Source-Based and Detector-Based Calibration of Qasume at PTB

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Outline

- Traceability chains for QASUME
- Detector-based calibration:
  - tuneable laser source
  - beam conditioning
  - reference trap detectors
- QASUME @ PTB
  - first measurements in 2013
  - second round in 2014
- Conclusions and outlook
QASUME

Quality Assurance of Spectral Ultraviolet Measurements in Europe through a transportable unit

- Portable reference UV spectroradiometer
  - Bentham DM 150 double monochromator with a PMT
  - Spectral range 250 nm to 500 nm
  - Temperature stabilization to ±0.5°C
  - Shaped Teflon diffuser (CMS-Schreder) with 4 m optical fiber

- Portable calibrator
  - Interchangeable 250 W tungsten-halogen lamps
  - Shaped to minimize reflections and allow natural cooling

QASUME irradiance reference

Based on a group of 7 transfer standard lamps (1000 W FEL) calibrated against the primary irradiance standard of the PTB

PTB

Primary standard source

Transfer standard 1000 W FEL lamp

Transfer standard 1000 W FEL lamp

Transfer standard 1000 W FEL lamp

…

WCC-UV

Portable QASUME irradiance reference

250 W portable lamp

250 W portable lamp

250 W portable lamp

…

High-temperature blackbody operated @ 2900 K – 3100 K

BB3200pg
Validation of the QASUME irradiance reference in 2004

Blackbody BB3200pg at PTB

Measurement of BB3200pg at PTB on 15 June 2004

Expanded uncertainty of PTB transfer standards ±3%

New expanded uncertainty of the QASUME irradiance reference (based on these blackbody measurements) ±2%

Gröbner J., and P. Sperfeld, Direct traceability of the portable QASUME irradiance scale to the primary irradiance standard of the PTB, Metrologia, 42, 134—139, 2005.
Motivation for EMRP “SolarUV”

- Long-term trends in surface solar radiation due to atmospheric induced changes of the order of 2% / decade over Europe
- Current calibration capabilities for solar UV monitoring instruments ±5 %, typical discrepancies 10 % - 15 %
- Enhance the reliability of spectral solar UV radiation measurement by developing new methods of observation (techniques and devices) to provide traceable solar UV irradiance with an uncertainty of less than 2 %.
- **Shorten traceability chain and reduce the transfer uncertainties**
Cryogenic radiometer

cw-laser sources

Si-trap detector + aperture

Spectrally tuneable source

Filter Radiometer

Blackbody + aperture

Transfer standards

Source-based

Detector-based

Tunable lasers

(Aim of the project)

Note: calibration is stored in monitoring sources

QASUME

QASUME
Tuneable laser source

- mode locked Ti:Sa laser (680 nm – 1080 nm, 80 MHz, 140 fs pulse)
- Frequency doubler (SHG) and tripler (THG) unit with autotracker
- Spectral bandwidth <0.1 nm
- High temporal stability
Beam conditioning

- Schematic representation of the beam conditioning unit:
  - Tapered-multimode fiber (TMF) (4 mm/1 mm)
  - Pulse-to-cw converter (fiber bundle of varying length fibers)
  - Microlens array (MA) beam homogeniser
  - 1° holographic diffuser used as a beam splitter
Beam conditioning

- Spectral irradiance uniformity at the plane of measurements (z = 550 mm) determined by a detector with 2 mm aperture

**280 nm**

Normalised signal

- Uncertainty contrib.: 0.03%

**350 nm**

Normalised signal

- Uncertainty contrib.: 0.03%

**400 nm**

Normalised signal

- Uncertainty contrib.: 0.10%

**450 nm**

Normalised signal

- Uncertainty contrib.: 0.02%
Beam conditioning

- Spectral irradiance at the plane of measurements
  (spectral bandpass < 0.1nm)
Reference trap detectors

- Two trap detectors of S1227 photodiodes built, characterised and calibrated against an absolute cryogenic radiometer
  - shunt resistance
  - spatial uniformity
  - pre-aged under UV irradiation
  - calibration in 2013 and 2014

Spatial uniformity of spectral responsivity at 350 nm
Reference trap detectors

- Spectral responsivity: 2013

- Stability of the trap: re-calibration in 2014
QASUME @ PTB

- Two campaignings planned: 2013 and 2014
- Aim: compare detector- vs. source-based calibrations each having shortest chain of traceability
- QASUME calibration maintained by a set of halogen lamps (monitor sources)
- Step 1: Validation directly against the primary standard of spectral irradiance at PTB, the blackbody radiator (source based calibration)
- Step 2: Calibration against the reference trap detectors using the tuneable laser source (detector based calibration)
QASUME calibration

- Spectral irradiance responsivity of the spectroradiometer is a quotient of its signal and the spectral irradiance

\[ s_Q(\lambda_0, \lambda) = \frac{\partial Y_Q(\lambda_0, \lambda)}{E_{\lambda}(\lambda) \partial \lambda} \]
QASUME calibration

- The spectroradiometer signal at $\lambda_0$ caused by $E(\lambda_0)$ of laser is obtained by spectral integration

$$Y_Q(\lambda_0) = \prod_{j=1}^{n} a_j(\lambda_0) \cdot \int s_Q(\lambda_0, \lambda) E_\lambda(\lambda) \ d\lambda = \prod_{j=1}^{n} a_j(\lambda_0) \cdot \int Y_Q(\lambda_0, \lambda) \ d\lambda$$

- Laser irradiance measured by trap

$$E(\lambda_0) = \frac{Y_{\text{Trap}}(\lambda_0)}{s_{\text{Trap}}(\lambda_0)} \cdot A \cdot \prod_{j=1}^{n} b_j(\lambda_0)$$

$$s_Q(\lambda_0) = \frac{Y_Q(\lambda_0)}{E(\lambda_0)}$$

Spectral irradiance of the laser source
(Echelle spectrograph data)

QASUME signal

±3 nm, 0.05 nm step
QASUME calibration : spring 2013

- Results of the QASUME calibration campaign in 2013
QASUME calibration : spring 2013

- Difference between the spectral irradiance responsivity obtained by the calibration against the trap detector and the sources

Reproducibility of the QASUME values at TULIP ±0.5% (error bars)
QASUME calibration: spring 2013

- Reproducibility of two consecutive QASUME scans:

![Graph showing signal and wavelength](image)

**Echelle spectrograph**

Trap: $E_1/E_2 - 1 = 0.005\%$

Integral value: $Y_1/Y_2 - 1 = 0.6\%$

**Signal / a.u.**

- $\lambda_0 = 378.971 \text{ nm}$
- $\lambda_0 = 378.95 \text{ nm}$

**Wavelength / nm**

- 378.5 to 379.5

**Signal / a.u.**

- 0.0 to 1.0

**Wavelength / nm**

- 376 to 382

**Signal / a.u.**

- 0.0 to 0.14
Measurements in spring 2014

- Effect of the MC drive cleaning in preparation for the measurements

![Graph showing the effect of MC drive cleaning on polarisation measurements.](image-url)
Measurements in spring 2014

- QASUME (PMT) signal as a function of time
  (laser wavelength & irradiance at TULIP const.)
Measurements in spring 2014

- Checking the reproducibility..
Measurements in spring 2014

- Measurements at a reduced irradiance level (I < 60 nA)
Measurements in spring 2014

- Effect of MC drive backlash

![Graph showing measurements with annotations for backlash at different scan widths and wavelengths.](image-url)
Measurements in spring 2014

- Results of the QASUME calibration campaign in 2014
# QASUME calibration

## Uncertainty budget for the QASUME calibration

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Standard uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference trap detector</td>
<td>0.08 %</td>
</tr>
<tr>
<td>Aperture area</td>
<td>0.04 %</td>
</tr>
<tr>
<td>Trap positioning</td>
<td>0.04 %</td>
</tr>
<tr>
<td>Spatial uniformity</td>
<td>0.10 %</td>
</tr>
<tr>
<td>Stability of laser irradiance</td>
<td>0.02 %</td>
</tr>
<tr>
<td>Laser wavelength</td>
<td>0.01 %</td>
</tr>
<tr>
<td>Spatial stray light</td>
<td>0.05 %</td>
</tr>
<tr>
<td>Photocurrent measurement</td>
<td>0.01 %</td>
</tr>
<tr>
<td>QASUME diff. reference plane</td>
<td>0.18 %</td>
</tr>
<tr>
<td>QASUME scan</td>
<td>0.20 %</td>
</tr>
<tr>
<td>QASUME non-linearity</td>
<td>0.25 %</td>
</tr>
<tr>
<td>QASUME monitor sources</td>
<td>0.20 %</td>
</tr>
<tr>
<td>QASUME drift</td>
<td>0.25 %</td>
</tr>
<tr>
<td>QASUME stability</td>
<td>0.10 %</td>
</tr>
<tr>
<td>Combined uncertainty</td>
<td>0.54 %</td>
</tr>
<tr>
<td>Expanded uncertainty (k=2)</td>
<td>1.04 %</td>
</tr>
</tbody>
</table>
Conclusions and outlook

- Calibration of the reference QASUME spectroradiometer has been carried out directly against reference detectors at the TULIP facility.
- Results of the calibration agree with those from a direct calibration against a blackbody radiator.
- Though, a number of systematic related to the spectroradiometer had to be taken into account.
- Calibration of the QASUME spectroradiometer with 1% uncertainty is possible.
- To reduce the uncertainties even further, a substantial upgrade of both the reference spectroradiometer and the monitoring schemes would be needed.
- Such activities (i.e. a replacement of the PMT, LED-monitoring sources, new entrance optics...) have been already initiated with the EMRP SolarUV project.