Suitability of a Fourier Transform Spectroradiometer as a reference instrument for Solar UV Irradiance Measurements

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EMRP-JRP ENV03 “Solar UV”
WP 3: Improvement of Reference Spectroradiometers

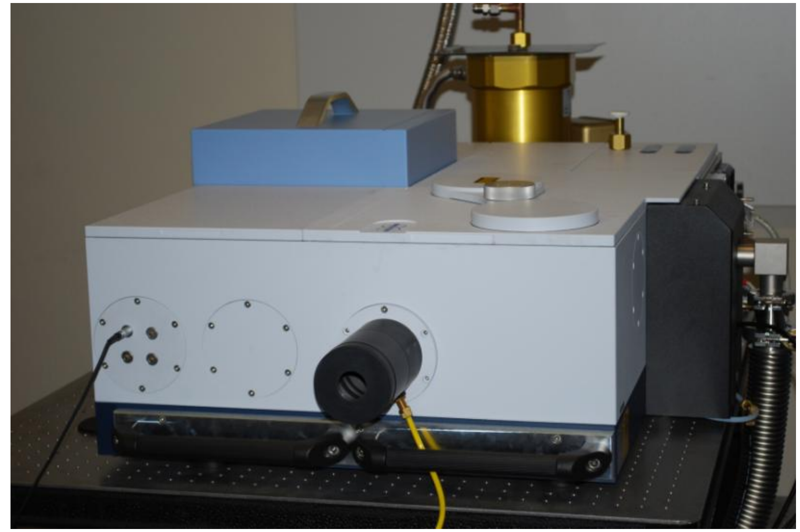
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Instrumentation

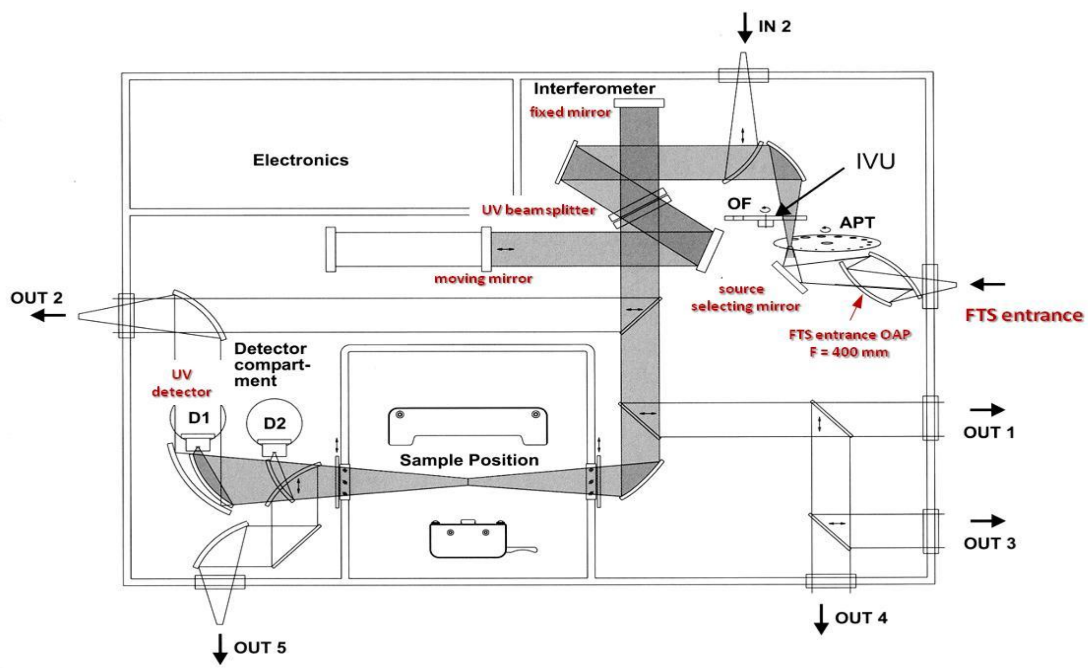
Commercially available FTS
- Bruker Vertex80v

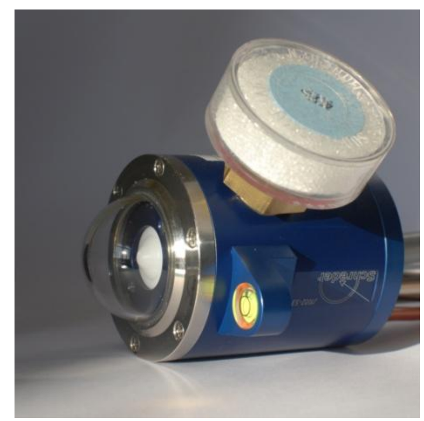
Global entrance optics (GEO)
- CMS Schreder, Austria

Detectors
- GaP diode (Bruker)
- Si diode (Bruker)
- Si diode (Hamamatsu S8552)
- **Hamamatsu photosensor module H10723-210**
  (with spectral filter Schott UG5 or UG11)



Bruker FTS Vertex80v





Global entrance optics
for irradiance measurements
(CMS Schreder, Austria)

Motivation: Why using an FTS as a reference instrument?

- **High wavenumber accuracy and wavenumbers are traced to SI by built-in HeNe laser with low uncertainty**

Wavelength scale of the FTS:

- direct traceable to the SI
- no on-site recalibration or wavelength check necessary
- wavelength uncertainty 5 pm to 11 pm in the range 250 nm to 500 nm
- resolution used for solar irradiance measurements: 20 cm^{-1}
  i.e. wavelength resolution of 0.32 nm at 400 nm or 0.18 nm at 300 nm
  (QASUME: 0.8 nm)
- best wavenumber resolution: 0.2 cm^{-1}

Motivation: Why using an FTS as a reference instrument?

- **High wavenumber accuracy and wavenumbers are inherently traced to SI by built-in HeNe laser with low uncertainty**

- **High throughput**
  - circular aperture has larger area compared to linear slits
  - no diffraction losses to higher-order spectra

→ **High SNR (semiconductor detectors can be used - but only down to 360 nm)**

- **FTS covers broad spectral ranges with high resolution, and all wavenumbers are measured simultaneously**

→ **Faster than scanning spectroradiometer!**

- **Instrumental distortions are often accurately calculable and correctable**

→ **Possibility of postprocessing of data!**

Calibration of spectral irradiance responsivity

Gold fixed-point
Black Body Radiator
National spectral radiance standard of PTB according to ITS90

↓

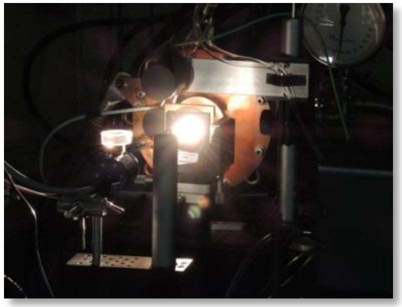
Radiation Thermometer LP3

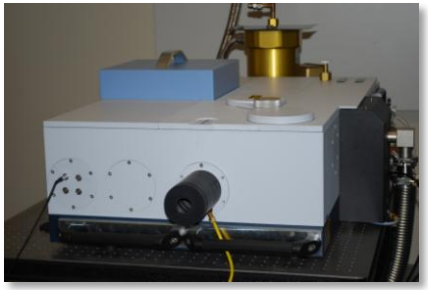
↓

High Temperature Black Body Radiator BB3200pg + aperture

↓

FTS





Cryogenic radiometer
National detector standard for the measurement of radiant power of PTB

↓

Si-trap detector + aperture

↓

Filter Radiometer

↓

High Temperature Black Body Radiator BB3200pg
\+ aperture
National spectral irradiance standard of PTB

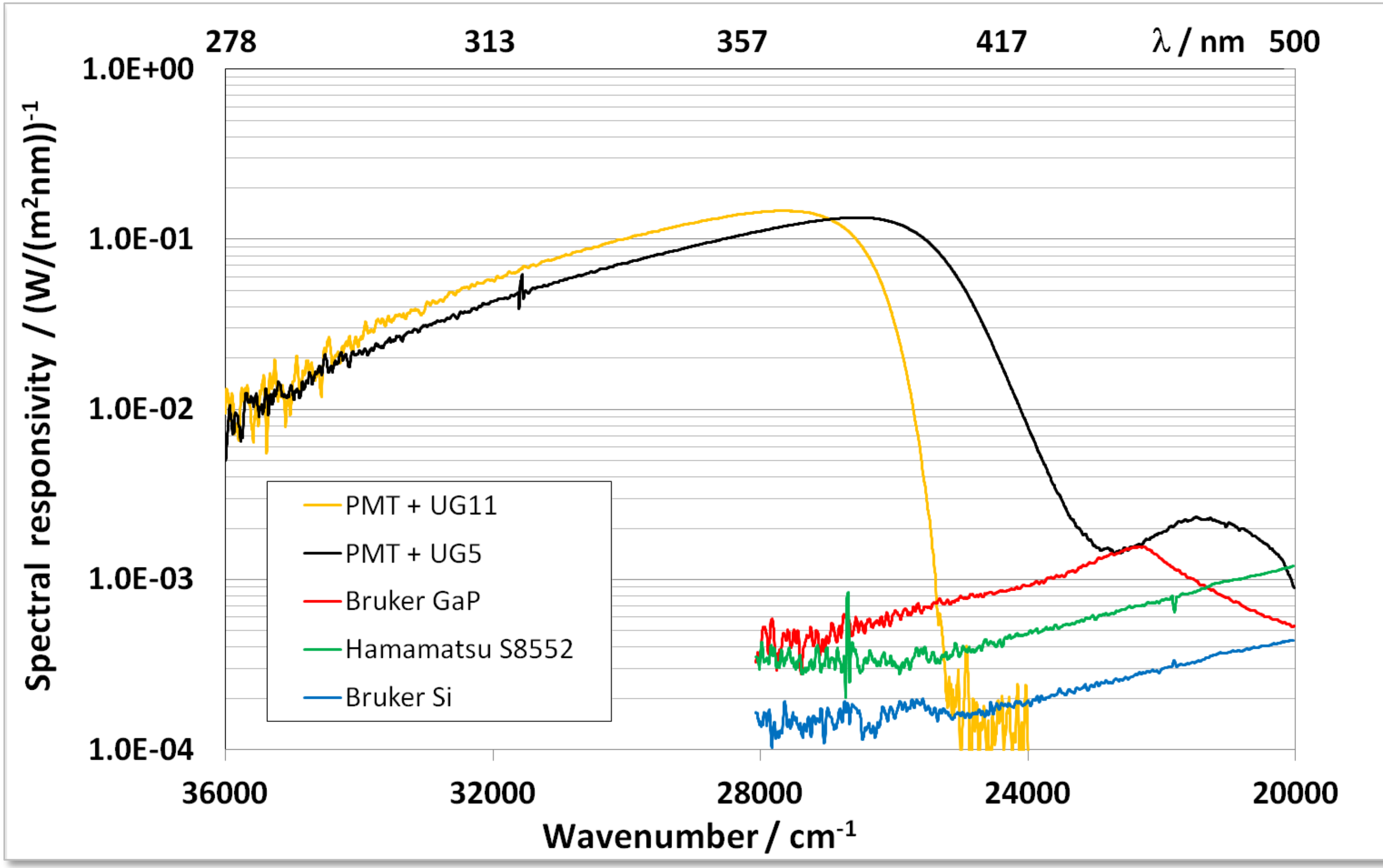
↓ ← Spectroradiometer

Secondary spectral irradiance standard (halogen lamp)

↓

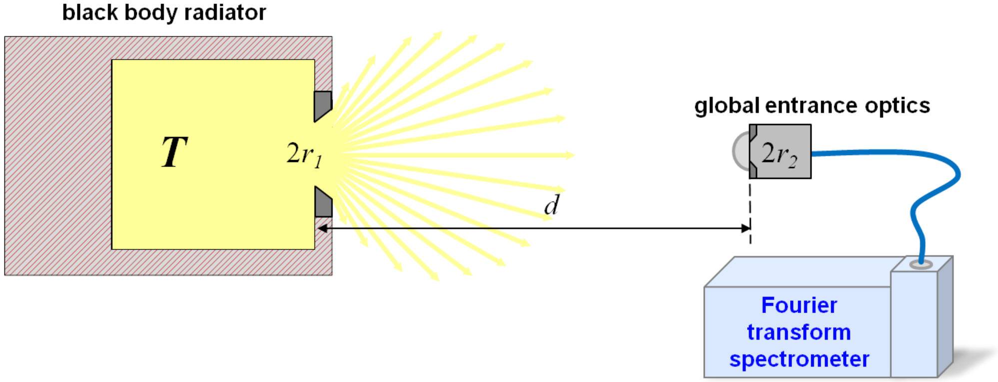
FTS

Spectral irradiance responsivity of FTS + GEO



Spectral irradiance responsivity of the FTS with global entrance optics for different types of detectors. Calibration against HTBB.

Uncertainty of radiometric calibration



T = 3010 K
r_1 = 10 mm
r_2 = 6.5 mm
d = 51.6 cm

	Relative standard uncertainty / % at			
Uncertainty contribution	**300 nm**	**350 nm**	**400 nm**	**500 nm**
Black-body temperature T	0.5	0.43	0.38	0.30
Black-body aperture $2r_1$	0.50	0.50	0.50	0.50
Global entrance optic aperture $2r_2$	0.0002	0.0002	0.0002	0.0002
Distance black-body aperture to entrance optic d	0.43	0.43	0.43	0.43
Measurement noise	2.2	0.27	0.22	2.3
Combined uncertainty	**2.4**	**0.84**	**0.79**	**2.5**

Calibration of the spectral irradiance responsivity of the FTS with photomultiplier tube and spectral filter UG5 against the high-temperature black-body radiator HTBB.

Interferograms averaged over 20 min; same spectral resolution as QASUME*.

*Appl. Opt., 44 (25), 5321-5331 (2005)

Uncertainty of radiometric calibration

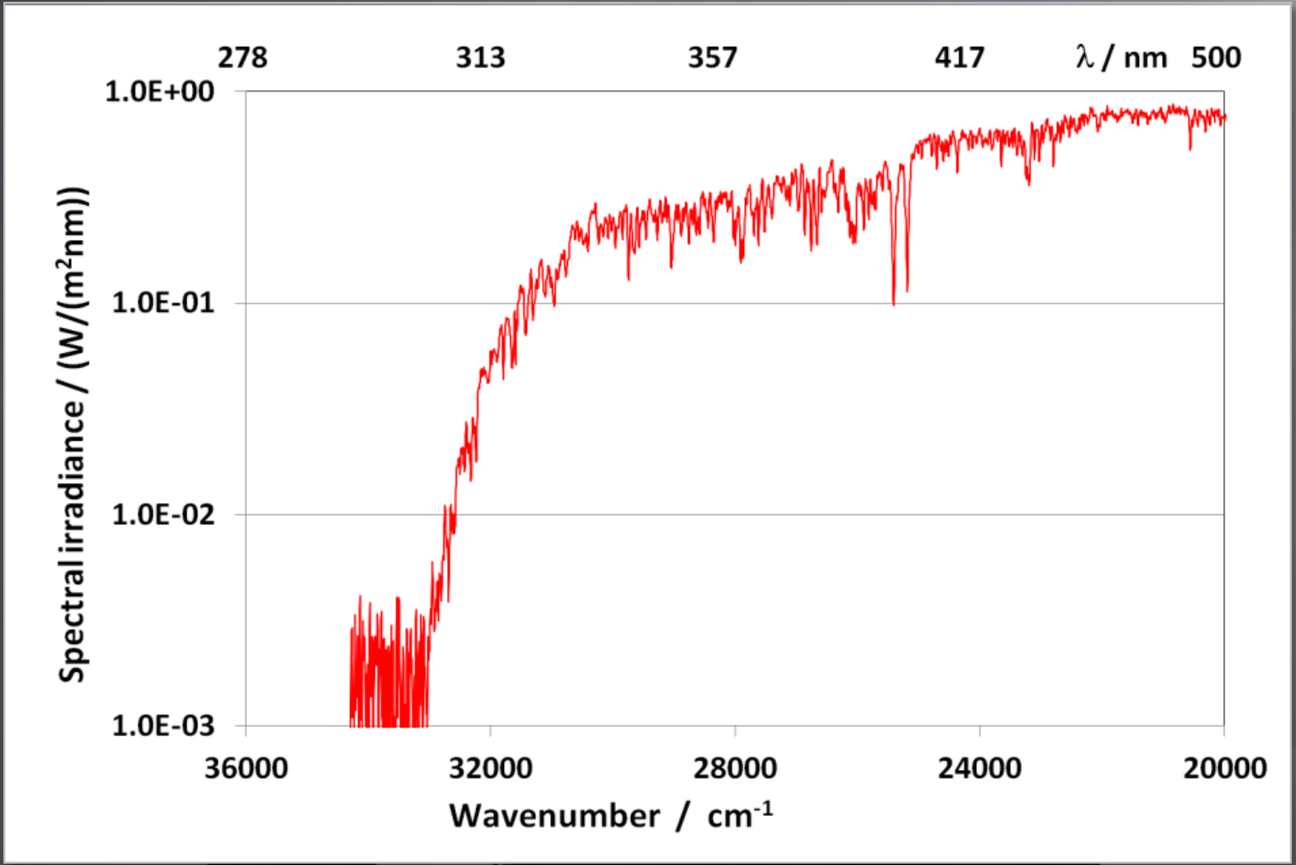
Calibration of the spectral irradiance responsivity of the FTS with photomultiplier tube and spectral filter UG5 against a secondary irradiance standard halogen lamp:

	Relative standard uncertainty / % at			
Uncertainty contribution	**300 nm**	**350 nm**	**400 nm**	**500 nm**
Secondary irradiance standard	0.78	0.67	0.57	0.55
Distance irradiance standard lamp to entrance optic d	0.73	0.73	0.73	0.73
Measurement noise	3.2	0.26	0.21	5.3
Combined uncertainty	**3.4**	**1.0**	**0.95**	**5.4**

Interferograms averaged over 20 min; same spectral resolution as QASUME*.

*Appl. Opt., 44 (25), 5321-5331 (2005)

Solar UV irradiance measurements



Solar UV irradiance measured in Berlin on 03-Apr-2014, 10:30 UTC with FTS using a photomultiplier tube and spectral filter Schott UG5

Solar UV irradiance measurements

	Relative standard uncertainty / % at			
Uncertainty contribution	**300 nm**	**350 nm**	**400 nm**	**500 nm**
Radiometric calibration	2.4	0.84	0.79	2.5
Transmittance of entrance optic*	0.60	0.60	0.60	0.60
Angular response of entrance optic*	0.40	0.80	0.80	0.80
Stability of spectral responsivity	1.4	0.50	0.79	4.0
Measurement noise	3.7	0.24	0.30	3.1
Combined uncertainty	**4.8**	**1.4**	**1.5**	**5.8**

QASUME: 2.3% to 3%*

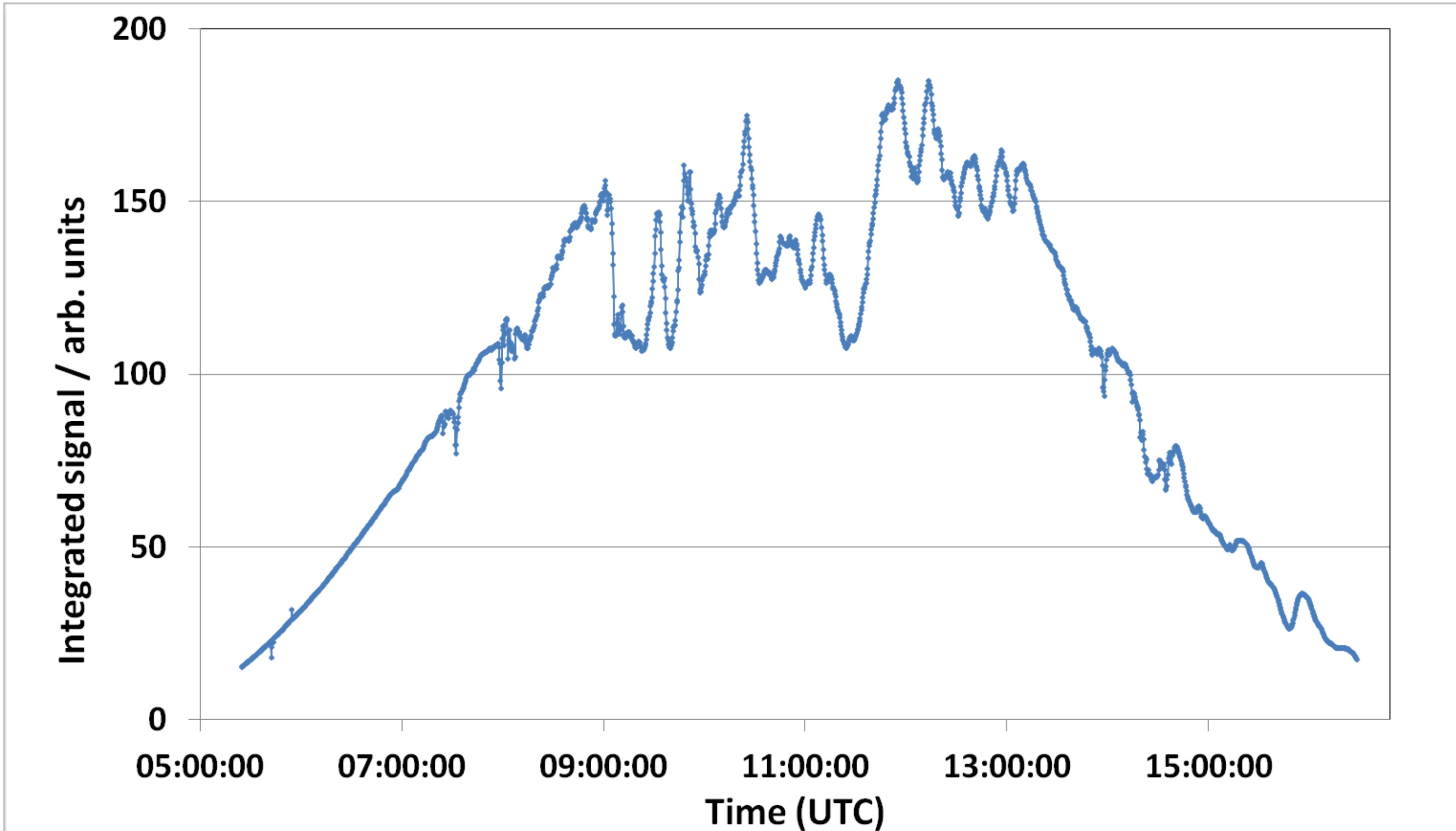
*Appl. Opt., 44 (25), 5321-5331 (2005)

Uncertainty budget for spectral solar UV irradiance measurement when using the FTS with photomultiplier and spectral filter UG5. Measurement performed in Berlin on 03-Apr-2014, 10:30 UTC, averaged over 12 minutes. Solar zenith angle < 60°. Spectral resolution reduced to the resolution of QASUME*.

Target of JRP ENV03 “SolarUV”:
Uncertainties around 1% to 2% to resolve changes of solar UV irradiance (2% per decade)

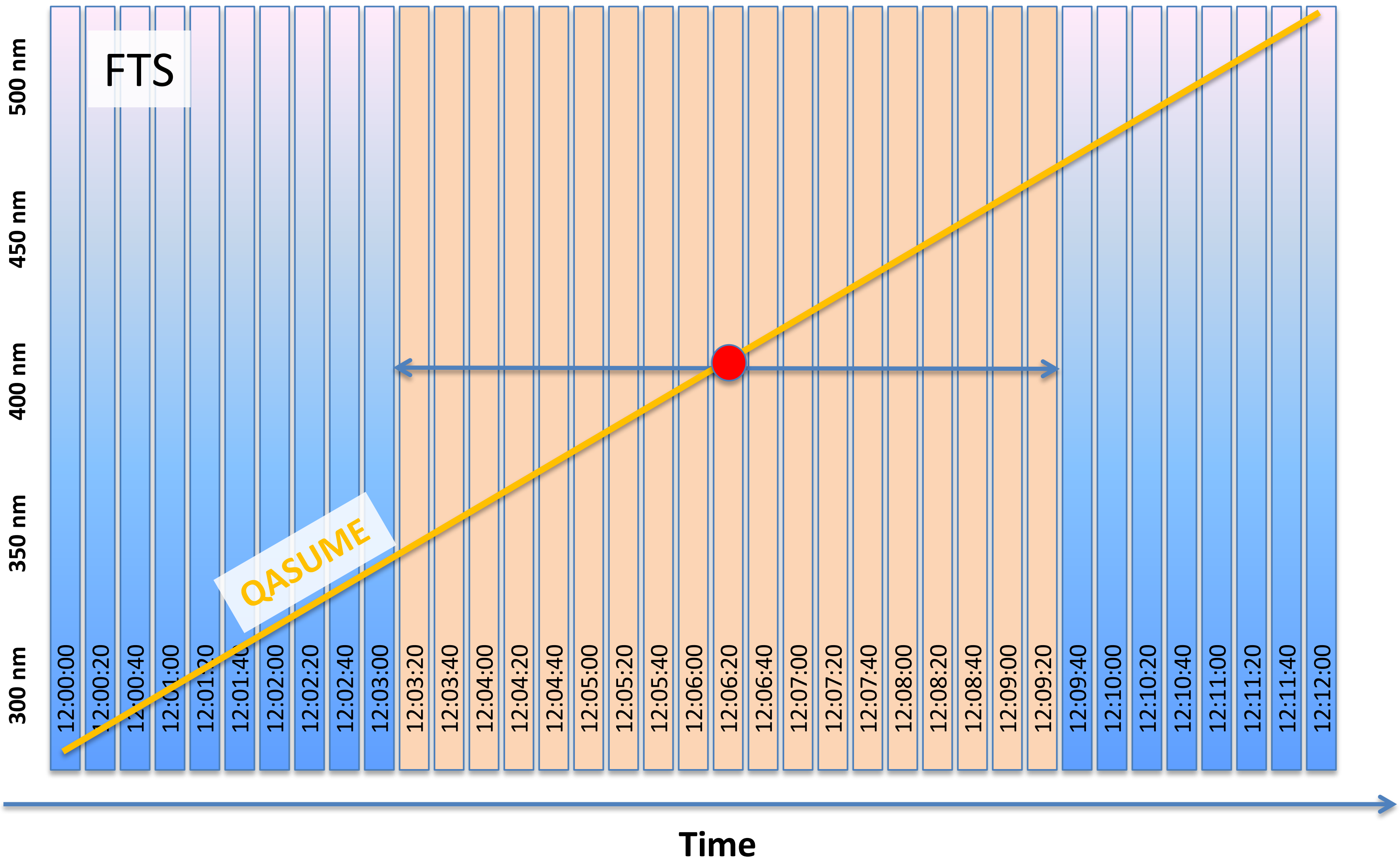
Comparison of FTS spectra with QASUME spectra

Variability of solar irradiance



Variability of solar irradiance measured on 01-Apr-2014 at PTB in Berlin (integrated signal from 333 nm to 400 nm)

How to compare spectra?

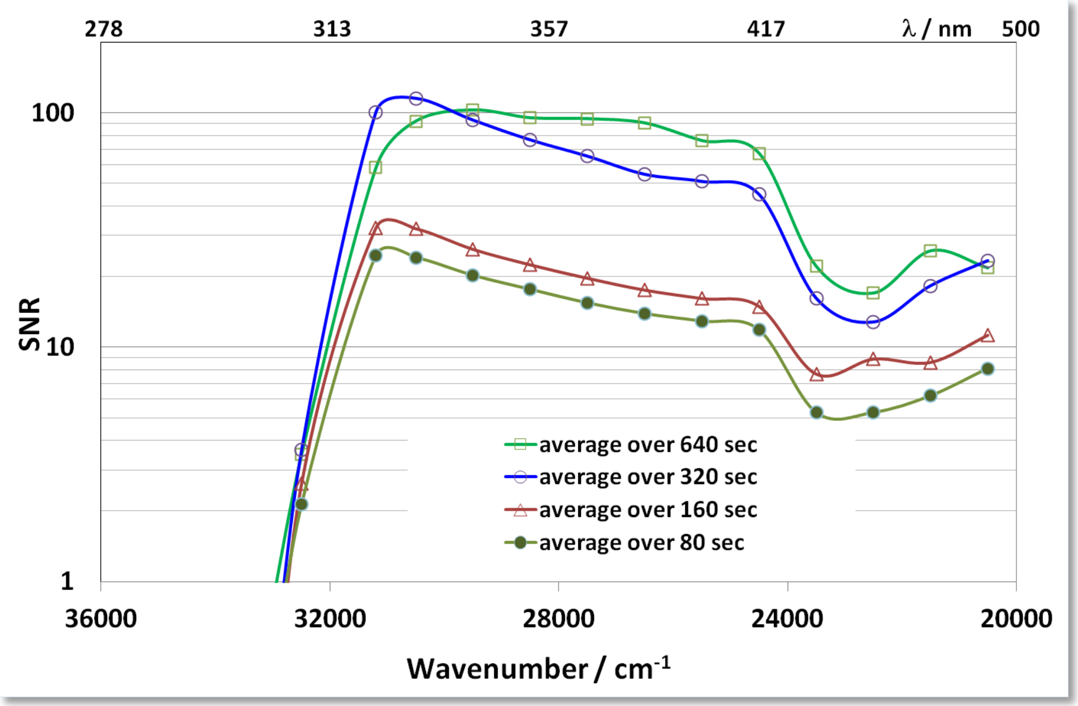


Optimization of SNR

Stable solar irradiance:
- averaging over longer time periods
- high SNR – low temporal resolution

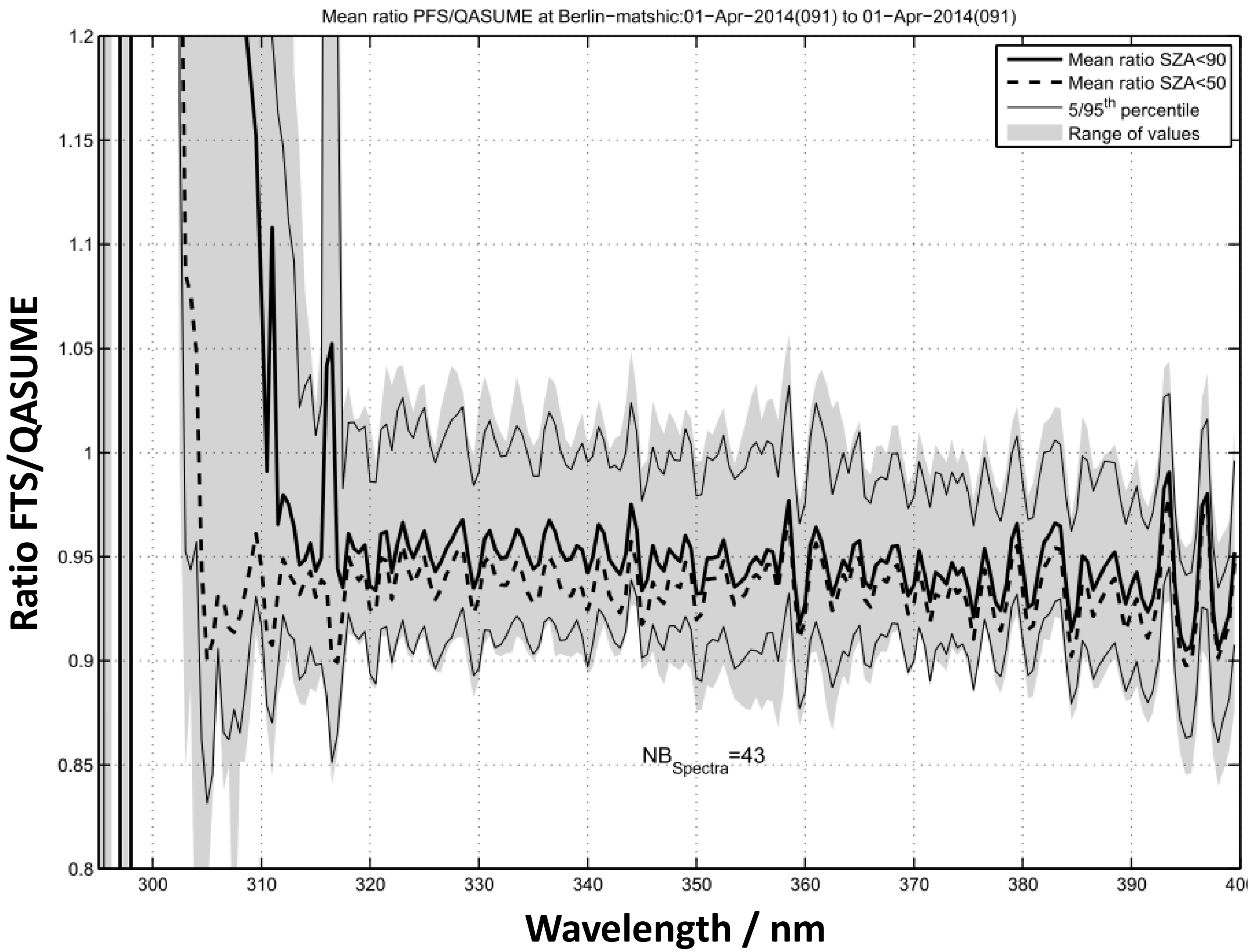
Solar irradiance quickly varying:
- averaging over shorter periods
- lower SNR – higher temporal resolution

- Averaging of FTS interferograms is flexibly possible after the measurement dependent on the demands on the SNR and on the solar variability.
- This is impossible with scanning spectroradiometers which measure the wavelengths sequentially one by one.

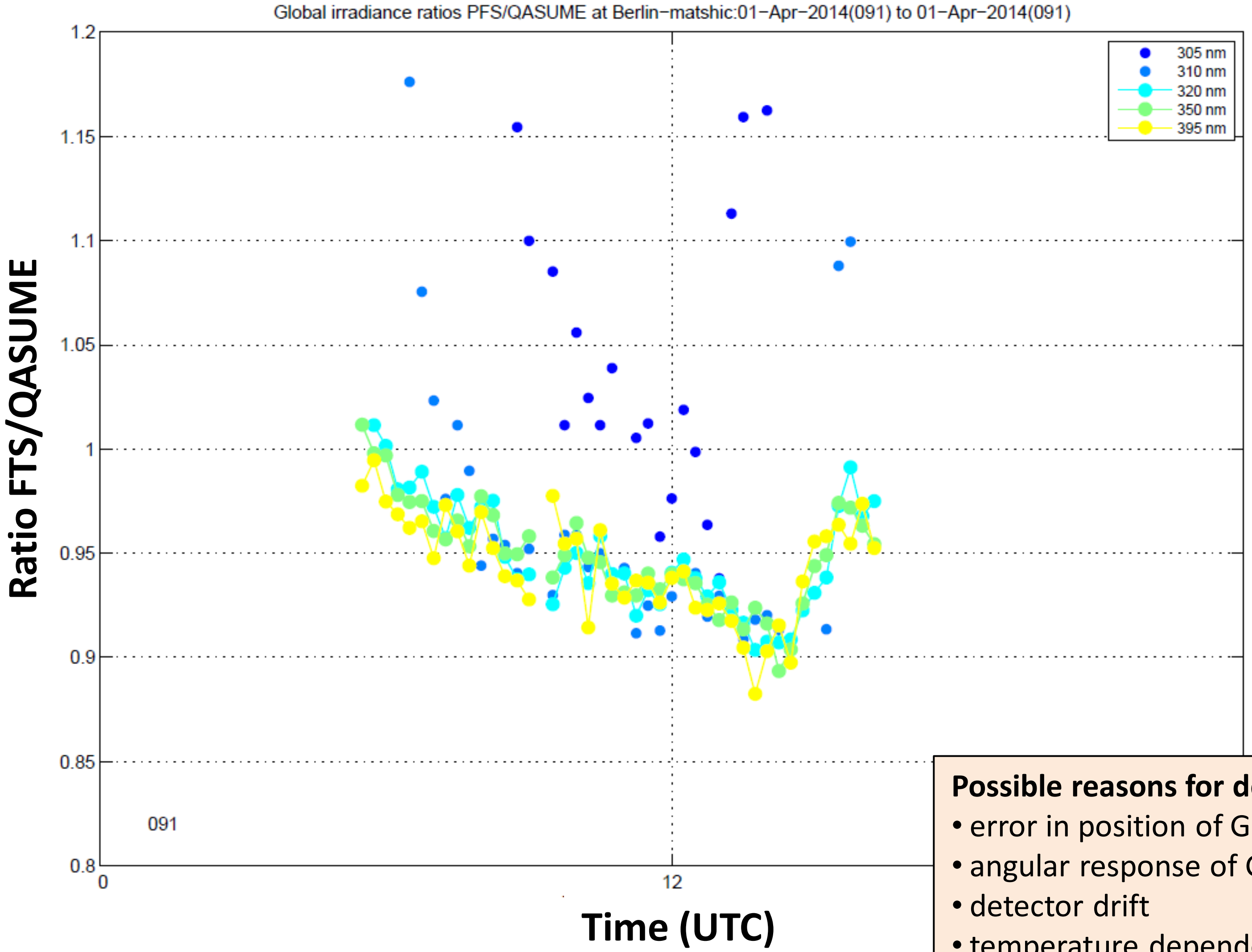


PM + UG5, 03-Apr-2014, 12:40 UTC

Comparison FTS - QASUME



Comparison FTS - QASUME



Possible reasons for deviation:

- error in position of GEO reference plane
- angular response of GEO
- detector drift
- temperature dependence of FTS or GEO
- …

Conclusion

Advantages:

- Wavelength scale of the FTS direct traceable to the SI - no on-site recalibration or wavelength check necessary
- Wavelength uncertainty 5 pm to 11 pm in the range 250 nm to 500 nm
- high wavelength resolution
- Semiconductor detectors (GaP, Si) usable for absolute spectral solar UV irradiance measurements down to 360 nm
- FTS with photomultiplier tube and spectral filter UG5 or UG11 useable for absolute spectral solar UV irradiance measurements down to 300 nm or below
- Measurement uncertainty for solar UV irradiance measurements ca. 1.5% in the spectral range from 315 nm to 400 nm depending on spectral filter and solar variability;
  (QASUME: 2.3% in the range 310 nm to 400 nm)
- FTS-interferograms can be averaged flexibly after the measurement depending on noise and solar variability. This enables an optimization of the uncertainty and temporal resolution.

Disadvantages:

- Used FTS is heavy and has a poor portability (in comparison to QASUME)
- Complex comparison of FTS spectra with scanning spectroradiometer spectra

Thanks to Peter Sperfeld, Klaus Anhalt and Lutz Werner from PTB for the providing of the irradiance sources and their support.

Thank you for your attention!

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