The World Calibration Center for UV (WCC-UV)

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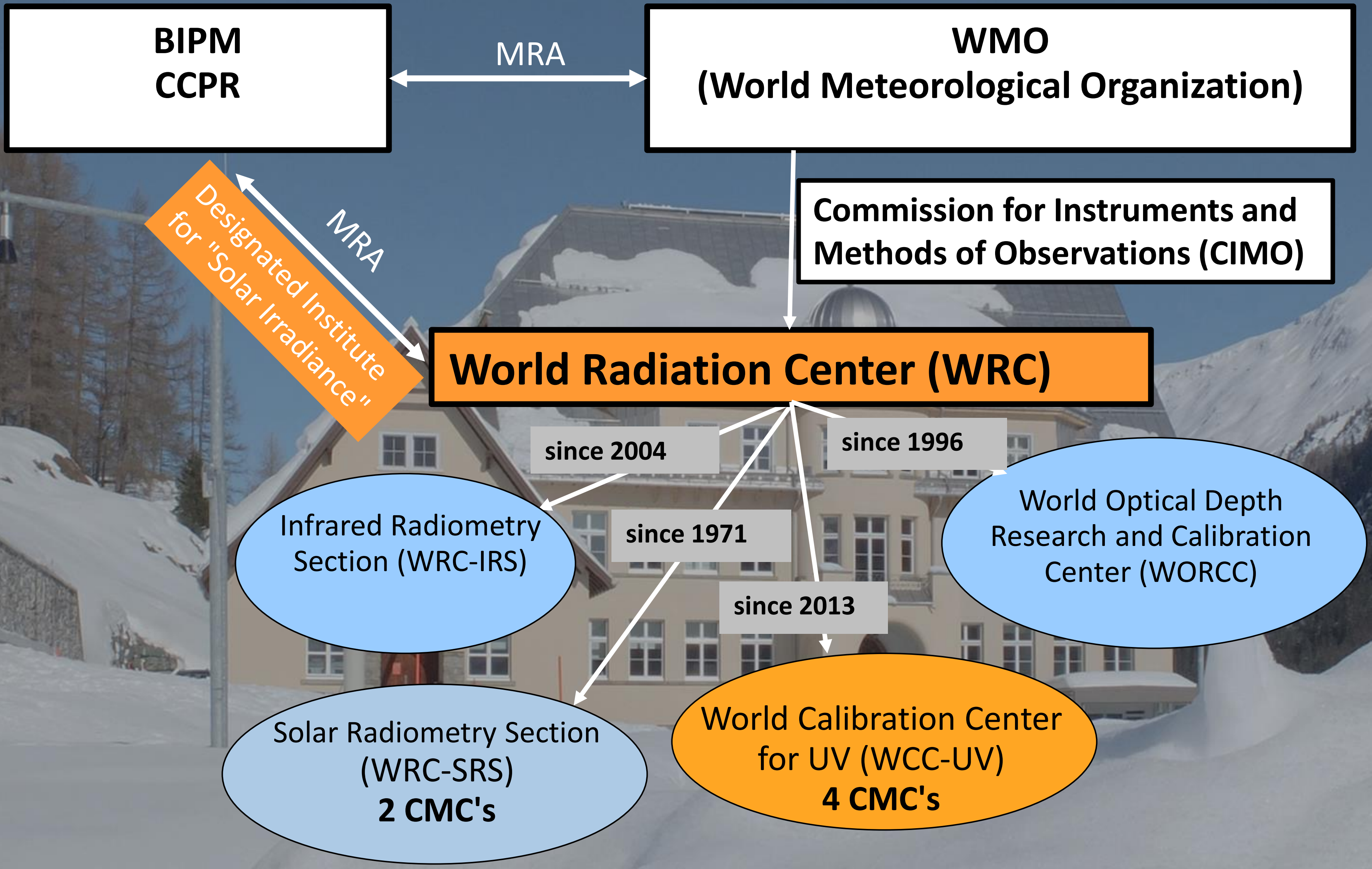
Davos Dorf, Switzerland

Outline

- The World Radiation Center of WMO
- Quality Assurance of solar UV measurements
- The Top of Atmosphere solar spectrum measured from the surface using QASUME

The Physikalisch-Meteorologisches Observatorium Davos and World Radiation Center (PMOD/WRC)



BIPM
CCPR

MRA

WMO
(World Meteorological Organization)

Commission for Instruments and Methods of Observations (CIMO)

Designated Institute for "Solar Irradiance"

MRA

World Radiation Center (WRC)

since 2004

since 1996

since 1971

since 2013

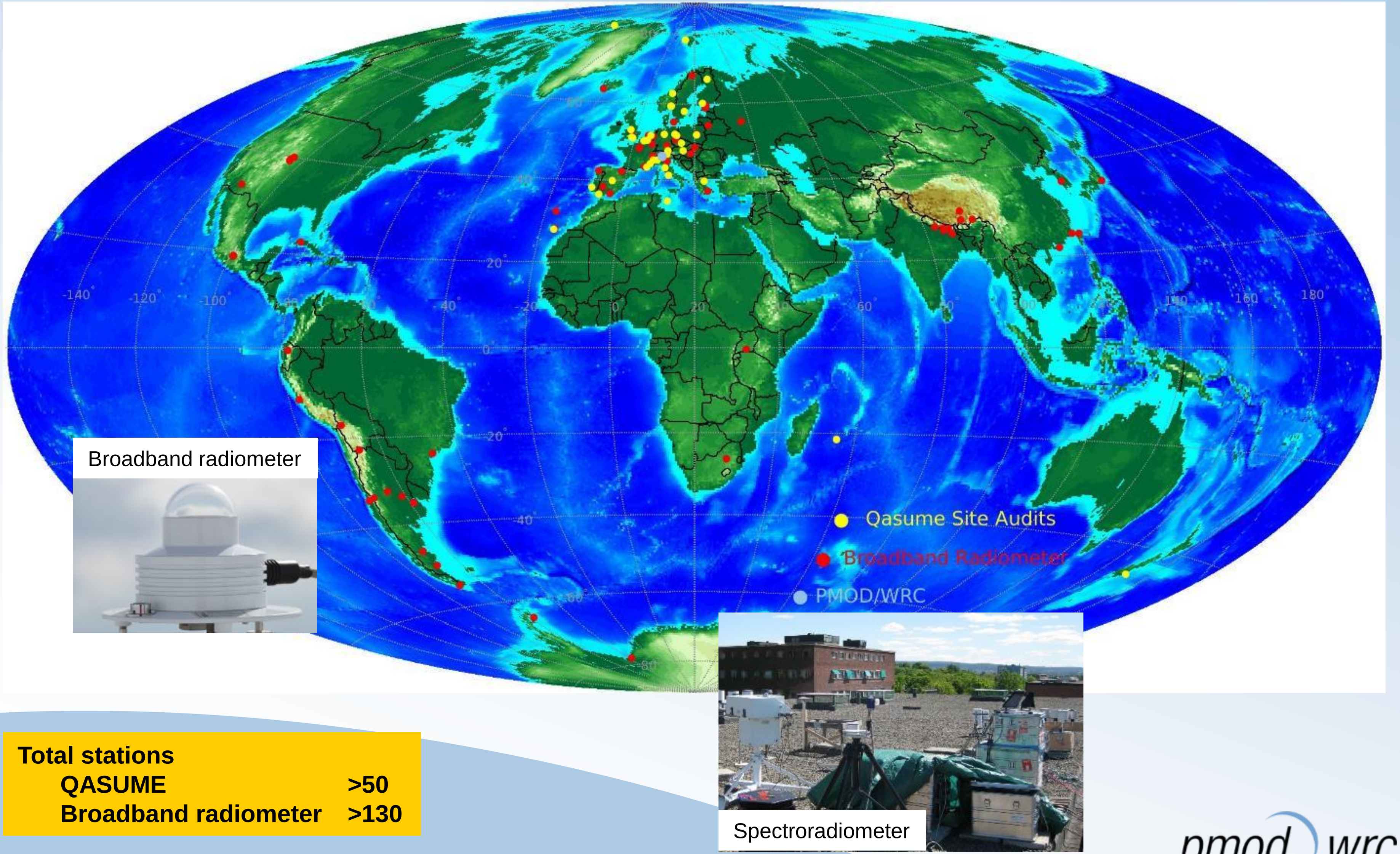
Infrared Radiometry Section (WRC-IRS)

World Optical Depth Research and Calibration Center (WORCC)

Solar Radiometry Section (WRC-SRS)
2 CMC's

World Calibration Center for UV (WCC-UV)
4 CMC's

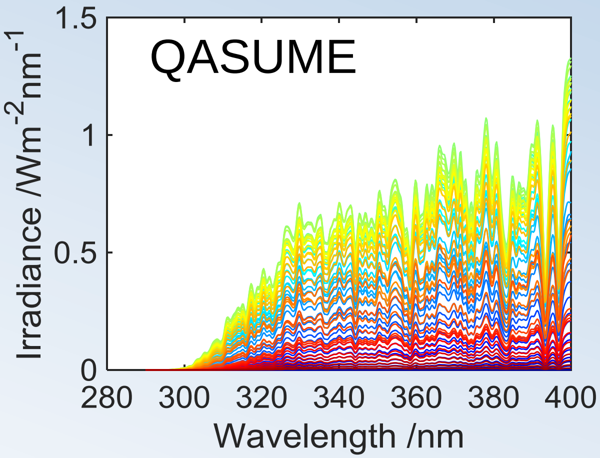
Solar UV monitoring stations traceable to WCC-UV



Total stations

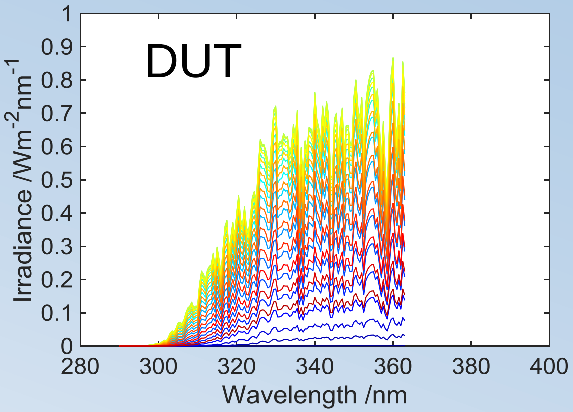
QASUME	**>50**
Broadband radiometer	**>130**

Comparison of solar spectra

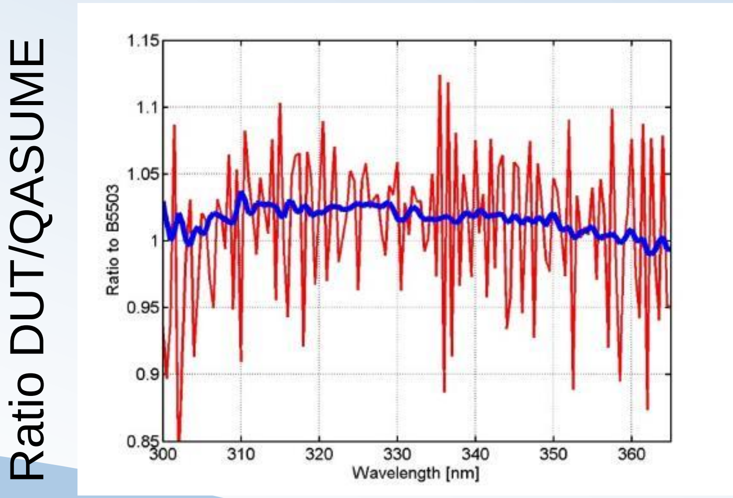


Convolution & high resolution ETS

matSHIC

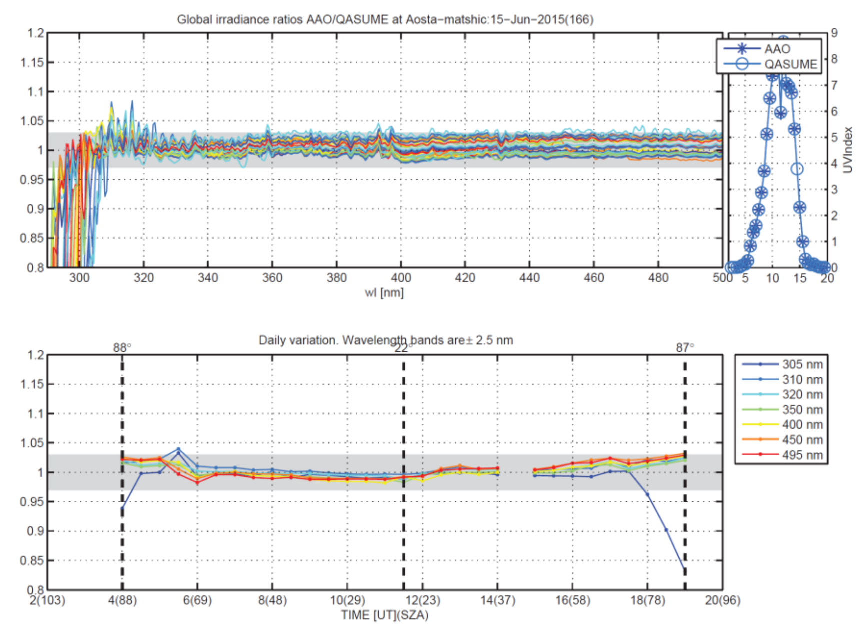


$$R(\lambda) = \frac{DUT(\lambda)}{QASUME(\lambda)}$$

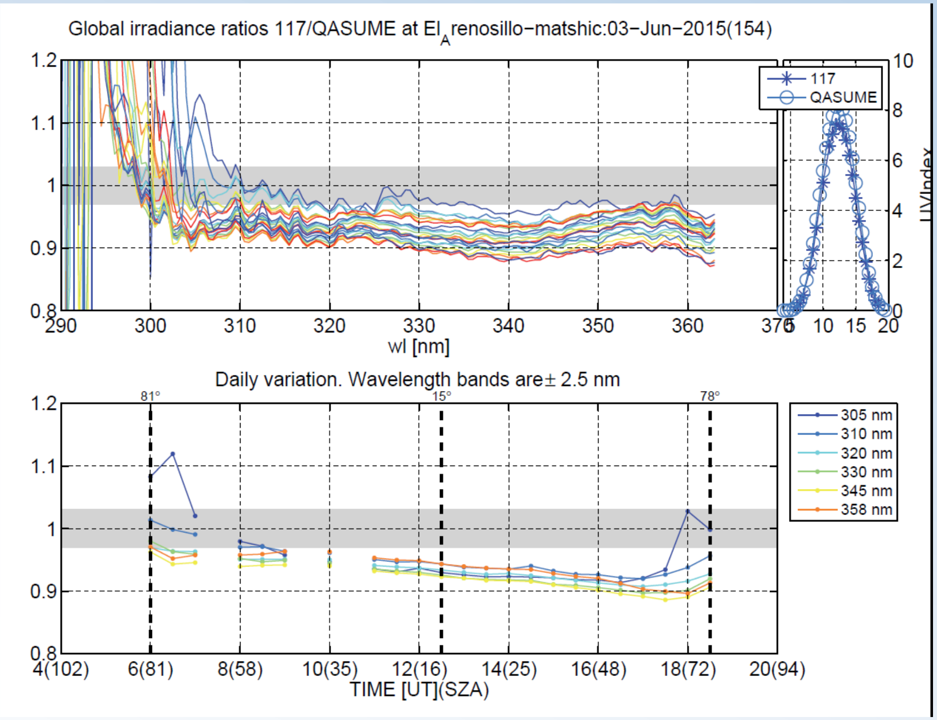


- Same wavelength scale
- Uniform slit width (1 nm default)

QASUME comparisons



GOOD…



BAD…

pmod wrc

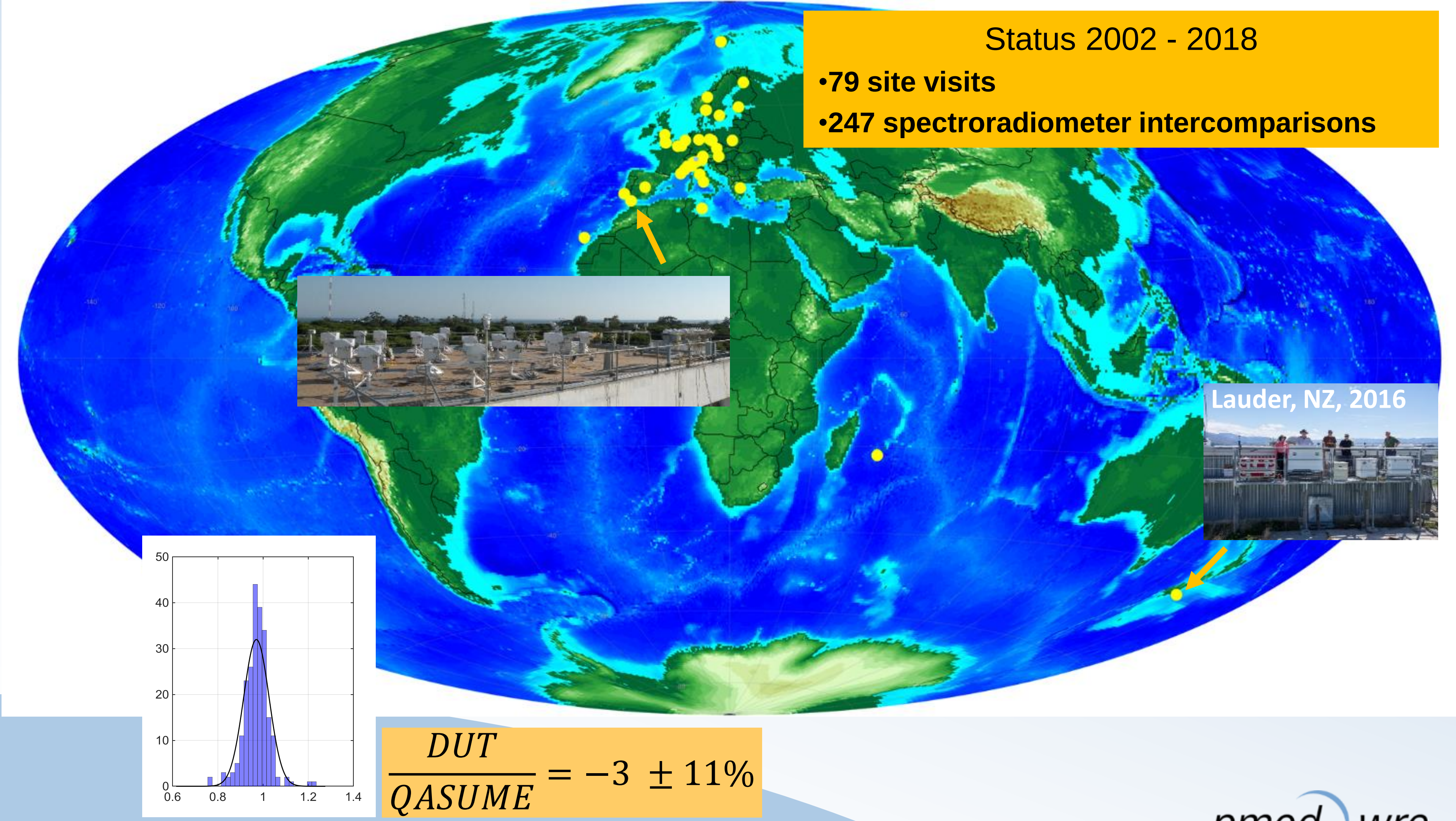
Spectral Solar UV Quality Assurance Program QASUME

“**Quality Assurance of Spectral Ultraviolet Measurements in Europe through the development of a transportable unit** “

➔ On site comparison with the portable QASUME reference spectroradiometer

Status 2002 - 2018

- **79 site visits**
- **247 spectroradiometer intercomparisons**



$$\frac{DUT}{QASUME} = -3 \ \pm 11\%$$

https://www.pmodwrc.ch/en/world-radiation-center-2/wcc-uv/qasume-site-audits/

Traceability chain for spectral irradiance

Detector-based

Source-based

🟦 Detector

🟧 Source

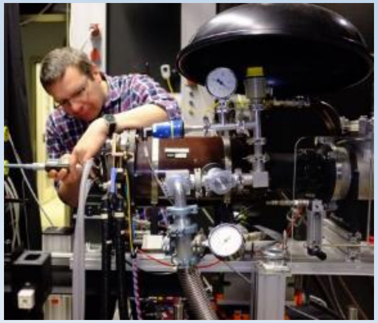
Cryogenic radiometer

cw-laser sources

Si-trap detector + aperture

Spectrally tuneable source

Filter Radiometer



Blackbody + aperture

Spectroradiometer

Transfer standards

U=±1.1%

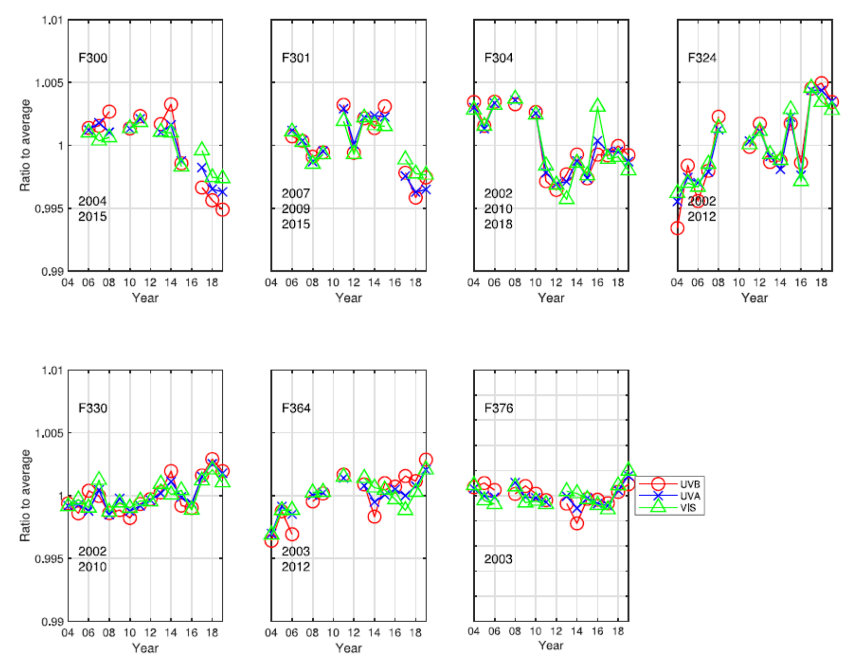
EMRP
European Metrology Research Programme
▸ Programme of EURAMET

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

Spectral irradiance reference at WCC-UV

Long-term stability of ~0.2%

2004 - 2019



Validation of the WCC-UV irradiance scale

Detector-based

Source-based

Cryogenic radiometer

cw-laser sources

Si-trap detector + aperture

Spectrally tuneable source

Filter Radiometer

Blackbody + aperture

Spectroradiometer

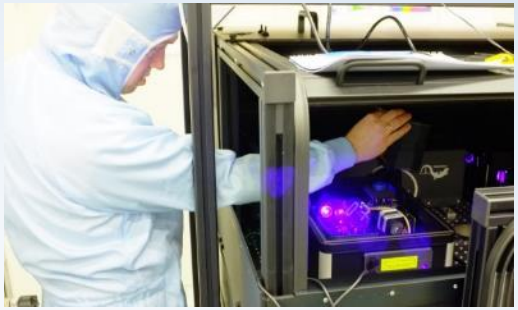
Transfer standards

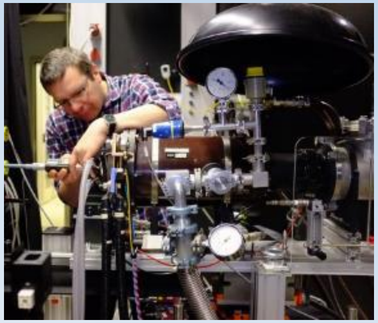
Tunable lasers

U=±0.3%

U=±1.1%

🟦	Detector
🟧	Source





PTB
Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

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Validation of the WCC-UV irradiance scale

Detector-based

Cryogenic radiometer

Source-based

🟦 Detector

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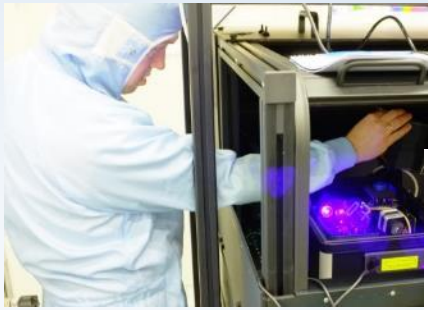

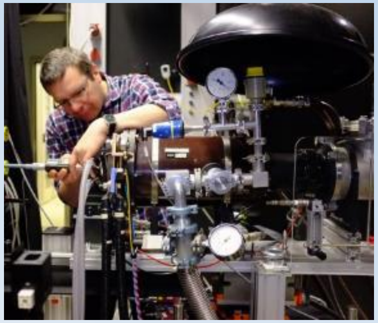

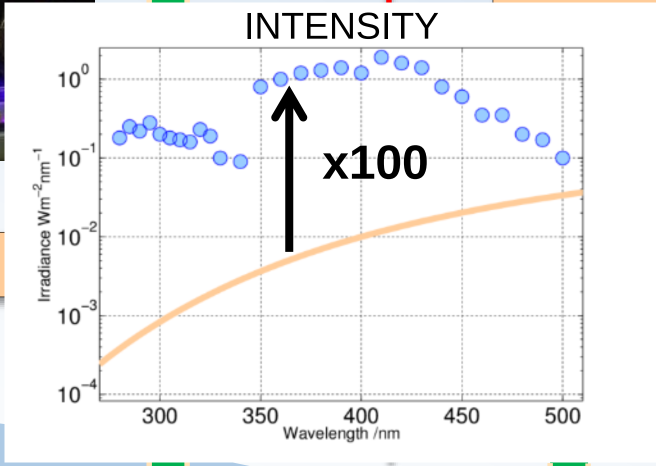

dy + aperture

Spectroradiometer

Tunable lasers

Transfer standards

U=±0.3%

U=±1.1%

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

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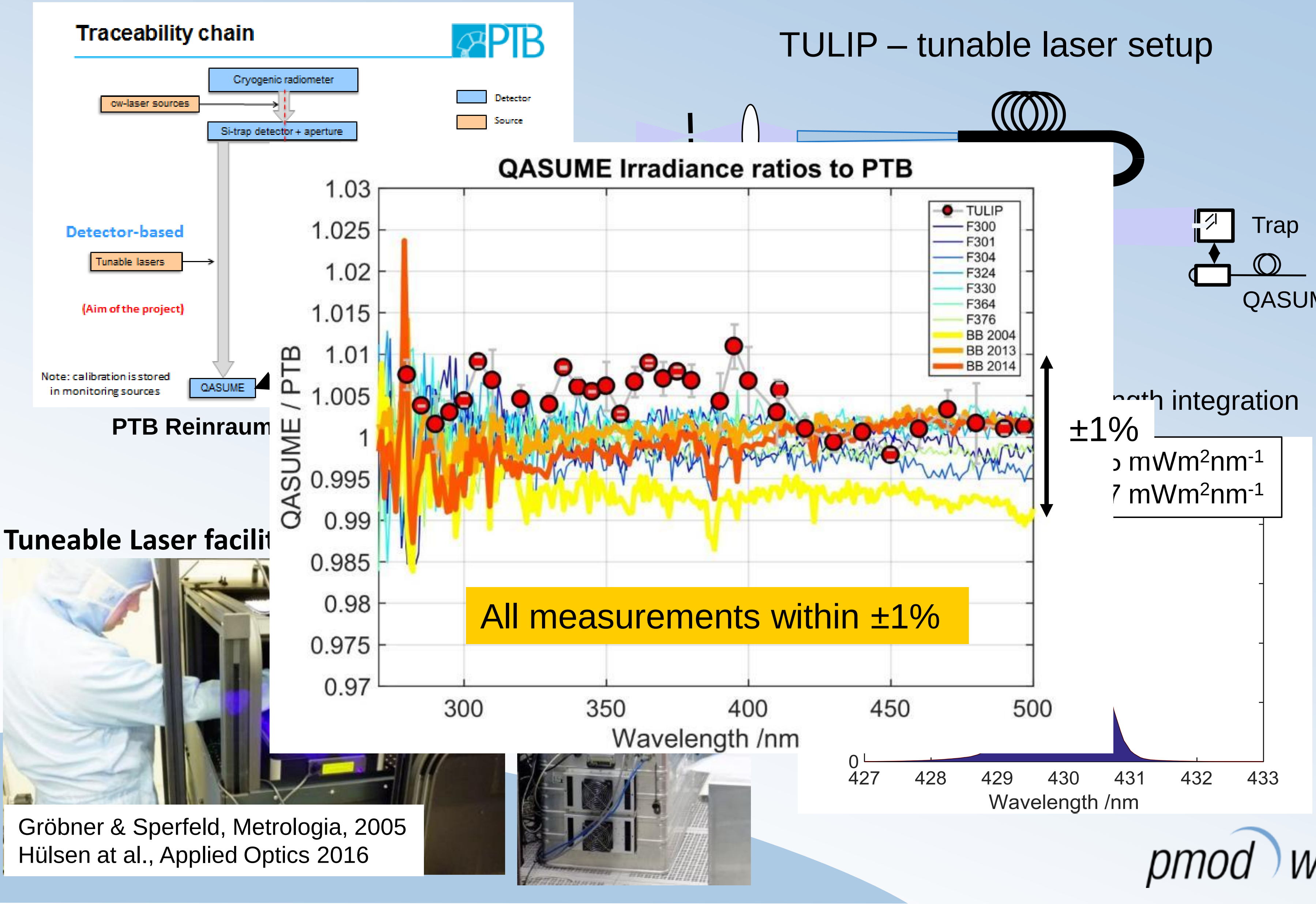
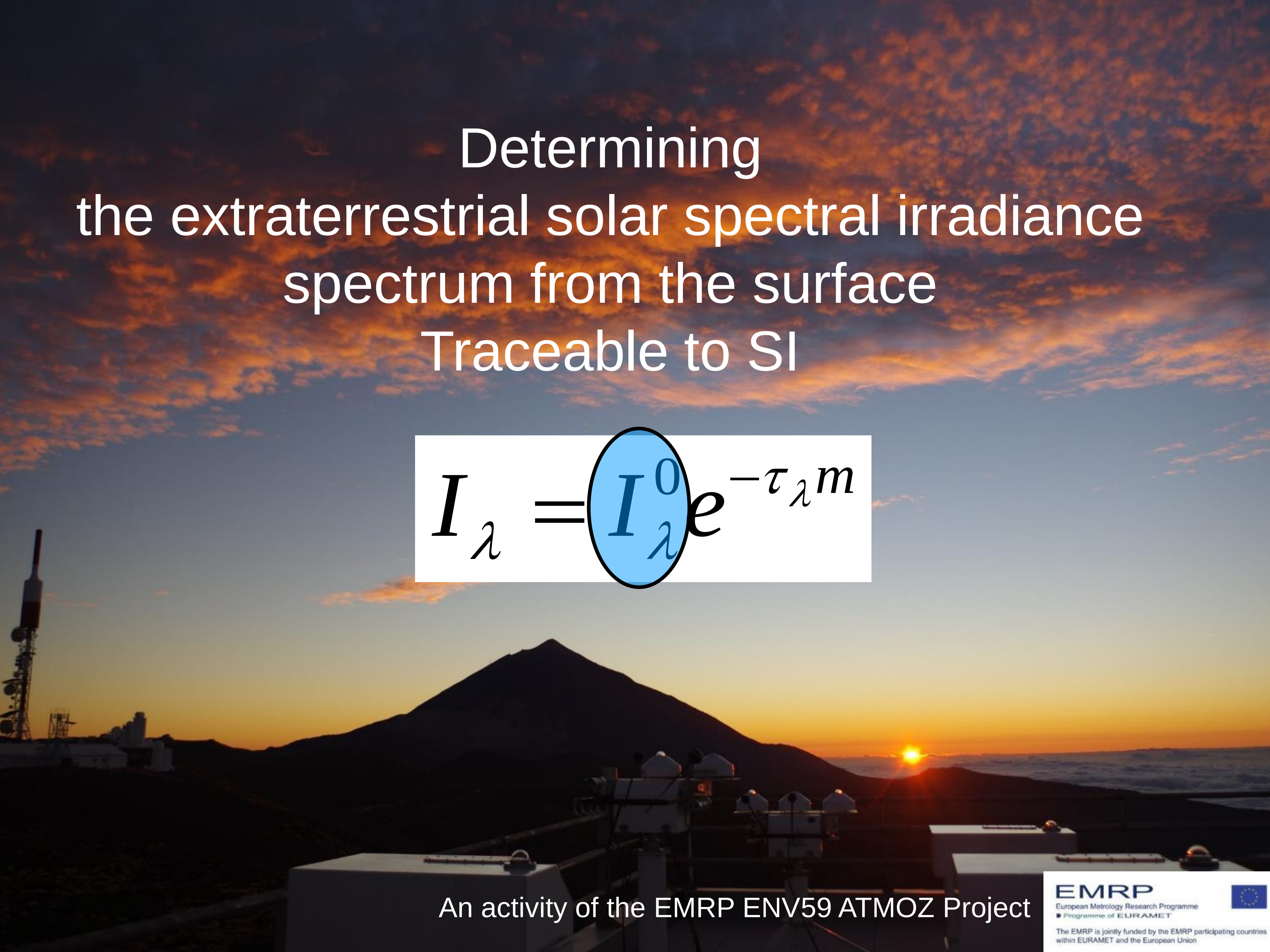
Validation of the WCC-UV irradiance scale



All measurements within ±1%

Gröbner & Sperfeld, Metrologia, 2005
Hülsen at al., Applied Optics 2016



Determining the extraterrestrial solar spectral irradiance spectrum from the surface Traceable to SI

$$I_\lambda = I_\lambda^0 e^{-\tau_\lambda m}$$

An activity of the EMRP ENV59 ATMOZ Project

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• Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

Measuring the ET SSI from the surface
What are the
advantages / disadvantages?

- Traceability to SI is possible
- Repeated calibrations before, during, and after the measurements
- Uncertainties are lower than what is currently achievable in space

- Limited wavelength range:
  - Only weakly absorbing atmospheric regions are accessible
- Need stable atmospheric conditions
- Depends (slightly) on an atmospheric model

Instrumentation

QASUME

Double monochromator spectroradiometer

Fourier Transform Spectroradiometer

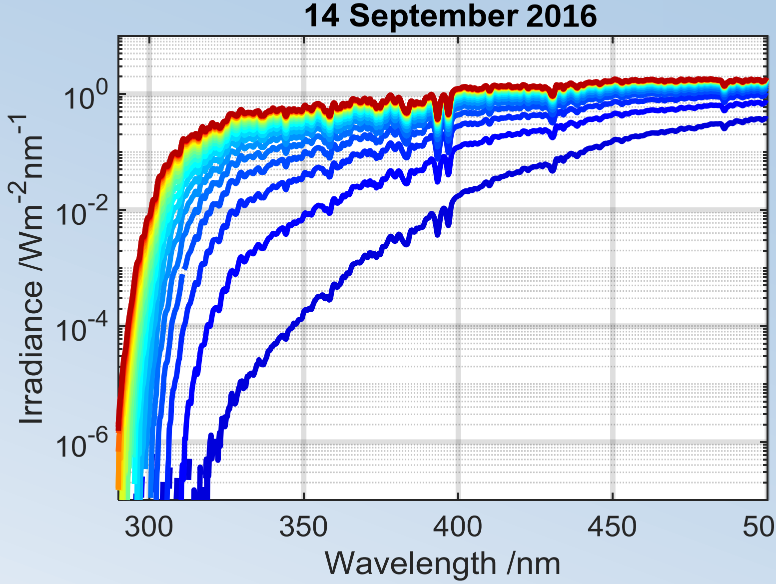
How to get the extraterrestrial solar spectrum from the surface:

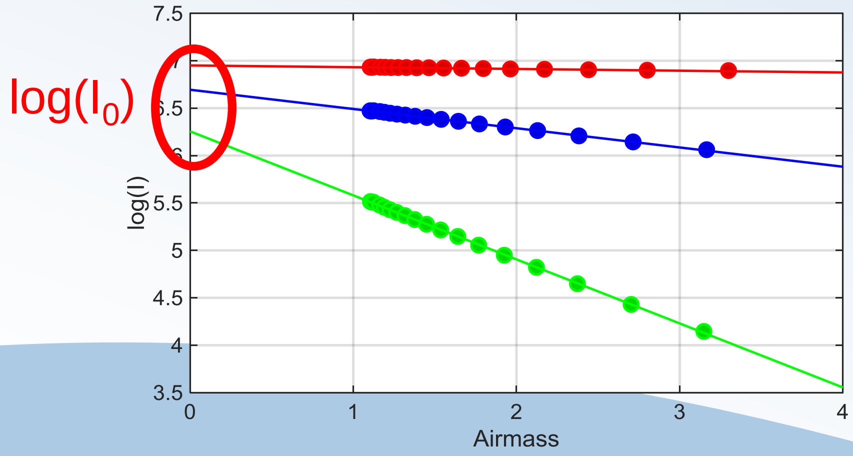
The langley-plot

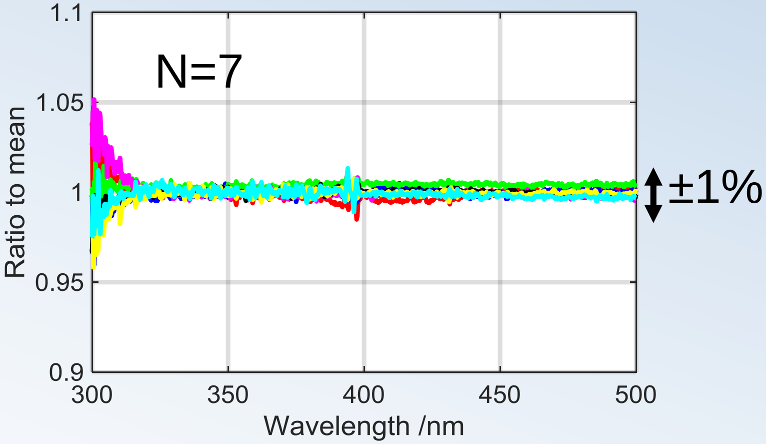
The Beer-Lambert law $I_\lambda = I_\lambda^0 e^{-\tau_\lambda m}$

$$\log \mathrm{I}_\lambda = \log \mathrm{I}_\lambda^0 - \tau_\lambda \mathrm{m}$$

$$y = a - bx$$


14 September 2016

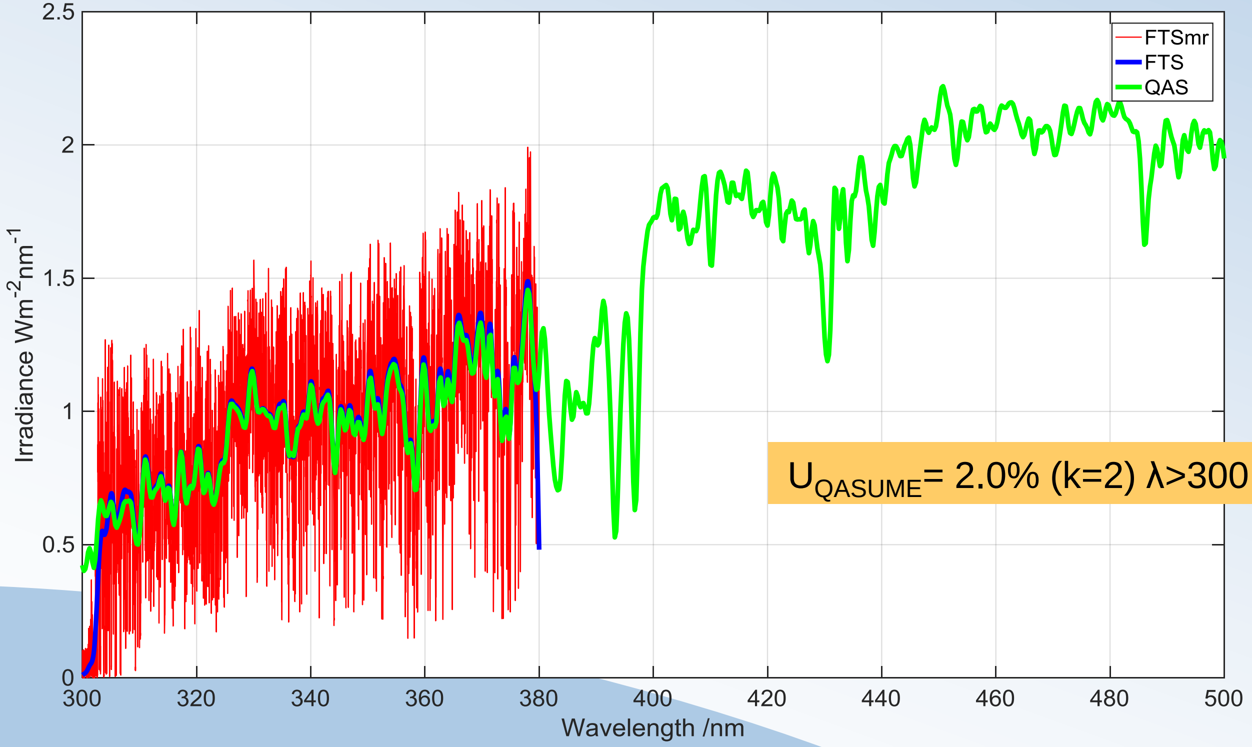




The optical depth τ is assumed constant during this period (half-day)

The high resolution extraterrestrial solar spectrum QASUMEFTS

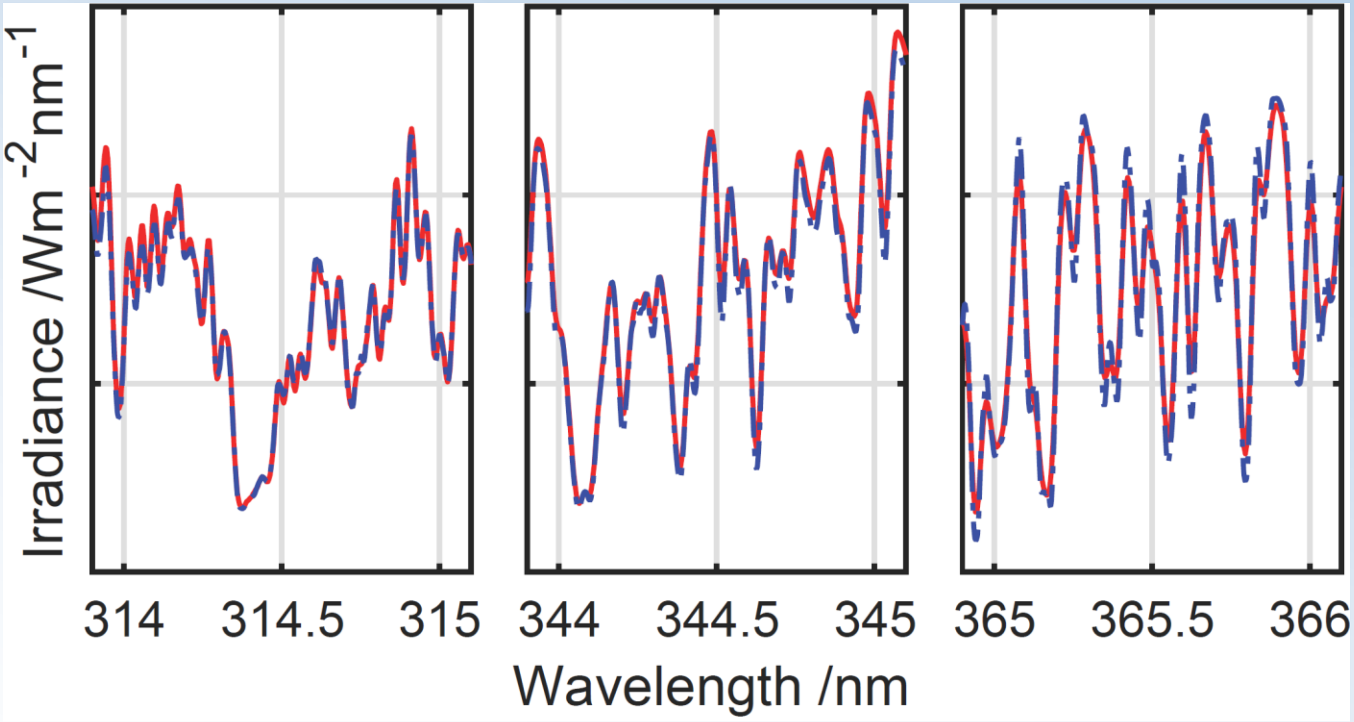
- 300 ≤ WL <304.8 nm: KittPeak normalised to QASUME
- **304.8 ≤ WL <379 nm : FTS normalised to QASUME**
- 379 ≤ WL <500 nm : KittPeak normalised to QASUME



U_{QASUME}= 2.0% (k=2) λ>300 nm

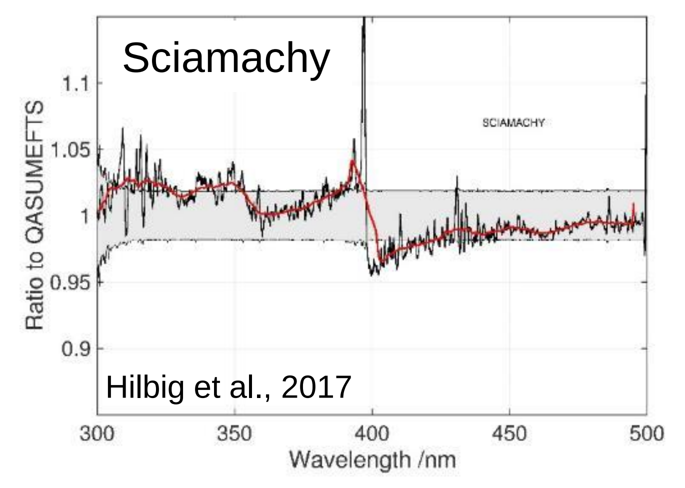
QASUMEFTS & KittPeak

With an FTS, the wavelength is inherently traceable to SI,
U_λ is estimated at 10 pm (0.01 nm)



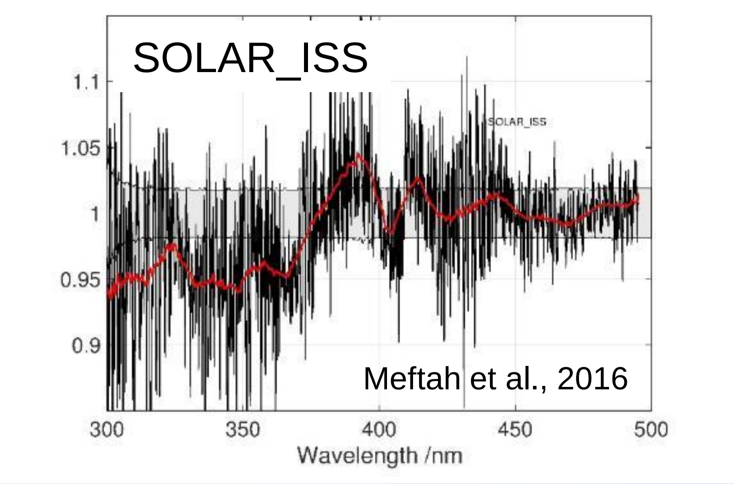
Wavelength agreement between FTS and KittPeak is 1 pm

Comparison to a few space based solar spectra



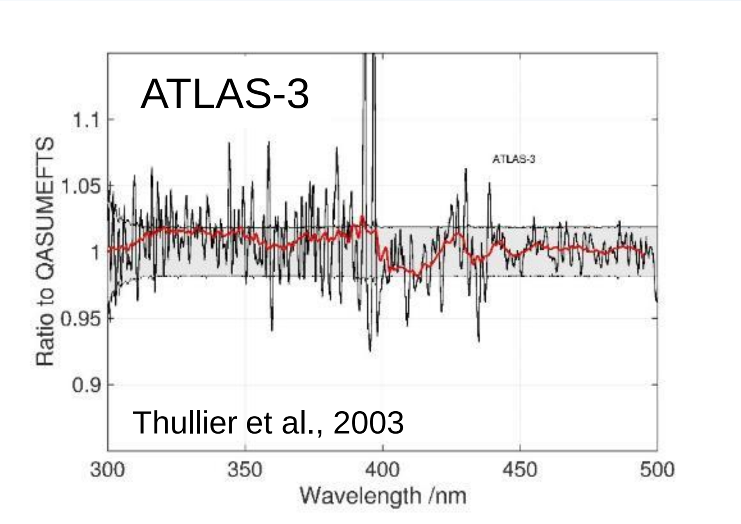
Sciamachy

Hilbig et al., 2017



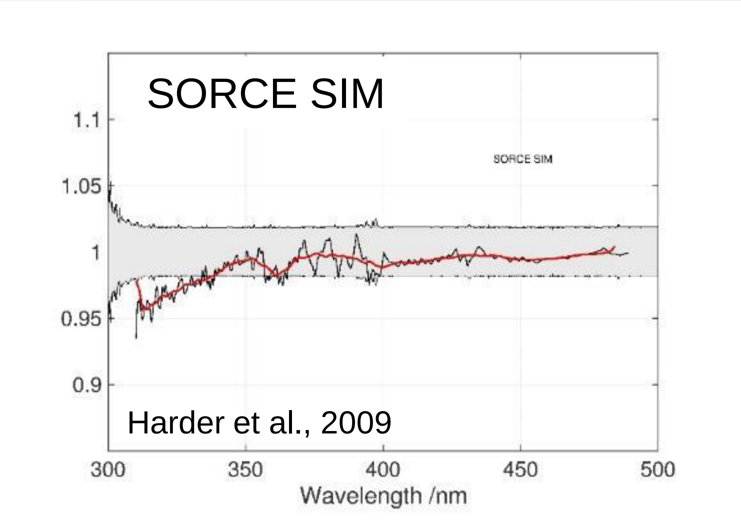
SOLAR_ISS

Meftah et al., 2016



ATLAS-3

Thullier et al., 2003



SORCE SIM

Harder et al., 2009

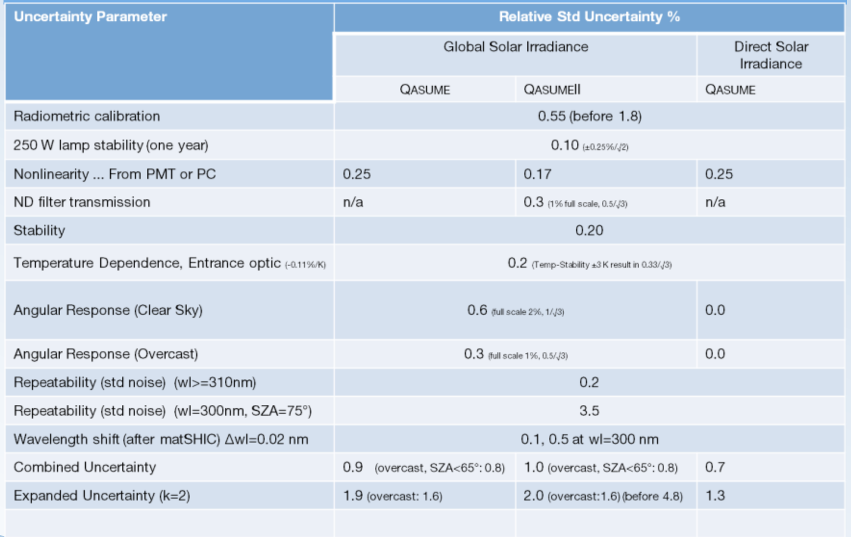
Gröbner et al., 2017

Summary

- PMOD/WRC follows the requirements for the competence of testing and calibration laboratories according to ISO/IEC 17025.
- PMOD/WRC is designated institute for solar irradiance of the Swiss Federal Office for Metrology METAS and signatory of the CIPM MRA.
- PMOD/WRC has submitted 6 Calibration and Measurement Capabilities (CMC) to the Key comparison database of the BIPM.

Global (direct) spectral solar UV irradiance measurements are traceable to SI with an expanded uncertainty (k=2) of 2% (1.3%).

Uncertainty budget for spectral solar UV irradiance measurements



Uncertainty Parameter	Relative Std Uncertainty %		
	Global Solar Irradiance		Direct Solar Irradiance
	QASUME	QASUMEII	QASUME
Radiometric calibration	0.55 (before 1.8)		
250 W lamp stability (one year)	0.10 (±0.25%/√2)		
Nonlinearity ... From PMT or PC	0.25	0.17	0.25
ND filter transmission	n/a	0.3 (1% full scale, 0.5/√3)	n/a
Stability	0.20		
Temperature Dependence, Entrance optic (-0.11%/K)	0.2 (Temp-Stability ±3 K result in 0.33/√3)		
Angular Response (Clear Sky)	0.6 (full scale 2%, 1/√3)		0.0
Angular Response (Overcast)	0.3 (full scale 1%, 0.5/√3)		0.0
Repeatability (std noise) (wl>=310nm)	0.2		
Repeatability (std noise) (wl=300nm, SZA=75°)	3.5		
Wavelength shift (after matSHIC) Δwl=0.02 nm	0.1, 0.5 at wl=300 nm		
Combined Uncertainty	0.9 (overcast, SZA<65°: 0.8)	1.0 (overcast, SZA<65°: 0.8)	0.7
Expanded Uncertainty (k=2)	1.9 (overcast: 1.6)	2.0 (overcast:1.6) (before 4.8)	1.3

Hülsen et al., Applied Optics, 2016