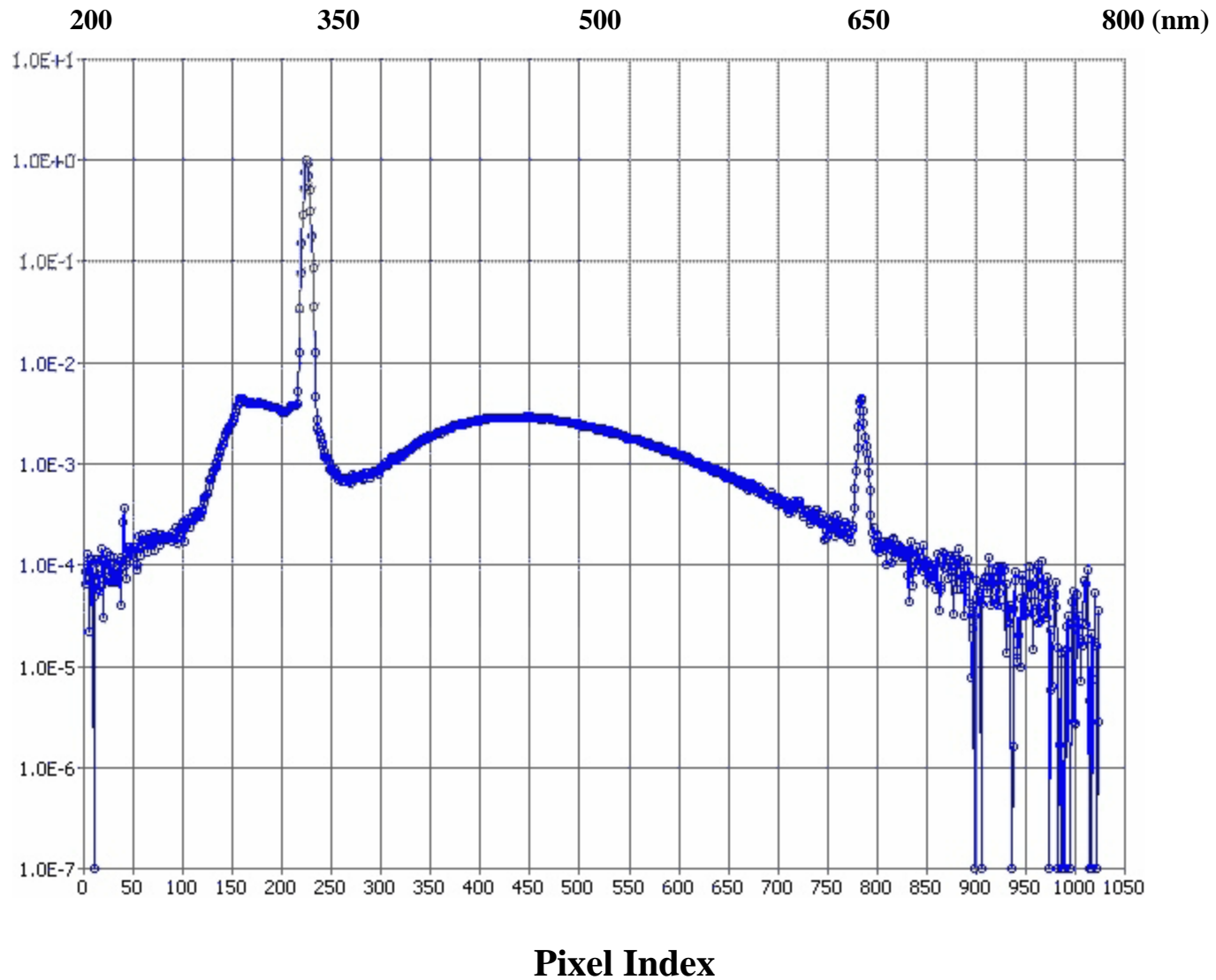


A measured Spectrum Line Spread Functions (LSF) of the measurement system

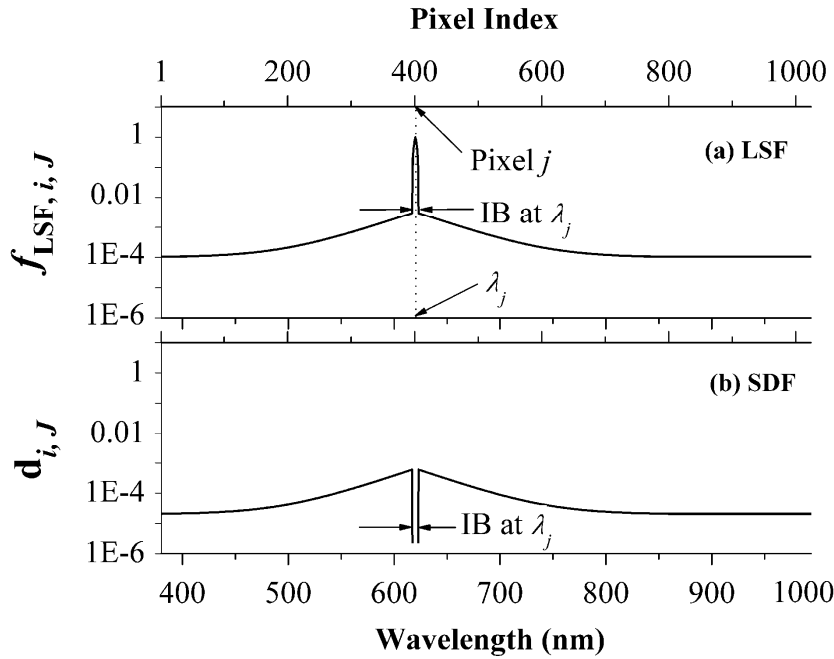


The stray light, fluorescence, and 2nd order diffraction:

Spectrum Line Spread Functions (LSF) across the spectral range



Derive Spectral Stray-light Correction matrix, C



The SDF matrix, D

$$D = \begin{bmatrix} d_{1,1} & d_{1,2} & \dots & d_{1,J} & \dots & d_{1,n-1} & d_{1,n} \\ d_{2,1} & d_{2,2} & \dots & d_{2,J} & \dots & d_{2,n-1} & d_{2,n} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ d_{i,1} & d_{i,2} & \dots & d_{i,J} & \dots & d_{i,n-1} & d_{i,n} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ d_{n-1,1} & d_{n-1,2} & \dots & d_{n-1,J} & \dots & d_{n-1,n-1} & d_{n-1,n} \\ d_{n,1} & d_{n,2} & \dots & d_{n,J} & \dots & d_{n,n-1} & d_{n,n} \end{bmatrix}$$

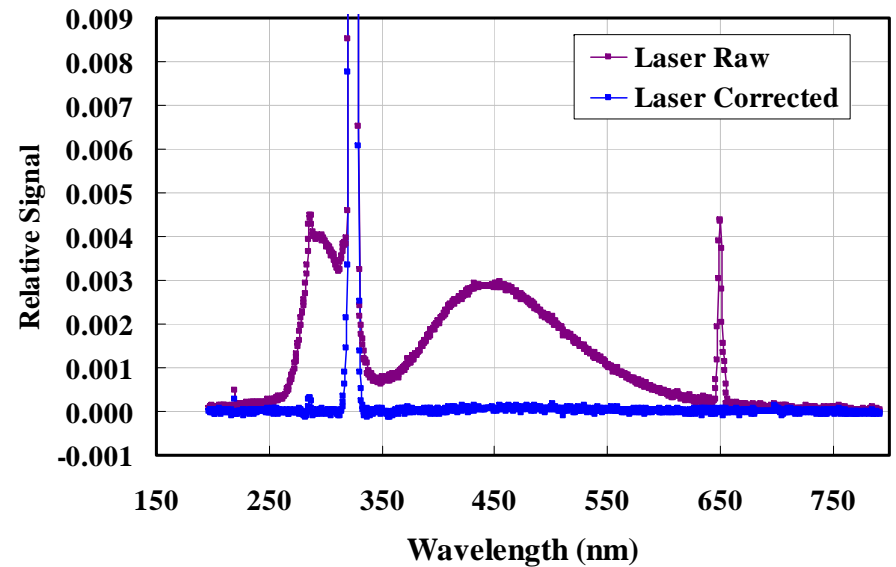
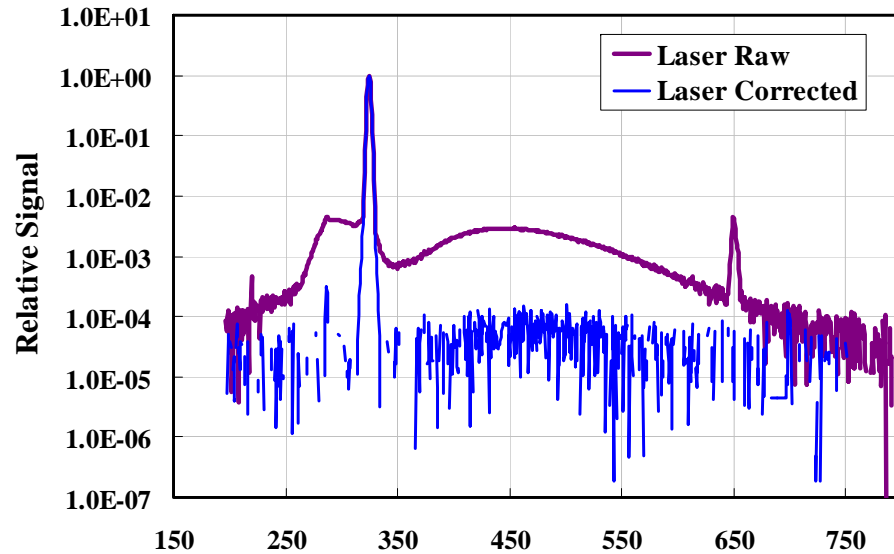
$$Y_{s_spec} = D \cdot Y_{IB}$$

$$Y_{meas} = Y_{IB} + Y_{s_spec} = Y_{IB} + D \cdot Y_{IB}$$

$$= [I + D] \cdot Y_{IB} = A \cdot Y_{IB}$$

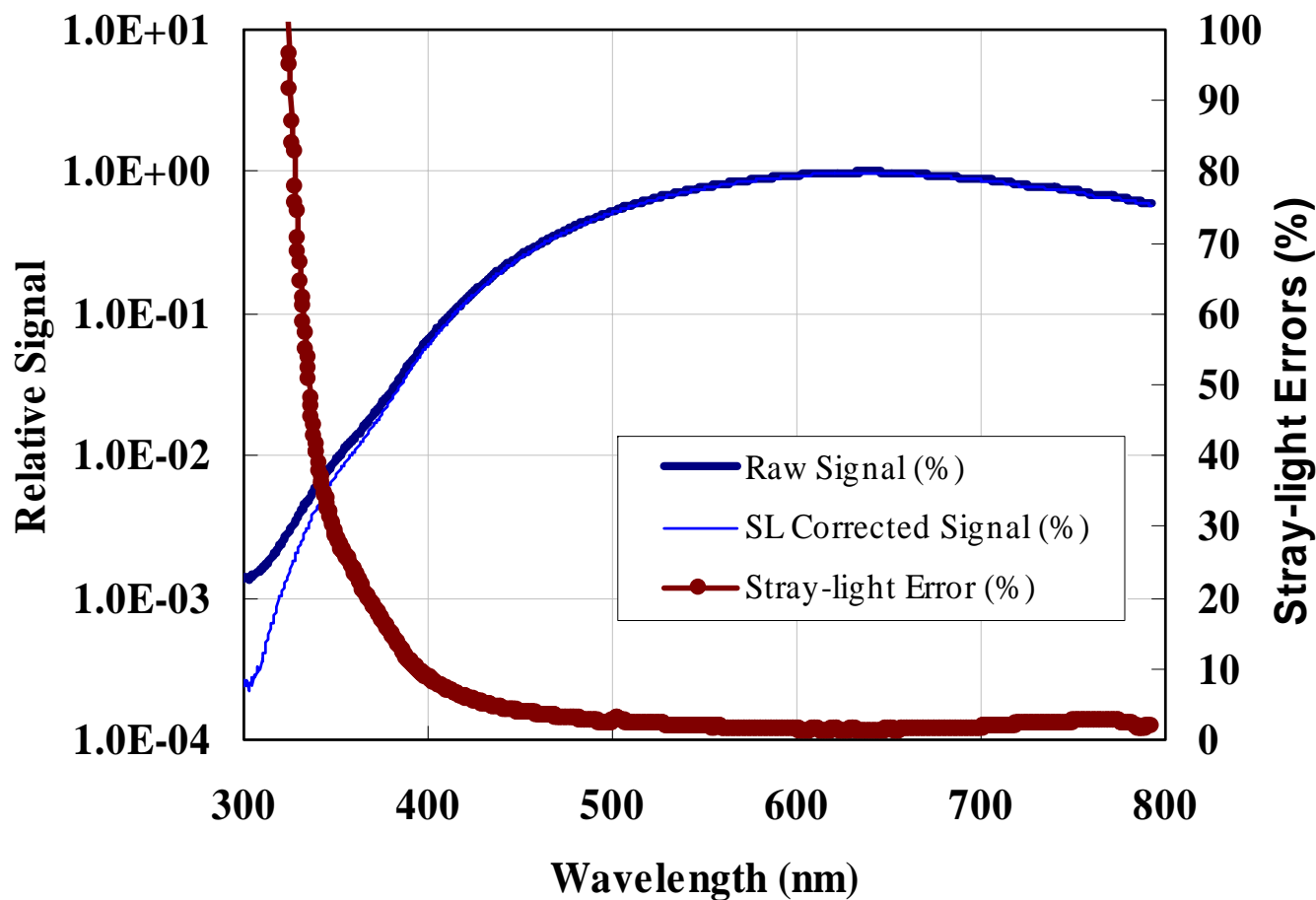
$$\Rightarrow Y_{IB} = A^{-1} \cdot Y_{meas} = C \cdot Y_{meas}$$

Validation: spectral stray-light and fluorescence corrections of the measurement system for a monochromatic laser



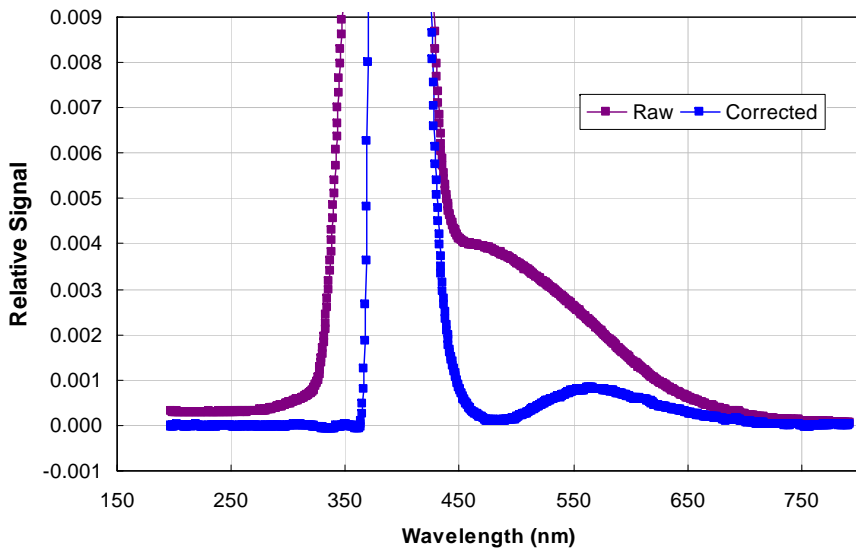
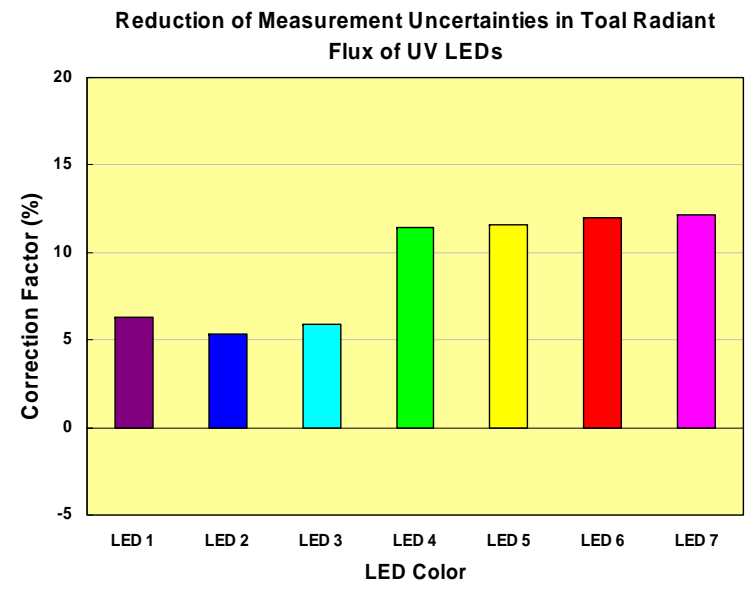
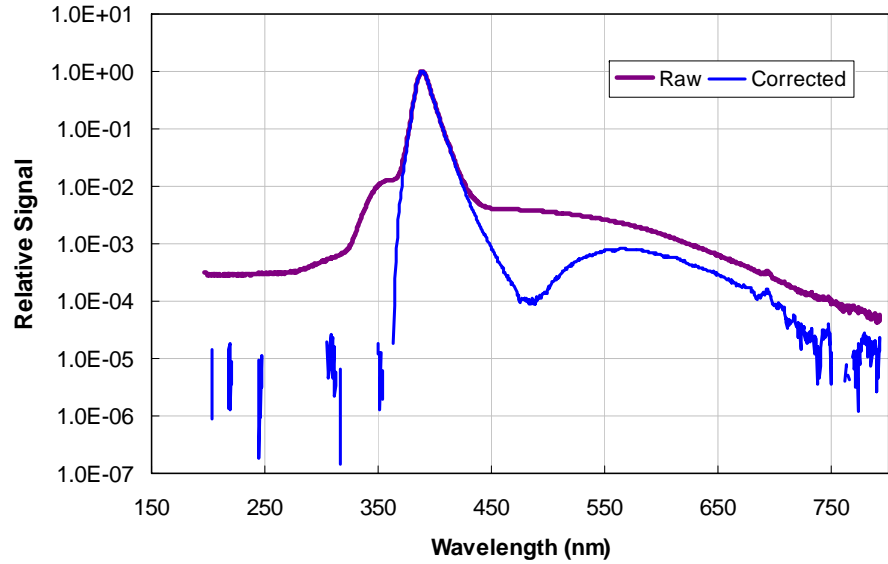
**1 ~ 2 orders reduction;
to ~ 1 bit of a 15-bit instrument.**

Stray-light and fluorescence corrections for calibration of the measurement system



Calibration Source: 3100 K FEL lamp.

Stray light and fluorescence corrections for the measurement of UV LEDs

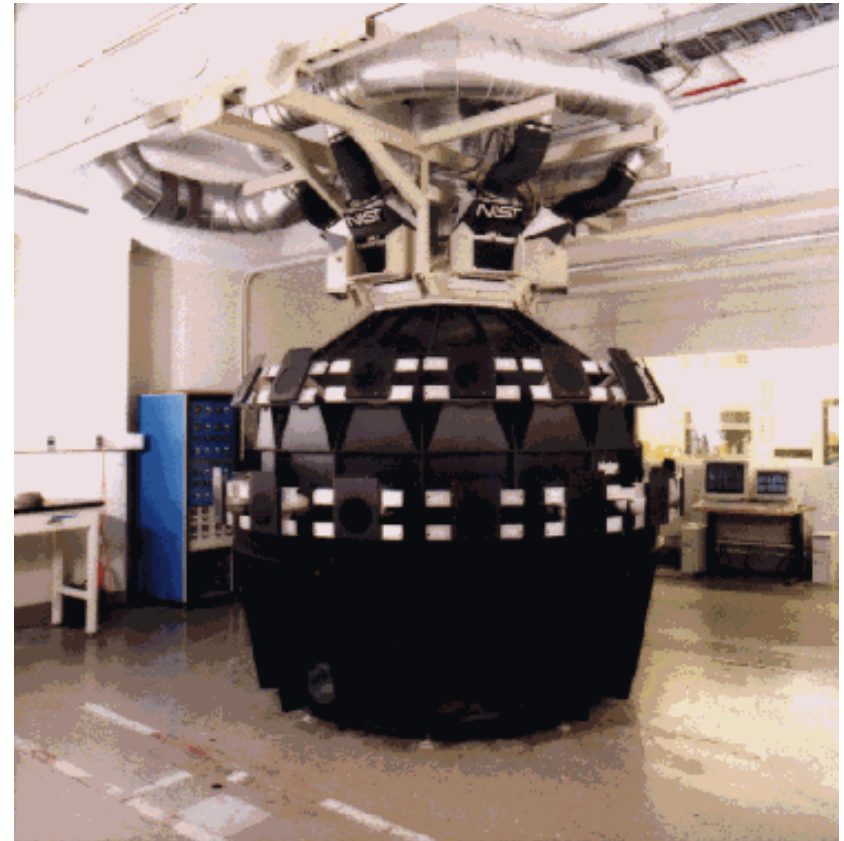


- LED 1 to 3: 390 nm, LED 4 to 7: 375 nm.
- Stray-light signals at left is eliminated.
- Fluorescence-light and Stray-light signals at right are eliminated, which reveals the fluorescence of UV LED itself.
- Meas. Uncertainty ($k=2$): ~ 3 %

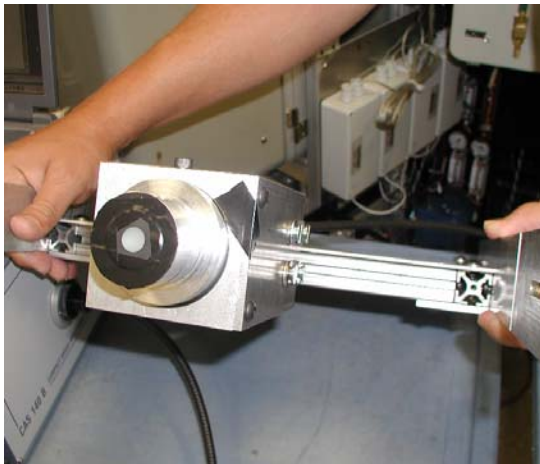
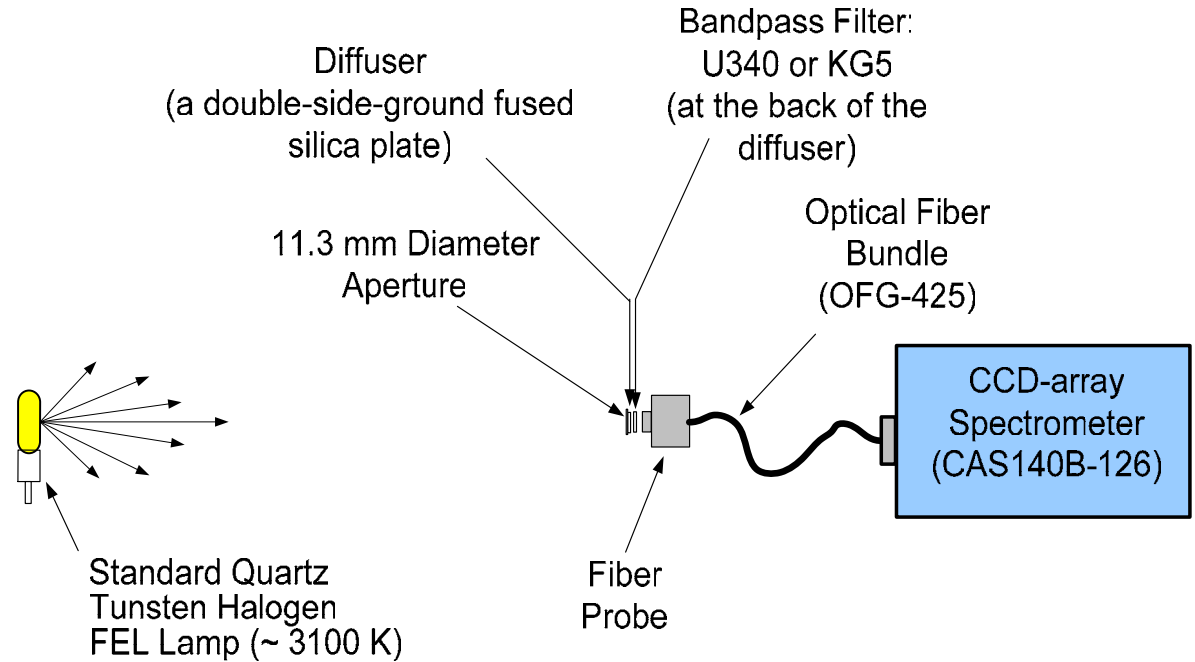
Example 2. Calibration of the spectroradiometer using a portable, stray-light-corrected array spectroradiometer as a transfer standard.

The NIST Simulated Photodegradation via High Energy Radiant Exposure (NIST SPHERE)

- Facility to study the service life of polymeric materials
 - PTFE sphere
 - 32 sample ports
 - Light source at the top
- Controlled environment
 - Temperature, humidity, irradiance levels
- Designed to approximate irradiance levels of ~ 22 “suns” solar ultraviolet radiation integrated from 300 nm to 400 nm

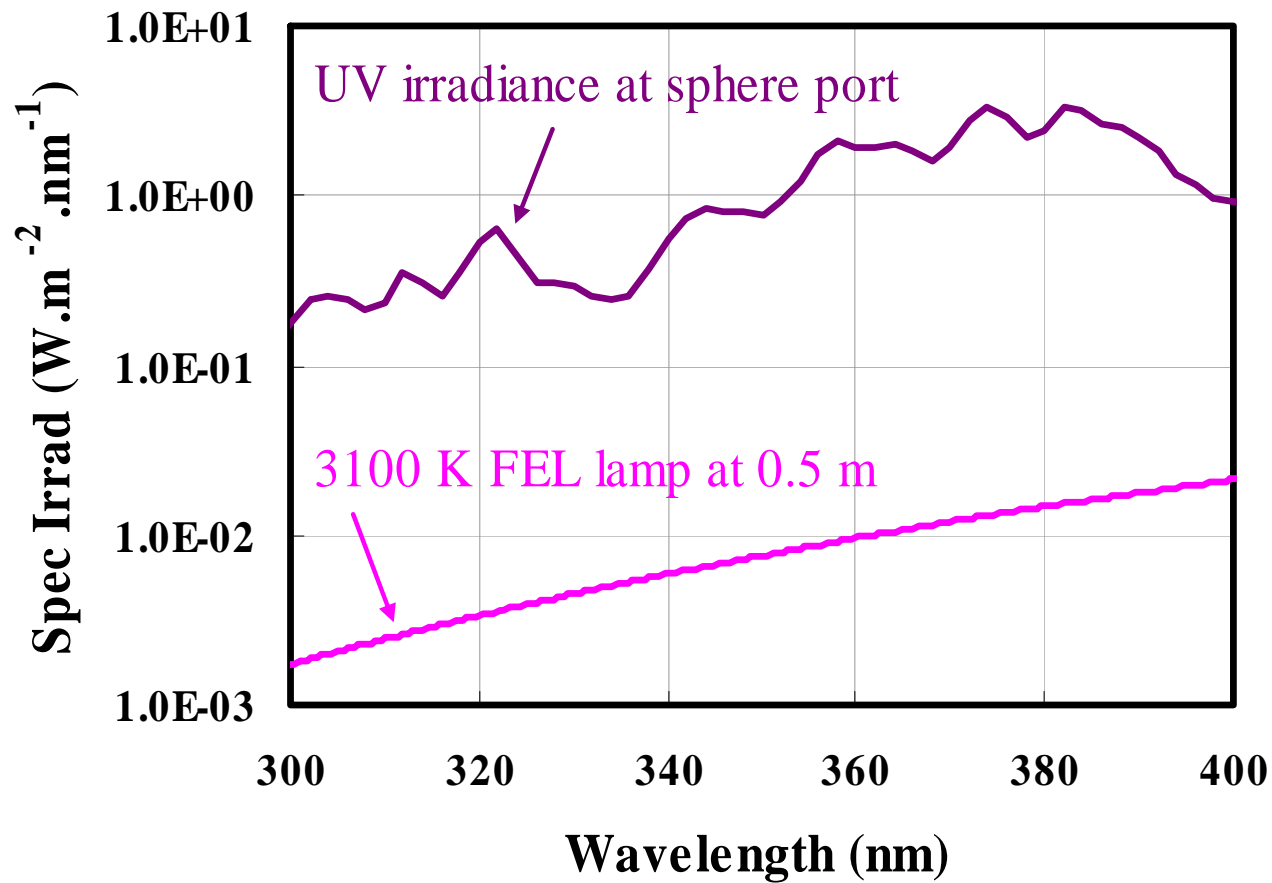


Calibration Method



- Using a portable stray-light corrected spectroradiometer as the transfer standards.
- Substitution method for calibration of the test array spectrometer using the UV sphere source.

Measurement of UV source using a CCD-array spectrometer



Uncertainty: ~ 2 %

Summary

- A simple, practical spectral stray light and fluorescence correction method has been developed for array spectroradiometers. By applying stray light and fluorescence corrections, the dominant measurement errors in UV array spectroradiometers can be reduced more than one order.
- A wide range of compact, affordable array spectroradiometers are commercially available now. By using stray-light-corrected array spectroradiometers, the discrepancies in UV measurements by using filter radiometers can be reduced considerably.
- The stray-light correction service is available now at NIST as special tests.

Acknowledgements

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