pmod wrc

Traceability of Lunar direct irradiance measured with a Precision FilterRadiometer

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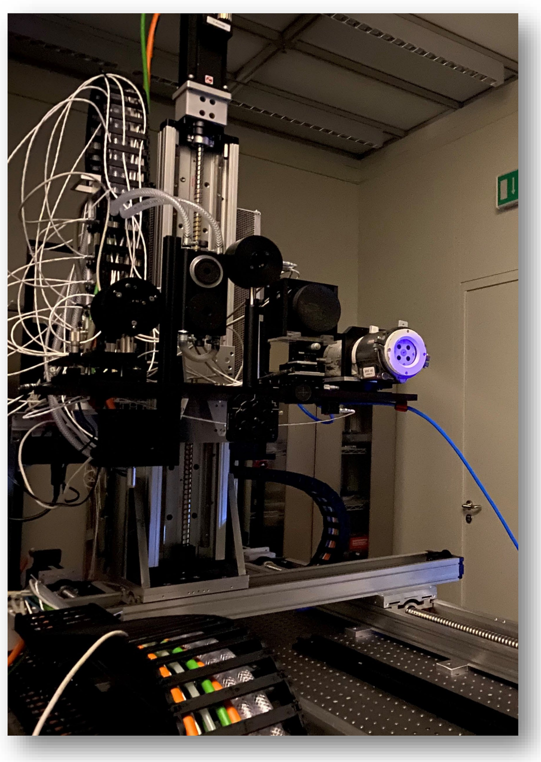
Introduction

The growing interest of nighttime observation of AOD led to the development of the Lunar Precision Filter Radiometer at PMOD/WRC. The instrument has been characterized and calibrated at the facilities of PMOD/WRC in frequent time intervals since 2015. The calibration was done using an OPO-based ns-pulsed tunable laser and an irradiance standard traceable to Physikalisch-Technische Bundesanstalt (PTB) with relative standard uncertainties in the order of 4% to 6%. In November 2021 and August 2024, the characterization and calibration was repeated at the of state-of-the-art calibration facilities of PTB, following identical procedure to the Sun Precision FilterRadiometer (Kouremeti et. al., 2022), reducing the uncertainties by a factor of 5 to less than 1%. We present the calibration procedure at PTB and the comparison results to ROLO, RIMO and LIME Top-of-Atmosphere (ToA) lunar irradiance models based on the dataset acquired at the Izaña Observatory (28.3° N, 16.5° W, 2.4 km) shortly after the calibration at PTB. Test results of lunar spectral irradiance measurements with the QASUME spectroradiometer (Gröbner et al., 2017) and comparison to ROLO are presented as well.

Lunar-PFR (PFR-L-002)

The Lunar Precision FilterRadiometer (PFR-L02) is a standard PFR instrument with enhanced sensitivity, that has been developed at PMOD/WRC based on experience on Sun- PFRs.
Measures at four wavelengths (412, 500, 675 and 862 nm), while the sensors are temperature-stabilized at 20°C.
The PFR uses a data acquisition system 22bit, with linearity better than 0.01%

Calibration at PTB 2021

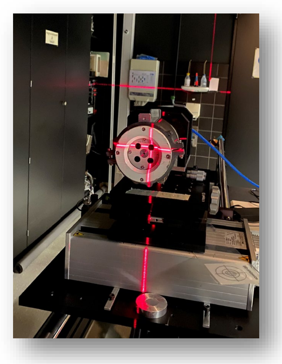


TUnable Lasers In Photometry (TULIP) setup
- fully automated system
- based on a quasi-cw ps-OPO system
- homogeneous irradiance field
- reference detector: 3-element trap detector equipped with a calibrated aperture, uncertainty less than 0.1 %
- wavelength scale measured with a laser spectrum analyser

Characterization & Calibration
- spectral irradiance responsivity (*s*)
- reference plane
- PFR gains

The gain settings of the PFR-L have been increasing the uncertainty of the responsivity due to the 3 orders of magnitude difference between gains 0 and 1. The gains were determined at the TULIP setup in 2021 and 2024 for all channels.

Comparison of Calibration Methods : Lamp Irradiance Standard vs Laser based



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

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

Gain uncertainty 0.3%

Gain	TULIP 2021 U=0.3%	TULIP 2024 U=0.3%	ATLAS 2019 U=1.5%
Laboratory: 0	1.0	0.00	0.0
1	934.6	0.04	-0.2
2	4451.4	0.04	-0.2
Lunar: 3	25164.0	-0.03	0.1

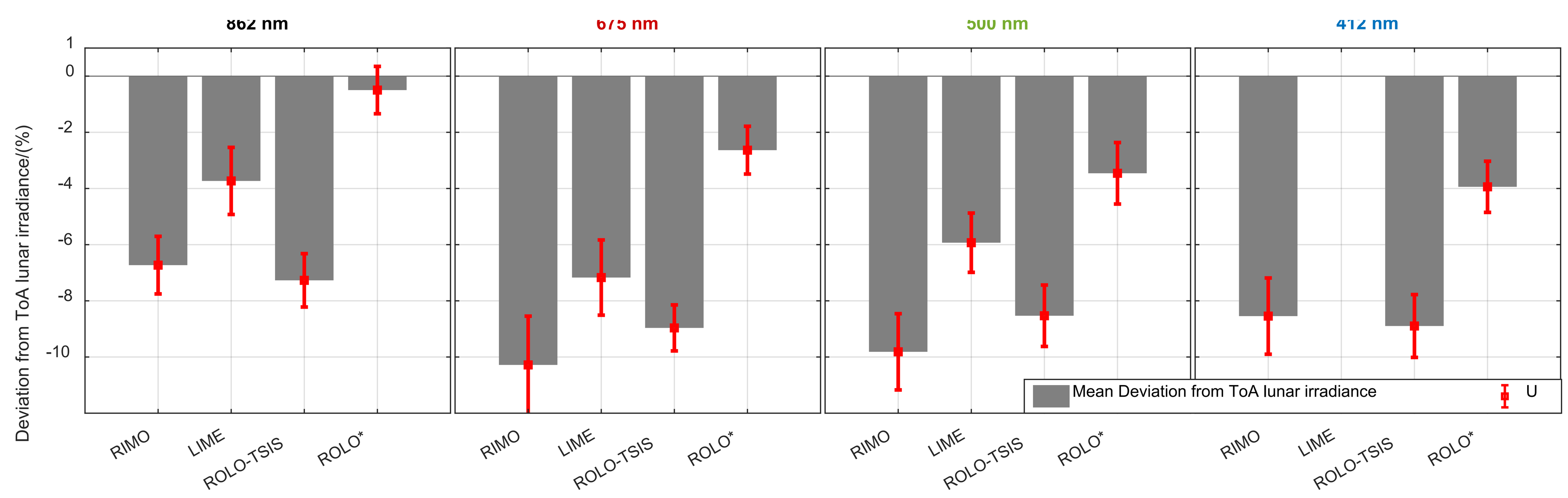
Spectral responsivity uncertainty 0.3%

TULIP - 2021		
λ (nm)	*s* (V/m²)	U (%,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

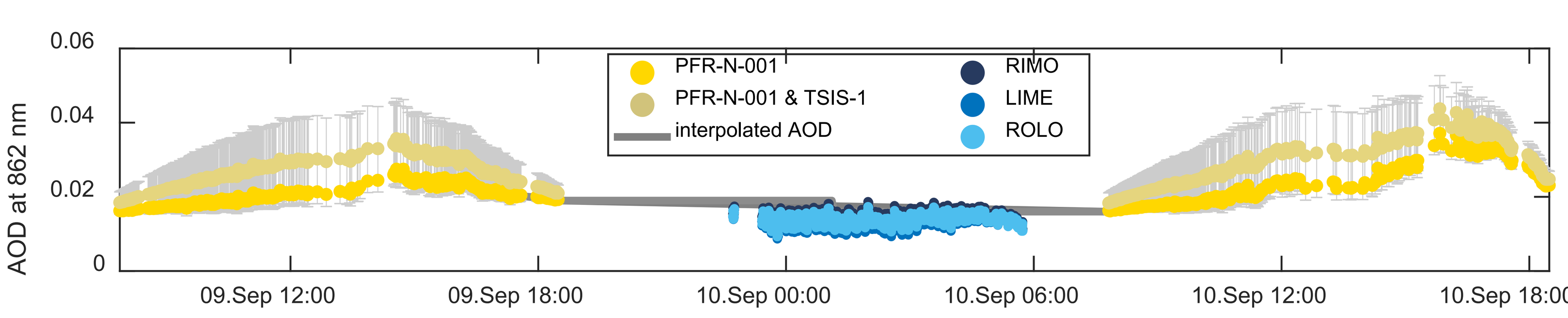
Top-of-Atmosphere Lunar Irradiance Comparison

A campaign was organized within a few months of the calibration at Izaña observatory during one lunar cycle,
- 7 nights were favorable for the retrieval of the top-of-atmosphere lunar irradiance.
- For the Langley extrapolation the lunar irradiance change was accounted using the following lunar irradiance models:

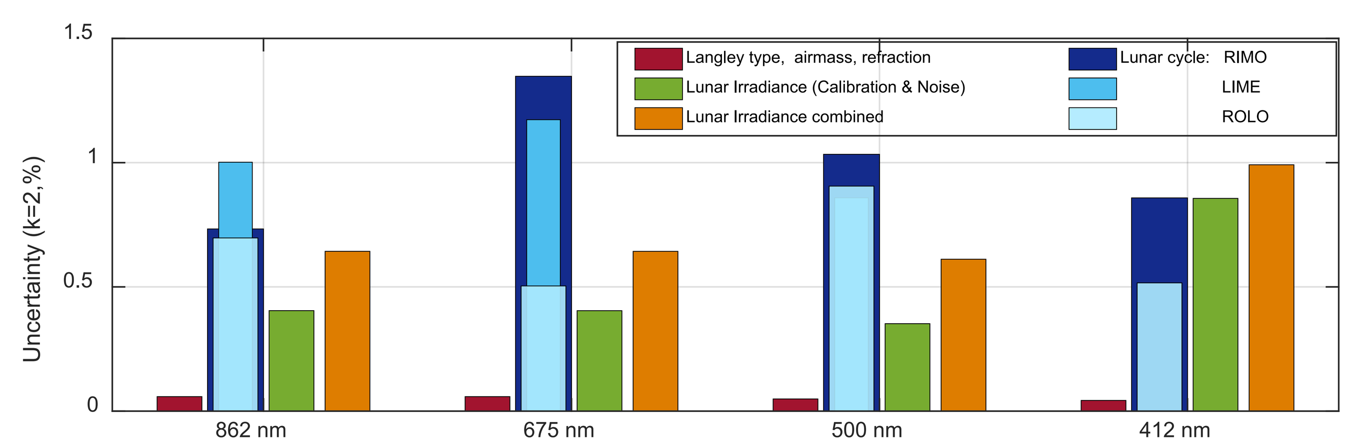
- RIMO (Barreto et al. , 2018) available online - spectral resolution 1 nm
- ROLO – accounting for the spectral responsivity of the PFR
  1. ROLO – TSIS-1 adjustment
  2. ROLO* TSIS-1 and air-LUSI adjustment (August 2023; Woodward et al. 2022)
- LIME (Toledano, C., et al., 2023)



Comparison of the PFR-L Top-of-Atmosphere lunar irradiance to the to lunar irradiance models. The errorbars indicate the combined expanded uncertainty of the the PFR-L retrieval over the lunar cycle.



Example of nighttime AOD retrieval based on the Langley of the night and for the 3 models. Daytime AOD based on Langley(yellow) and SI (dark yellow) retrievals.



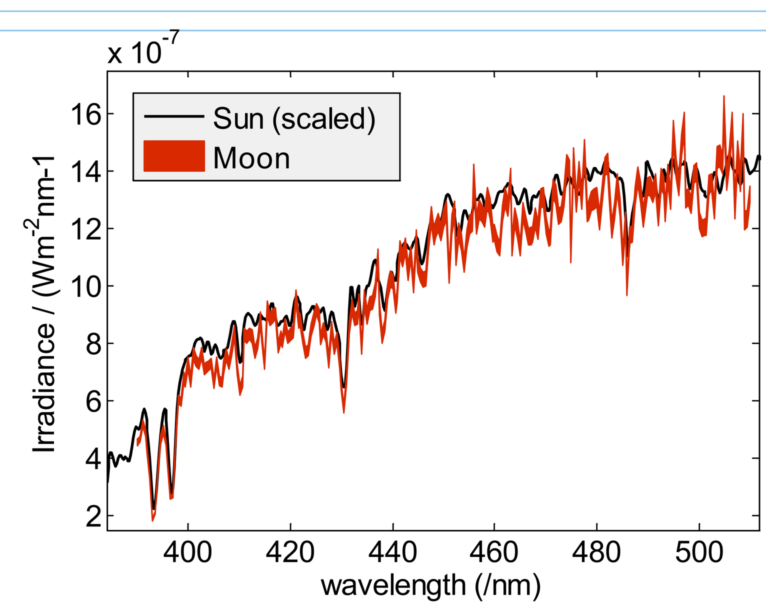
Uncertainty components of the ToA retrievals and comparison to the lunar irradiance models for the 7 days with lunar phases ranging from 6° to 58°.

Spectral Lunar Irradiance measurements QASUME

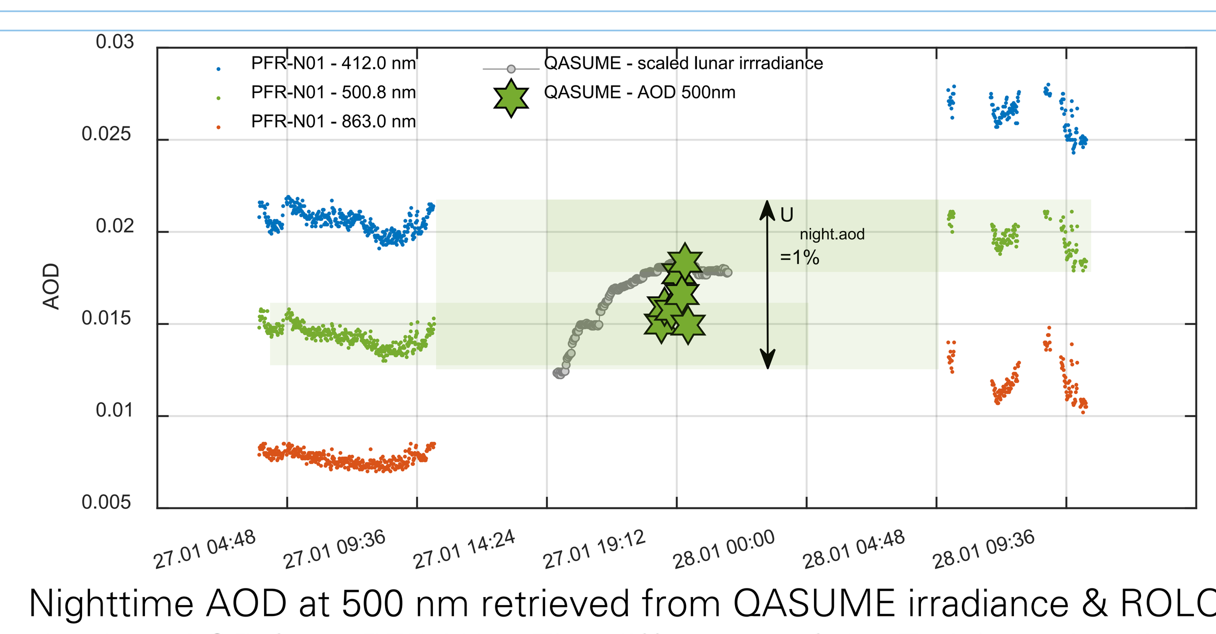
An independent SI-traceable validation dataset of lunar irradiance measurements has been acquired at Davos using the QASUME spectroradiometer, with an expanded relative uncertainty of 2% for the measured irradiance levels.

A Langley extrapolation for mean irradiance over the spectral region 490 nm to 510 nm was validated against the day-time AOD and compared to the ROLO model.

The agreement of this preliminary dataset to the Lunar-PFR results are within the uncertainty of the QASUME spectroradiometer.



Lunar and Solar (scaled) irradiance spectrum measured by QASUME - lunar phase angle 45°



Nighttime AOD at 500 nm retrieved from QASUME irradiance & ROLO, daytime AOD from PFR-N01. The difference of the ToA lunar irradiance to ROLO agrees with one from PFR-L within 1%.

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Conclusions

- ❑ The responsivity of the Lunar-PFR has been determined with an expanded combined uncertainty of 0.5%.
- ❑ The irradiance offsets of the lunar models are higher than the 1% requirements for SI AOD retrievals
- ❑ The ROLO model accounting for the PFR spectral responsivity has the minimum variability over the measured lunar cycle
- ❑ High consistency between PFR-L and Air-LUSI irradiance levels especially at 862 nm.
- ❑ High consistency between PFR-L and QASUME irradiance levels at 500 nm.