Direct traceability of the portable QASUME irradiance scale to the primary irradiance standard of the PTB

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Abstract. The portable QASUME irradiance scale has been directly compared to the primary irradiance standard (black-body BB3200pg) of the PTB using the travelling spectroradiometer QASUME. The average black-body spectral irradiance scale based on three different temperatures (2940 K, 2997 K, and 3059 K) was on average 0.6% greater than the QASUME irradiance scale based on the average of three low-power lamps. This is fully consistent with the expanded uncertainty of 3.8% at 300 nm to 3.6% at larger wavelengths of the QASUME irradiance scale. If these black-body measurements are used to establish directly the portable QASUME irradiance scale, then its expanded uncertainty is substantially reduced to 2.1% at 300 nm to 1.6% at larger wavelengths.

I. Introduction

The travelling unit used for the quality assurance of solar spectral ultraviolet irradiance measurements in Europe (QASUME) consists essentially of a spectroradiometer and its associated calibration unit. The portable irradiance scale used by this spectroradiometer is realised in the ECUV laboratory by a transfer of the irradiance scale from a set of secondary transfer standards (1000 W quartz halogen FEL lamps) calibrated at the PTB and traceable to the primary irradiance standard of the PTB (black-body BB3200pg) to a number of low-power lamps (100 W and 250 W lamps).

The calibration chain from this primary irradiance standard to the portable lamp irradiance scale is shown in Figure 1.

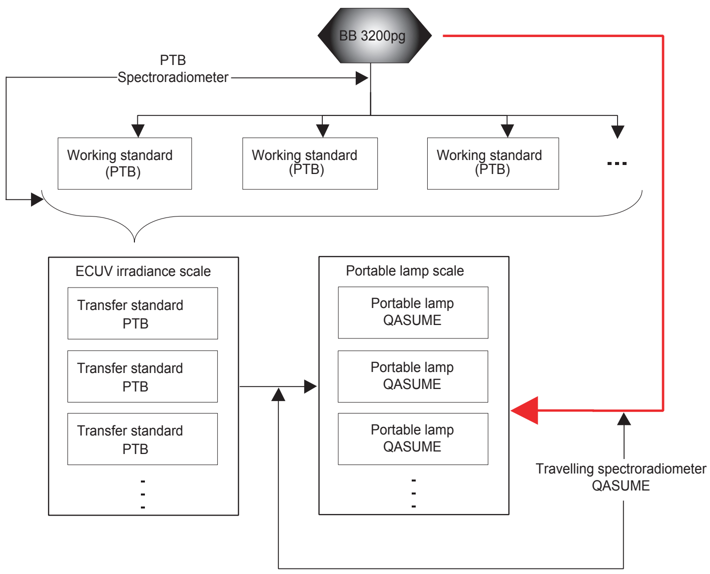

Figure 1 Schematic view of the irradiance calibration chain. The red bold arrow represents the new chain based on measurements discussed in this study.

The low-power lamps are used within the calibrating unit during site visits to provide an absolute calibration traceable to the ECUV irradiance scale. After each return to the ECUV they are recalibrated to detect changes in their output due to ageing or transportation. The calibration unit and the low-power lamps are shown in Figure 2 below.

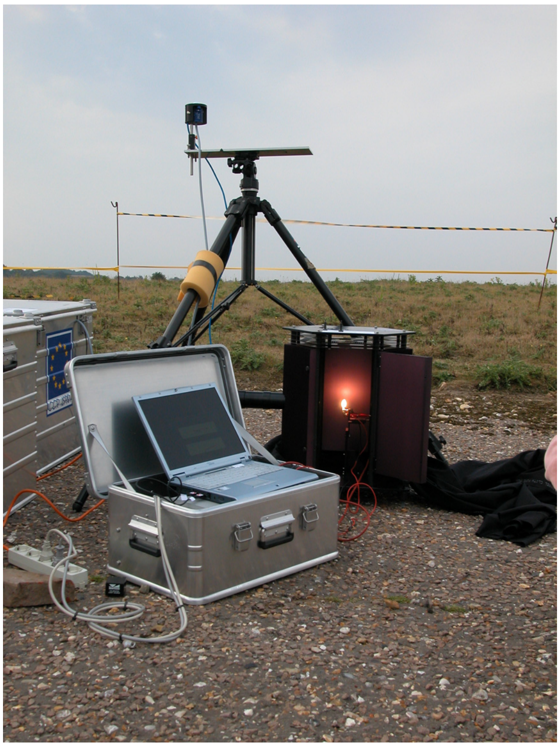

Figure 2 The calibration unit is shown on the left. The detector fits to the end of the horizontal tube which protrudes on the left of the enclosure. The lamps, shown on the right, are mounted within the calibration unit.

II. Realisation of the ECUV irradiance scale

At the PTB, up to three transfer stages are used to transfer the irradiance scale from the black-body to the transfer standard used at the ECUV. Similarly, at the ECUV several successive measurements of these transfer standards are used to establish and maintain the ECUV irradiance scale which is then transferred to the low-power lamps. To shortcut this chain by directly transferring the irradiance scale from the primary irradiance standard of the PTB to the low-power portable lamps provides invaluable information on the quality of the original transfer chain.

III. Measurement setup

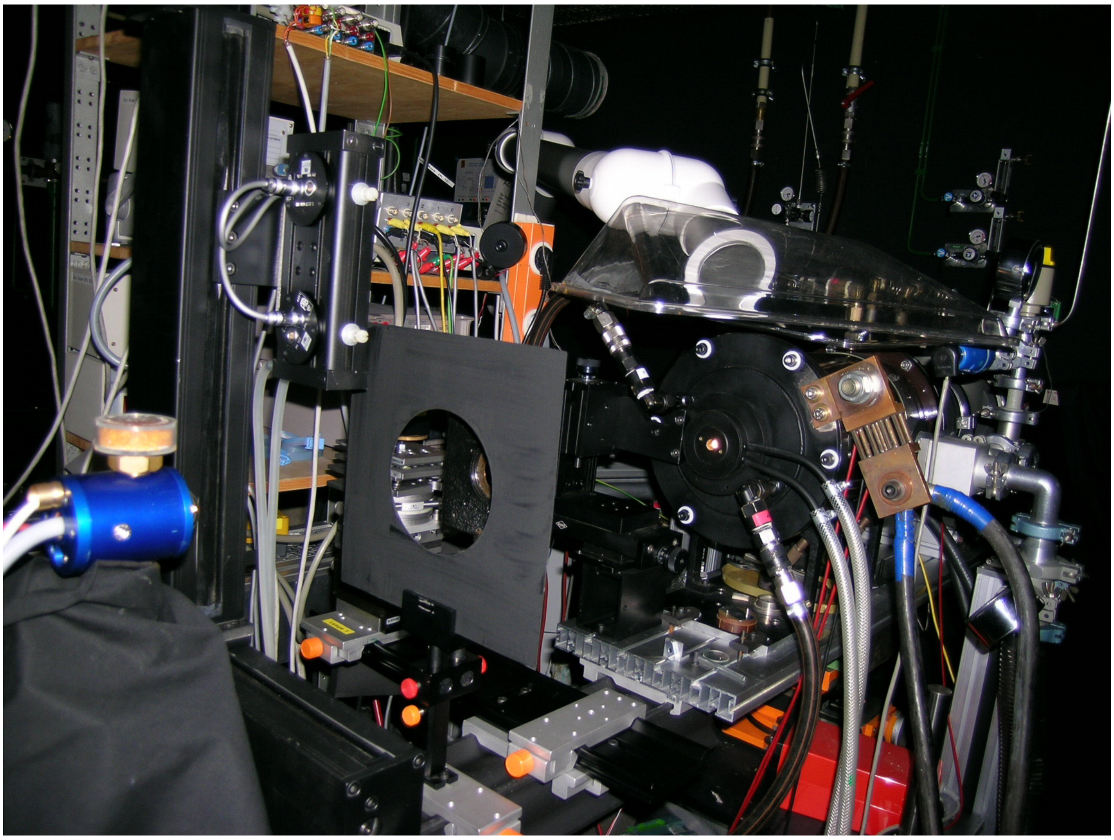

Figure 3 Measurement setup for the measurement of the black-body at the PTB. The blue detector to the left is the entrance optics of the QASUME spectroradiometer. Several baffles placed between the detector and the black-body reduce any remaining stray light.

The measurements were performed during one day of measurements, on June 15, 2004 in the laboratories of the PTB. The black-body BB3200pg was used as the primary irradiance standard [1]. Its temperature was determined before and after each spectral measurement to calculate the absolute spectral irradiance for each spectrum using Planck's law (3 to 6 spectra at each black-body temperature). During the warm-up phase of the black-body, the QASUME spectroradiometer was calibrated using three portable lamps, two of which were used routinely within previous site visits, while the third was hand carried from the ECUV to the PTB.

All spectral measurements were obtained with the QASUME spectroradiometer in the wavelength range 250 nm to 500 nm at wavelength increments of 1 nm. The acquisition of one spectrum required 6 minutes; during that time the black-body temperature drifted by less than 0.5 K, which corresponds to an irradiance variation of less than 0.3% at 300 nm and 0.2% at 400 nm.

The measurement setup is shown in Figure 3. The distance between the detector reference plane and the black-body was set at about 650 mm, with a reproducibility of about 0.1 mm.

IV. Results

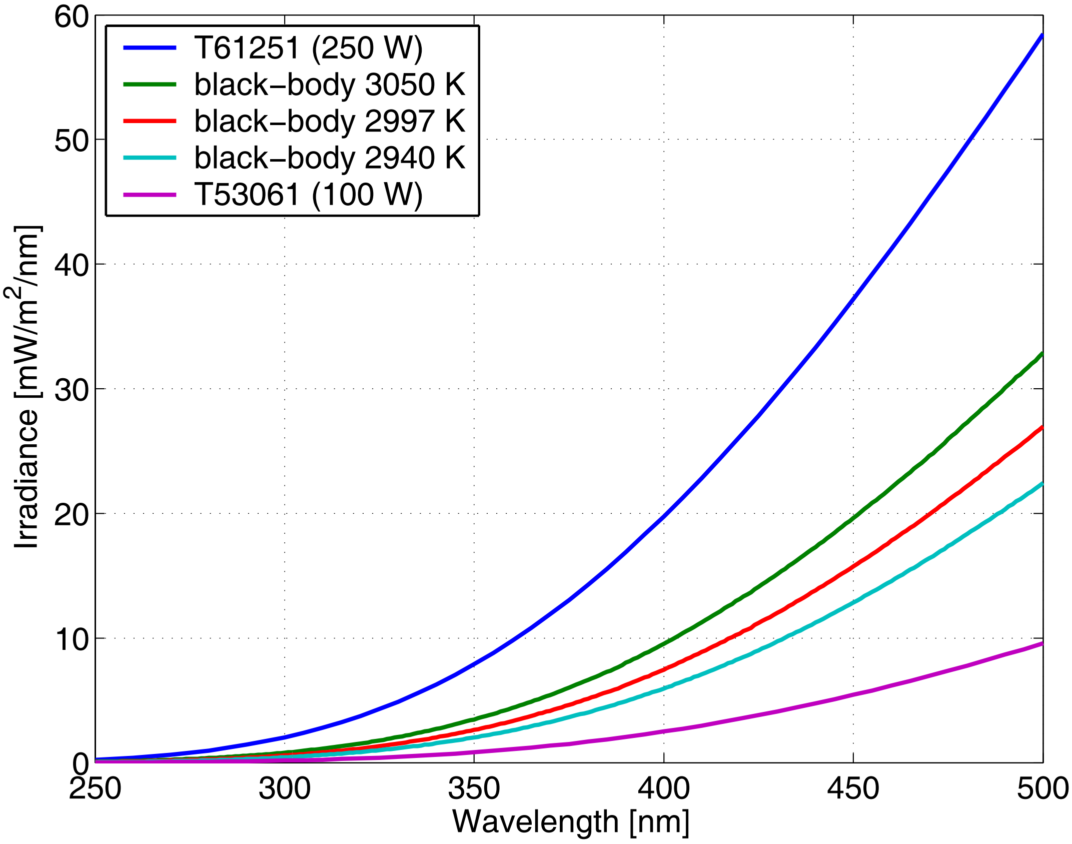

Figure 4 Black-body irradiance measurements at 2941 K, 2997 K, and 3059 K. Each curve in the figure is an average of three to six successive measurements at the same temperature. The irradiance of two low-power lamps used in the calibrating unit are also shown. The irradiance of the T61251 lamp is greater than the black-body due to the short distance between the lamp and the detector.

The black-body was heated to three temperatures, approximately 2940 K, 2997 K, and 3059 K. At each temperature level, several spectra were obtained with the QASUME spectroradiometer while the corresponding temperature of the black-body was obtained from temperature measurements carried out before and after each spectral scan. The repeatability of these measurements was better than 0.2% at wavelengths greater than 310 nm, while at shorter wavelengths the higher measurement noise increased the scatter between successive measurements. Figure 4 shows the spectral measurements at the three selected temperatures. For the comparison to the portable irradiance scale, an average of all measurements of the black-body was used to reduce the measurement noise at short wavelengths. This average black-body irradiance scale based on the three different temperatures does not differ significantly from using only the average of the measurements at the highest temperature of 3059 K.

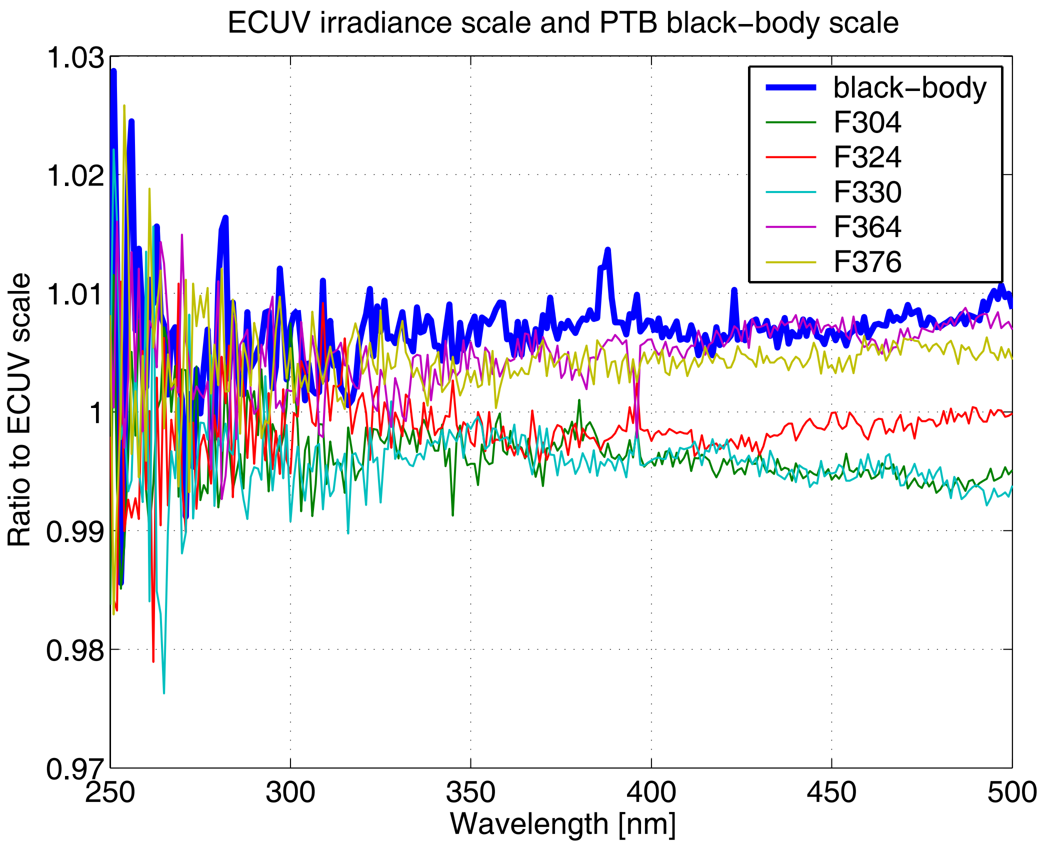

Figure 5 Irradiance scale comparison between the black-body PTB scale and the ECUV irradiance scale. The transfer standards defining the ECUV irradiance scale are shown too. The mean ratio (over wavelength) are 1.007, 0.996, 0.999, 0.996, 1.005, and 1.004 for the black-body, F304, F324, F330, F364, and F376 respectively.

Figure 5 shows the ratio between the irradiance scale of the black-body and the ECUV scale maintained by the portable lamp system. The black-body irradiance ratio is higher by about 0.6%, and spectrally flat over the measured wavelength range. In the same figure we have included all transfer standards which form the ECUV irradiance scale. These transfer standards were calibrated by the PTB against the same black-body irradiance scale, but over a time period of nearly three years. Thus, F304 was calibrated on June 12, 2001, while the latest calibration was on F376 on November, 13, 2003. The differences between the irradiance standards are due to successive realisations of the primary irradiance scale at the PTB, as well as to the uncertainty, reproducibility, and drift of the transfer standards.

A small absorption feature, centred at about 388 nm can be seen in the black-body measurements in Figure 5. Actually, it is not present at the lowest temperature of 2940 K but only at the two higher temperatures of 2997 K and 3059 K (without figure). This small absorption feature has been observed before and is likely due to the second ionisation of Carbon and Cyanide (several C II and CN absorption peaks between 382.5 and 388.3 nm) [2].

V. Conclusion

The expanded measurement uncertainty (k=2, coverage probability 95%) of the portable irradiance scale realisation by the QASUME spectroradiometer has been estimated at 3.8% at 300 nm to 3.6% at larger wavelengths [3].

These estimations include the expanded uncertainty from the calibration certificate of the transfer standards delivered by the PTB of 3%. On the other hand, the standard measurement uncertainty (k=1, coverage probability 65%) of the absolute black-body irradiance scale realisation is mainly depending on the temperature measurement using calibrated filter radiometers with a standard uncertainty of 0.5 K at about 3090 K. Taking also into account the uncertainty of the realisation itself, this primary spectral irradiance scale realisation leads to a standard uncertainty of the order of 0.3% at 300 nm which decreases to 0.2% at 400 nm [4]. Thus, the irradiances of the black-body at the PTB based on the temperature measurements by the calibrated filter radiometers of the PTB are fully consistent with the measurements by the QASUME spectroradiometer using its portable irradiance scale.

Finally, these black-body measurements can be used not only to verify the portable irradiance scale, but also to establish it directly from the measurements of the black-body. In that case, the uncertainties of the portable irradiance scale can be substantially decreased as will be discussed below:

- The standard measurement uncertainty associated with the measurement and transportation of the portable irradiance scale has been estimated to 0.9% at 300 nm and 0.6% at larger wavelengths [3].
- The standard measurement uncertainty of the black-body irradiance within the detector reference plane is less than 0.3% for the wavelength range between 300 nm and 500 nm.
- The temporal stability of the QASUME spectroradiometer over the duration of these measurements was checked by repeated lamp measurements between successive measurements of the black-body. Based on these and previous measurements at the ECUV, a measurement reproducibility of at least 0.3% can be assumed over the full wavelength range.
- The estimated uncertainty in the determination of the reference plane of the entrance optic (quartz dome and spherical diffusing surface) of 0.5 mm leads to a spectrally independent standard uncertainty of 0.15%.
- The estimated uncertainty due to inhomogeneities of the black-body radiation within the detector plane (less than 1 cm^2) and alignment uncertainties of the detector with respect to the black-body is less than 0.3%.
- It is noted that the absolute spectral irradiance of the black-body was measured with a wavelength interval of 1 nm; Thus the uncertainty due to the interpolation of the calibration values of the transfer standards (usual wavelength interval of 10 nm) is not relevant here.

A combination of these points leads to substantially reduced expanded measurement uncertainties for the absolute irradiance scale as realised by the QASUME spectroradiometer in combination with the portable calibration unit. The expanded uncertainty of the portable irradiance scale could be reduced from 3.8% at 300 nm (based on the ECUV irradiance scale) to 2.1% (traced directly to the black-body measurements). Similarly, at larger wavelengths the expanded measurement uncertainty is reduced from 3.6% to 1.6%.

Acknowledgment
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References

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