SOLSPEC onboard the International Space Station: Absolute Solar Spectral Irradiance in the Infrared Domain and Comparison with Recent Solar Models

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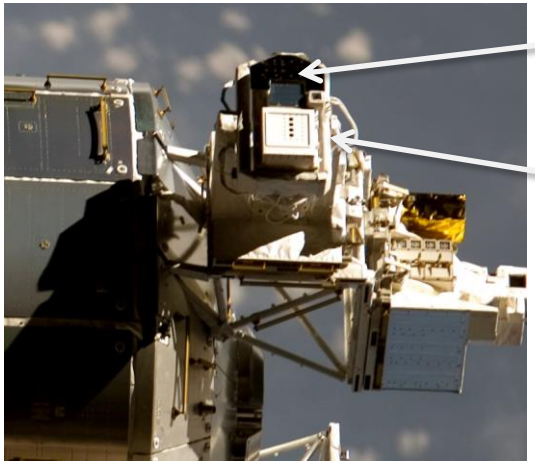
SORCE Meeting 9-13 November 2015, Savannah, Ga



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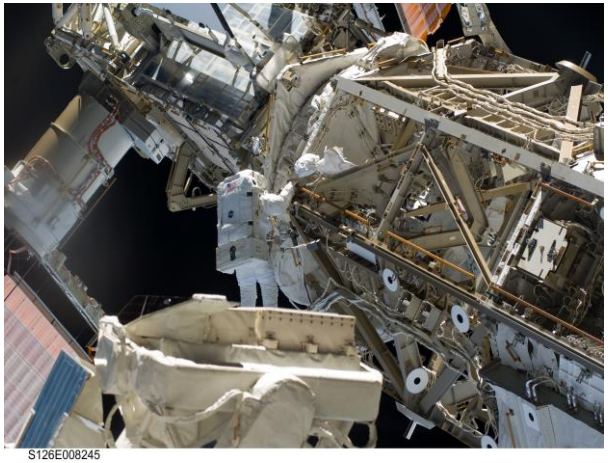


SOLAR on COLUMBUS Laboratory

SOLSPEC: A triple spectromer having a spectral range: 170-3000 nm using double holographic gratings. The spectral range 170-3000 nm is measured in 11 minutes.

UV spectrometer: 170-380 nm, spectral width: 1 nm, sampling 0.4 nm
VIS spectrometer: 300-980 nm, spectral width: 1 nm, sampling 1.0 nm
IR spectrometer: 800-3000 nm, spectral width 9 nm, sampling 4 nm

SolACES: A 4 grazing incidence grating spectrometers and two three-ionization chambers with exchangeable band pass filters to determine absolute fluxes from 17 to 150 nm.

SolACES has several gas reservoirs allowing to absorb the incident solar photons as a function of pressure, which determines the characteristics of the spectrometers.

INITIAL OBJECTIVE: THE SOLAR MINIMUM OF 2008 FROM 17 to 3000 nm USING SolACES and SOLSPEC ONBOARD THE ISS

- Solar Spectral Irradiance (SSI) minimum may be used as the baseline of SSI reconstructions.

- Furthermore, it is used for running a climate models in low solar activity periods such as the Dalton minimum.

- By comparing successive SSI minima, the long term trend of the solar activity can be studied. Nevertheless, the accuracy of the data used in this comparison is the key point. They are essential to the solar physicists to investigate the cause of the minimum, in particular the recent 2008 minimum, lower than the two others (cycles 21 to 22 and 22 to 23).

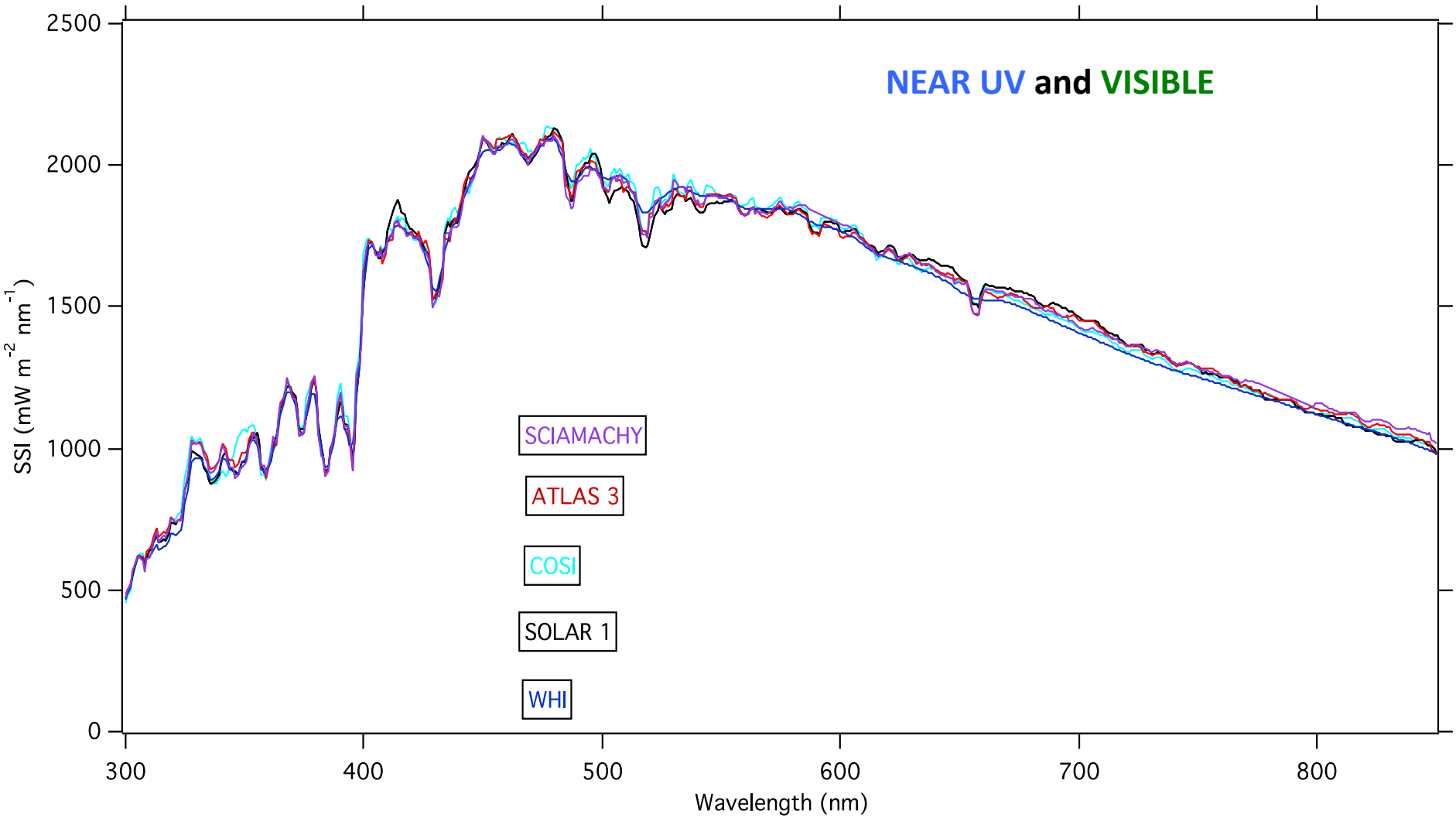
Thuillier G., Bolsée, D., Schmidtke, G., et al. The Solar Irradiance Spectrum at Solar Activity Minimum Between Solar Cycles 23 and 24, Solar Physics, doi: 10.1007/s11207-013-0461-y, 2014

DATA AND MODELS USED IN THE PRESENT STUDIES

- Existing spectra:
- ATLAS 3 (Thuillier et al., 2004). SSI at the transition cycle 22 to 23
- Whole Heliospheric Interval (WHI, Woods et al., 2009) dated of 14 February 2008.
- SCIAMACHY (Weber, private communication, 2013)
- SOLAR2, measured by SOLSPEC onboard the ISS
- SOLAR1 = SOLAR2 up to 1000 nm, above, it is ATLAS3

- Theoretical Models:
- COSI (Shapiro et al., 2010) and SRPM (Fontenla et al., 2011)

- SSI reconstruction models:
- SATIRE (Yeo et al., 2014) and NRLSSI (Lean et al., 2011)

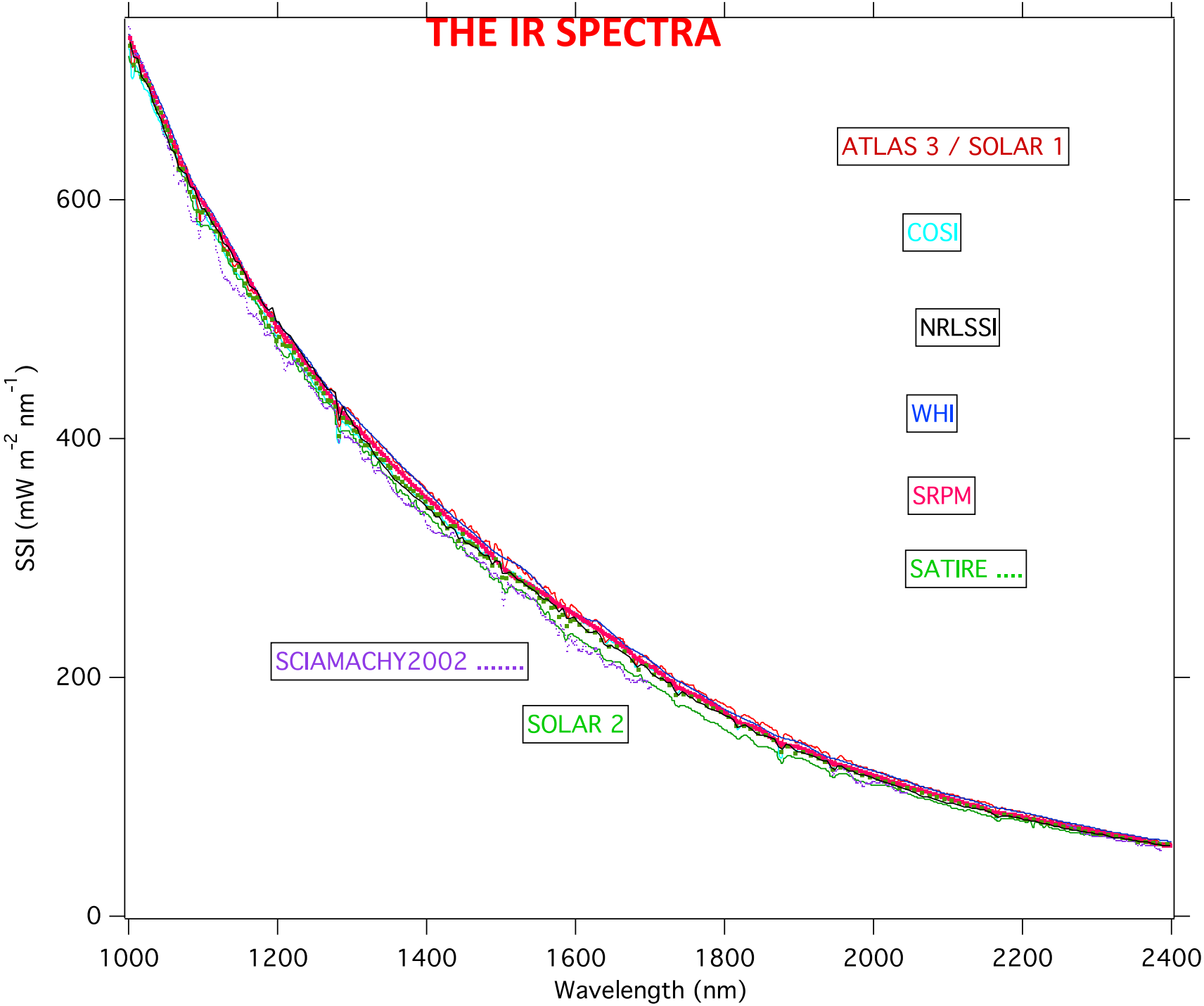

NEAR UV and VISIBLE
SCIAMACHY
ATLAS 3
COSI
SOLAR 1
WHI
SSI (mW m-2 nm-1)
Wavelength (nm)
0
500
1000
1500
2000
2500
300
400
500
600
700
800

COMPARISON BETWEEN WHI, COSI, SOLAR 1, SOLAR 2, ATLAS 3, SRPM

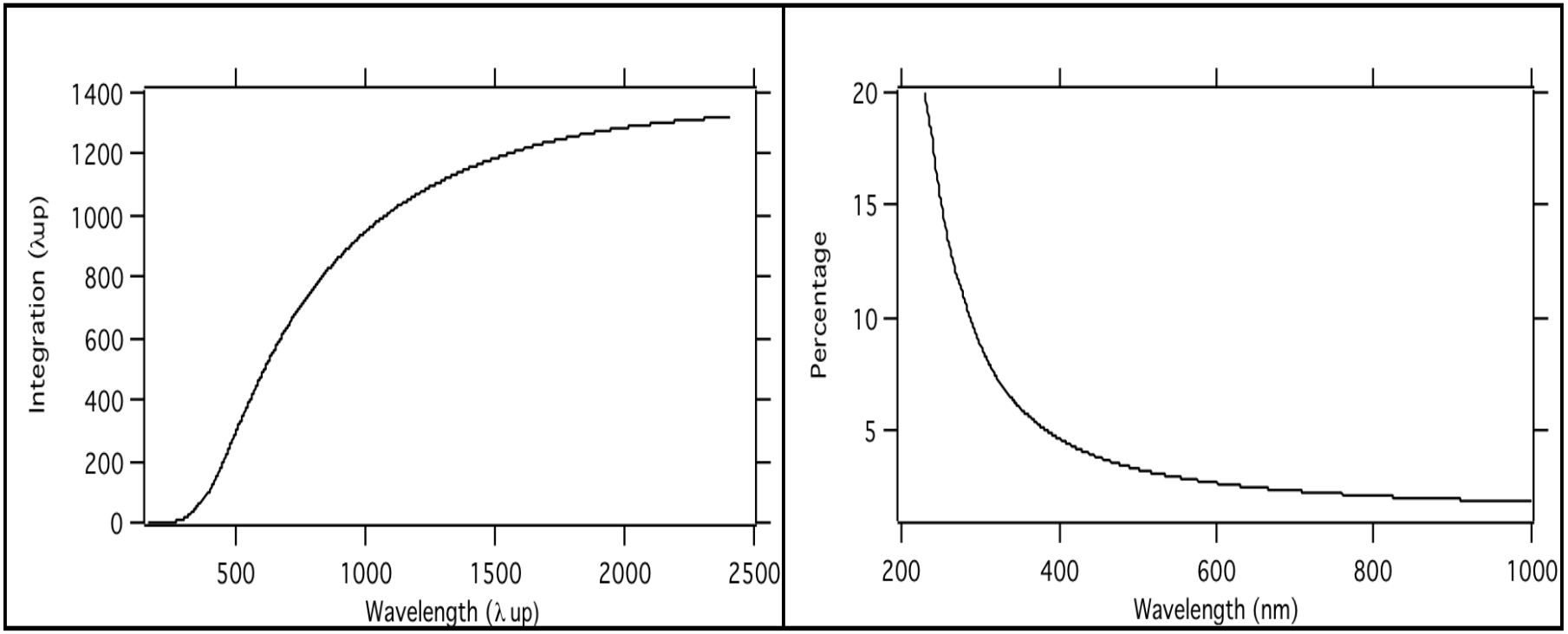
Δλ (nm)	SRPM/SOL	COSI/SOL	A3/SOL	WHI/SOL	WHI/A3	WHI/COSI	SRPM/COSI
210--350	0.96	1.01	1.03	0.98	0.95	0.96	0.95
350--500	0.99	1.00	1.00	0.99	0.99	0.98	0.98
350--850	1.01	1.00	1.00	0.99	0.99	0.99	1.01
220--260	0.95	1.00	1.09	0.98	0.90	0.99	0.95
260--300	0.85	0.97	1.02	0.97	0.94	0.99	0.87
300--340	1.01	1.02	1.03	0.98	0.95	0.96	0.99
340--370	0.96	1.02	1.00	0.99	0.98	0.97	0.95
350--425	0.97	1.00	0.99	0.99	0.99	0.98	0.96
425--500	1.00	1.00	1.00	0.99	0.99	0.99	1.00
500--575	1.05	1.02	1.01	1.02	1.01	1.00	1.02
575--650	1.01	0.99	0.99	0.99	0.99	0.99	1.01
650--725	1.00	0.98	0.99	0.97	0.98	0.99	1.02
725--800	1.02	0.99	1.00	0.98	0.98	0.99	1.02

Dl (mm)	COSI/A3	WHI/A3	SOL1/A3	SOL2/A3	SCIA/A3	COSI/SOL2
210-2400	0.992	0.993	0.997	0.984		
1000-2000	0.997	1.003	0.996	0.950		
1000-1761	0.983	1.005	0.999	0.958	0.980	
1000-2400	0.976	1.004	0.997	0.949		
1936-2042	0.947	0.992	0.992	0.909	0.939	
2260-2384	0.965	1.011	1.000	0.949	0.965	
2400-2900						1.042

THE IR SPECTRA



DEFICIT SOLAR 2/ATLAS 3 in the interval 1000-2400 nm: 19 W/m^2

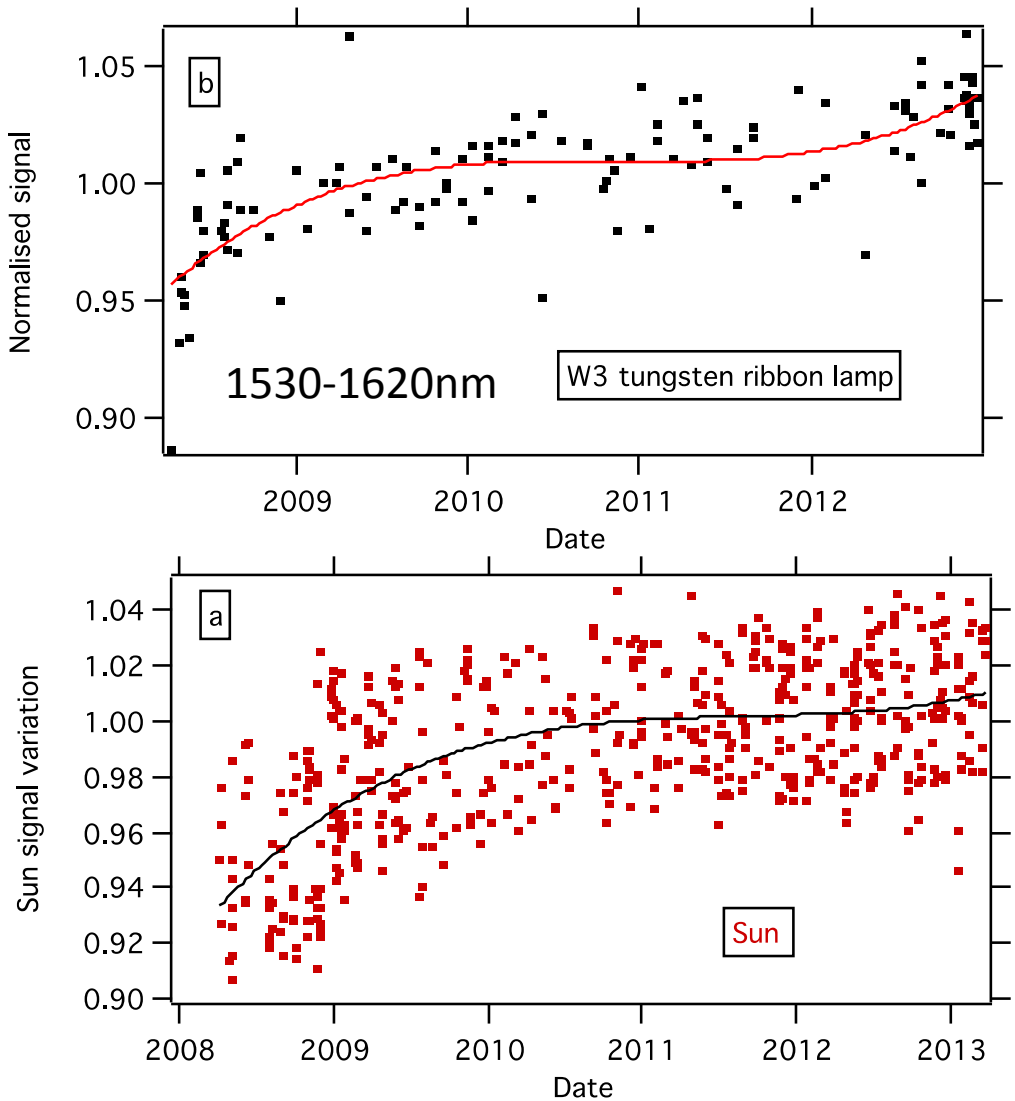


The left panel shows the variation of the integrated **WHI** spectrum as a function of λ_{up}. The right panel shows the percentage of **systematic** overestimation of SSI to represent 19W/m^2 as a function of λ_{up}.

The right panel shows that with 2% constant uncertainty, the corresponding domain extends to 1000 nm. However, a systematic 2% uncertainty is not possible given the distribution of contributing sources uncertainties as a function of wavelength (BB, lamps, detectors, linearity). With 5% uncertainty, the corresponding domain extends to 400 nm.

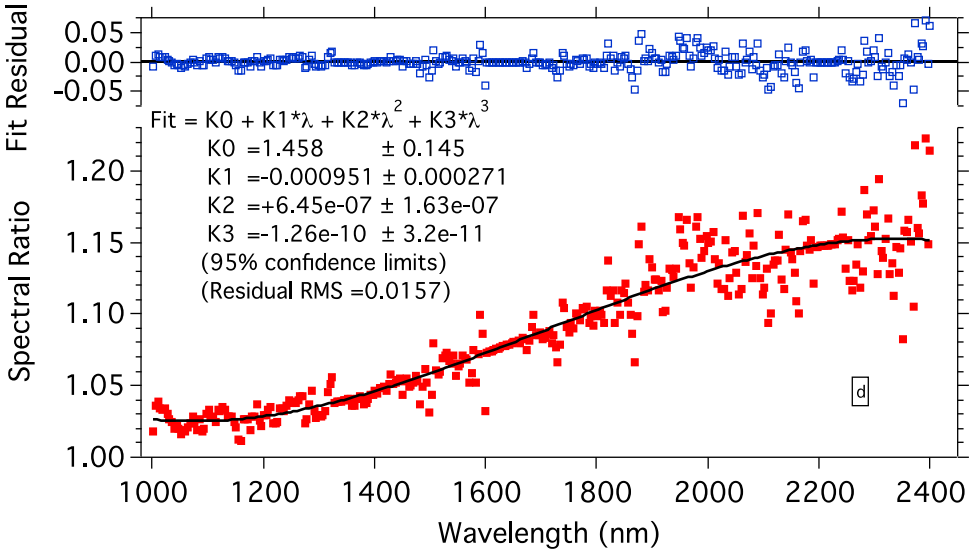
Such uncertainties are not compatible with the accuracy of the SIM-SORCE instrument absolute calibration.

IR SPECTROMETER RESPONSIVITY STABILIZATION WITH TIME

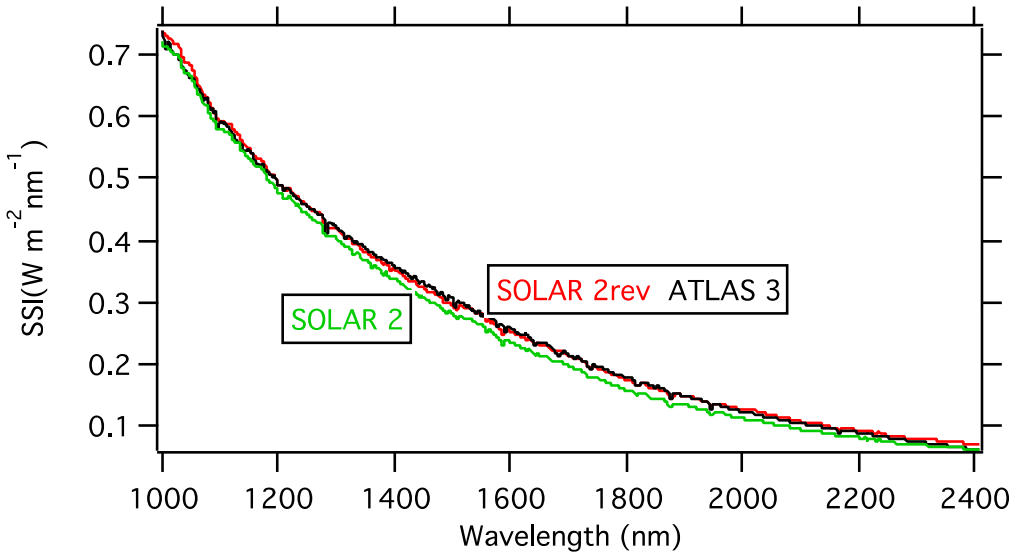


SOLAR 2 was measured at **first light**. The deficit of 7% at 1700 nm mainly originates from the IR spectrometer responsivity change with time (contamination on ground, at launch, by internal outgassing?). Is that ratio function of wavelength?

CORRECTION OF IR SOLAR 2: METHOD

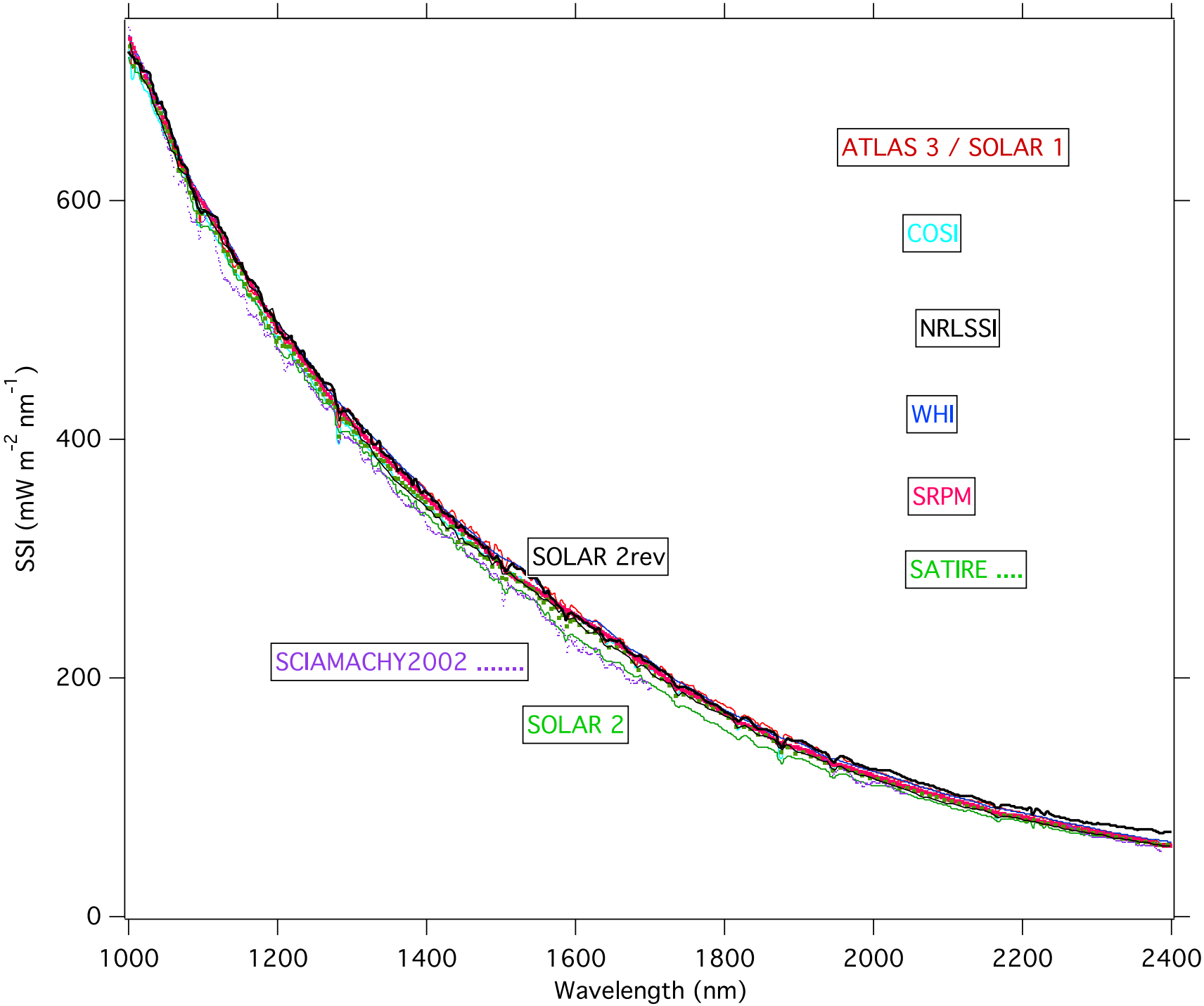


The ratio of the 2010 mean spectrum to 2008 mean spectrum is displayed as a function of wavelength. Around 1330, 1600 and 2200 nm, there are spectrometer filter changes, that generates variations in the ratio amplitude of about ± 5%, which is removed by using the polynomial fitting.



The trend 2010/2008 with wavelength depicted in the above Figure has been fitted by a 3rd order polynomial and applied to SOLAR 2.
The resulting spectrum is named SOLAR 2rev. It is shown with ATLAS 3 and SOLAR 2.

As the difference between SOLAR 2rev and ATLAS 3 is within the thickness of the lines, the next panel displays one versus the other.


ATLAS 3 / SOLAR 1
COSI
NRLSSI
WHI
SRPM
SATIRE ....
SOLAR 2rev
SCIAMACHY2002 .....
SOLAR 2
SSI (mW m^{-2} nm^{-1})
0
200
400
600
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)

IR SOLAR 2revised: TSI IMPLICATION

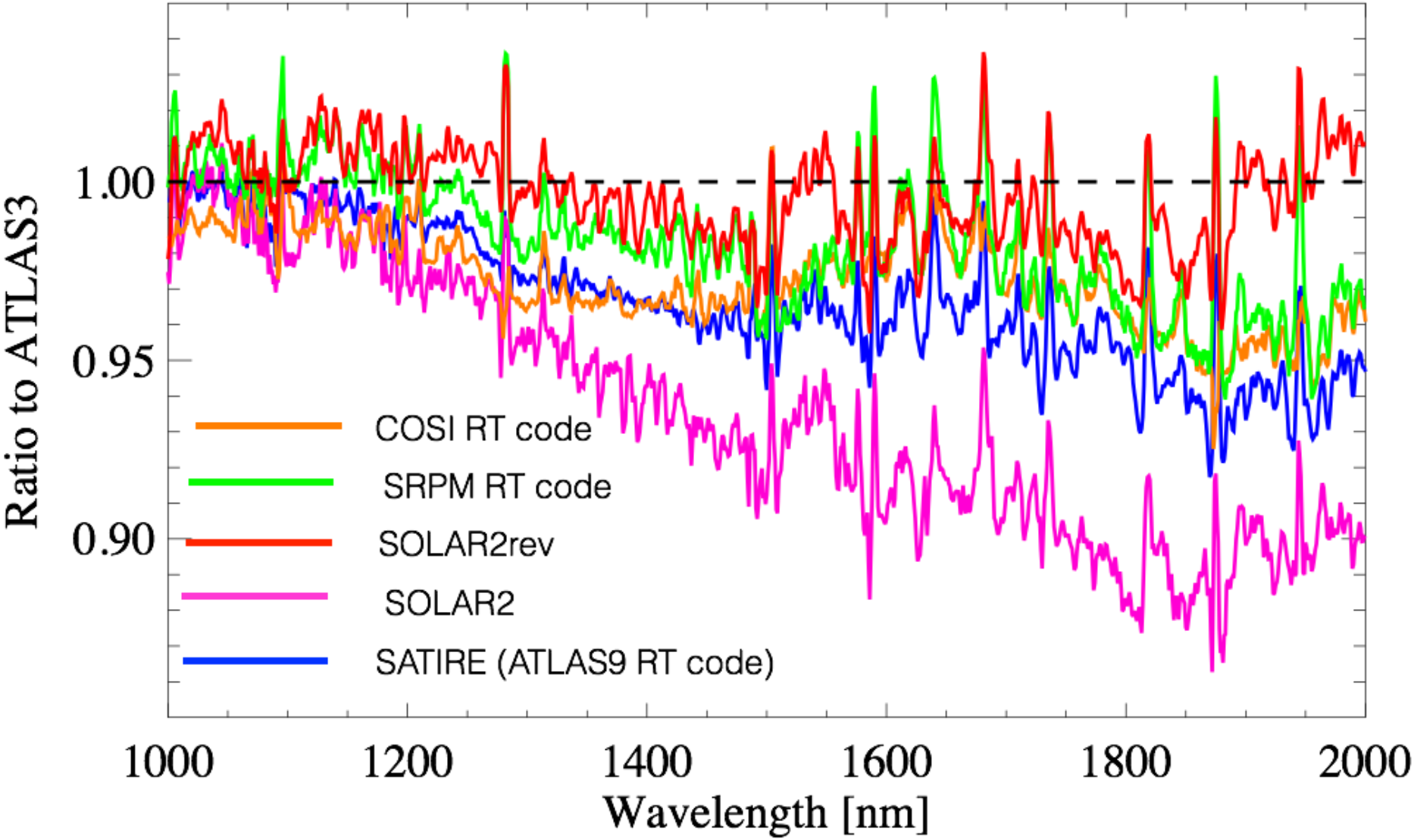
The IR spectrometer responsivity is increasing with time as shown.
It is also a slight function of wavelength as shown by the ratio of a spectrum in 2010 (instrument stabilized) to the spectrum at first ligth (SOLAR 2).
This correction is applied to the IR SOLSPEC measurements (SOLAR2) providing SOLARrev.

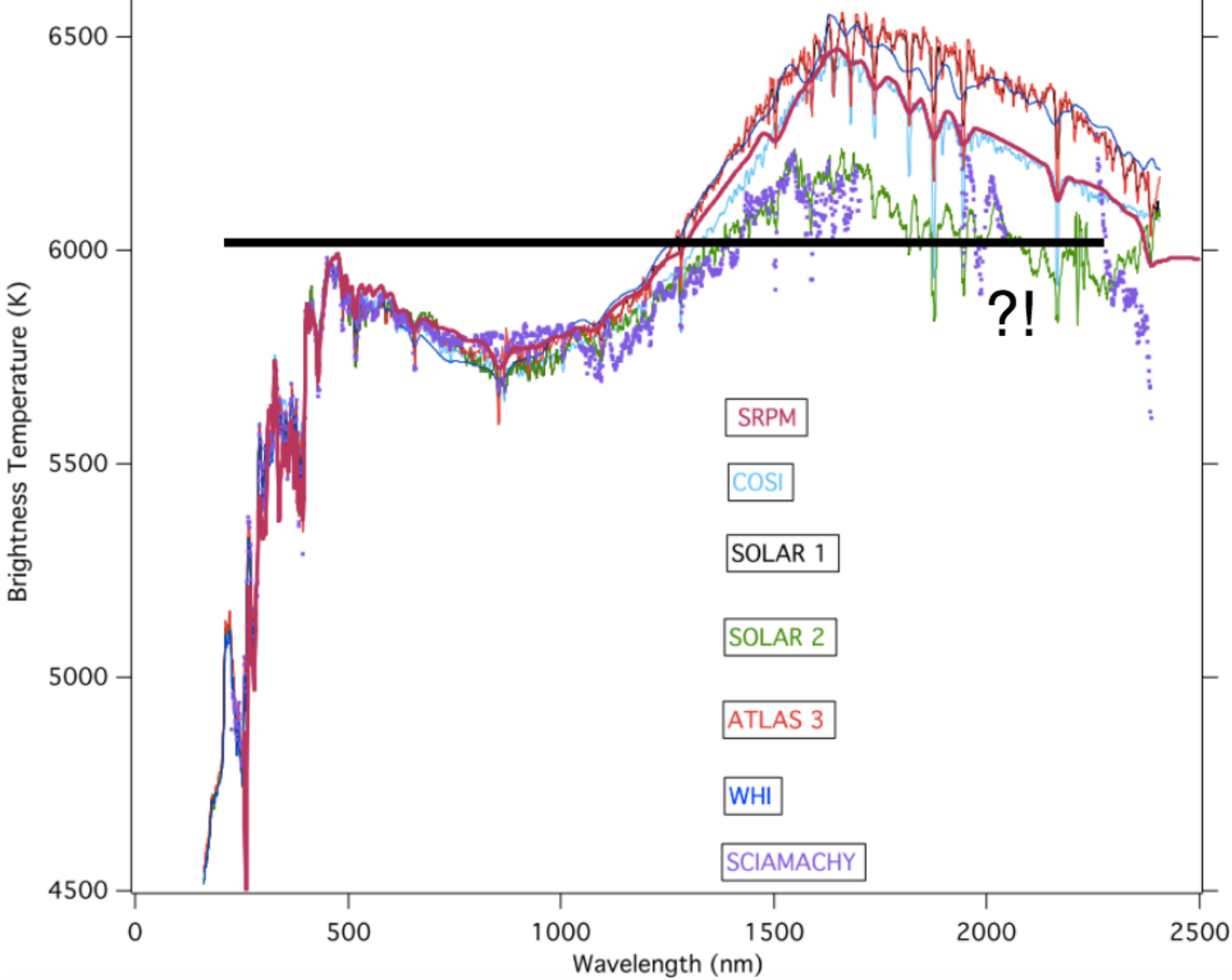
The power provided by these spectra obtained by integration between 1000 and 2400 nm, is displayed below:

Spectrum	Power between 1 and 2.4 μm	Difference/ To ATLAS 3	Missions/ comments
SOLAR 1	373.0 Wm^{-2}	0.	ATLAS 3
SOLAR 2	354.2 Wm^{-2}	19 Wm^{-2}	SOLSPEC-ISS
SOLAR2rev	369.3	3.7 Wm^{-2}	SOLAR 2 revised

This correction allows to reduce the difference SOLAR 2 to ATLAS 3 to 1%.
Such a difference is compatible with the uncertainty affecting these two spectra.
Consequently, SOLAR 2revised with the wavelength trend is in agreement with ATLAS 3.

IR SOLAR 2revised: SSI COMPARISON




6500
6000
5500
5000
4500
Brightness Temperature (K)
0
500
1000
1500
2000
2500
Wavelength (nm)
?!
SRPM
COSI
SOLAR 1
SOLAR 2
ATLAS 3
WHI
SCIAMACHY

CONCLUSIONS

1) The SOLAR 2 spectrum extending from 17 to 2400 nm has been obtained by the SOLSPEC and SolACES spectrometers both running on the ISS.
It is compatible with WHI and compatible with ATLAS 3 in the visible range. In UV , the SSI is lower than ATLAS 3 given the very low solar activity period during which it was measured

2) The **IR** SSI SOLAR 2 is lower than ATLAS 3

The origin of the discrepancy in the IR domain between ATLAS 3 and SOLAR 2-ISS is due to a late stabilization of the IR spectrometer. Its origin remains unknown up to now.

SOLAR 2-ISS in the IR domain is incompatible
- with the TSI
- with the solar models in IR (Irradiance and brightness temperature)
- with the absolute calibration of both SIM-SORCE (up to 1.3 μm) and SOLSPEC-ISS in the visible

3) SOLSPEC-ISS calibration coefficients are correct if applied when the IR spectrometer has reached its stability. The long time to recover this stability remains unexplained.

4) Using data when the stabilisation is achieved, IR SOLAR $2_{revised}$ becomes compatible with ATLAS 3, TSI and solar models (SATIRE, NRLSSI, COSI, SRPM), however incompatible with ground based measurements as provided by Menang et al., 2013 and Bolsée et al., 2014.

Thuillier et al., Solar Physics, 2015, 29(6), pp.1581-1600. <10.1007/s11207-015-0704-1>

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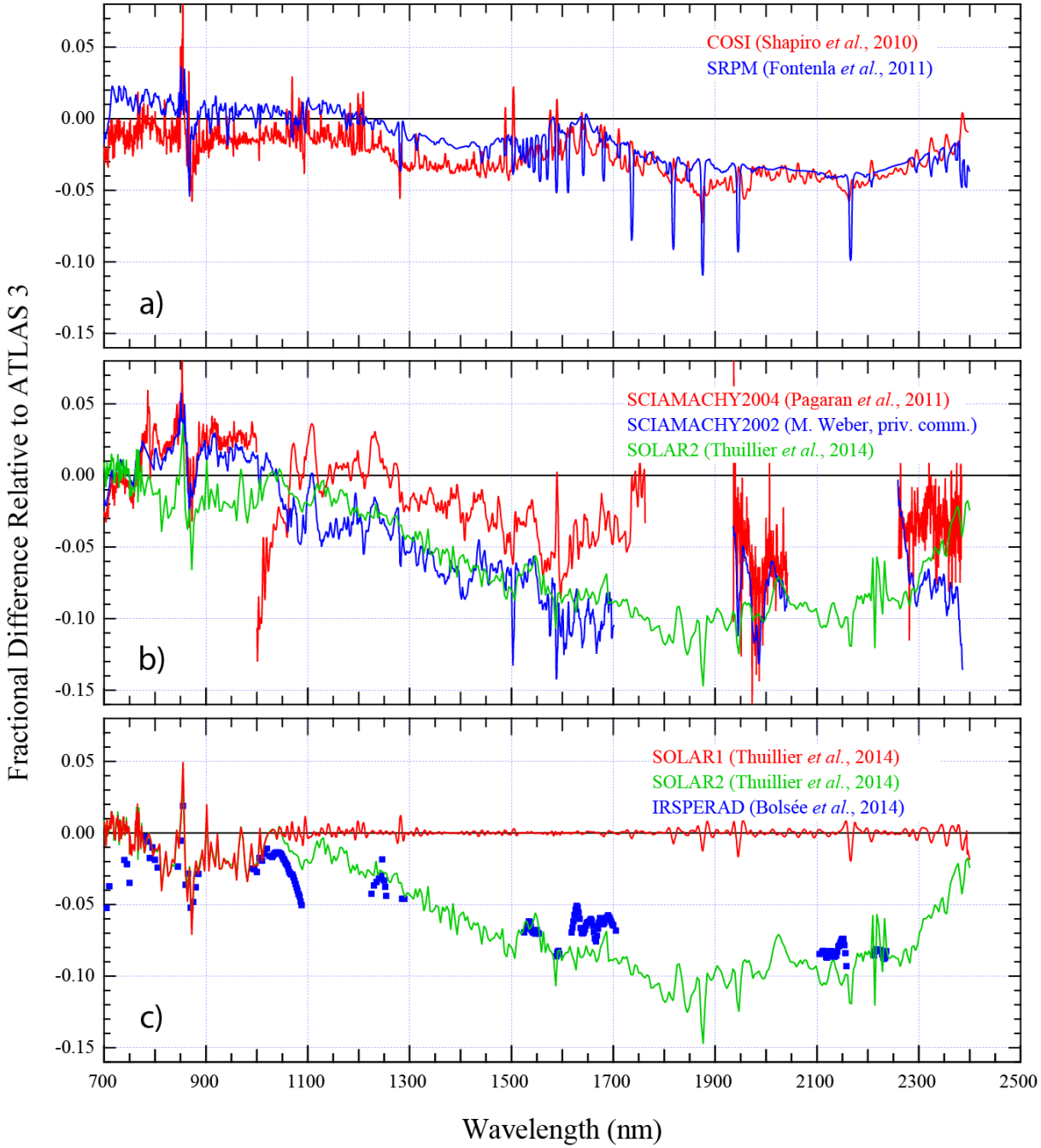
COSI (Shapiro et al., 2010)
SRPM (Fontenla et al., 2011)
a)
SCIAMACHY2004 (Pagaran et al., 2011)
SCIAMACHY2002 (M. Weber, priv. comm.)
SOLAR2 (Thuillier et al., 2014)
b)
SOLAR1 (Thuillier et al., 2014)
SOLAR2 (Thuillier et al., 2014)
IRSPERAD (Bolsée et al., 2014)
c)
Fractional Difference Relative to ATLAS 3
Wavelength (nm)
0.05
0.00
-0.05
-0.10
-0.15
700
900
1100
1300
1500
1700
1900
2100
2300
2500