Measurements for LIME: Lunar Irradiance Model of ESA

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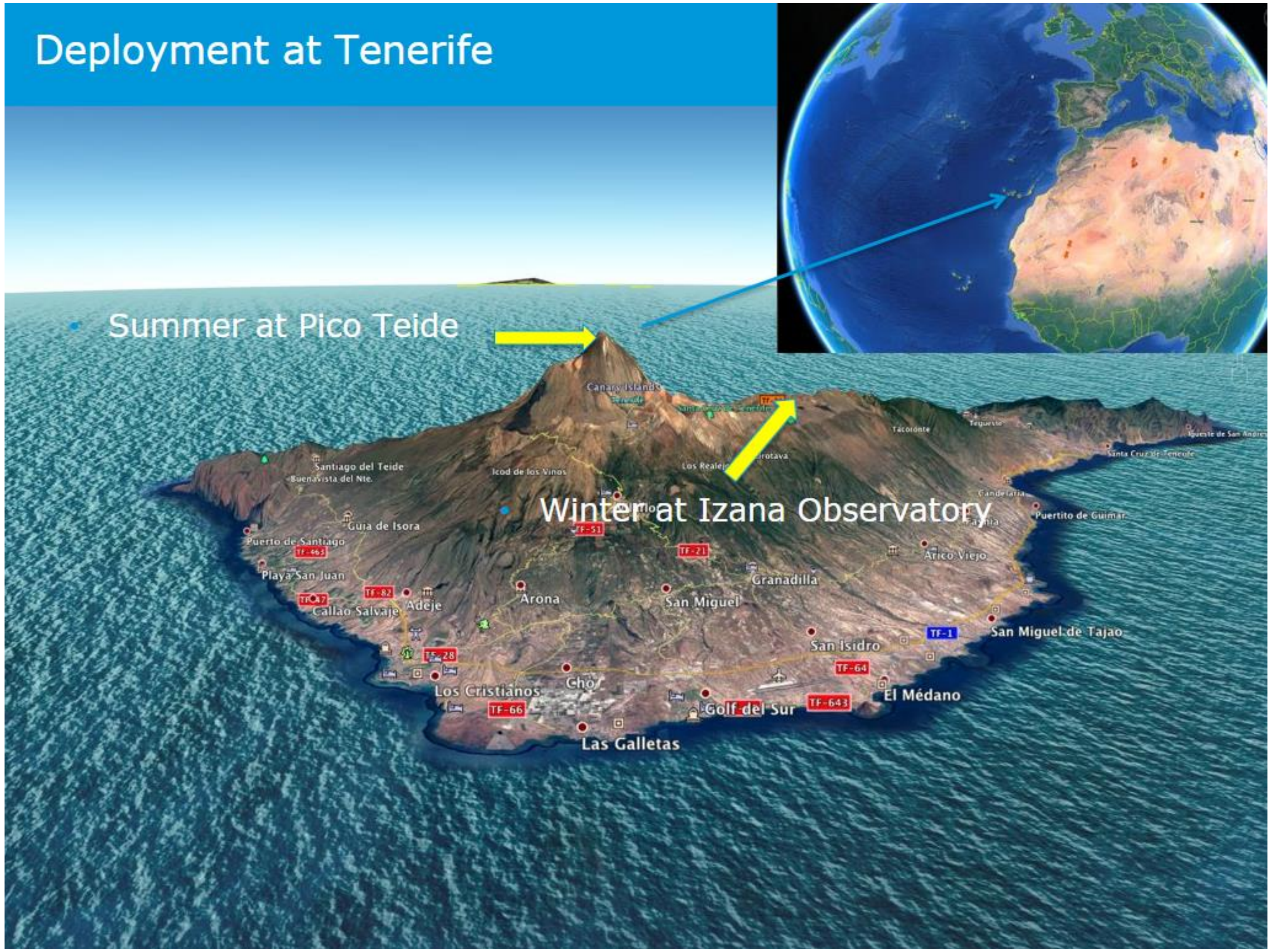
Overview

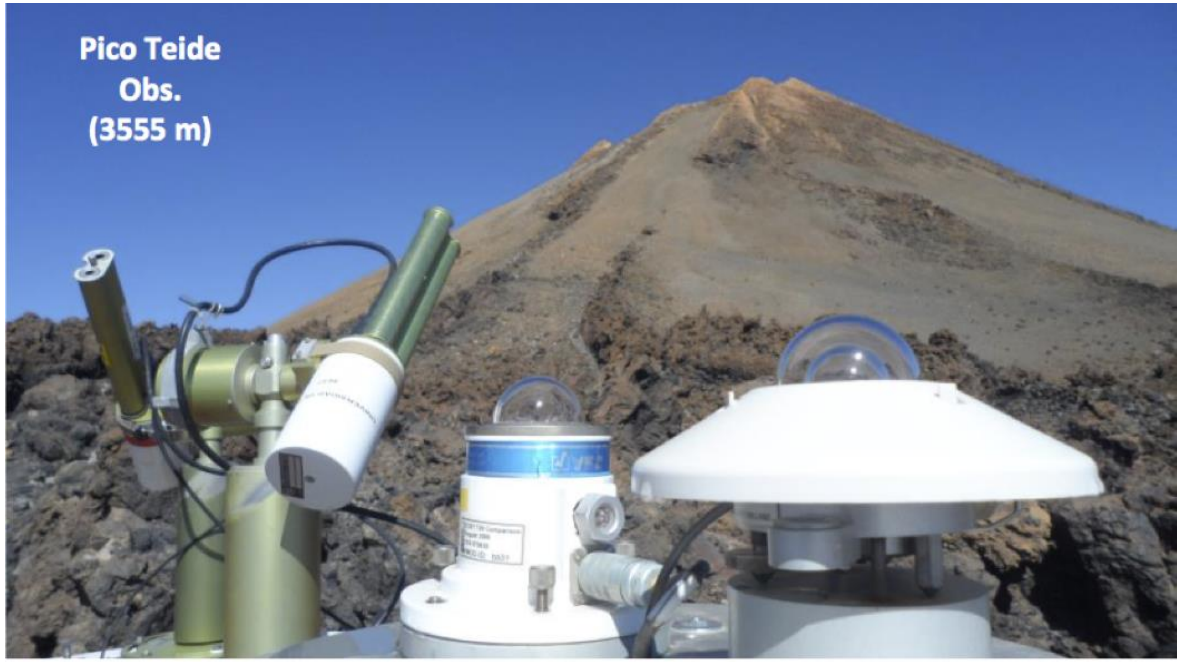
- The LIME model input measurements in situ
  - Site
  - Instrument
  - Laboratory measurements
- Hyperspectral measurements
  - Site
  - Instrument
  - Laboratory measurements

The LIME model

- LIME is based upon ROLO model
- Derived using SI-traceable ground-based measurements acquired with CIMEL 318-TP9 photometer from high altitude location at Teide Peak and Izaña Atmospheric Observatory in Tenerife
- Characterization and calibration at NPL and University of Valladolid
- Uncertainty computation based on Monte Carlo simulations accounting for calibration, modelling and measurement uncertainties

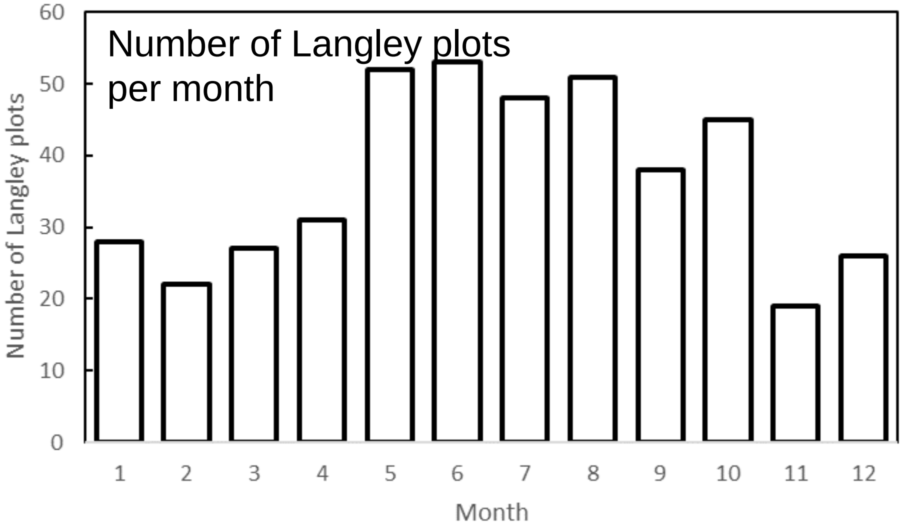


The Site



	tau_{a500}	sigma
JAN	•••	•••
FEB	•••	•••
MAR	•••	•••
APR	•••	•••
MAY	0.020	0.009
JUN	0.042	0.085
JUL	0.091	0.160
AUG	0.078	0.082
SEP	0.018	0.021
OCT	0.010	0.005
NOV	0.009	0.004
DEC	0.007	0.000

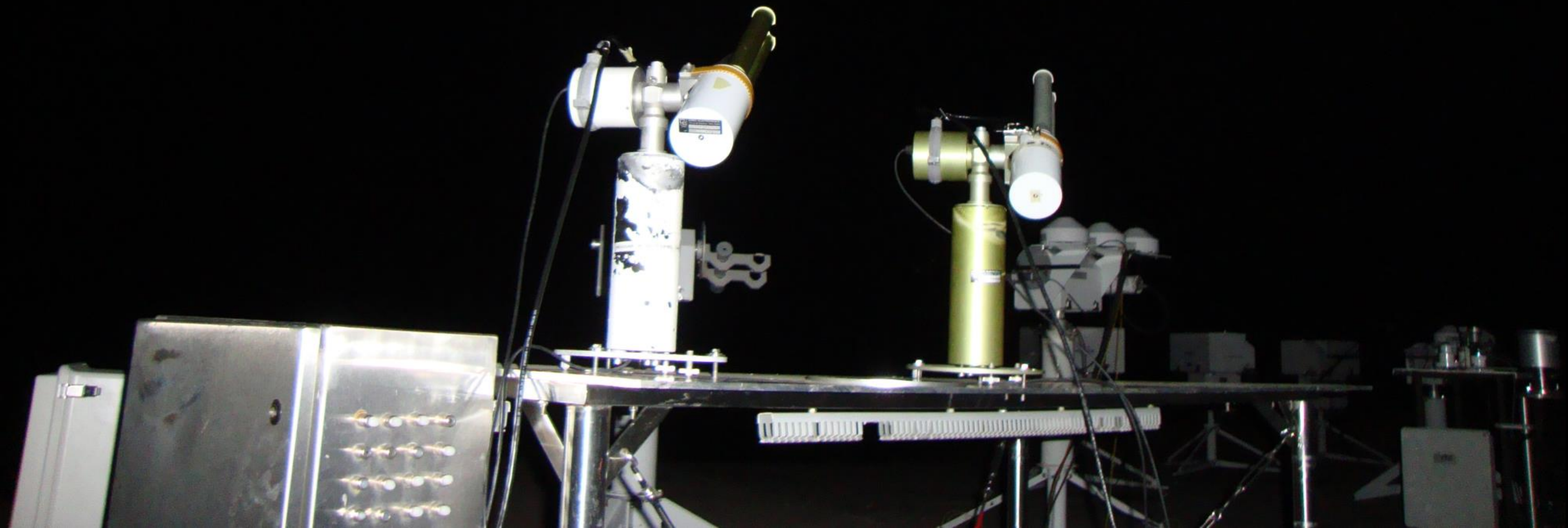
Barreto et al., 2022



450 Langley plots in 5 years!

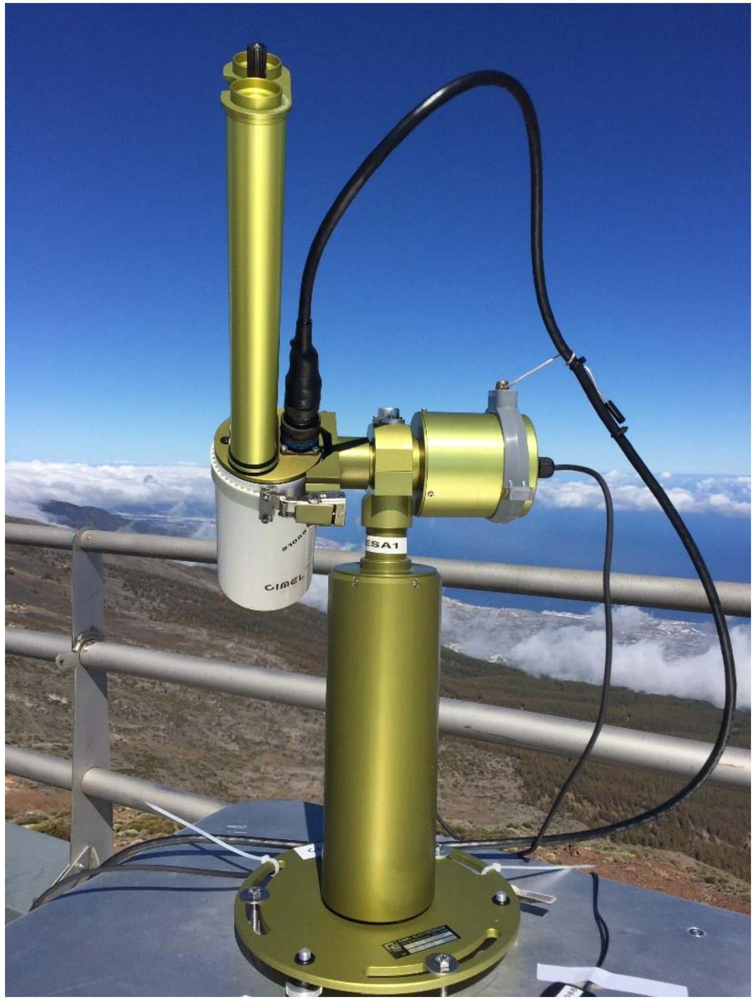
Measurement principle

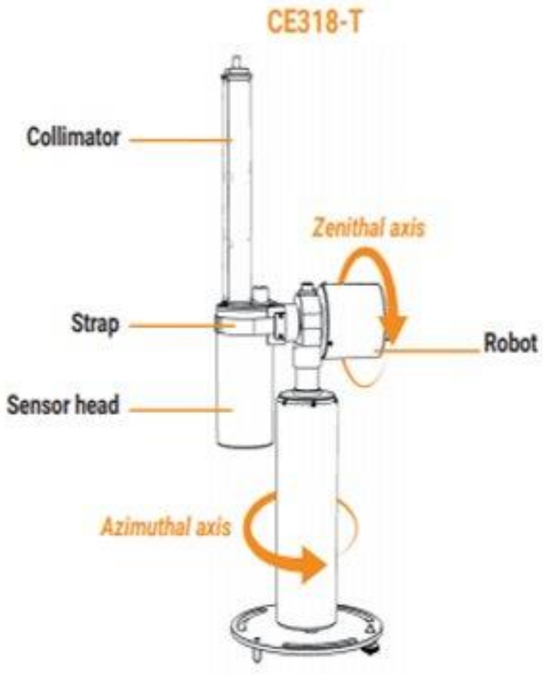
- Lunar Langley plots for AOD and TOA lunar irradiance measurements
- Sun Langley plots used for radiometric calibration stability monitoring



The instrument

CIMEL 318-TP9

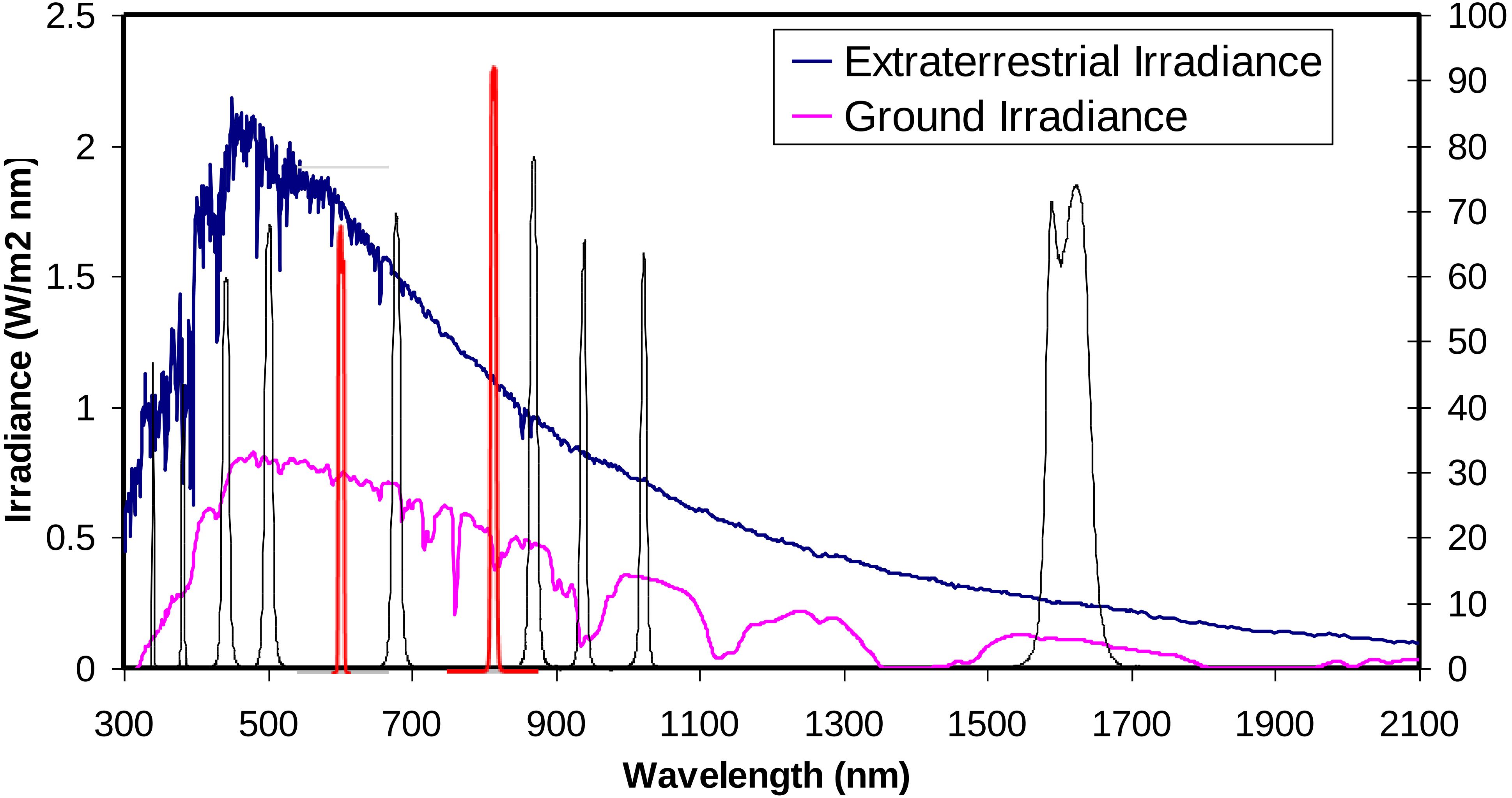


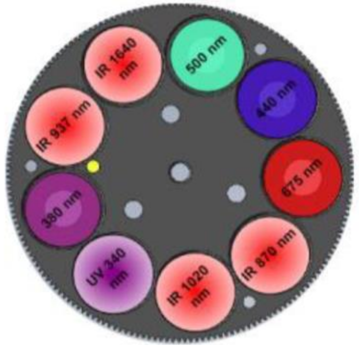


Specification	value
Irradiance precision	< 0.1%
Field of view	1.3°
Minimal scaterring angle from the sun	2°
Spectral range	340 to 1640 nm
Optical filter drift	< 1% / year
Automated mount	Azimuth and zenith motors
Sky angular scanning	Whole sky : Azimuth: 0 – 360° Zenith: 0 – 180°
Mechanical precision spot	0.003°
Solar tracking precision	0.01°
Power consumption	< 2W
Interferential filter bandwidth	< 30 nm
Total weight without support	25 kg
Power supply	Autonomous through solar panel
Mode	Sun, Sky, Lunar
memory	32 GB on SD card
Solar and moon scanning	4 quadrant sensor
Temperature	-30 to 70° C
humidity	0 to 100 %
RS232 (up to 100 m cable)	9600 baud/s
Numeric count dynamic	0 to 2 097 152

Proposed wavelengths

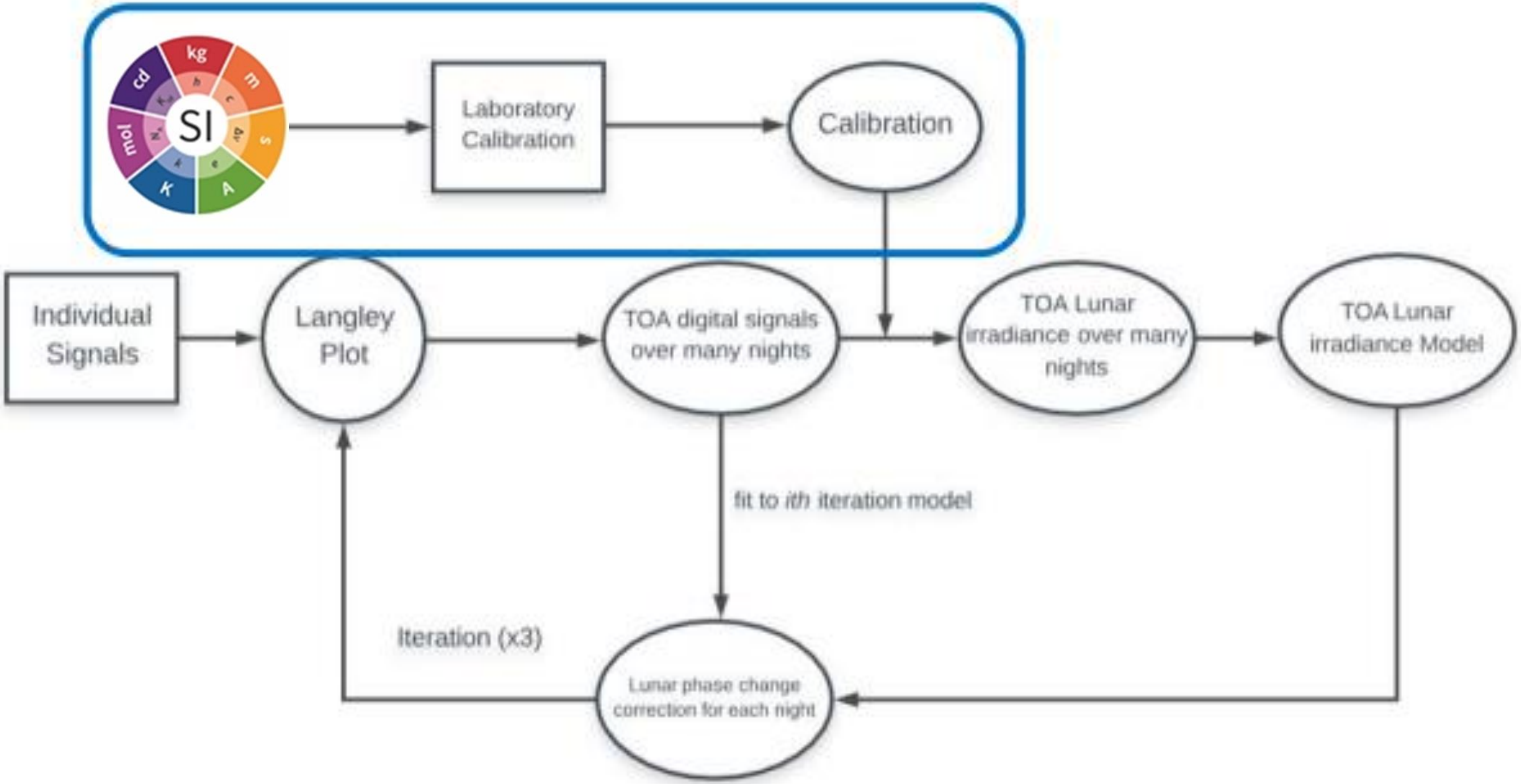
- New filters: 550 and 780nm





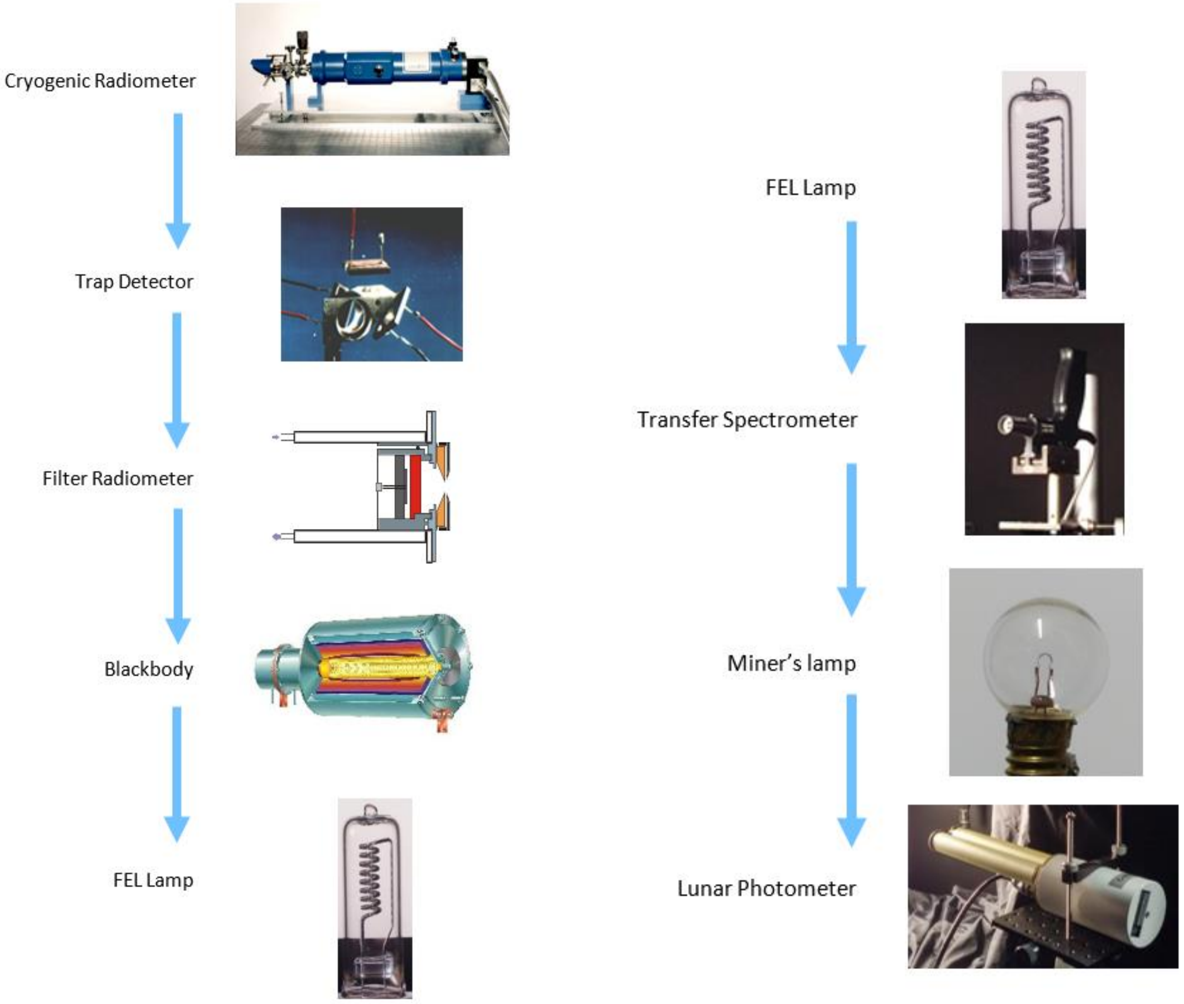
Si
~~340~~
~~380~~
440
500
550
675
780
870
936
1020
1640
InGaAs

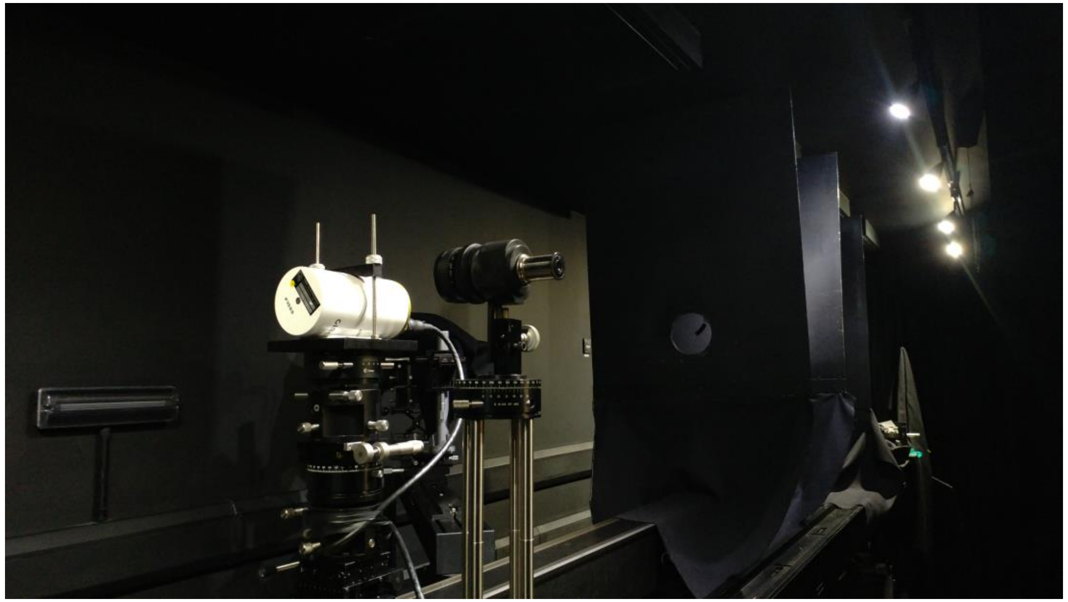
SI traceability



Irradiance Responsivity

Spectral Channel	Calibration Coefficient (MOON gain)	Standard uncertainty
440 nm Si	5.759×10^{-10}	0.97%
500 nm Si	4.481×10^{-10}	0.96%
675 nm Si	3.205×10^{-10}	0.92%
870 nm Si	2.547×10^{-10}	0.91%
937 nm Si	2.431×10^{-10}	0.97%
1020 nm Si	2.735×10^{-10}	1.05%
1020 nm InGaAs	2.119×10^{-10}	1.01%
1640 nm InGaAs	4.893×10^{-11}	1.06%



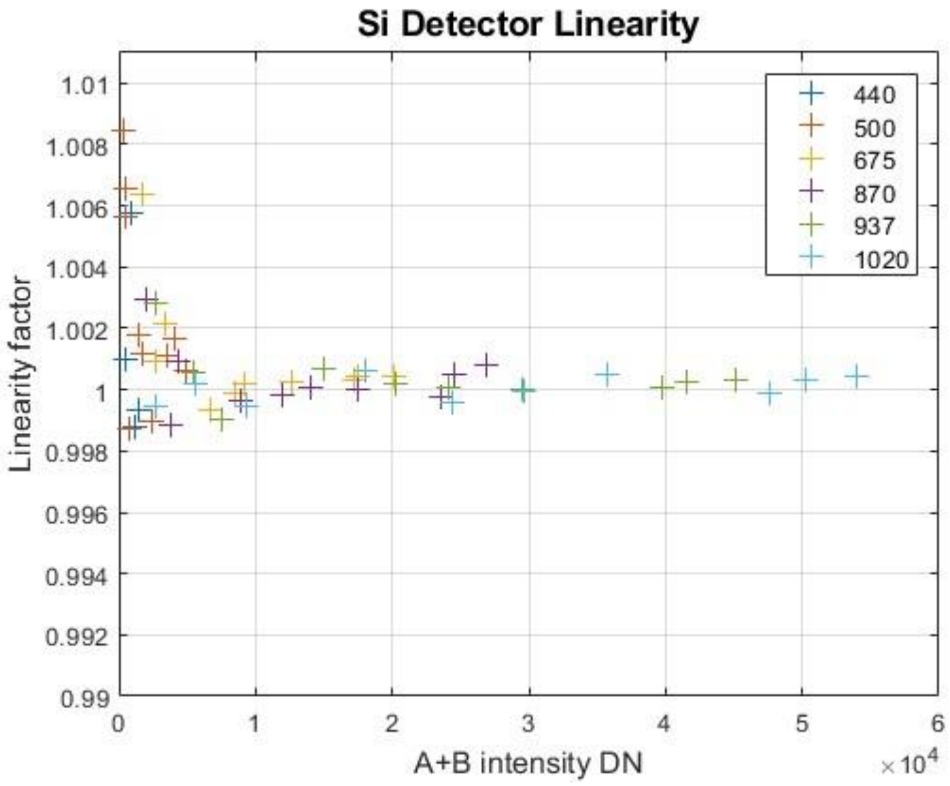


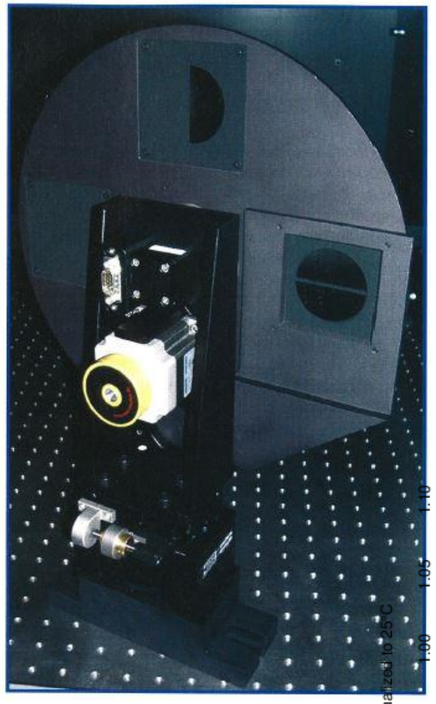
CIMEL Stability by Solar Langley Calibration

WLN	Extraterrestrial Sun counts on 23/06/2018	Extraterrestrial Sun counts 15/03/2022	Difference(%)
1020	628596.4	626432	-0.34
1640	1114638.9	1112269	-0.14
870	882649.8	880983	-0.19
675	1111487.4	1106959	-0.41
440	760622.6	756339	-0.56
500	1026944.7	1022573	-0.43
1020i	805945.7	802153	-0.47
935	827605.4	803760	-2.92
380	129951	1012197*	
340	43550.4	842014*	

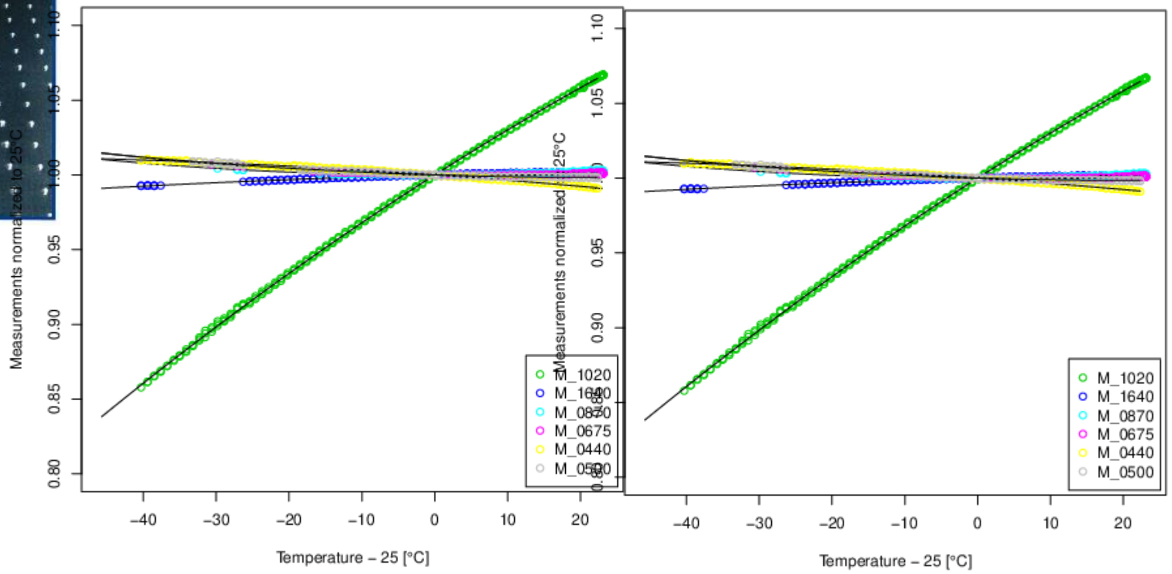
*New filters 780 and 550nm

Linearity and temperature sensitivity





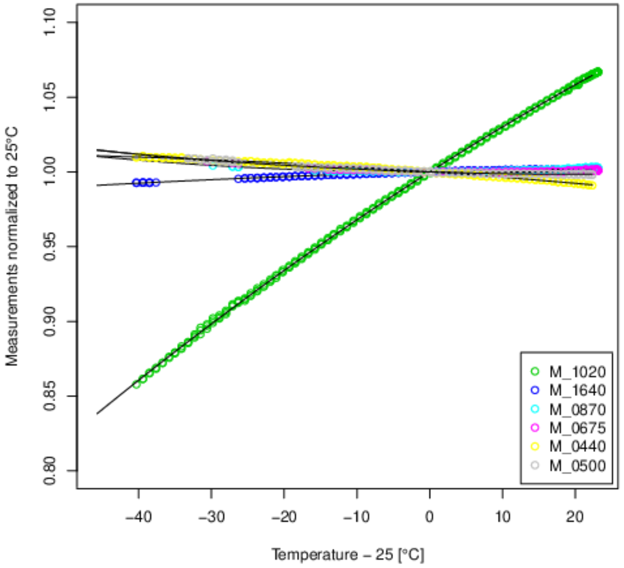
$$F_T = \left[1 + C_{1,i}(T - T_{\text{ref}}) + C_{2,i}(T - T_{\text{ref}})^2\right]$$

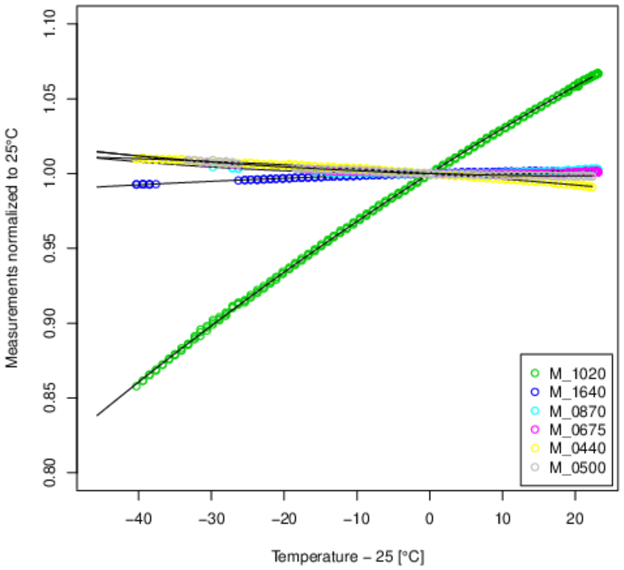


$$L(V_{\text{A+B}}) = \frac{V_{\text{A+B}}}{(V_{\text{A}} + V_{\text{B}})}$$

Temperature Sensitivity (UVa)

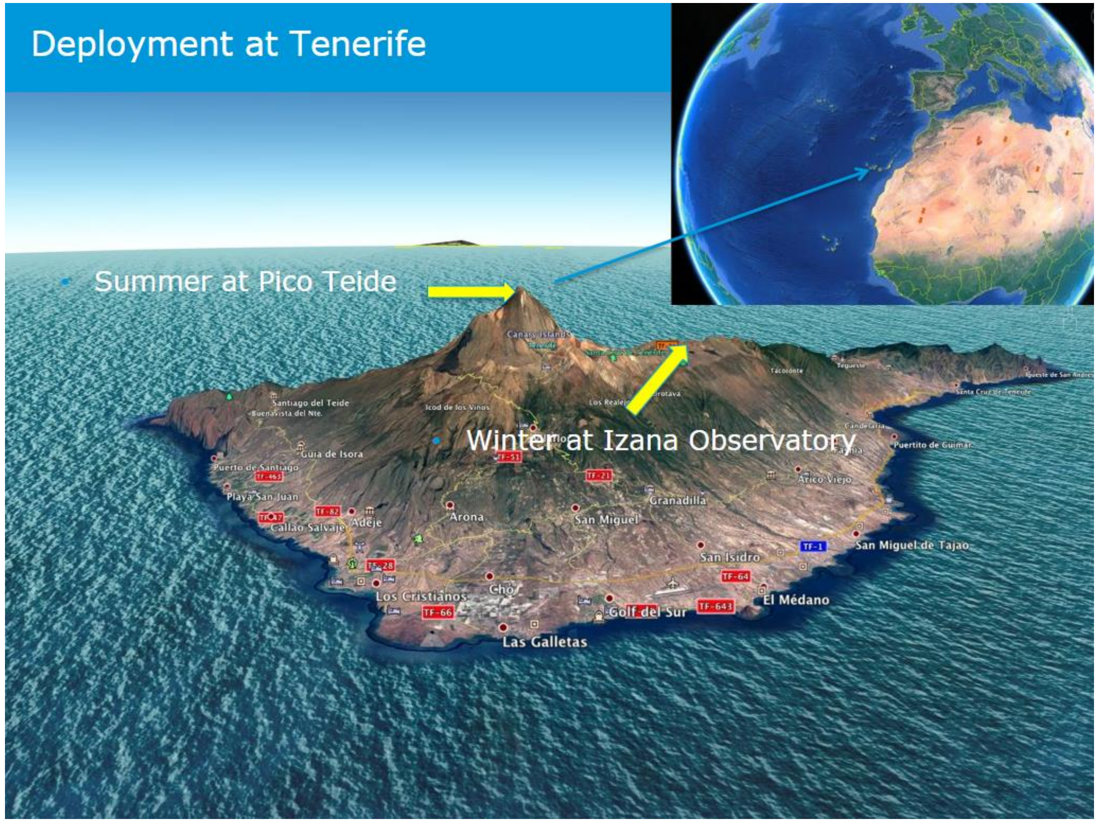
Pico Teide	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Percentile 98 [°C]	7.7	8.0	8.7	11.7	14.1	16.6	18.7	18.8	15.1	13.0	9.9	7.5
Percentile 2 [°C]	-9.5	-12.0	-8.1	-5.7	-2.7	1.8	5.0	5.0	1.9	-3.5	-5.9	-8.2





$$F_T = \left[1 + C_{1,i}(T - T_{\mathrm{ref}}) + C_{2,i}(T - T_{\mathrm{ref}})^2\right]$$

The site – Izana Observatory



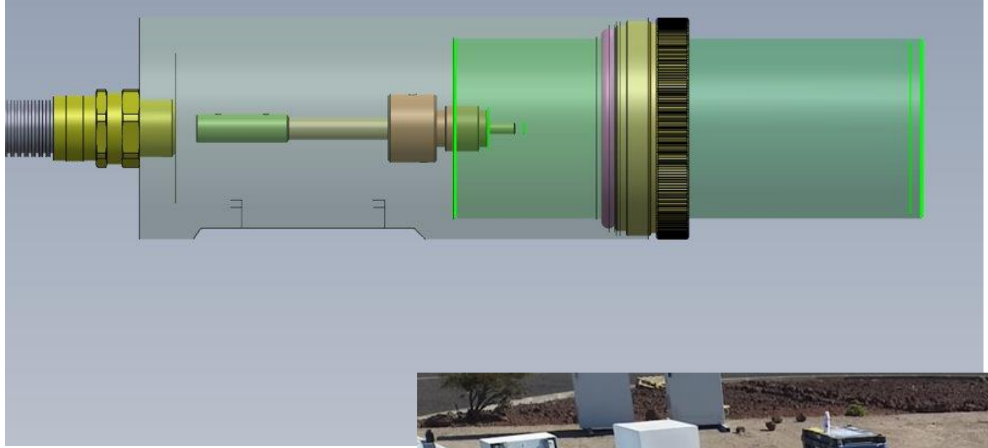
The instrument

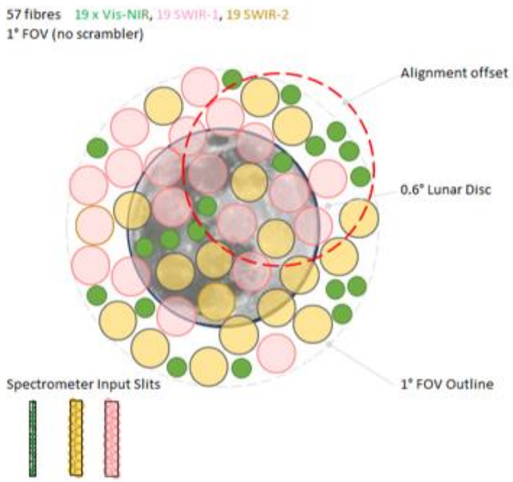
ASD FieldSpec

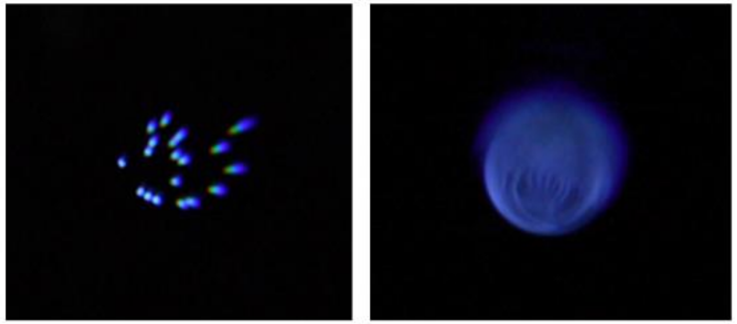
Performance Specifications	Standard-Res	Hi-Res	Hi-Res NG
Wavelength range	350 nm – 2500 nm		
Resolution VNIR @ 700 nm	3 nm		
Resolution SWIR @ 1400 & 2100 nm	10 nm	8 nm	6 nm
Spectral Sampling (Bandwidth) VNIR @ 700 nm	1.4 nm		
Spectral Sampling (Bandwidth) SWIR @ 1400 & 2100 nm	1.1 nm		
Scanning time	100 milliseconds		
NEdL (Noise Equivalent Radiance) - VNIR @ 700 nm	1.0×10^{-9} W/cm²/nm/sr		
NEdL - SWIR 1 @ 1400 nm	1.2×10^{-9} W/cm²/nm/sr	1.4×10^{-9} W/cm²/nm/sr	8.0×10^{-9} W/cm²/nm/sr
NEdL - SWIR 2 @ 2100 nm	1.9×10^{-9} W/cm²/nm/sr	2.2×10^{-9} W/cm²/nm/sr	8.0×10^{-9} W/cm²/nm/sr
Wavelength reproducibility	0.1 nm		
Wavelength accuracy	0.5 nm average error of wavelength calibration fit. Wavelength accuracy +/- 1 nm for any one line		
Maximum radiance - VNIR	2x Solar		
Maximum radiance - SWIR	10x Solar		
Data collection speed	2 spectra per second		
Channels	2151		
VNIR (350-1000 nm) detector	512 element NIR-enhanced silicon array		
SWIR 1 (1000-1800 nm) detector	Graded Index InGaAs Photodiode, 2 Stage TE Cooled		
SWIR 2 (1800-2500 nm) detector	Graded Index InGaAs Photodiode, 2 Stage TE Cooled		
Input	1.5 m fiber optic (25° field of view); optional fore optics and optional longer fiber optic cables available		
Weight	5.44 kg (12 lbs.)		
Calibrations	Wavelength, absolute reflectance, radiance*, irradiance*. All calibrations are NIST traceable. (*radiometric calibrations are optional)		
Instrument Controller	Dell Latitude 5490 or other Windows 10 compatible laptop		
Warranty	One-year full warranty including expert customer support		
Storage temperature (°C)	-15 to 45		
Operational temperature range (°C)	0 to 40		

Modification for autonomous use

Fore optics

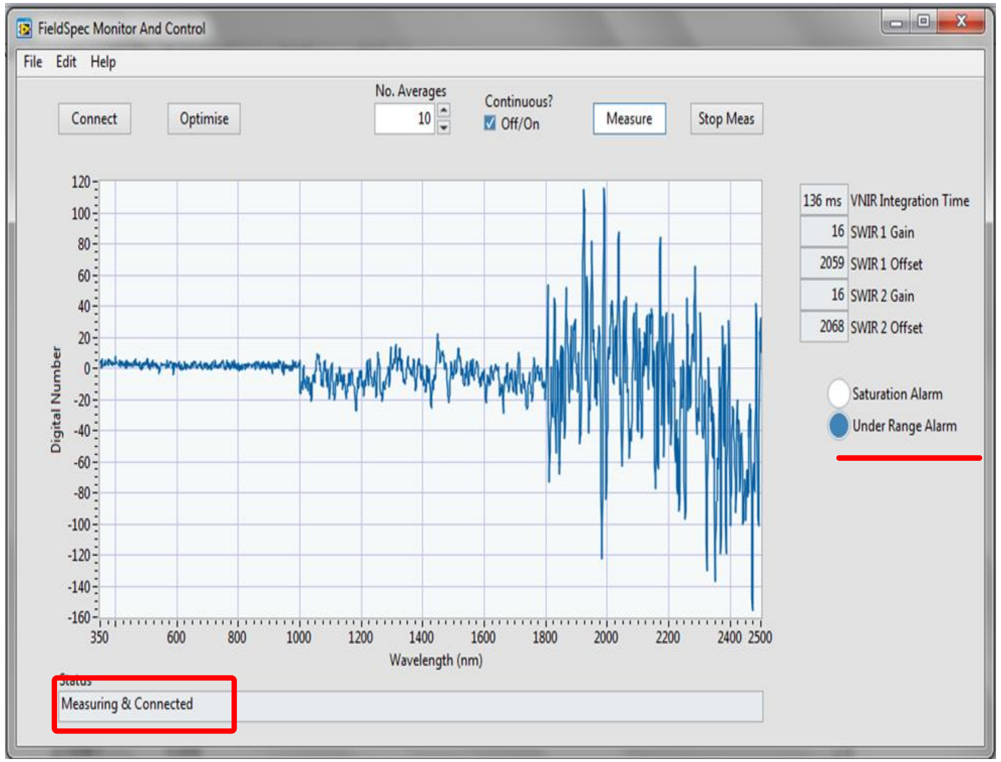




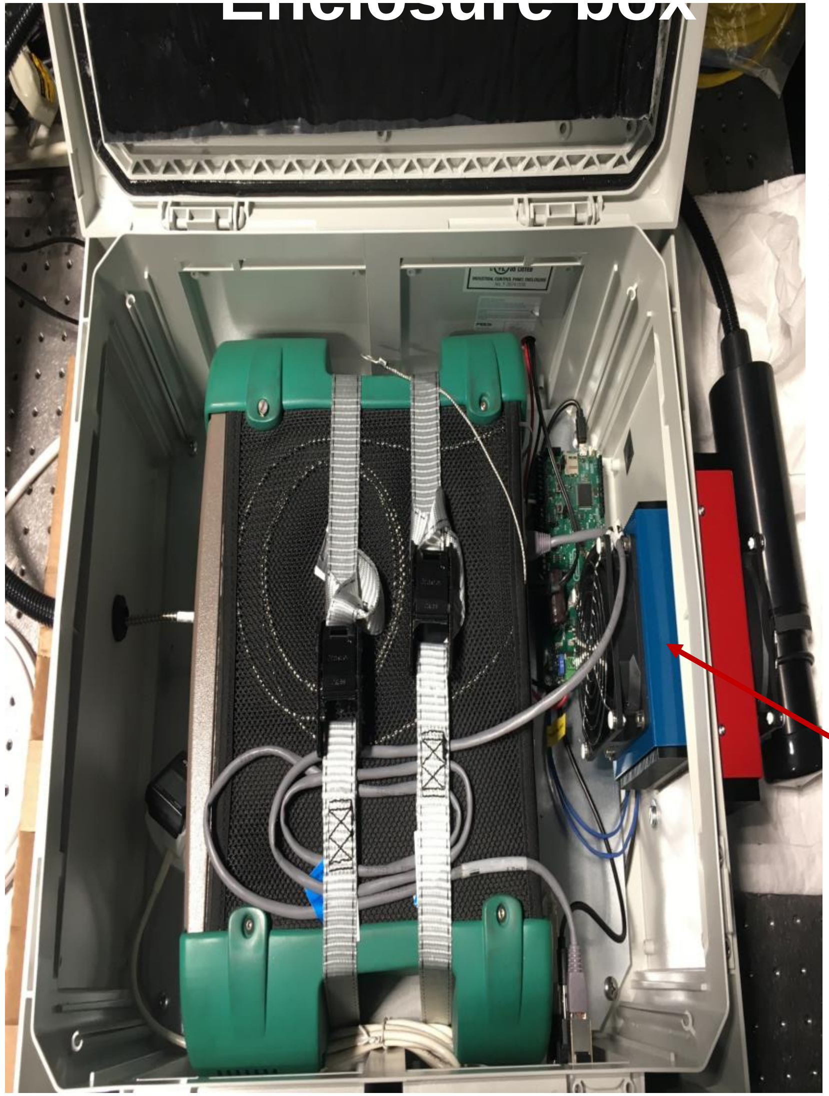


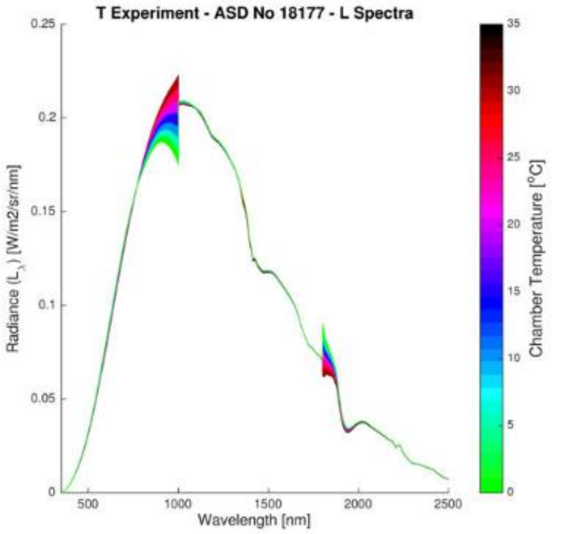
Solys2 tracker with custom made software for Moon tracking

Modification for autonomous use



Acquisition software



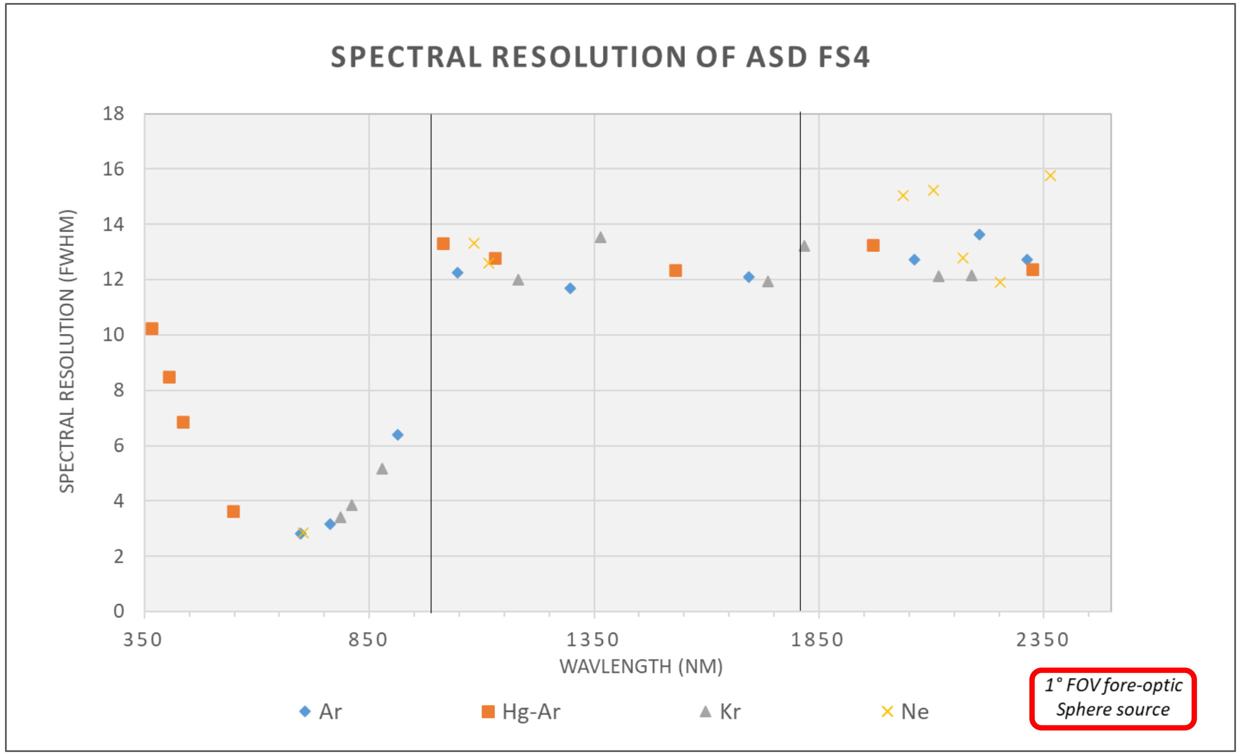


Hunei and Bialek, 2017

TE air-to air cooler with fan

Additional characterisation SRF

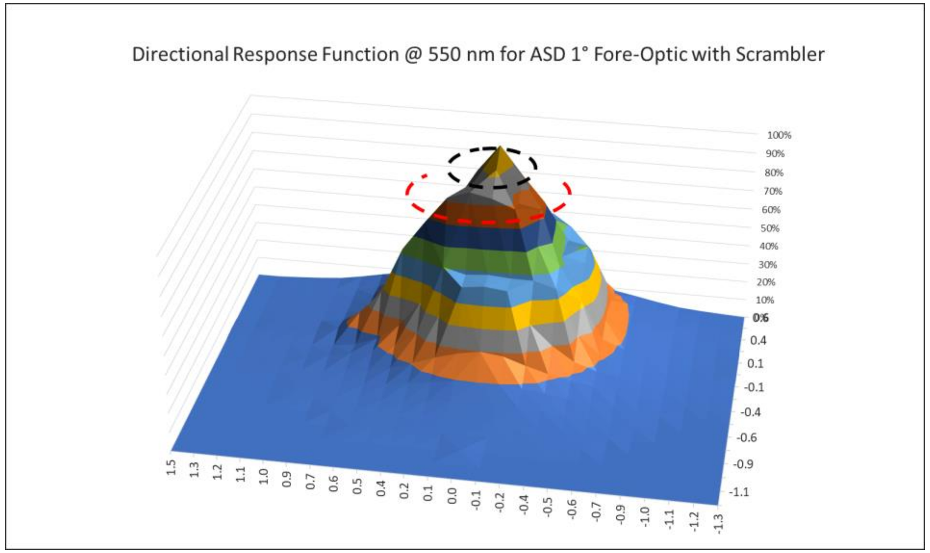
Performance Specifications	Standard-Res	Hi-Res	Hi-Res NG
Wavelength range	350 nm – 2500 nm		
Resolution VNIR @ 700 nm	3 nm		
Resolution SWIR @ 1400 & 2100 nm	10 nm	8 nm	6 nm



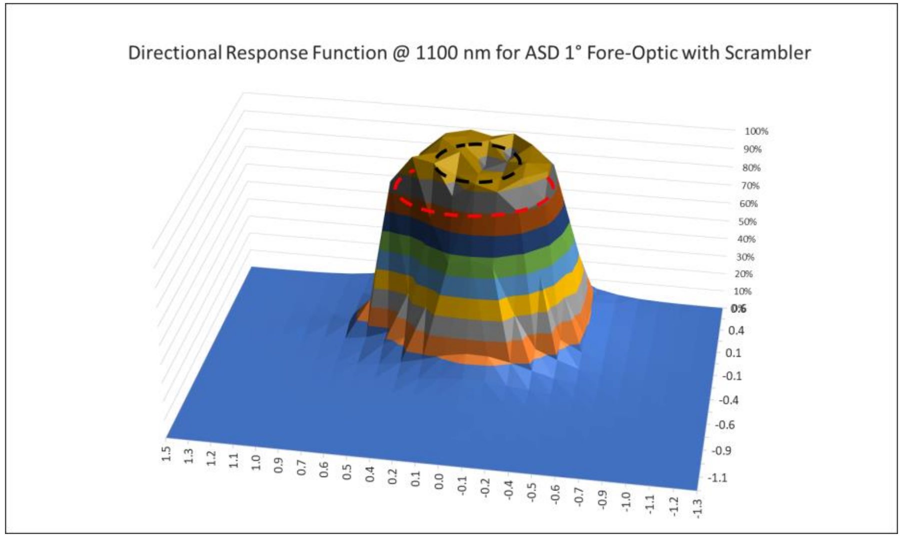
	VNIR Spectrometer	SWIR-1 Spectrometer	SWIR-2 Spectrometer
Spectral Uncertainty	0.2 – 0.4 nm	0.2 – 0.4 nm	0.5 – 2.0 nm
Spectral Resolution	3 – 10 nm	12 – 14 nm	11 – 15 nm
Sampling Interval	1.31 – 1.38 nm	1.1 – 2.2 nm	1.1 – 2.2 nm

Additional characterisation FOV

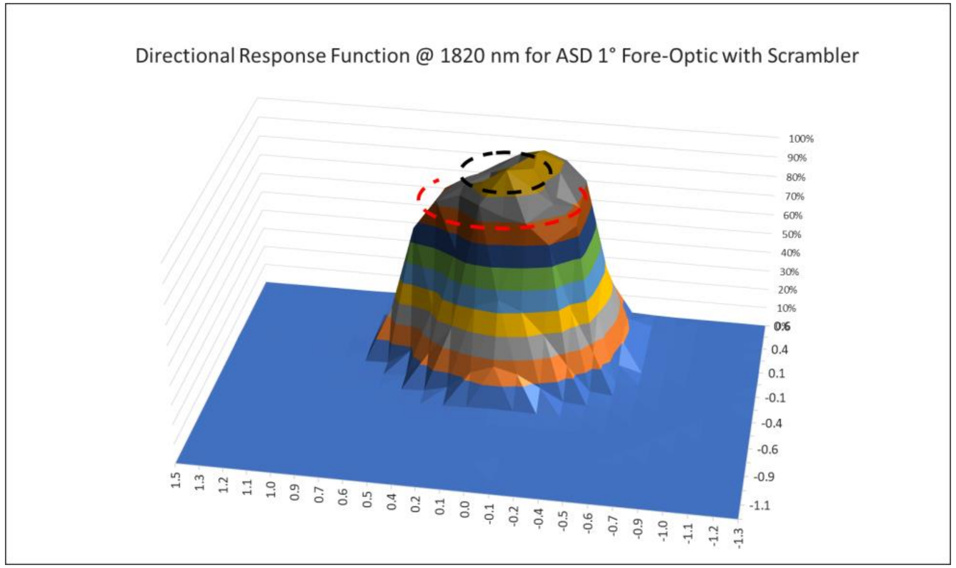
VNIR detector

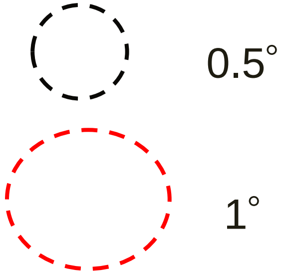


SWIR 1 detector

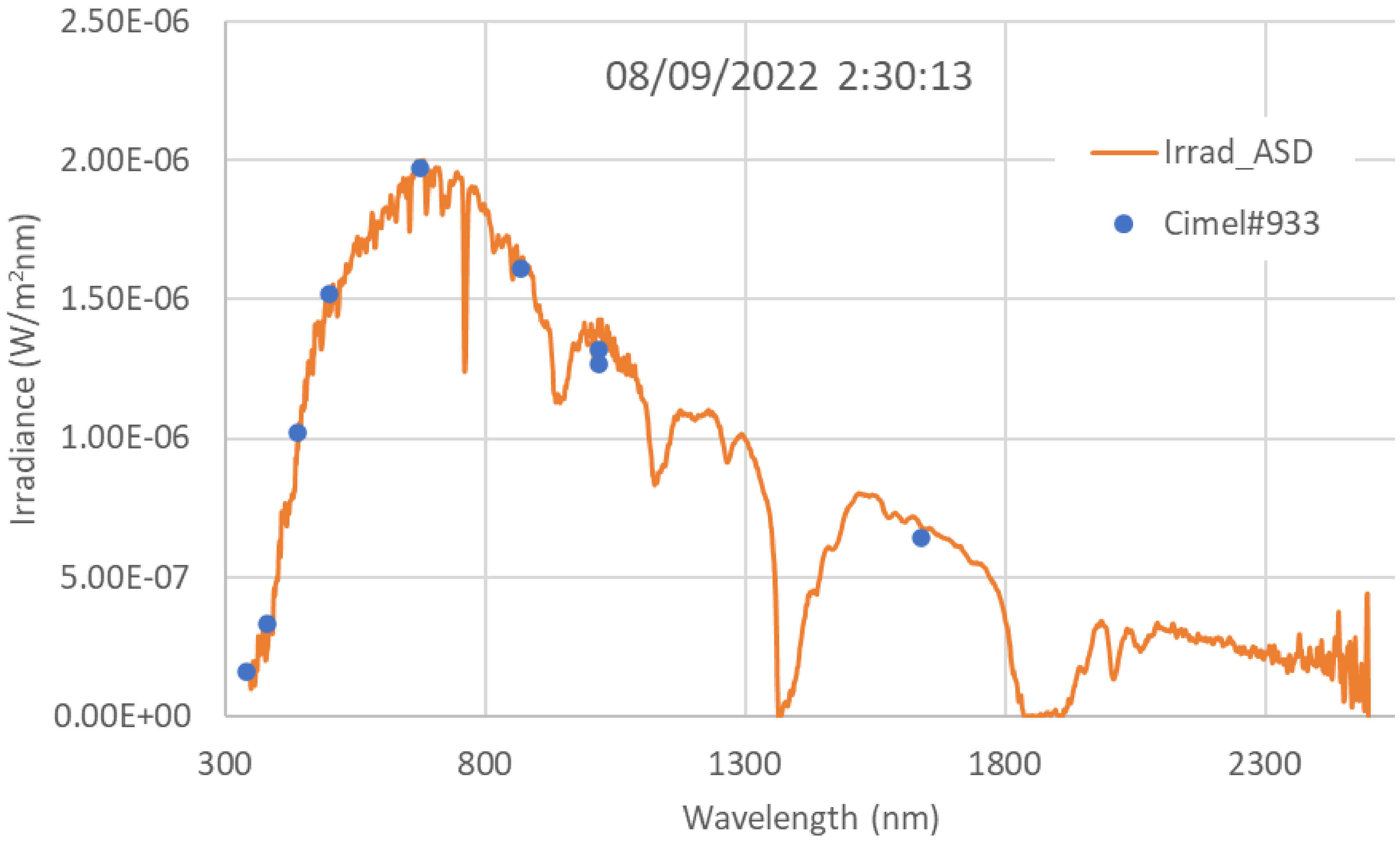


SWIR 2 detector





ASD measured irradiance



Next steps

- Extent Cimel bands into 2.1 um wavelength range
- Conduct another 3 months hyperspectral campaign with improved fore optics

Conclusions

- Moon irradiance hyperspectral measurements provide useful information about spectral shape and its variation with phase angle

- Hyperspectral measurements still in R&D mode are always anchored with extremely stable multiband CIMEL measurements

Thank you!

http://calvalportal.ceos.org/lime

LUNAR IRRADIANCE MODEL OF ESA

vito vision on technology

Universidad de Valladolid

esa

NPL National Physical Laboratory