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

S. Nevas[1], J. Gröbner[2], M. Schuster[1], P. Sperfeld[1], L. Egli[2], G. Hülsen[2], A. Sperling[1], P. Meindl[1], S. Pendsa[1], S. Pape[1]

[1] Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin, Germany

[2] Physikalisch-Meteorologisches Observatorium Davos (PMOD), World Radiation Center, Davos Dorf, Switzerland

PTB

pmod wrc

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

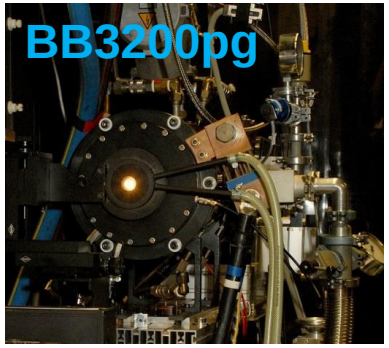
- **Q**uality **A**ssurance of **S**pectral **U**ltraviolet **M**easurements in **E**urope through a transportable unit
  - Portable reference UV spectroradiometer
    - Bentham DM 150 double monochromator with a PMT
    - Spectral range 250 nm to 500 nm
    - Temperature stabilization to ±0.5°C
    - 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

Gröbner J. ***et al***, Traveling reference spectroradiometer for routine quality assurance of spectral solar ultraviolet irradiance measurements, App. Optics, **44**, 5321—5331, 2005.

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



High-temperature blackbody operated @ 2900 K – 3100 K

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

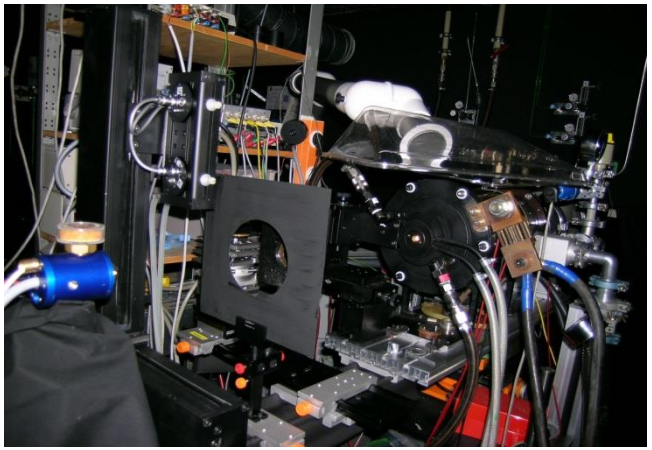
250 W portable lamp

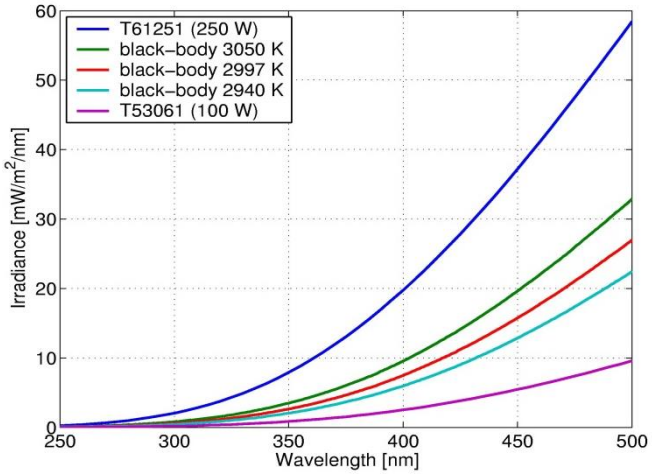
250 W portable lamp

⋮

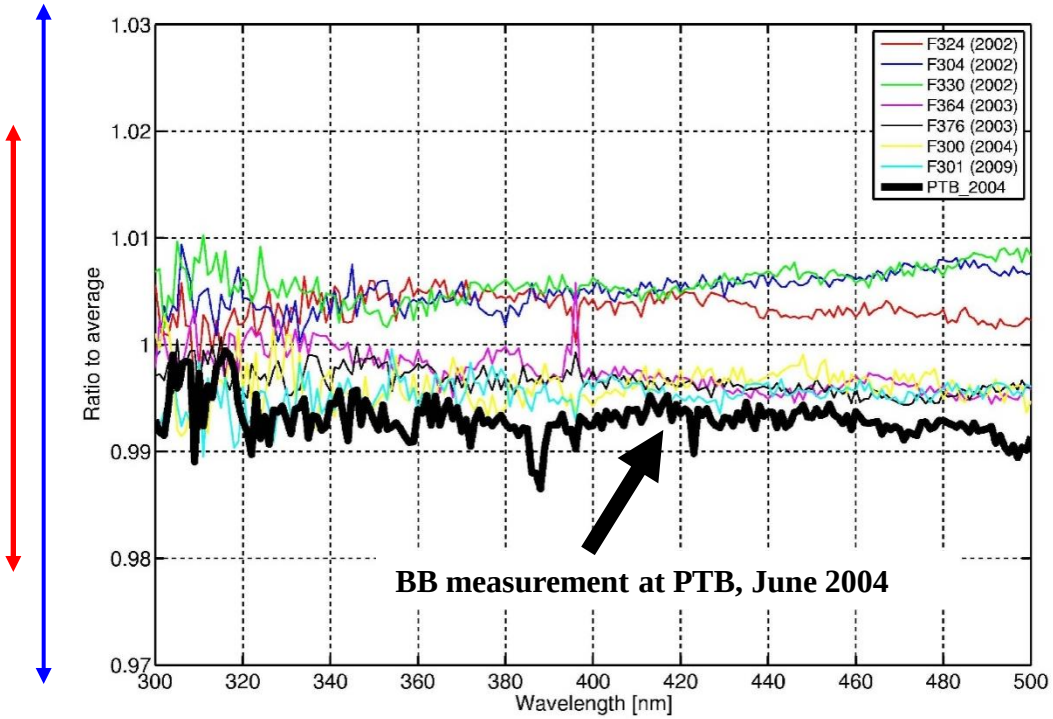
Validation of the QASUME irradiance reference in 2004

Blackbody BB3200pg at PTB





Measurement of BB3200pg at PTB on 15 June 2004



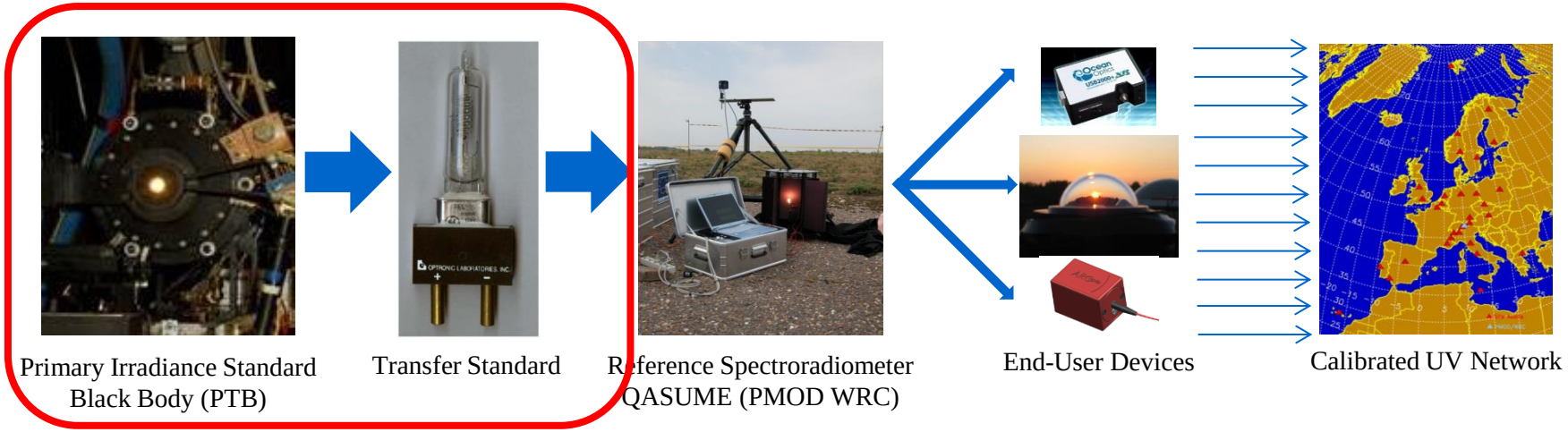
Expanded uncertainty of PTB transfer standards ±3%

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

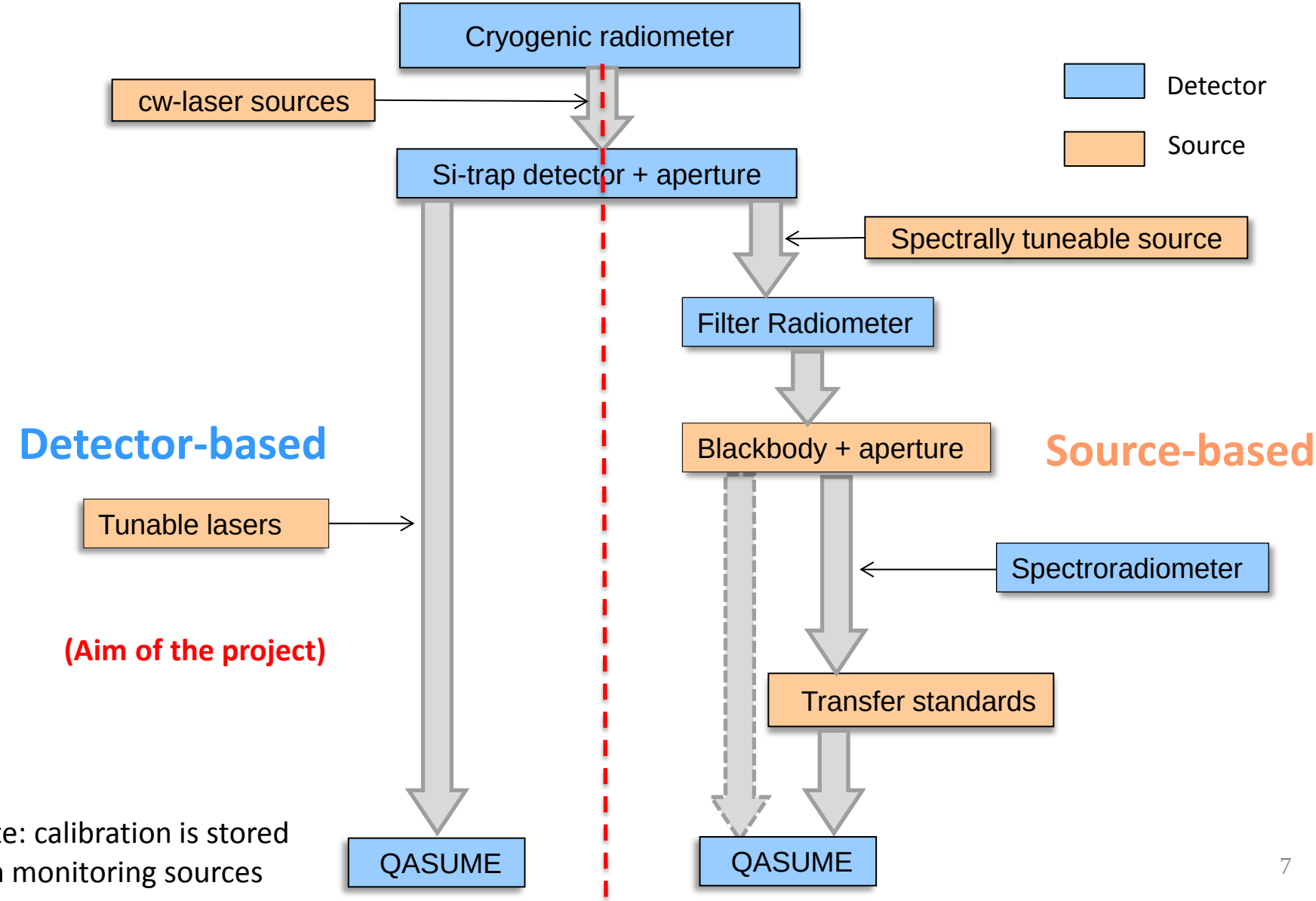
Gröbner J., and P. Sperfeld, Direct traceability of the portable QASUME irradiance scale to the primary irradiance standard of the PTB, Metrologia, **42**, 134—139, 2005.

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**



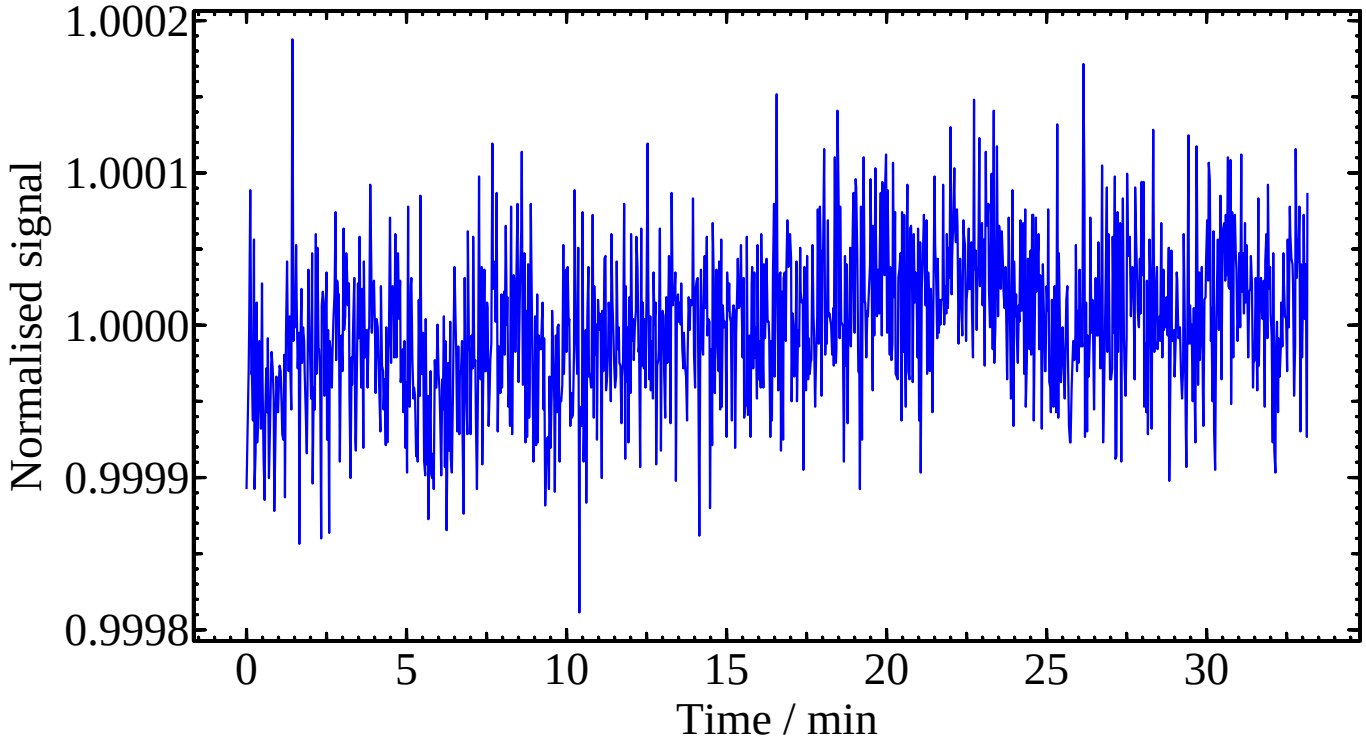
Traceability chain



Note: calibration is stored in monitoring sources

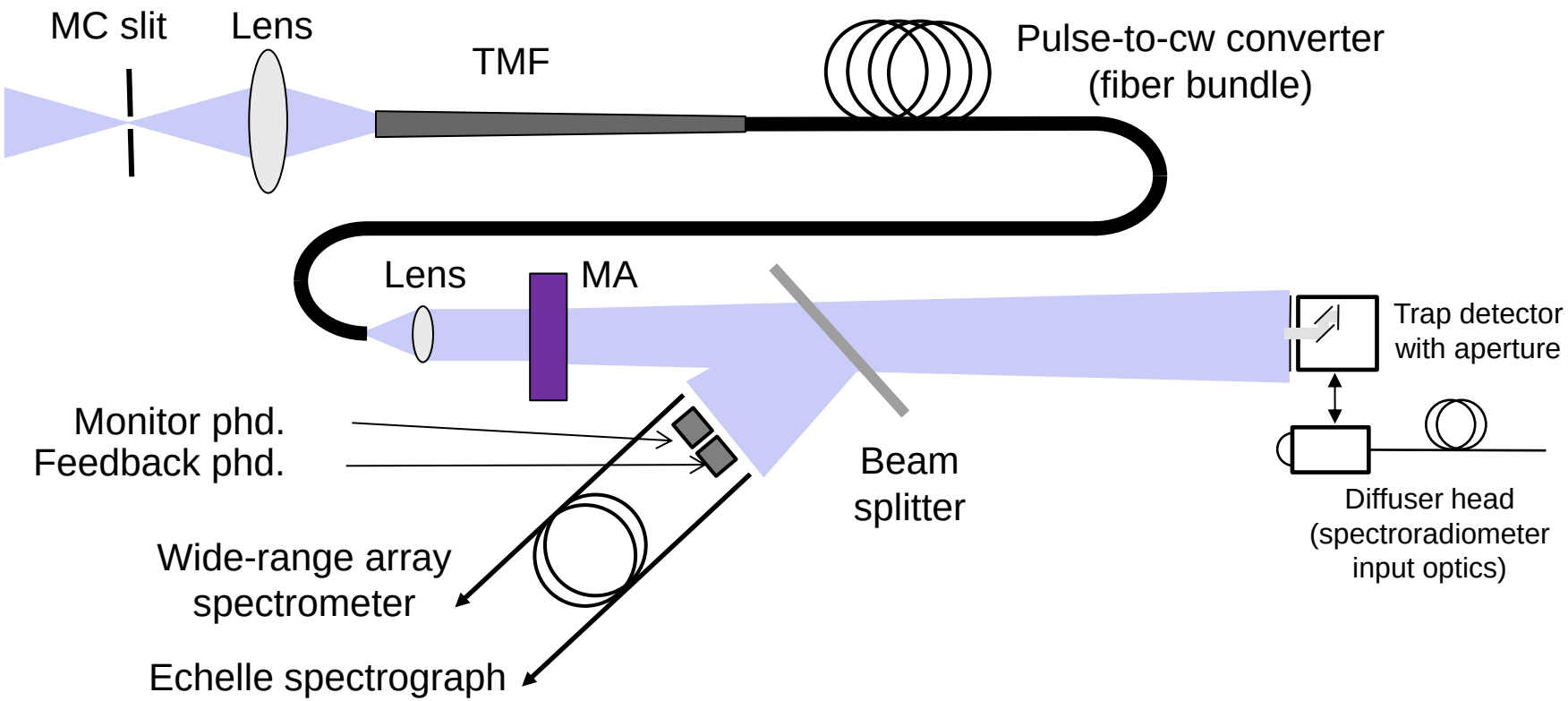
Tuneable laser source

- 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



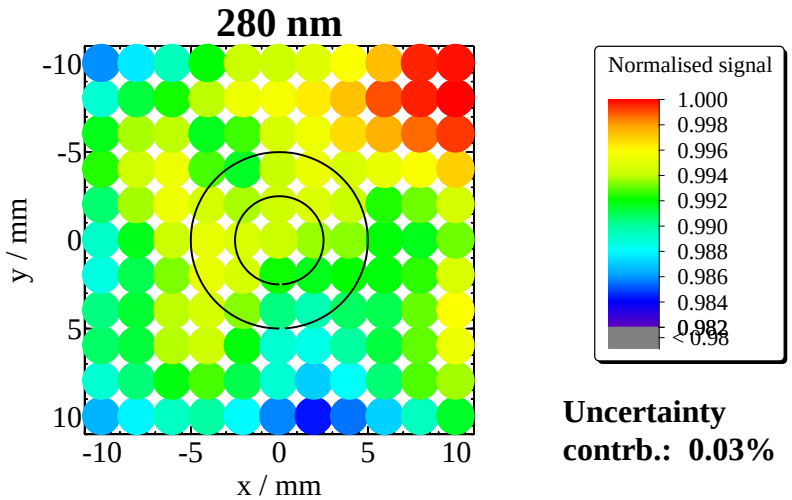
Beam conditioning

- 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

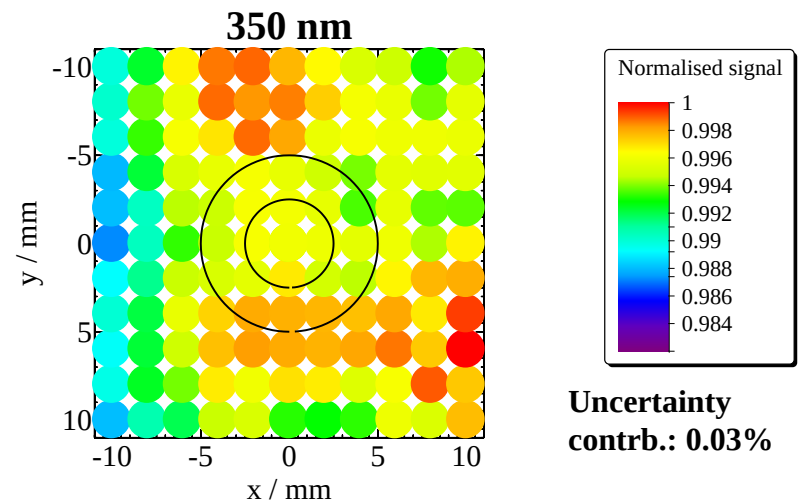


Beam conditioning

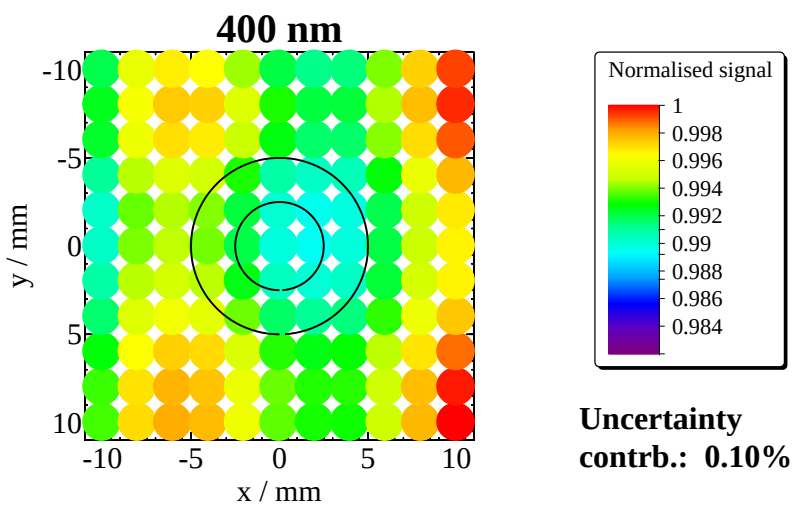
- Spectral irradiance uniformity at the plane of measurements (z = 550 mm) determined by a detector with 2 mm aperture



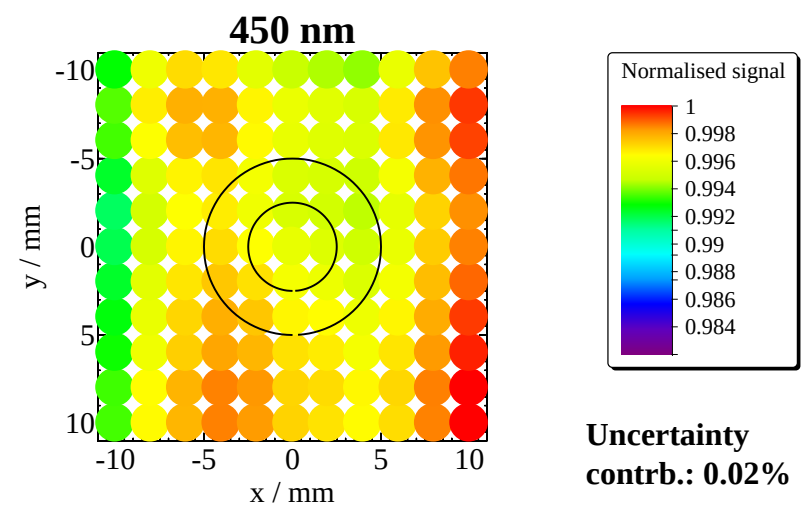
Uncertainty contrb.: 0.03%



Uncertainty contrb.: 0.03%



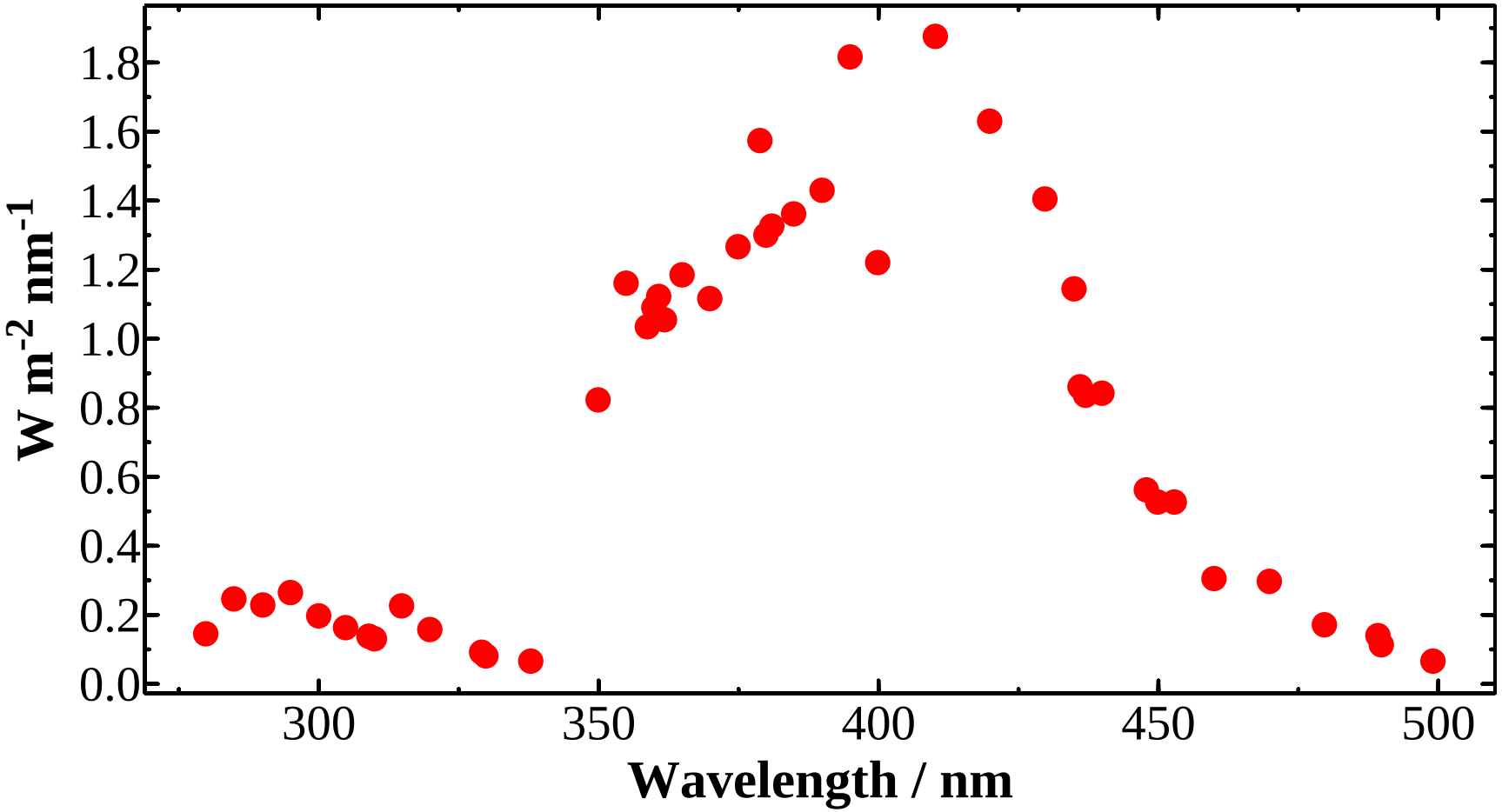
Uncertainty contrb.: 0.10%



Uncertainty contrb.: 0.02%

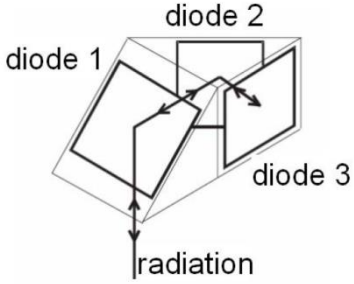
Beam conditioning

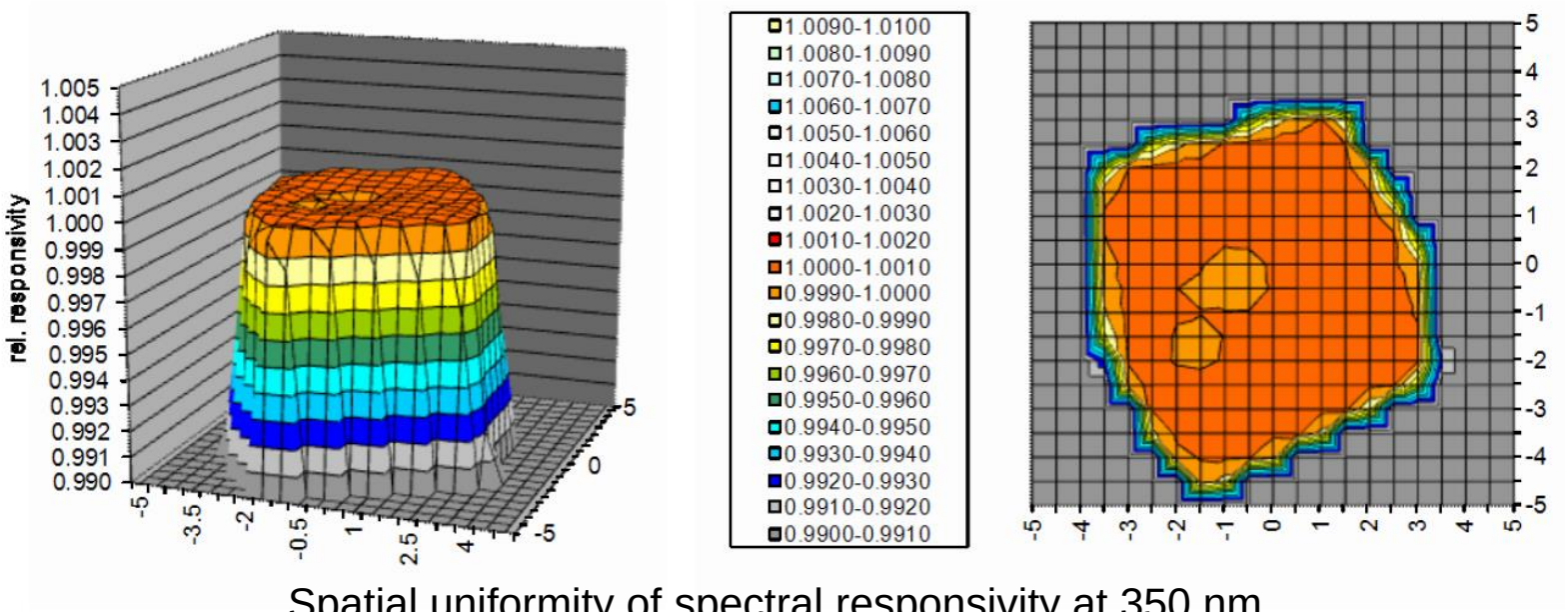
- Spectral irradiance at the plane of measurements (spectral bandpass < 0.1nm)



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**

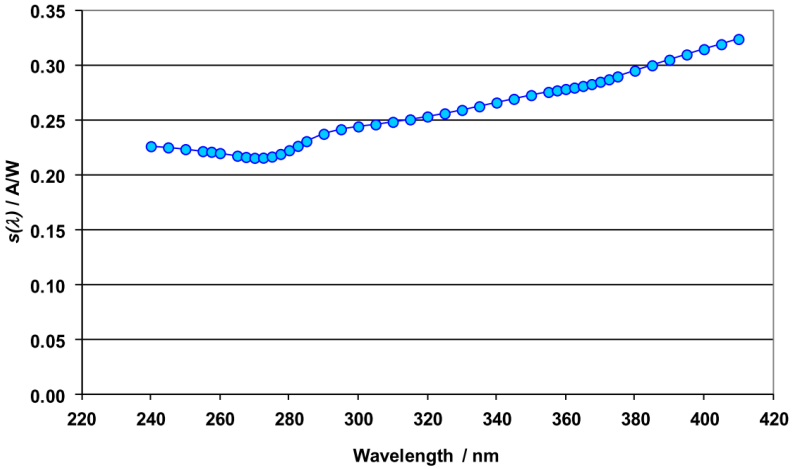


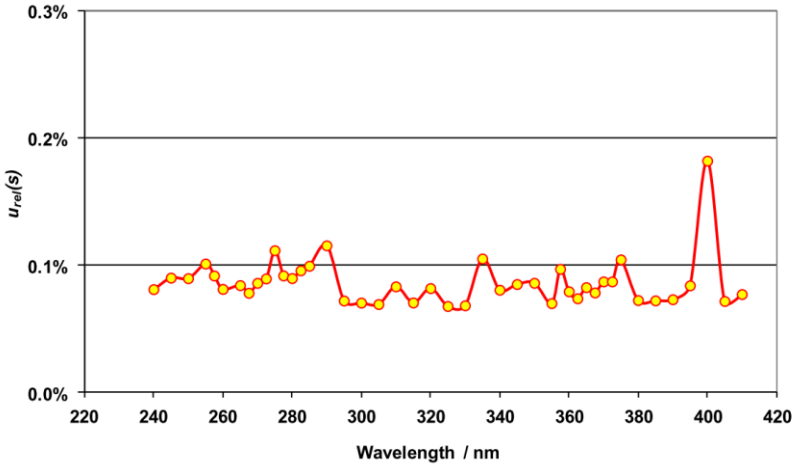


Spatial uniformity of spectral responsivity at 350 nm

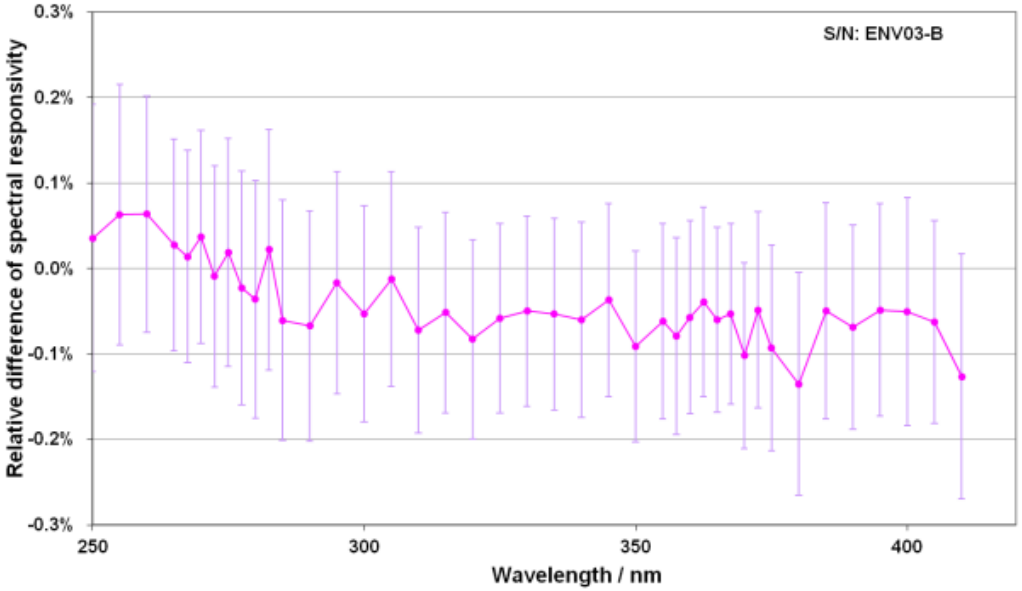
Reference trap detectors

- Spectral responsivity: 2013





- Stability of the trap: re-calibration in 2014



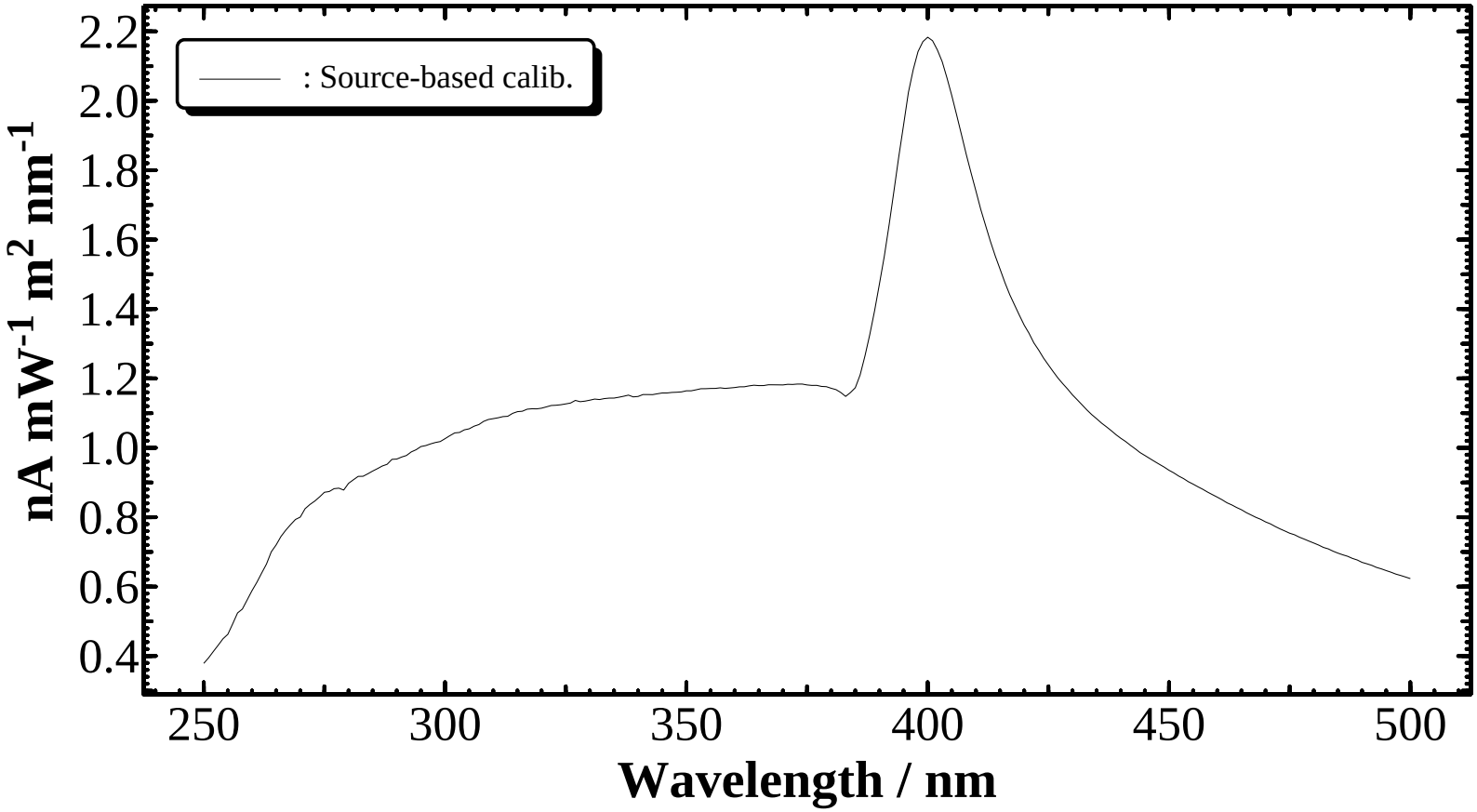
QASUME @ PTB

- Two campaings 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

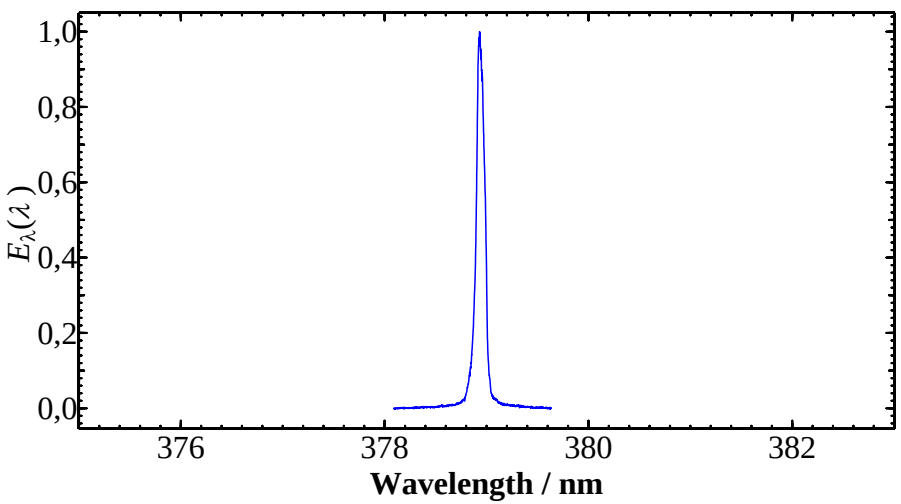
- The spectroradiometer signal at λ_0 caused by $E(\lambda_0)$ of laser is obtained by spectral integration

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

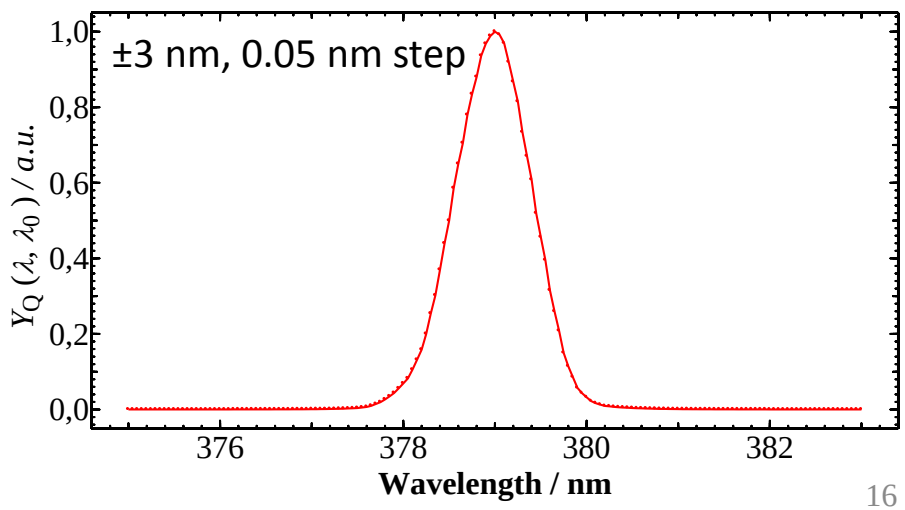
- Laser irradiance measured by trap

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

Spectral irradiance of the laser source (Echelle spectrograph data)

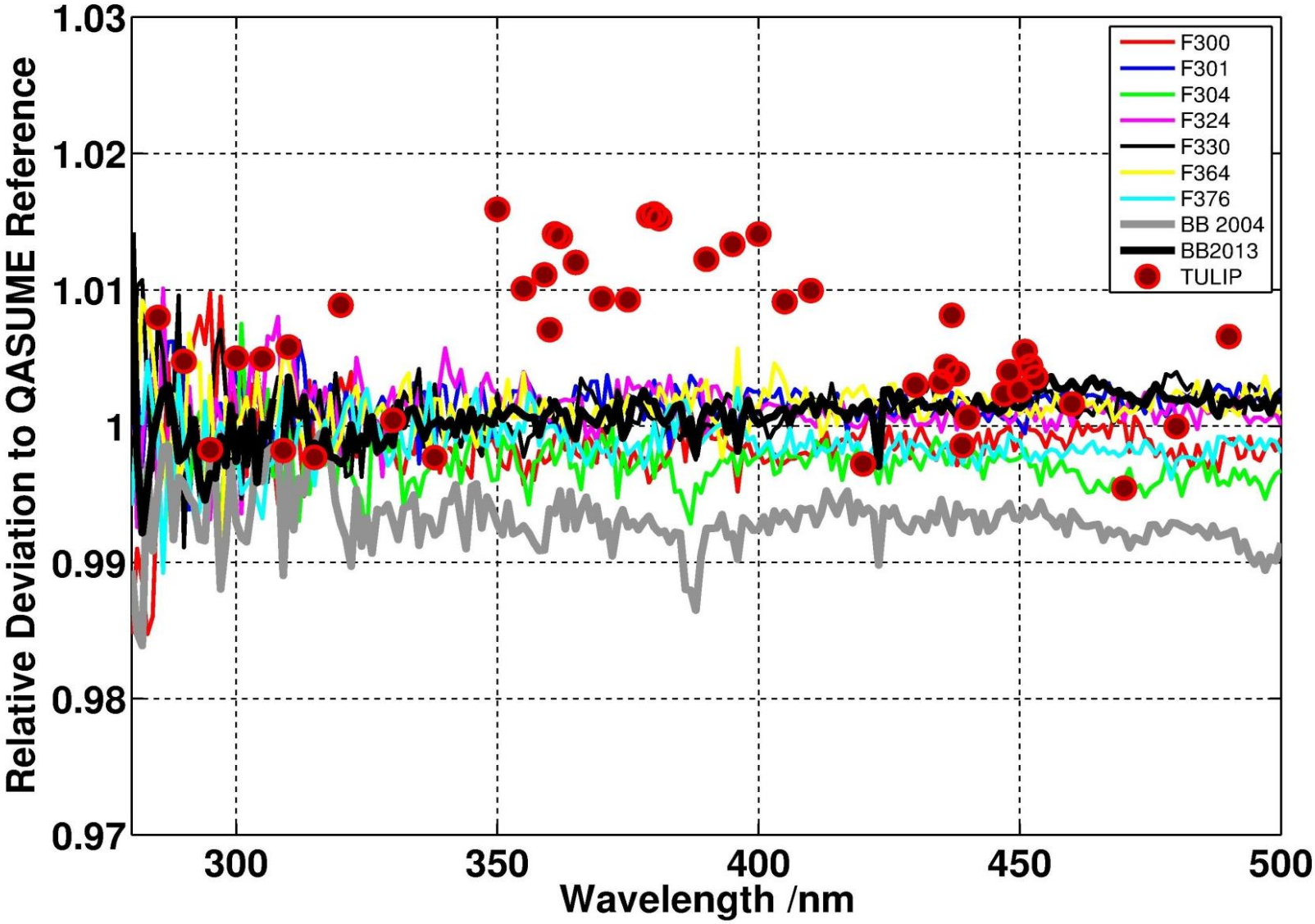


QASUME signal



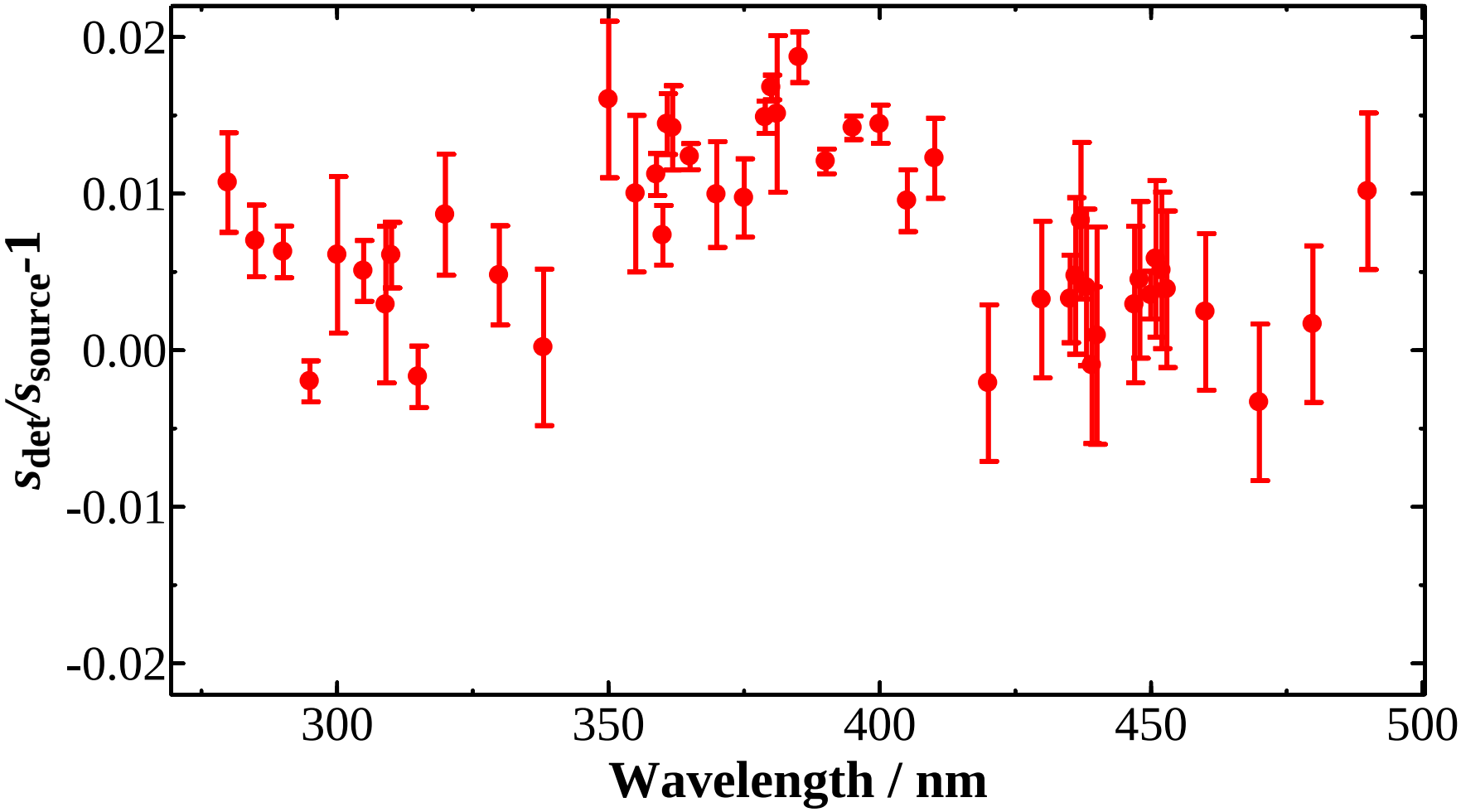
QASUME calibration : spring 2013

- Results of the QASUME calibration campaign in 2013



QASUME calibration : spring 2013

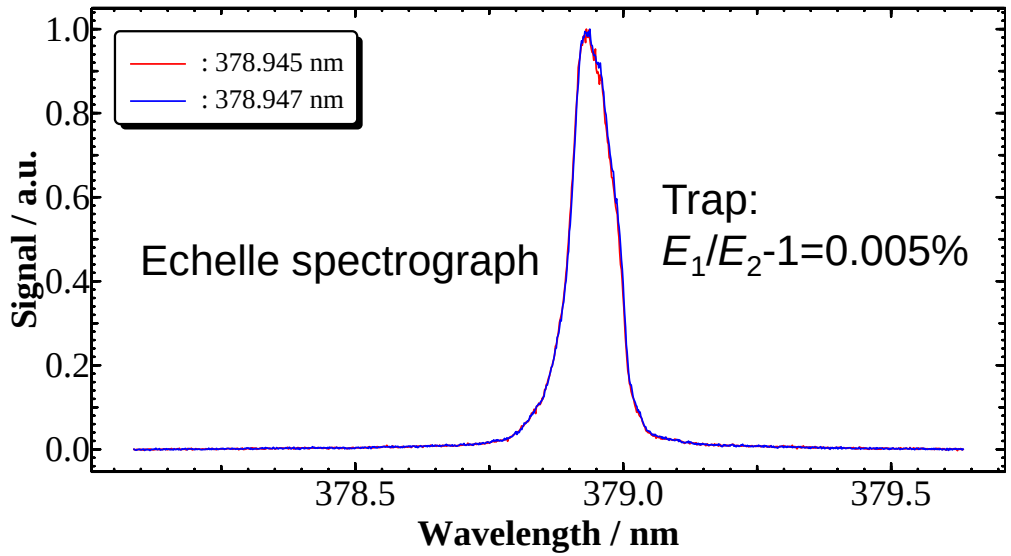
- Difference between the spectral irradiance responsivity obtained by the calibration against the trap detector and the sources



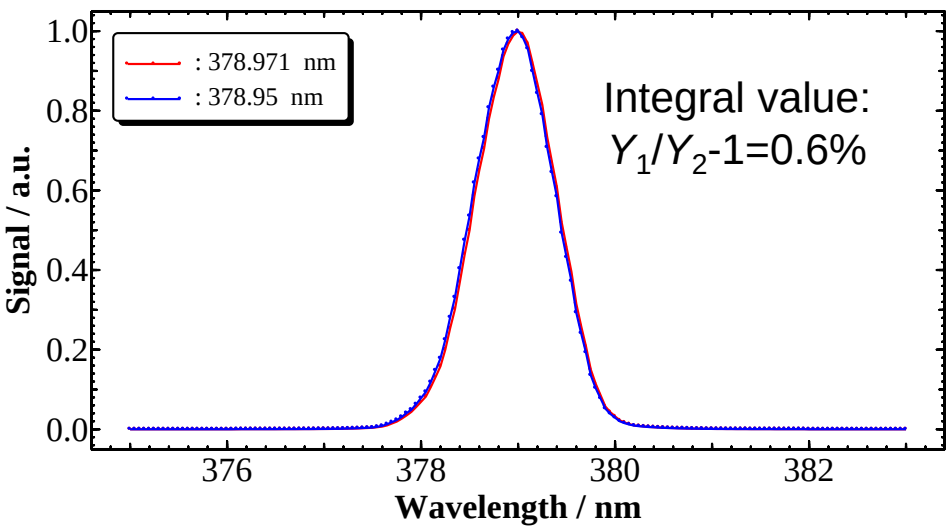
Reproducibility of the QASUME values at TULIP ±0.5% (error bars)

QASUME calibration : spring 2013

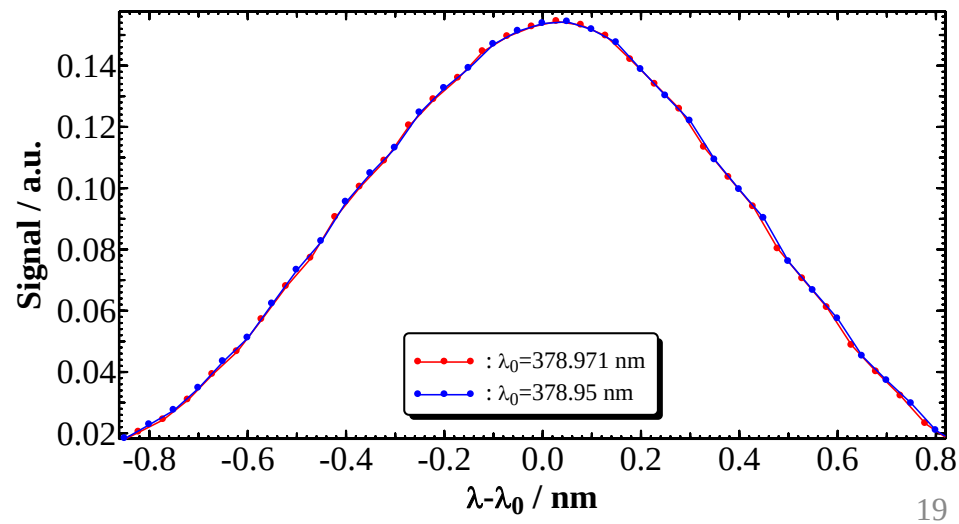
- Reproducibility of two consecutive QASUME scans:



QASUME signal

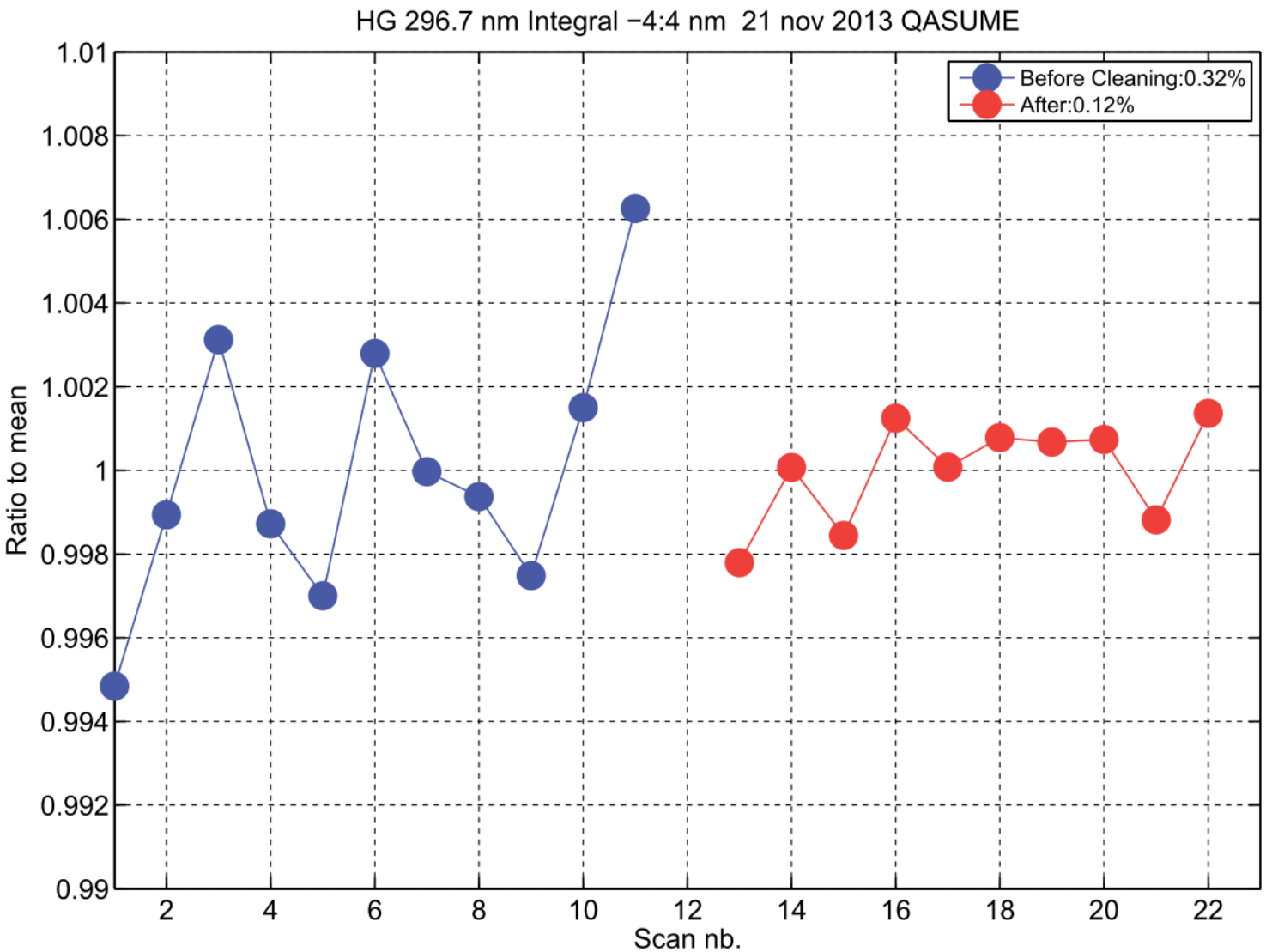


QASUME signal



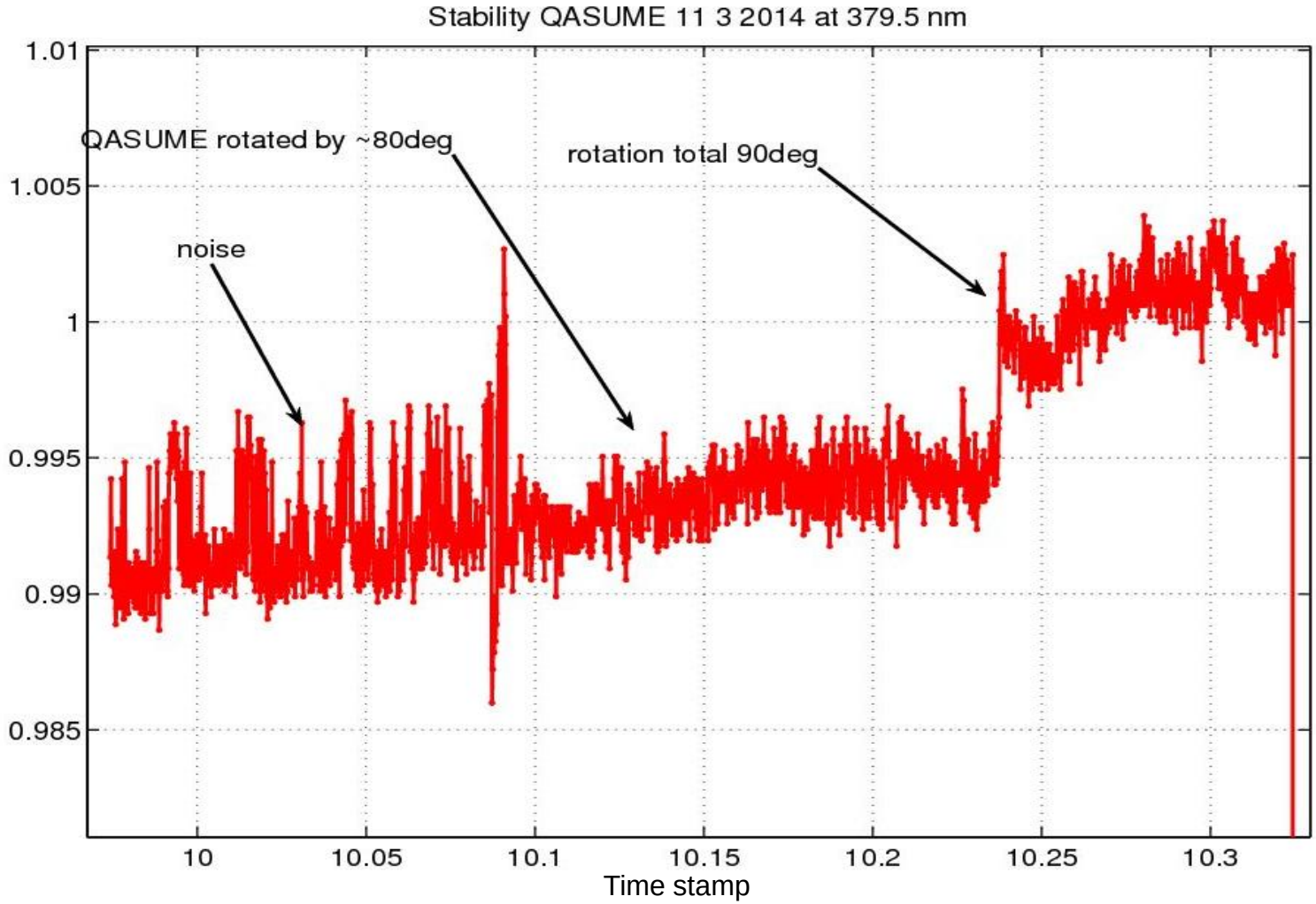
Measurements in spring 2014

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



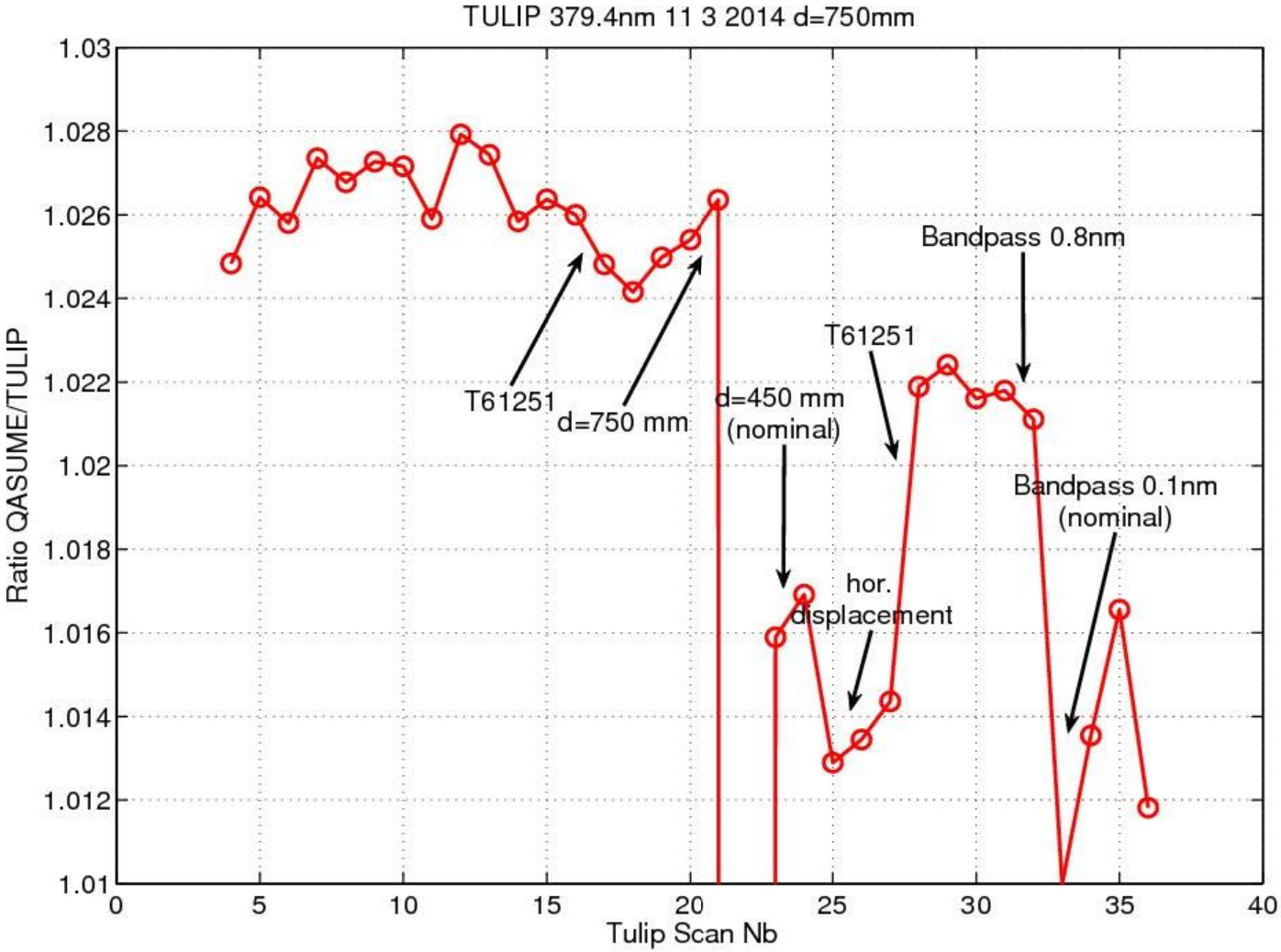
Measurements in spring 2014

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



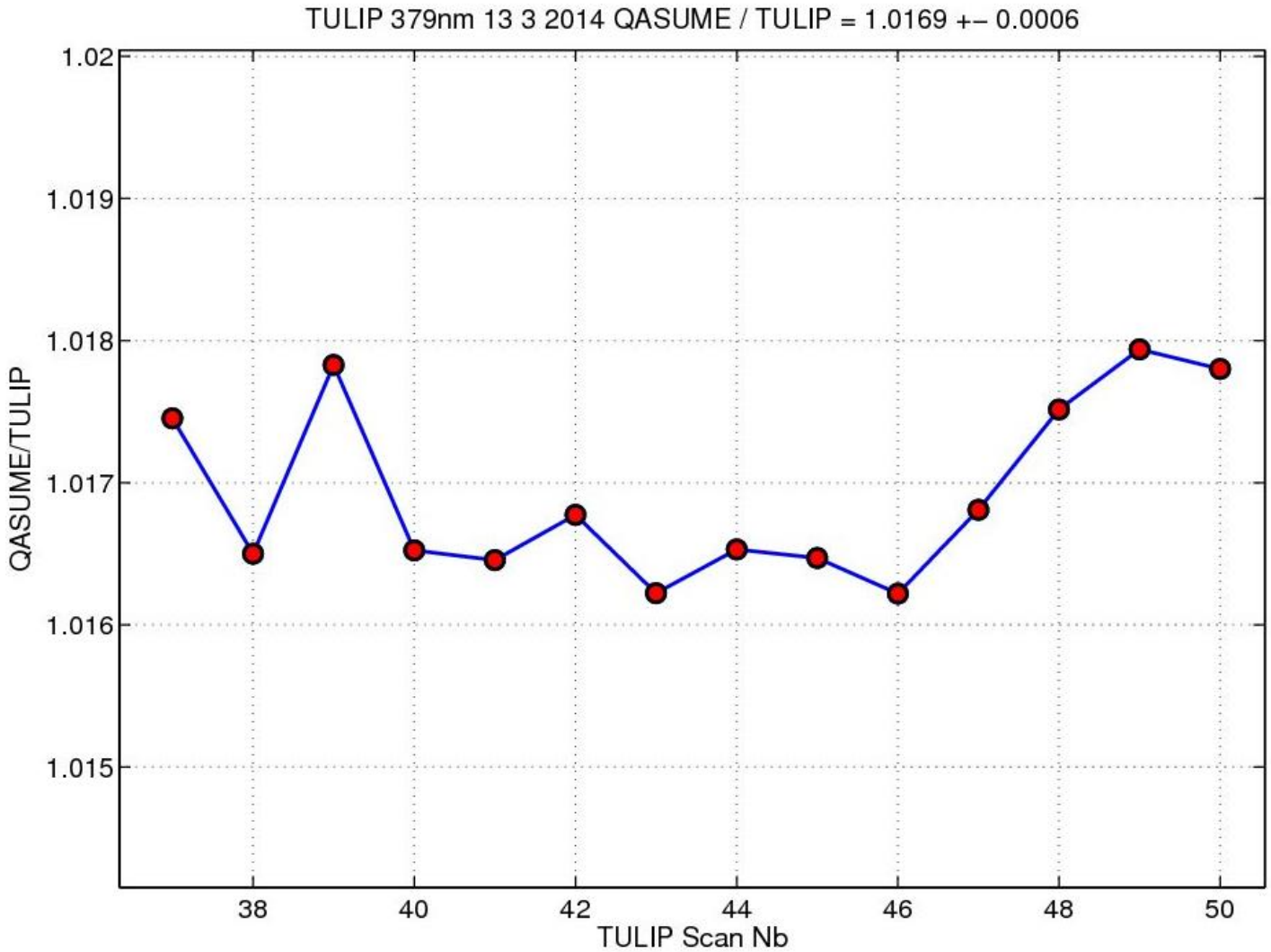
Measurements in spring 2014

- Checking the reproducibility..



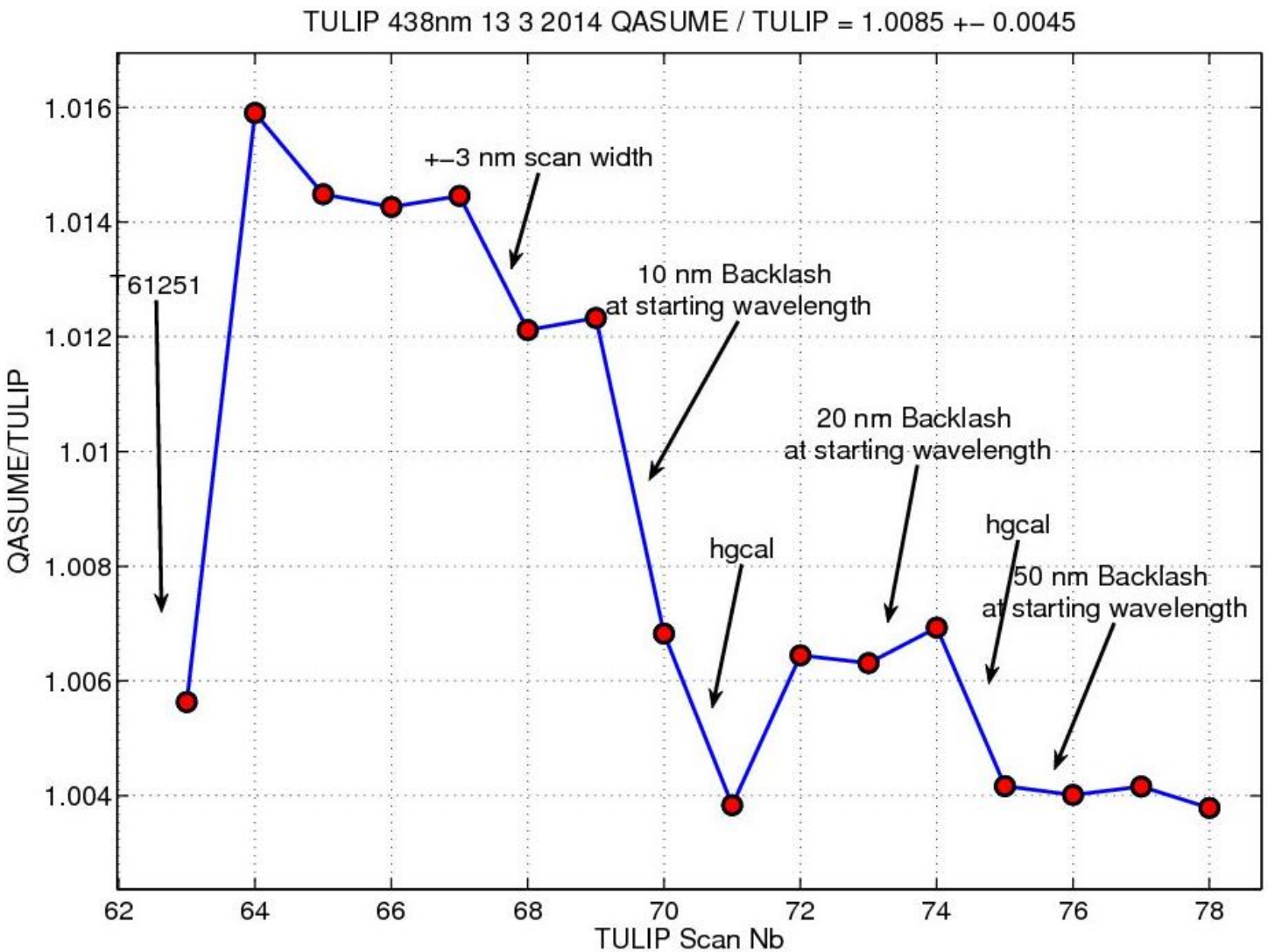
Measurements in spring 2014

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



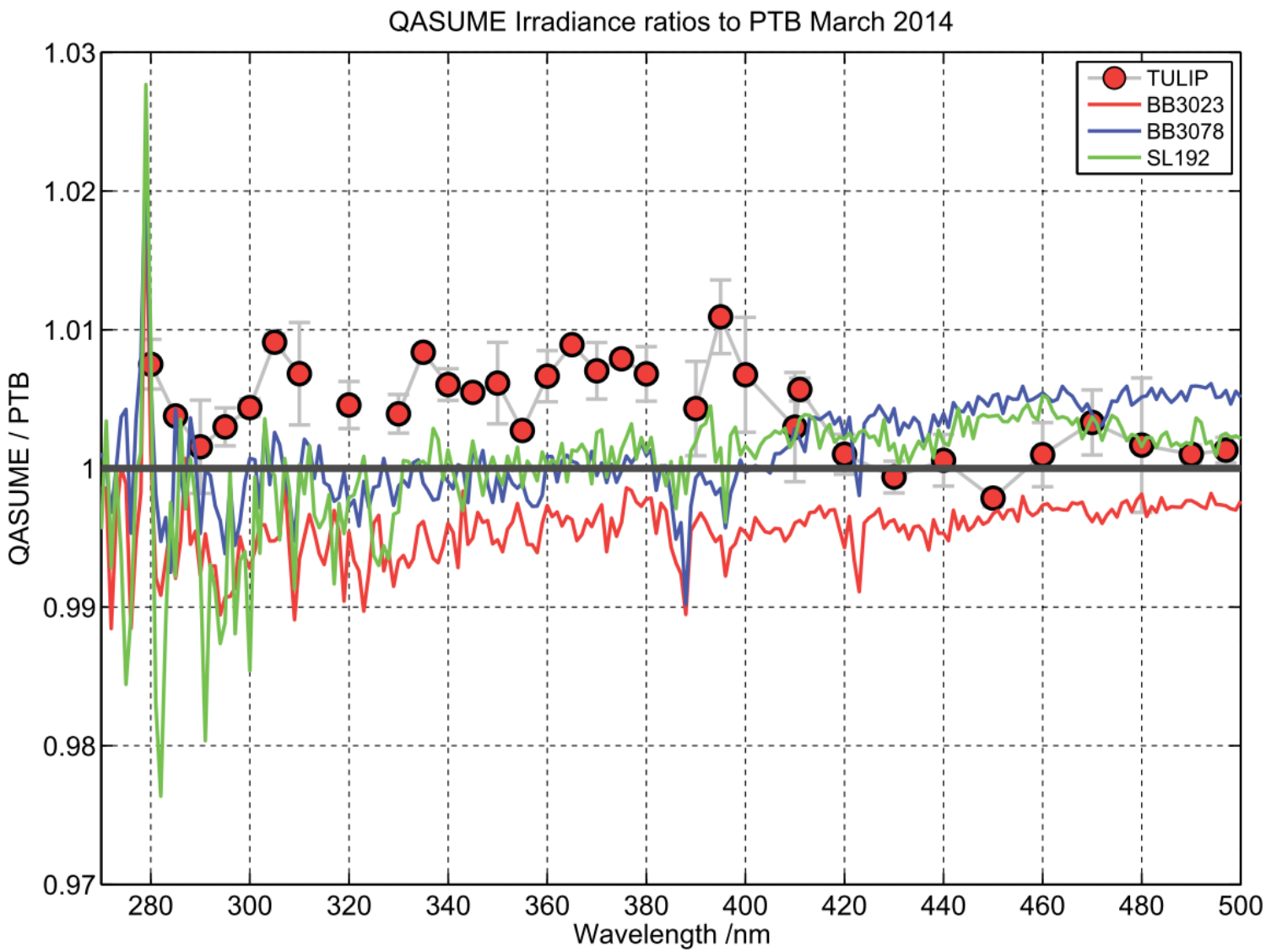
Measurements in spring 2014

- Effect of MC drive backlash



Measurements in spring 2014

- Results of the QASUME calibration campaign in 2014



QASUME calibration

Uncertainty budget for the QASUME calibration

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

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