SI-Traceable System Development (WP-2220)

Lunar Irradiance measurements with a Precision Filter Radiometer

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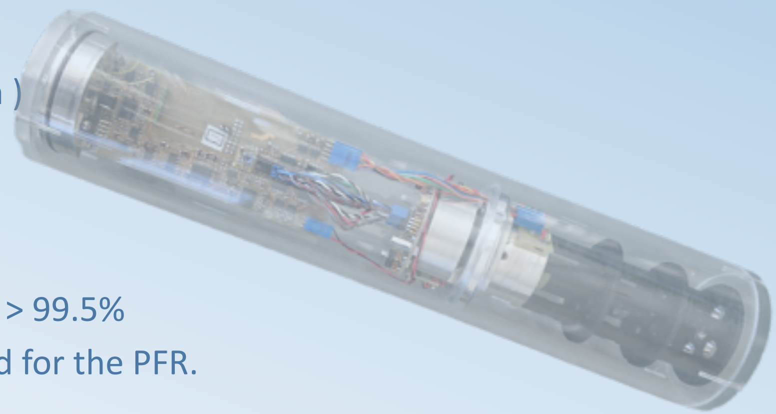
Lunar Precision Filter Radiometers

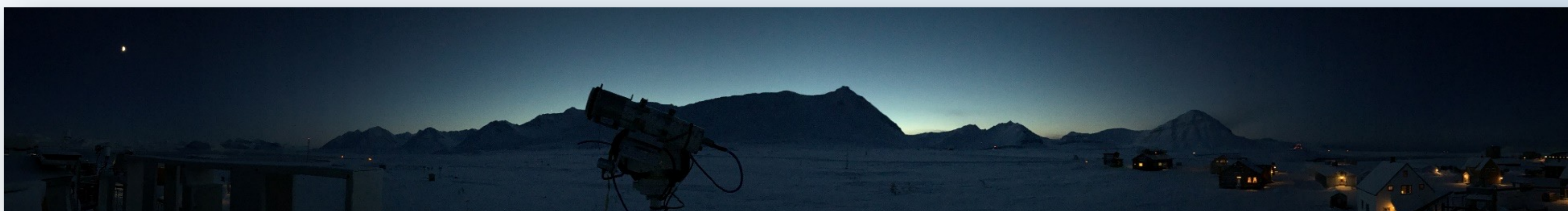
- **Filter radiometer with 4 channels in a grid**

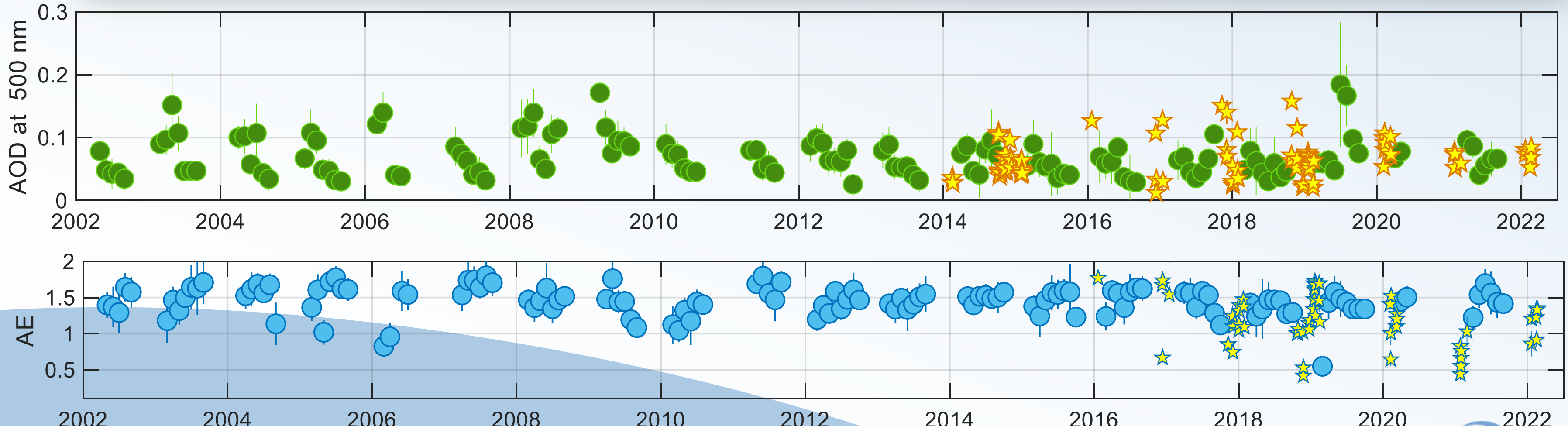
Lunar version: 675 nm, 412 nm , 500 nm, 862 nm (FWHM: ~5 nm)

Optimized for Irradiance Measurements

- **Temperature stabilized photodiodes**
- **Reference Plane: the precision aperture**
- **FOV : 1.2º plateau** , 0.7º slope angle, homogeneity in plateau > 99.5%
- 22-bit data acquisition system (SACRAM) specifically designed for the PFR.







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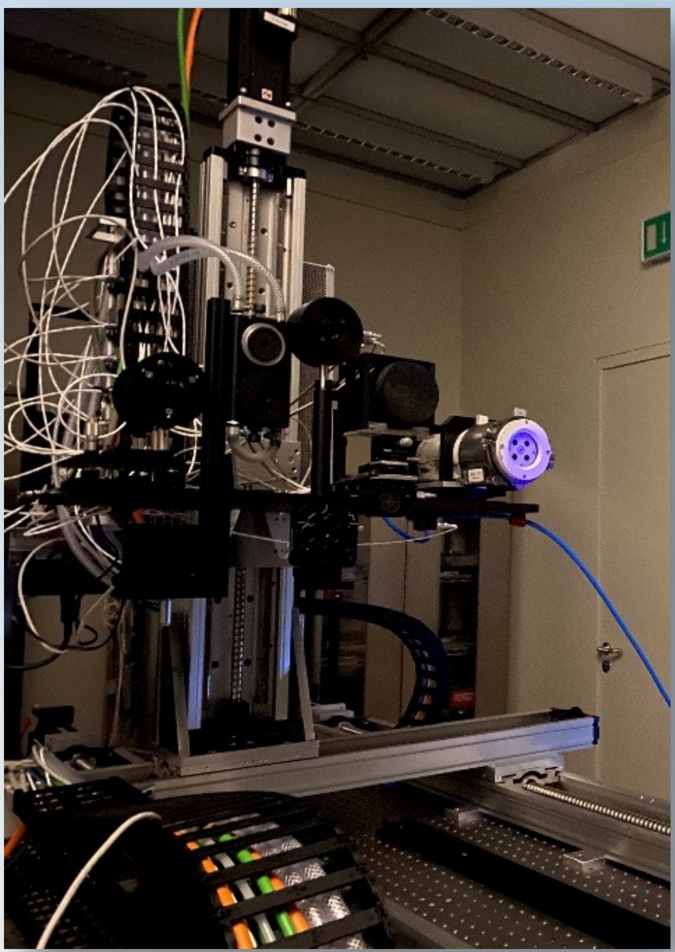
PFR-L Characterisation

Lunar-PFR PFR-L-002 has been characterized at PTB, Braunschweig, Germany and provides irradiance measurements with an uncertainty of 0.3% at 412 nm, 500 nm, 675 nm and 862 nm with the framework of 19ENV04 MAPP.



TUnable Lasers In Photometry (TULIP) setup

- ps-OPO system
- Homogenized beam
- Reference detector: 3-element trap detector and equipped with a calibrated aperture, giving an uncertainty better than 0.1 %
- Wavelength scale: LSA
- Fully automated system

Characterization Measurements

- Spectral responsivity (*s*)
- Reference plane
- PFR Gain

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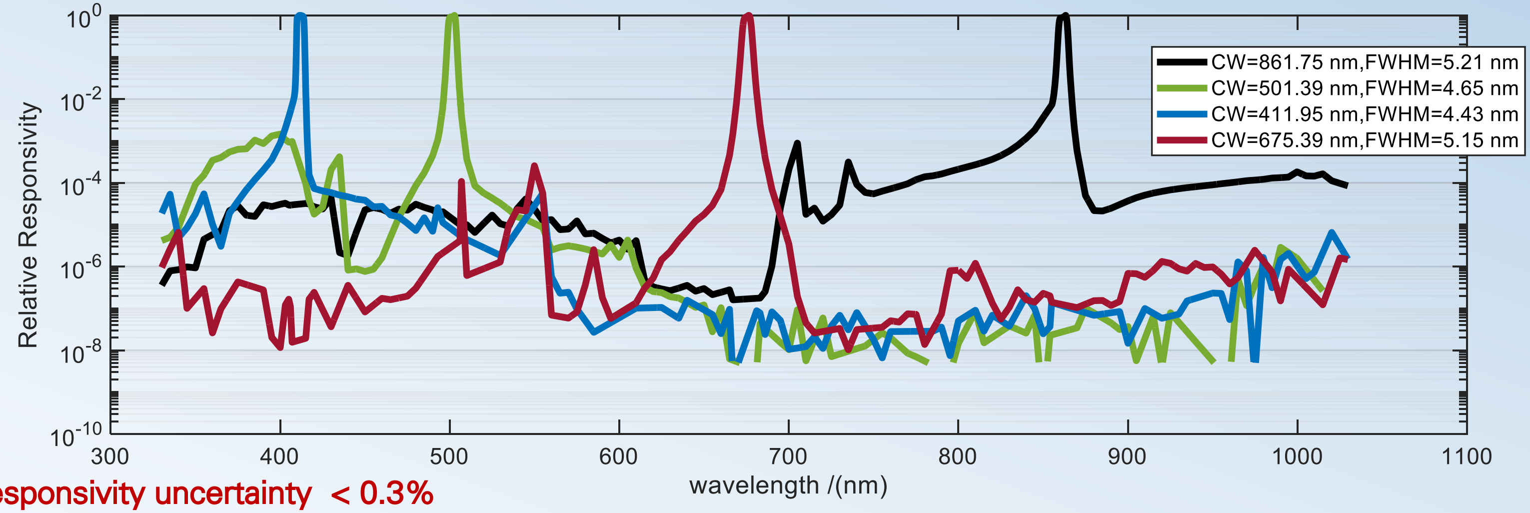
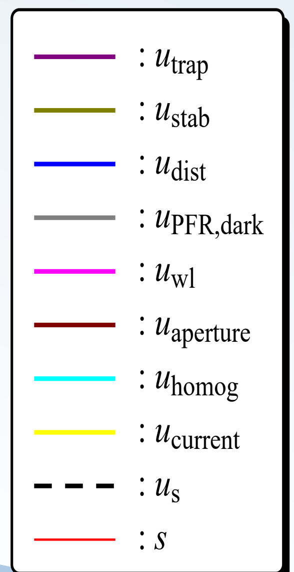
PFR-L Characterization



Spectral responsivity uncertainty < 0.3%

TULIP - 2021		
λ (nm)	s (mV/(W/m²))	U_s (%,k=2)
861.75	12.96	0.26
501.39	9.78	0.25
411.95	10.88	0.27
675.39	6.80	0.18

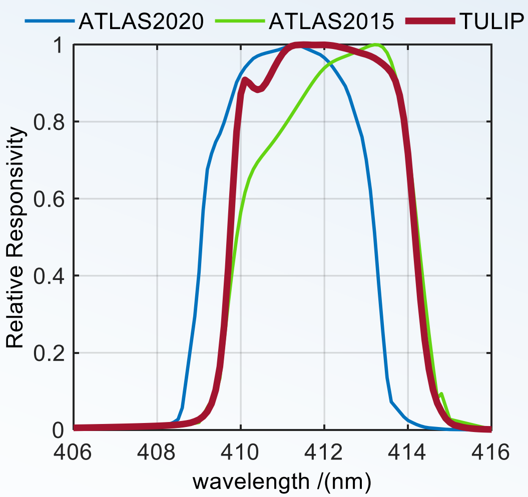


Gain uncertainty 0.3%

Gain	TULIP 2021 U=0.3%
Laboratory: 0	1.0
1	934.6
2	4451.4
Lunar: 3	25164.0

PFR-L Characterisation : ATLAS (Pulsed) vs TULIP

Spectral Responsivity: the spectral characteristics of The interference filters highly depend on the measuring geometry.



Relative responsivity of 412 nm channel retrieved from measurements at TULIP and ATLAS setups.

highest discrepancies

Gain uncertainty reduced by a factor of 3

Gain	TULIP 2021 U=0.3%	ATLAS 2017 U=2.5%	ATLAS 2019 U=1.5%
Laboratory : 0	1.0	0.0	0.0
1	934.6	-1.8	-0.2
2	4451.4	-1.9	-0.2
Lunar: 3	25164.0	-1.8	0.1

Spectral responsivity uncertainty reduced from 1.5% to 0.3%

TULIP - 2021			Differences to TULIP ATLAS-2020	
λ (nm)	s (W/m^2)	U (%,k=2)	δλ (nm)	δs (%)
861.75	12.96	0.26	**0.2**	**-1.4**
501.39	9.78	0.25	**1.1**	**0.8**
411.95	10.88	0.27	**0.8**	**5.1**
675.39	6.80	0.18	**0.1**	**-2.5**

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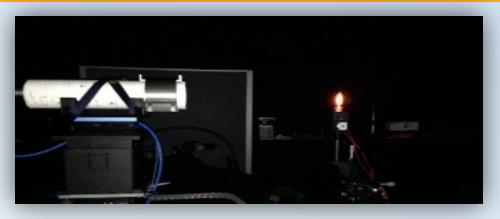
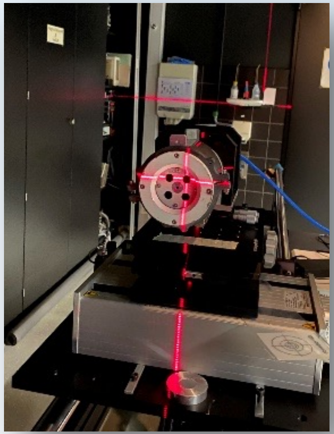
PFR-L Characterisation - Comparison of Calibration Methods





Irradiance Standard vs Monochromatic Irradiance

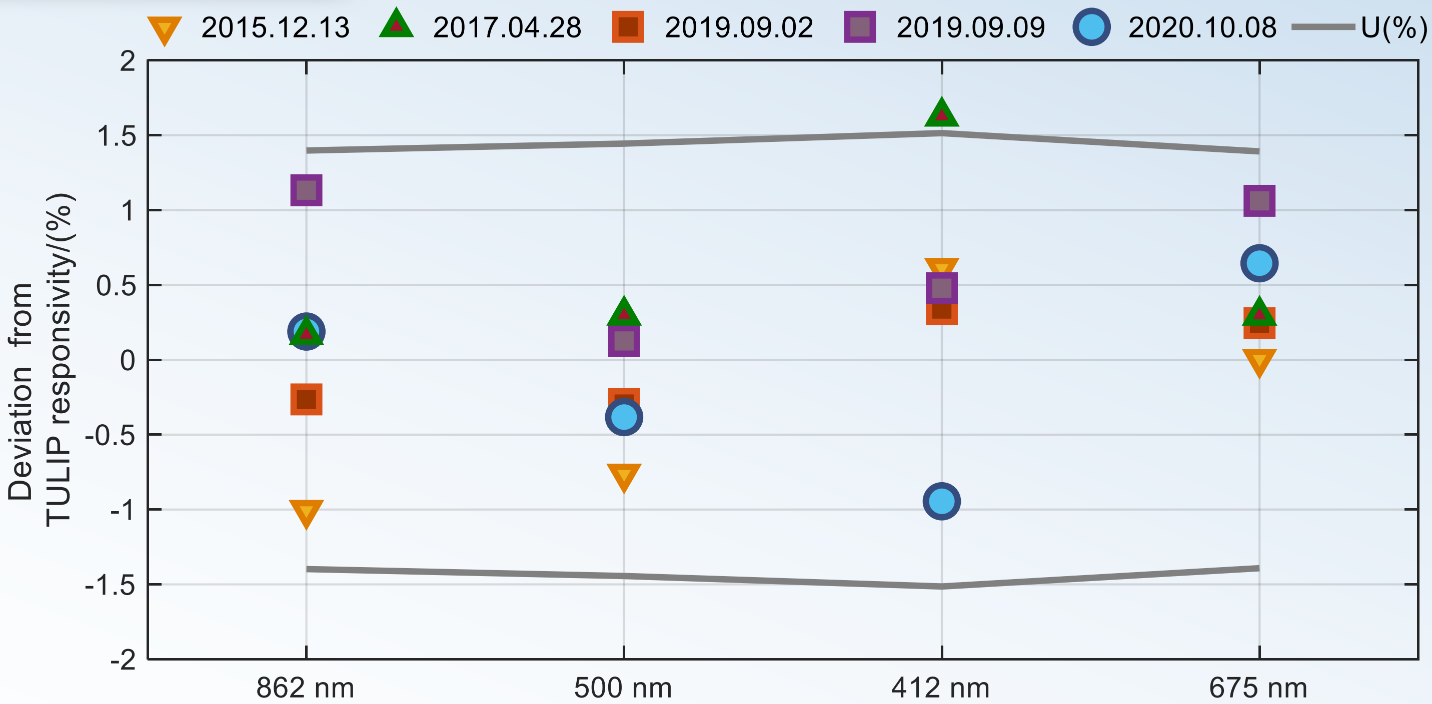
An irradiance calibration was performed at PTB after the TULIP calibration using 200 W lamps. The 2 calibration methods gave equivalent results, well within their uncertainties.

channel	862 nm	500 nm	412 nm	675 nm
1000 mm	-0.30%	-0.40%	-0.90%	0.30%
1500 mm	-0.10%	0.20%	0.30%	0.20%

PFR-L Characterisation - Stability 2015-2021

Direct Irradiance Calibration Setup

- Reference irradiance source (1000W FEL-type lamp) calibrated at PTB.
- Motorized XYZ linear translators
- Motorized Rotation stages for azimuth and zenith angles.



Comparison of lamp calibrations performed since 2015 to TULIP calibration.

The gray lines: uncertainty of the lamp calibration.

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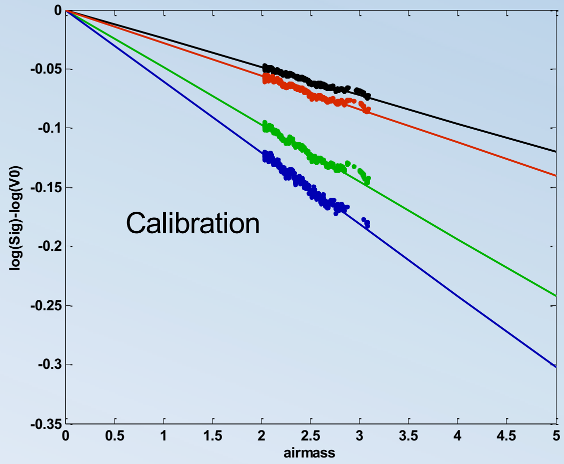
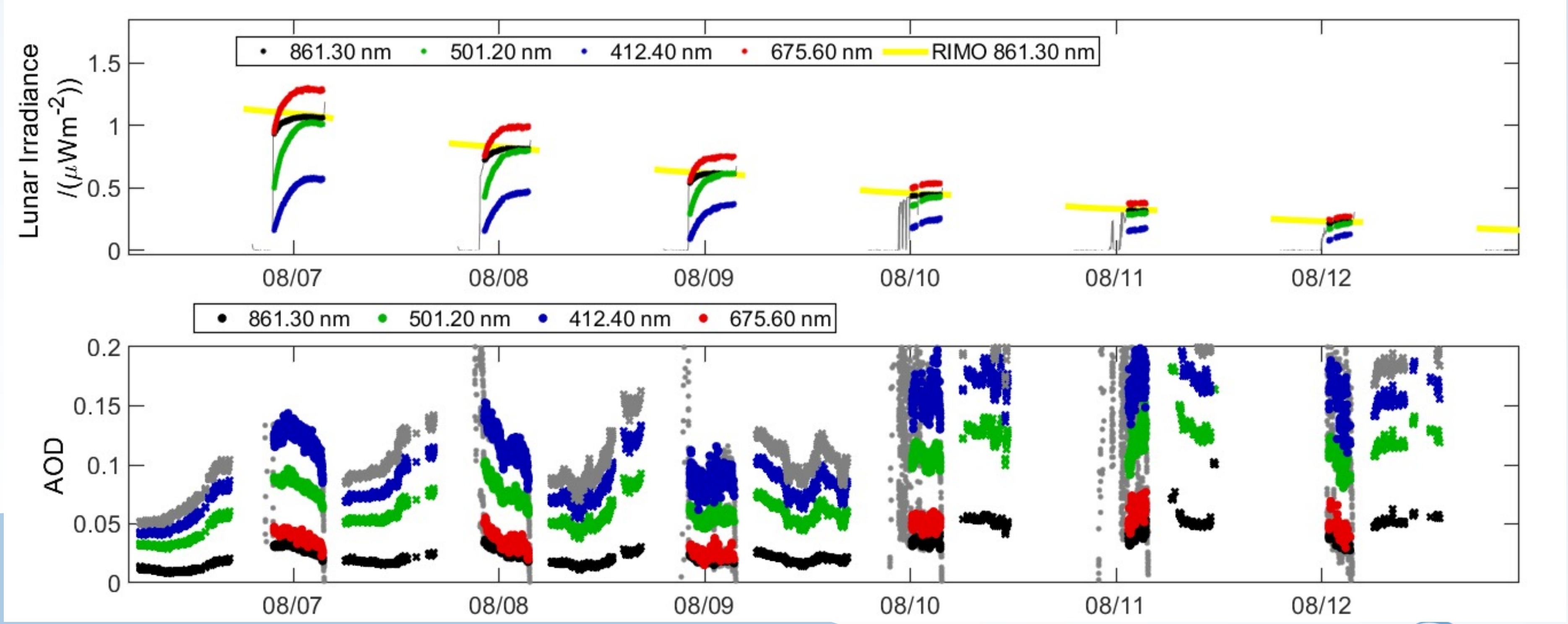
Top-Of-Atmosphere Lunar Irradiance

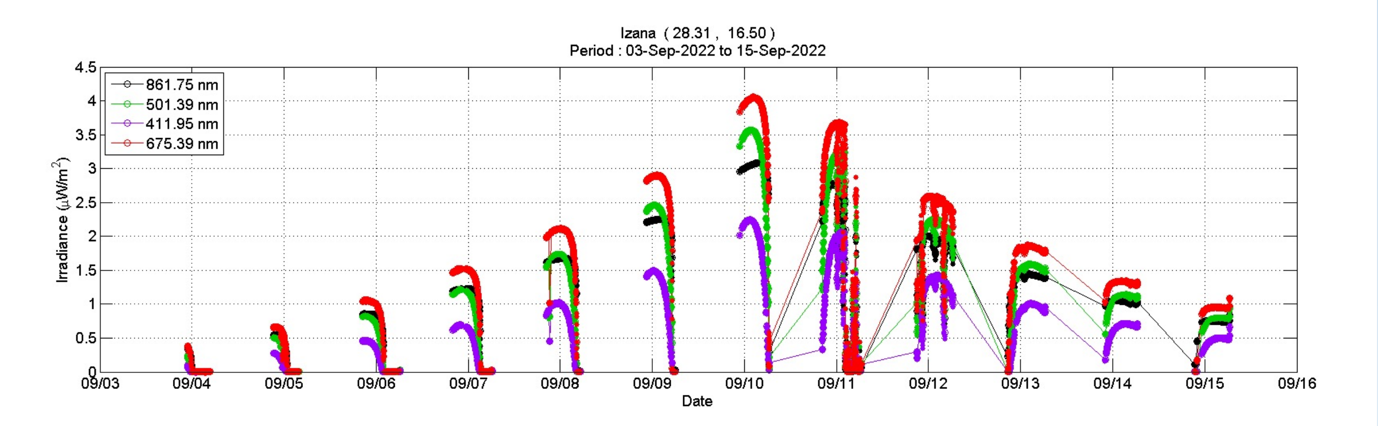
$$\ln\left(\frac{Ipfr(\lambda)}{I_{RIMO}(\lambda)}\right) + t_{ray}m + t_{O_3}m_{O_3} = -mt_{aod}$$



Successful Langley Example:



Top-Of-Atmosphere Lunar Irradiance



	Difference LunarPFR-RIMO TOA Lunar Irradiance (%)				Combined calibration and regression uncertainty (%, k=2)				
	862 nm	500 nm	412 nm	675 nm	862 nm	500 nm	412 nm	675 nm	Lunar Phase
Individual Langley retrievals	7.47	9.47	7.80	10.27	0.33	0.35	0.50	0.29	-47
	7.09	9.16	7.69	10.03	0.33	0.35	0.51	0.28	-33
	6.46	9.79	7.92	9.91	0.33	0.33	0.37	0.27	-19
	6.64	9.97	7.79	10.25	0.33	0.32	0.35	0.27	-6
	6.16	9.22	8.00	10.07	0.35	0.34	0.37	0.29	58
Mean TOA difference (%)	**6.76**	**9.52**	**7.84**	**10.10**	**0.40**	**0.40**	**0.47**	**0.36**	
standard deviation (%)	**0.52**	**0.36**	**0.12**	**0.15**					
Combined expanded uncertainty of TOA Lunar irradiance of PFR (k=2, %)	**1.60**	**1.41**	**1.27**	**1.25**					

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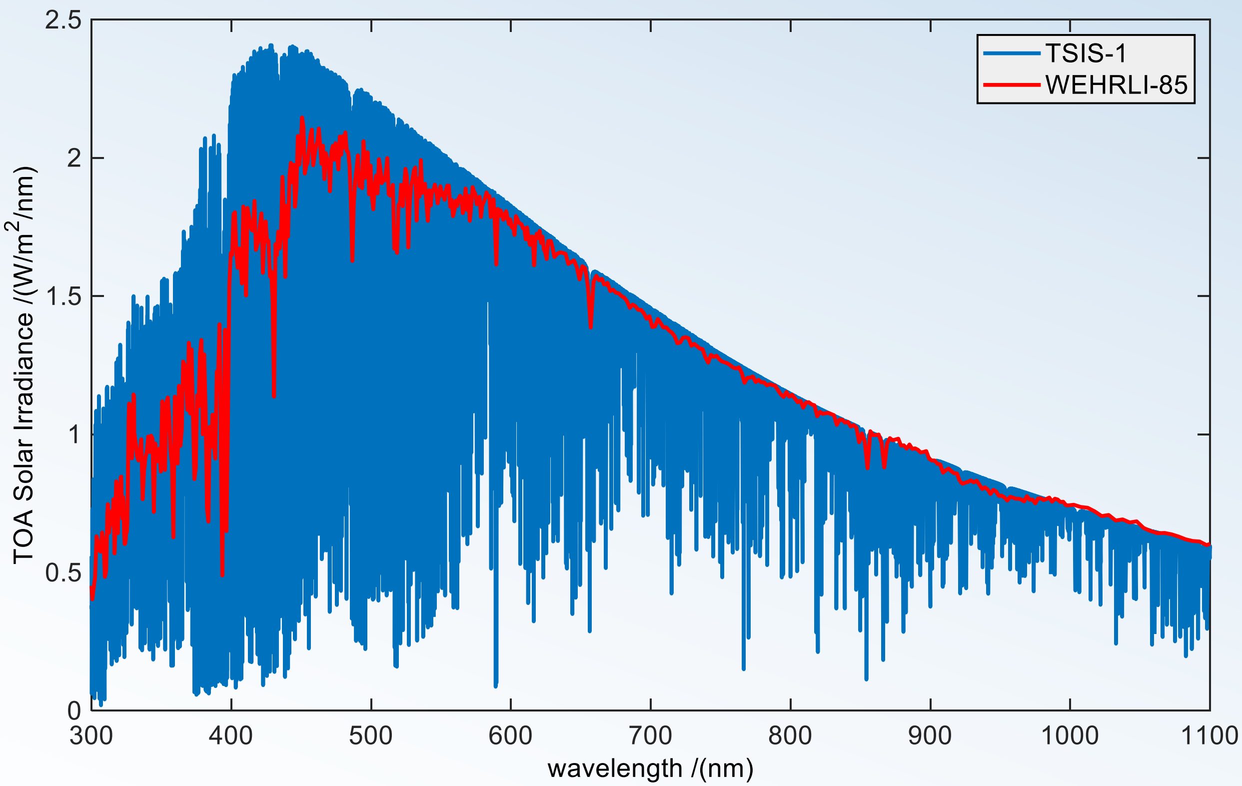
Top-Of-Atmosphere Lunar Irradiance

Mean TOA difference (%)	**6.76**	**9.52**	**7.84**	**10.10**
Difference WEHRLI -TSIS-1 (%)	**1.52**	**-2.17**	**-2.24**	**-0.24**



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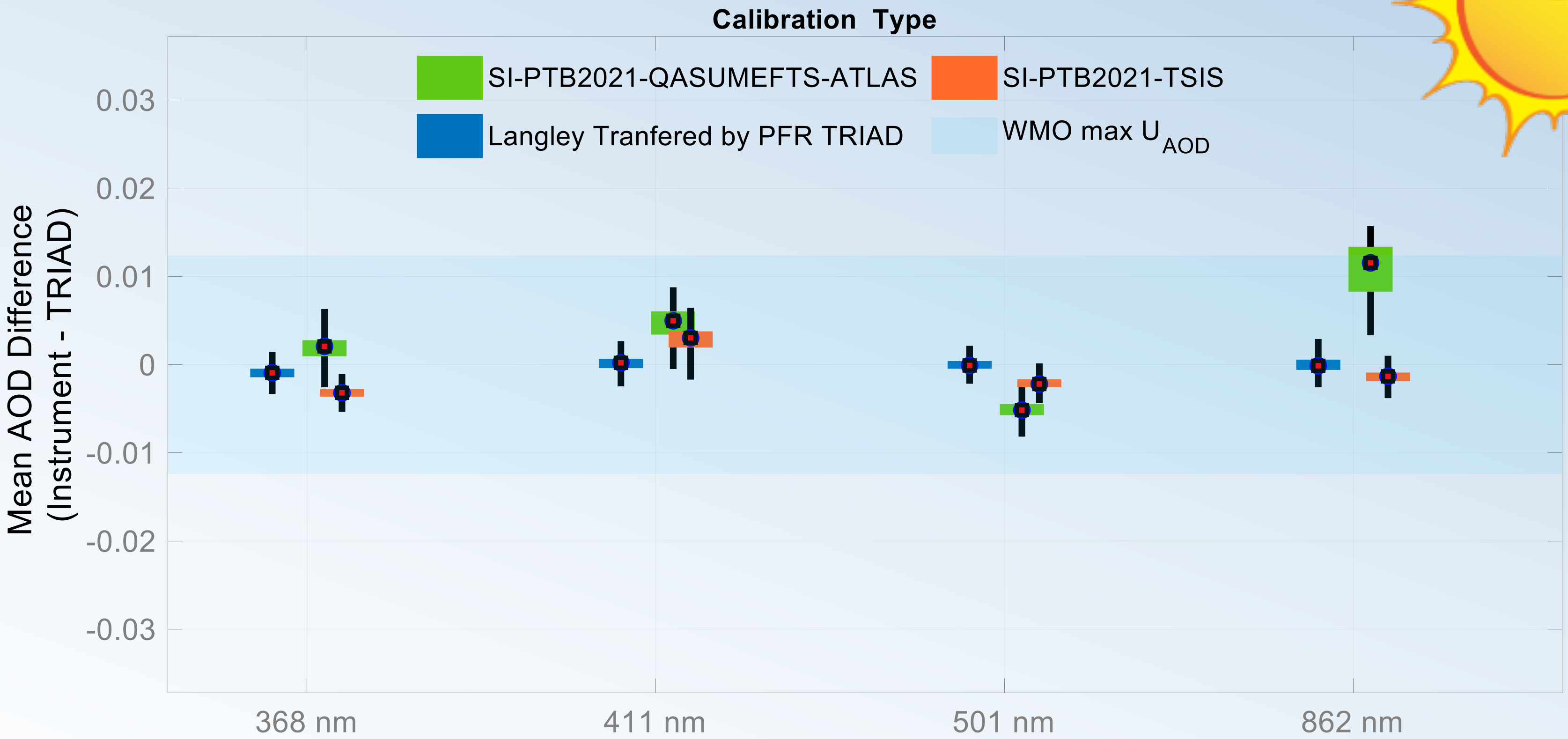
SI- Traceable AOD retrieval for Sun- PFR



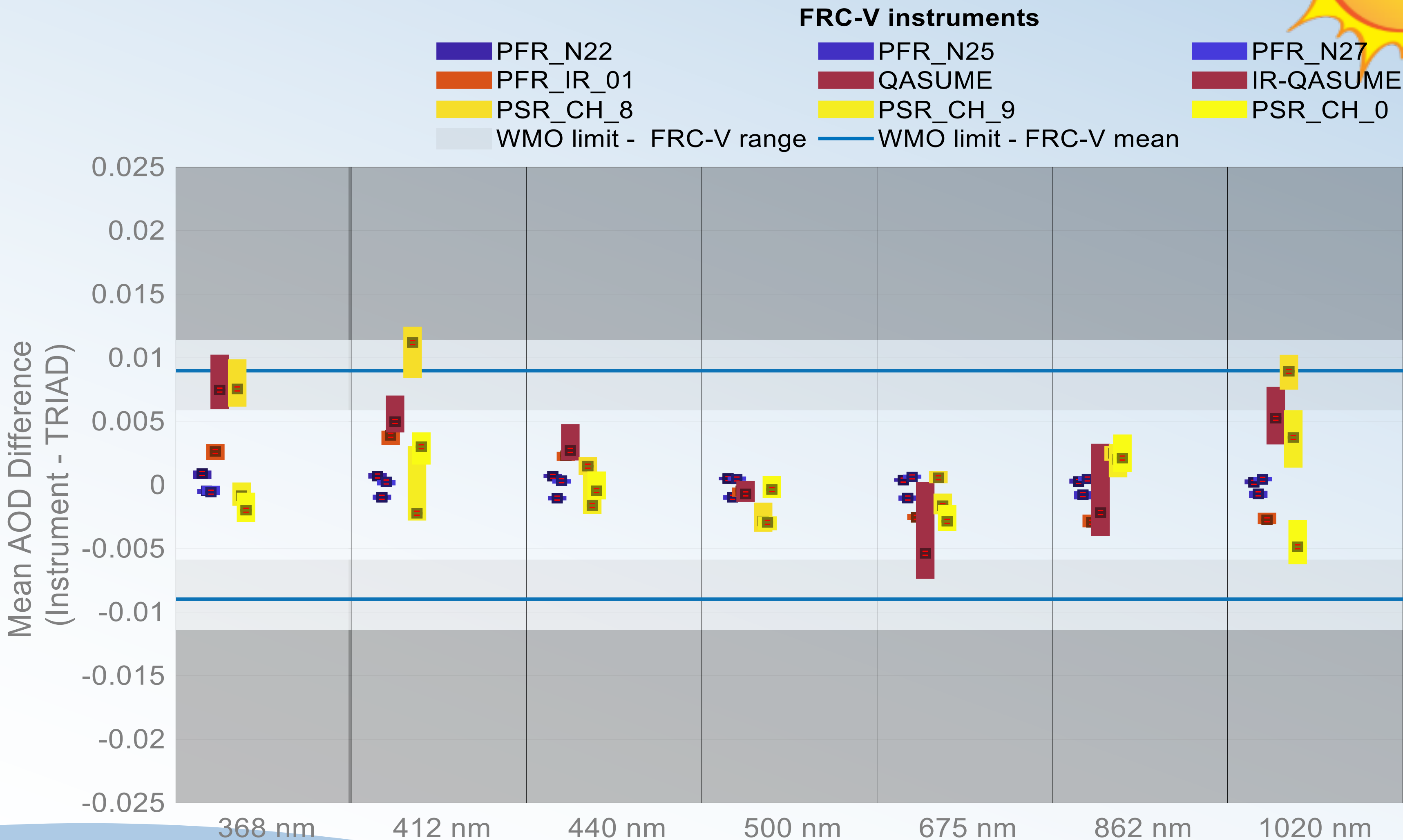
Achieved:

- ✓ **Calibrations with U< 0.5%**
- ✓ **ToA consistent with calibration <1%**

⇨ Δ_{AOD} ~ 0.005 ±0.005

Kouremeti N., Nevas S., Kazadzis S., Gröbner J., Schneider P. and Schwind K.,
"SI-traceable solar irradiance measurements for aerosol optical depth retrieval" 2012, Metrologia (submitted)

Comparison Campaign against the WMO AOD reference – FRC-V(Davos,2021)



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SI-Traceable System Development (WP-2220)

- Lunar PFR characterized and can provide lunar irradiance with an expanded relative uncertainty U< 0.5%

- The SI-traceable AOD retrievals for the characterized Sun-PFR and TSIS-1, QASUME-FTS TOA solar spectra provides AOD equivalent to the standard Langley calibration.

- The lunar irradiance phase variation from ROLO/RIMO seems be predicted well with an uncertainty of less 1% (k=2) (within the lunar ± 50º phase).

- It is essential to use lunar reflectivity to use state-of –the-art solar spectra (TSIS-1)

Next steps …

- Analyze Davos data
- Increase our reference data set.
- Development of a second Lunar-PFR to expand the information to 45
- Organize field campaigns for solar and lunar measurements

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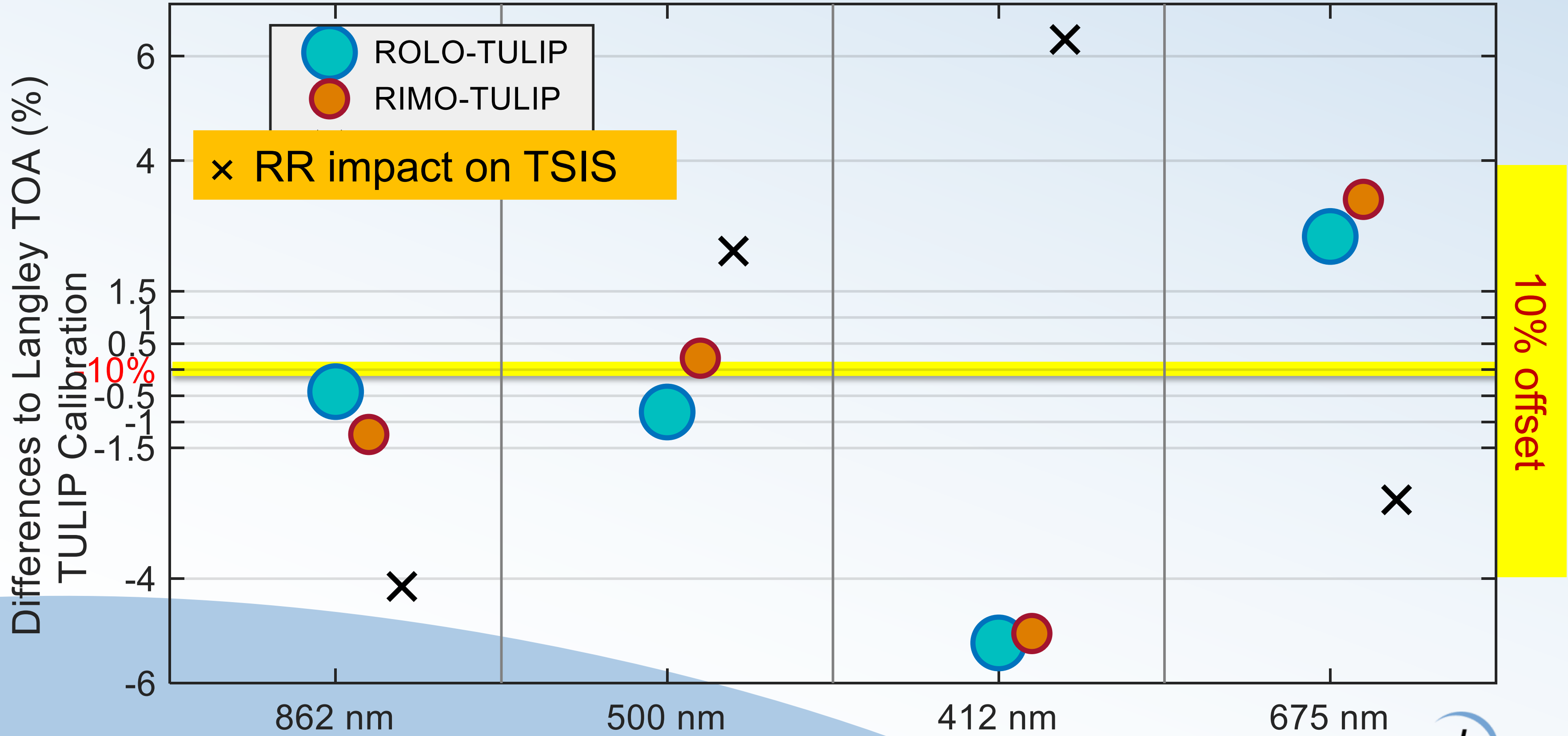
Top-Of-Atmosphere Lunar Irradiance

- The lunar irradiance seems to be underestimated by 10%
  - ROLO - old relative responsivity of PFR (Tom Stone)
  - RIMO – resolution 1 nm, generic relative responsivity
- Differences on the convolved solar spectrum due to responsivity: ~10%



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SI-traceable system development (WP-2220)
Lunar Irradiance measurements with a PFR

- Spectral responsivity calibration of Solar/Lunar Precision Filter Radiometer and Precision Solar Spectroradiometer traceable to the SI.
- Measurements of solar & Lunar spectral irradiances with PFR and spectral solar irradiance with PSR at PMOD/WRC and retrieval of spectral AOD.
- Field campaign at pristine measurement site for validation of solar & Lunar spectral irradiance measurements from Solar/Lunar PFR. Location will be selected during the first half of the project.

Outputs:

- D.2.2.2-1 Report on the laboratory calibration of PFR and PSR.
- D.2.2.2-2 Dataset of solar & lunar spectral irradiance and AOD from Precision filter radiometer and PSR during the phase 2 period of the project.
- D.2.2.2-3 Dataset of spectral solar/lunar irradiance from field campaign with solar/lunar Precision Filter Radiometer.
- D.2.2.2-4 Report on the field campaign for the validation of solar & lunar spectral irradiance measurements with the Solar/Lunar PFR.

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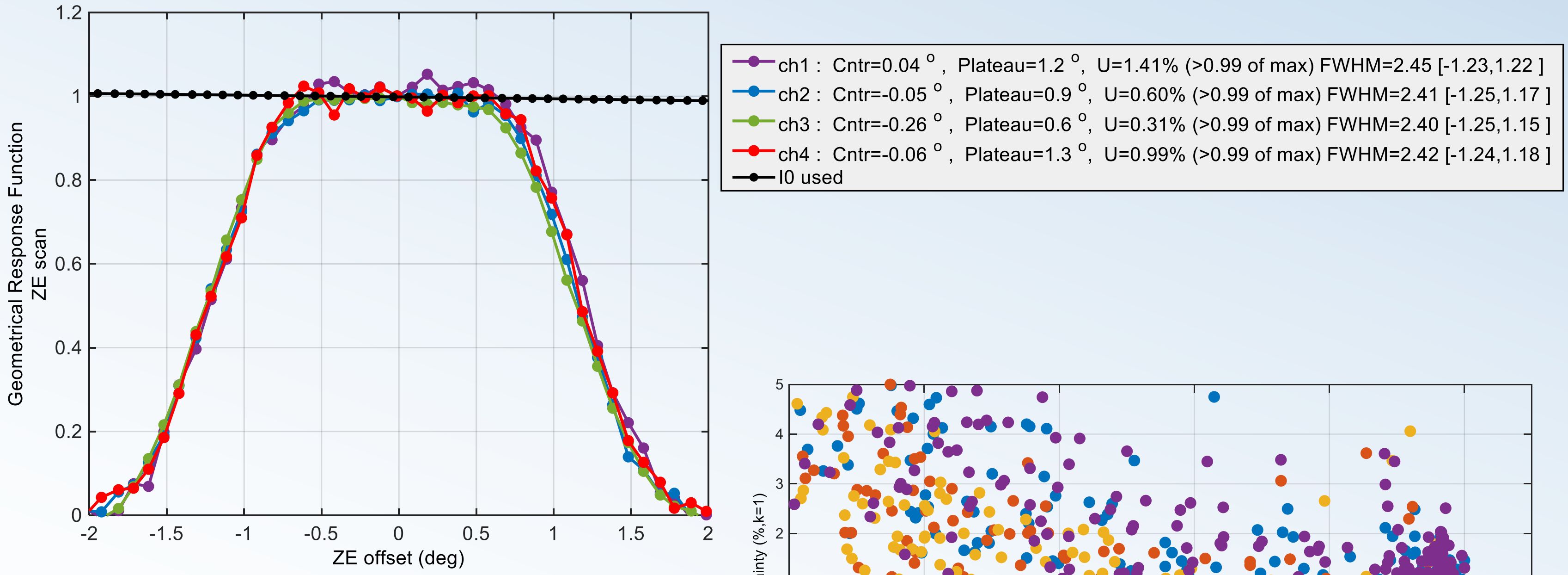
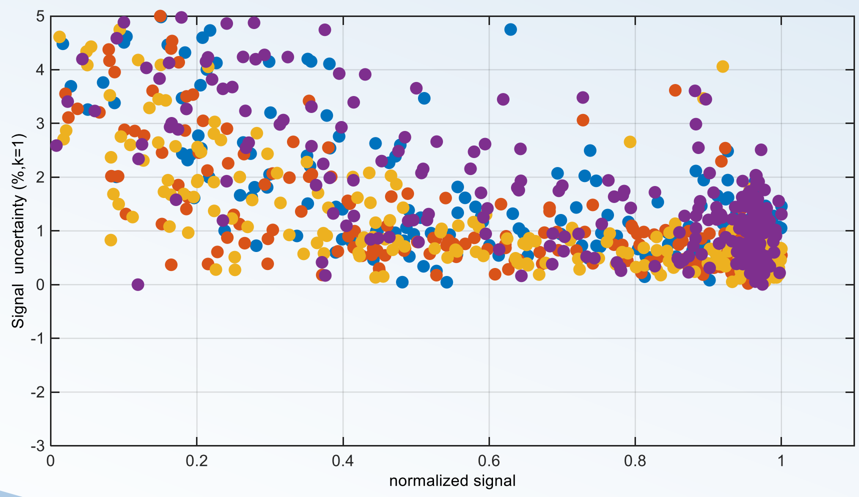
WP1 Task 1.3: Field of view properties

A1.3.3: FOV measurements using the MOON

Lunar – PFR-L-109





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Precision Filter Radiometers description

- **Filter radiometer with 4 channels in a grid**

Interference filters :

Sun version: 368 nm, 412 nm , 500 nm, 862 nm

Lunar version: 675 nm, 412 nm , 500 nm, 862 nm

FWHM: ~5 nm

Optimized for Irradiance Measurements

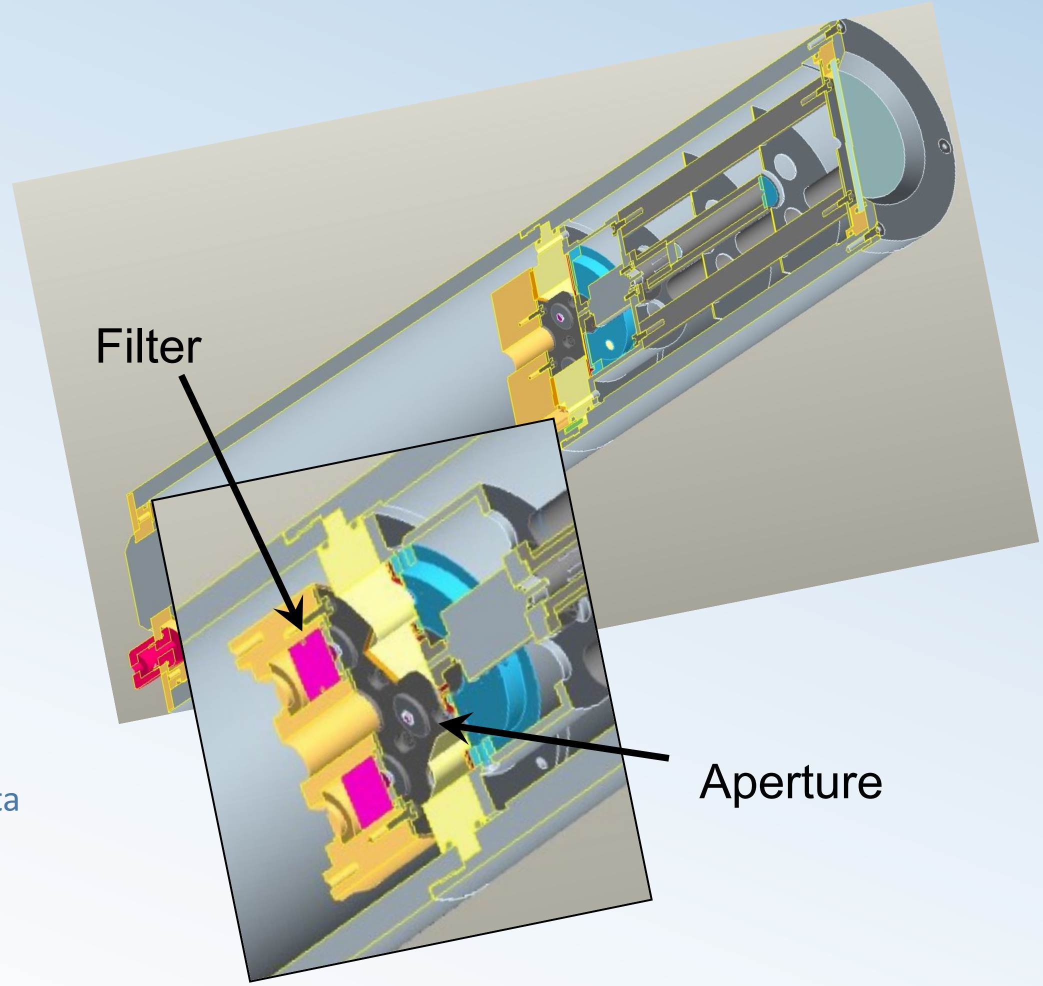
- **Temperature stabilized photodiodes**

- **Reference Plane: the precision aperture**

- **FOV : 1.2° plateau** , 0.7° slope angle, homogeneity in plateau > 99.5%

- The PFR signal (V) is provided by a 22-bit data acquisition system (SACRAM) specifically designed for the PFR.

- SACRAM Linearity checked against a reference source calibrated at Metas



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