Traceability chain of the WMO AOD reference and GAW-PFR network

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Precision Filter Radiometers (PFR) description

- **Filter radiometer with 4 channels in a grid**
- Si-photodiodes
- Dielectric interference filters manufactured by the ion-assisted deposition technique

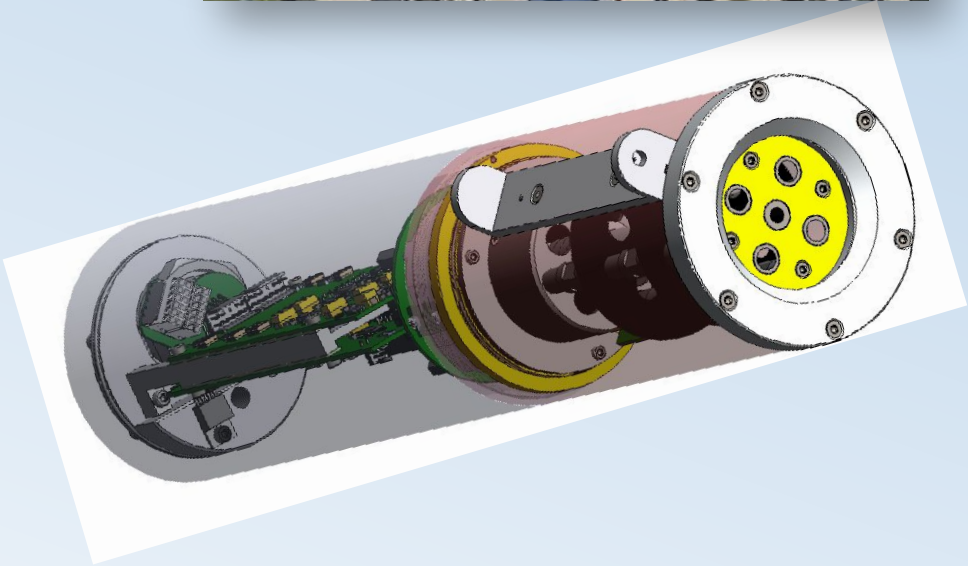
Centroid wavelength based on WMO recommendation

Standard (N) 368 nm, 412 nm , 500 nm, 862 nm

Band pass at FWHM : 3 nm to 5 nm

Direct Solar irradiance measurements
1 min time resolution

- **Sealed tube – purged with N_2 to 2bar**
- **Temperature stabilized photodiodes (20°C either 25°C)**
- **Well defined reference plane – precision aperture**
- **Two amplification stages**



- **Sun sensor for monitoring alignment to Sun**
- **FOV : 1.2° plateau , 0.7° slope angle, inhomogeneity in plateau < 0.5%**

- **Internal PFR pressure monitor**
- **Ambient atmospheric pressure**

Data Acquisition Systems

- Campbell Scientific (CR10X,CR1000,CR1000x)
- SACRAM 22-bit data acquisition system specifically designed for the PFR.

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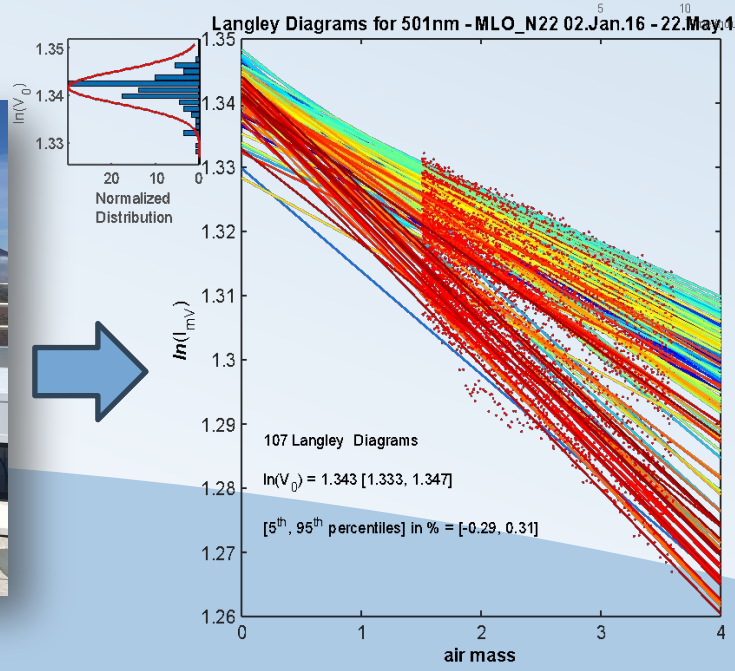
WMO AOD reference – GAW-PFR_TRIAD at PMOD/WRC, Davos

Service & Calibration

- GAW-PFR-Triad = 3 PFR instruments
- Almost identical spectral characteristics (wavelength, bandpass)
- Well maintained
- The scale is realized by comparison to Langley standards.
- The stability and precision are assessed annually.
- Pool of 9 traveling standards for deployment at the Langley calibration sites.

Service & Calibration

Izaña,Tenerife(ES)



Mauna-Loa, Hawaii (US)

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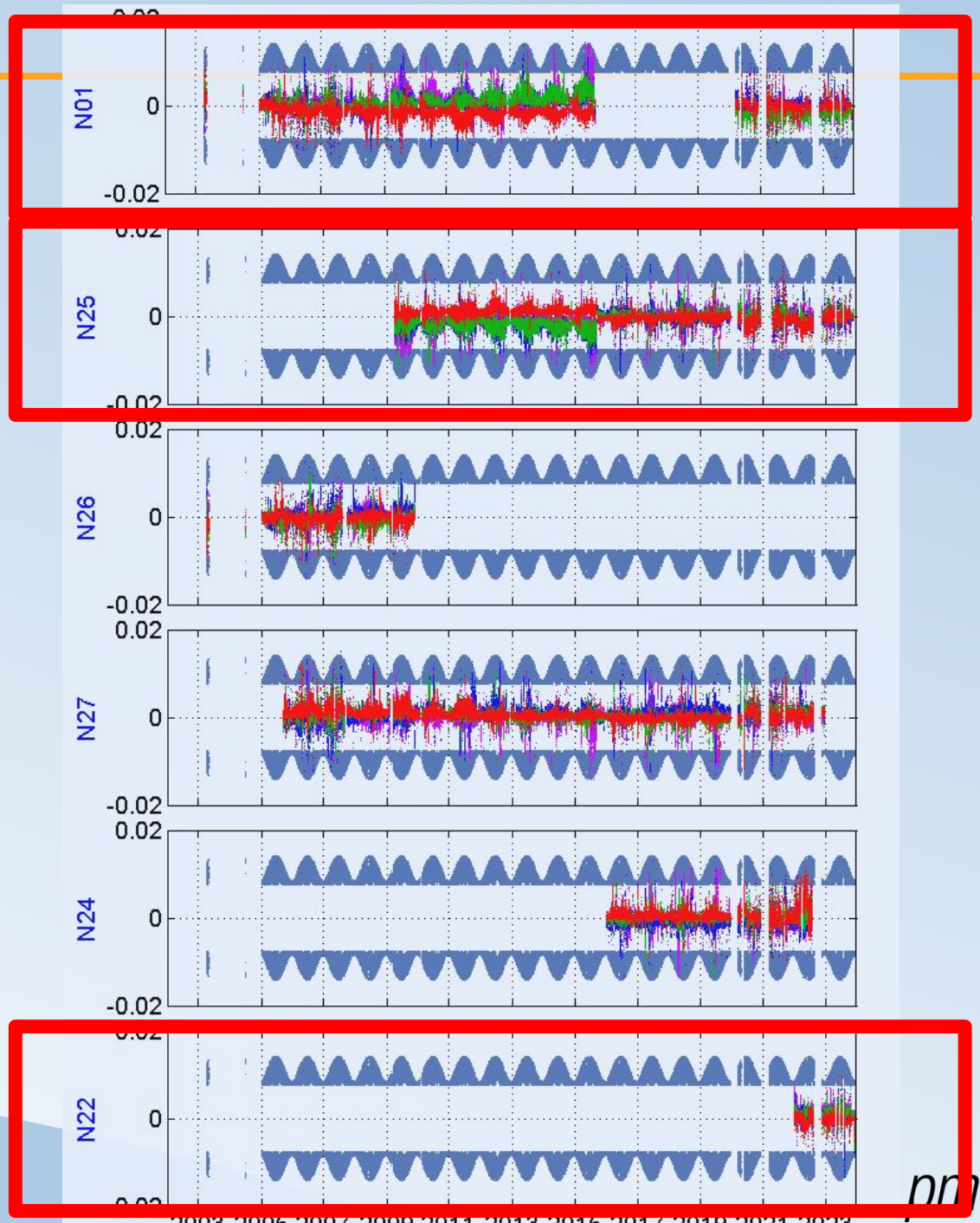
GAW_PFR-Triad – WMO AOD reference

GAW-PFR-Triad calibration stability better than 1%

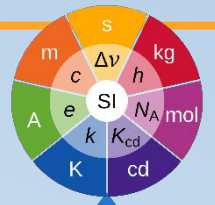


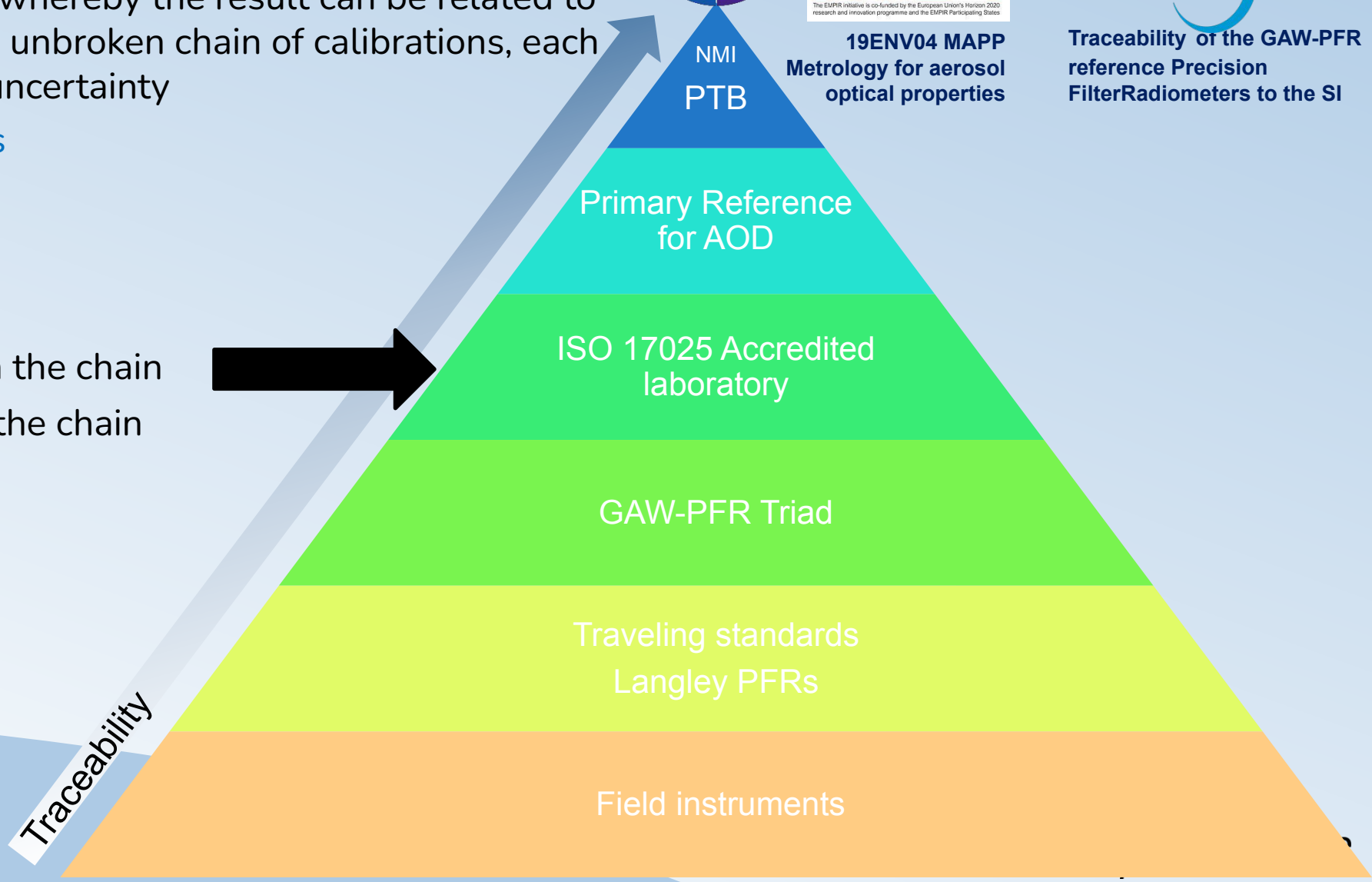
Traceability of GAW-PFR-Triad and GAW-PFR network instruments

International vocabulary of metrology (VIM)

Metrological Traceability:
Property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty

- ✔ Unbroken chain of comparisons
- ✔ Uncertainty of measurement
- ✔ Reference to SI units
- ✔ Calibration intervals
- ☐ Documentation for each step in the chain
- ☐ Prove competence of realizing the chain





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19ENV04 MAPP
Metrology for aerosol optical properties

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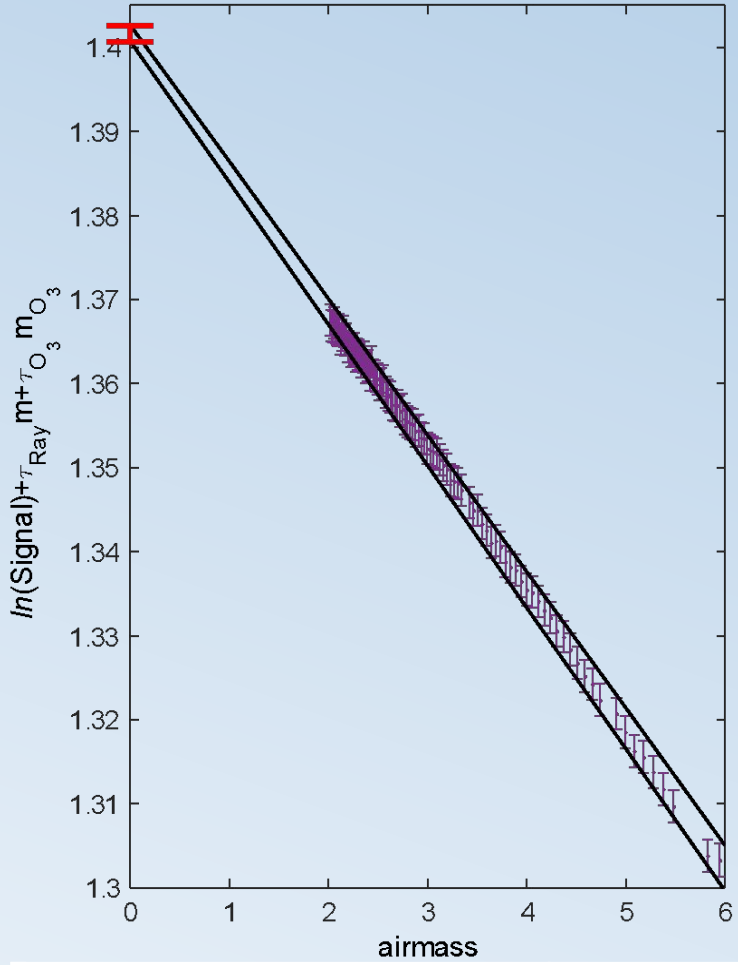
Traceability of the GAW-PFR reference Precision FilterRadiometers to the SI

Langley Calibration - Uncertainty

$$\boldsymbol{ln}(I_\lambda) + \sum_i \tau_{att(i)} m_{att(i)} = \boldsymbol{ln}\left(I_\lambda^0\right) - AOD_\lambda m$$

Component	Description	Type	Value
Signal Noise Atmospheric	Standard deviation of the 10 sequential measurements	A	
Dark Noise	Standard deviation of the day	A	
Pressure	Uncertainty of pressure measurement	B	3mbar
Total column of ozone	Daily value of ozone measurement (OMI)	B	2%
Ozone airmass	Height of ozone layer	B	3km
Airmass			
Equation	Comparison of 2 different algorithms	B	<0



Wavelength(nm)	862	500	412	368
Langley regression expanded uncertainty (%,k=2)	**0.003**	**0.019**	**0.038**	**0.060**

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Calibration Uncertainty budget

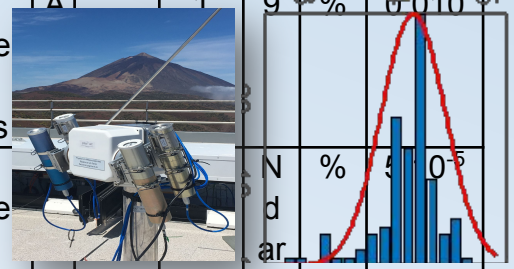
example for 500 nm

PFR signal uncertainty

Signal combined relative uncertainty						**%**	**0.246**	

Reference PFR uncertainty

Combined relative uncertainty		**A**				***Ni*** **%**	**0.273**	
Component	**Description**	**Type**	**Symbol**	**Sensitivity Coefficient**	**DF**	**units**	**Value**	
Measurement repeatability	Standard deviation of the 10 sequential measurements	A		1	9	%	0.010	
Dark signal noise	Standard deviation of the day / period	A		1	Ndark-1	%	$5 \cdot 10^{-5}$	
PFR-DAQ	Standard deviation of the reference 2500 mV over the calibration period	B		1		%	0.008	
Electronic Noise								
FOV	0.2 % within ±10 arcmin of the center of the plateau	B		1		%	0.200	
DAQ precision	0.1% signal range 1-5000 mV	B		1		%	0.010	
Non-Linearity PFR-Gain	Gain uncertainty : estimated to 0.1% at PTB	B		1		%	0.100	



Calibration of reference PFRs against 3-Langley transfer PFRs

Component	**Description**	**Type**	**Symbol**	**Sensitivity Coefficient**	**DF**	**units**	**Value**
Sign							
Ratio uncer							
	RI						
Daily mean ratio	standard deviation of the signals' ratios acquired during one day	A			N_i	%	0.100
				1	*Nj*	%	0.472
Combined relative uncertainty		**A**			***Ni***	**%**	**0.273**

GAW-PFR network & customer PFRs

Corrections for wavelength mismatch (368 nm, 412 nm)

Deviation between uncorrected V_0 and

- Radiative transfer model correction
- and airmass extrapolation of the ratios.

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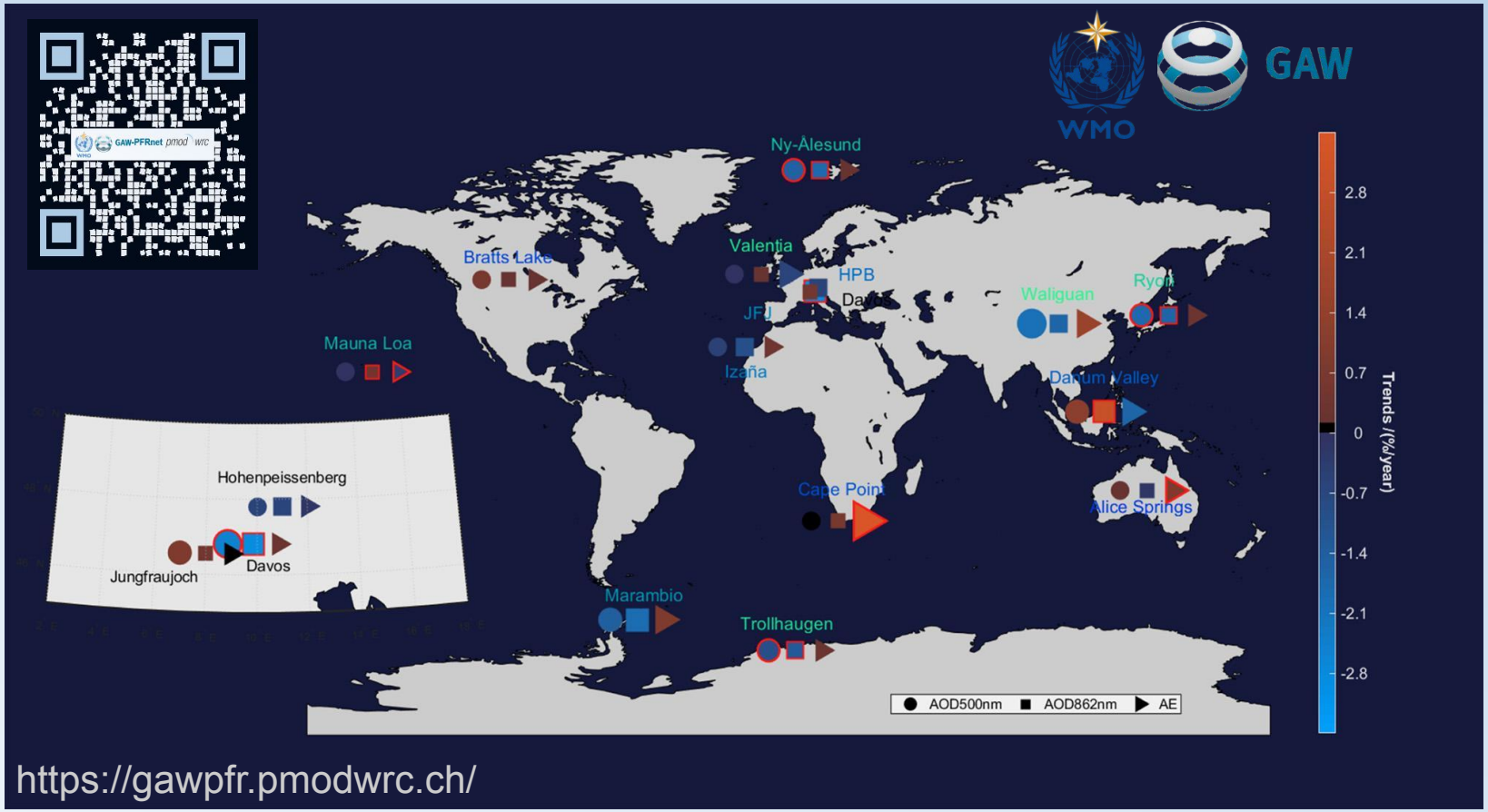
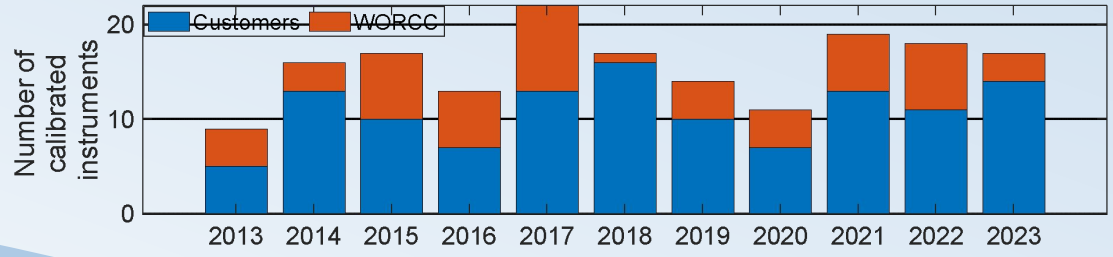
GAW-PFR TRIAD scale transfer to GAW-PFR network



Provide Calibration traceable to WMO AOD reference.



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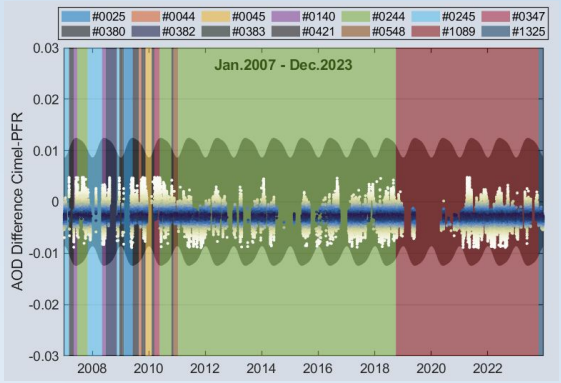
WMO AOD reference – Calibration activities

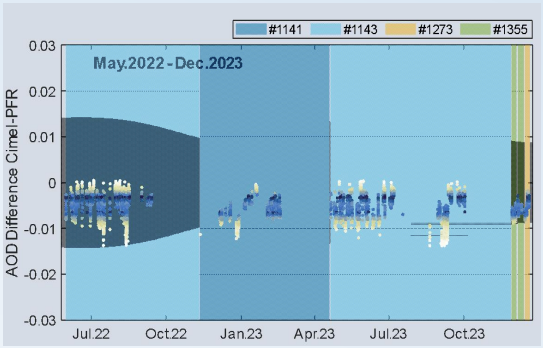
Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) - Centre for Aerosol Remote Sensing (CARS)

AERONET -Europe calibration transfer facilities

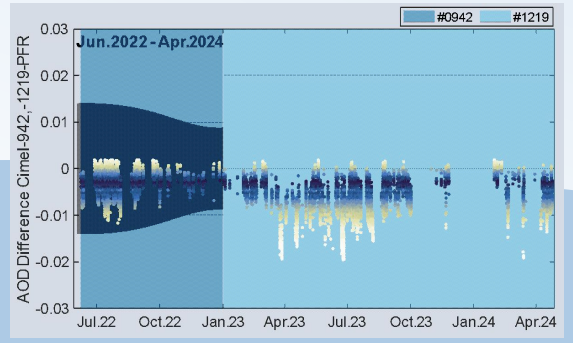
Izaña, Spain



OHP, France



Valladolid, Spain

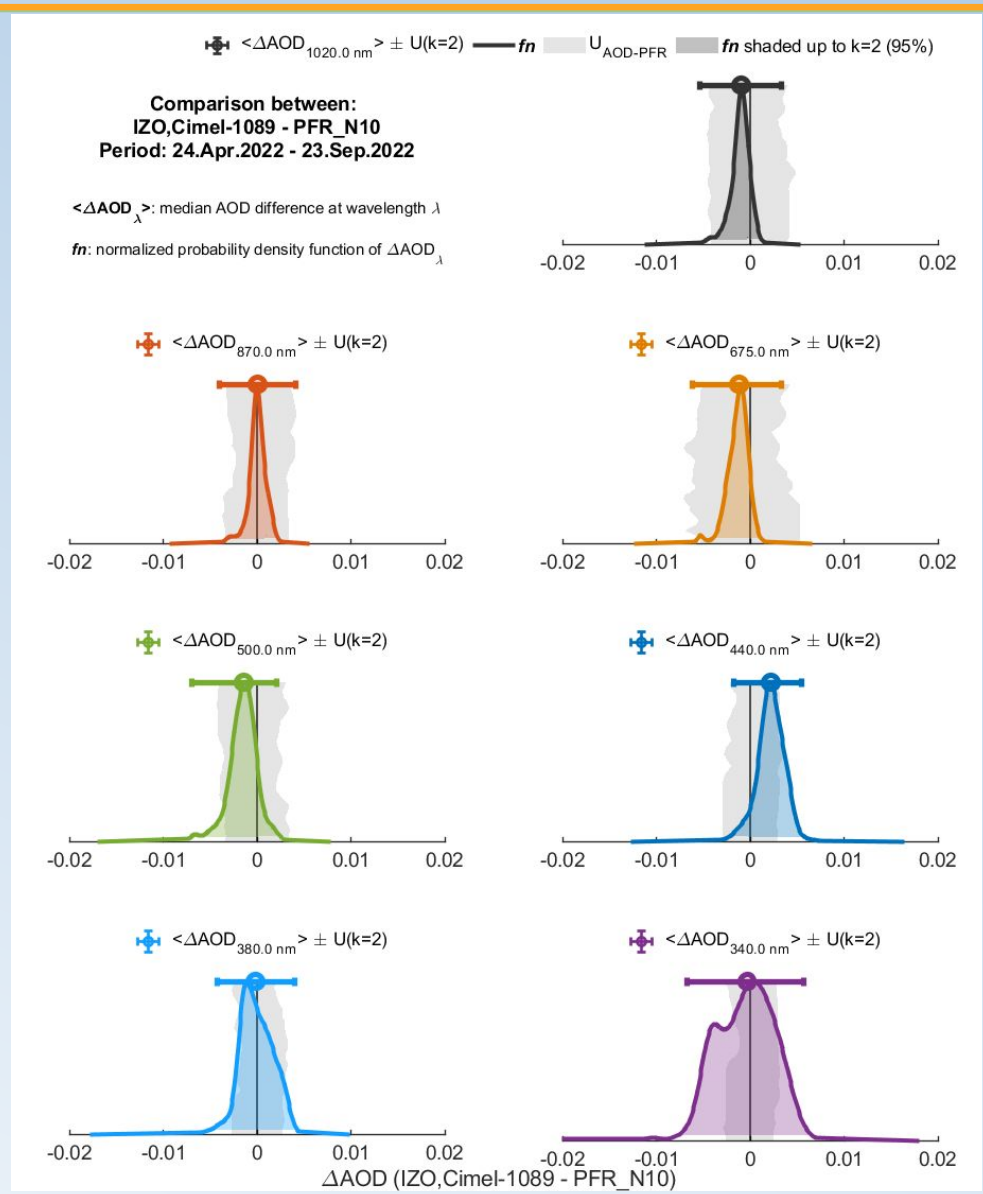


- PFR AOD uncertainty
  - calibration, signal, pressure, airmass, O_3, NO_2

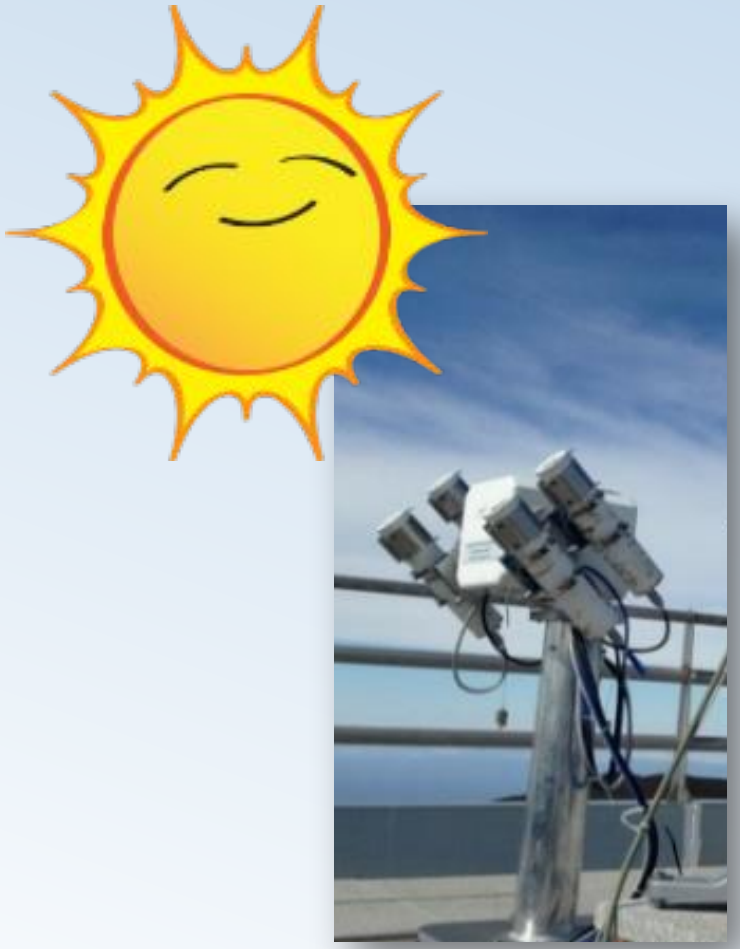
Work in progress

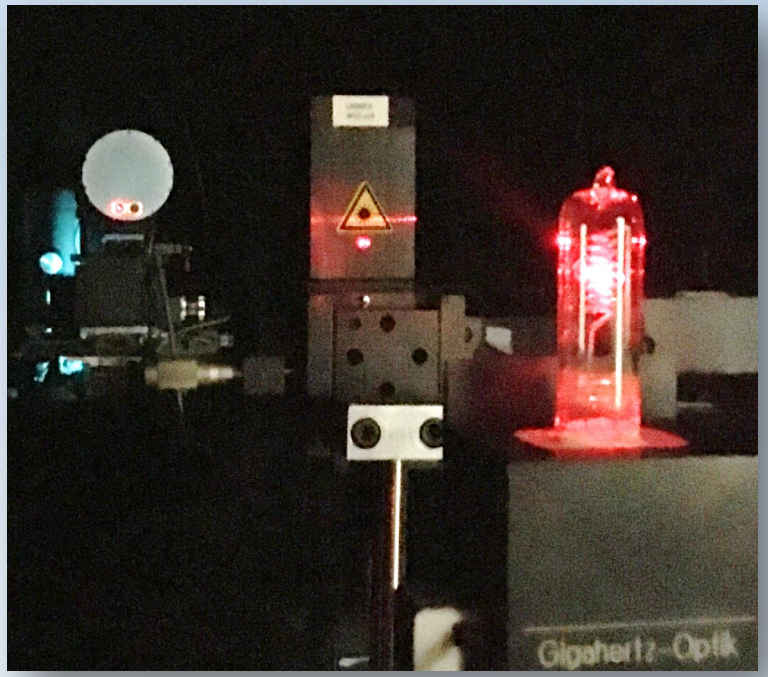
- Revise uncertainties of PFR for the extrapolated wavelength 340 nm(Monte Carlo approach on linear fit - add 2nd order fit)
- Optimize PFR operation in OHP, VLD

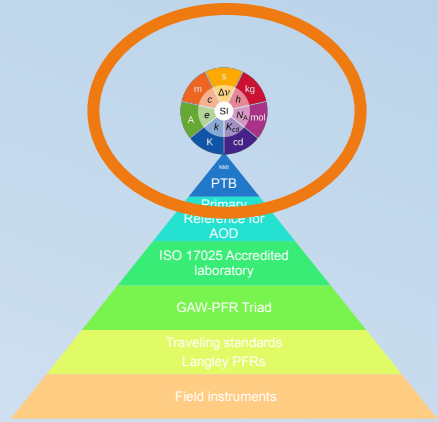
Goddard Space Flight Center, USA



SI-Traceable Calibration & AOD Retrievals







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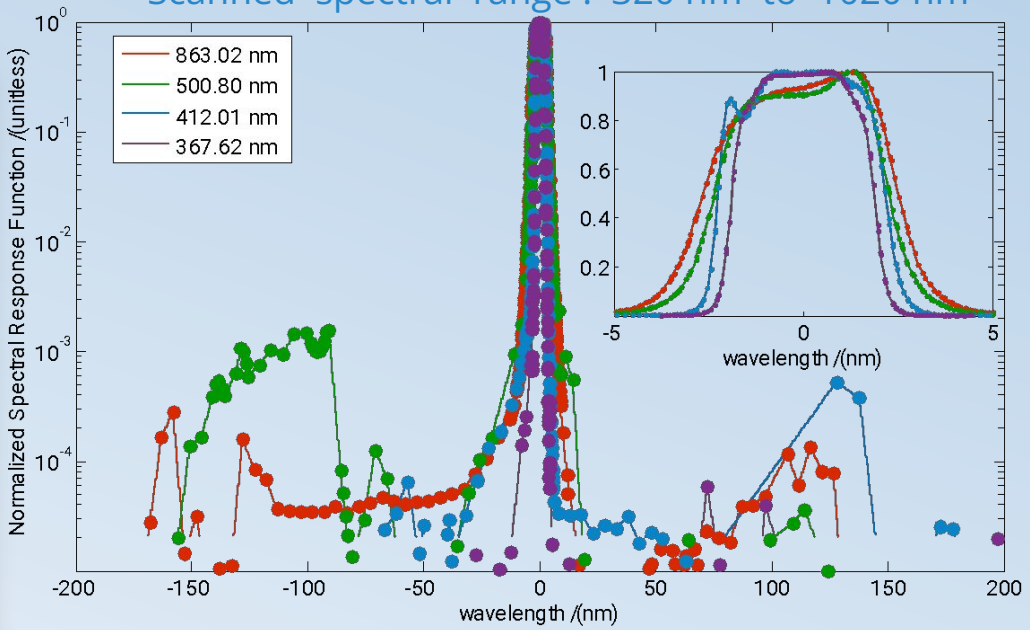
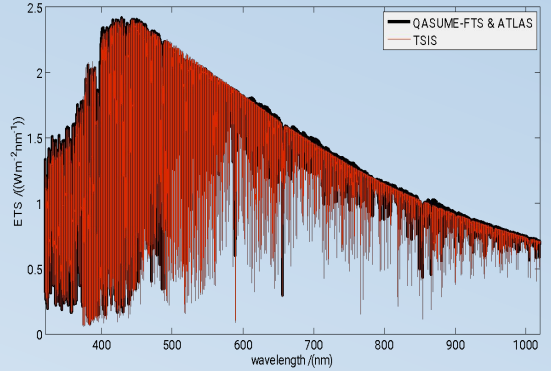
SI-traceable Solar irradiance

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

Scanned spectral range : 320 nm to 1020 nm



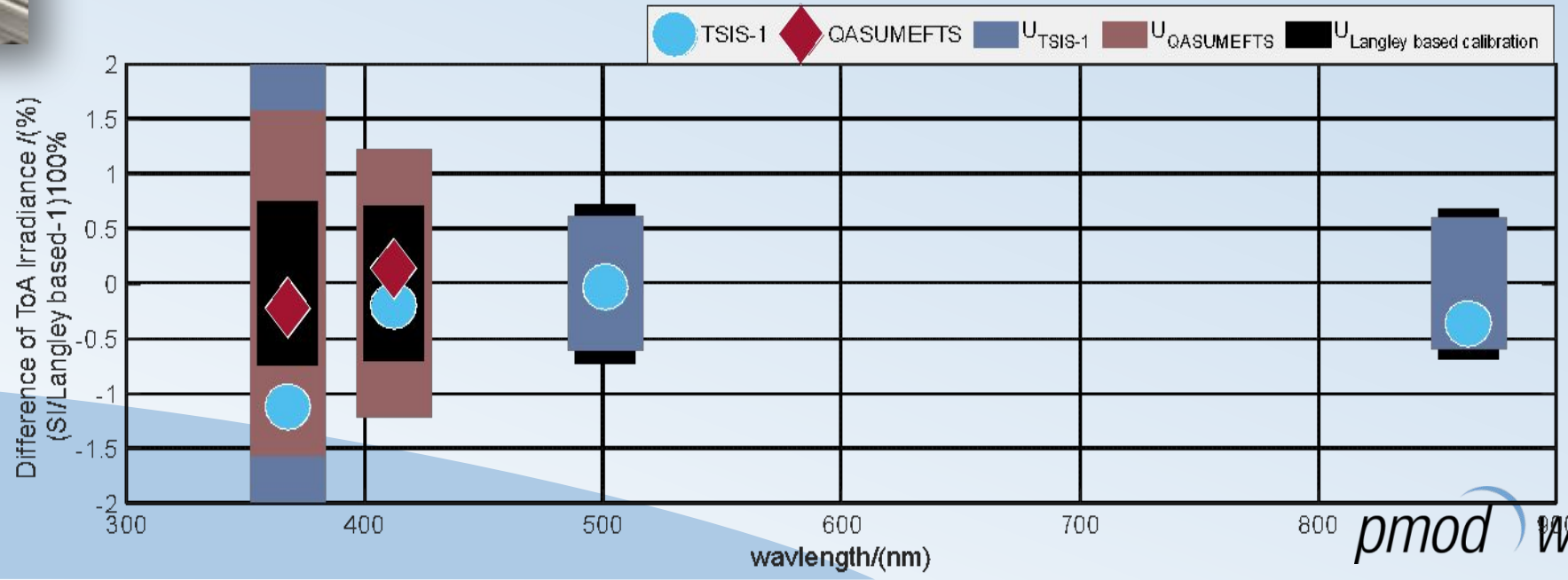
Top-of-Atmosphere High Resolution Solar Irradiance Spectrum



TUnable Lasers In… metry (TULIP)

- fully automat…
- based o…
- hom… …eld
- … …ement trap u… …an 0.1 %
- wav… …le measured with a laser s… …trum analyser

Calibration uncertainty < 0.3%



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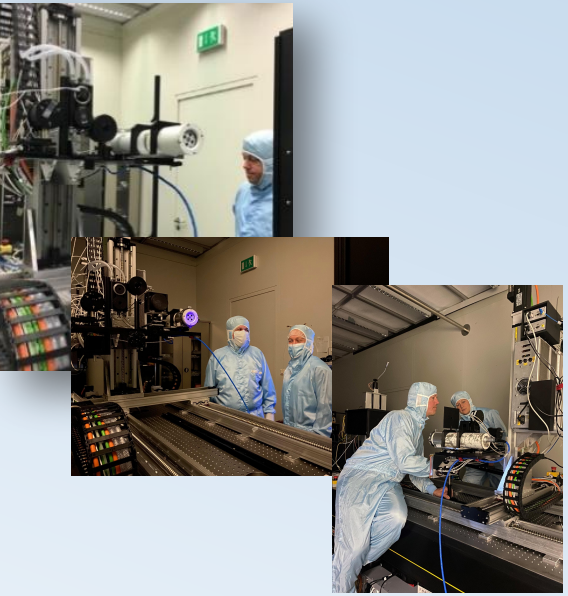
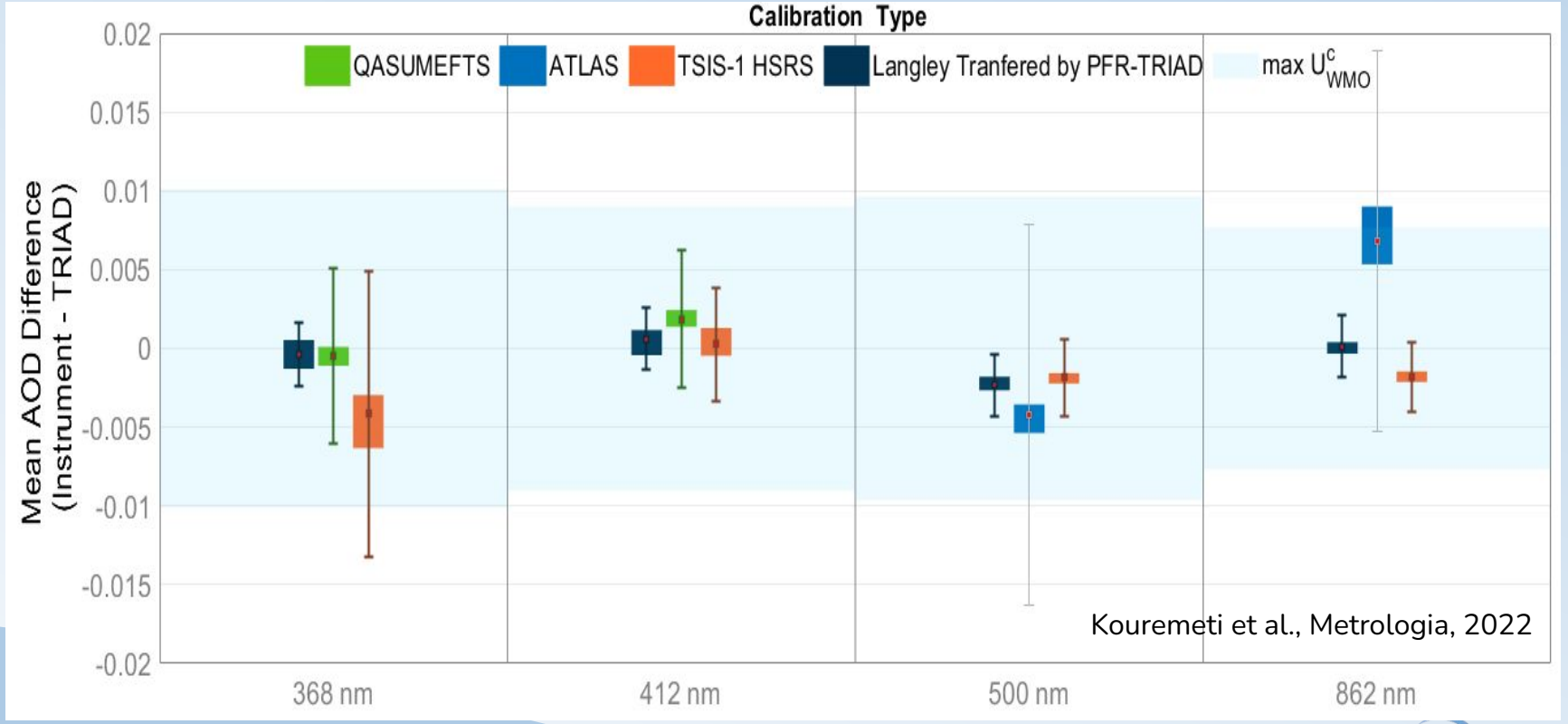
SI-traceable Solar irradiance



	Change in responsivity (%)				Change in centroind wavelength (pm)			
	863.0	500.8	412.0	367.6	863.0	500.8	412.0	367.6
2018 (-3 years)	0.27	0.40	0.81	0.80	-58	10	5	0
2021	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2024 (+3 years)	-0.28	-0.34	-0.92	-1.00	0	0	2	-2



SI- and Langley based calibrations produce equivalent AOD within the WMO requested uncertainty.

Other check points

- 2021, FRC-V (GAW Report 208)
- 2022, MAPP Izaña campaign (Gröbner, et.al,2023)

Summary

- Working on establishing Metrological Traceability for the GAW-PFR references and field instrument

- SI-traceable direct solar irradiance and AOD retrievals give equivalent result to the Langley calibration

- Disseminate the traceability through AOD comparison at ACTRIS/CARS sites, and exploring possibilities of SI-calibration transfer

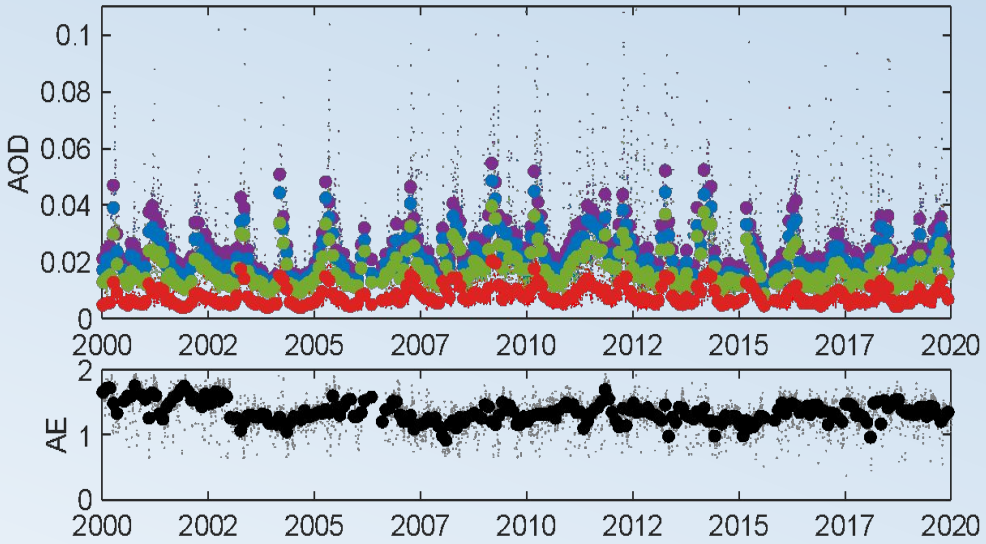
Thank you for your attention !

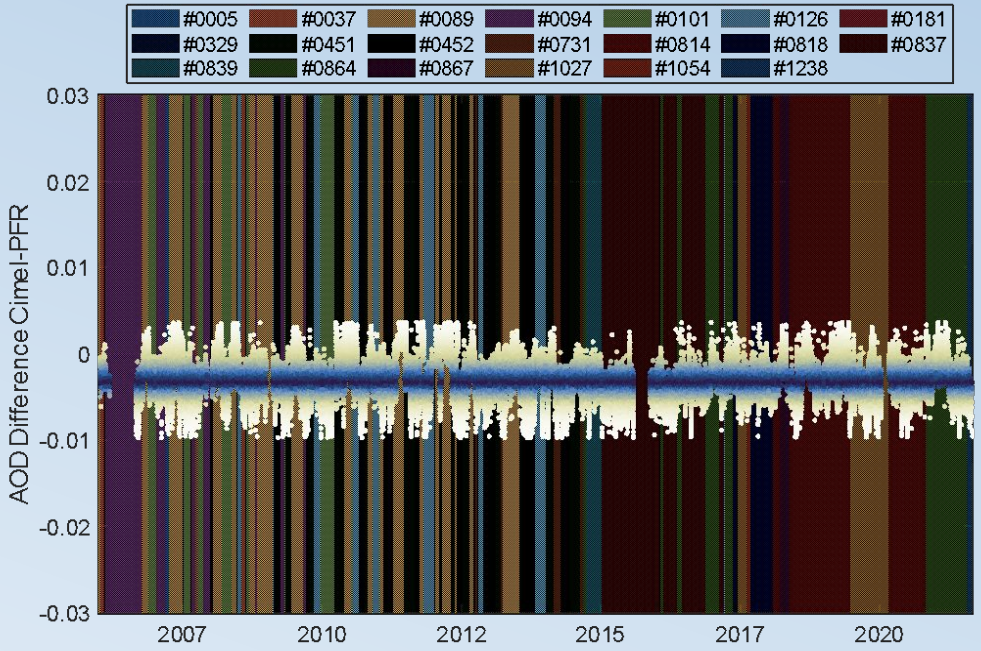
WMO AOD reference – Calibration activities

@Langley sites

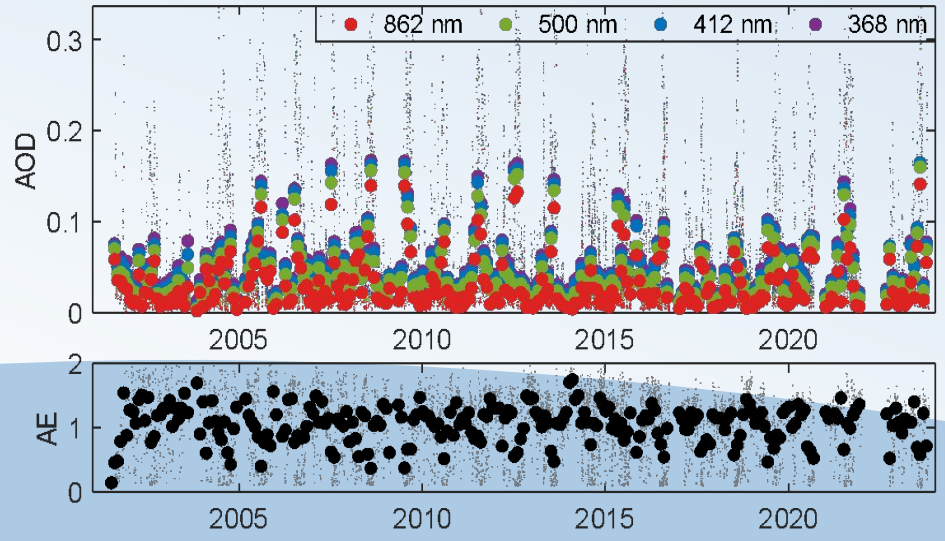
~20 years

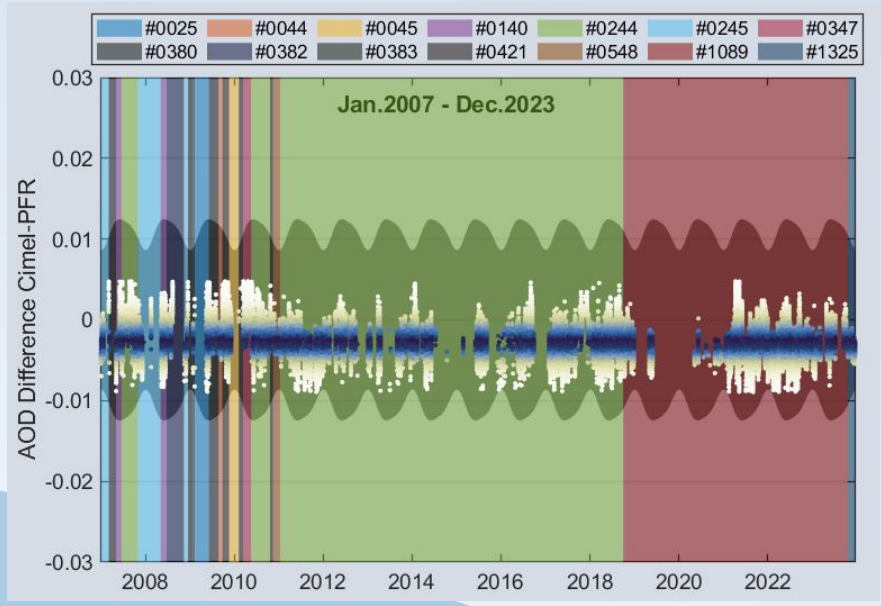
Mauna Loa, USA





Izaña, Spain





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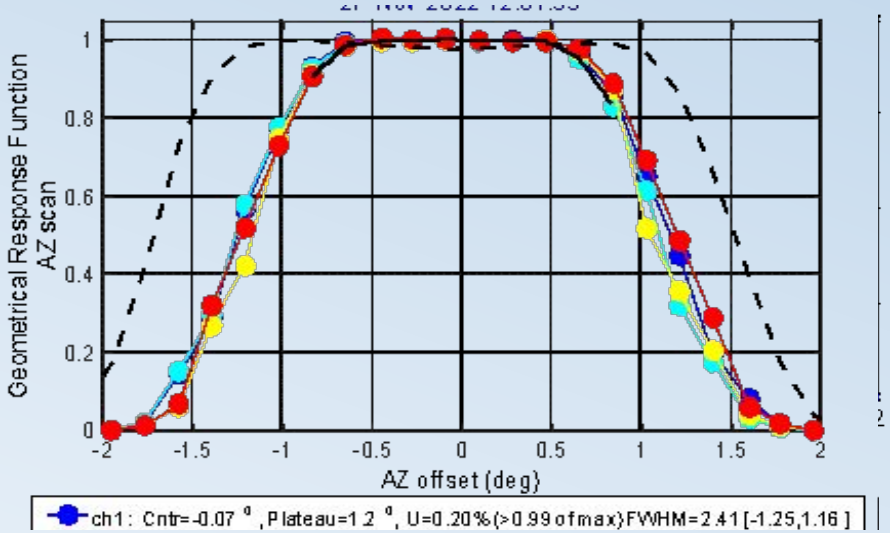
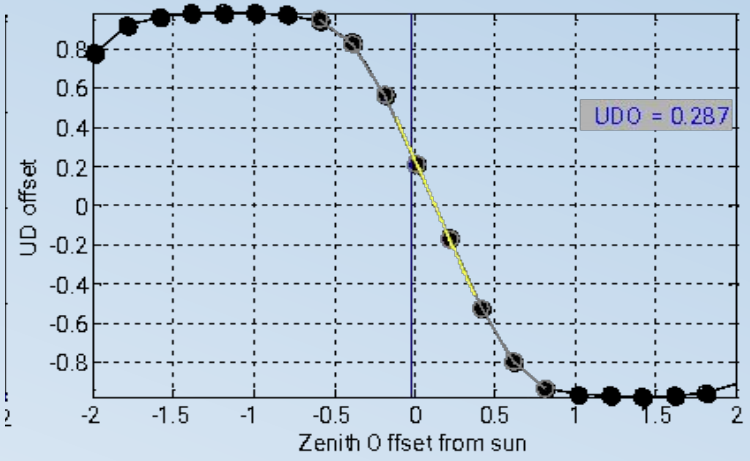
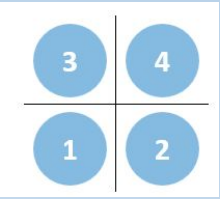
Data Quality Assurance - Sources of Highest uncertainties

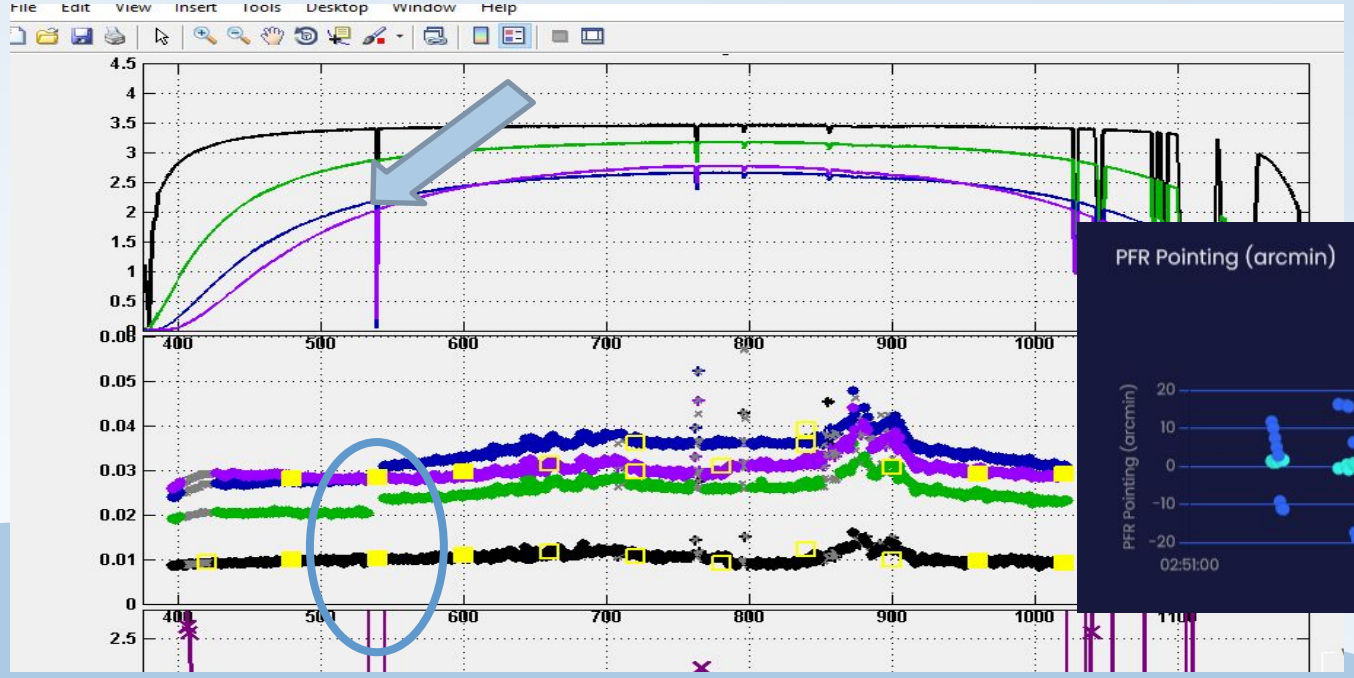


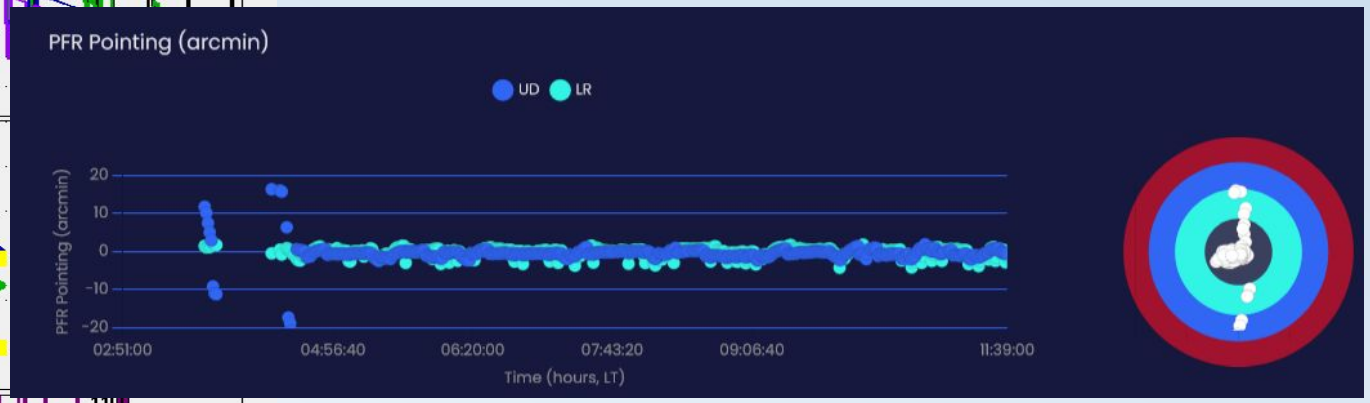




$$LR = cf\left(((Q_1 + Q_3) - (Q_2 + Q_4))/\sum_{i=1}^{4} Q_i - LRO\right)$$

$$UD = cf\left(((Q_1 + Q_2) - (Q_3 + Q_4))/\sum_{i=1}^{4} Q_i - UDO\right)$$





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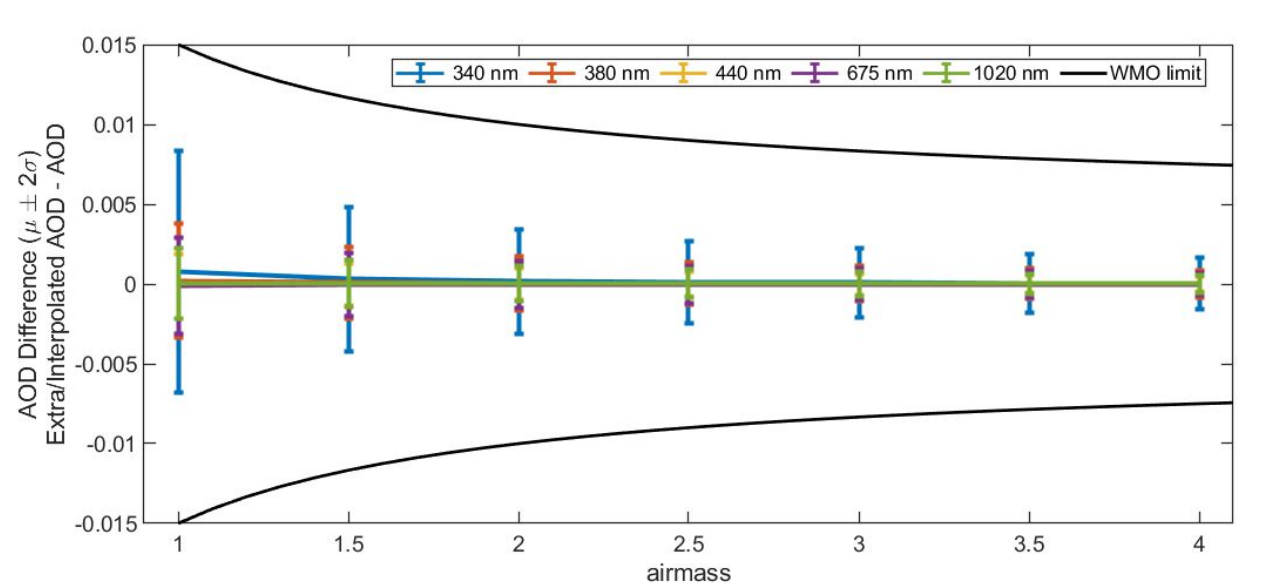
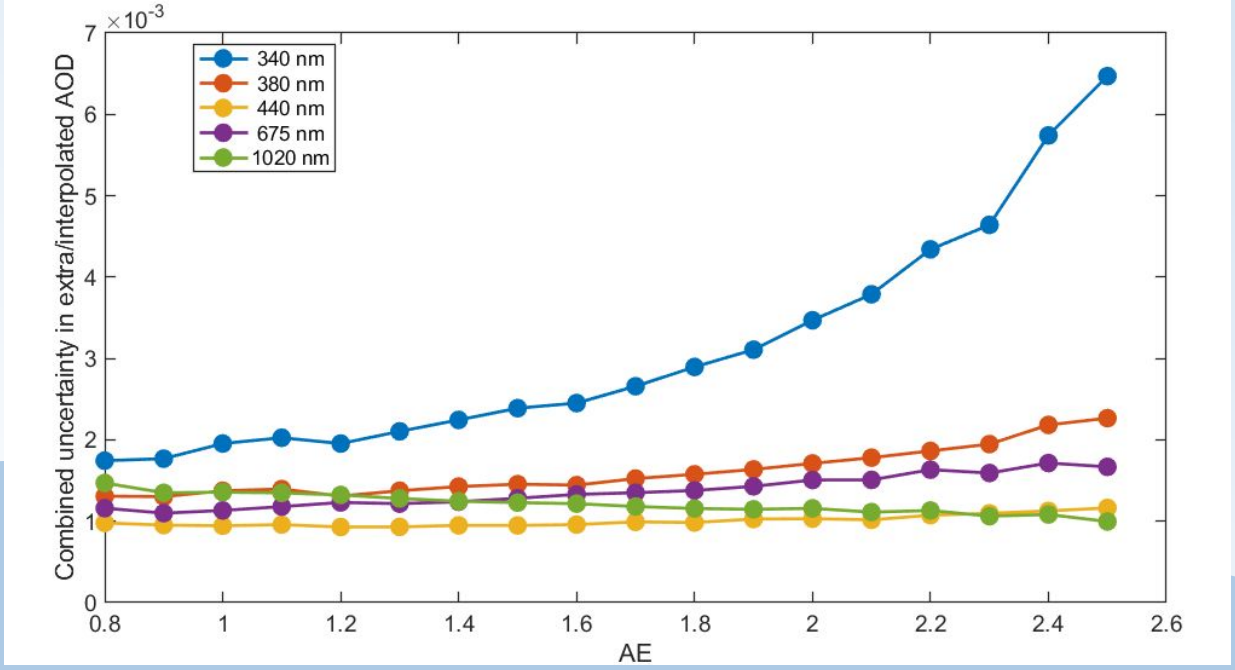
GAW-PFR TRIAD scale maitenance





$$0.9 \leq AE \leq 2.2 \; and \; AOD(500\,nm) < 0.5$$

The selected synchronized PFR -TS AOD at AOD data at the wavelength of the DUT are subtracted from the DUT AOD. A control of differences with respect to errors in the quality control of both PFR-TS and DUT is applied, excluding extreme values. Days with more than 10 synchronous measurements are selected. The atmospheric conditions filter with respect the aerosol load and uncertainty of extra\interpolation is applied on the differences :

Figure : Example of combined uncertainty introduced to extra/interpolated AOD to 340nm,380 nm, 440 nm, 675 nm 1020 nm, due to the extrapolation method and uncertainties the measured atmospheric transmittance by the PFR at 368 412 nm, 500 nm and 862 nm with a combined expanded rela irradiance uncertainty of 0.32%, 0.32% , 0.30% 0.2 respectively (AOD at 500 nm = 0.01).

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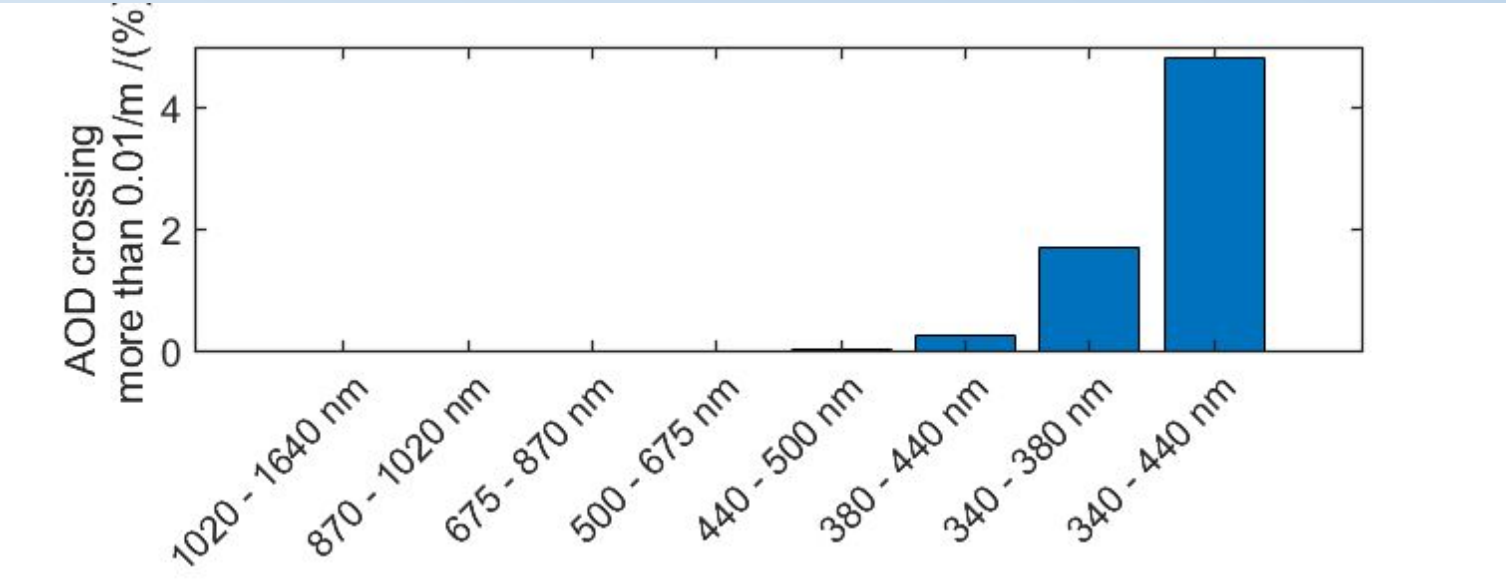
GAW-PFR TRIAD scale maitenance



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