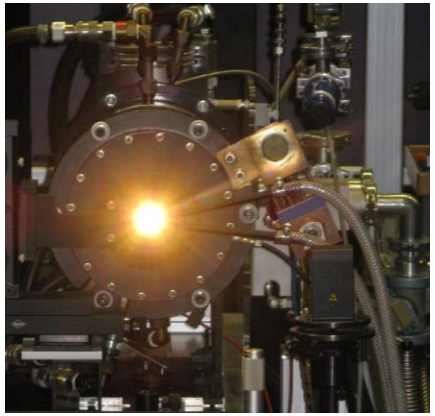
2014 SORCE Science Meeting

Accurate Determination of the TOA Solar Spectral NIR Irradiance Using a Primary Standard Source and the Bouguer-Langley Technique.



D. Bolsée, N. Pereira, W. Decuyper, D. Gillotay, H. Yu
Belgian Institute for Space Aeronomy (BIRA-IASB, Belgium)

P. Sperfeld, S. Pape – Physikalisch-Technische Bundesanstalt (PTB, Germany)

E. Cuevas, A. Redondas, Y. Hernandéz
Izaña Atmospheric Research Center (AEMET, Spain)

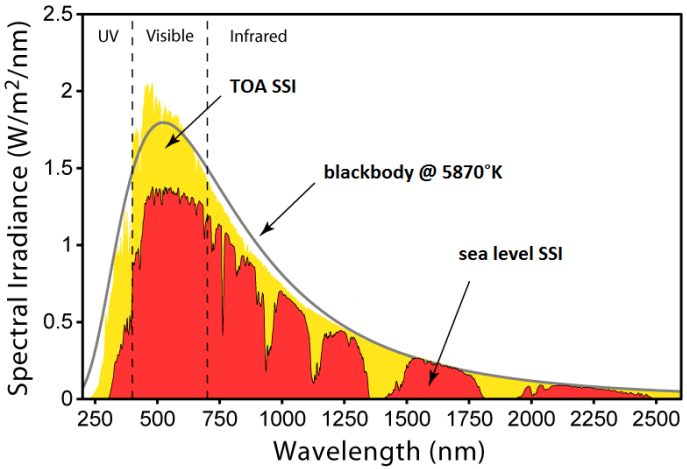
M. Weber – Institut für Umweltphysik, Universitaët Bremen (Germany)

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

2014 SORCE Science Meeting

Scientific background

Objectives → to provide new measurements of *Top Of Atmosphere* (TOA) *Solar Spectral Irradiance* (SSI) in the NIR



→ Preferably measured from space, airborne or balloon payloads

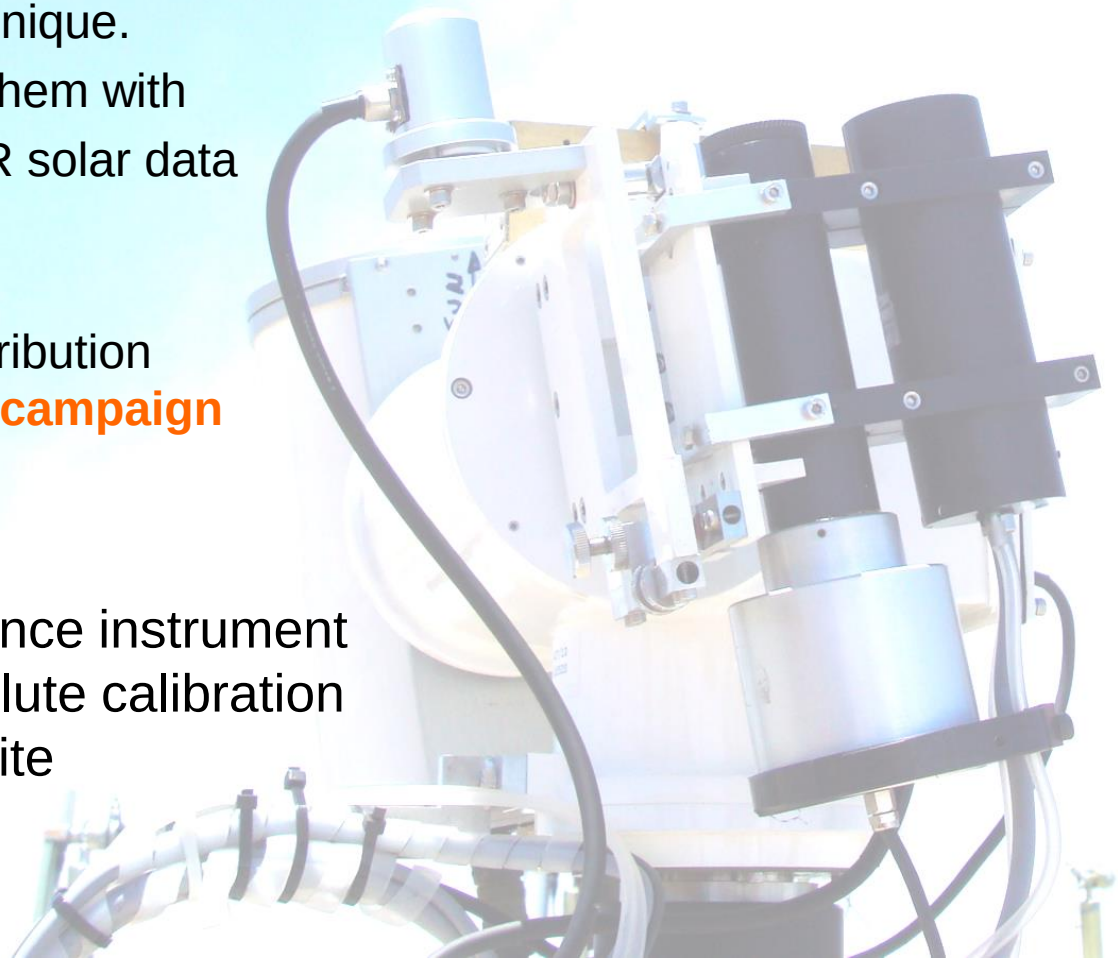
TOA SSI from 700 nm to 2400 nm
→ ~1/2 TSI

- Absorption by the atmosphere (CO_2, H_2O, O_3, O_2) & upper layer of the oceans
  → role in the Earth's radiative budget
- Applications: climate research & validation of semi-empirical modeling of the solar atmosphere
- Relative paucity of available TOA SSI NIR set of data
  (SORCE, SOLSPEC, SCIAMACHY, data from Arvesen, Neckel & Labs)
- Reported discrepancies: 6% to 10% mainly around 1.6 µm

2014 SORCE Science Meeting

- Balance: fast implementation & low cost – but accurate results
  - → Ground-based measurements were performed through few atmospheric NIR windows. TOA SSI values were extrapolated using the Bouguer–Langley technique.
  - → to compare them with available NIR solar data

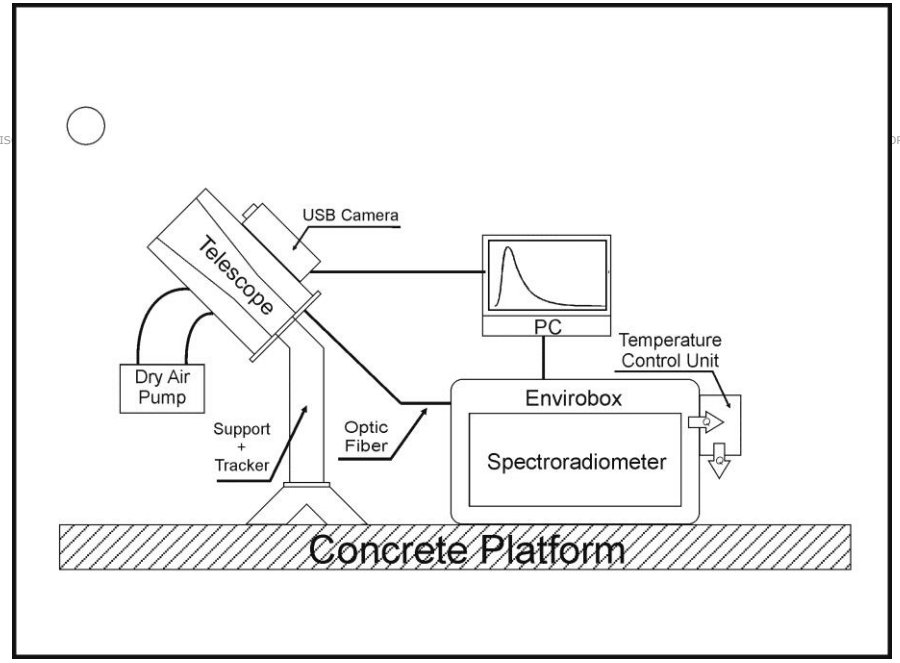
The BIRA-IASB contribution
→ **IRSPERAD campaign**



Challenge:

- High performance instrument
- Accurate absolute calibration
- High altitude site

2014 SORCE Science Meeting

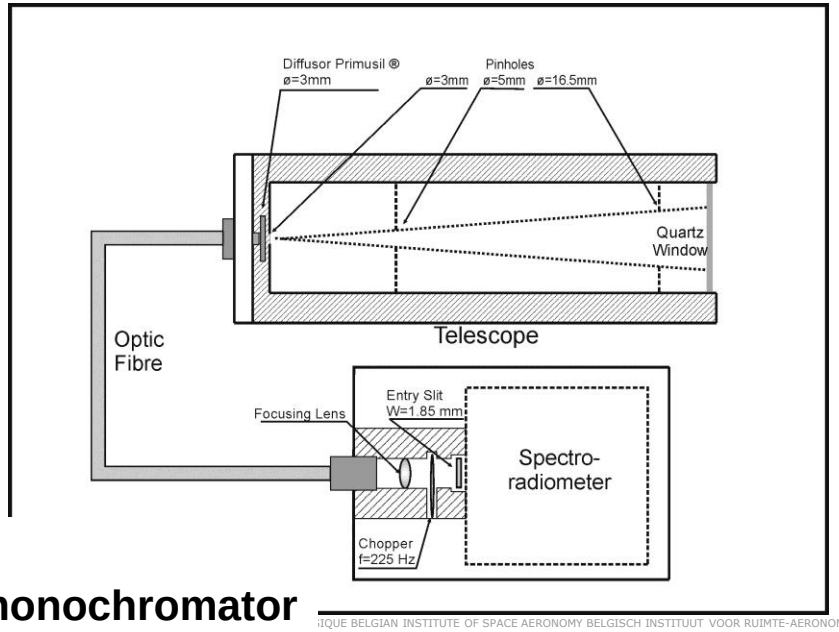


IRSPERAD

600 – 2300 nm
10 nm bandwidth
PbS detector
Phase sensitive detection

Entrance optic:

→ **tube designed for SSI measurements (concentric pinholes & frosted quartz)**
FOV 7.2°



Bentham
Double monochromator

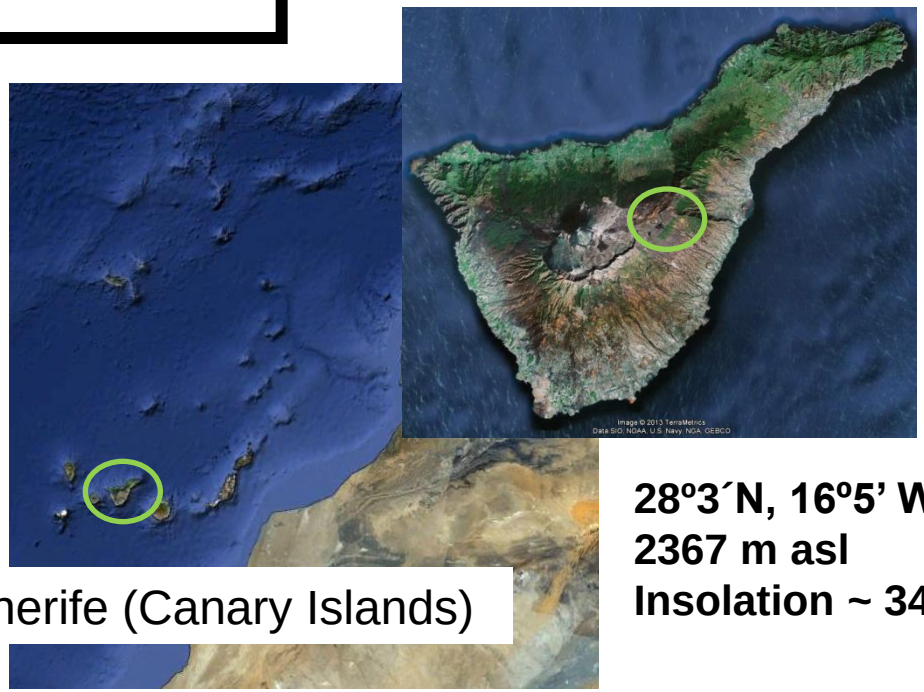
BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY

2014 SORCE Science Meeting

High-mountain Izaña Observatory (IZO)

The site

→ **Managed by the Izaña Atmospheric Research Centre (IARC), from the State Meteorological Agency of Spain (AEMET)**



Tenerife (Canary Islands)

28º3´N, 16º5' W
2367 m asl
Insolation ~ 3400 h/year

- **IZO is part of the GAW Precision Filter Radiometer (PFR) network, managed by the World Radiation Centre (Davos, Switzerland)**
- **IZO hosts the reference triad of the WMO-GAW Regional Brewer Calibration Centre for Europe (RBCC-E)**
- **IZO is a direct-Sun calibration site of AErosol RObotic NETwork (AERONET)**

2014 SORCE Science Meeting

The methodology

BELGISCH INSTITUUT ISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

→ Bouguer-Langley method using WTLS algorithm

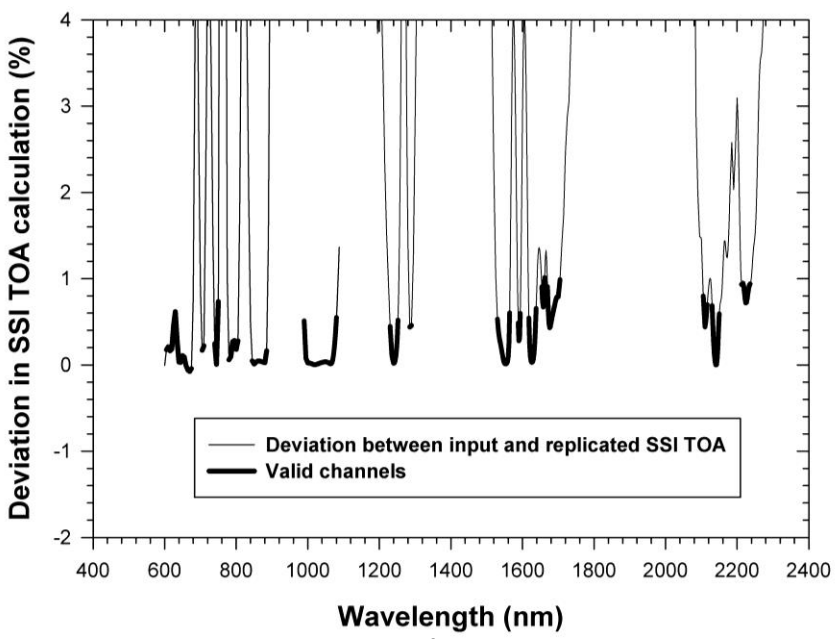
$$\log\left(E(\lambda)\right) = \log\left(E_0(\lambda)R^{-2}\right) - m(\theta)\tau(\lambda)$$

$E_0(\lambda)$ → TOA SSI at 1 UA

$E(\lambda)$ → ground-based SSI

θ = Solar zenith angle
τ = optical depth
AMF (m) between 2 and 8

Selected wavelengths



→ Atmospheric windows (164 channels)

Method: *Kindel et al., Appl. Opt, 2001, pp 3483-3494*

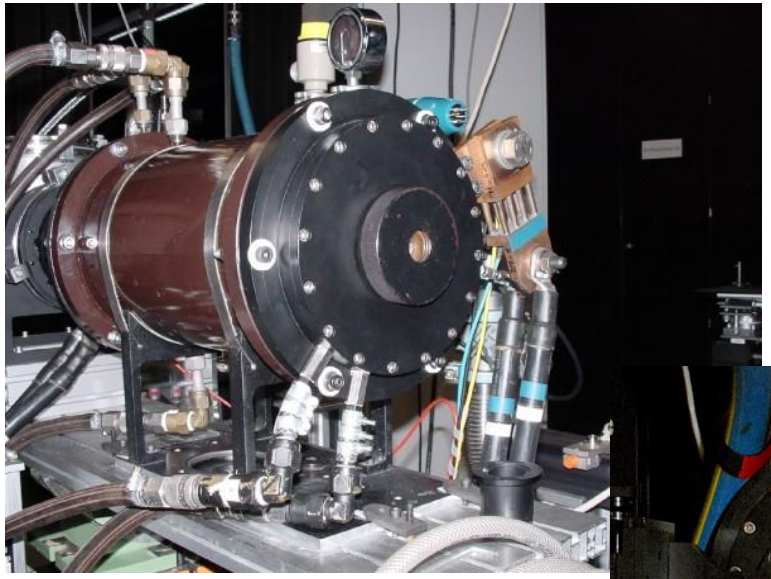
BELGISCH INST UIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

2014 SORCE Science Meeting

Absolute calibration & radiometric characterization

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

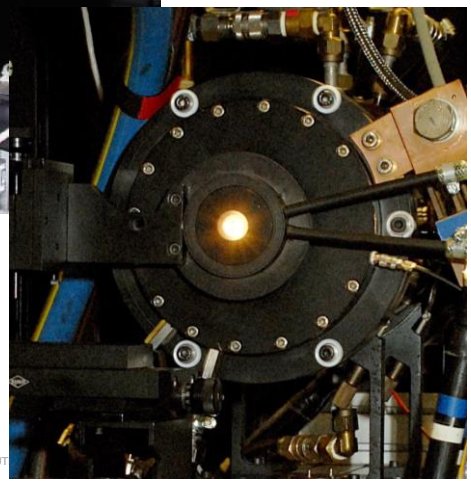
Data quality reliability → one day of absolute calibration at the PTB
& relative calibration for trend detection



Blackbody radiator BB3200pg of the PTB
→ primary standard for dissemination of spectral irradiance

$$E_{BB}(\lambda,T) = \frac{\pi.L(\lambda,T).D^2}{4d^2}$$

Cavity Temperature : 2890 K
Uncertainty = 0.44 K
Drift < 0.1 K/h



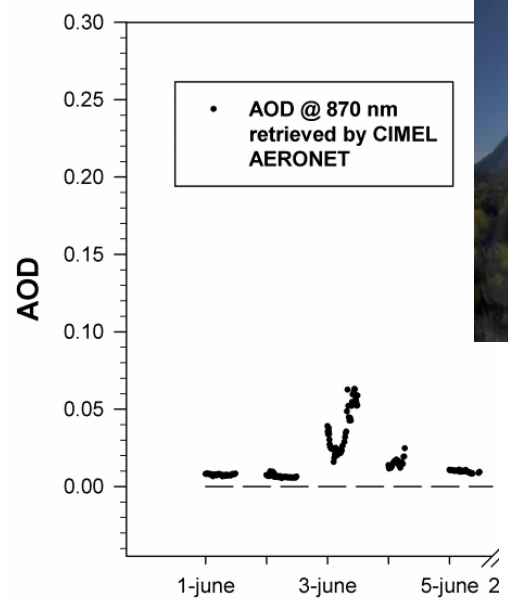
- IRSPERAD *relative calibration*
  → Four 1000 W NIST FEL lamps

- IRSPERAD characterization
  → λ scale, thermal behavior, …

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

2014 SORCE Science Meeting

The campaign



1-June 18:30

Results presented here:
from first two weeks (June 2011)

→ optimal weather conditions and strong control of all scales (radiometric, λ)

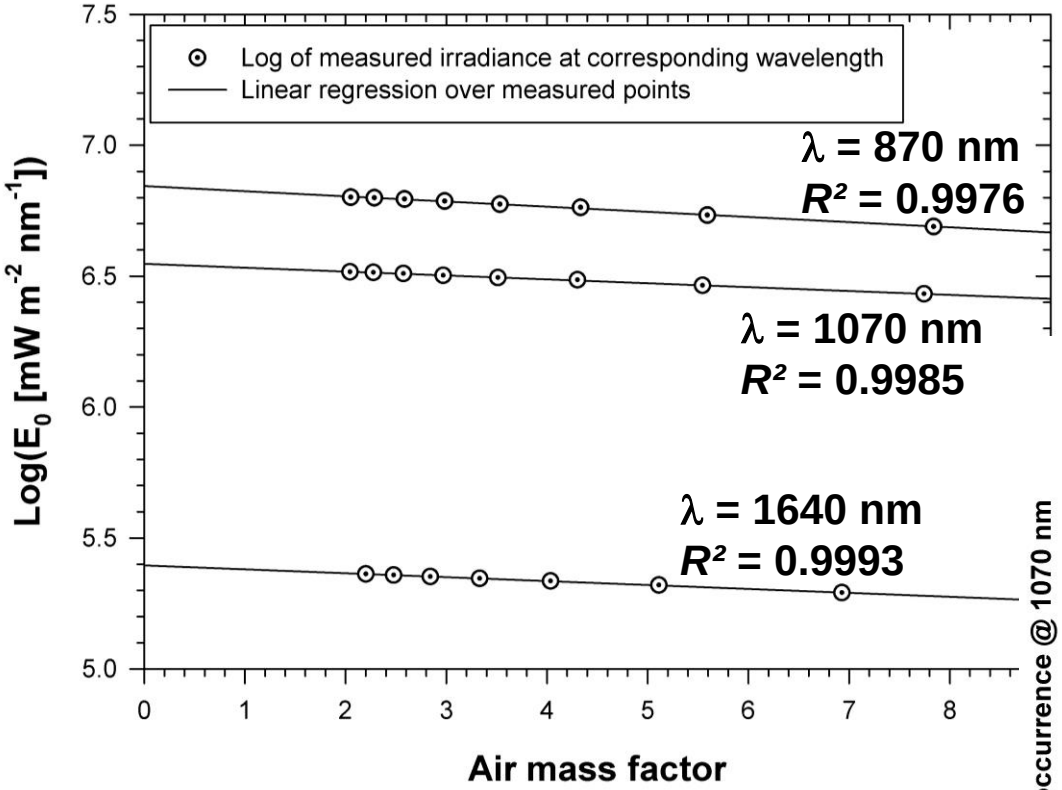
Data selection

→ clear sky, free of visible clouds
→ free of any tin (invisible) cirrus clouds
(LIDAR monitoring)
→ low Aerosol Optical Depth (AOD), *AERONET data* & low variability
→ Bouguer-Langley plots: coefficient of regression > 0.99

2014 SORCE Science Meeting

The campaign

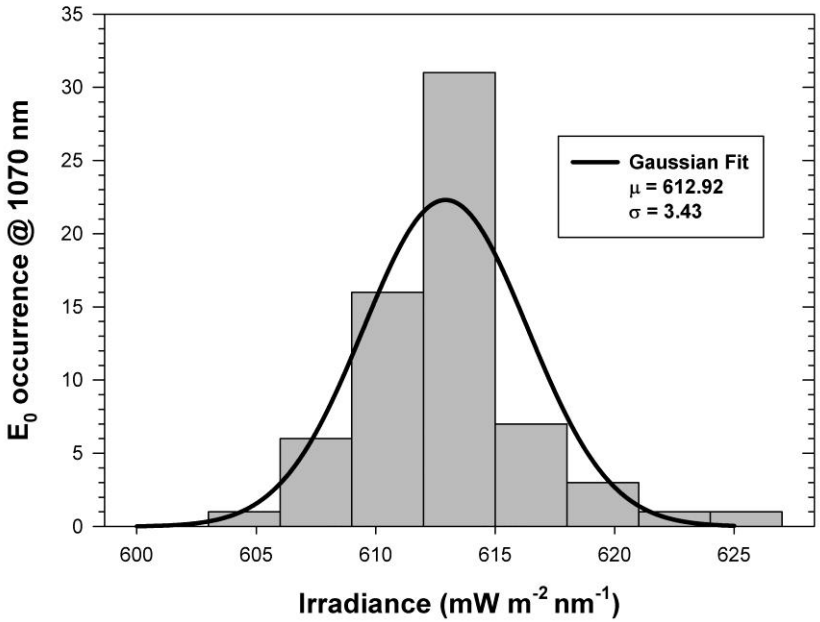
BELGIS NOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO



Langley plots:

→ 66 available events for the whole campaign

→ one third for the first two weeks



Gaussian fit for the 164 channels:

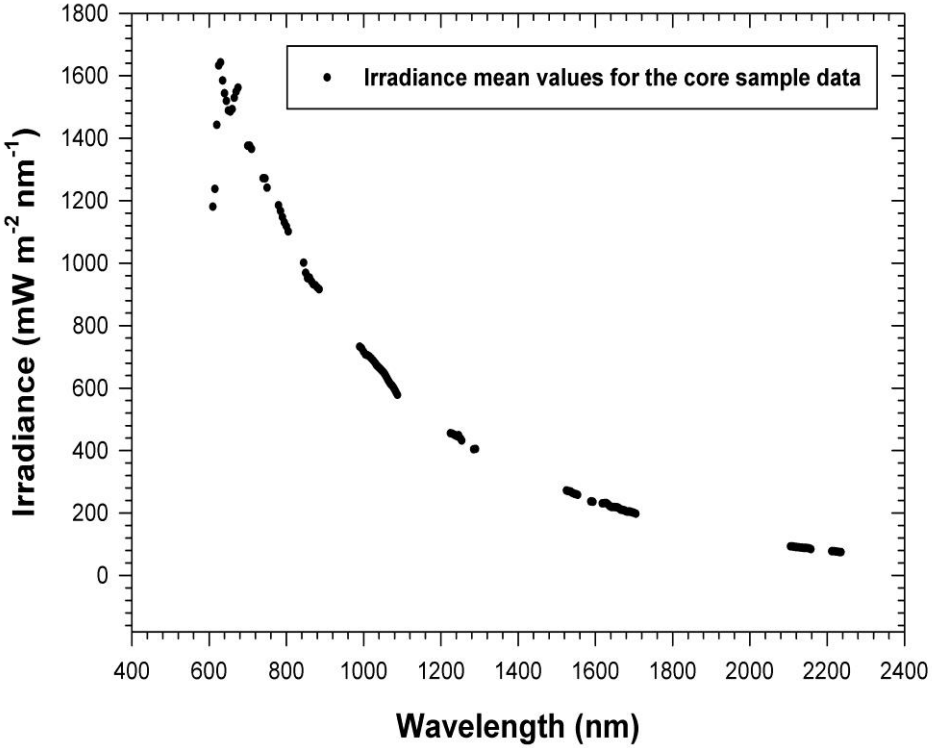
→ example for λ = 1070 nm

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

2014 SORCE Science Meeting

Results & uncertainties

Standard uncertainties → calculated using the Law of Propagation of Uncertainties (LPU) for 11 relevant wavelengths



$$E = \frac{S_{Iz} + C_{\lambda}}{1 - \frac{\alpha_T \Delta T}{100}} R.Corr$$

S_{Iz} → electronic output signal obtained for a given solar measurement

C_{λ} → stability of λ scale

Denominator → thermal correction (if required) for the detector response

$$R = \frac{E_{BB}}{S_{BB}}$$ → response curve

Corr → response change (relative units)

2014 SORCE Science Meeting

Results & uncertainties

Table 3 Relative standard uncertainties (in %) for the input variables of Equation (6) and its final estimate E for a given instantaneous solar irradiance. The two last columns represent the standard uncertainty for E_0 by two different methods: application of LPU to the Langley plots and the experimental standard deviation of the E_0 sample, as depicted in the example histogram in Figure 11. The calculation was made for 11 reference wavelengths.

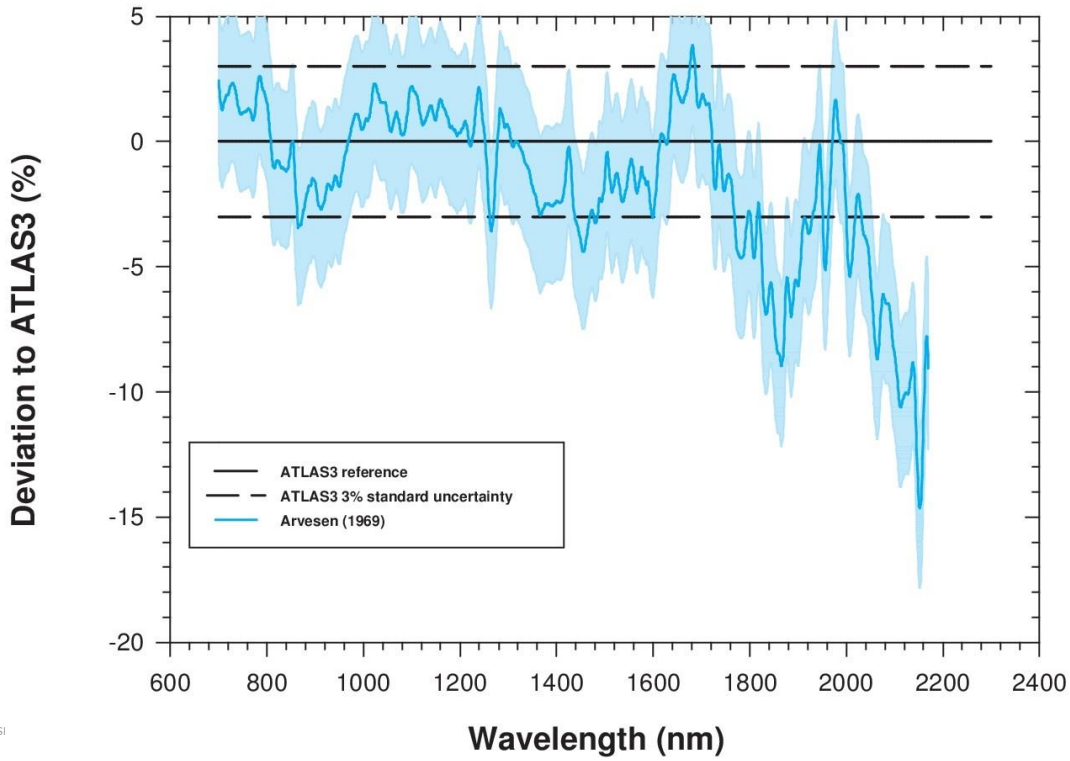
λ(nm)	$u(S_{BB})$	$u(E_{BB})$	$u(R)$	$u(S_{FEL})$	$u(\text{Corr})$	$u(S_{Iz})$	$u(E)$	$u_{LPU}(E_0)$	$u_{distr}(E_0)$
700	8.04	0.17	8.35	3.86+0.5	2.88	2.32	9.13	7.87	1.74
800	2.68	0.16	2.69	0.76+0.5	0.87	0.91	2.97	2.54	1.37
850	1.86	0.16	1.88	0.66+0.5	0.78	0.64	2.14	1.82	1.00
1000	0.46	0.15	0.51	0.14+0.5	0.44	0.22	0.72	0.61	0.59
1070	0.31	0.15	0.34	0.10+0.5	0.42	0.18	0.58	0.49	0.50
1240	0.14	0.14	0.20	0.08+0.5	0.41	0.14	0.49	0.41	0.38
1550	0.18	0.14	0.23	0.09+0.5	0.42	0.16	0.51	0.57	0.35
1620	0.21	0.14	0.36	0.08+0.5	0.41	0.18	0.58	0.65	0.29
1690	0.39	0.14	0.41	0.07+0.5	0.40	0.19	0.62	0.67	0.51
2120	0.68	0.13	0.69	0.15+0.5	0.47	0.42	0.94	1.00	0.79
2200	0.95	0.13	0.97	0.32+0.5	0.61	0.62	1.30	1.37	0.50

2014 SORCE Science Meeting

Discussion & comparisons

1) SOLSPEC ATLAS3 → SOSP version of SOLSPEC (EURECA 1992 – 1993)
Absolute calibration (blackbody of Heidelberg)
Announced standard uncertainty around 3 %

2) Arvesen → airborne set data at 12 km of altitude (1969)
Calibration using a 1000 W quartz-halogen lamp
Standard uncertainty around 3 %



2014 SORCE Science Meeting

Discussion & comparisons

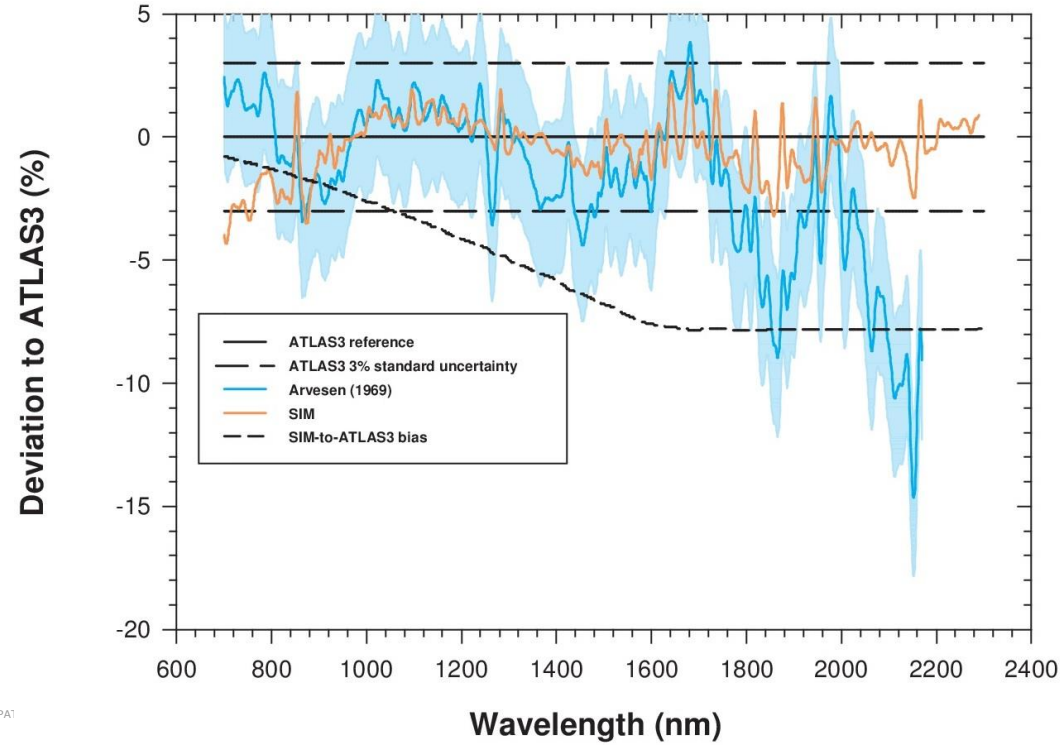
3) SIM on SORCE → prism spectrometer (2003 –)

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

A SIM-to-ATLAS3 deviation was found and corrected because:

→ the calculated uncertainties reached 8 % for SIM above 1.35 µm

→ the need to achieve both a more plausible TSI and solar brightness temperature values (around 1.6 µm) as ATLAS3 did



BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPA
OMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

2014 SORCE Science Meeting

Discussion & comparisons

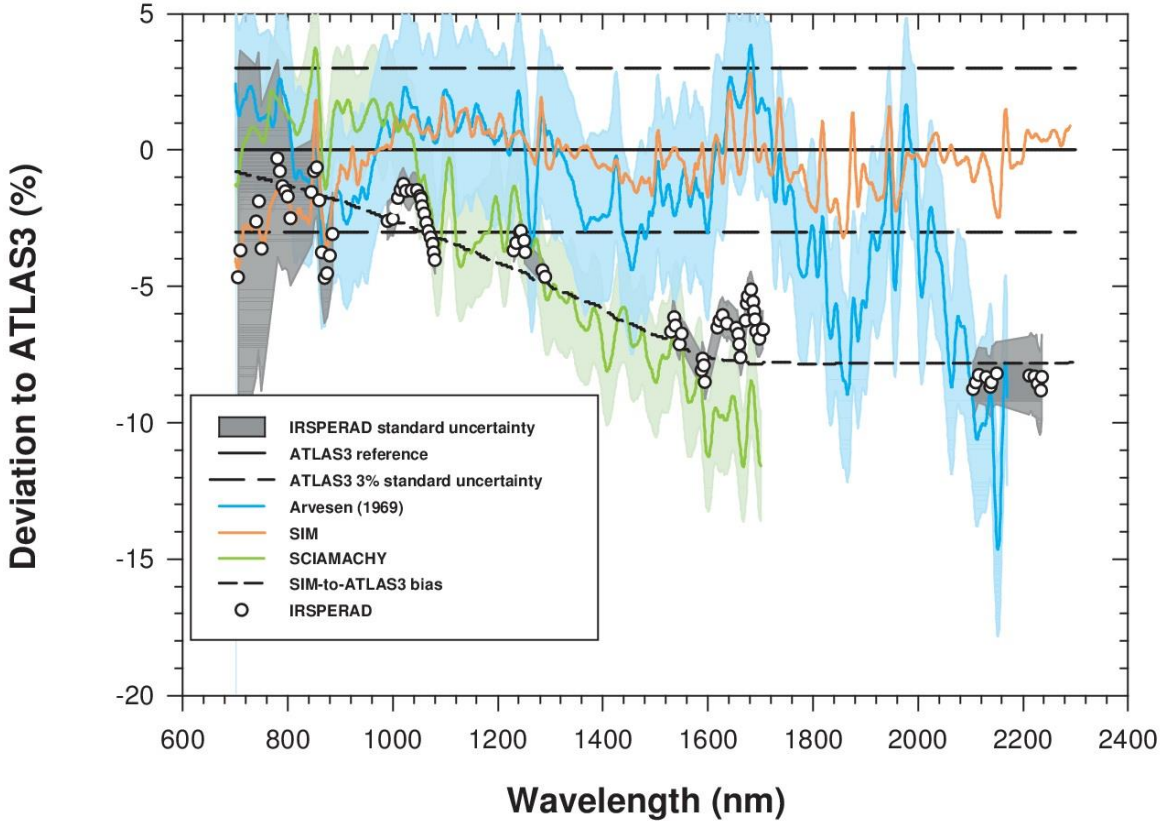
4) SCHIAMACHY → remote-sensing spectrometer with NIR channels (2002 – 2012)

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

Absolute calibrated

Estimated standard uncertainty: 2 %

5) IRSPERAD



BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

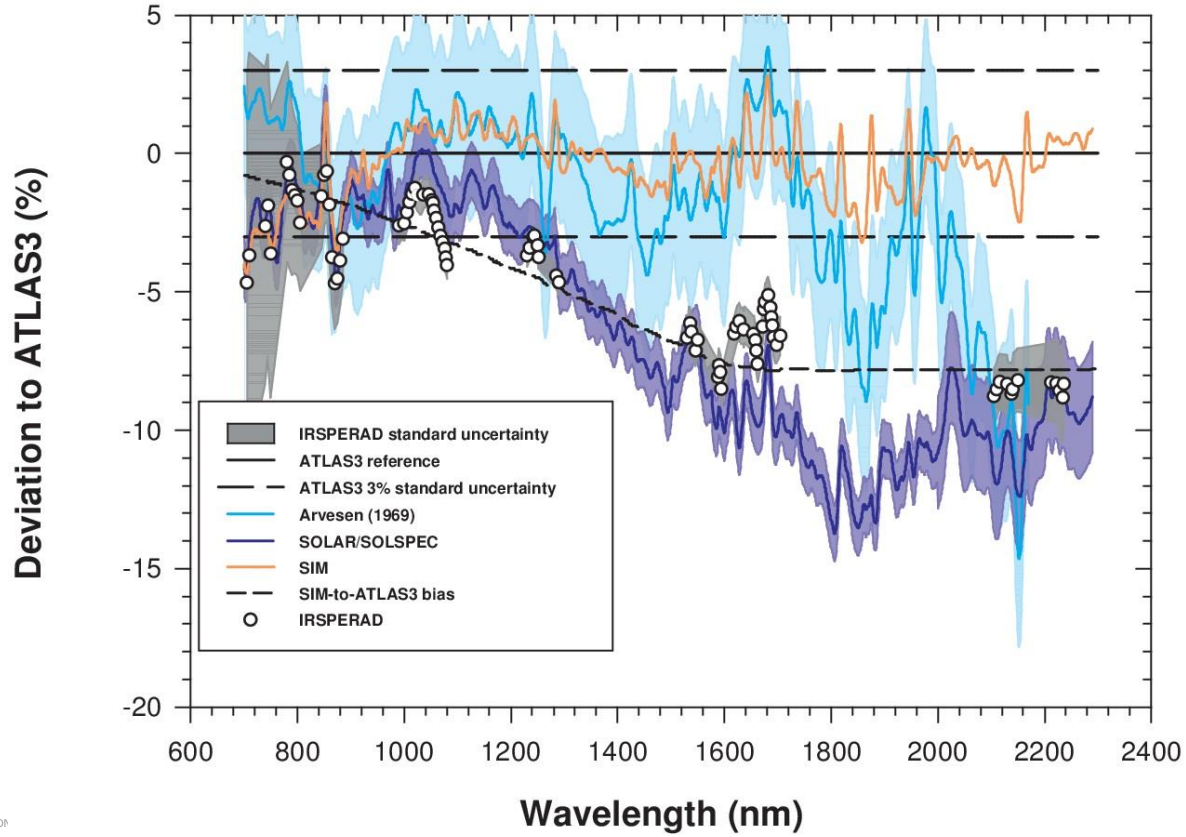
2014 SORCE Science Meeting

Discussion & comparisons

6) SOLAR/SOLSPEC → SOLAR mission on ISS (2008 – ---)

Renewed NIR channel, absolute calibrated at the PTB (blackbody)

Estimated standard uncertainty: lower than 2 % for most of the NIR range



2014 SORCE Science Meeting

Discussion & comparisons

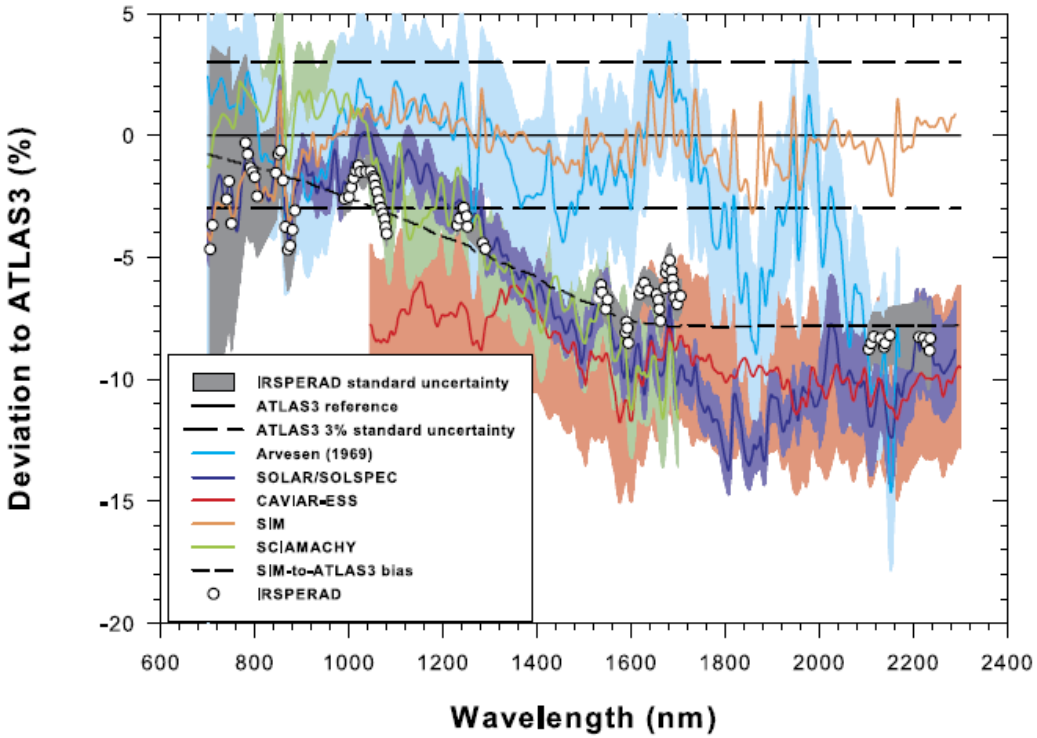
7) CAVIAR ESS → high-resolution Fourier Spectrometer (2008)

TOA SSI retrieved using the Bouguer-Langley method (at sea level)
Absolute calibrated at the NPL (blackbody)
Estimated standard uncertainty in the range of 3.3 % to 5.9 %

→ Composite results:

All sets of data are independent (hardware, methodology, calibration)

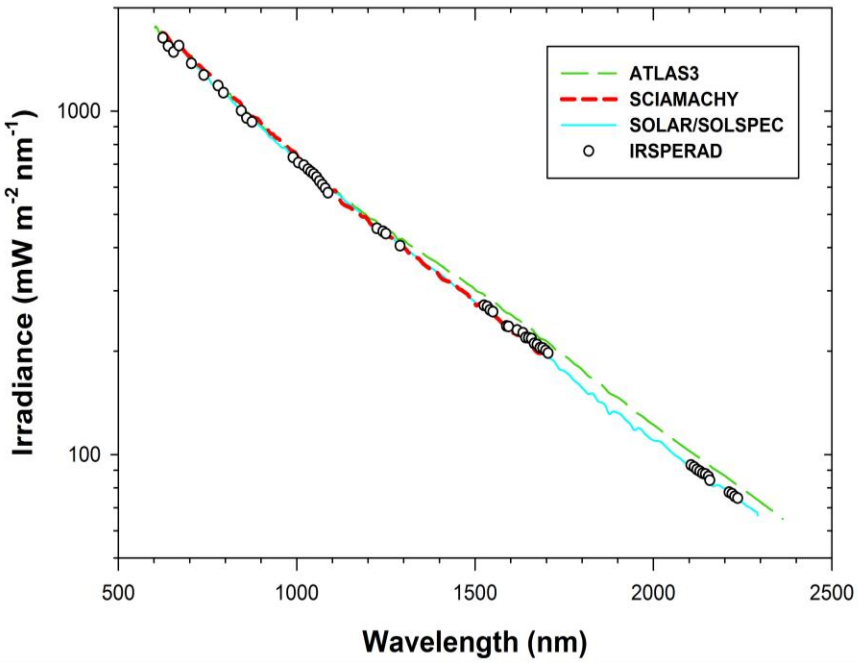
Except:
1) IRSPERAD – SOLAR/SOLSPEC (blackbody)
2) CAVIAR ESS – IRSPERAD (Bouguer-Langley)

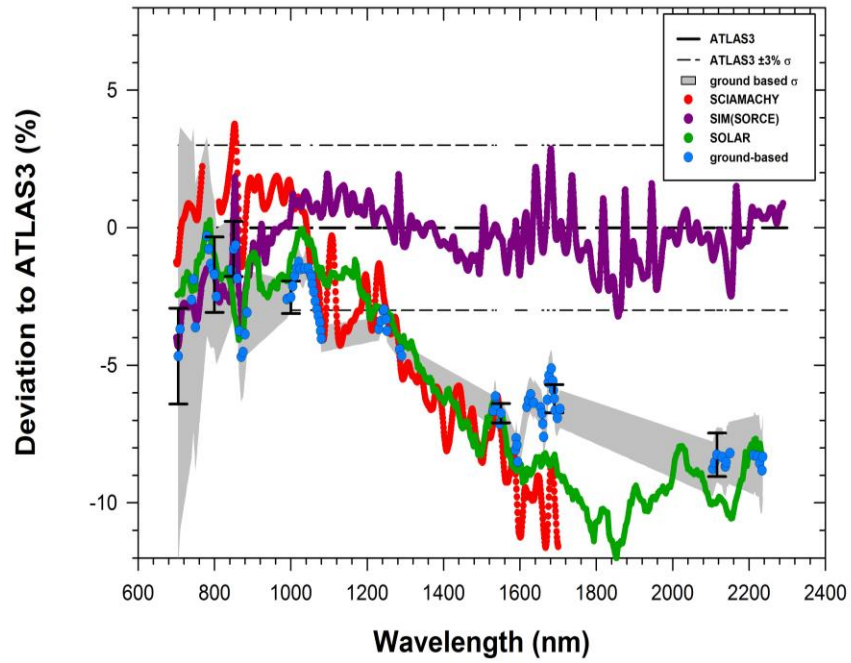


2014 SORCE Science Meeting

Discussion & comparisons

Comparison between IRSPERAD and space NIR SSI measurements





IRSPERAD agrees with the expected local SSI maximum at 1.6 µm
but → **brightness temperature ~350 K below ATLAS3**

2014 SORCE Science Meeting

Conclusions

BELGISCH INSTITUUT VOOR RUIMT

IRSPERAD

RUIMTE-AERONOMIE INSTITUT D'AERO

- Based on a simplified methodology (Bouguer–Langley) providing an easy access to the TOA solar spectral irradiance.
- Stable instrumentation (full radiometric control over the experimental setup and the error sources).
- Reliability of the calibration using the blackbody of the PTB as primary standard source.
- Benefit of the ideal atmospheric conditions at IZO

→ This measurement campaign could provide a reference NIR SSI data set from the ground. However, limited to a series of NIR wavelengths that correspond to the atmospheric windows.

This work was intended to bring some contributions to the actual discussions on the solar irradiance around 1.6 µm.

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO
belspo .be

2014 SORCE Science Meeting

Thank you for your attention

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

This work is published in Solar Physics since 17th January 2014
→ online version *DOI 10.1007/s11207-014-0474-1*

In memory of W. Decuyper († 20th January 2014)
involved in SOLSPEC during nearly 40 years

Acknowledgement

We wish to thank:

- **The staff of the IZO and the PTB**
- **B. C. Kindel (University of Colorado, Boulder, USA) for kindly providing us the calculations with MODTRAN of the valid Bouguer–Langley channels in the NIR for our instrument.**

This work was funded by Belgian Federal Science Policy Office (BELSPO) through the ESA-PRODEX program and the funding of the Solar-Terrestrial Centre of Excellence (STCE). This work received the financial support from the EU SOLID project.

BELGISC ONOMIE INSTITUT D'AERO