SOLSPEC MEASUREMENTS OF THE SOLAR SPECTRAL IRRADIANCE FROM 170 to 2900 nm ON BOARD THE INTERNATIONAL SPACE STATION

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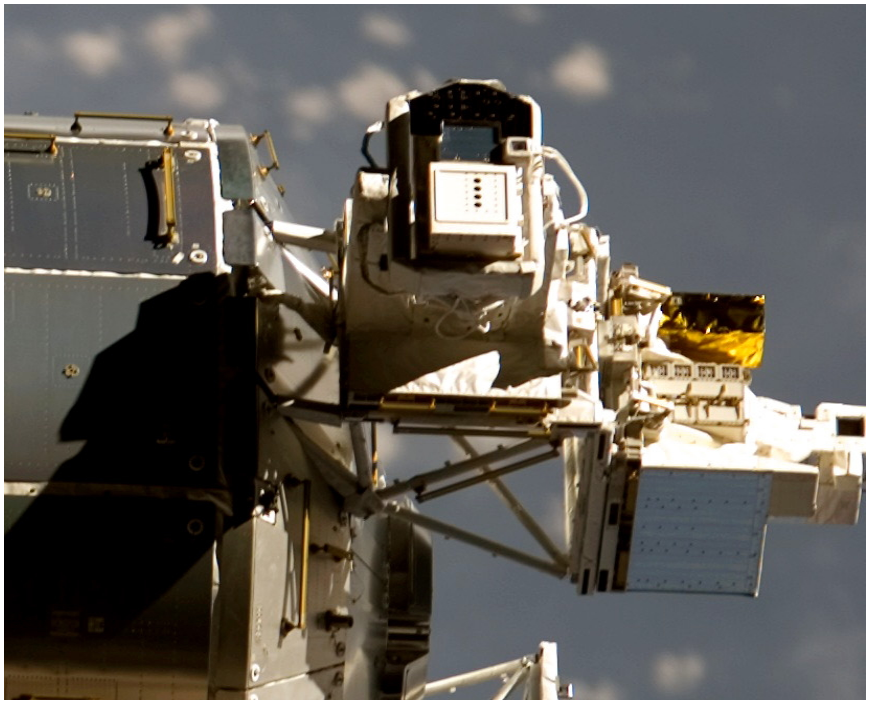
SORCE meeting 27-31 January 2013

SOLSPEC and SoLACES SSI MEASUREMENTS FROM 170 to 2900 nm ON BOARD THE INTERNATIONAL SPACE STATION

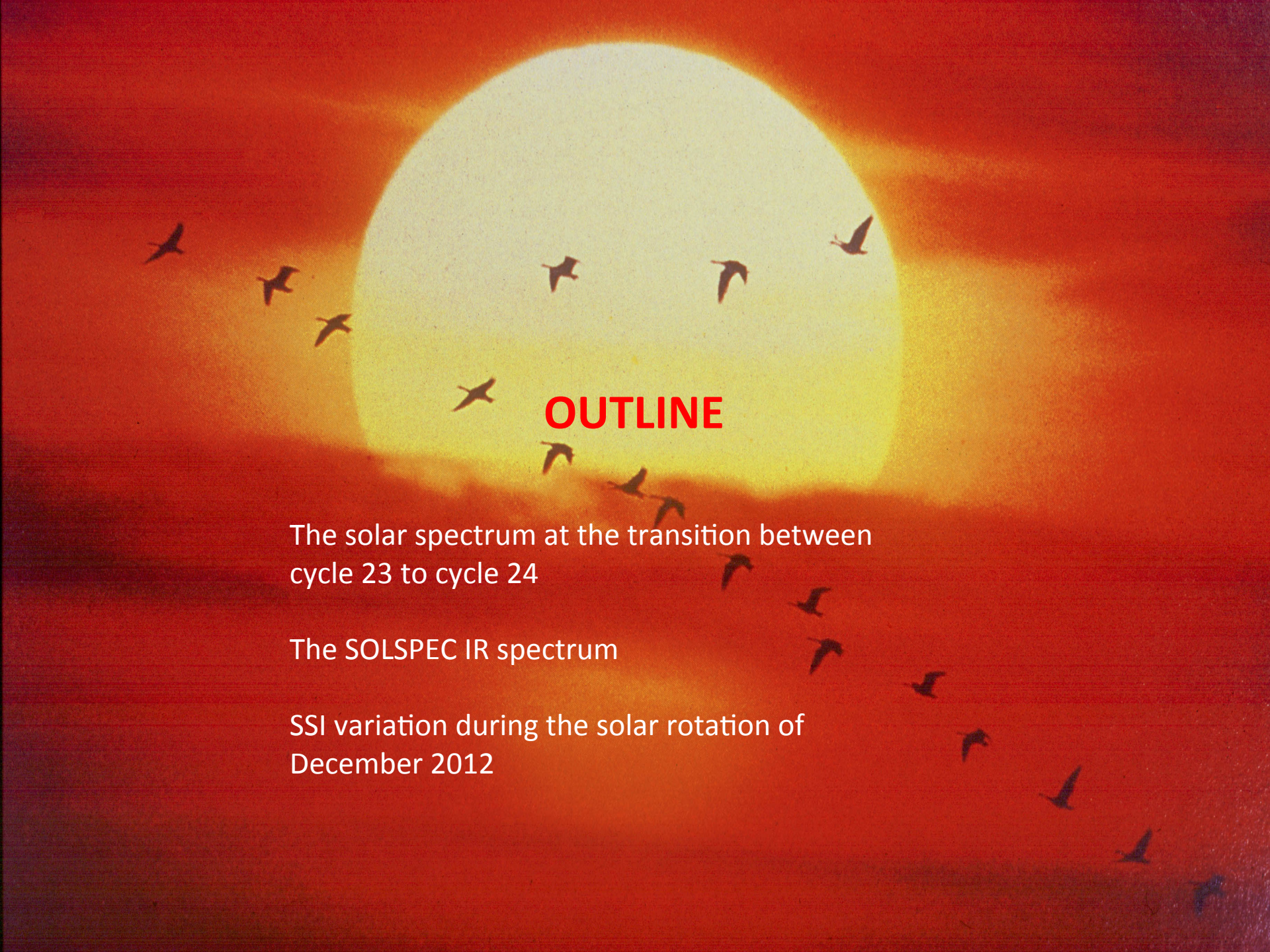
S126E008245



SOLAR on COLUMBUS Laboratory

Launched on 7 February 2008

SORCE meeting 27-31 January 2013



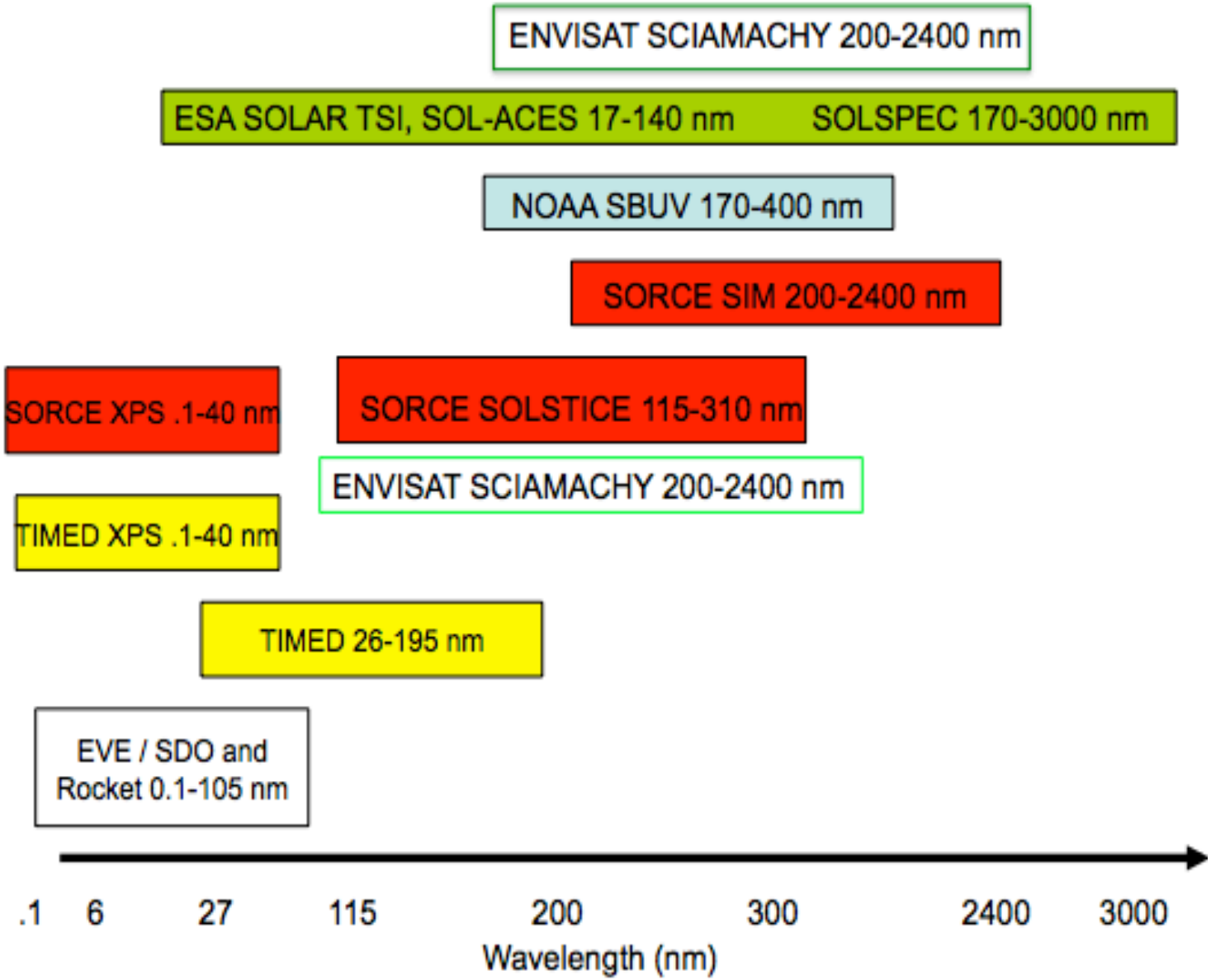
OUTLINE

The solar spectrum at the transition between cycle 23 to cycle 24

The SOLSPEC IR spectrum

SSI variation during the solar rotation of December 2012

SOLAR SSI INSTRUMENTS IN OPERATIONS



SOLAR SPECTRAL IRRADIANCE at SOLAR MINIMUM ACTIVITY

IMPORTANCE OF THE SOLAR MINIMUM OF 2008

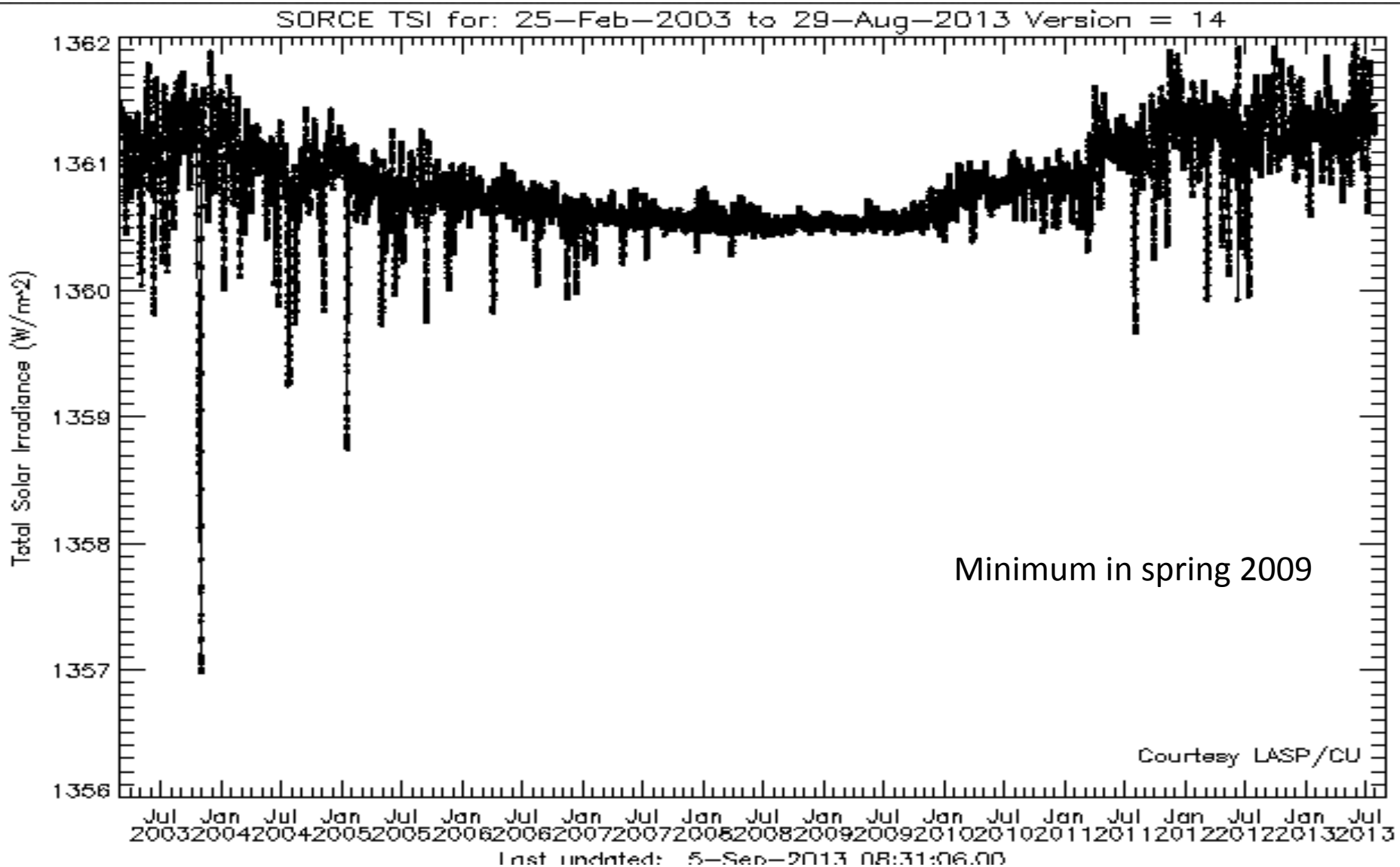
- Solar Spectral Irradiance (SSI) minimum is the baseline of several SSI reconstructions.

- Furthermore, it can be used for checking the accuracy of a SSI reconstruction, before running 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 a key point.

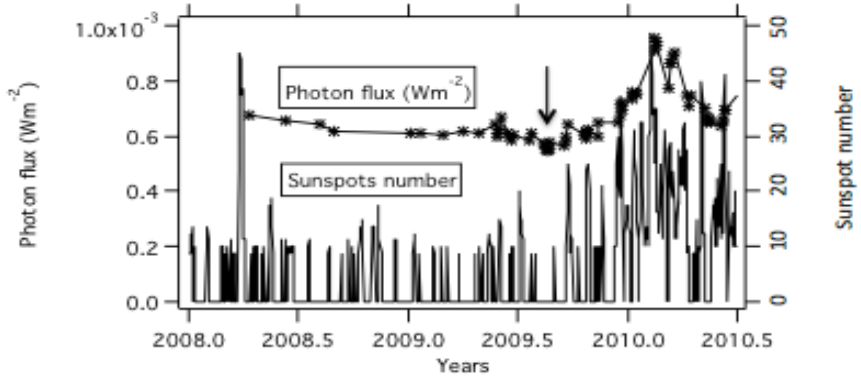
- The values of the different solar parameters at solar minimum (SSI, TSI, proxies,...) are essential to solar physicists to investigate the cause of the minimum, in particular the recent 2008 minimum, lower than the two others (cycles 21 to 22 and 22 to 23).

WHERE IS THE SOLAR MINIMUM ACTIVITY?

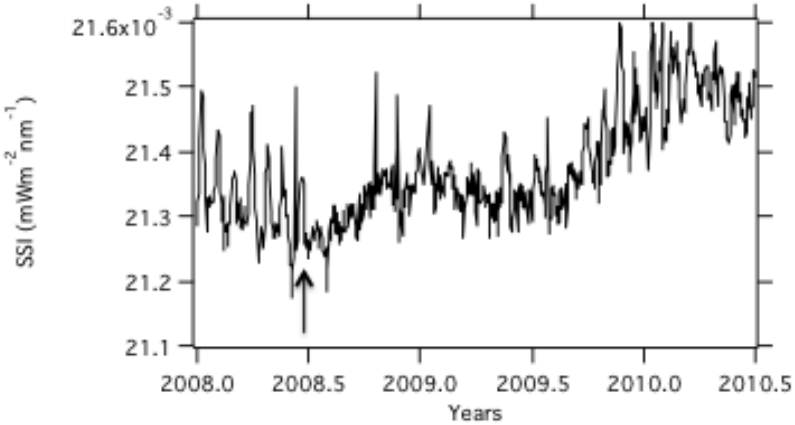


White et al. (2011) found three different times for minimum of TSI, F10.7 and Mg II index

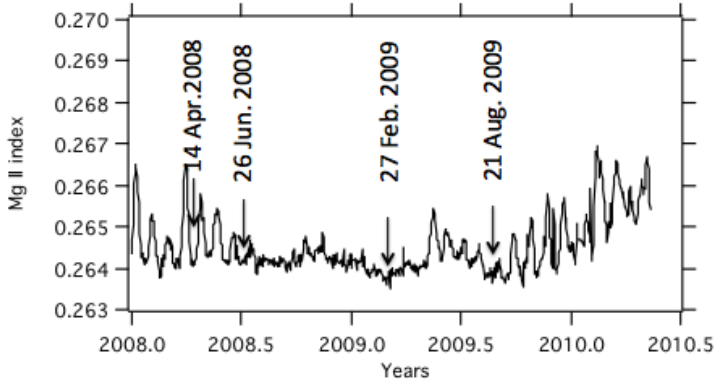
TIME FOR SOLAR SPECTRAL IRRADIANCE MINIMUM?



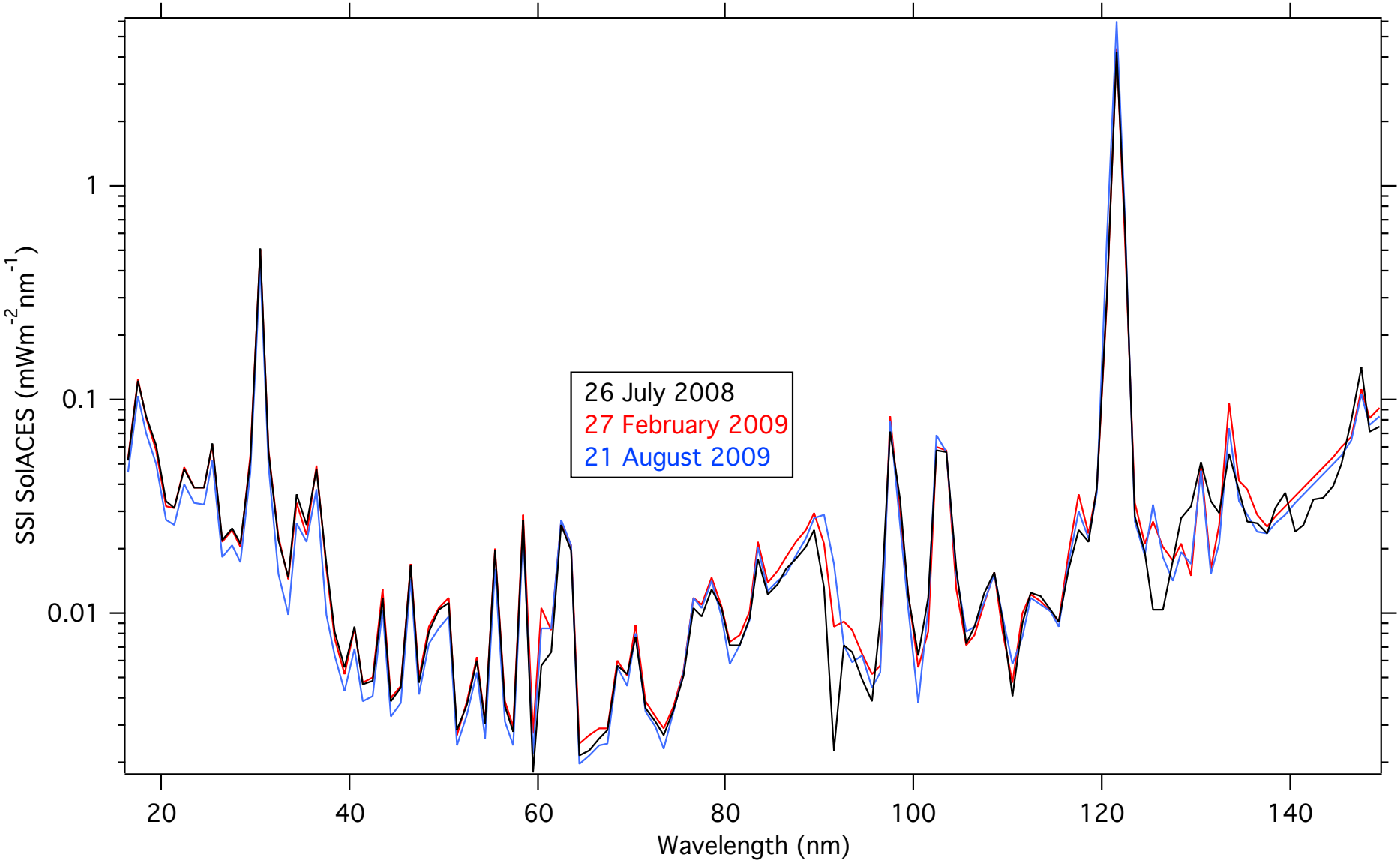
SolACES photon flux (Wm^{-2}) integrated from 16 to 29 nm and sunspots number during the solar minimum period between Solar Cycles 23 and 24 (Nikutowski *et al*., 2011). The arrow shows the minimum EUV SSI that occurred on 21 august



SORCE-SIM data at 210 nm show a minimum located around 26 June 2008.



Mg II index variation as a function of time.
The arrows point to the values on 14 April 2008, 26 June 2008, 27 February 2009 and 21 August 2009.



For these three dates, the SSI's are very close. As variability is the greatest at the shortest wavelength, the lowest SSI is searched in this range. The ratios at 21 August to the two other are found greater than the combined uncertainties of each spectrum.

SOLAR ACTIVITY FOR THE EPOCHS OF THE SSI MINIMUM and ATLAS 3

	ATLAS 3	WHI	SOLSPEC	SOLSTICE	SOLACES	EVE
Date	10 Nov. 1994	10, 16 Apr.	5, 8 Apr. 2, 4, 5, May 2008	5 Apr. 2008	21 Aug. 2009	14 Apr. 2008
SSN	18	<2>	<3>	0.	0.	7
F10.7	80.	<68.9>	<68>	71.3	67.	68.9
Mg II index	0.26747	<0.26416>	<0.26433>	0.26465	0.26375	0.26416

	SSN	**F10.7**	**Mg II**
ATLAS 3	18	80.0	0.26747
SOLAR 1	2.4	68.8	0.26421

SSI at the 2008 minimum

-The minimum is not occurring at the same time for all wavelengths.

- The EUV minimum occurs after the UV minimum.

By combining the data sets at their lowest value, we have generated the absolute minimum SSI

Results:

- It is the smallest with respect to 1978.

- For the spectral interval 200-350 nm, there is a 3% difference with respect to 1994 (transition between cycle 22 to cycle 23)

- The 2008 minimum is close to the Dalton minimum.

DATA USED TO CONSTRUCT THE MINIMUM SSI

- SolACES onboard the ISS. It is an EUV spectrometer self calibrated using gas cell. SSI is measured from 17 TO 150 nm.

- SOLSPEC onboard the ISS. It is an EUV spectrometer measuring from 170 TO 2900 nm, using onboard lamps to maintain the stability of the absolute photometric scale.

  Both instruments were calibrated at PTB (G).

- SOLSTICE onboard SORCE to fill the gap between 150 and 170 nm.

The name of the SSI at solar minimum activity using these data is **SOLAR 1**.

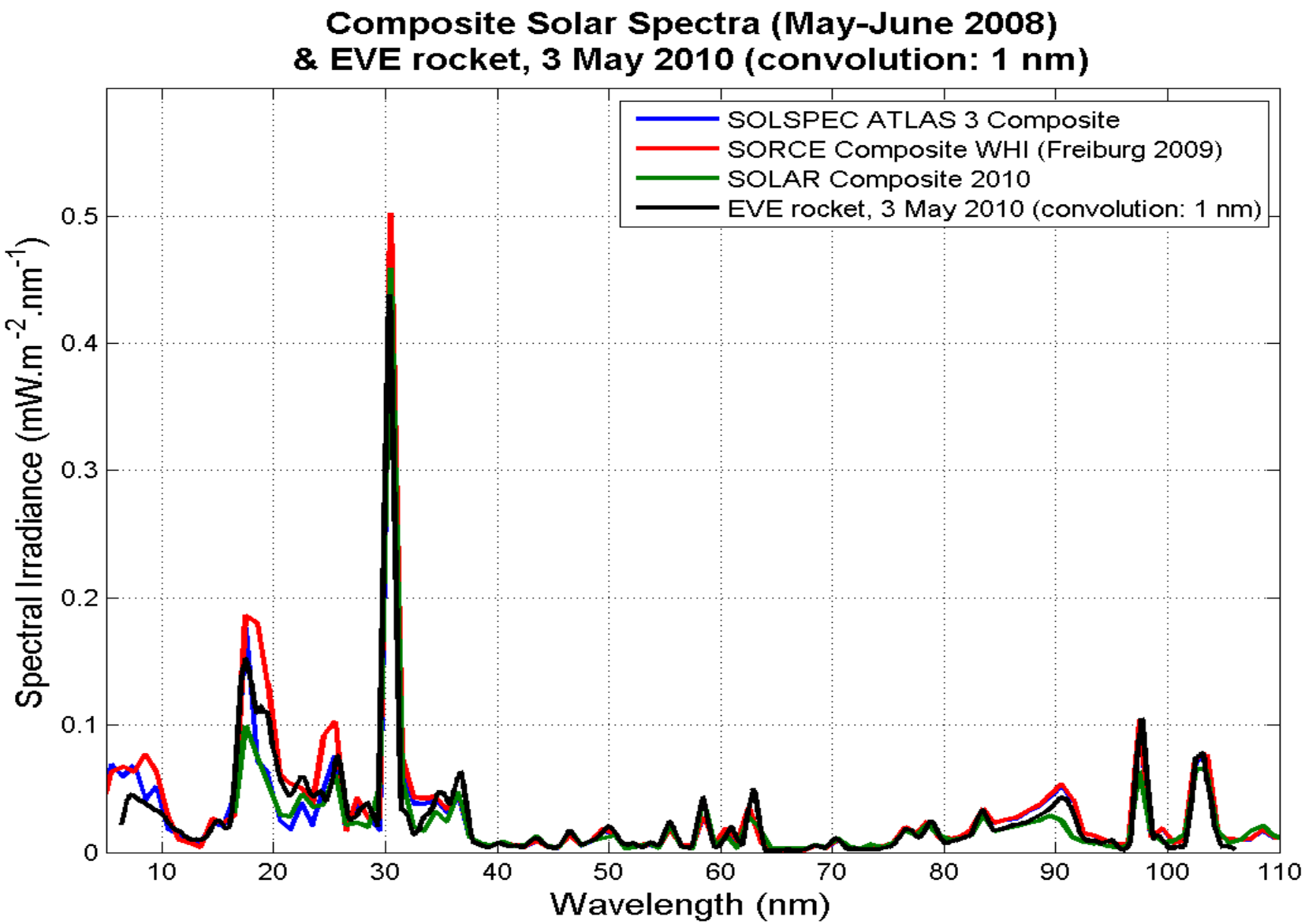
OTHER MEASURED SPECTRA and MODELS SPECTRA USED IN THIS STUDY

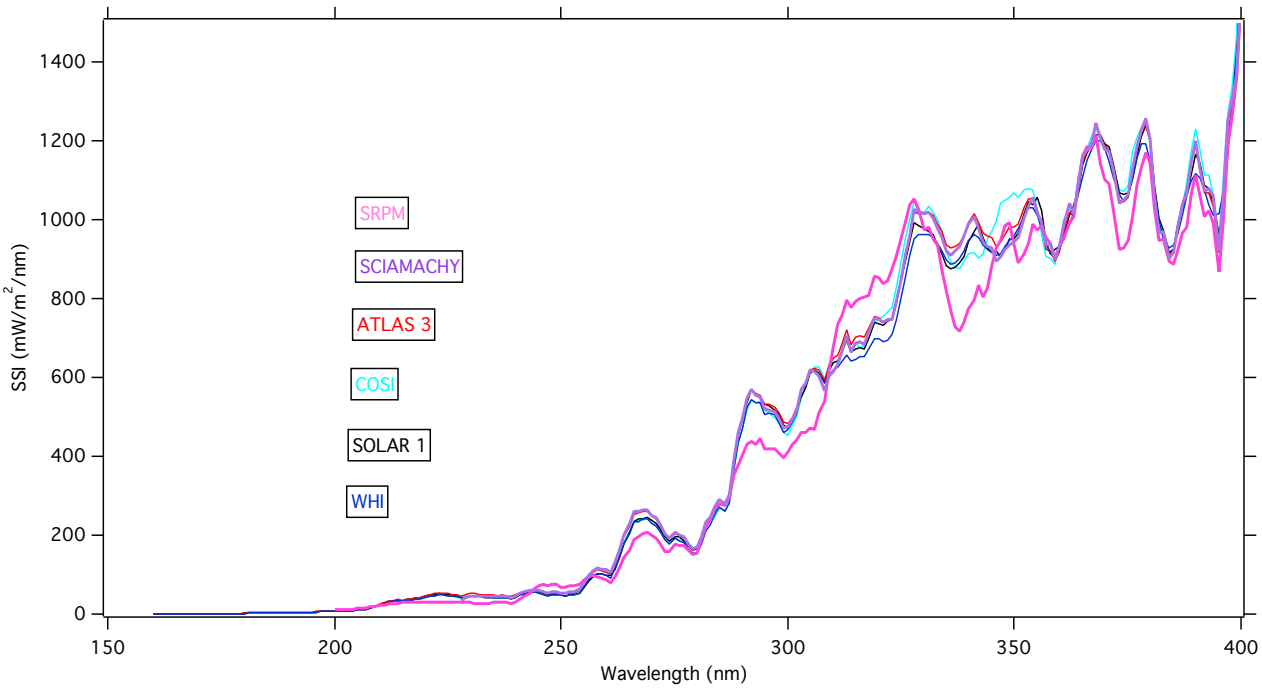
MEASURED SPECTRA:

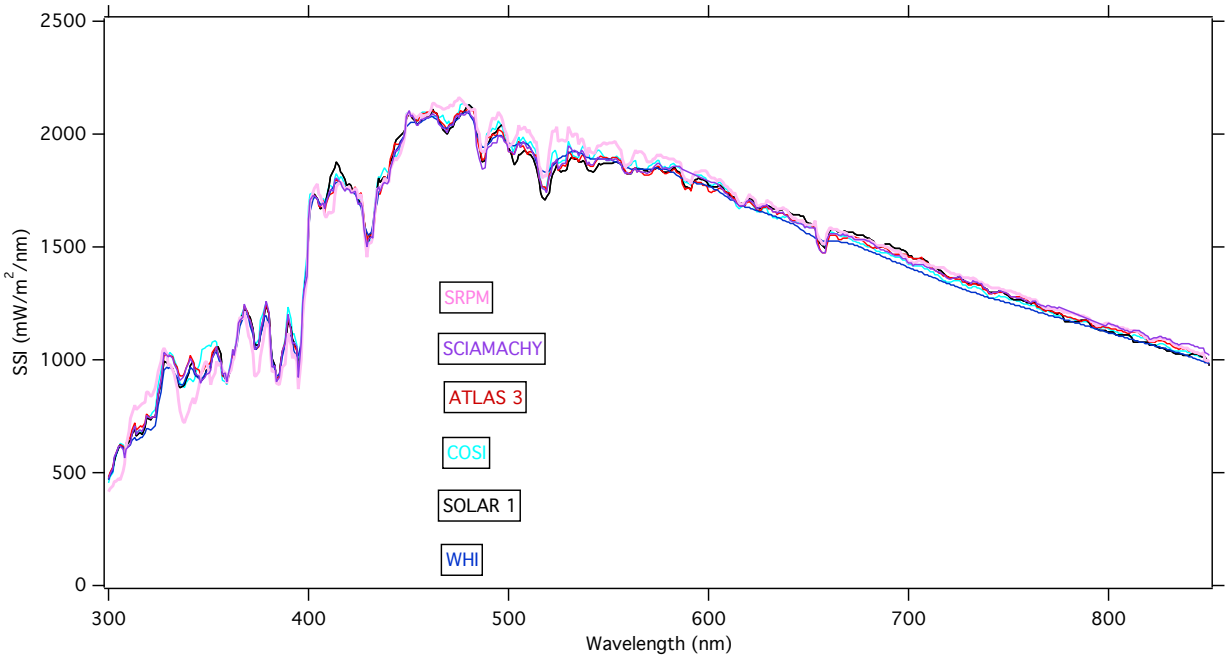
- ATLAS 3 (Thuillier et al., 2004). SSI at the transition between cycle 22 to 23
- Whole Heliospheric Interval (WHI, Woods et al., 2009) dated of 14 February 2008.
- EVE / SDO for the preparation of the SDO launch (14-4-2008).
- SCIAMACHY (Weber et al., 2010), (2002 in the IR part).
- SOLAR: SOLSPEC + SOLACES onboard the ISS.

SSI RECONSTRUCTIONS

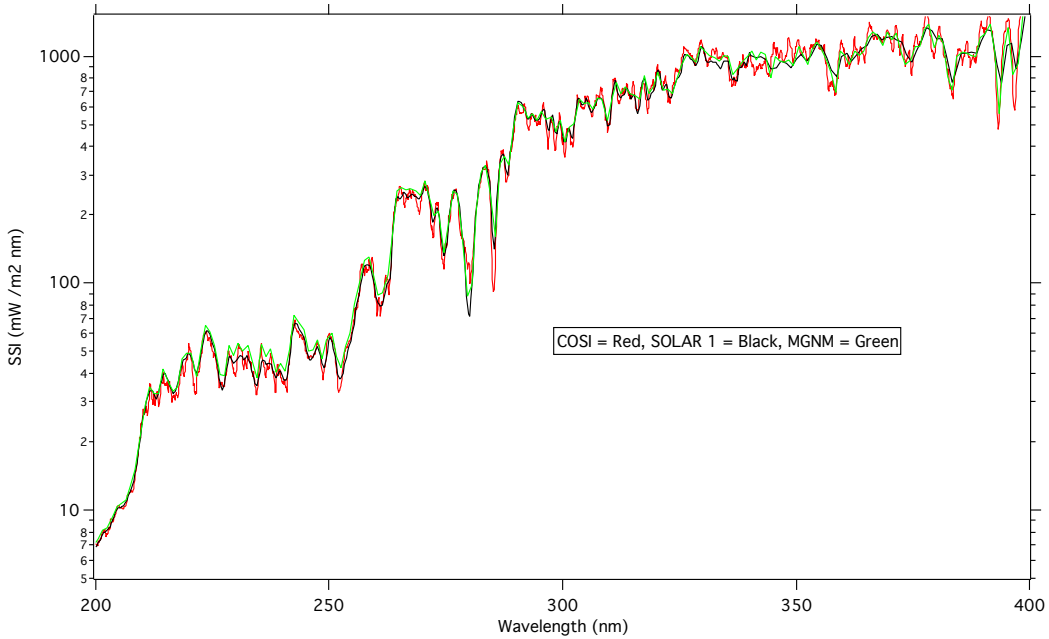
- NRLSSI (Lean et al.); SATIRE (Krivova et al.),
- COSI (Shapiro et al., 2011); SRPM (Fontenla et al., 2011)
- MOCASSIM (Bolduc et al.); MGNM (Thuillier et al., 2012)

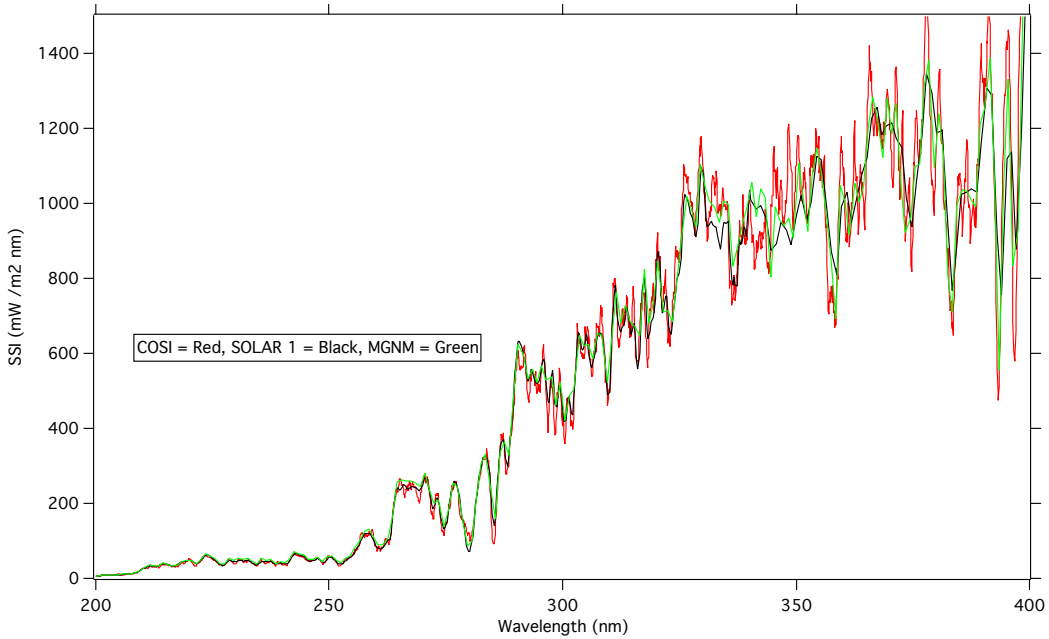

Composite Solar Spectra (May-June 2008)
& EVE rocket, 3 May 2010 (convolution: 1 nm)
SOLSPEC ATLAS 3 Composite
SORCE Composite WHI (Freiburg 2009)
SOLAR Composite 2010
EVE rocket, 3 May 2010 (convolution: 1 nm)
Spectral Irradiance (mW.m-2.nm-1)
0
0.1
0.2
0.3
0.4
0.5
10
20
30
40
50
60
70
80
90
100
110
Wavelength (nm)


SSI (mW/m^2/nm)
Wavelength (nm)
SRPM
SCIAMACHY
ATLAS 3
COSI
SOLAR 1
WHI

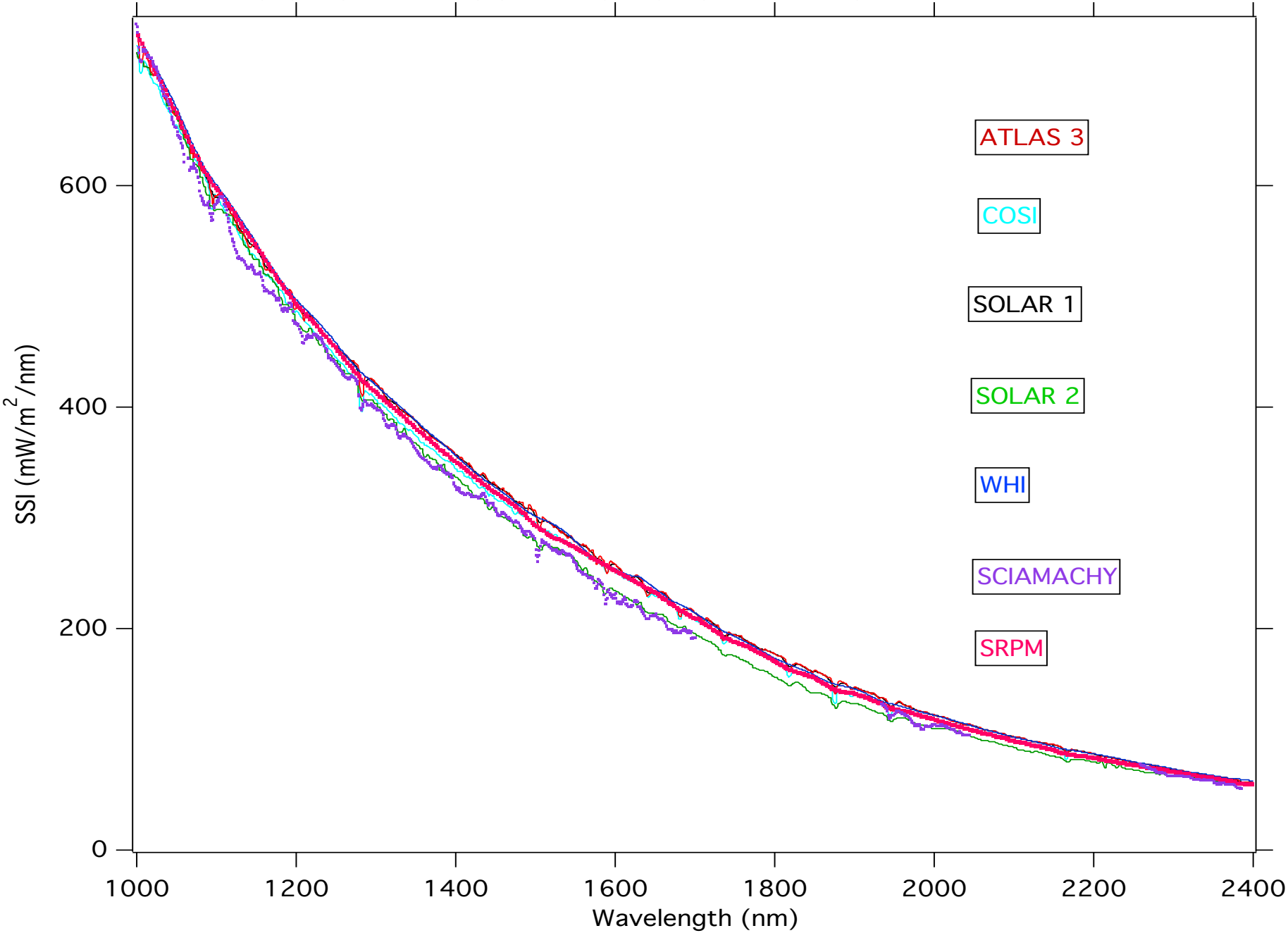

SSI (mW/m^2/nm)
Wavelength (nm)
SRPM
SCIAMACHY
ATLAS 3
COSI
SOLAR 1
WHI

COMPARISON COSI-SOLAR 1 RECONSTRUCTED USING MgII INDEX





SOLSPEC-ISS IR and OTHER SPECTRA



SOLSPEC-ISS IR SPECTRUM

THE SSI-SOLSPEC-ISS in the IR is about 10% lower around 1800 nm. Extended investigations were made, and up to now, no explanation has been found.
Consequently, we built two composites:
SOLAR 2 uses SolACES (16-149.5 nm), SOLSTICE (150-170 nm) and SOLSPEC-ISS (170-2900 nm).
SOLAR 1 is identical to SOLAR 2 except in the range 1100 to 2400 nm where ATLAS 3 IR SSI is used.

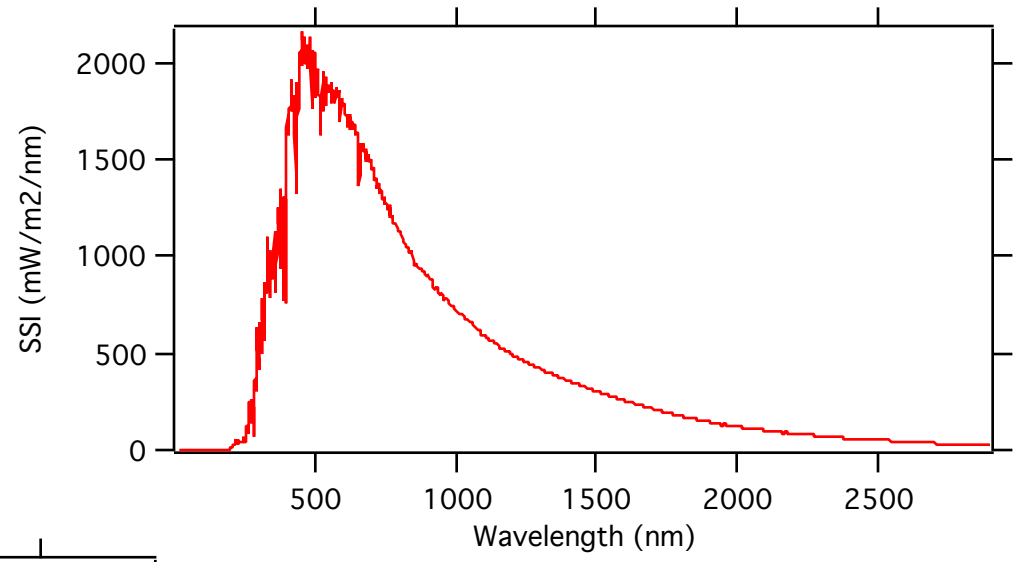
We compare:

SPECTRA: ATLAS 3 (Thuillier et al., 2004)
Whole Heliospheric Interval (WHI, Woods et al., 2009) dated of 14 Feb. 2008
SCIAMACHY (Weber et al., 2010), (2002 in the IR part)
SOLAR 2 = SOLACES + SOLSTICE + SOLSPEC onboard the ISS
SOLAR 1 = SOLACES + SOLSTICE + SOLSPEC + ATLAS 3 (1100-2400 nm)

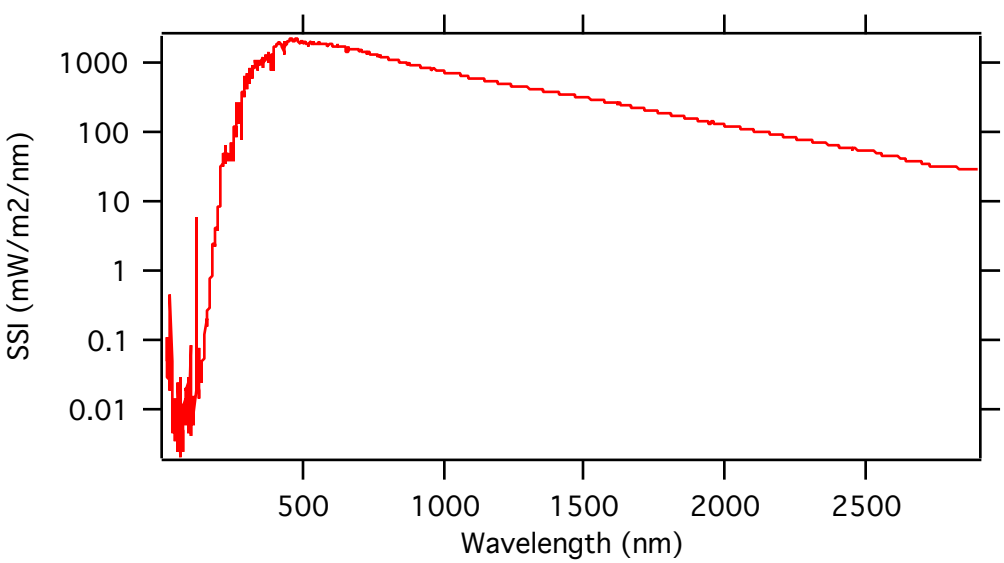
Theoretical models: COSI (Shapiro et al., 2011)
SRPM (Fontenla et al., 2011)

THE SOLAR SPECTRAL IRRADIANCE AT THE TRANSITION BETWEEN SOLAR CYCLES 23 AND 24

Linear scale

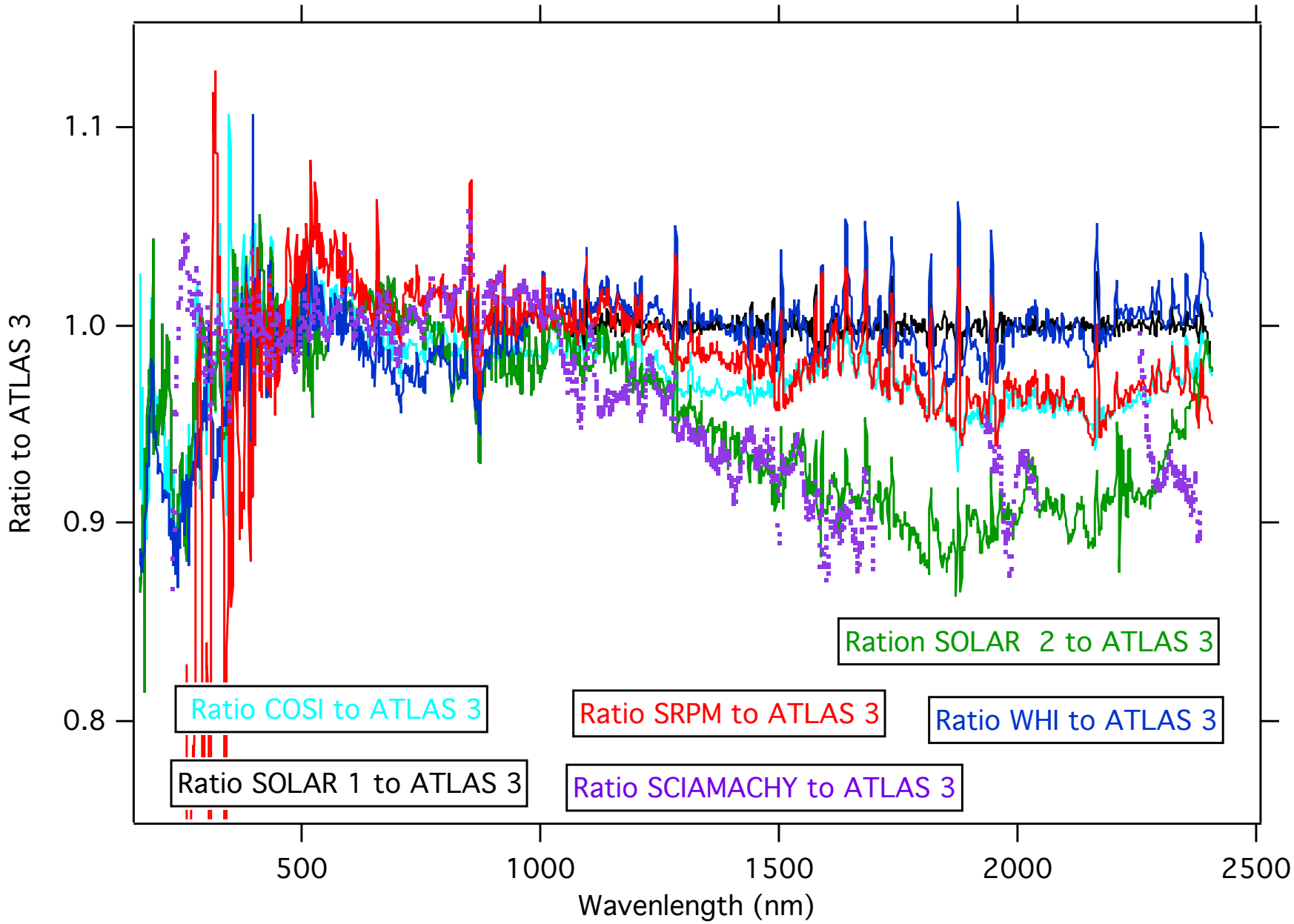


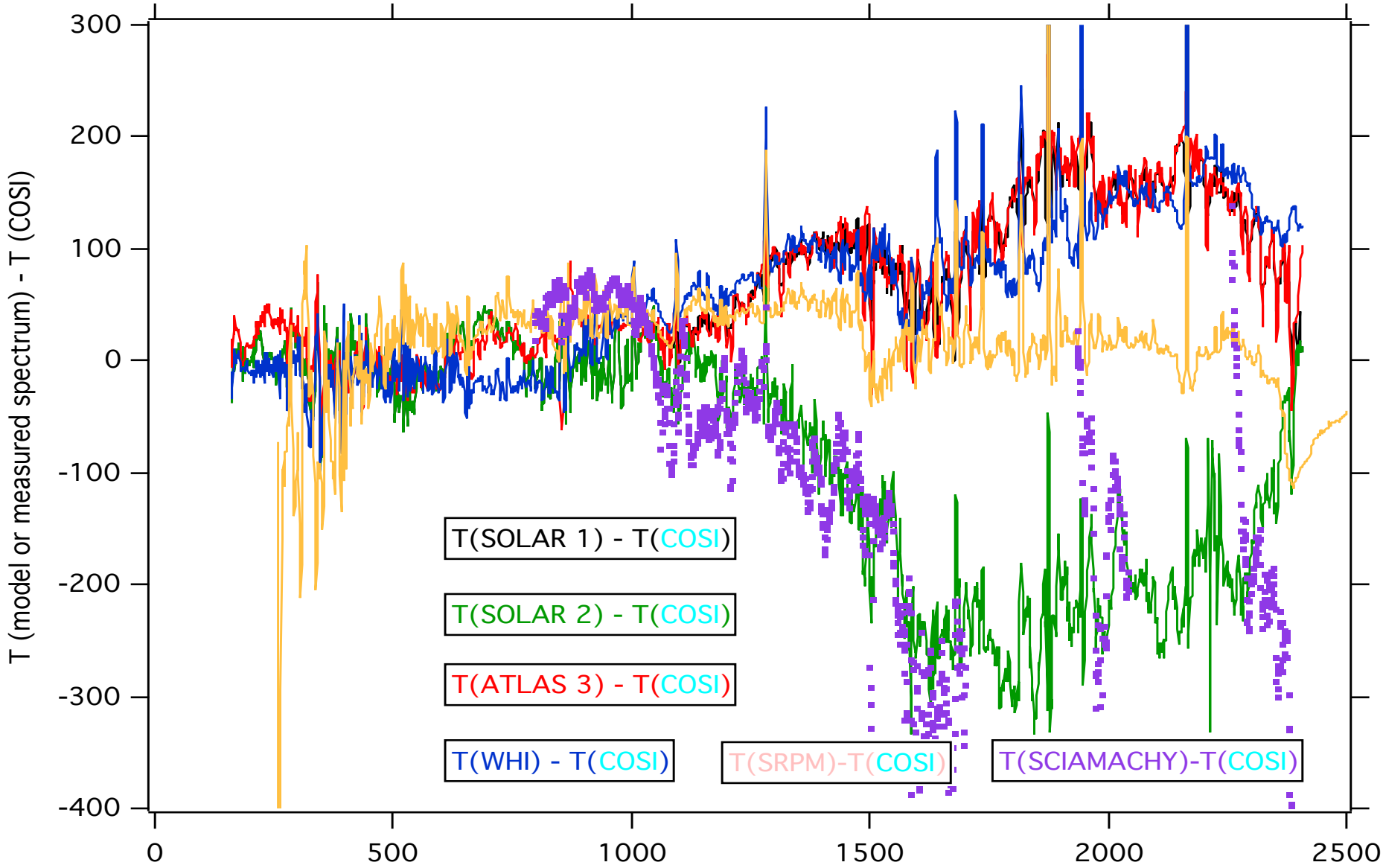
Logarithmic scale



➔ The linearity in the IR (without any linear fit of the data) allows us to derive the brightness temperature.

RATIO OF DIFFERENT SPECTRA TO ATLAS 3




T (model or measured spectrum) - T (COSI)
300
200
100
0
-100
-200
-300
-400
0
500
1000
1500
2000
2500
T(SOLAR 1) - T(COSI)
T(SOLAR 2) - T(COSI)
T(ATLAS 3) - T(COSI)
T(WHI) - T(COSI)
T(SRPM)-T(COSI)
T(SCIAMACHY)-T(COSI)

POWER (W/m^2) in the SPECTRAL DOMAIN 1100-1761 nm

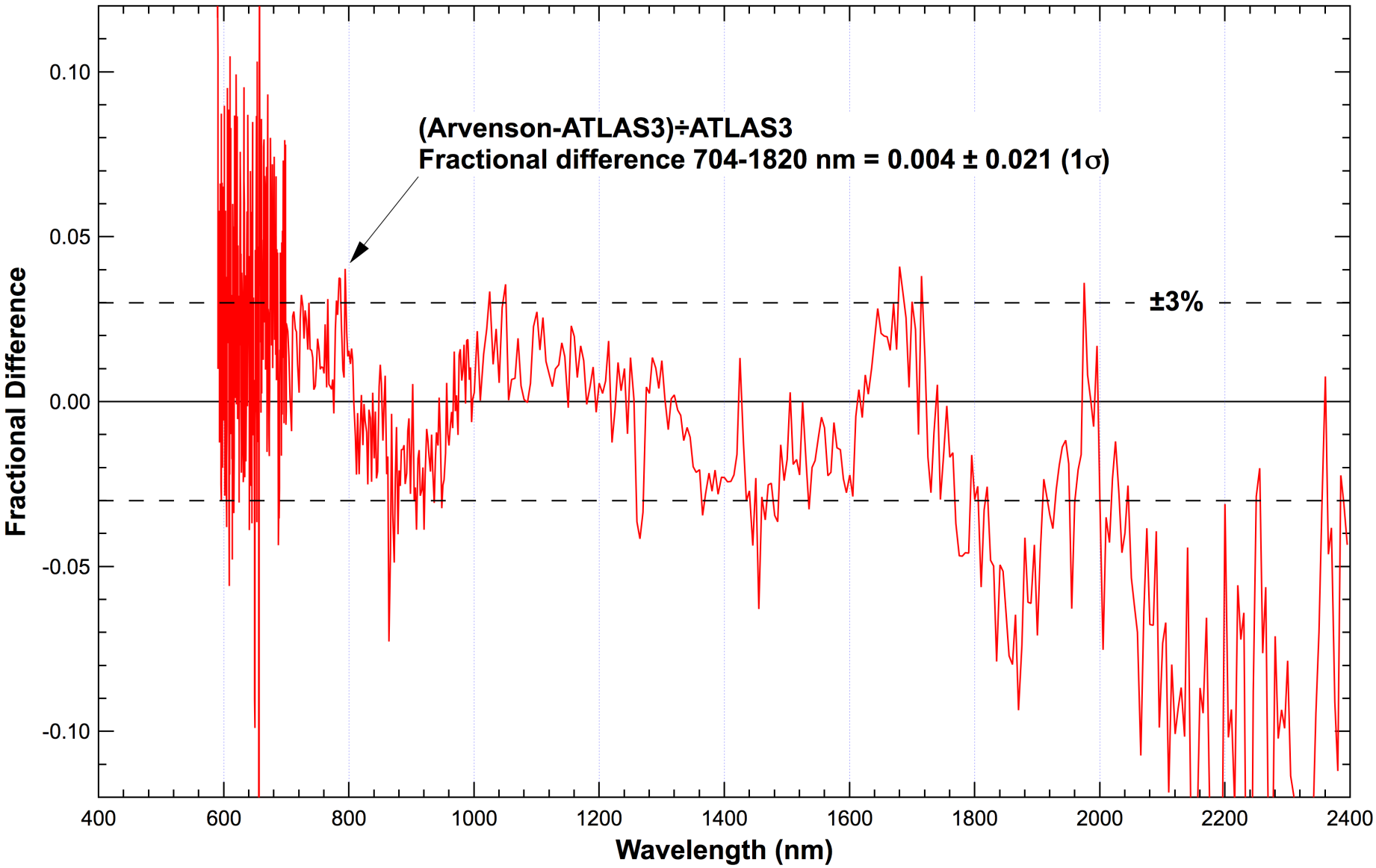
SRPM	COSI	A 3	WHI	SOL 1	SOL 2	SCI
299.4	294.9	300.9	302.7	299.8	288.6	286.6

Power (W/m^2) in the spectral domain 1000-1761 nm for each spectrum. Dataset names have been abbreviated in the column headings

DETAILED COMPARISON BETWEEN THE SPECTRA USED IN THIS STUDY

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

Δλ (nm)	SRPM/A3	COSI/A3	WHI/A3	SOL1/A3	SOL2/A3	COSI/SOL2	SRPM/SOL2
210--2400	1.00	0.99	0.99	0.99	0.98	1.01	1.02
1000--2000	0.99	0.98	1.00	1.00	0.95	1.03	1.04
1000--1761	0.99	0.98	1.00	1.00	0.96	1.02	1.03
1000--2400	0.99	0.98	1.00	1.00	0.95	1.03	1.04
2100--2200	0.96	0.95	1.00	1.00	0.90	1.06	1.06
2400--2900						1.05	1.04



Courtaisy of J. Harder

The November-December 2012 Solar Rotation

The ISS orientation generally does not permit to permanently point the Sun.
Periods of no Sun visibility varies from 14 days to a few days per month, season dependent, which consequently does not allow the measurements of the effects of the active regions during a **complete** solar rotation.

The smallest duration of the no sun visibility occurs at solstices lasting just a few days.

From 20 November to 31 December 2012, the ISS attitude was slightly modified to achieve a complete observation of the solar rotation.

We have observed Carrington rotation # 2131.

SSI RECONSTRUCTIONS USED IN THIS STUDY

- NRLSSI (Lean et al. 2000); SATIRE (Krivova et al. 2010),
- COCOSIS (Cessateur et al., 2014); MOCASSIM (Bolduc et al. 2013)
- MGNM (Thuillier et al., 2012)

SCIENTIFIC RATIONAL OF THE DECEMBER ROTATION STUDY

Just a few months ago, we have published (Solar Physics, Thuillier et al., 2013), an article dedicated to a detailled study of five SSI reconstructions properties, namely, absolute value, and long term variability.

Using the same five reconstructions, we aim to study their short term predictions using available measurements gathered at the same time.
Furthermore, EUV data is included in this study.

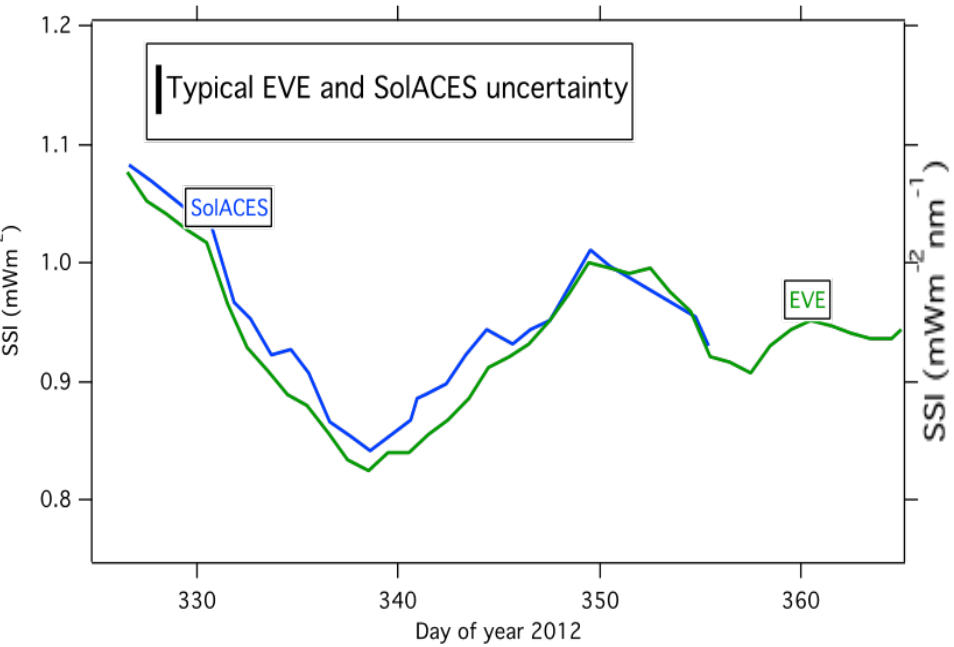
We have used the following data from:

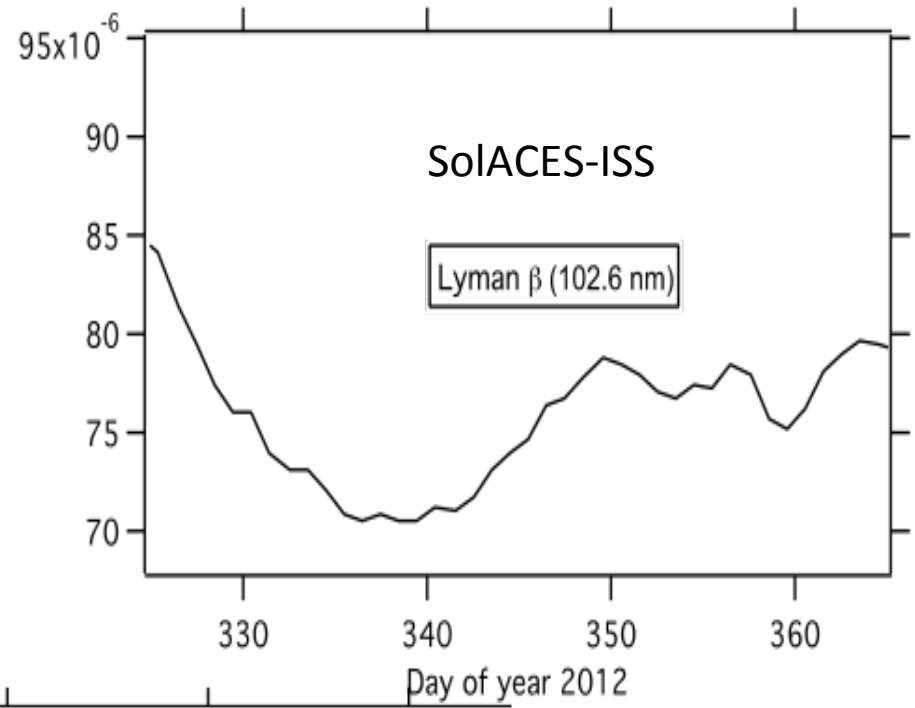
SolACES-ISS, SOLSPEC-ISS, PREMOS-PICARD, EVE-SDO, and models predictions:

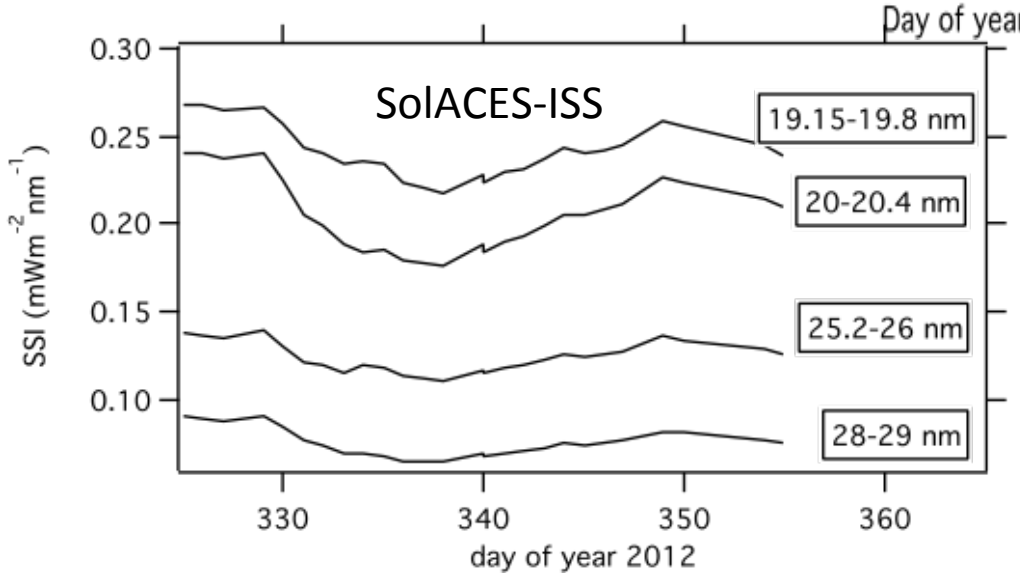
The solar rotation generates a variation of SSI from a minimum to a maximum occurring at a specific times. We determine this timing from EUV to UV using measurements and compare with Predictions in terms of SSI absolute value and variability:

Phase of this variation, the percentage of the variation (max/min), and the SSI absolute value.

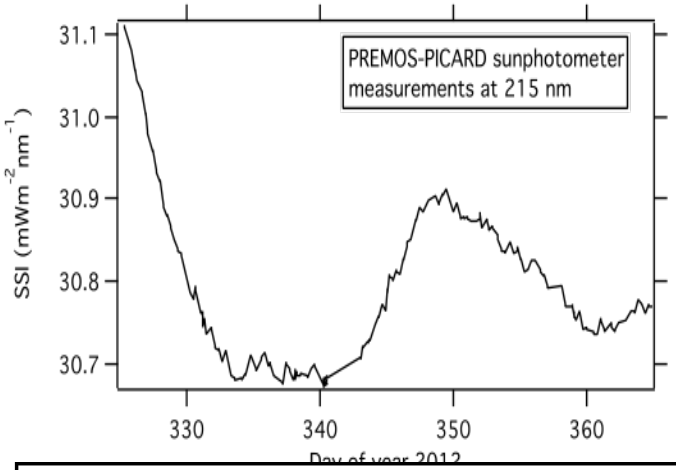
EUV RESULTS

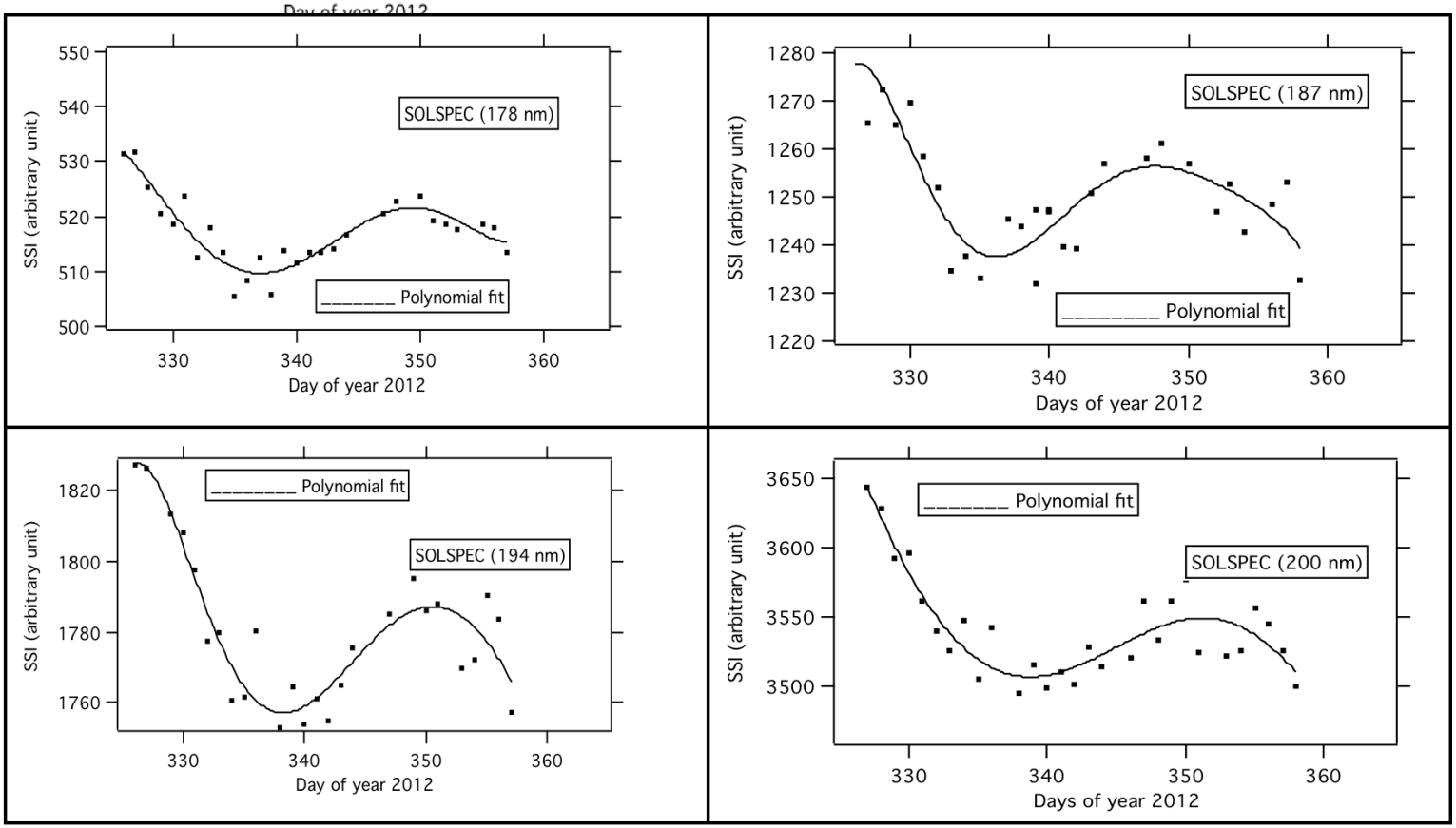

Typical EVE and SolACES uncertainty
SolACES
EVE
SSI (mWm^{-2}nm^{-1})
Day of year 2012


SolACES-ISS
Lyman β (102.6 nm)
95x10^{-6}
Day of year 2012

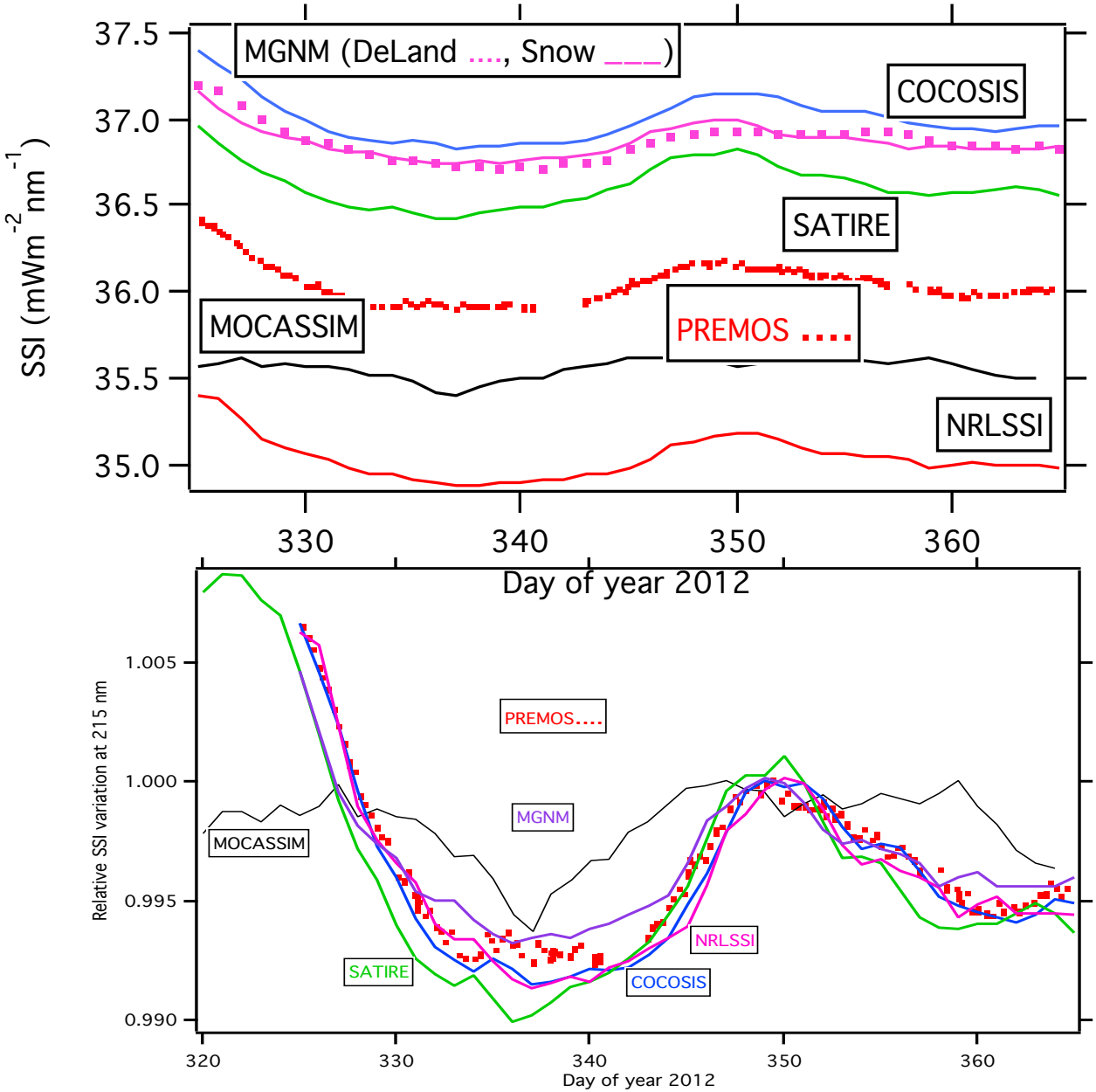

SolACES-ISS
19.15-19.8 nm
20-20.4 nm
25.2-26 nm
28-29 nm
SSI (mWm^{-2}nm^{-1})
day of year 2012

MEASUREMENTS IN UV





RECONSTRUCTION OF THE SOLR ROTATION 2131 WITH MODELS

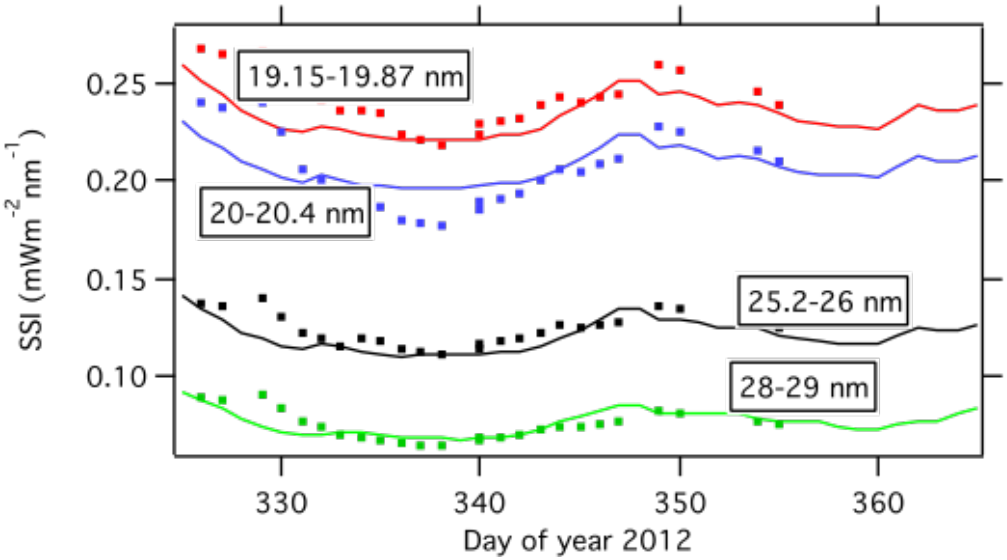


ABSOLUTE IRRADIANCE and VARIABILITY IN UV

Instruments/ Reconstructions	Maximum to minimum ratio	Maximum SSI ($mW\ m^{-2}\ nm^{-1}$)	Day of SSI minimum	Day of SSI maximum
PREMOS	*1.006*	30.9	338	350
SOLSPEC	*1.010*	NA	338	349
COSI	1.008	37.15	340	350
MGNM (Snow's series)	1.006	36.99	340	350
MOCASSIM	1.007	35.5	338	350
NRLSSI	1.008	35.15	338	350
SATIRE	1.013	36.80	339	350

Maximum SSI: ± 2 %
Phase: 1 day
Variability: 0.6 to 1.3 %

RESULTS IN EUV



Instruments/ Reconstruction	Maximum to minimum ratio	Day of SSI minimum	Day of SSI maximum
SolACES	*1.19 to 1.27*	*339*	*350*
SolMOD	1.17 to 1.43	339	350-352

SOLMOD: Haberreiter et al., 2014

CONCLUSIONS

SOLAR 1 in agreement with WHI

ATLAS 3 in IR in agreement with COSI and SRPM

Solar Rotation of November December 2012:

- UV

- Predicted spectral irradiance are found within ±2%
- Phase measured within one day in agreement with observations
- Predicted variability extends from 0.6 to 1.3 %
- PREMOS and SOLSPEC confirm these results (0.6 to 1%)

- EUV

- Phase measured and predicted within one day
- Measured variability (1.19 to 1.27) to compare with prediction (1.17 to 1.43)
- Predicted spectral irradiance needs some adjustment wvelength dependent

Thuillier, G.,· DeLand, M.,· Shapiro, ·A., Schmutz , W., Bolsée, ·D., Melo, S.M.L.: 2012, *Solar Phys.* doi:10.1007/s11207-011-9912-5.

Thuillier, G., S. M. L. Melo , J. Lean, N. A. Krivova, C. Bolduc, V. I. Fomichev, P. Charbonneau, A. I. Shapiro, W. Schmutz, D. Bolsée, Analysis of Different Solar Spectral Irradiance Reconstructions and their Impact on Solar Heating Rates, Solar Physics, DOI 10.1007/s11207-013-0381- 2013

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