SOLSPEC MEASUREMENT OF THE SOLAR ABSOLUTE SPECTRAL IRRADIANCE FROM 165 to 2900 nm ON BOARD THE INTERNATIONAL SPACE STATION

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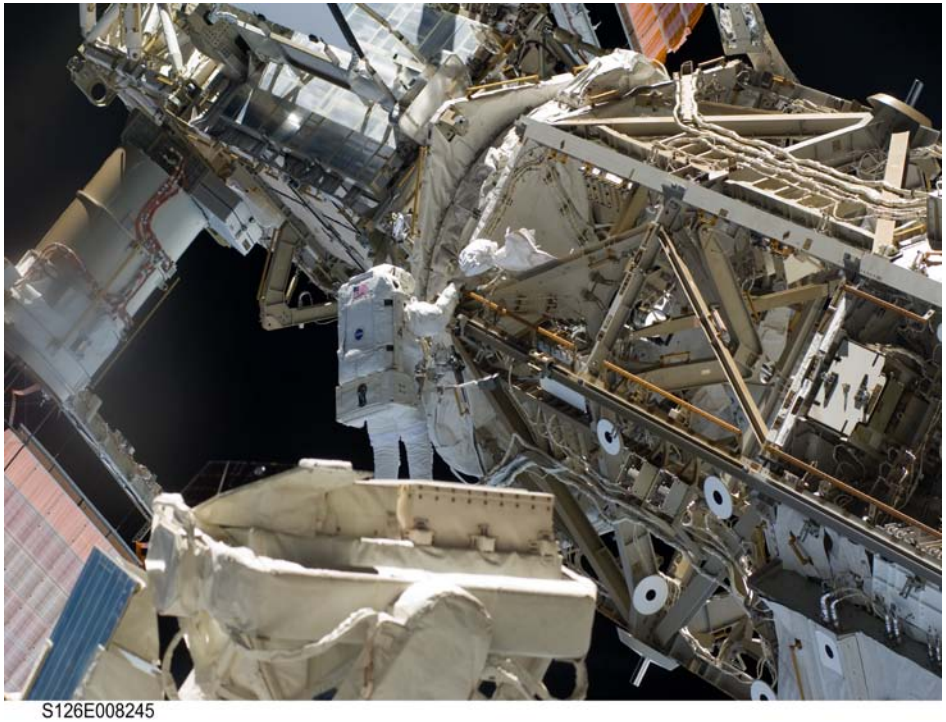
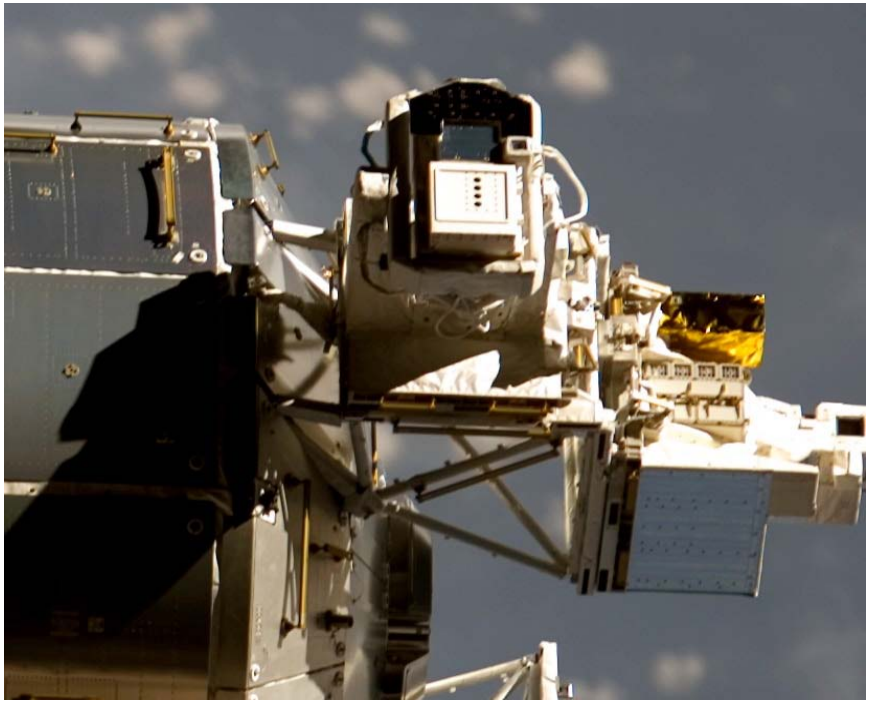


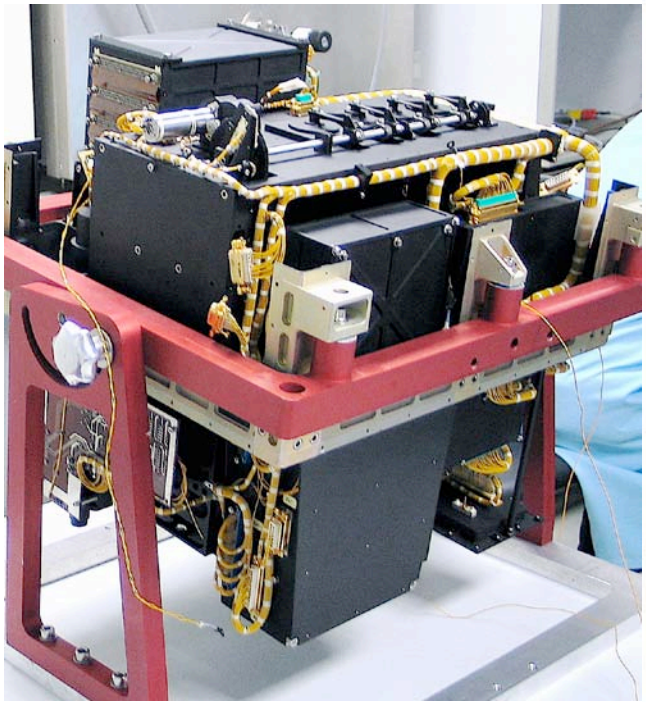
SOLAR on COLUMBUS Laboratory



Launched on 7 Feb. 2008

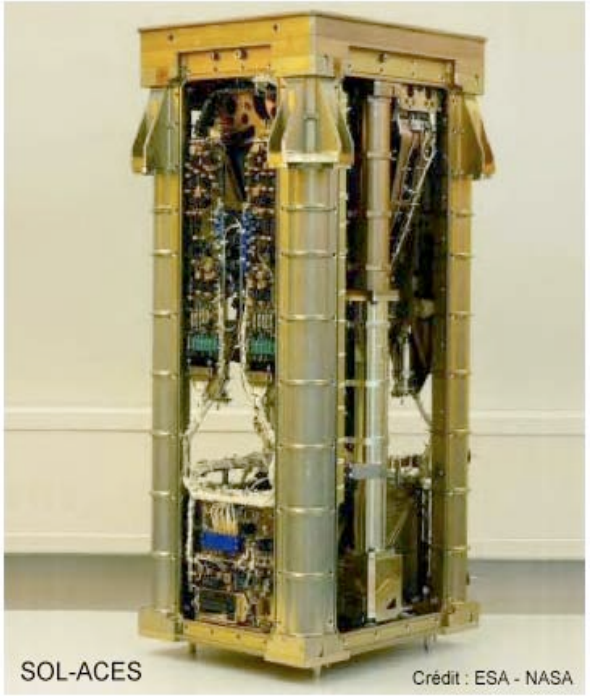
INSTRUMENTS PRESENTLY IN SPACE: SOLAR (5/6)

SOLSPEC



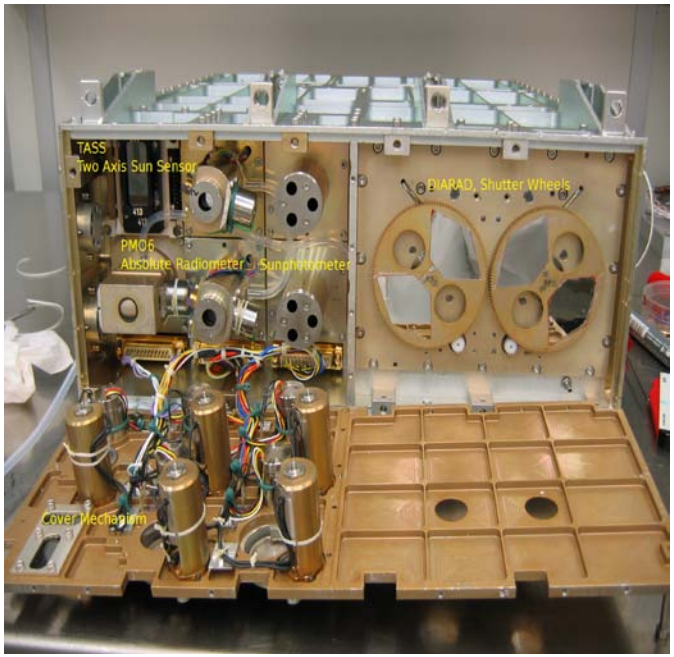
Triple double grating spectrometer using D2, W, HC lamps. Range: 170 -3000 nm. Calibrated with the PTB blackbody. SOLSPEC was built in cooperation between France, Belgium and Germany.

SOL-ACES



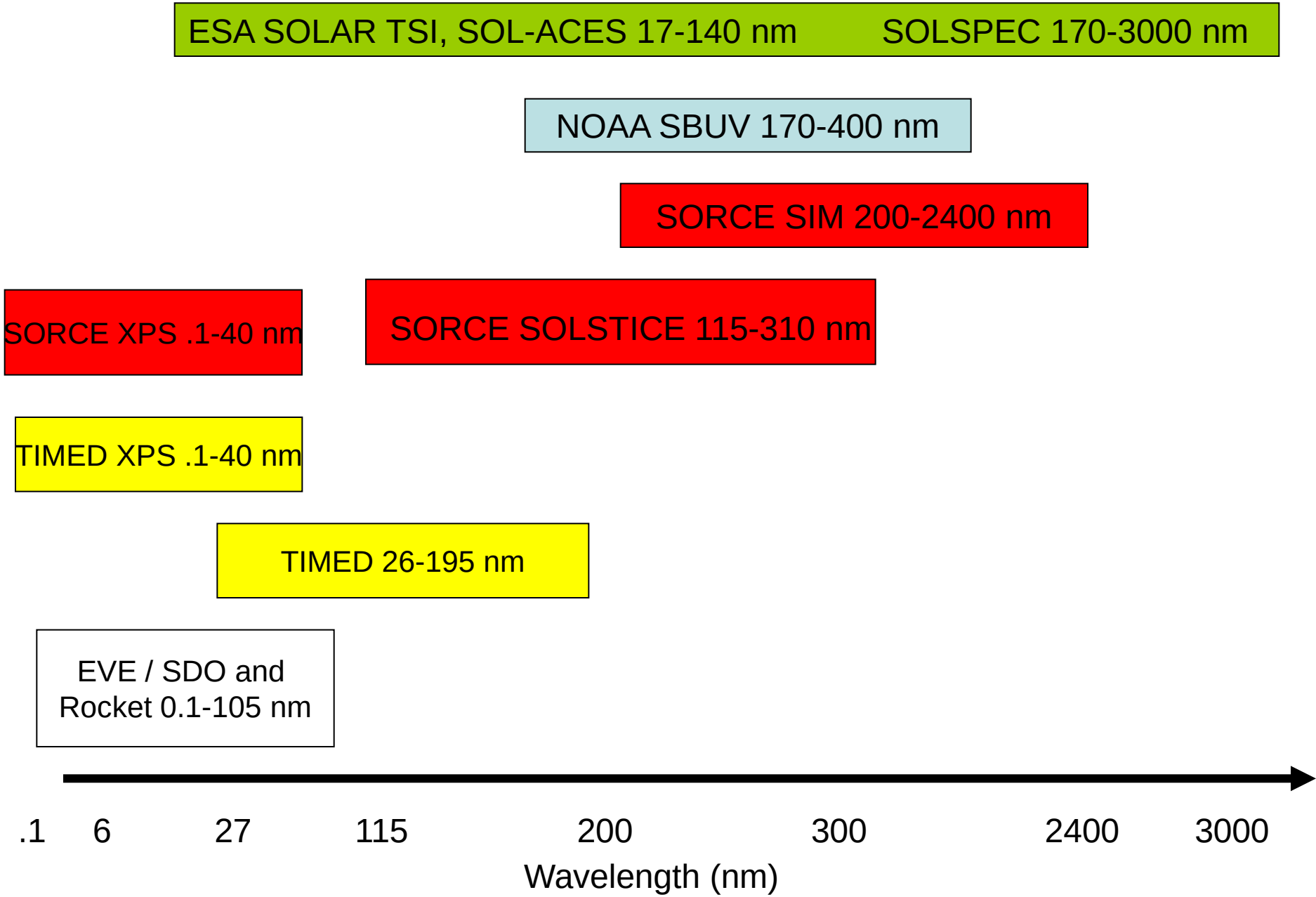
SOL-ACES (G) is a-4 grazing incidence grating spectrometers plus two three-ionization chambers with exchangeable band pass filters to determine absolute fluxes from 17 to 140 nm.

SOVIM



Four absolute radiometers (PMO6 (Ch) and DIARAD (B) as on board SoHO, and two sunphotometers.

PRESENT SOLAR SPECTRAL IRRADIANCE MEASUREMENTS (2/6)



METHODS OF CALIBRATION

Instruments	Missions	Absolute calibration	On-board control
SIM	SORCE	Characterization	2 twin instruments
SOLSTICE	SORCE	Surf[1] and D_2 lamps	Stars
SEE	TIMED	Absolute detectors	
SOL-ACES	SOLAR-ISS	SURF[2]	Absorption cell
SOLSPEC	SOLAR-ISS	PTB Blackbody	D2,W, HC lamps
EVE	SDO	Surf[1]	Led (flatfield)

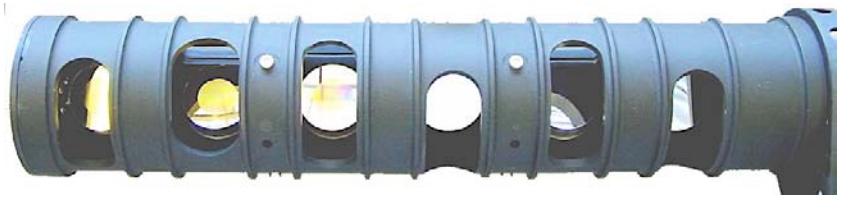
The different techniques ensure to minimize the systematic uncertainties. Agreement between data sets gathered by instruments based on different concepts also ensure that measurements are achieved in the absolute scale.

SURF: Synchrotron UltravioletRadiation Facility. 1= NIST; 2= PTB

Principle of the SOLSPEC spectrometer (1/2)

- 3 double-monochromators (**UV**, **VIS**, **IR**) allow to cover the range 165-3080 nm

- The six gratings simultaneously rotate



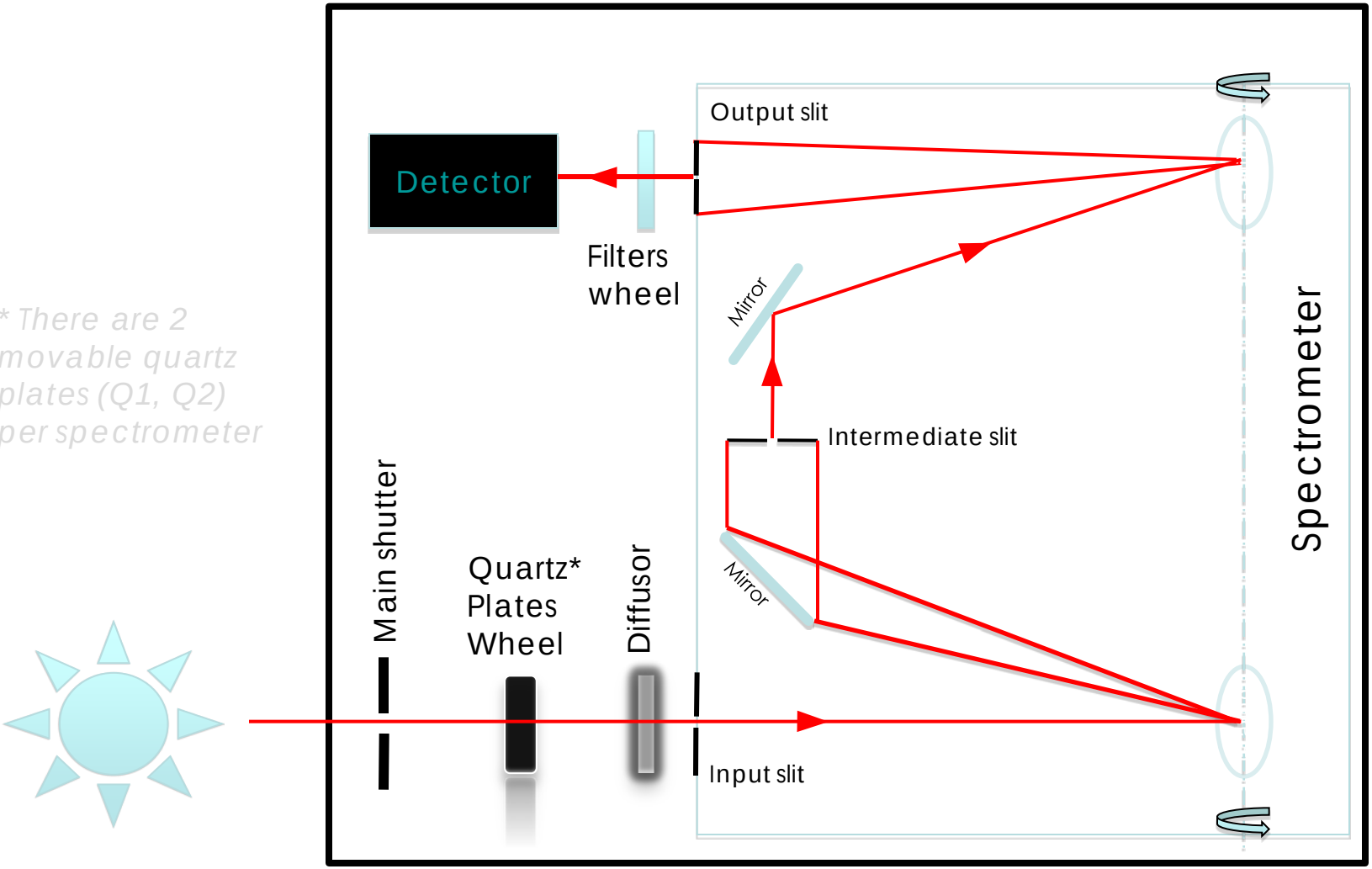
- References on board:

  - One hollow cathode lamp (HCL) providing lines from Argon, Zn and Cu to measure the slit function and the dispersion law.
  - Four tungsten ribbon lamps for the VIS and IR spectrometers calibration
  - Two deuterium lamps for the UV spectrometer calibration

- Entrance slits are covered by diffusors

- Quartz plates and a hole are carried by a wheel. The plates can be placed in front of the entrance diffusors to ensure their protection.

- A sensor measures the Sun position/platform axis.



** There are 2 movable quartz plates (Q1, Q2) per spectrometer*

Principle of the SOLSPEC spectrometer (2/2)

Detectors: PMT in UV and visible domains, PbS cell in IR.
Vis and IR detectors are cooled.

Signals: Counting for PMT's, synchronous detection in IR (16 bits, 3 gains)

PMT's data acquisition works with two modes

- at fixed integration time
- at fixed counts (fixed precision)

Spectral characteristics:

Total spectral range: 165-3080 nm

UV spectrometer: 165-380 nm, spectral width: 1 nm, sampling 0.1 nm

VIS spectrometer: 300-980 nm, spectral width: 1 nm, sampling 0.25 nm

IR spectrometer: 800-3080 nm, spectral width 9 nm, sampling 1 nm

INSTRUMENT CALIBRATION

	Ground	Orbit
Absolute photometry	X	
Relative photometry	X	X
Linearity	X	
Slit Function	X	X
Dispersion law	X	X
Scattered light	X	X
Flatfield	x*	X
Second order contribution	X	X

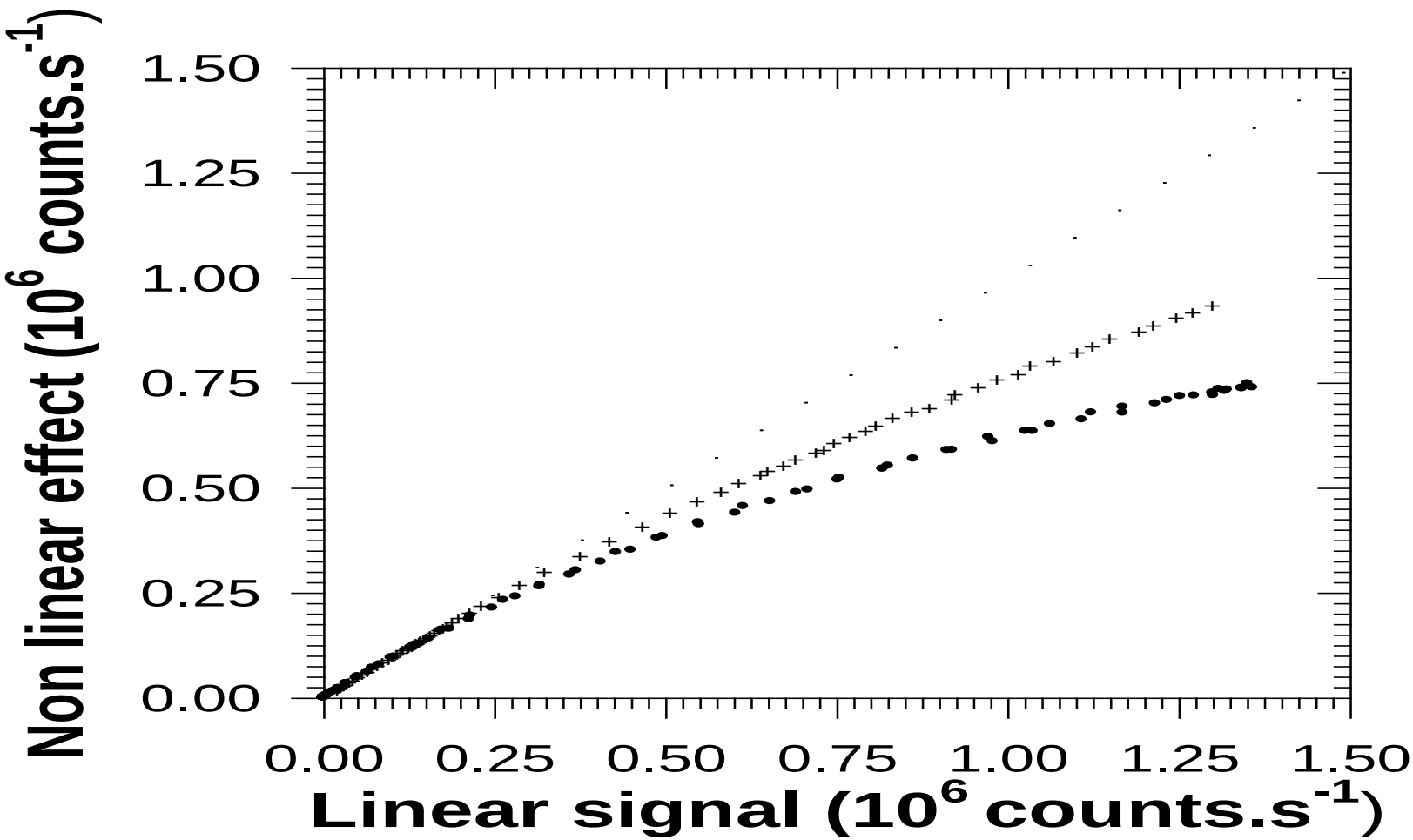
* More precise in space

CALIBRATION MEASUREMENTS ONLY ACHIEVABLE ON GROUND

- Absolute photometric response

- Linearity

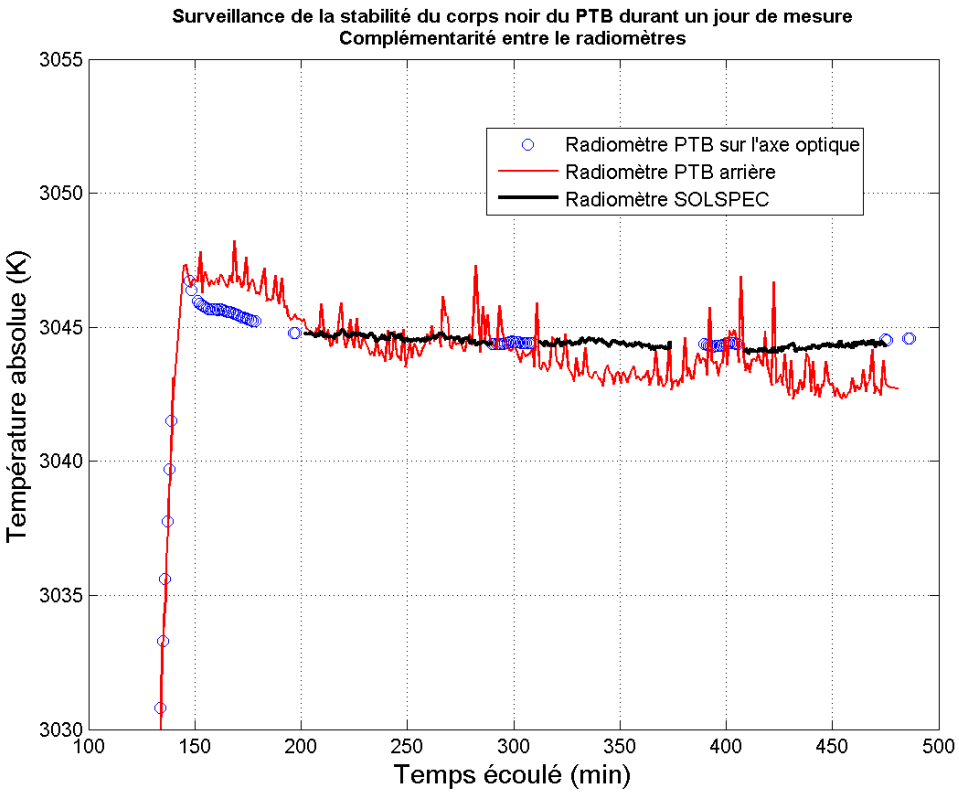
INSTRUMENT LINEARITY

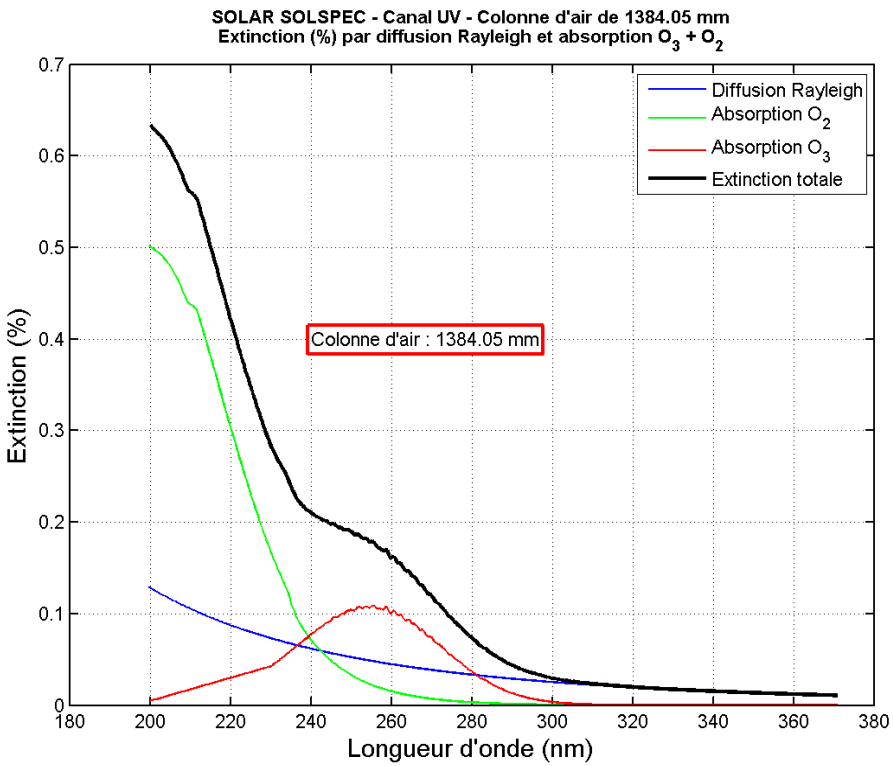


The Sun will not generate a signal greater than 10^5.

ABSOLUTE CALIBRATION AT PTB

We use the Blackbody at PTB (Braunscheiwg, Germany)
NIST FEL lamps and a D2 lamp (V0132 calibrated by PTB below 250 nm

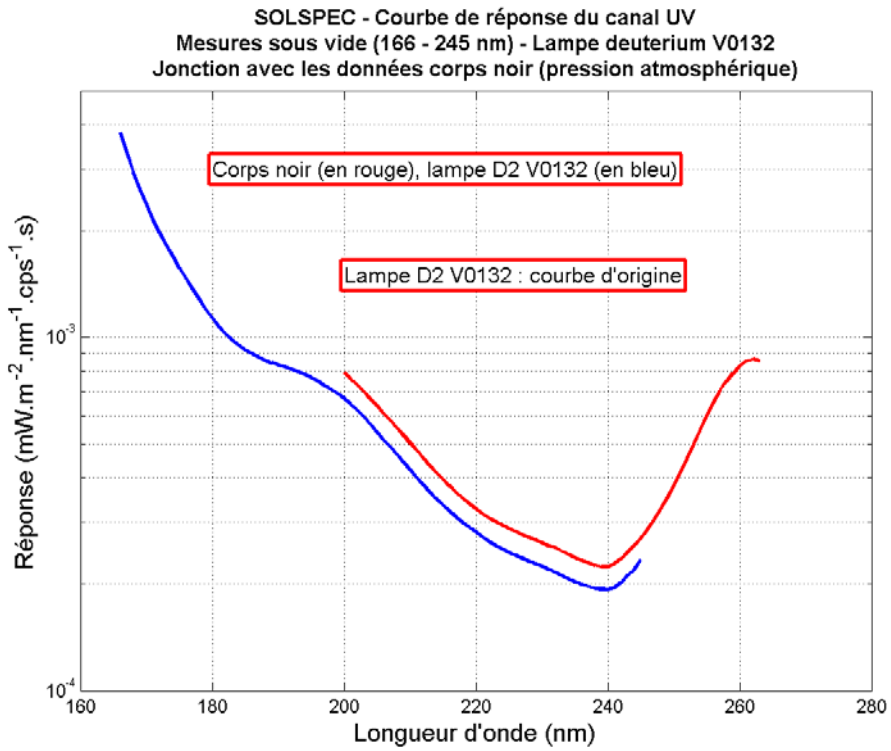


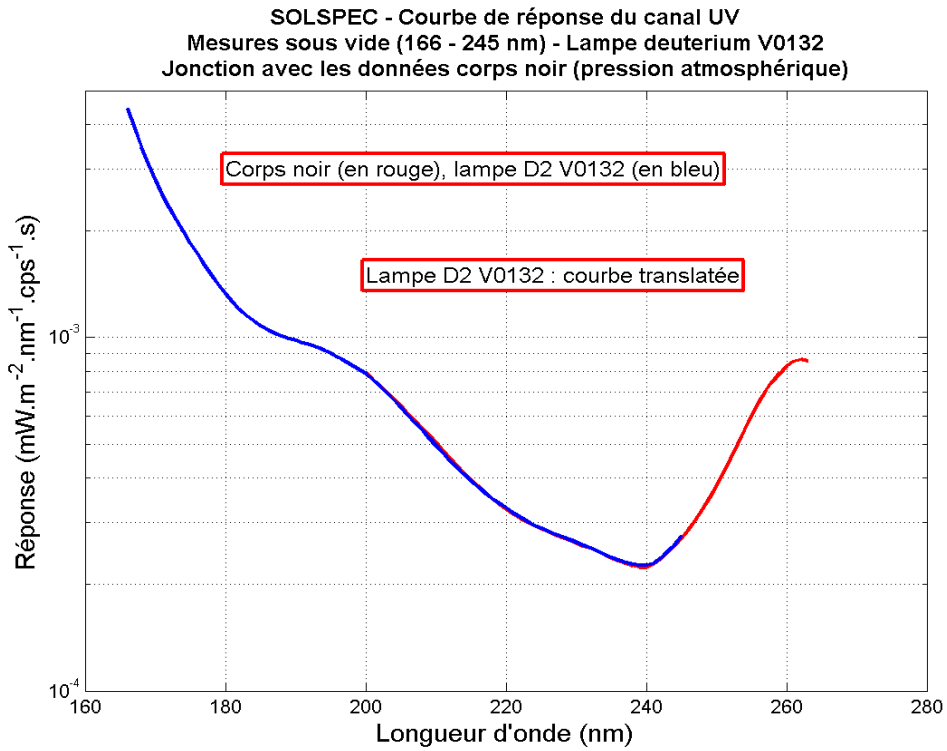


Temperature is recorded by three radiometers: at rear of BB for control (red, PTB), In front (blue, PTB), in front (black, SOLSPEC).

PTB ensures an absolute temperature at 0.44 K accuracy.

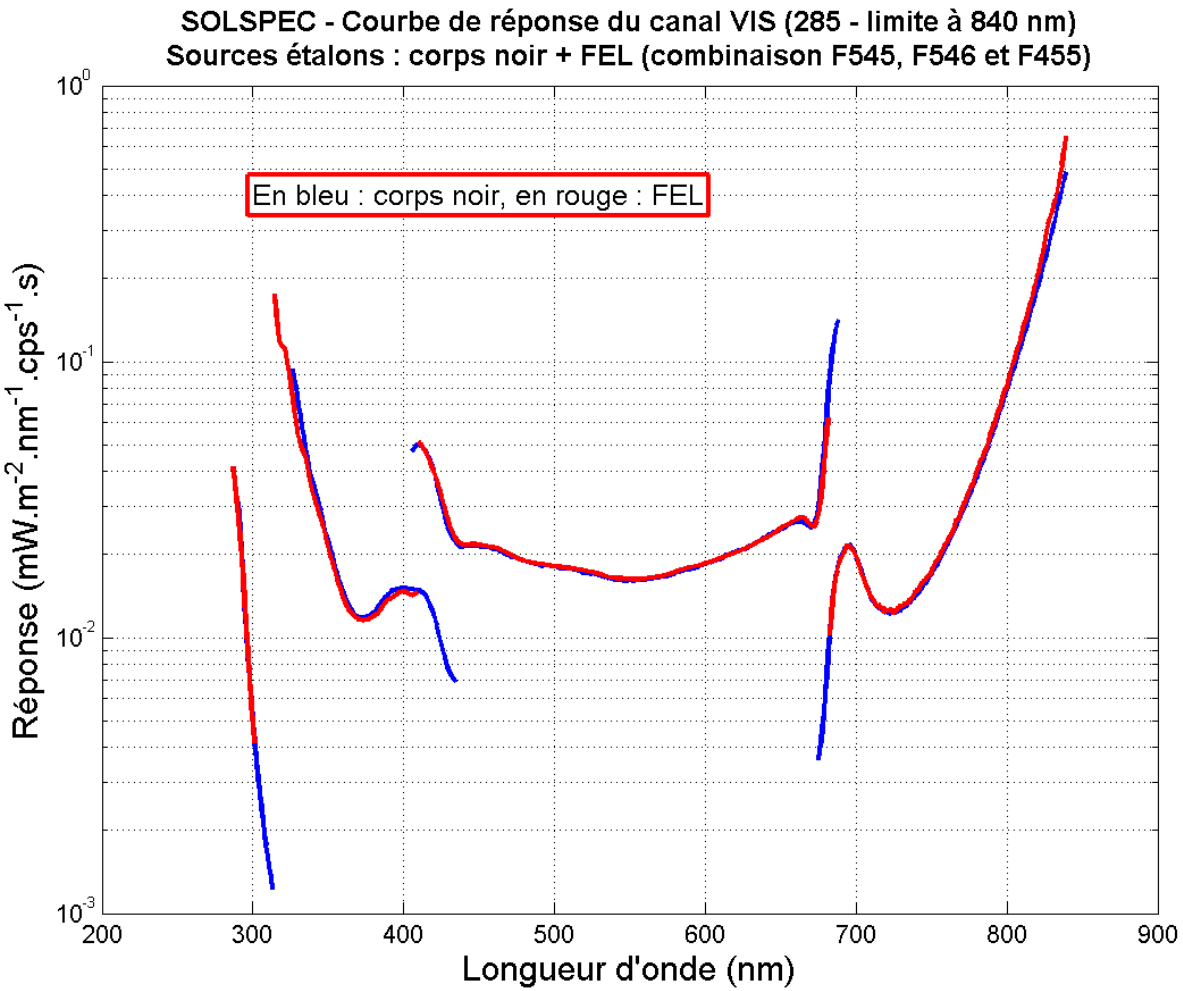
UV Spectrometer calibration using PTB BB and NIST D2 lamps





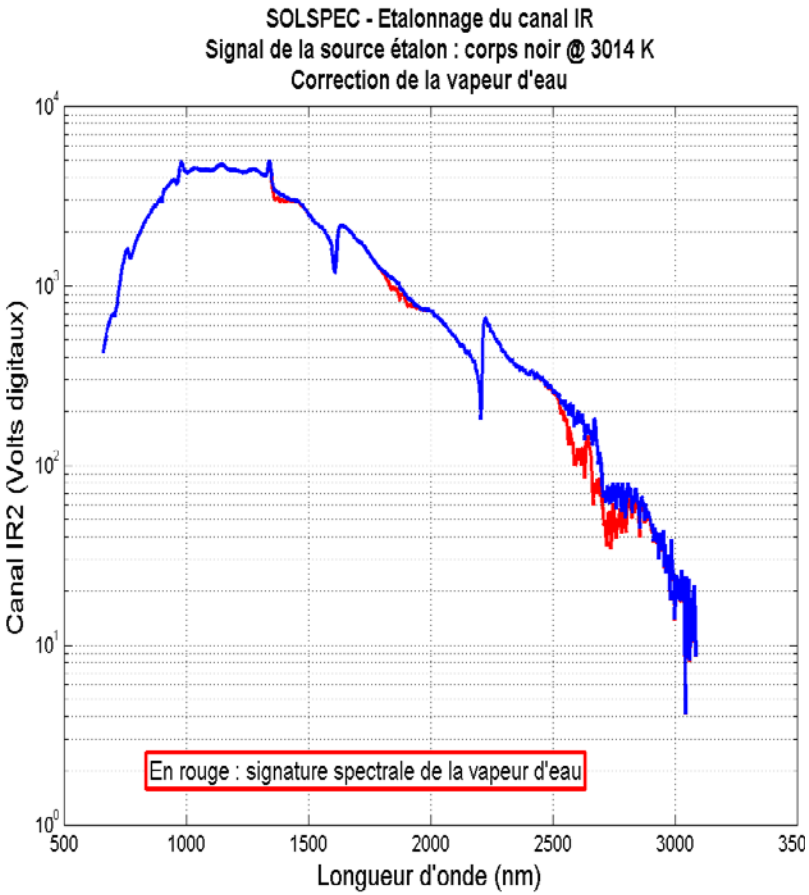
SOLSPEC responsivity using BB: in red. As the BB is not usable below 200 nm, a D2 lamp was used (blue) calibrated by PTB in vaccum. This lamp and SOLSPEC were set in a vaccum chamber. Given the dimension of the chamber, the distance Instrument/lamp was very short → scattered light. After taking into account this effect, an agreement was found in the overlapping region.

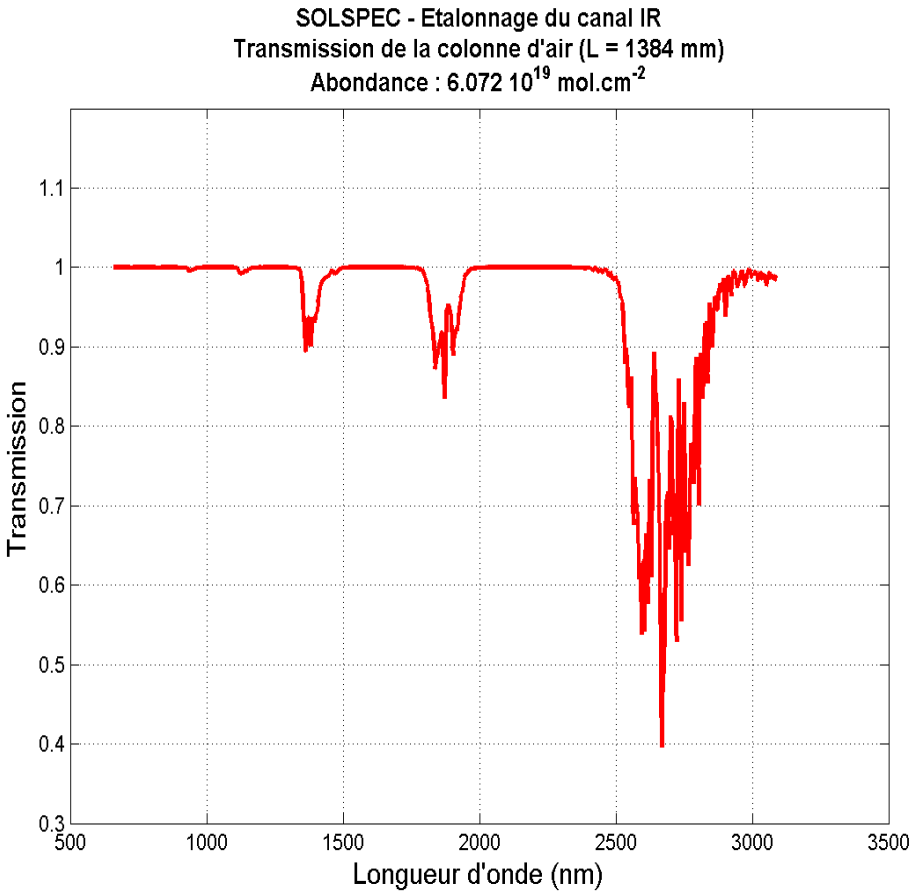
VISIBLE SPECTROMETER ABSOLUTE CALIBRATION



We used PTB BB and FEL NIST lamps. <u>They provide consistent results</u>. The discontinuities shown above are due to the filter change as a function of wavelength (second order and density filters).

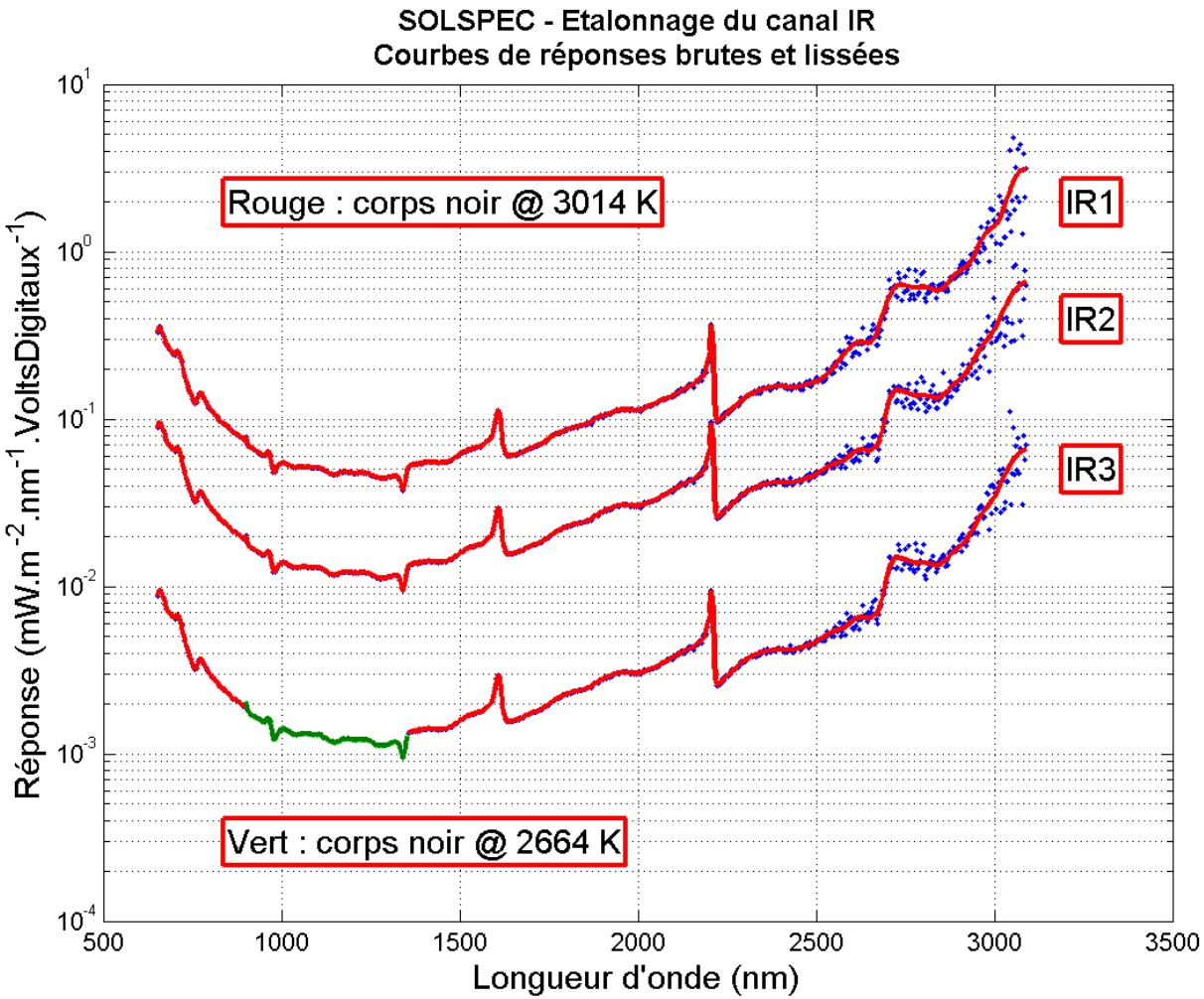
IR SPECTROMETER ABSOLUTE CALIBRATION





The discontinuities are due to the filters (second order and density). Special care was taken about the water vapor on the optical path (shown in red).

IR SPECTROMETER ABSOLUTE CALIBRATION



IR1, IR2, IR3 are the three outputs of different gains. Discontinuities are due to filters change.

UNCERTAINTIES TAKING PART IN THE MEASUREMENTS

A: Ground calibration

A1 aligment instrument/source
A2 optical path
A3 distance instrument/source
A4 Source intensity
A5 Source stability in time

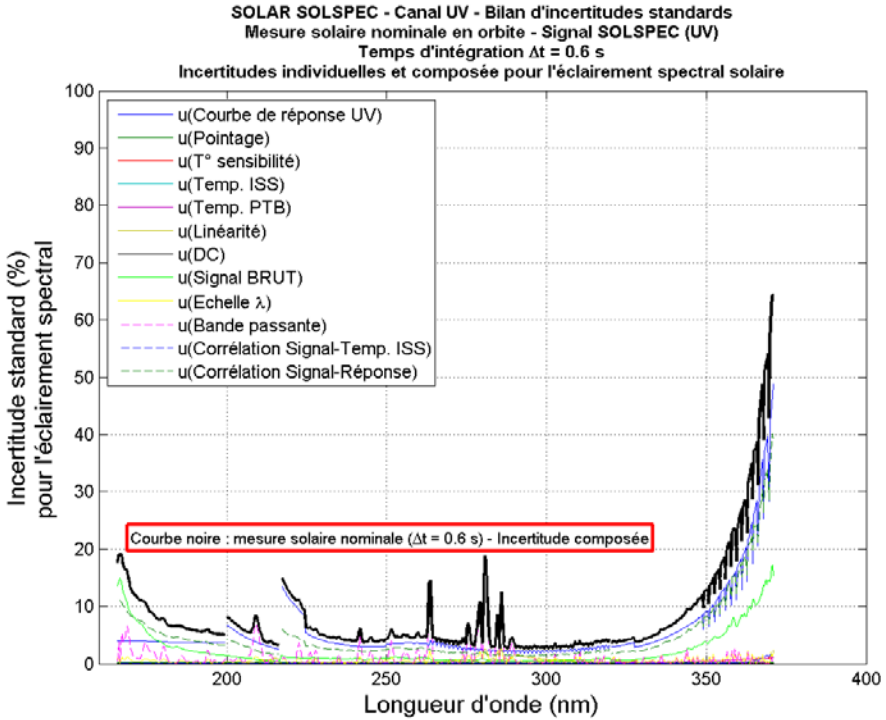
B: In orbit

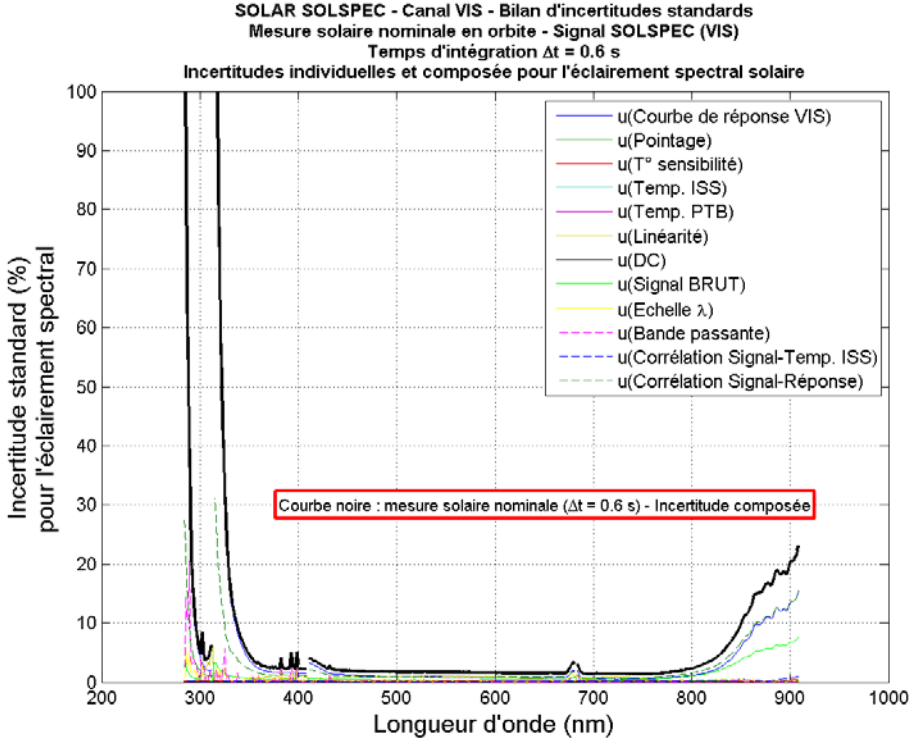
B1: Depointing

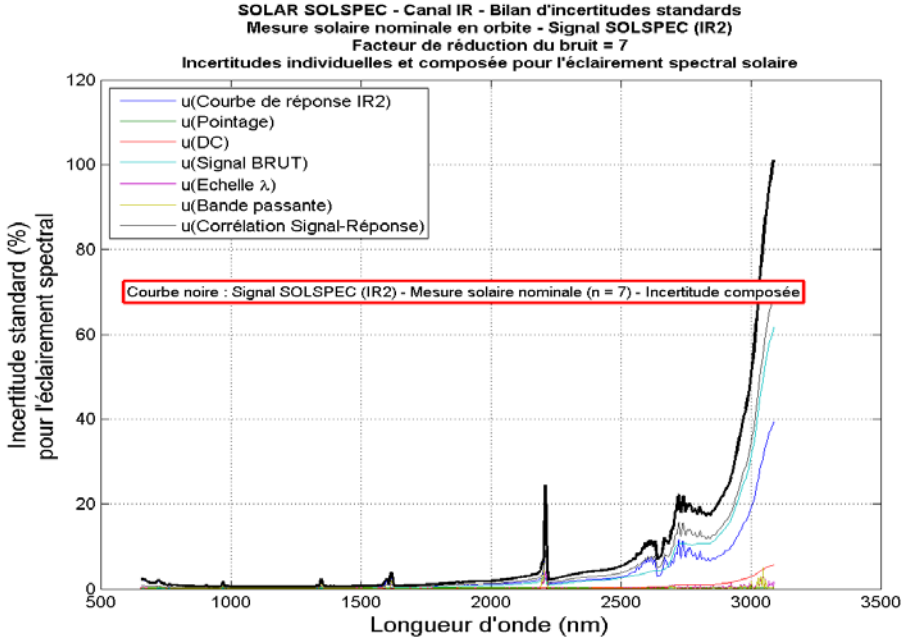
C: In orbit and on ground

C1: Counting
C2: Detectors linearity
C3: Dark current
C4: Wavelength scale
C5: Slit function
C6: Scattered light
C7: Temperature effect (detector, …)
C8: HV stability

Then, uncertainties are geometrically combined.
Dominant uncertainties are: ground calibration and counting in orbit.


SOLAR SOLSPEC - Canal UV - Bilan d'incertitudes standards
Mesure solaire nominale en orbite - Signal SOLSPEC (UV)
Temps d'intégration Δt = 0.6 s
Incertitudes individuelles et composée pour l'éclairement spectral solaire
u(Courbe de réponse UV)
u(Pointage)
u(T° sensibilité)
u(Temp. ISS)
u(Temp. PTB)
u(Linéarité)
u(DC)
u(Signal BRUT)
u(Echelle λ)
u(Bande passante)
u(Corrélation Signal-Temp. ISS)
u(Corrélation Signal-Réponse)
Courbe noire : mesure solaire nominale (Δt = 0.6 s) - Incertitude composée
Incertitude standard (%) pour l'éclairement spectral
Longueur d'onde (nm)


SOLAR SOLSPEC - Canal VIS - Bilan d'incertitudes standards
Mesure solaire nominale en orbite - Signal SOLSPEC (VIS)
Temps d'intégration Δt = 0.6 s
Incertitudes individuelles et composée pour l'éclairement spectral solaire
u(Courbe de réponse VIS)
u(Pointage)
u(T° sensibilité)
u(Temp. ISS)
u(Temp. PTB)
u(Linéarité)
u(DC)
u(Signal BRUT)
u(Echelle λ)
u(Bande passante)
u(Corrélation Signal-Temp. ISS)
u(Corrélation Signal-Réponse)
Courbe noire : mesure solaire nominale (Δt = 0.6 s) - Incertitude composée
Incertitude standard (%) pour l'éclairement spectral
Longueur d'onde (nm)


SOLAR SOLSPEC - Canal IR - Bilan d'incertitudes standards
Mesure solaire nominale en orbite - Signal SOLSPEC (IR2)
Facteur de réduction du bruit = 7
Incertitudes individuelles et composée pour l'éclairement spectral solaire
u(Courbe de réponse IR2)
u(Pointage)
u(DC)
u(Signal BRUT)
u(Echelle λ)
u(Bande passante)
u(Corrélation Signal-Réponse)
Courbe noire : Signal SOLSPEC (IR2) - Mesure solaire nominale (n = 7) - Incertitude composée
Incertitude standard (%) pour l'éclairement spectral
Longueur d'onde (nm)

HOLLOW CATHODE LAMP

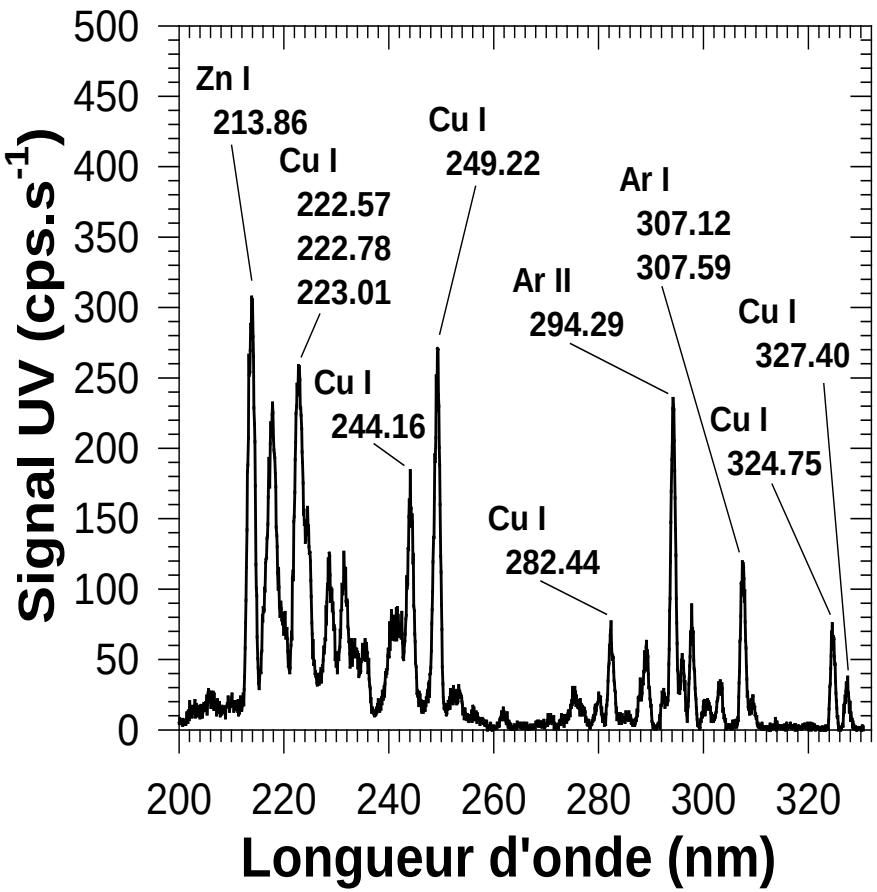
Role:

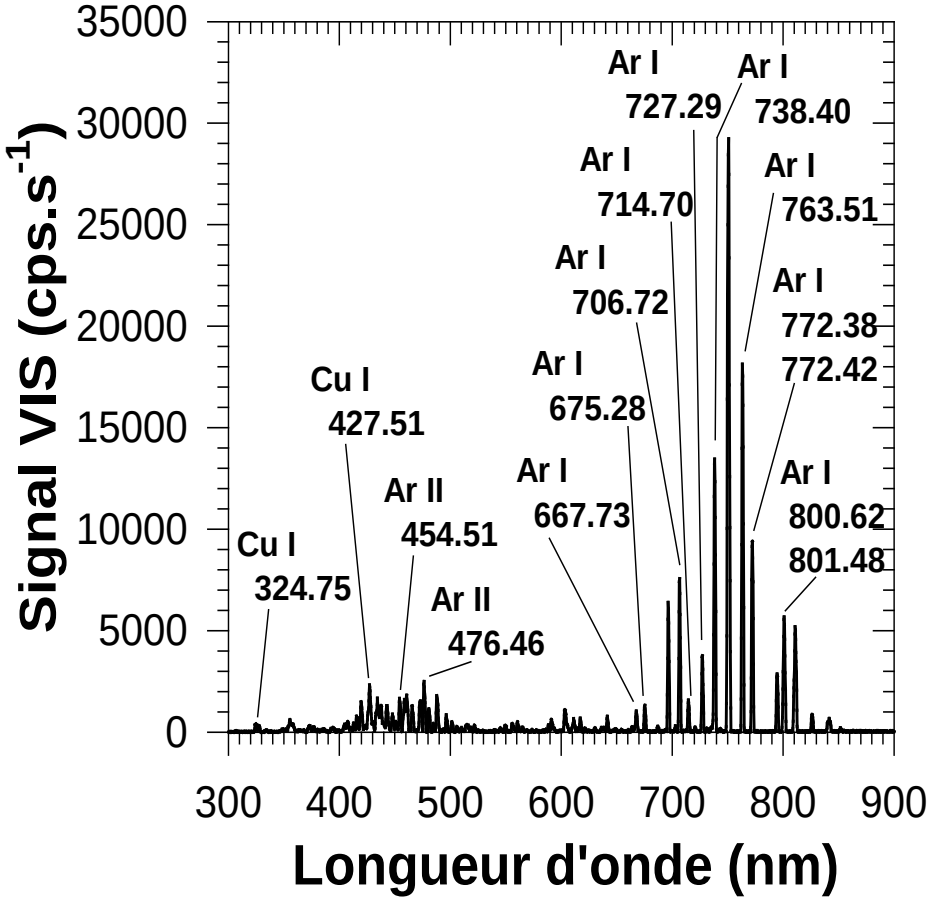
- Measures in orbit the slit function

- Measures in orbit the dispersion law

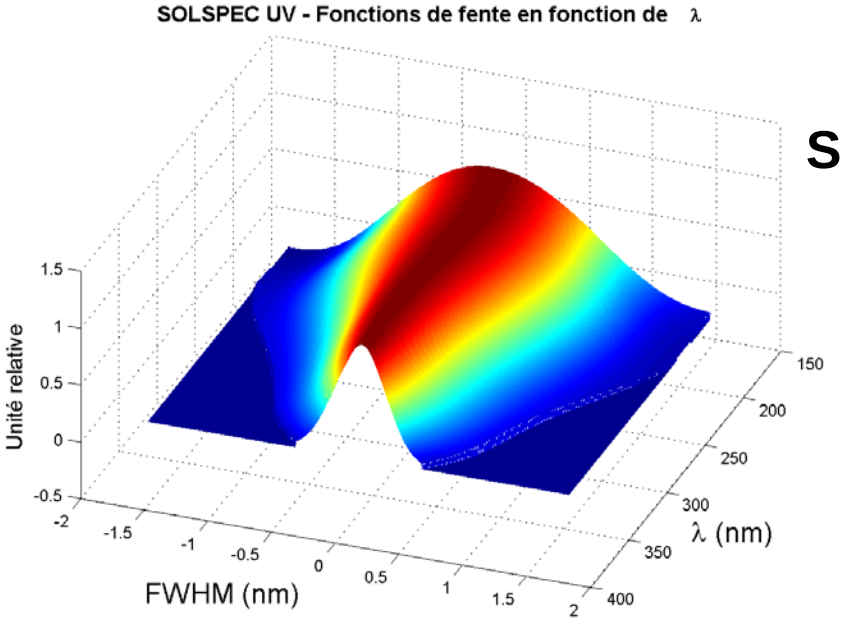
- Used as reference source

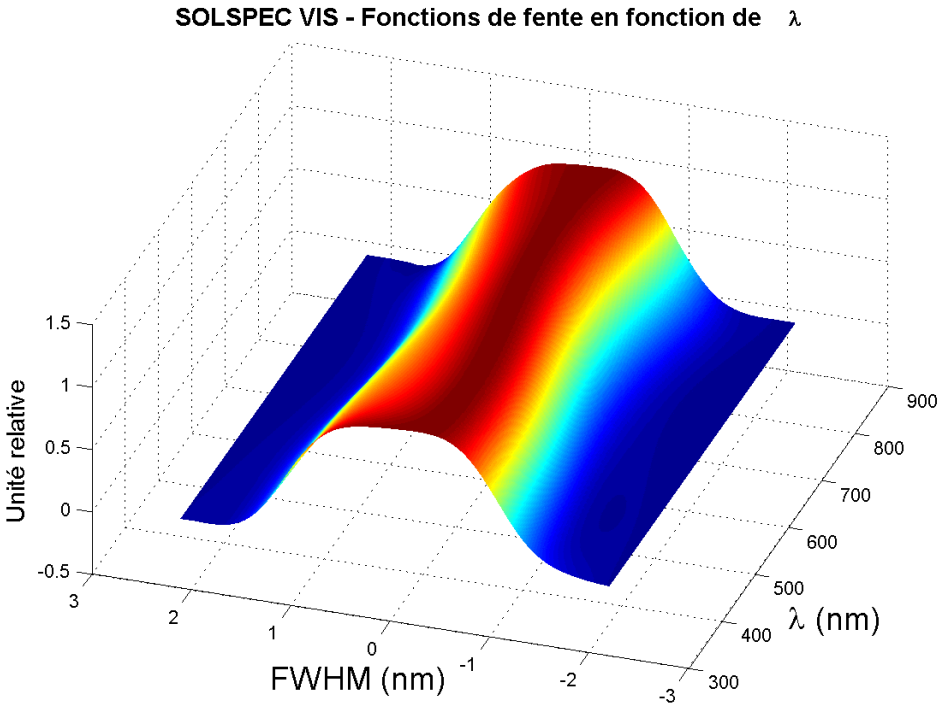
LINES PROVIDED BY THE HOLLOW CATHODE LAMP

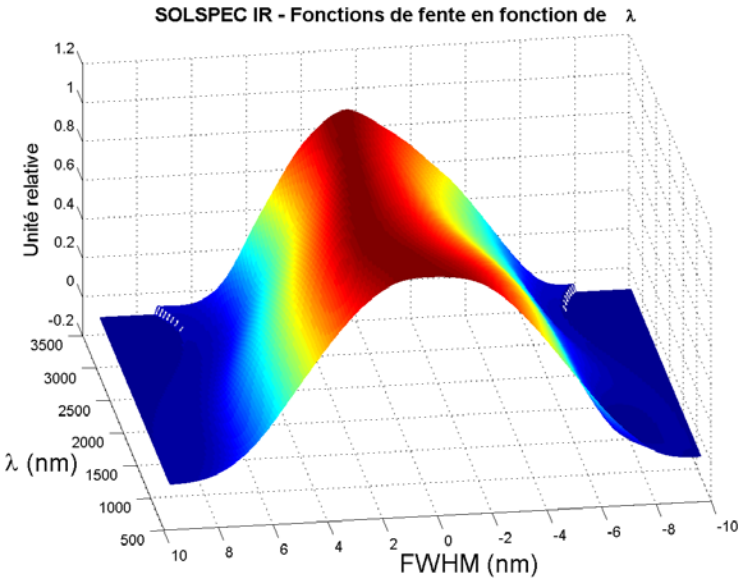




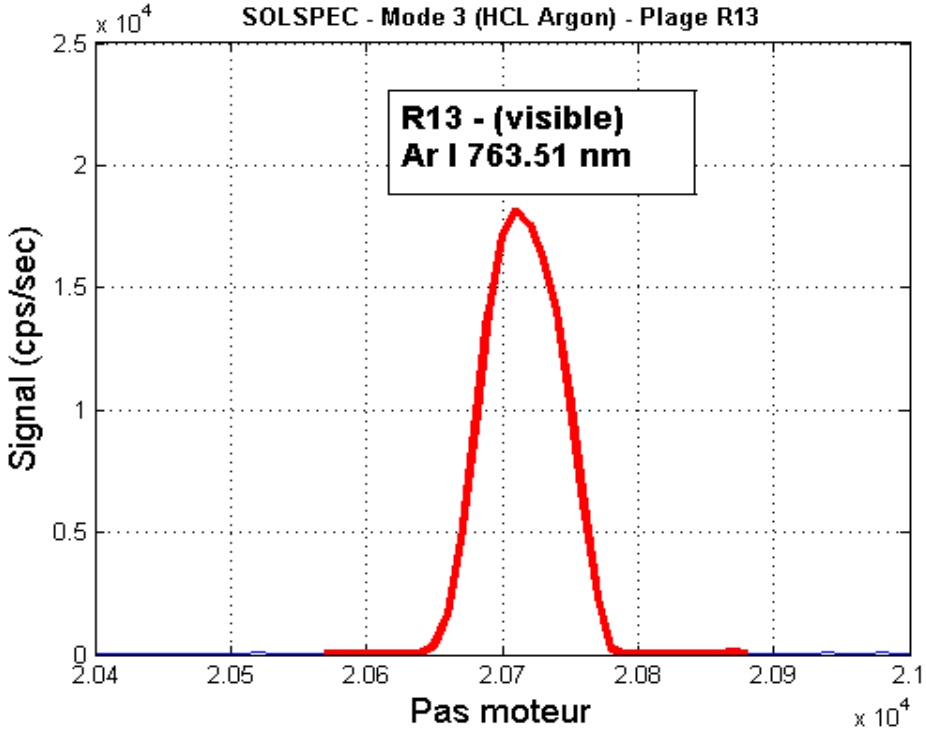
Spectrometers Slit Functions in UV, VIS, IR



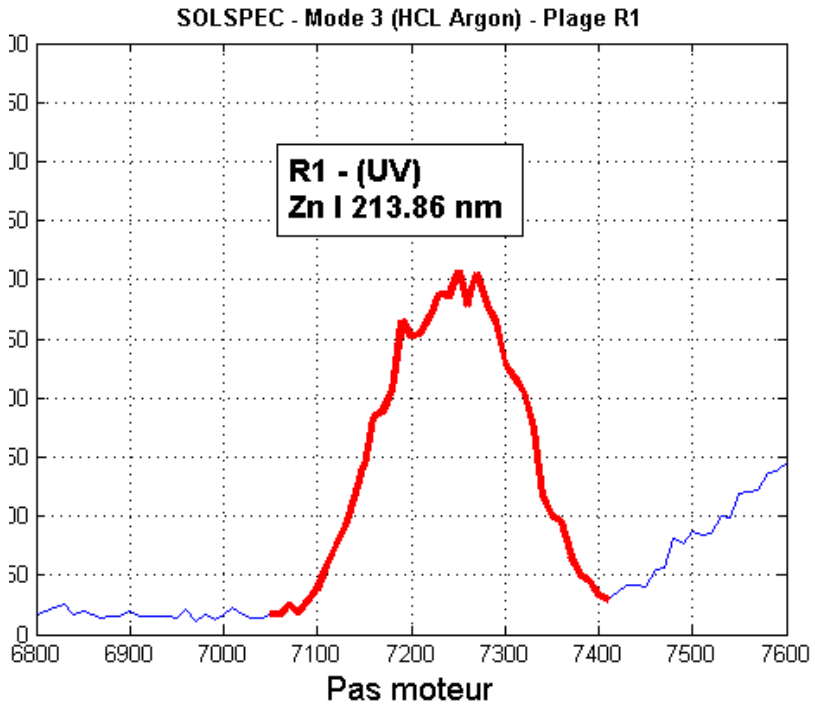




SLIT FUNCTION

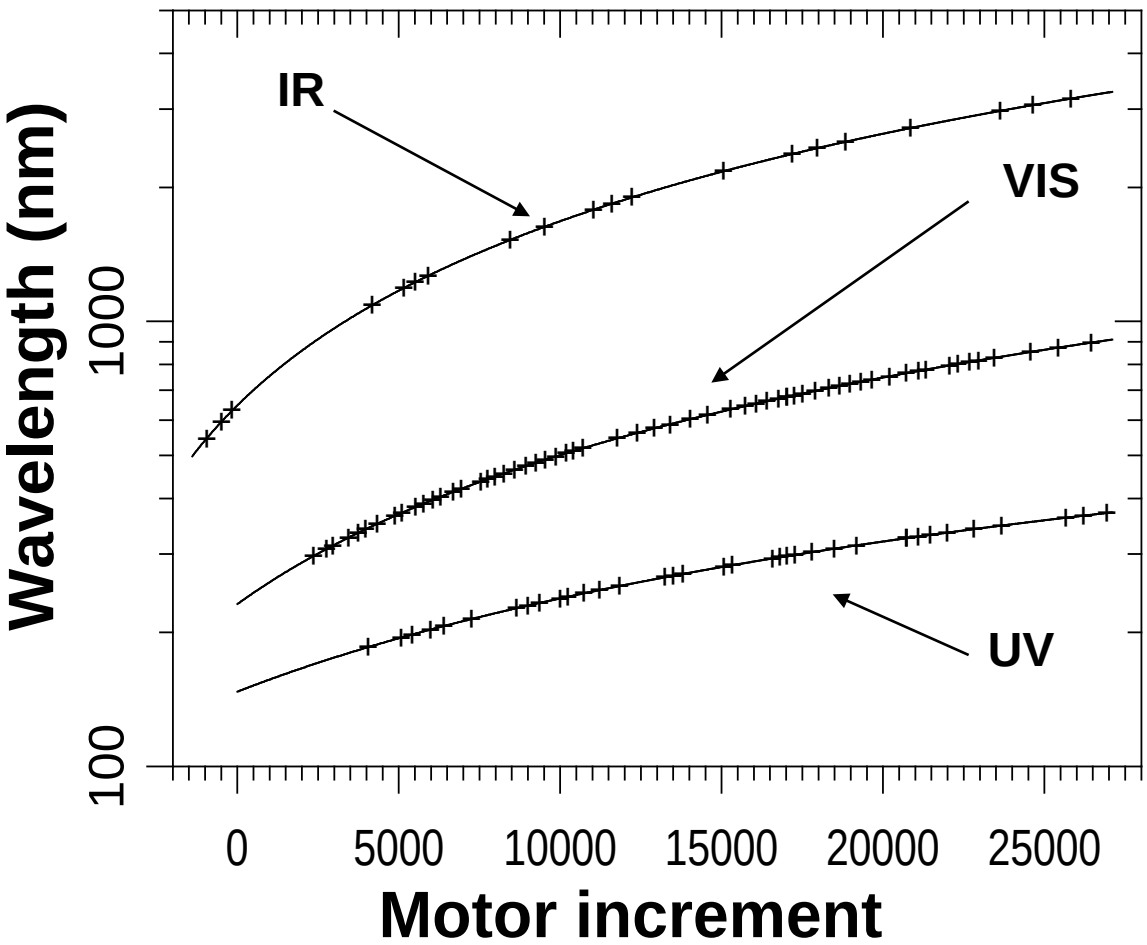


With an isolated line



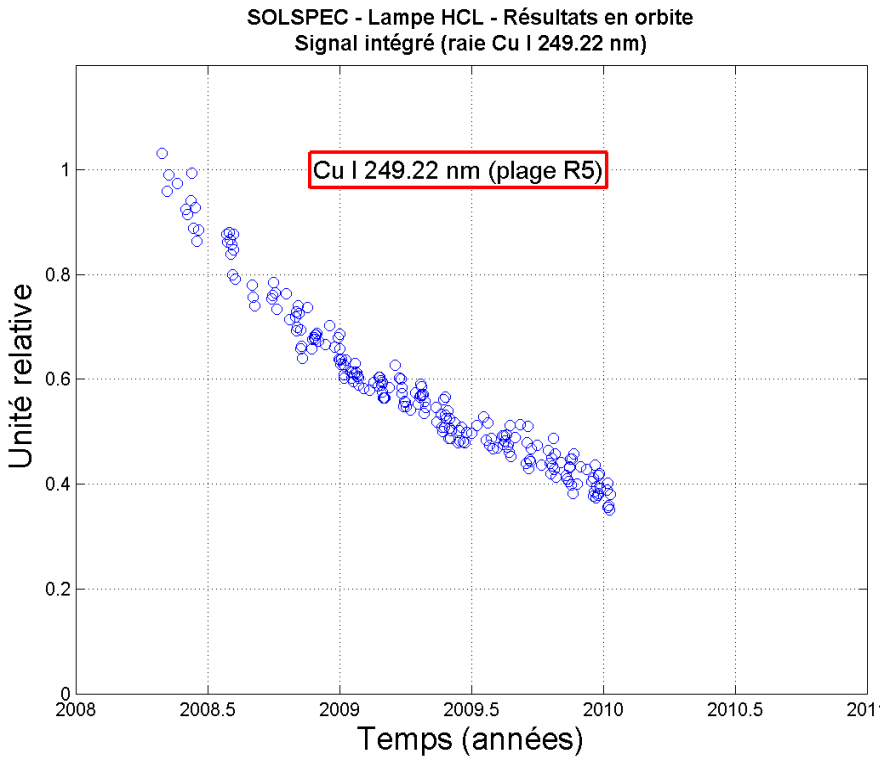
When two lines are adjacent in the slit function

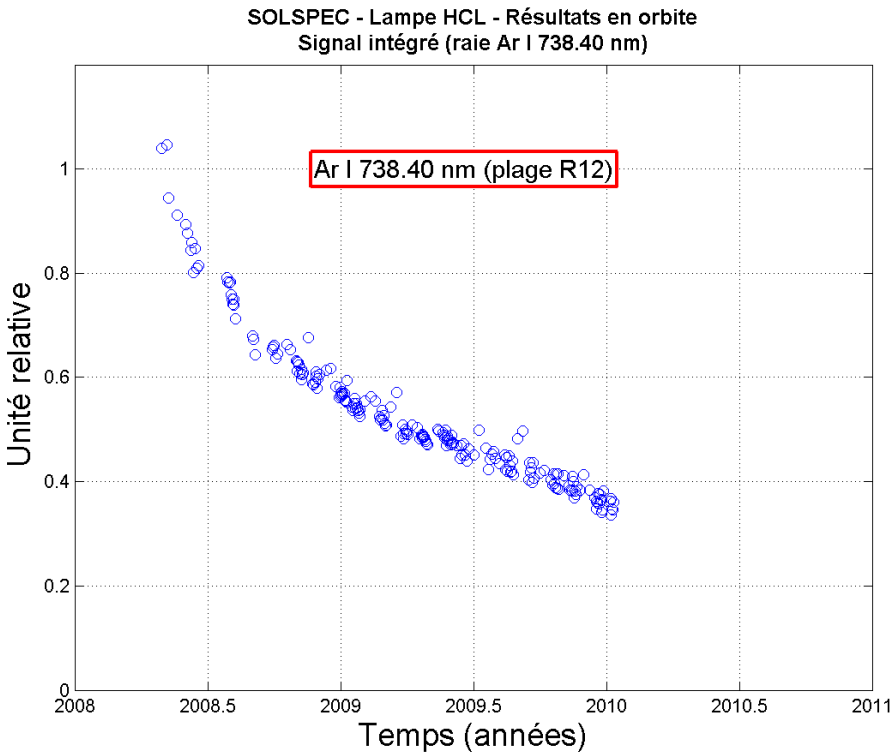
INSTRUMENT DISPERSION LAW



The line wavelength associated to the corresponding step number allows to derive the dispersion law. It is consistent with the theoretical law.

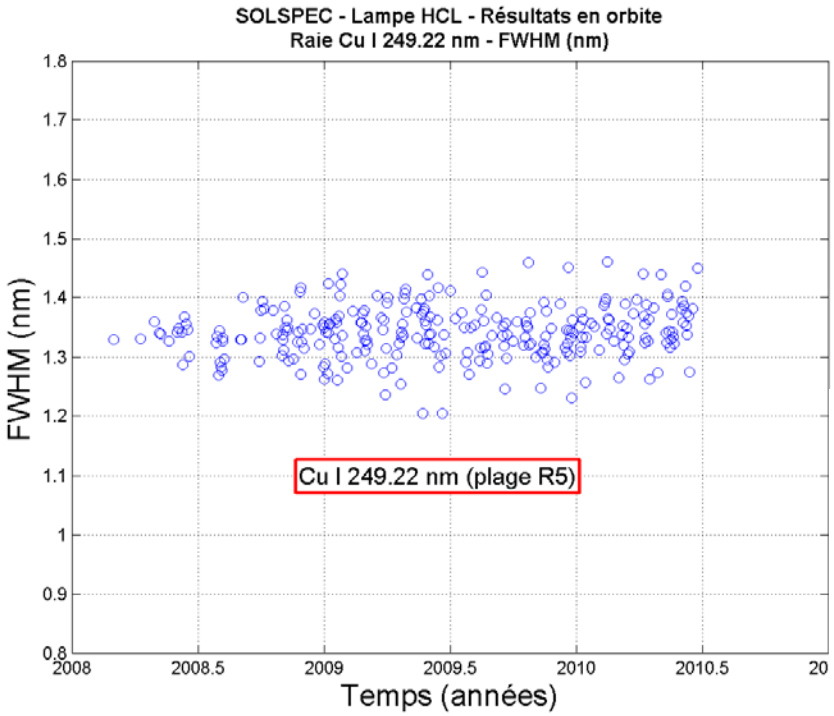
BEHAVIOR OF THE HOLLOW CATHODE LAMP IN SPACE

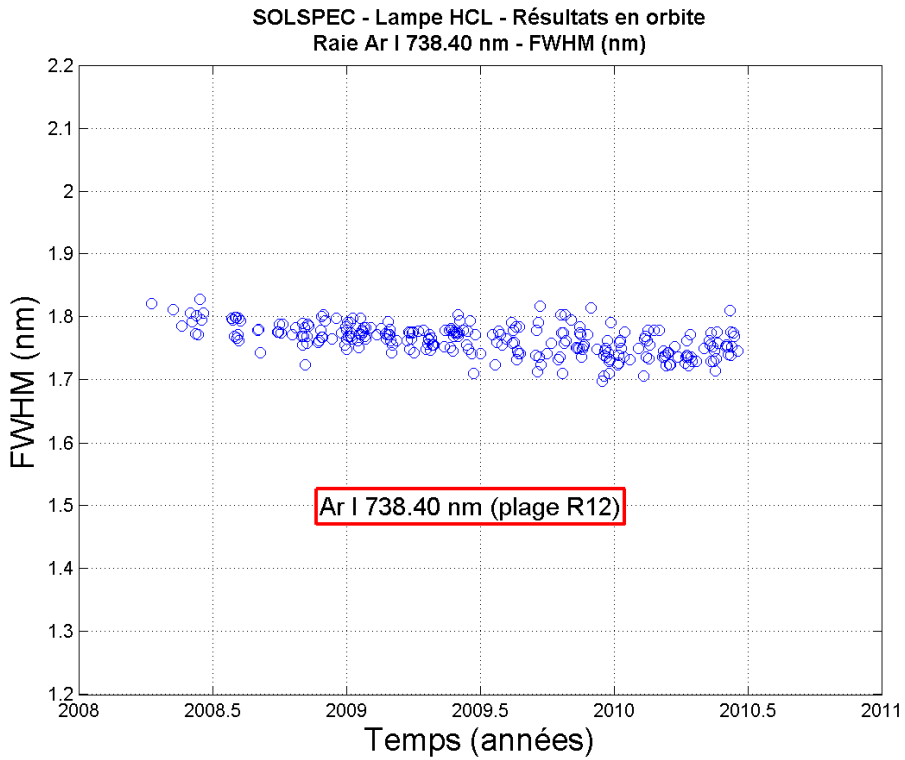




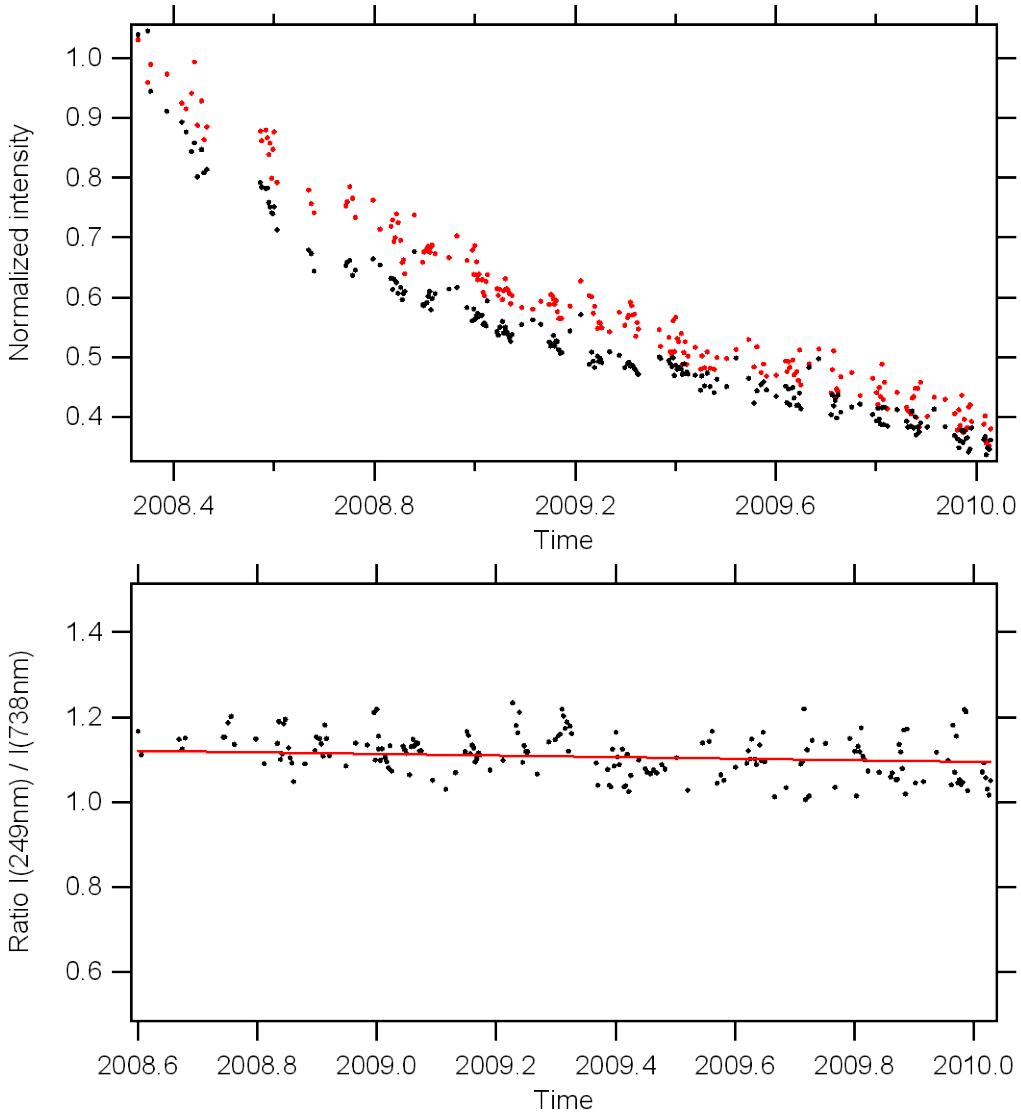
The s/n ratio remains acceptable.

BEHEVIOR SPECTRAL CHARACTERISTICS IN SPACE AS A FUNCTION OF TIME



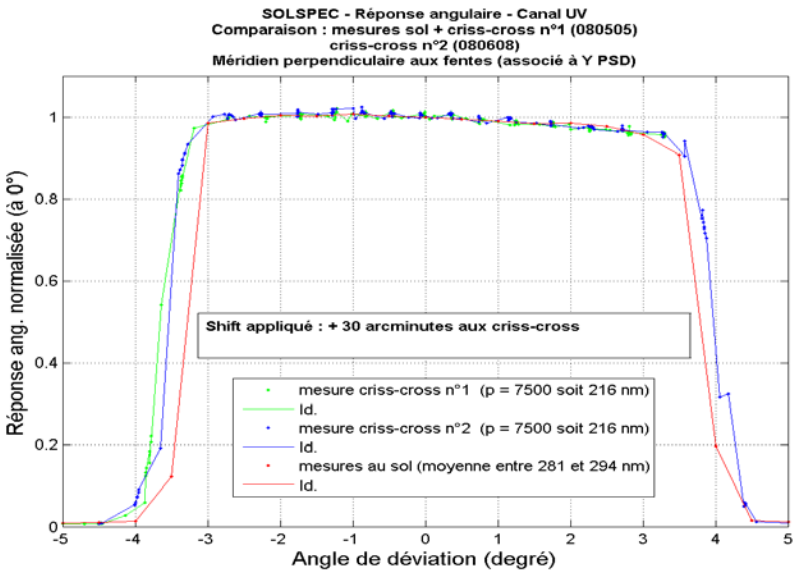


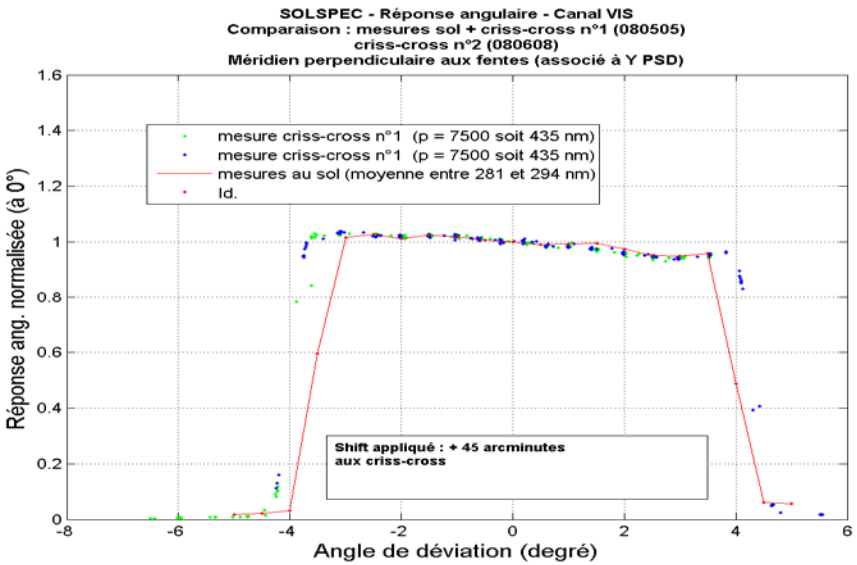
THE LINE INTENSITY COVARIANCE

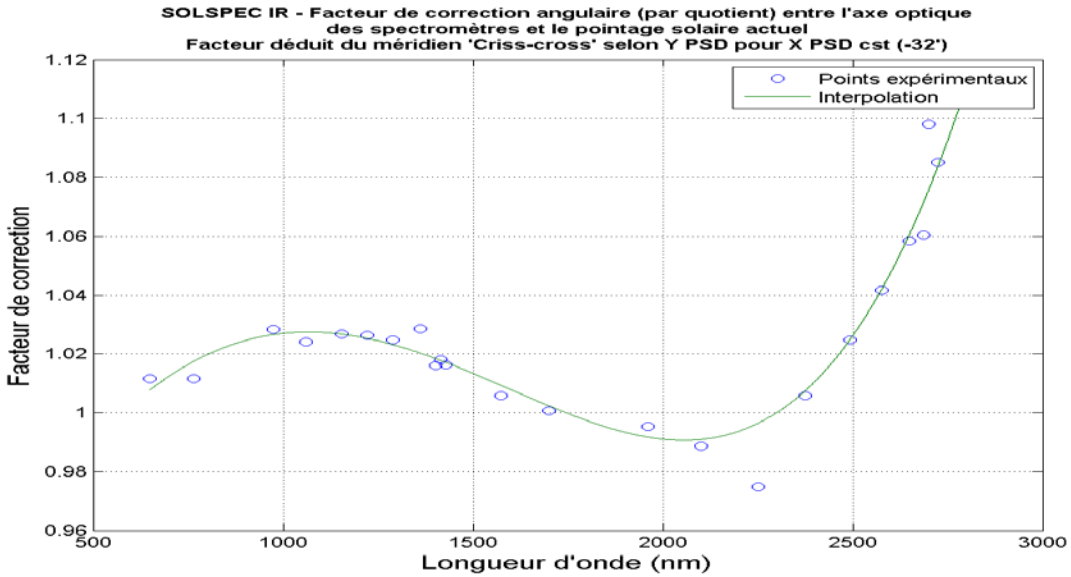


Line 249 nm (red)
Line 738 nm (black)

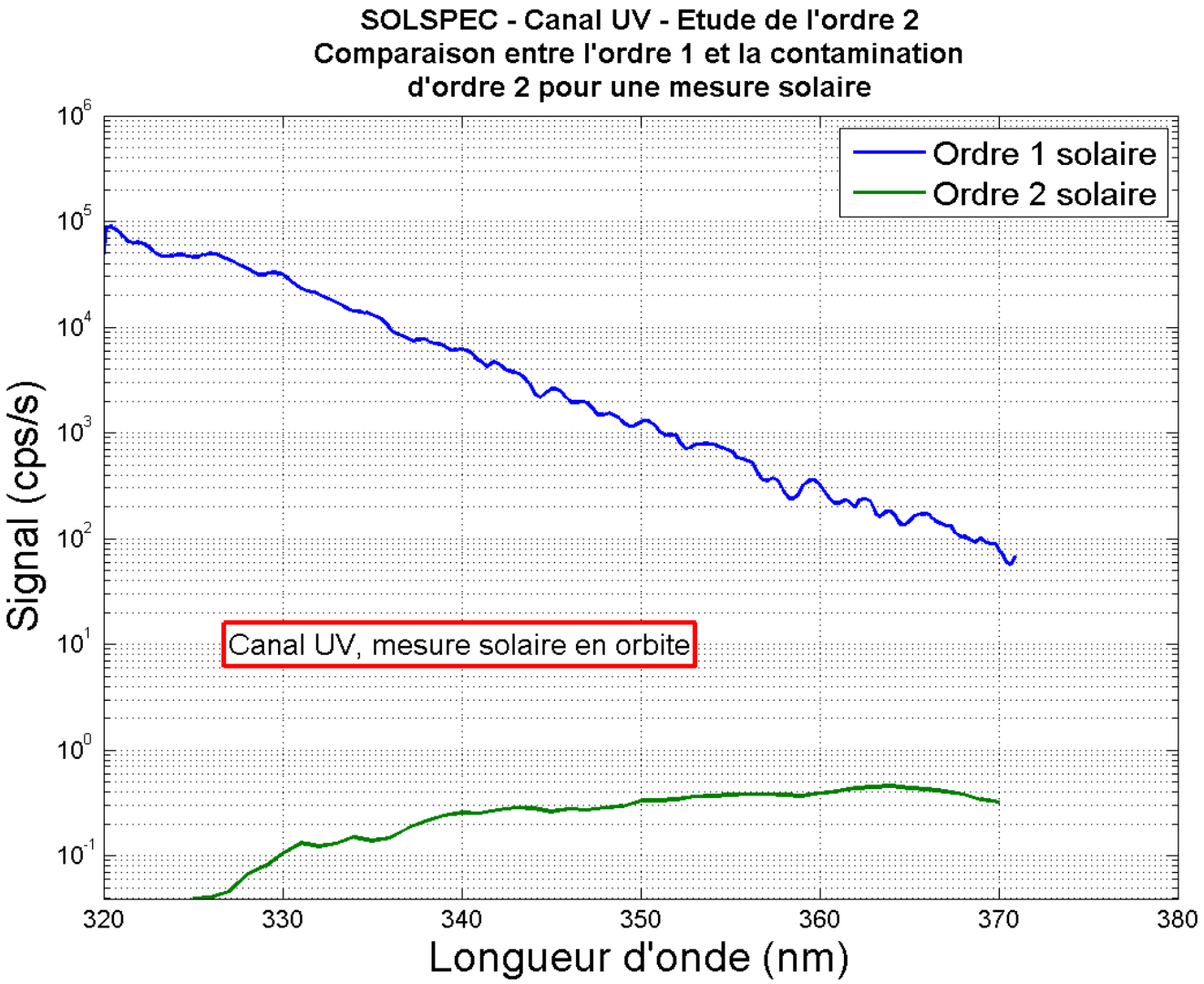
FLATFIELD MEASUREMENTS IN ORBIT







SECOND ORDER EFFECT



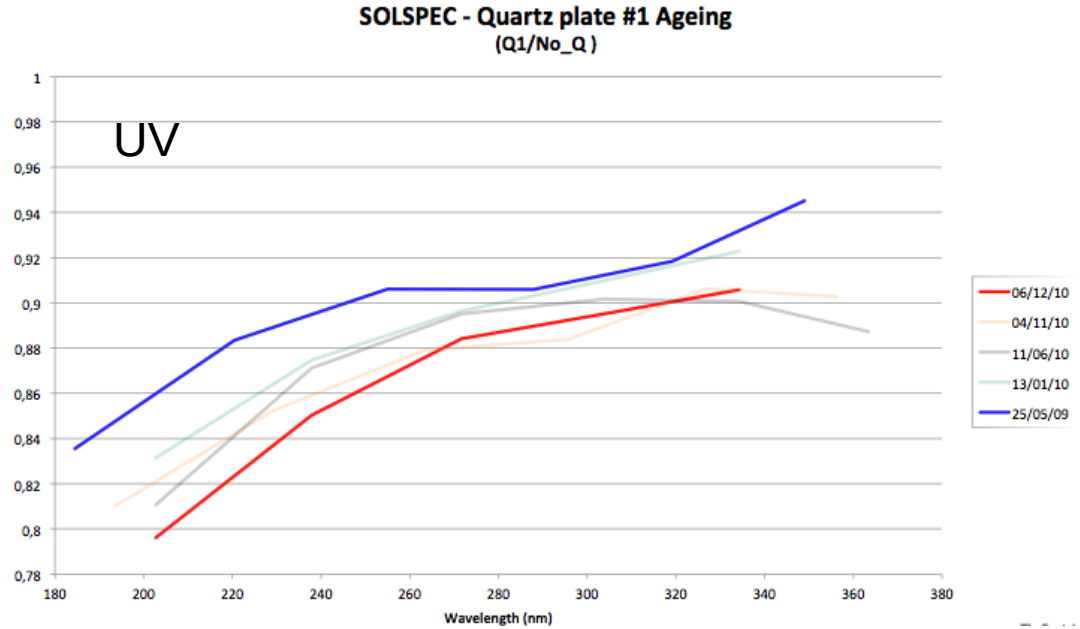
STRATEGY OF QUARTZ PLATES USE

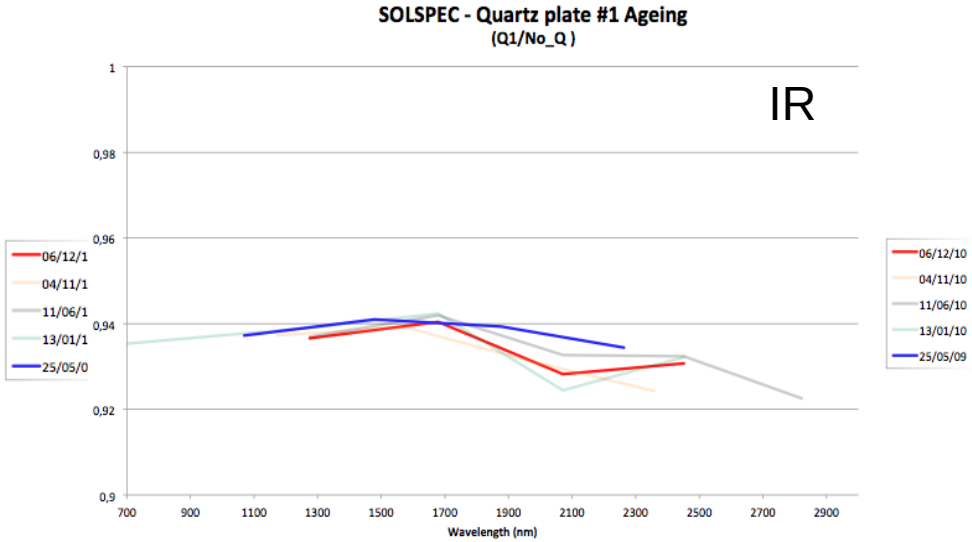
Each spectrometer is equipped by two quartz plates.
They are set on a wheel together with a hole. They allow to protect the entrance diffusors from the hard radiation.

Operations:

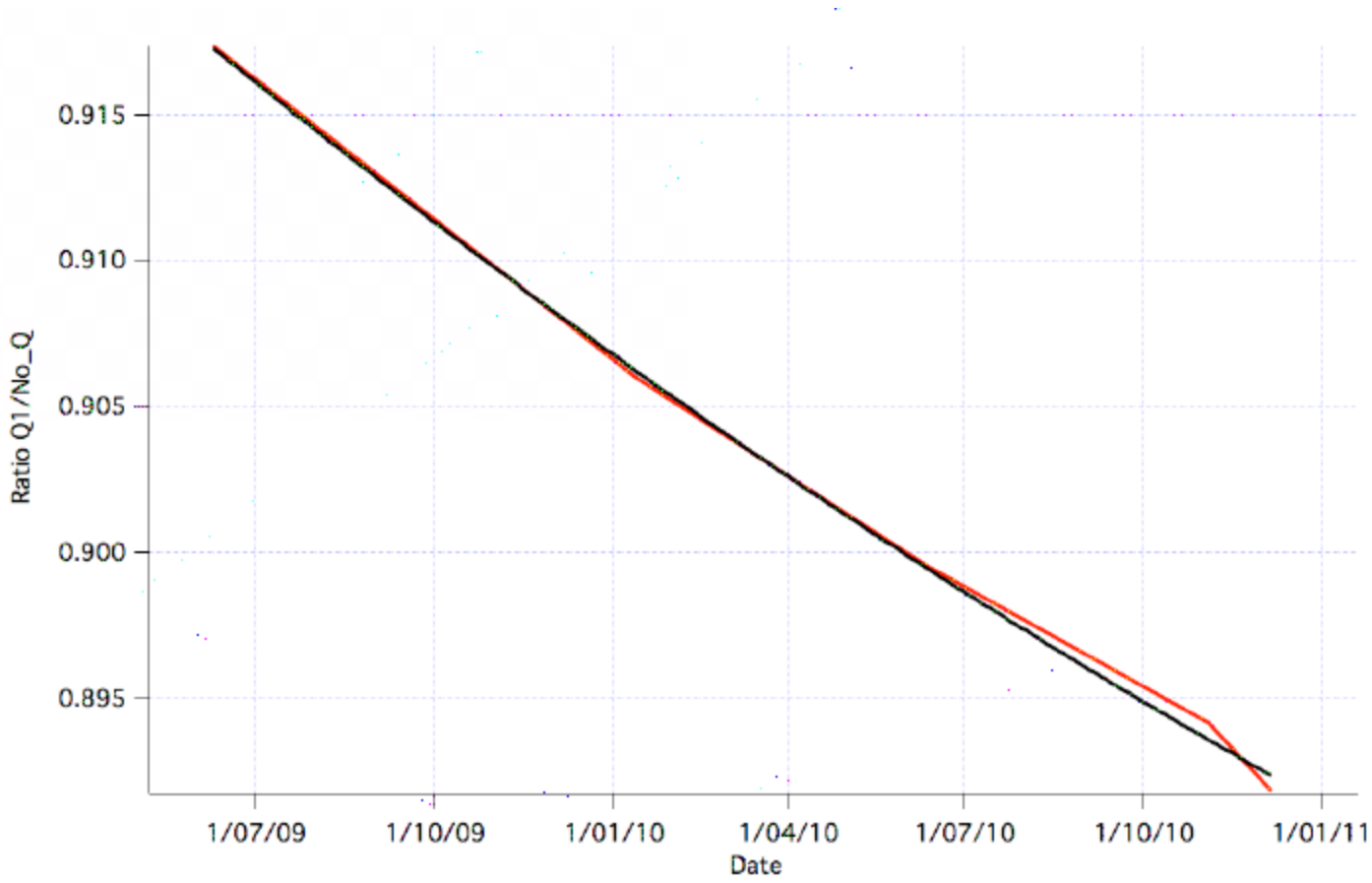
- Solar measurements are daily made with Q1
- Once per month, Q2 is exposed to measure the transmission ratio Q1/Q2
- Q1 transmission is also measured by measuring the ratio Q1/hole.

BEHAVIOR OF QUARTZ PLATES IN ORBIT



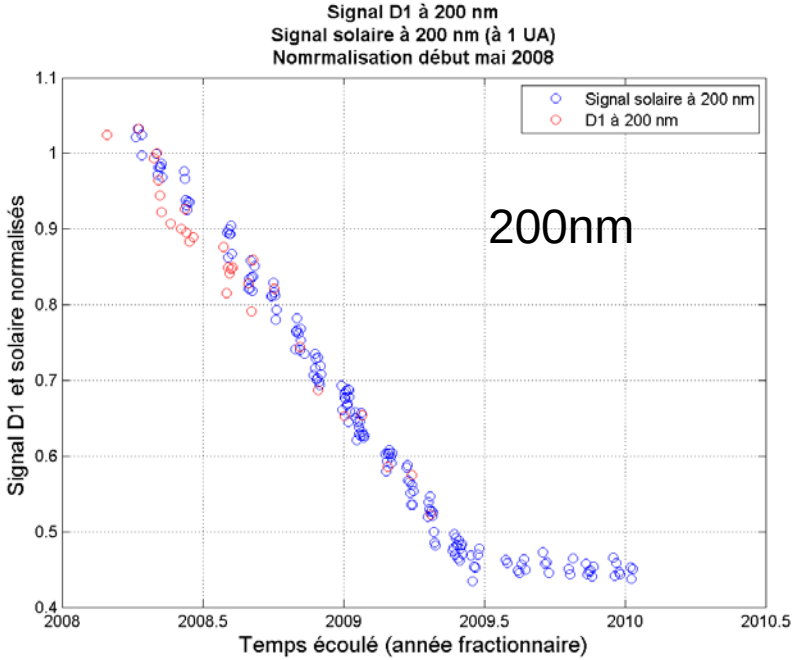


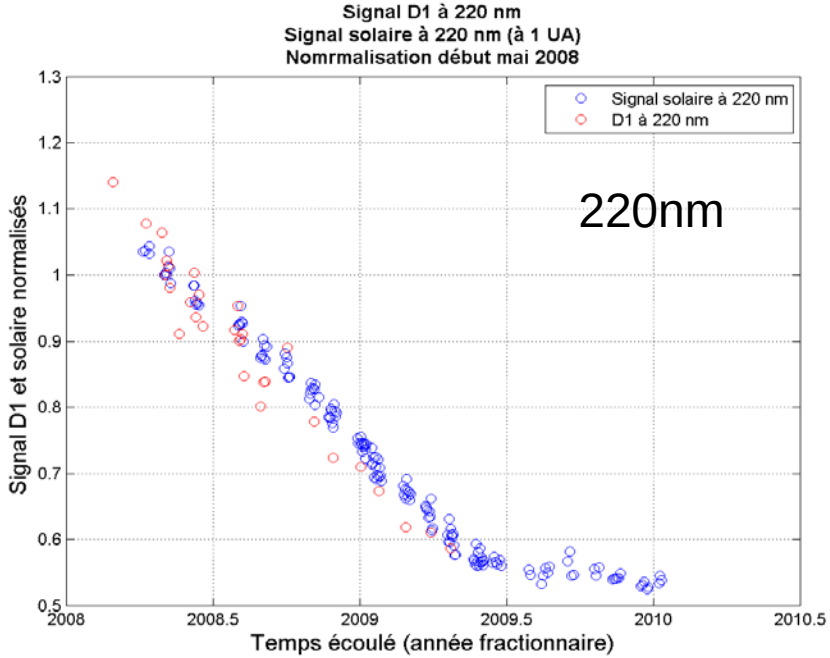
QUARTZ Q1 AGING AT 288 nm

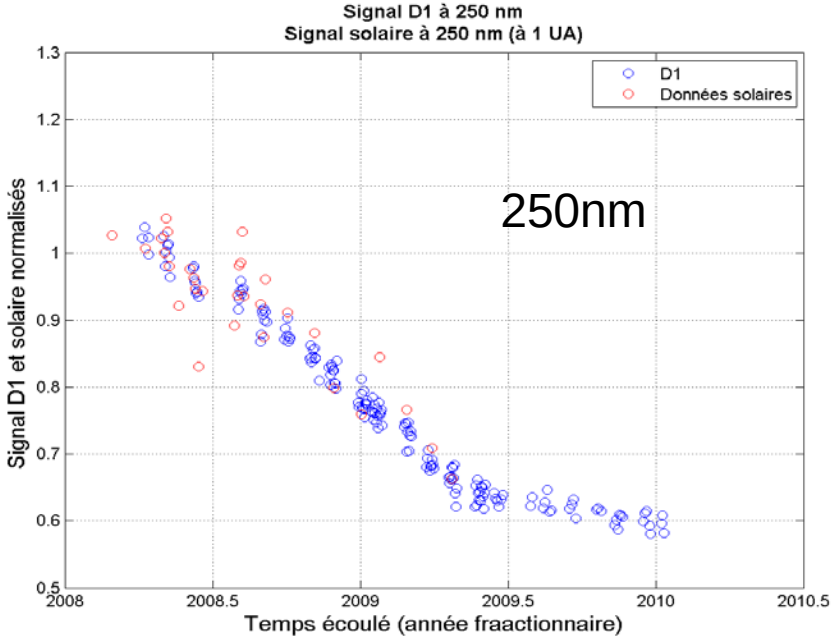


Q1 is the most frequently used quartz plate.

BEHAVIOR OF D2 LAMP IN ORBIT







D2 LAMPS POWER SUPPLY

It failed. Then, no D2 can be activated.

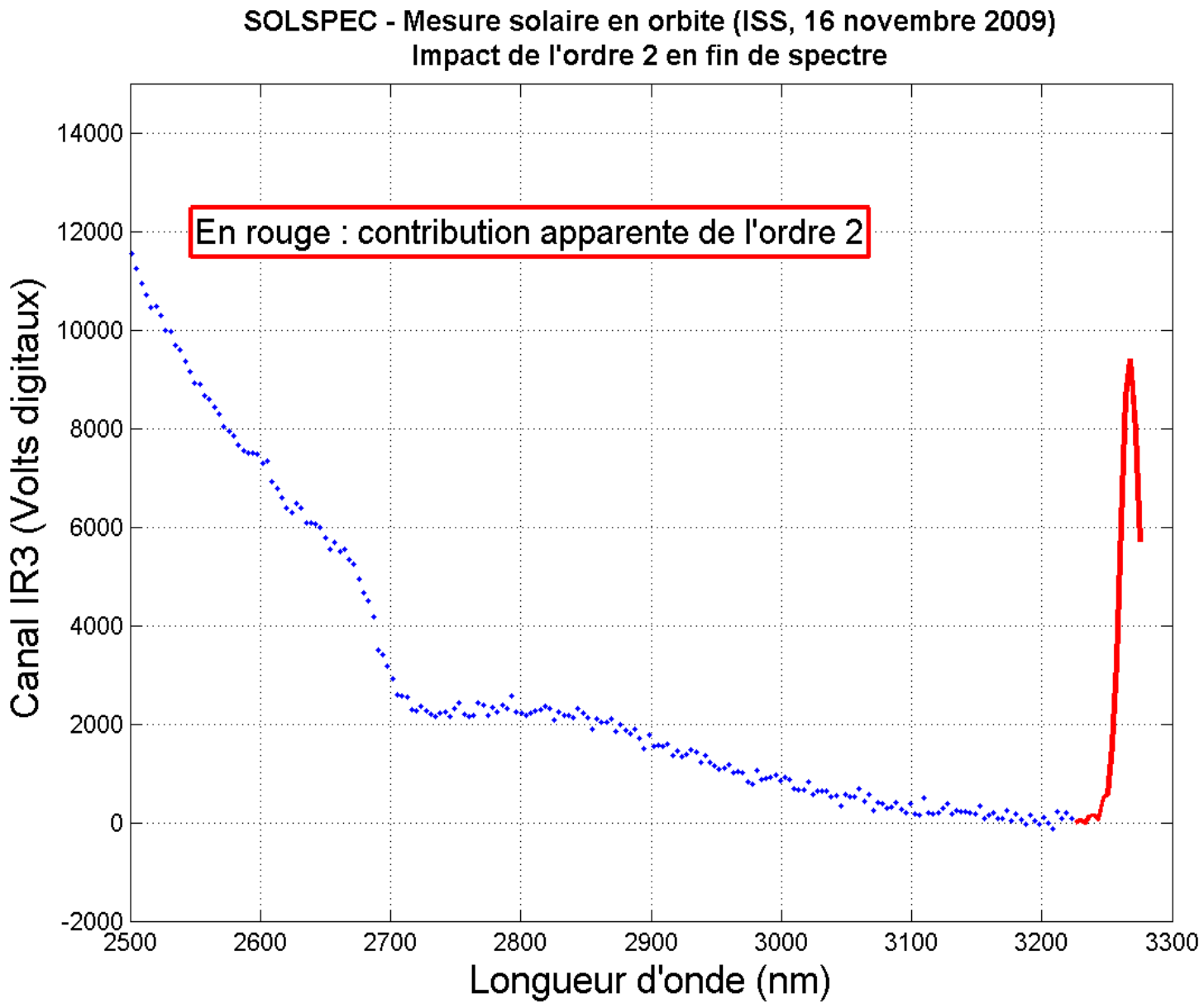
How to solve this problem?

We use the following facts:

- the aging in visible and IR is very small and furthermore it is controlled by use of the two tungsten ribbon lamps,
- the covariance of the lines hollow cathode lamp allows to monitor the line intensity in UV.

This procedure has been validated for the period where the D2 were still working.

IR: LIMIT OF DETECTION



CONCLUSIONS

NIST lamps and BB from PTB are providing consistent results for the instrument responsivity determination.

SOLSPEC and SOL-ACES are operating on a daily basis. Up to now, all days in a solar rotation cannot be observed given the position of the ISS solar panels.

This situation will be improved soon.

The instrument has lost the D2 power supply.

Given the use of the other available lamps, the monitoring the intensity scale can be made to take into account the aging effect in space.

Quasi no aging exists inth visible and IR. In UV, it is compensated by use of the aboard lamps (D2, then HCL).

On board, many types of calibration can be run (scattered light, quartz transmission, FF, wavelength scale, psf, …).

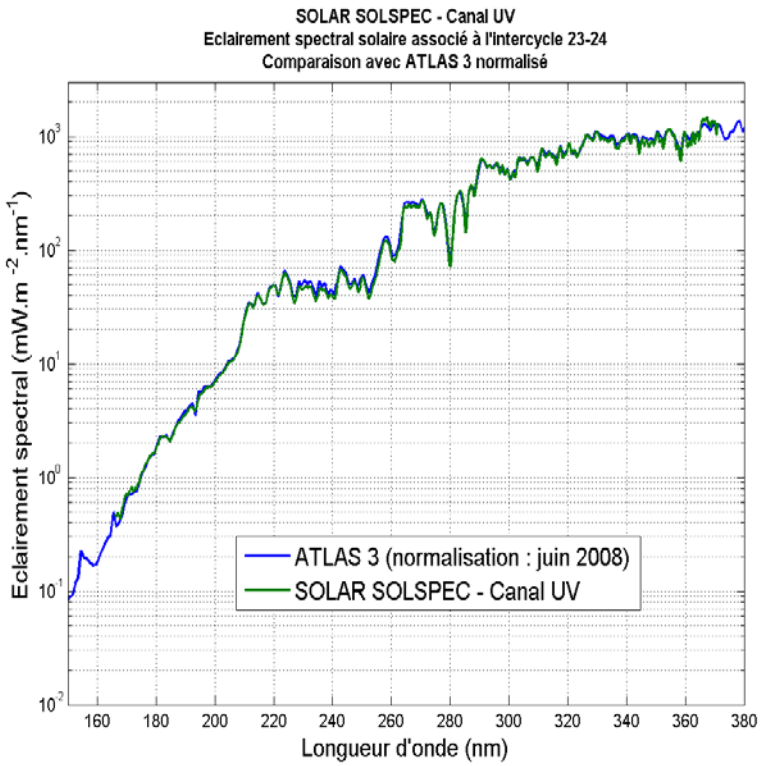
Main problem: lack of staff to produce time series.

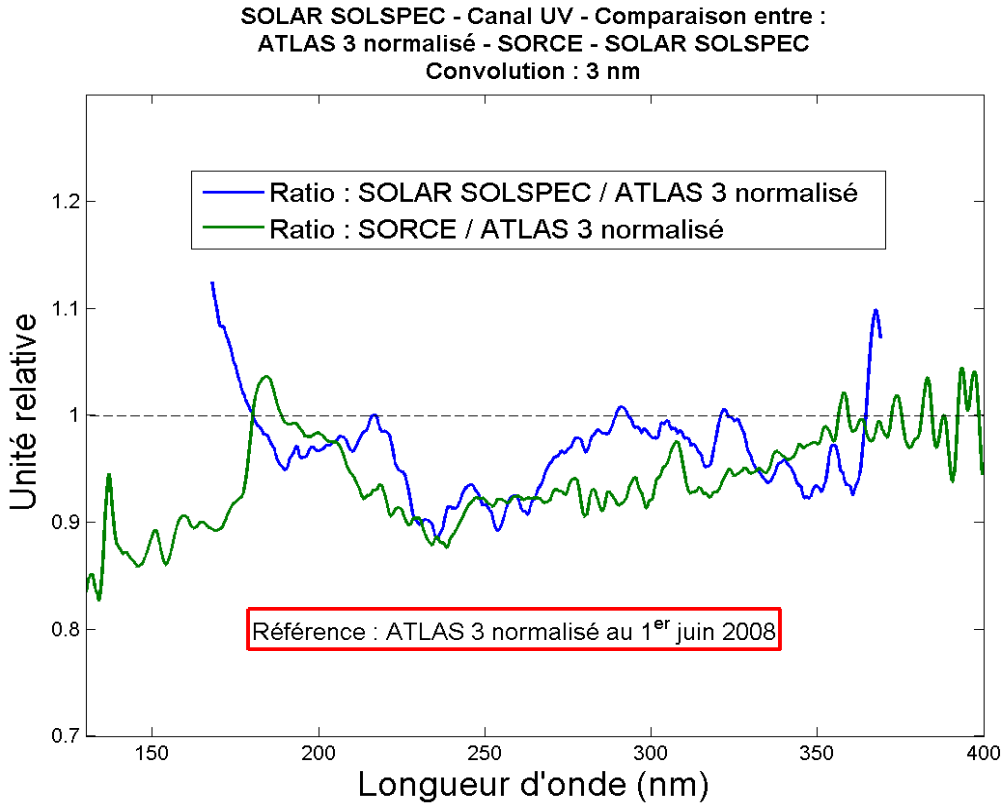
SOLAR-ISS SSI RESULTS IN ORBIT AND COMPARISONS WITH SORCE

G. Thuillier and G. Schmidtke

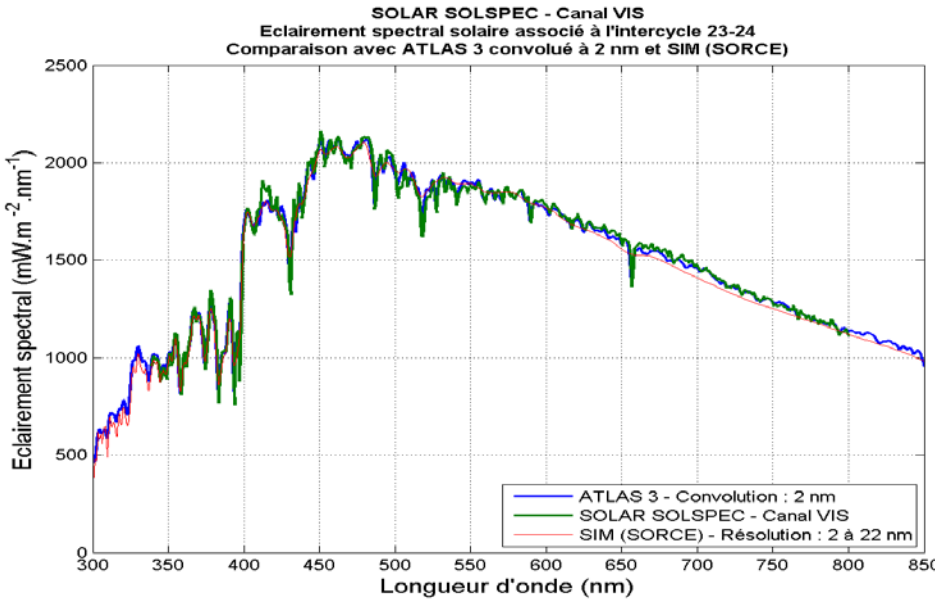
Below 140 nm, data were provided by SOL-ACES team.

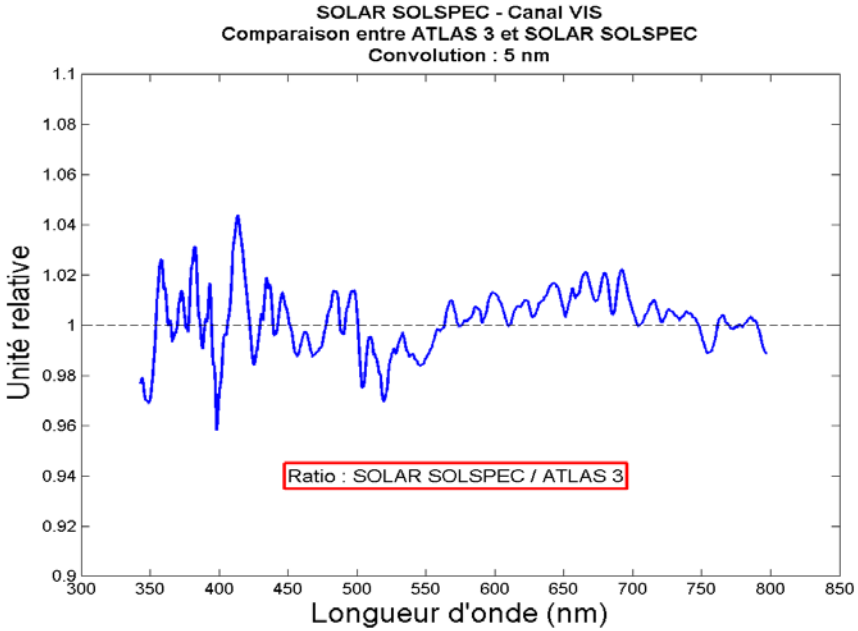
COMPARISON SORCE SOLSPEC / ATLAS 3





COMPARISON SORCE SOLSPEC / ATLAS 3



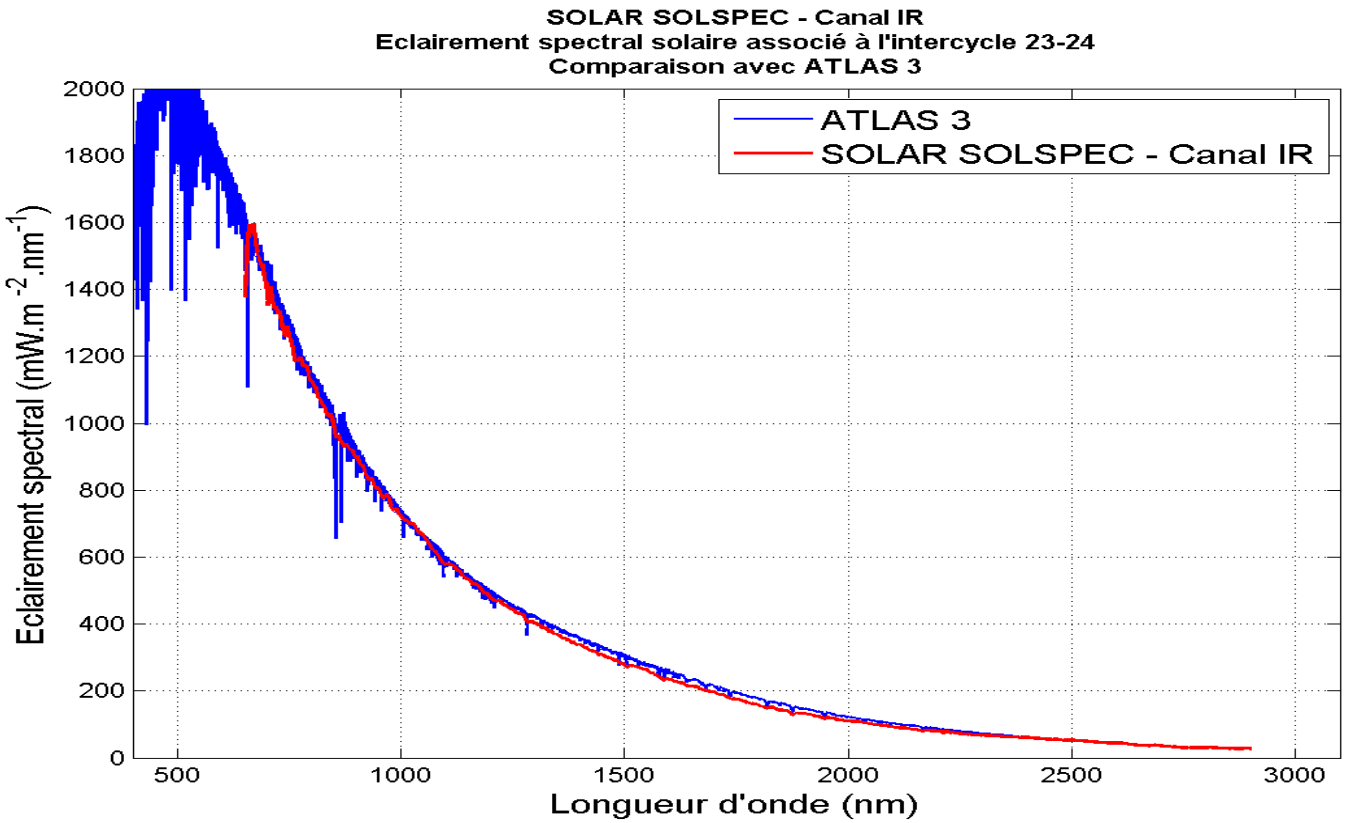


COMPARISON SORCE / SOLSPEC

Ratios to ATLAS 3	**166-180 (nm)**	**180-220 (nm)**	**220-260 (nm)**	**260-300 (nm)**	**300-340 (nm)**	**340-370 (nm)**
SOLSPEC	1.069 ± 0.047	0.974 ± 0.013	0.919 ± 0.023	0.968 ± 0.027	0.973 ± 0.019	0.965 ± 0.051
SORCE	0.914 ± 0.024	0.976 ± 0.034	0.906 ± 0.015	0.924 ± 0.008	0.945 ± 0.014	0.982 ± 0.015

350-425	350-425 (nm)	425-500 (nm)	500-575 (nm)	575-650 (nm)	650-725 (nm)	725-800 (nm)
SOLSPEC	1.005 ± 0.018	1.001 ± 0.009	0.991 ± 0.009	1.007 ± 0.005	1.010 ± 0.006	0.999 ± 0.005

THE IR SPECTRUM



A discrepancy exists centred at 1800 nm reaching 10%.

THE DIFFERENCE ATLAS 3 / SOLSPEC-ISS IN IR?

An exhaustive research has been carried out to find the origin of this difference.

The possible causes are:

- Distance source to entrance pupil,

- BB temperature,

- Absorption by H_2O during ground calibration

- Diaphragm diameter,

- Flatfield,

- Dark current,

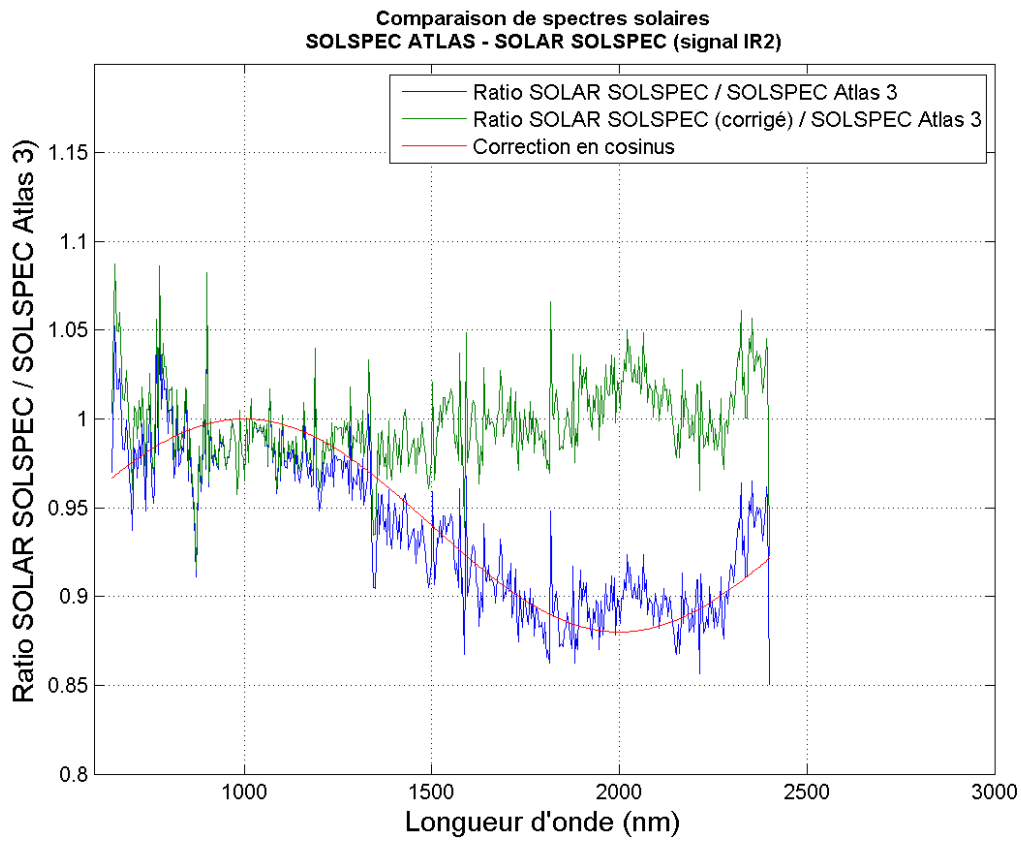
- IR detection: detector linearity

- signal numerisation linearity

THE IR DISCREPANCY ATLAS 3/SOLSPEC-ISS

Using ZMAX, we have simulated a drift of the intermediary slit.
The size and position of the light spot is a weak function of wavelength and may fall not perfectly on the slit for all wavelength.

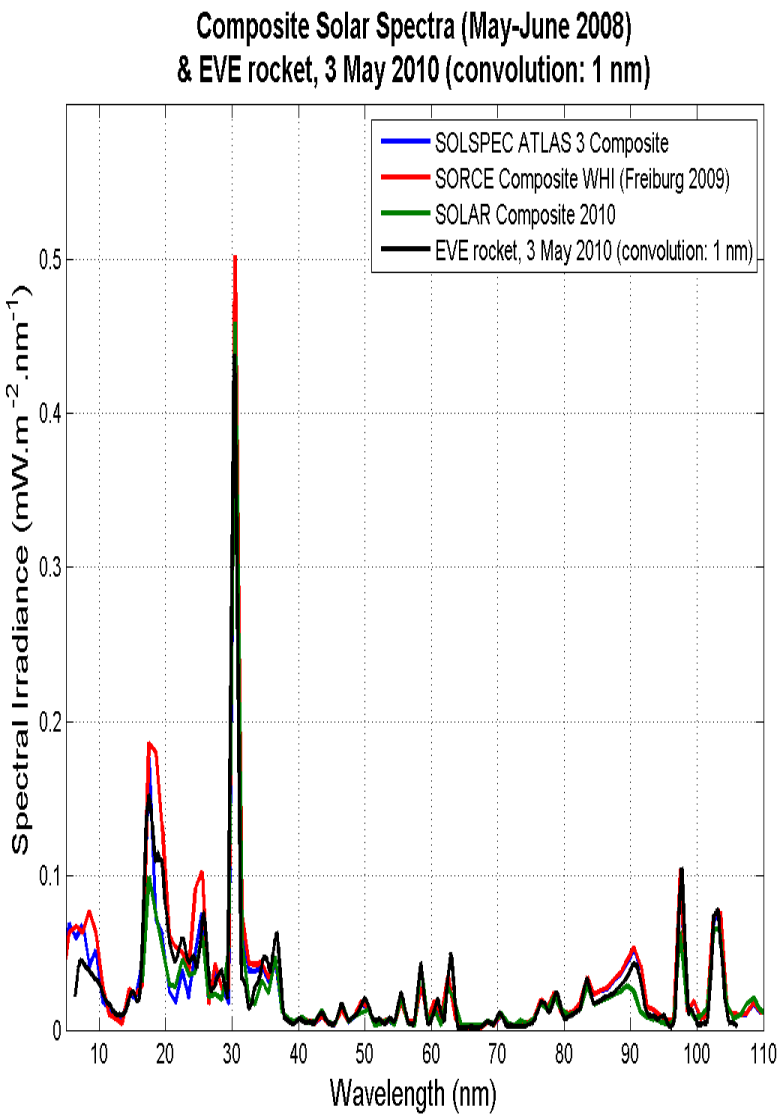
As a first approximation, it is a cosine effect. We have numerically verified this effect.

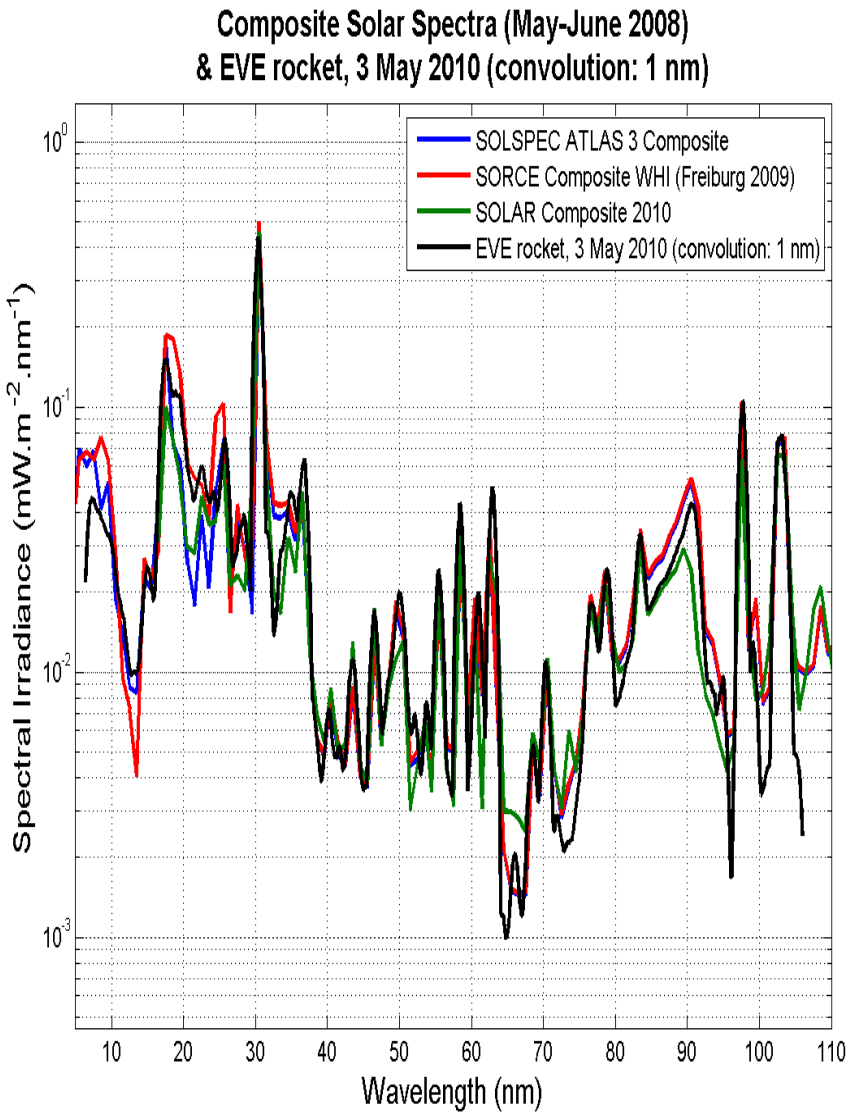


Other scenario:

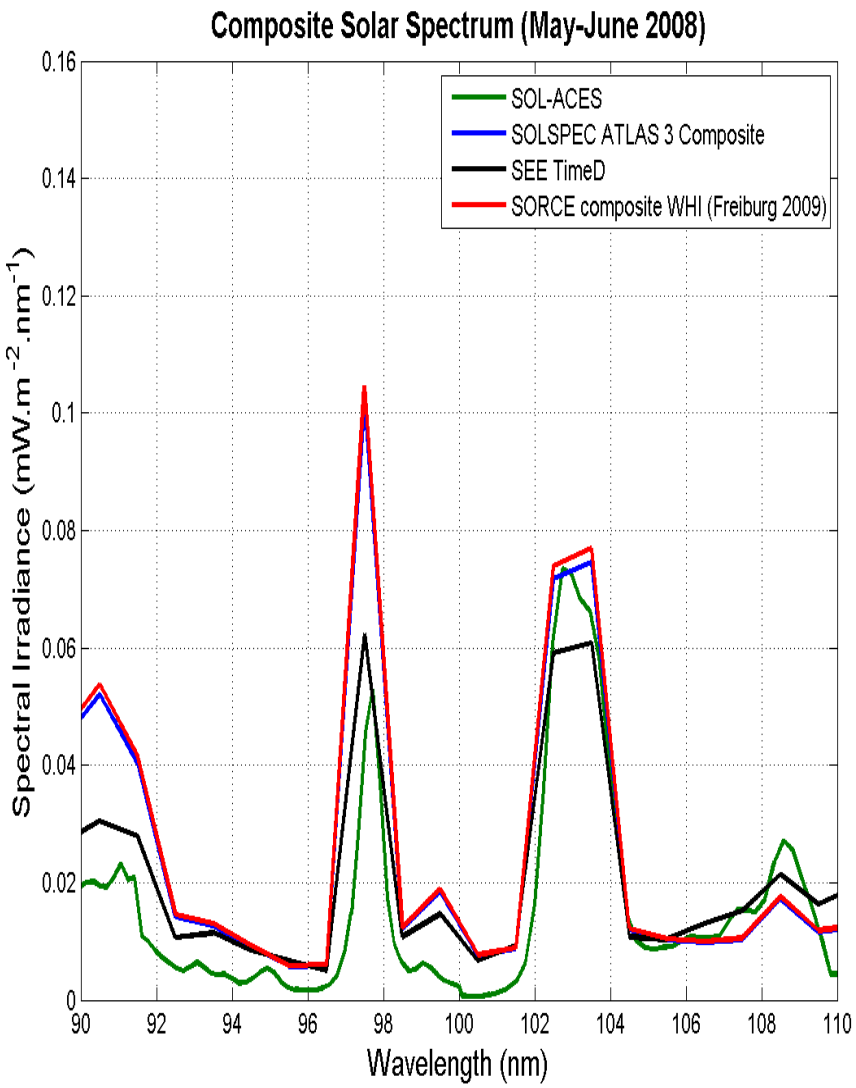
W lamp prior and at first light

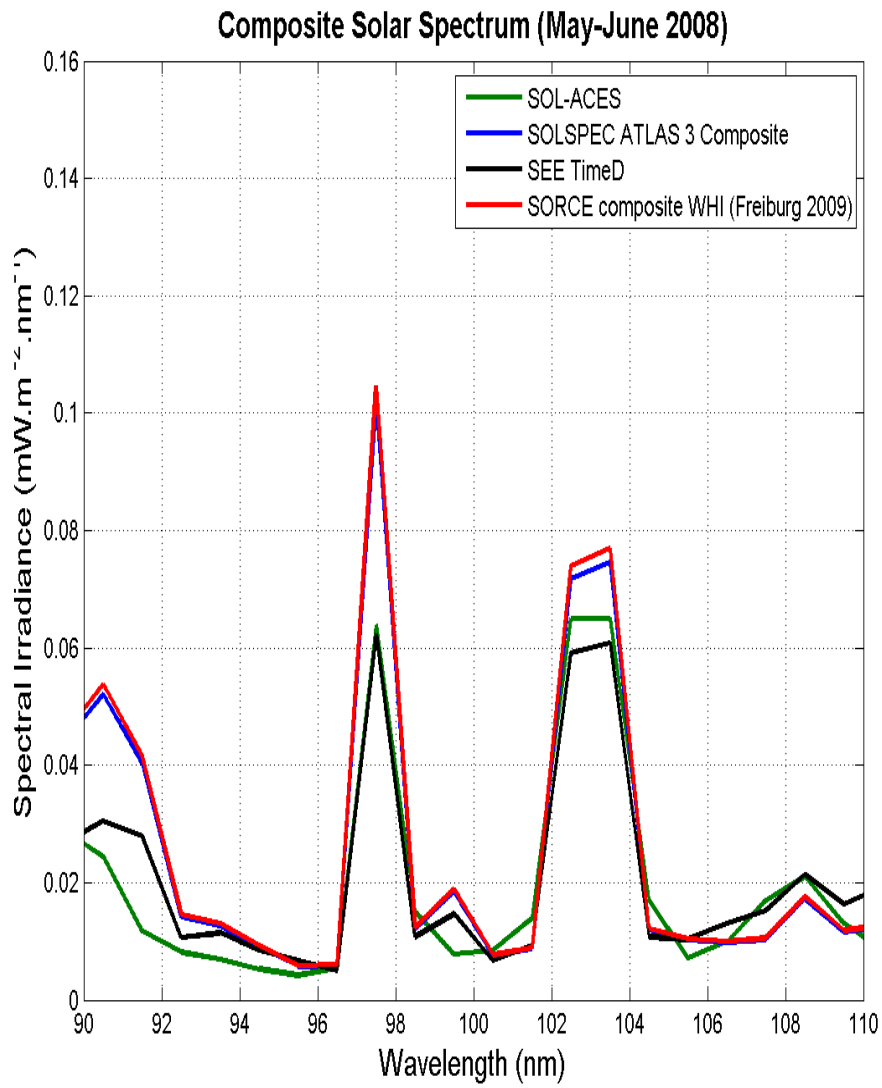
COMPARISION WITH ROCKET EVE (3 MAY 2010)



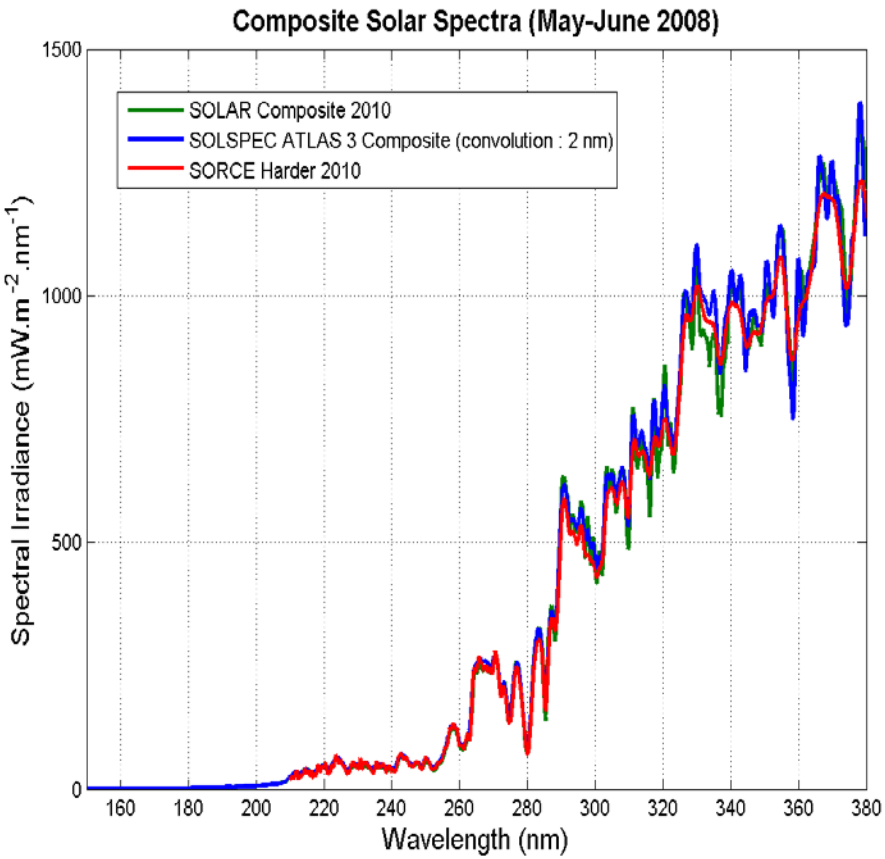


COMPOSITE SPECTRA COMPARISON (2/6)

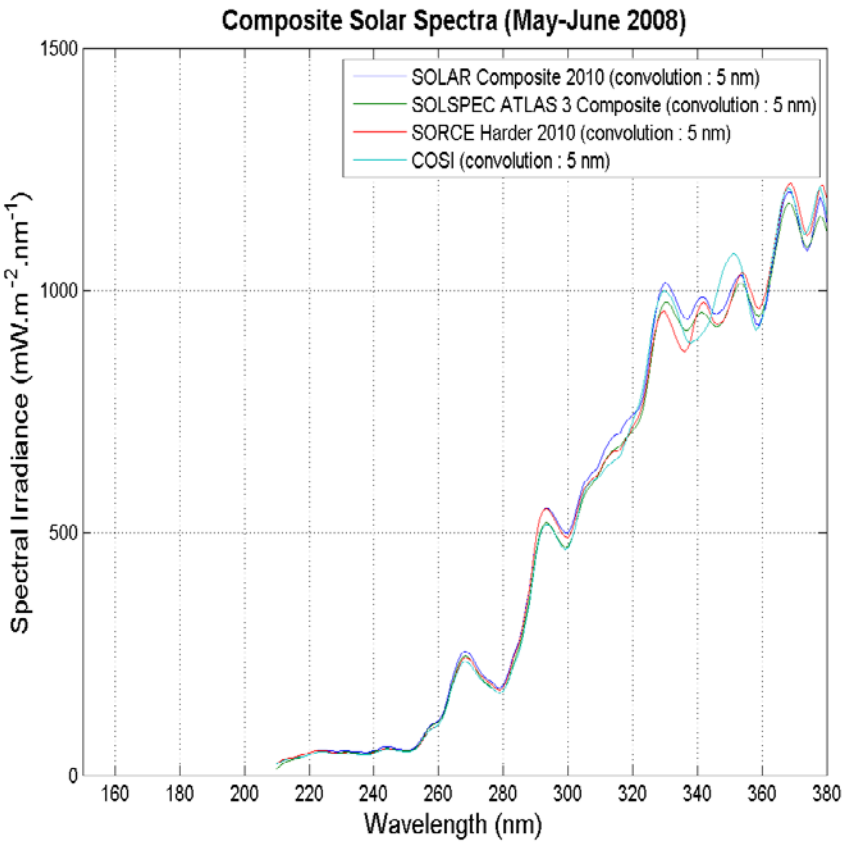


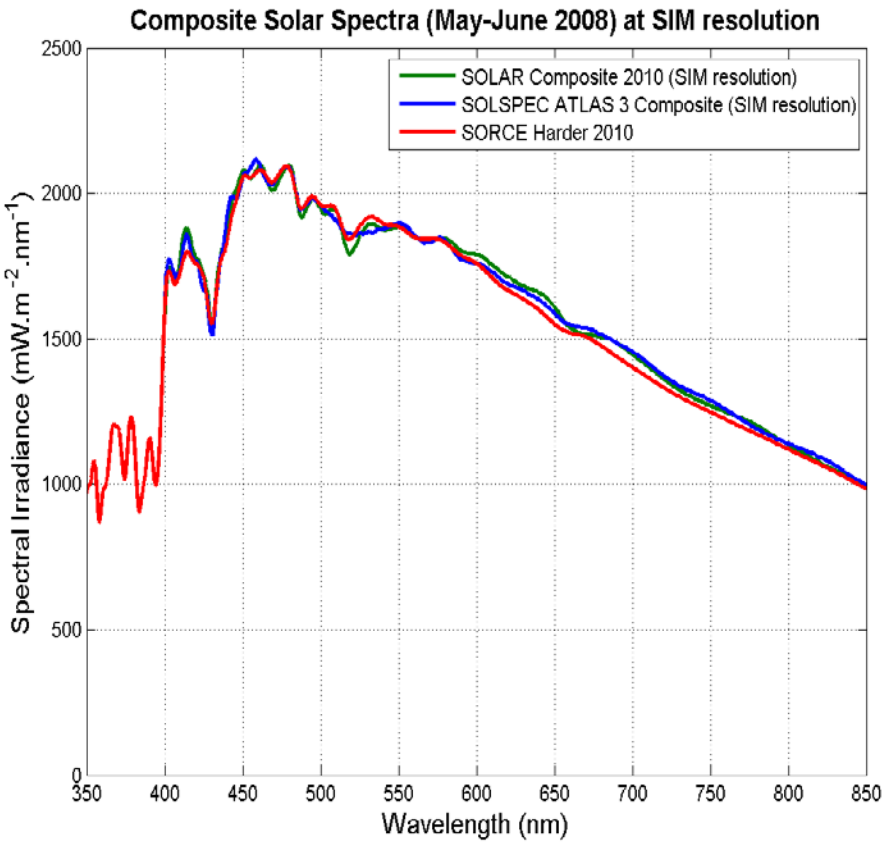


COMPOSITE SPECTRA COMPARISON (4/6)



COMPOSITE SPECTRA COMPARISON AT LOW RESOLUTION (5/6)





DISTRIBUTION PER SPECTRAL INTERVALS (W/m^2): DOMAIN 200-2400 nm

Range (µm)	ATLAS3 Wm^{-2}	SORCE Wm^{-2}	SOLSPEC Wm^{-2}	COSI Wm^{-2}
0.21-0.35	55.02	53.6	53.9	53.9
0.35-0.50	241.4	243.7	246.3	246.7
0.35-1.	888.9	893.3	900.9	901.9
1-2	332.8	338	337.3	329.9
0.21-2.4	1311.4	1320.2	1327.3	1285.7 (0.21-2.0)

DISTRIBUTION PER SPECTRAL INTERVALS (mW/m2): DOMAIN 17-200 nm

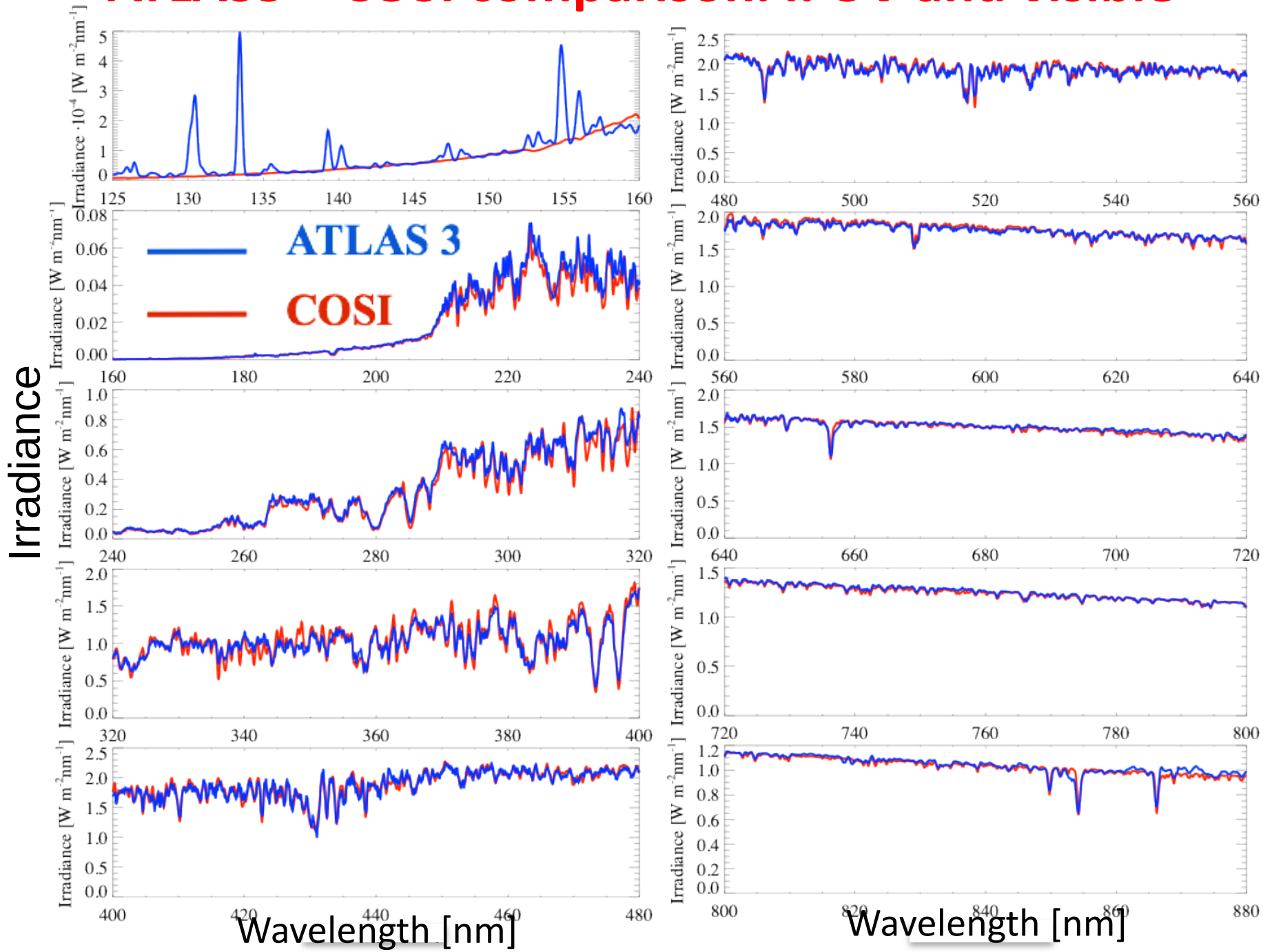
Range (nm)	ATLAS3 mWm^{-2}	SORCE mWm^{-2}	SOLSPEC mWm^{-2}
17-120	2.72	3.11	2.52
120-200	106.89	106.91	102.23

COMPARISON WITH MODELS

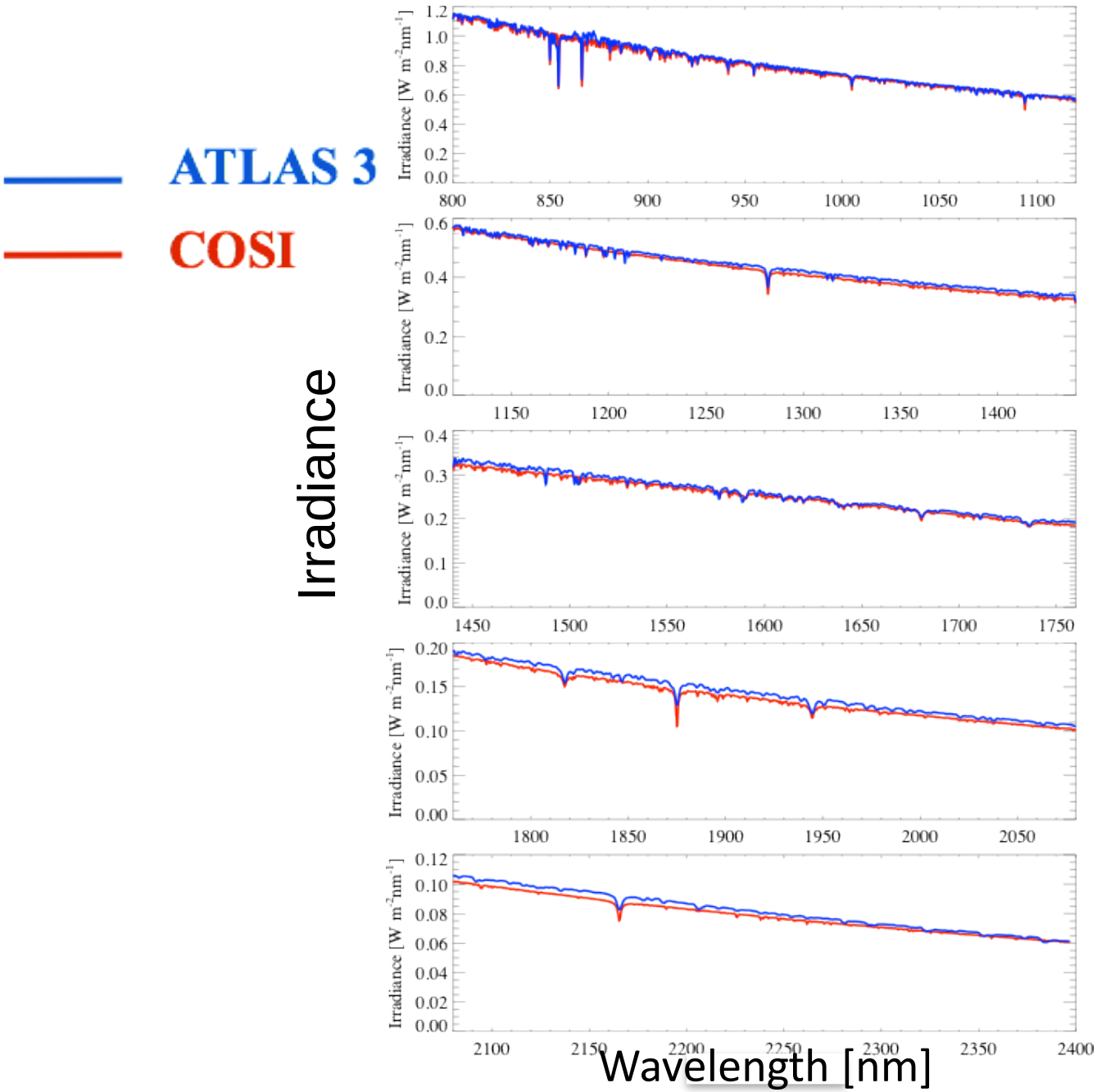
- Fontenla et al.(2004): agreement between model and derived temperature

- COSI (Shapiro et al., 2010)

ATLAS3 – COSI comparison. I. UV and visible

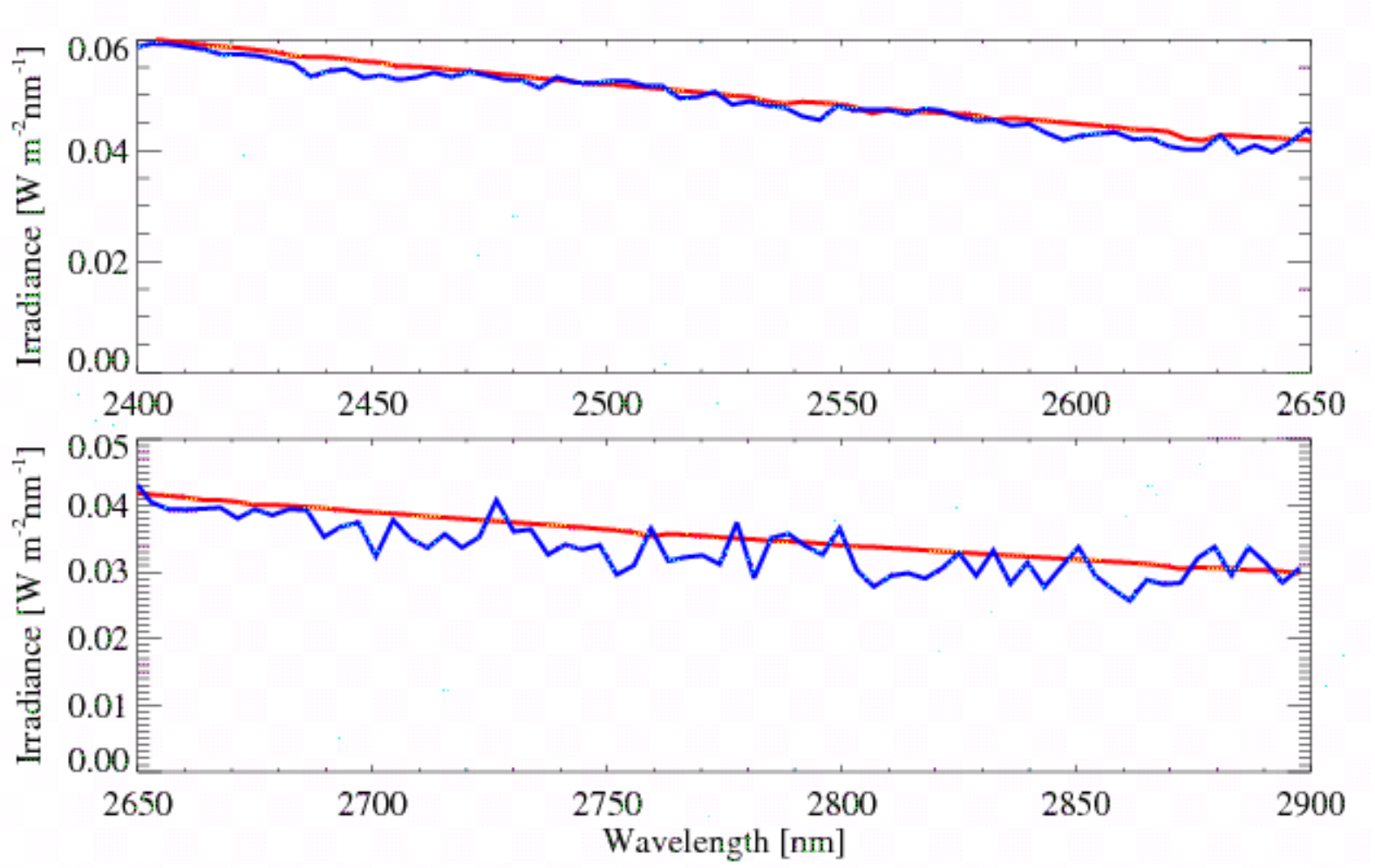


ATLAS3 – COSI comparison. II. Infrared



Disagreement at 1800-2300 nm will be addressed in the new release of the COSI data

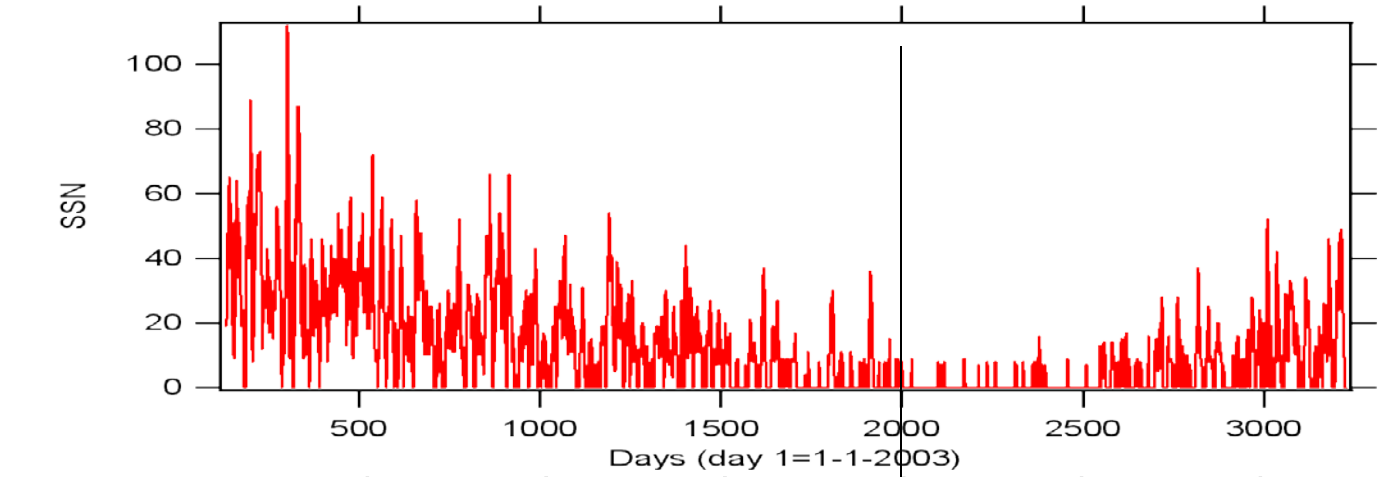
SOLSPEC-ISS and COSI COMPARISON

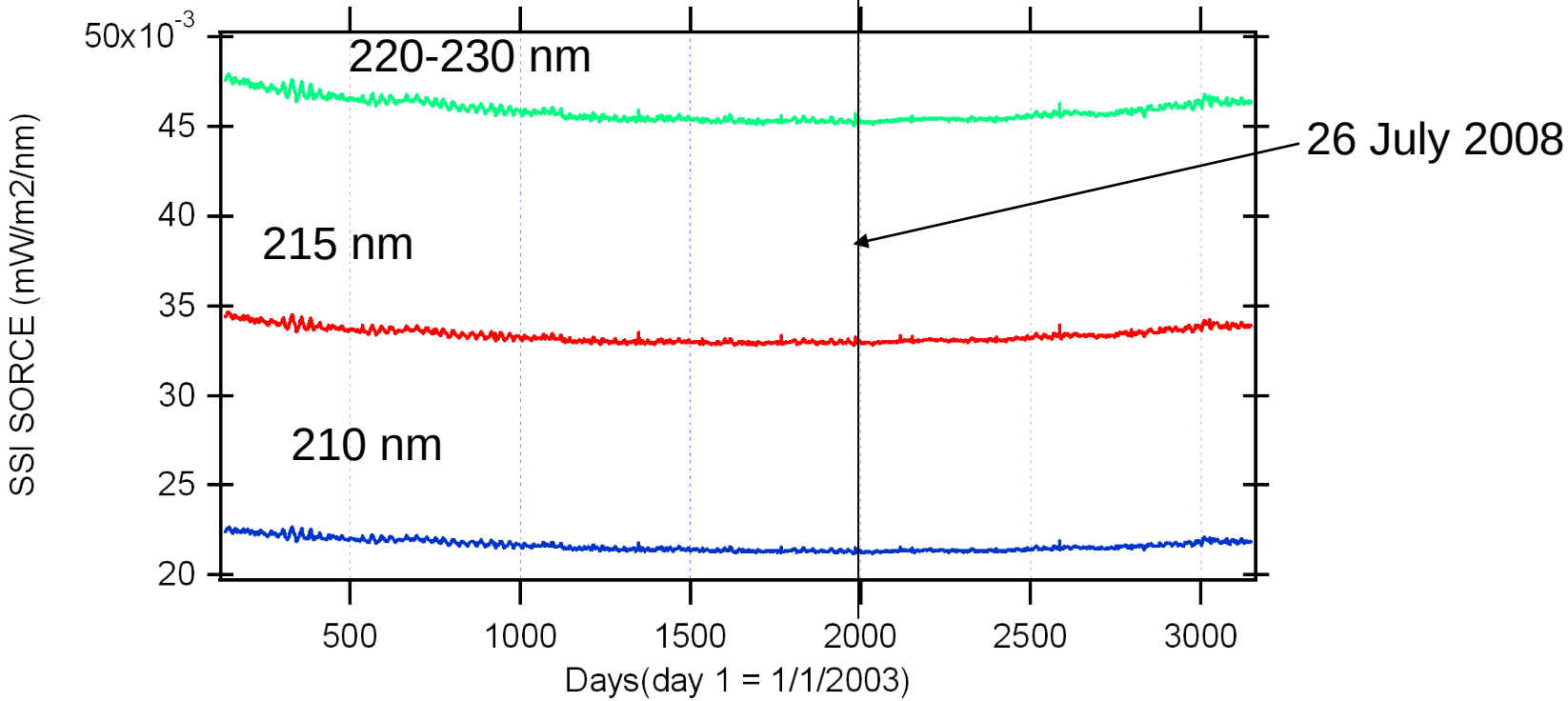


Above 2650 nm, the sun irradiance becomes weak as well as the instrument responsivity. Several spectra have to be used together.

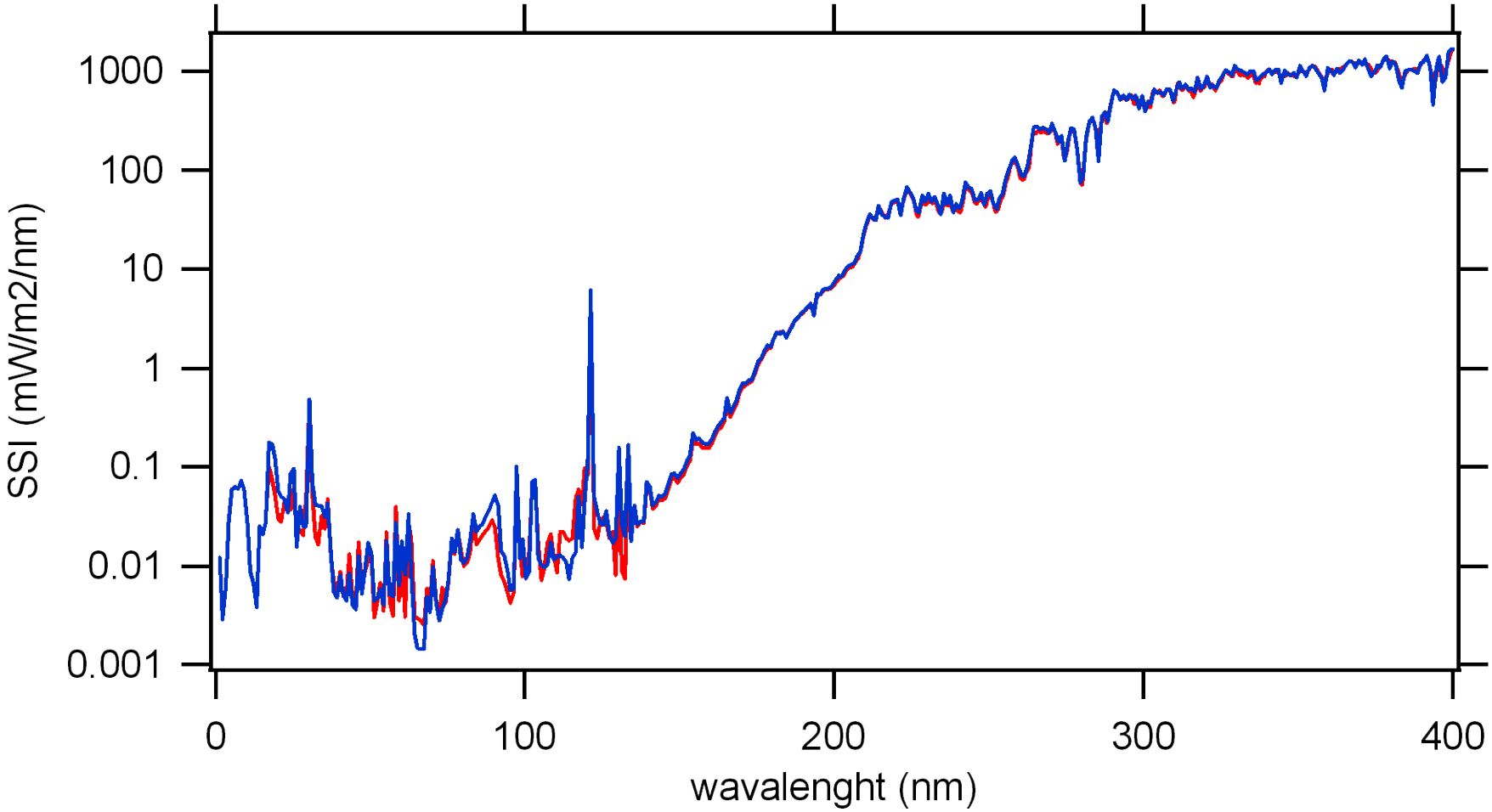
SSI VARIABILITY DETECTED BY SORCE

Can we detect the minimum of SSI during the cycles 23-24 transition?





Minimum solar activity around June-July 2008

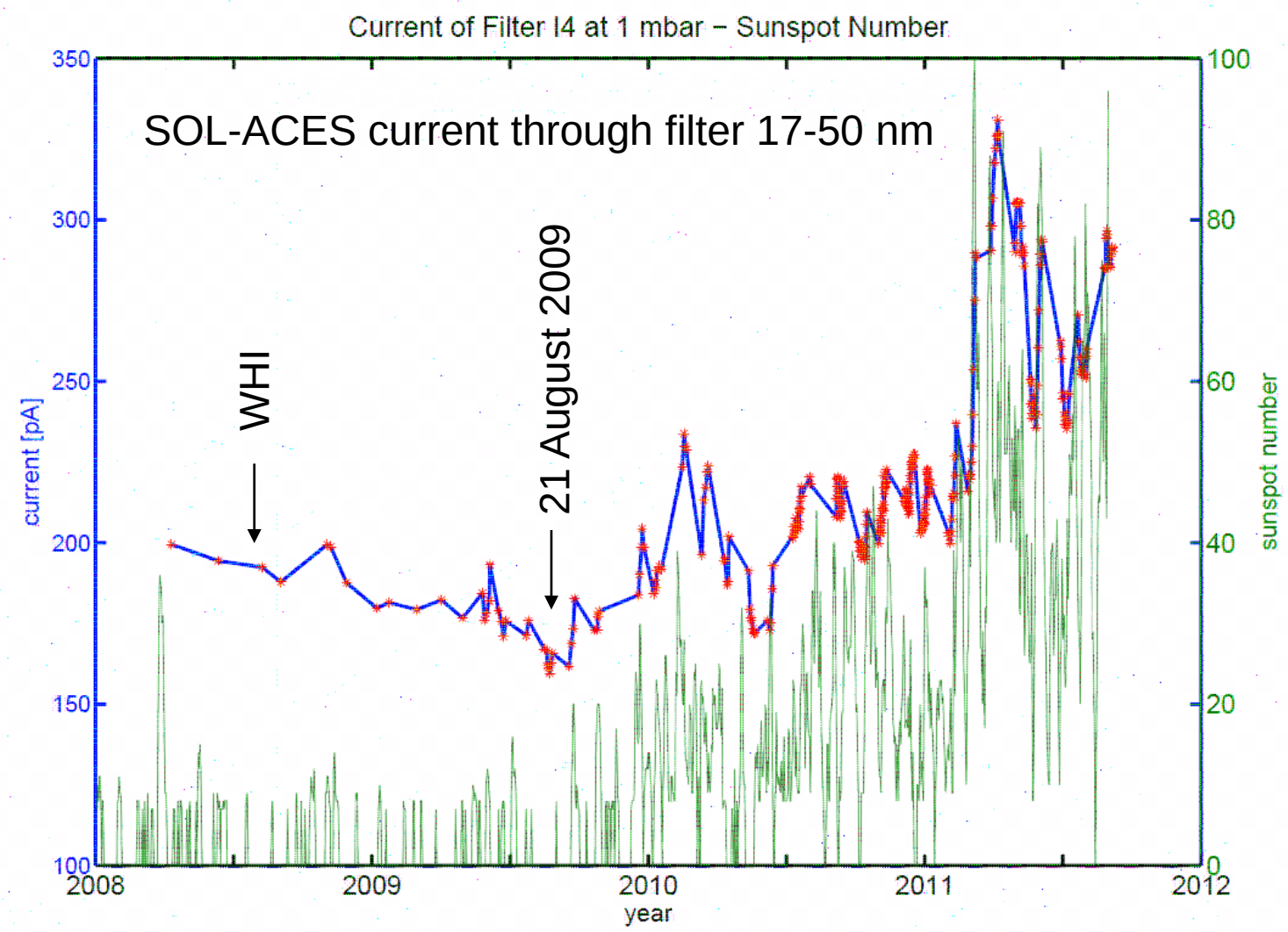


Red= WHI (SORCE plus several other instruments) spectrum (Woods et al., 2009)
Blue = ISS-SOLAR (SOLSPEC and SOL-ACES) spectrum (Thuillier et al., 2012)

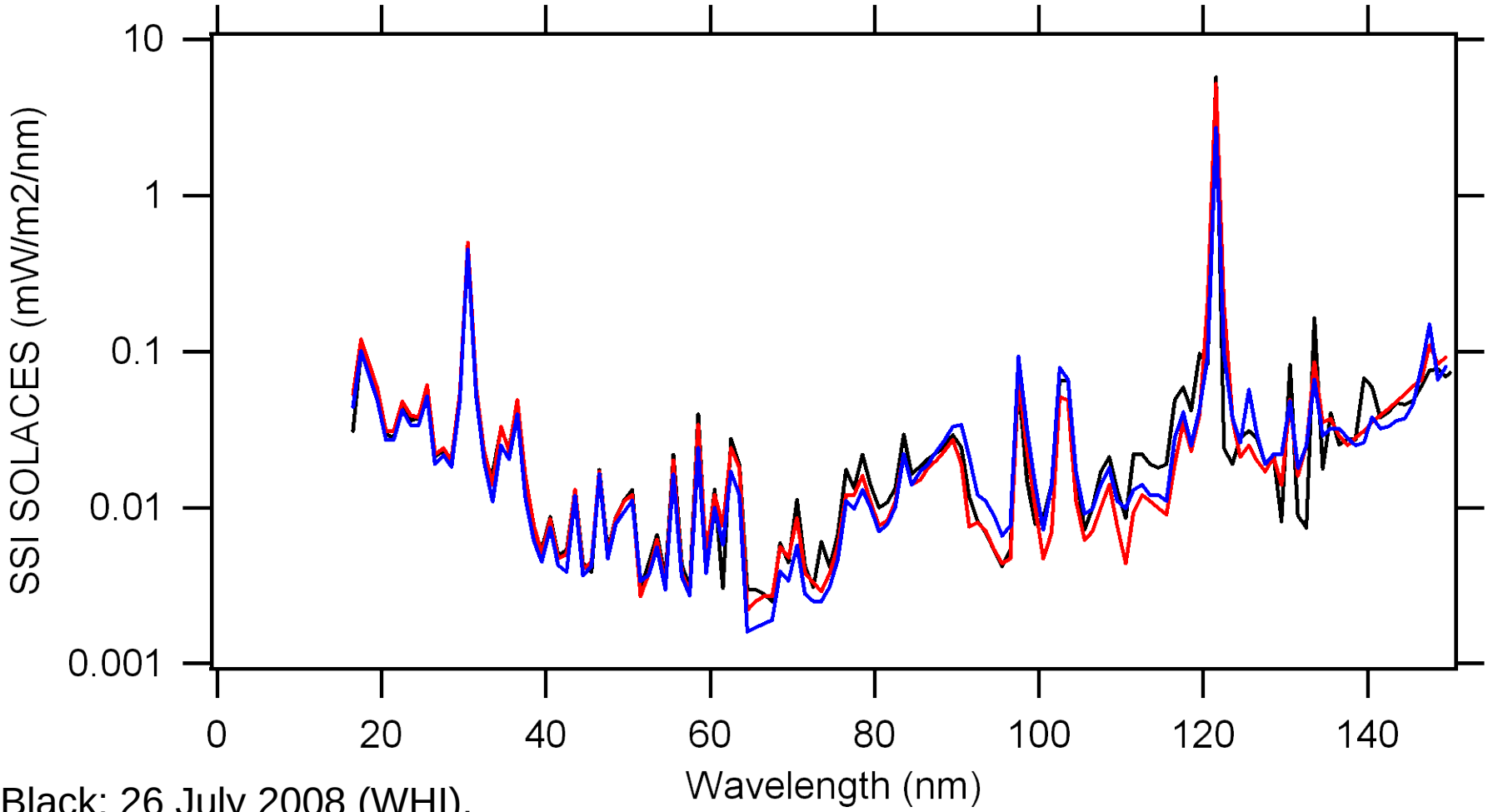
SSI VARIABILITY DETECTED BY SOL-ACES

Can we detect the minimum of SSI during the 23-24 cycles transition?

SSI: is June 2008 the solar minimum at the cycles 23-24 transition?

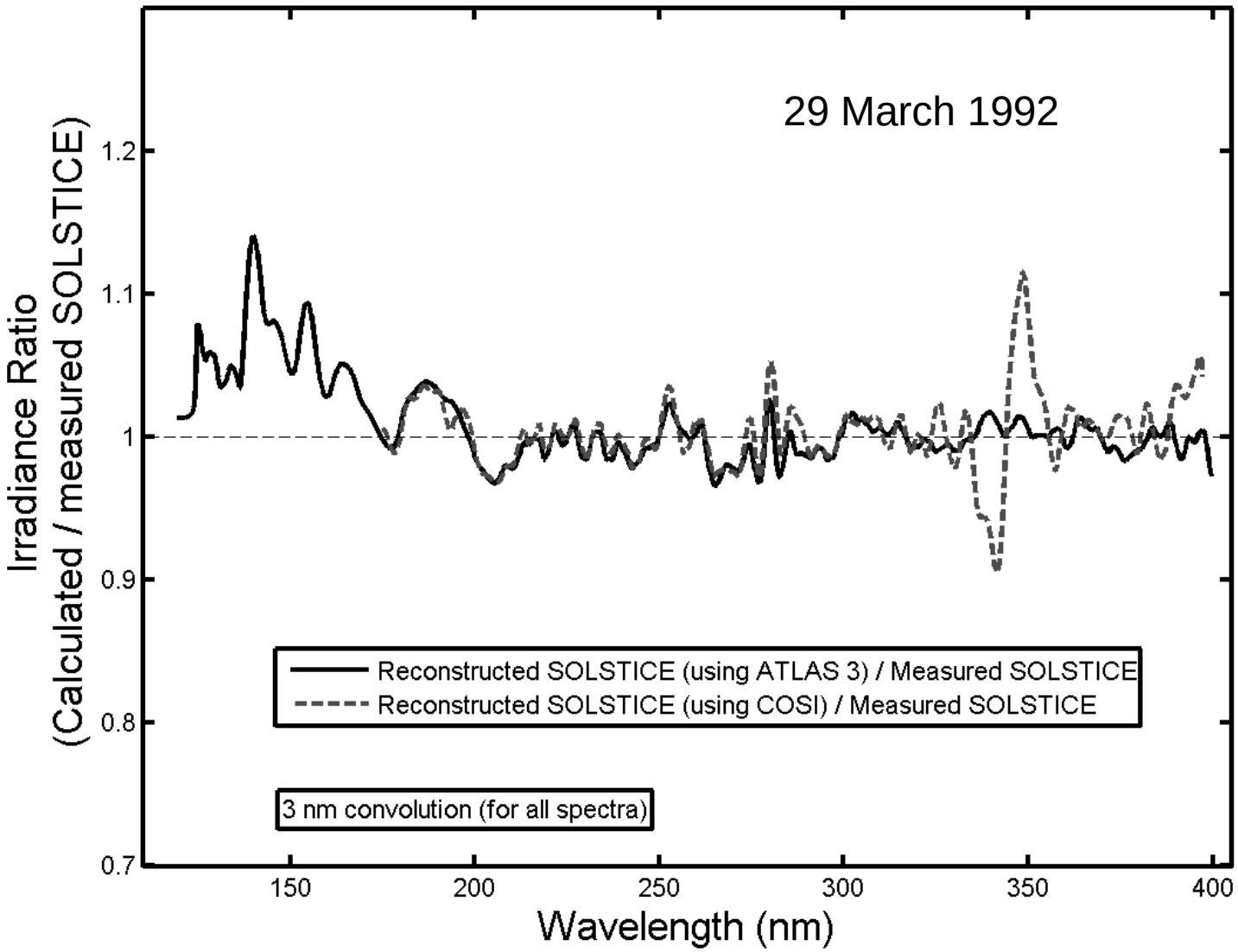


LOOKING FOR THE SOLAR MINIMUM at SSI



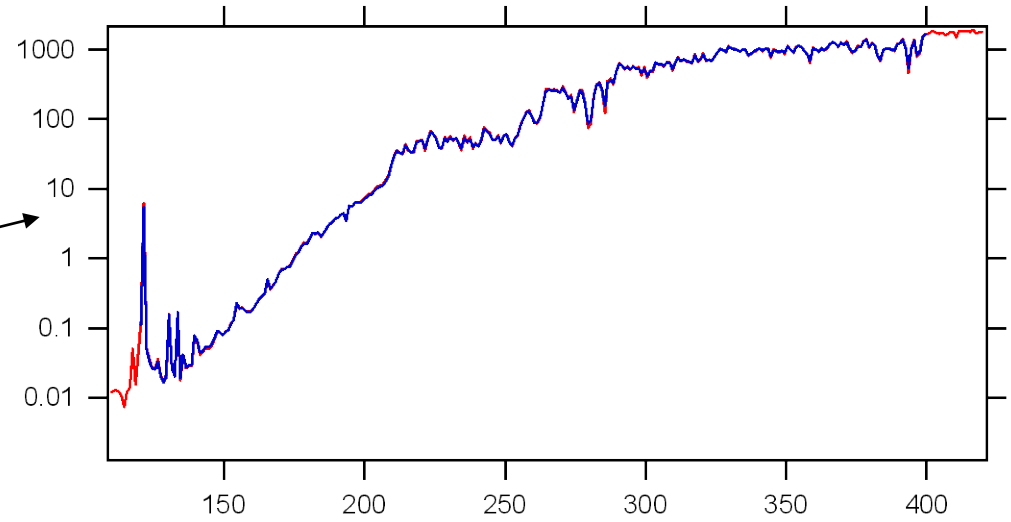
Black: 26 July 2008 (WHI),
SOL-ACES spectra:
Red: 27 February 2009
Blue: 21 Aug. 2009
The differences are wavelength dependent.

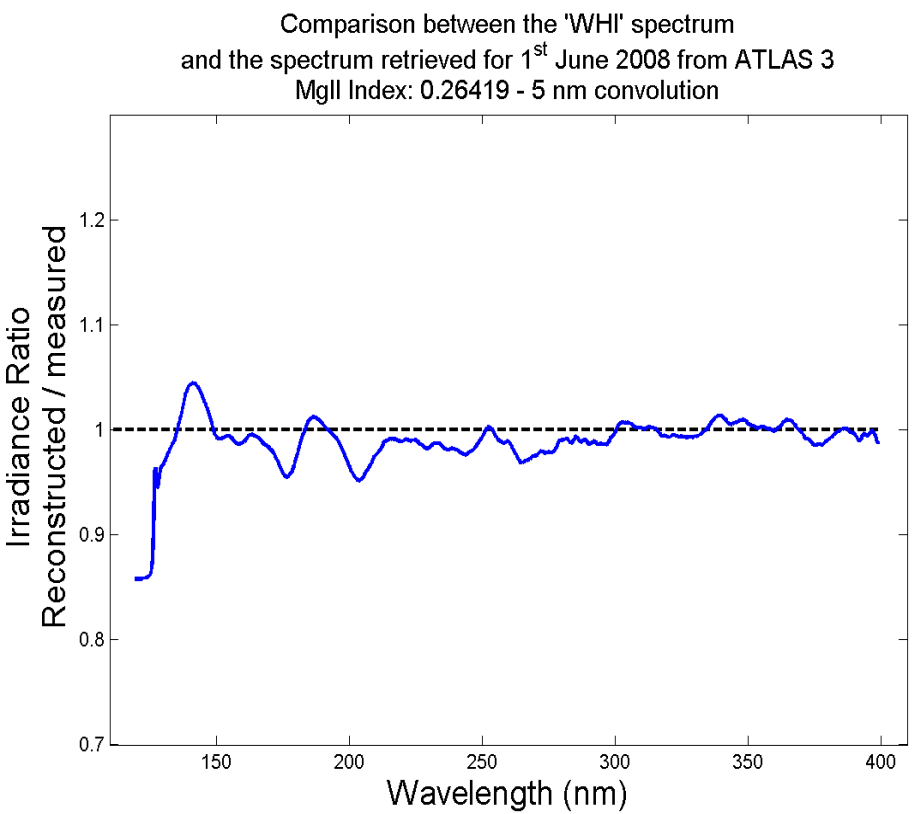
RECONSTRUCTION OF THE SOLSTICE SPECTRUM



RECONSTRUCTION OF THE WHI SPECTRUM FROM MG II INDEX

HWI is in red. Its reconstruction using ATLAS 3 and the Mg II coefficients is shown in blue.





Ratio of the HWI and its reconstruction

CONCLUSIONS

1) In general, there is a convergence of different instruments in terms of SSI absolute value and variability;

2) Looking in details, around 60 nm SOL-ACES (ISS) shows smaller SSI values than SEE (ISS);

3) The transition from cycle 23 to 24 as seen at the SSI is not uniform and in fact presents several quasi minima.

4) The agreement ATLAS 3/SOLSPEC-ISS is better using a correction based on the Mg II index at the time of the SOLSPEC-ISS measurements;

5) SIM (SORCE) measurements in UV shows a minimum occurring prior to the minimum in EUV.

6) The SSI can be reconstructed from a reference spectrum assuming its variability and referencing it to MgII index (e. g. SOLSTICE and SIM spectra).