Near Infrared Ground-based Spectrum

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Outline

- Historical of the ground-based SSI
- Fundaments of the measurement
- Rationale for a ground based NIR campaign
- NIR campaign
  - Instrumentation
  - Calibration
  - Uncertainity budget
- Results comparison

Historical of SSI ground-based measurements

	Site	Range	Instrument	Calibration standard
Arvesen 1969	Aircraft 12 Km	UV-Vis-NIR	Spectrometer	On board secondary standard, traceable to NIST
Shaw 1982	MLO	UV-Vis-NIR	10-channel Radiometer	1000W lamps Traceable to NIST
Kindel 2001	MLO	UV-Vis-NIR	Spectrometer	1000W lamps Traceable to NIST
Gröbner 2001	MLO	Vis	Brewer	1000W lamps Traceable to NIST
Gröbner 2017	IZO	UV	Spectrometer	PTB Blackbody

+ see G. Rottman poster about the TSI value APO network

IZO: Izaña Atmospheric Observatory. Canary Islands, 2373 m.a.s.l.
MLO: Mauna Loa Observatory. Hawaii, 3397 m.a.s.l

Prime sites for atmospheric observations
Absolute calibration centers of NASA AERONET (Aerosol RObotic NETwork)

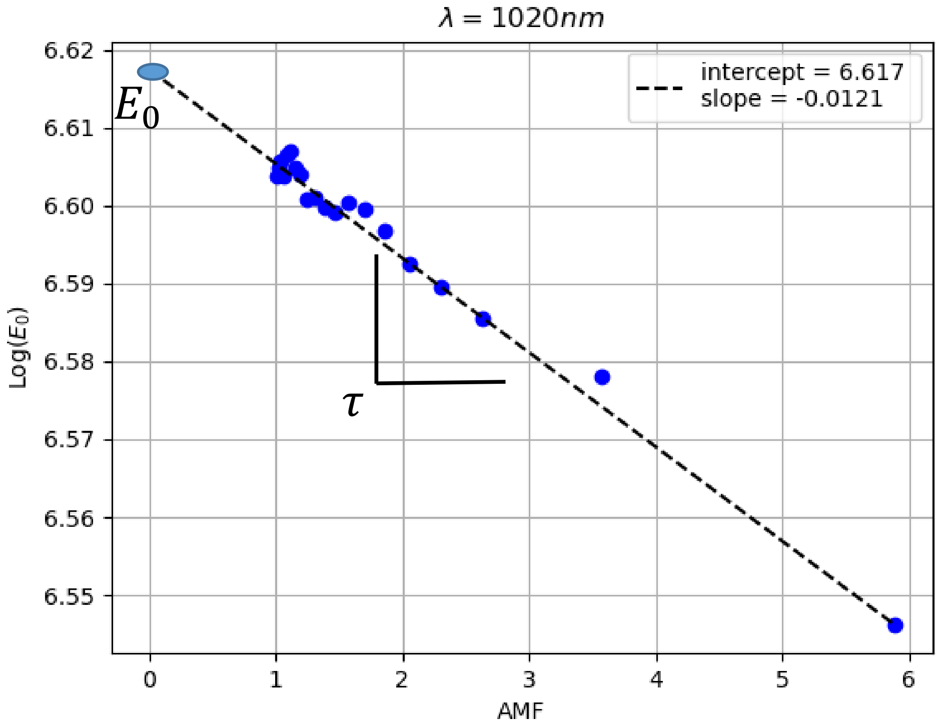
Langley-Plot method: Retrieval of TOA quantities

Beer-Bouguer-Lambert Law

$$E = E_0 . \exp(-m\tau)$$

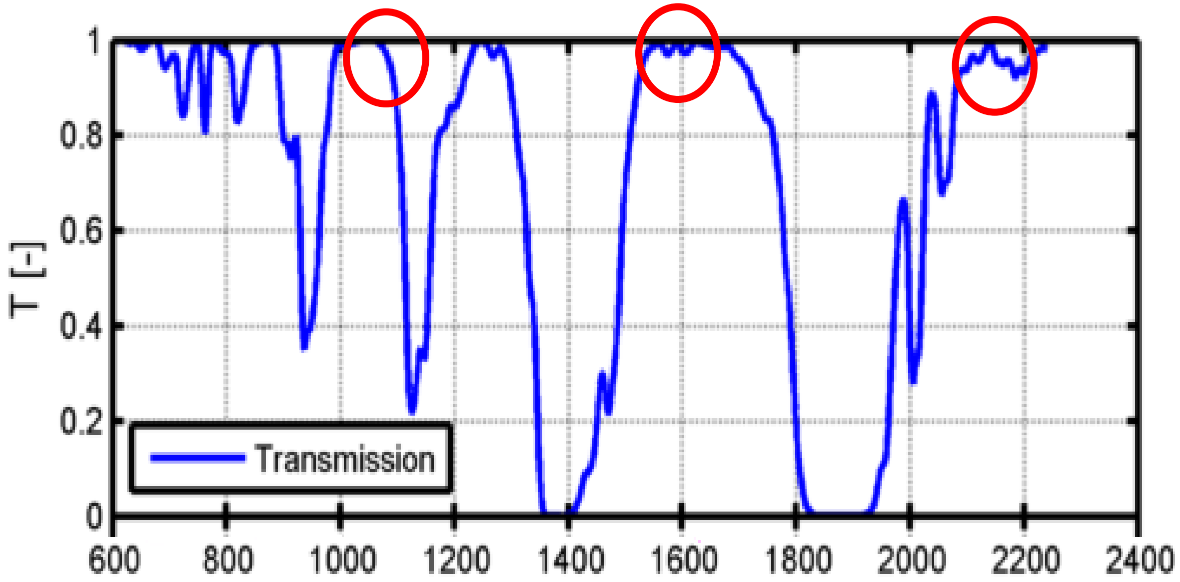
$$\log(E_i) = \log(E_0) - m_i\tau$$

$$Y_i = \alpha . X_i + \beta$$

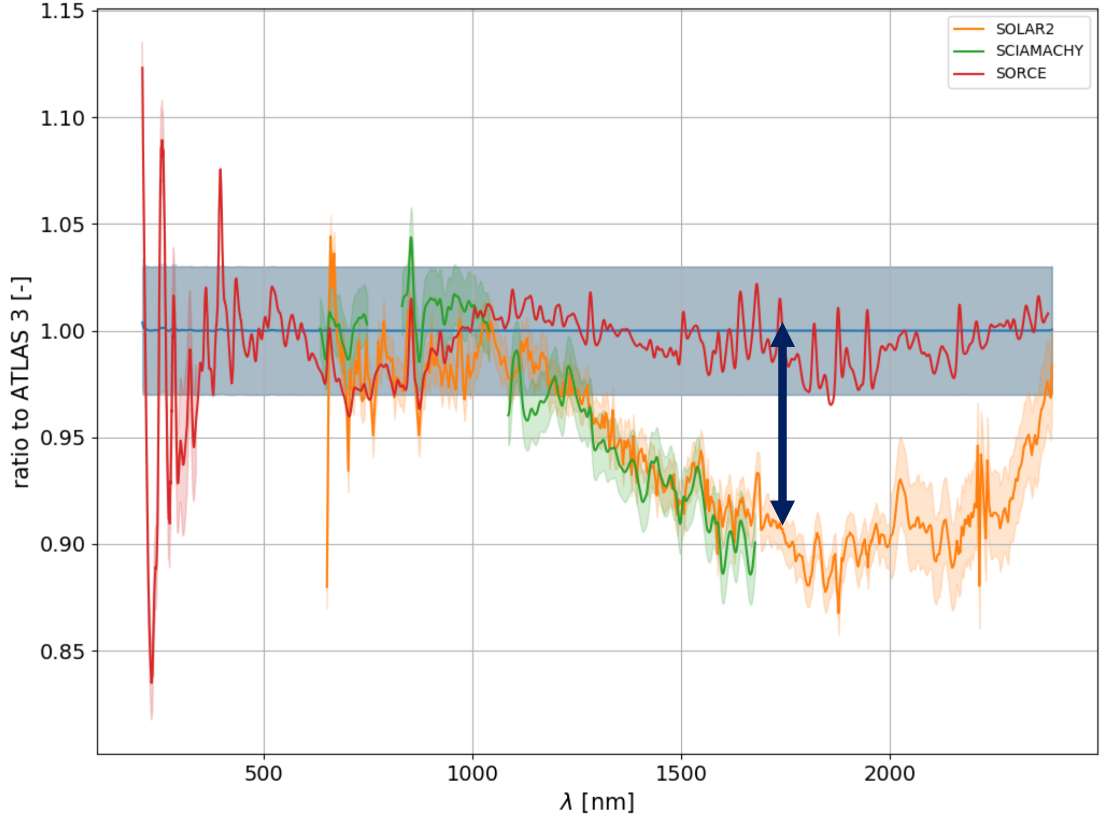


Conditions of application

- Pristine and stable atmospheric conditions
- Absorption-free wavelength regions
- Constant optical depth



NIR absolute level: state of the art (2012)



High disagreement in the NIR

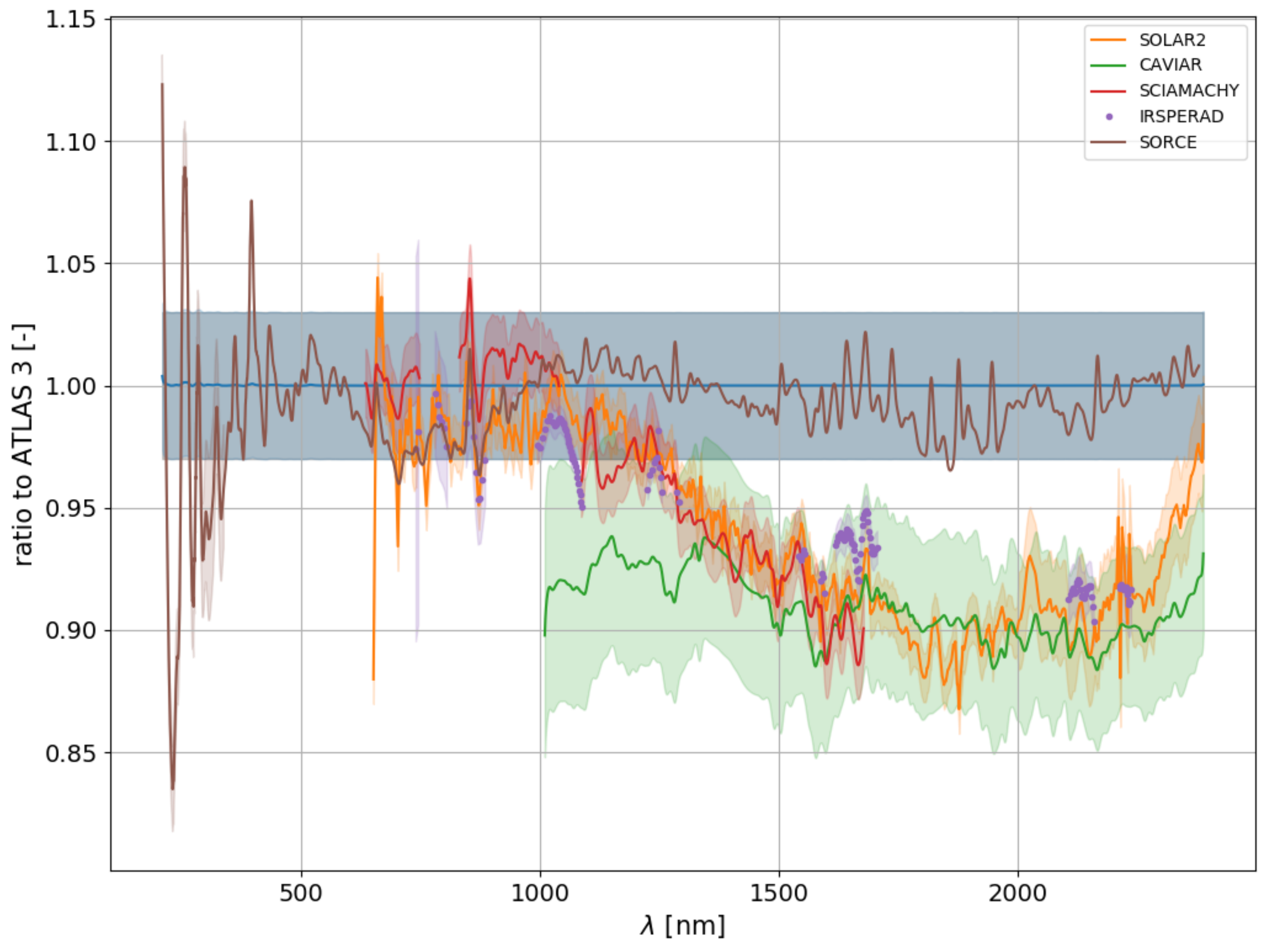
- Up to 10% at 1.6µm between SORCE and SOLAR/SOLSPEC
- No overlap of error bars
- Need for and independent measurements

Ground based-measurement using Langley-plot

- Sound methodology
- Low-cost mission
- Possibility of using high-altitude reference observatory (IZO)

	Site	Range	Instrument	Calibration standard
Menang 2013 ***CAVIAR***	Camborne (UK) 88 m.a.s.l.	NIR	FTIR	NPL standards
Bolsée et Pereira 2014 ***IRSPERAD***	IZO	NIR	Spectrometer	PTB Blackbody

NIR absolute level: state of the art (2014)



Still high disagreement in the NIR

- New ground-based on lower stack of datasets
- Ground-based datasets not so well accepted in the SSI community

- Big discrepancy at 1.6µm remains
- No overlap of error bars

- Disagreement in the NIR remains

- Need for and independent measurements, again!

	Site	Range	Instrument	Calibration standard
Pereira et Bolsée, 2018 ***PYR-ILIOS***	MLO	NIR	Spectrometer	PTB Blackbody

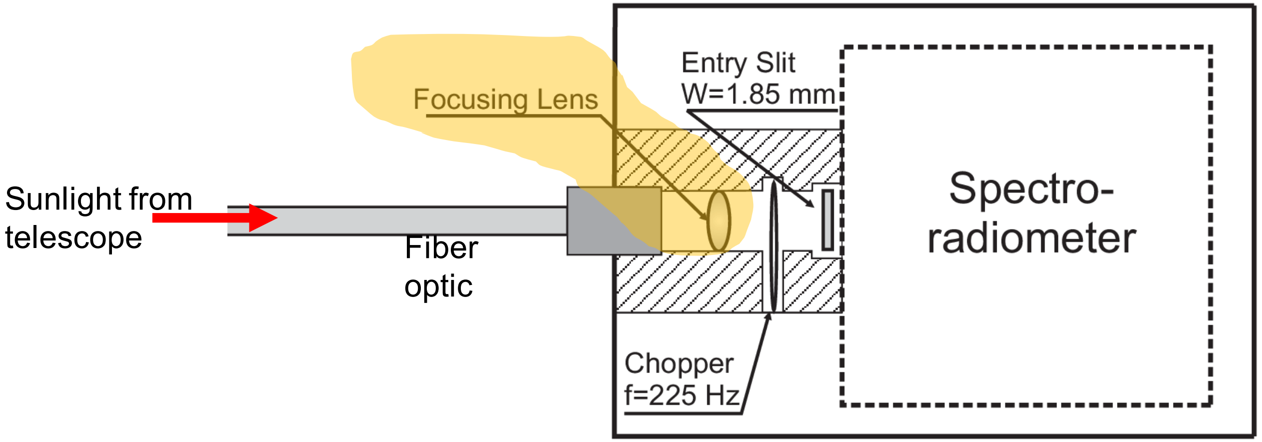
Ground-based campaign

Izana Observatory (IZO) 2011

- 2373 masl
- 4-month campaign
- 4 FEL lamps, 2 relative calibrations
- PTB Black Body Calibration
- Spectrometer outdoors

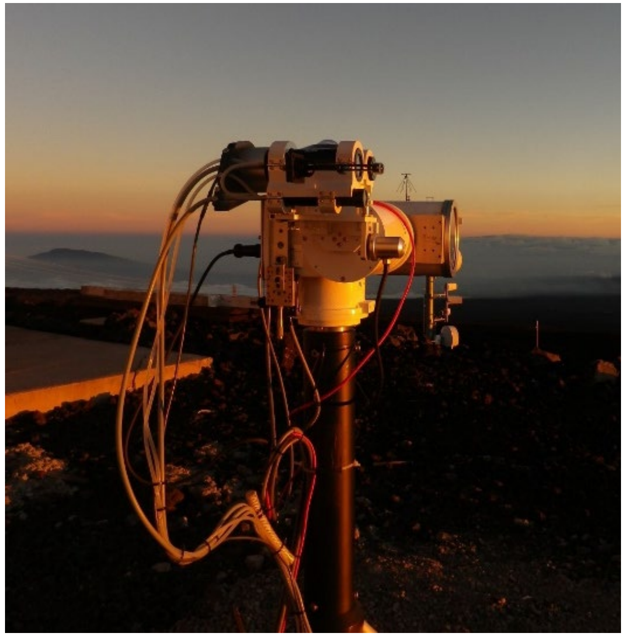
Mauna Loa Observatory (MLO) 2016

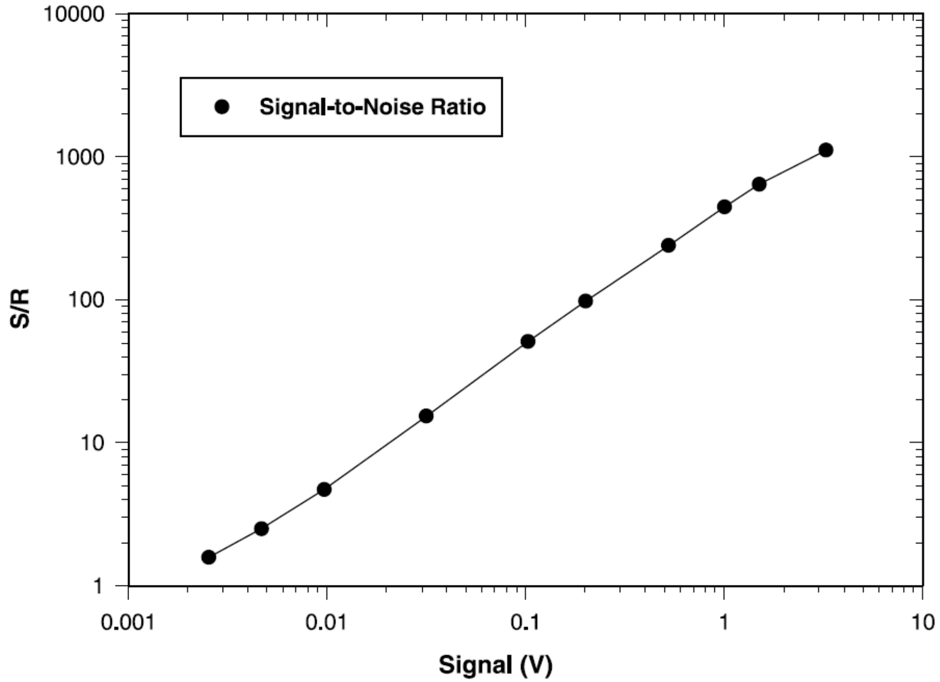
- 3397 masl
- 20-day campaign
- 6 FEL lamps, 4 relative calibrations
- PTB Black Body Calibration
- Spectrometer indoors
- Hardware improvement



Spectrometer more robust to displacement

Ground-based campaign

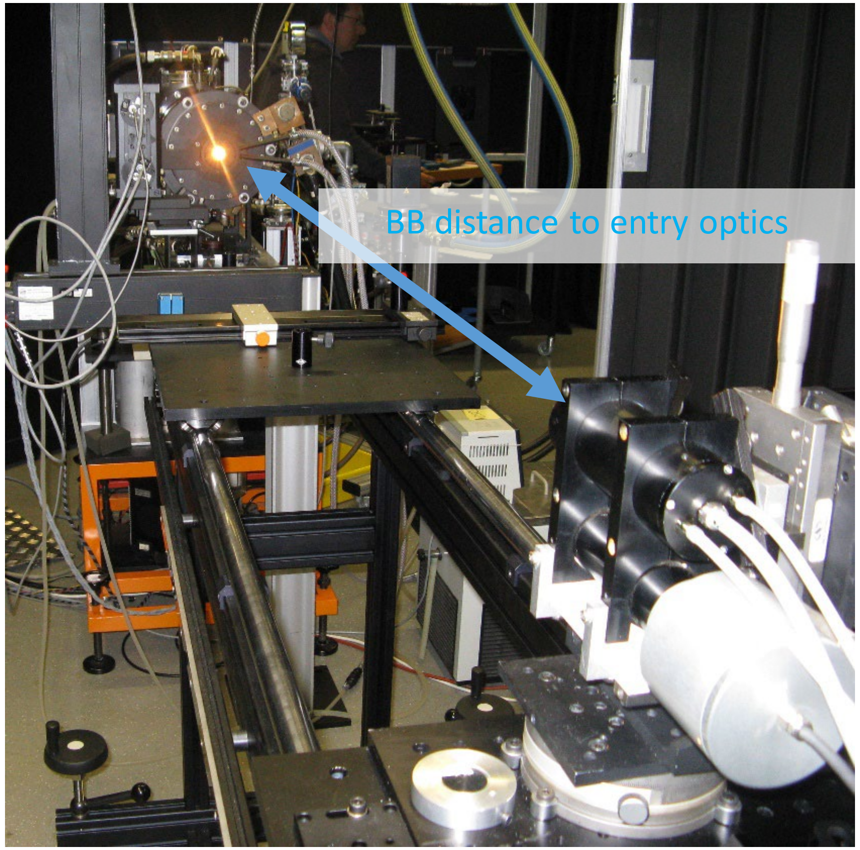




Spectrometer	
Type	Double Czerny-Turner Plane grating configuration
Spectral range	600-2400 nm
Nominal Bandwidth	10 nm
Detector	
Type	PbS cell
Peak sensitivity	2.7 micron

Absolute calibration

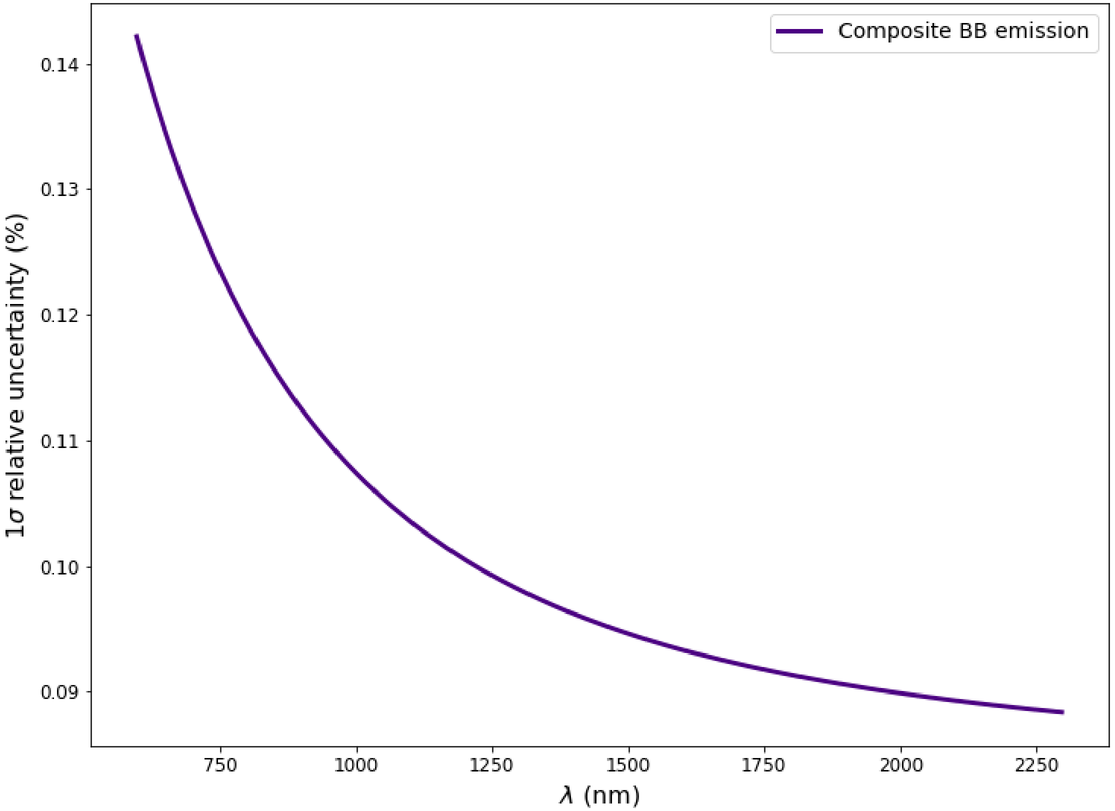
PTB (Braunschweig, Germany) as primary standard of irradiance



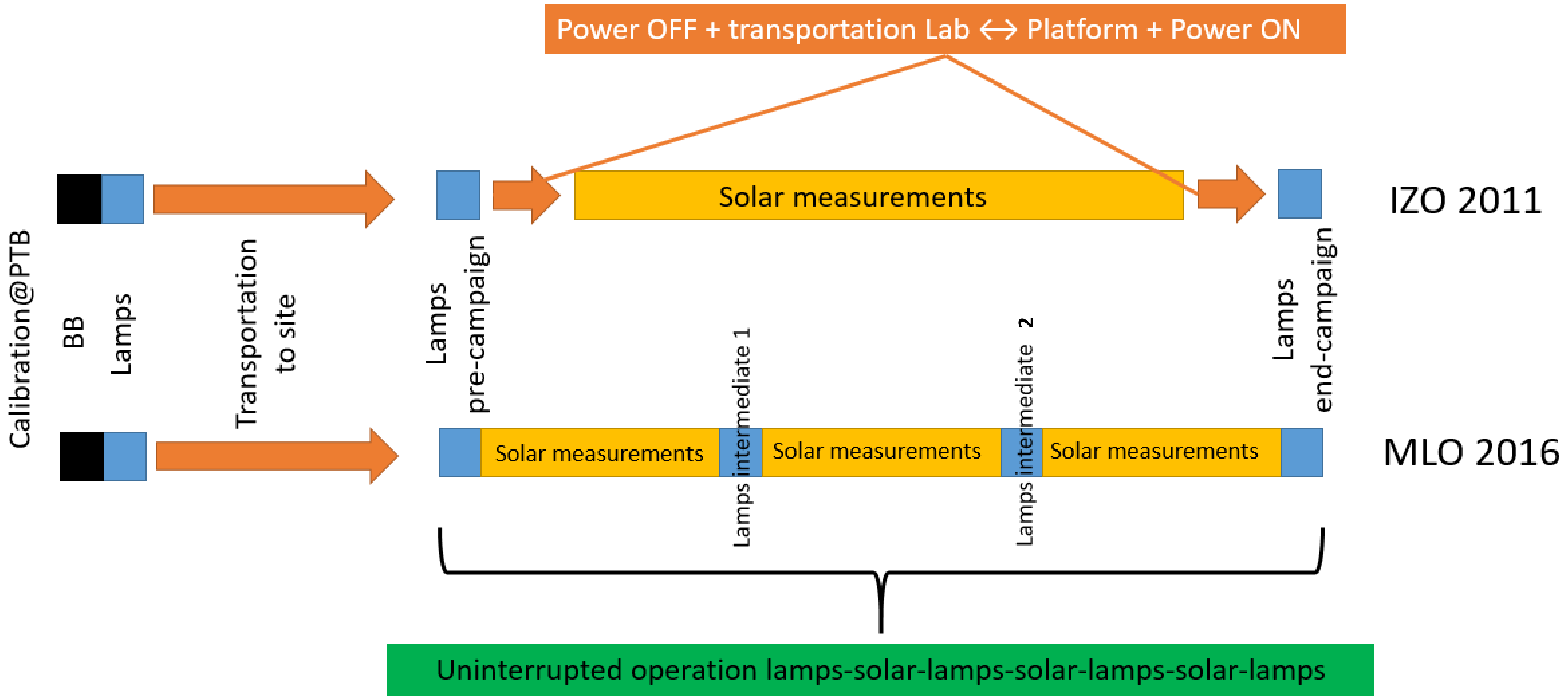
Two temperatures used for calibration
3016.5 K and ***2847.6 K***

$$E = \varepsilon \frac{A}{d^2} \frac{c_1}{n^2 \lambda^5} \frac{1}{\exp\left(\frac{c_2}{n\lambda T}\right) - 1}$$

emissivity ~ 0.9998 ± 0.01%
d ~ 1384.05 m ± 0.04%
A ~ 111.388 mm^2 ± 0.04%
u(T) = 0.44 K, drift(T) < 0.5 K/hour



Relative calibration



Uncertainties reduction

$$E(\lambda) = S(\lambda).R(\lambda).K(\lambda)$$

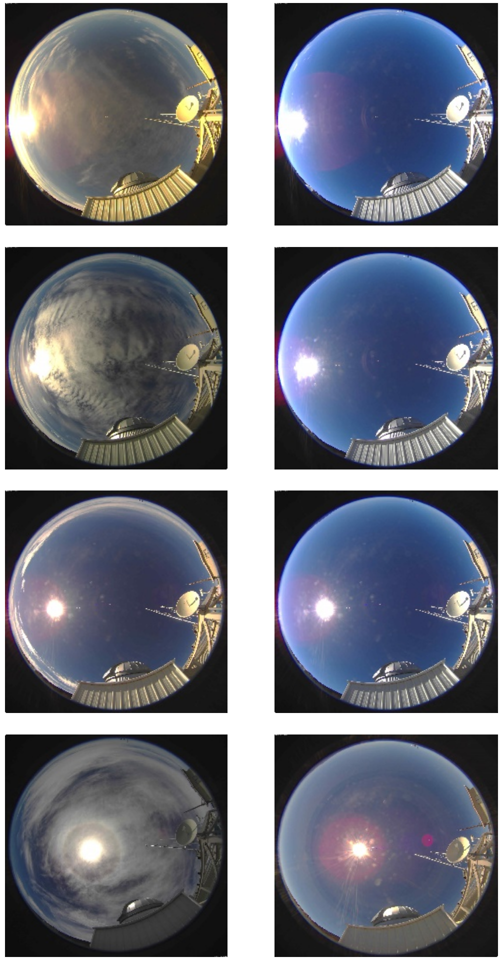
	Relative calibration: K	Uncertainty at 1000nm	Absolute Calibration: R	Unc (1000nm)	Solar Signal: S	Unc (1 micron)
IZO (2011)	4 lamps, 2 relative calibrations • Start campaign • End campaign	0.44%	BB at 3016.5K	0.52%	Same response	0.20%
MLO (2016)	6 lamps, 4 relative calibrations • Start campaign • Mid-campaign x 2 • End campaign	0.16%	BB at 3016.5k and 2847.5K	0.45%		

- Loss of response between end and beginning of campaign (~2% @ 1000nm)
- Spectrometer outdoors => Thermal correction for instrument response (up to 1% @ 1000nm)

- High-frequency relative calibration detected small measurable changes in instrument response
- Spectrometer indoors => No thermal correction for instrument response

Data selection and processing

1 July ✗ 2 July ✓

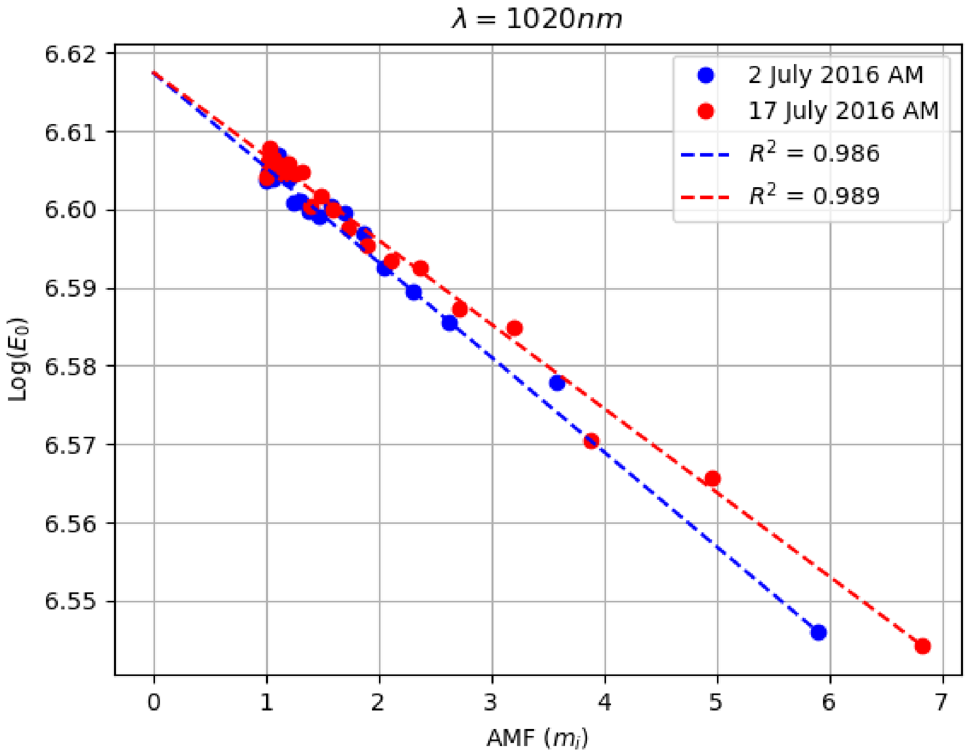


- SZA calculated with Meeus algorithms
- SZA corrected for atmospheric refraction
- Air masses calculated with K&Y algorithm

- Data screened for clouds
- Selection for $R^2 \geq 0.9$

↓

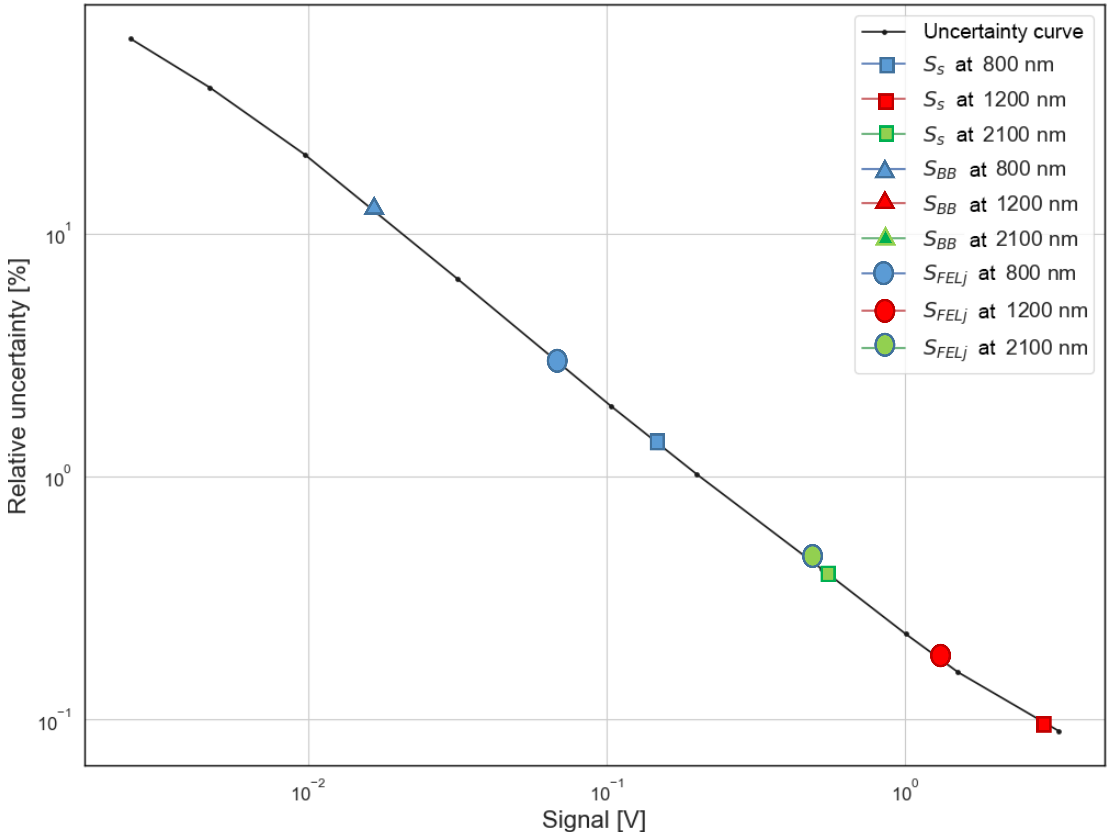
12 high-quality half-days

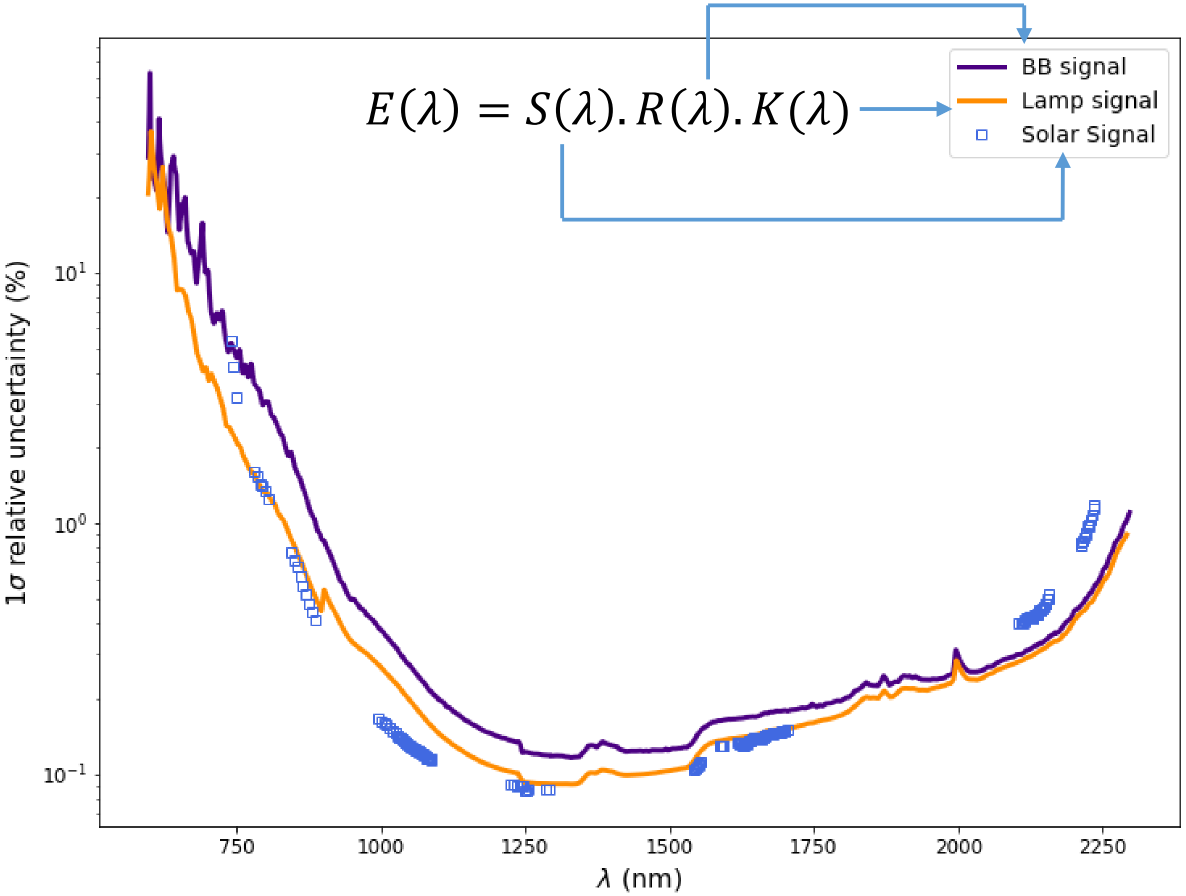


Meeus, J.: Astronomical Algorithms, Willmann-Bell, 1998.
Kasten, F. and Young, A. T., Appl. Opt., 28, 4735

Uncertainty on spectrometer signals

Derived from spectrometer SNR curve

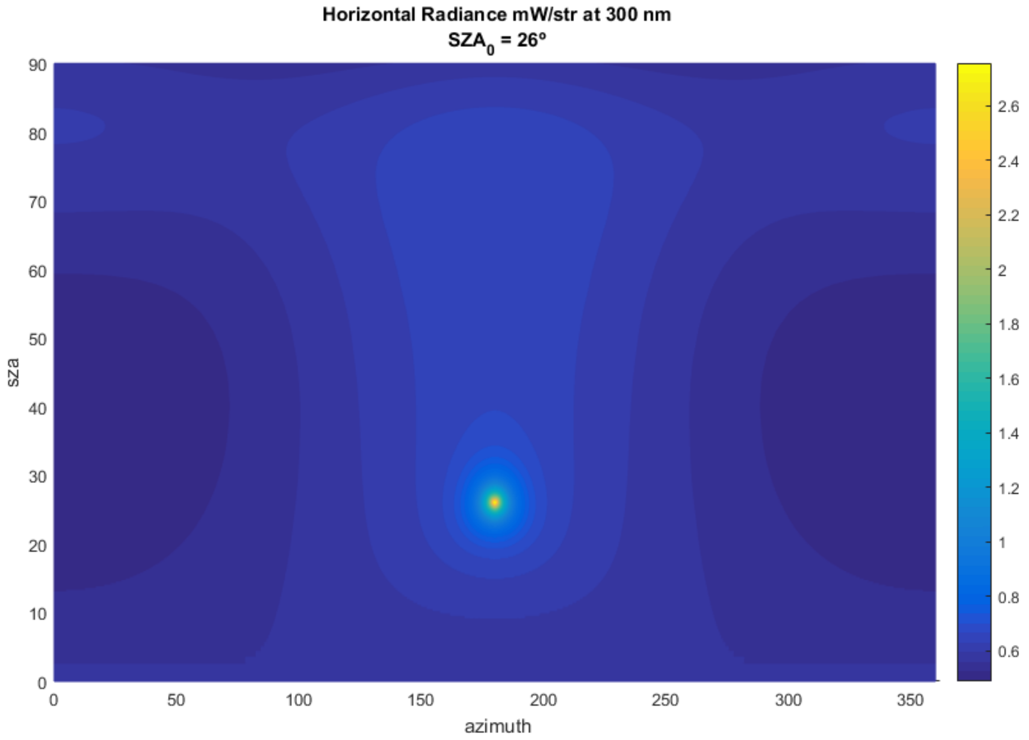


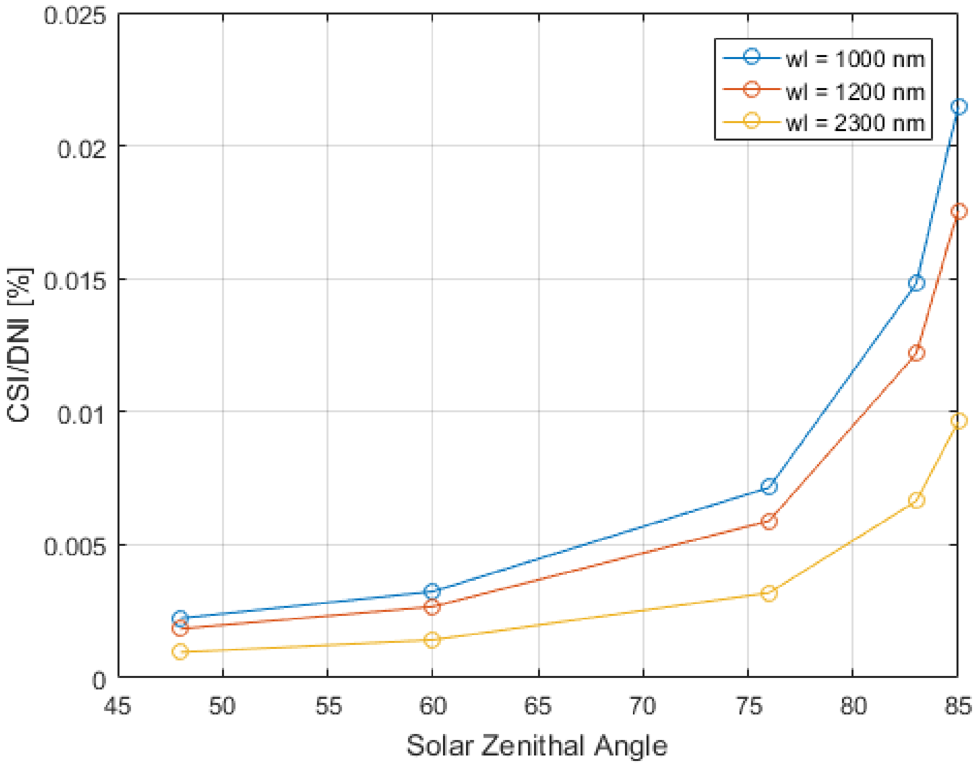


Circumsolar radiation

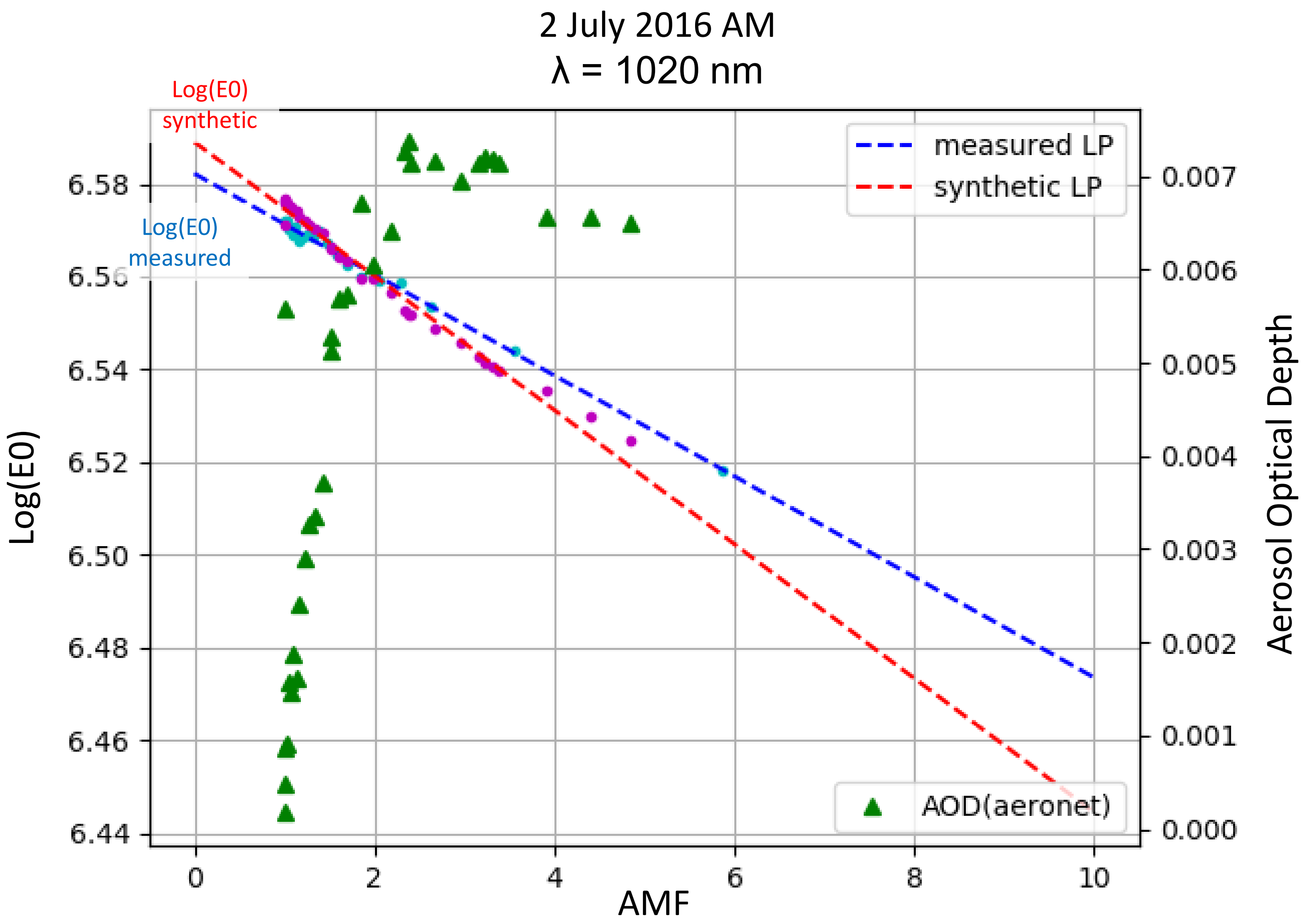
Radiance modeling with LibRadtran RTM
Parameters: Atmospheric condtions at MLO
- Pressure/Altitude
- Aerosol charge

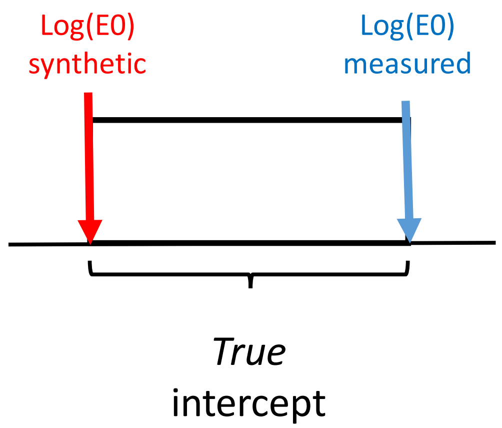
$$CSI \propto SZA, \lambda^{-1}$$





Sensitivity to non-constant aerosol optical depth

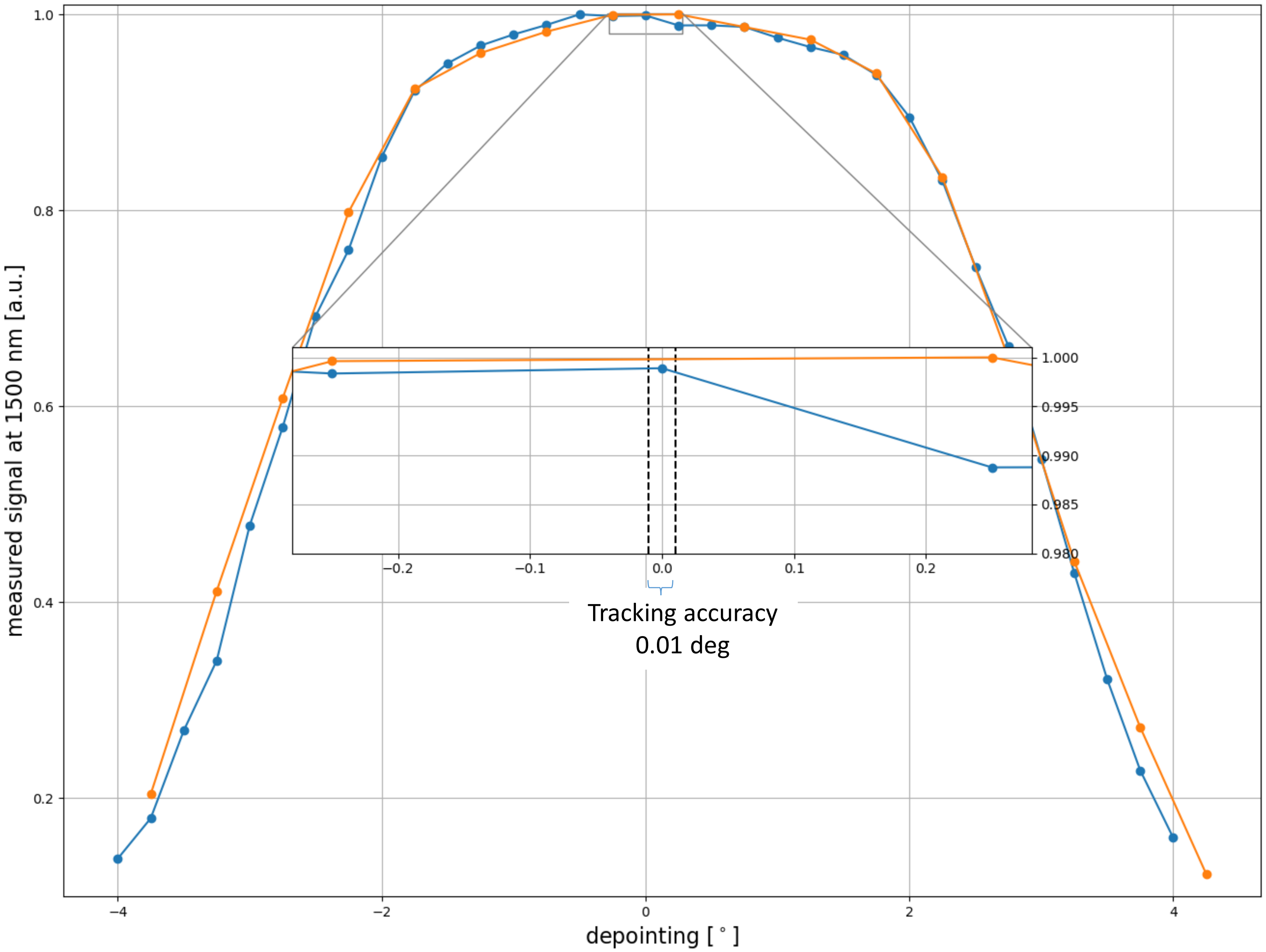




	870nm	1020nm	1640nm
Unc %	0.06	0.11	0.06

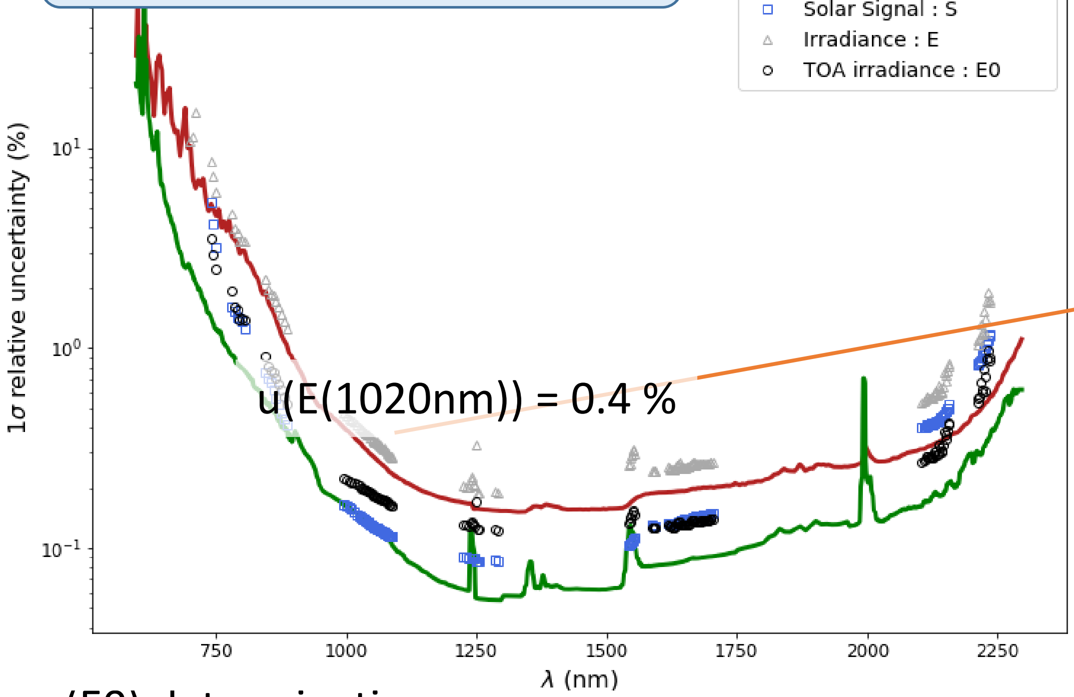
AErosol RObotic NETwork data:
https://aeronet.gsfc.nasa.gov/

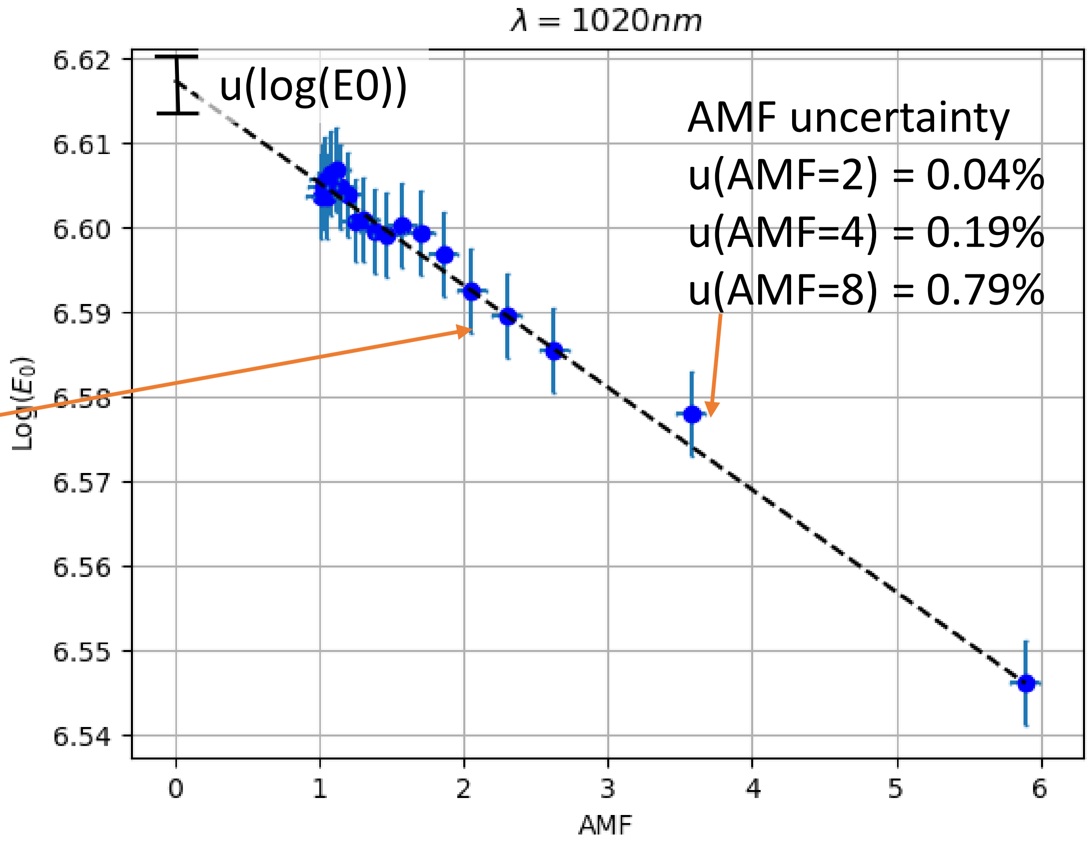
Flat-field of the entrance optics



Uncertainty budget on TOA irradiance

$$E(\lambda) = S(\lambda).R(\lambda).K(\lambda)$$





u(E0) determination

1) Monte-Carlo method

$$LP(m_i + u(m_i), E_i + u(E_i)) \Rightarrow \overline{E_0} \sim Normal(<\overline{E_0}>, \sigma)$$

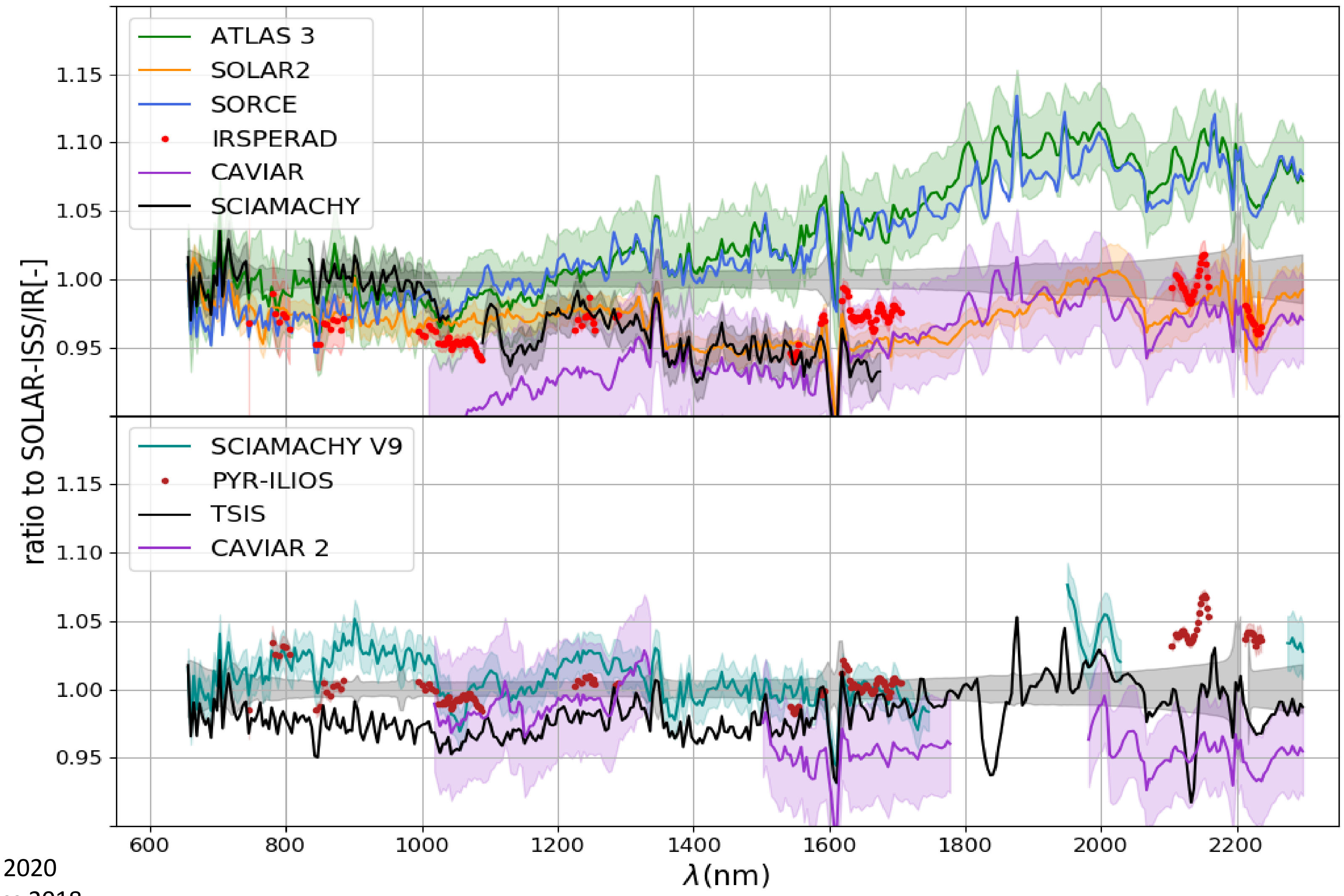
2) From linear regression algorithm*

$$LP(m_i, u(m_i), E_i, u(E_i)) \Rightarrow (E_0, \tau, u(E_0), u(\tau))$$

* Krystek, M. and Anton, M. Meas. Sci. Technol., 18, 3438–3442, 2007.

Results and NIR comparison

SOLSPEC SOLAR-ISS as reference spectrum



SOLAR-ISS: Meftah M. et al., Solar Physics, 2020
SCIAMACHY V9: Hilbig, T. et al., Solar Physics 2018
PYR-ILIOS: Pereira, N., Bolsée, et al., AMT 2018
TSIS: <2018-03-14 : 2018-11-15>
CAVIAR 2: Elsey et al., GRL, 2017

Conclusions

- PYR-ILIOS is the most robust ground-based NIR dataset
  - Robust Hardware
  - Intra-campaign recalibration strategy adapted to monitor eventual response changes
  - Recalibration frequency assures traceability to Black Body primary standard of irradiance

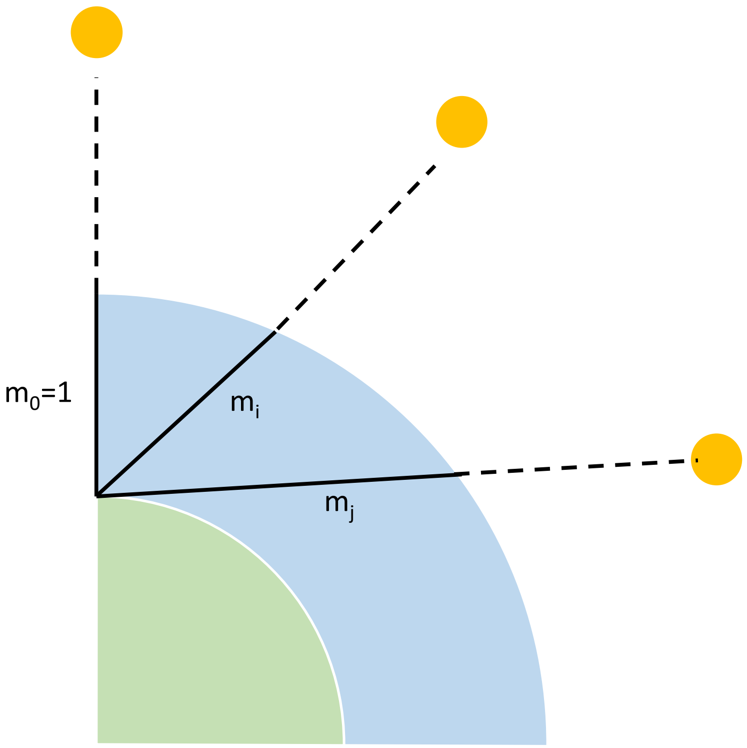
- Ground-based SSI gained visibility in the SSI community

- SOLAR-ISS replacing ATLAS3 as reference spectrum of the SOLSPEC instrument family

- Improved data processing of SCIAMACHY and SOLAR-ISS and TSIS agree with PYR-ILIOS

- Agreement of the absolute level in the NIR is growing, along with accuracy

$$E = E_0 . \exp(-m_R\tau_R - m_A\tau_A)$$
$$m_R \approx m_A, \tau_R + \tau_A = \tau$$
$$m = m(SZA)$$



Schimt, Wherli 95
wl = 946 nm