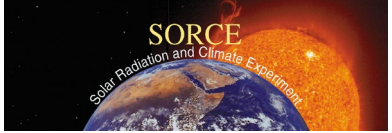
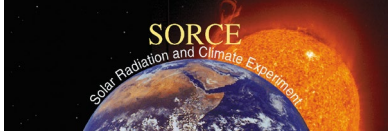


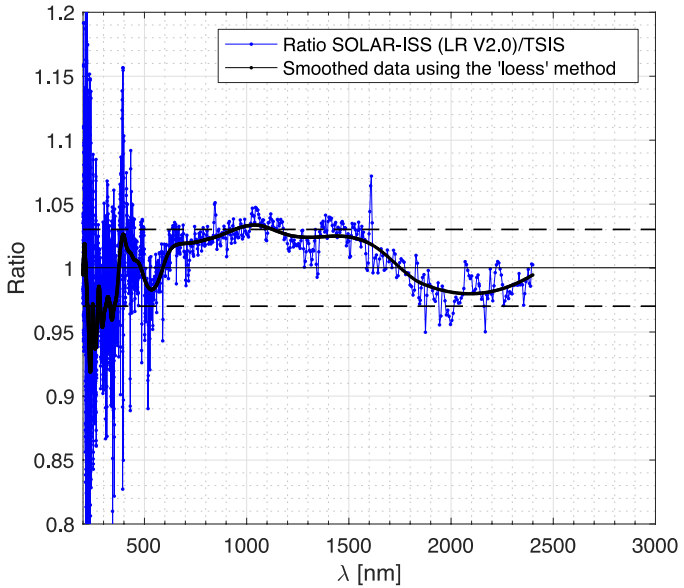
New Absolute Reference Spectrum SOLAR-ISS2 at 2008 solar minimum and its extension at very high resolution (better than 0.01 nm) from 600 nm up to 4200 nm for atmospheric modeling and remote sensing

Luc Damé[1], Mustapha Meftah[1], Alain Hauchecorne[1], Slimane Bekki[1], David Bolsée[2], Nuno Pereira[2] and Gaël Cessateur[2]

[1] LATMOS/IPSL, CNRS, Paris-Saclay UVSQ Yvelines University, Guyancourt, France (luc.dame@latmos.ipsl.fr)

[2] BIRA-IASB, Brussels, Belgium





Ratio of SOLAR-ISS2 and TSIS-1 from 200 to 2400 nm: agreement to ± 5% above 300 nm

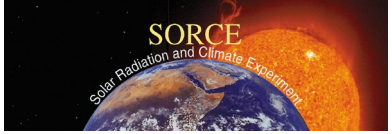
Outline

2 topics:

① **New SOLAR-ISS2 spectrum (SOLAR-ISS v2.0) improved for FUV (<180 nm), MUV near 220 nm and NIR (2.4 to 3 µm), and comparison/agreement with other recent spectra and models**

② **New SOLAR-ISS2-HR, very high resolution (better than 0.01 nm), 500 to 4200 nm for inversion purposes (climate models, MicroCarb CO2 mission, planetary atmospheres)**

Conclusions



We start with the SOLAR-ISS v1.1 (2008) absolute reference spectrum

Kurucz & SRPM high resolution spectra

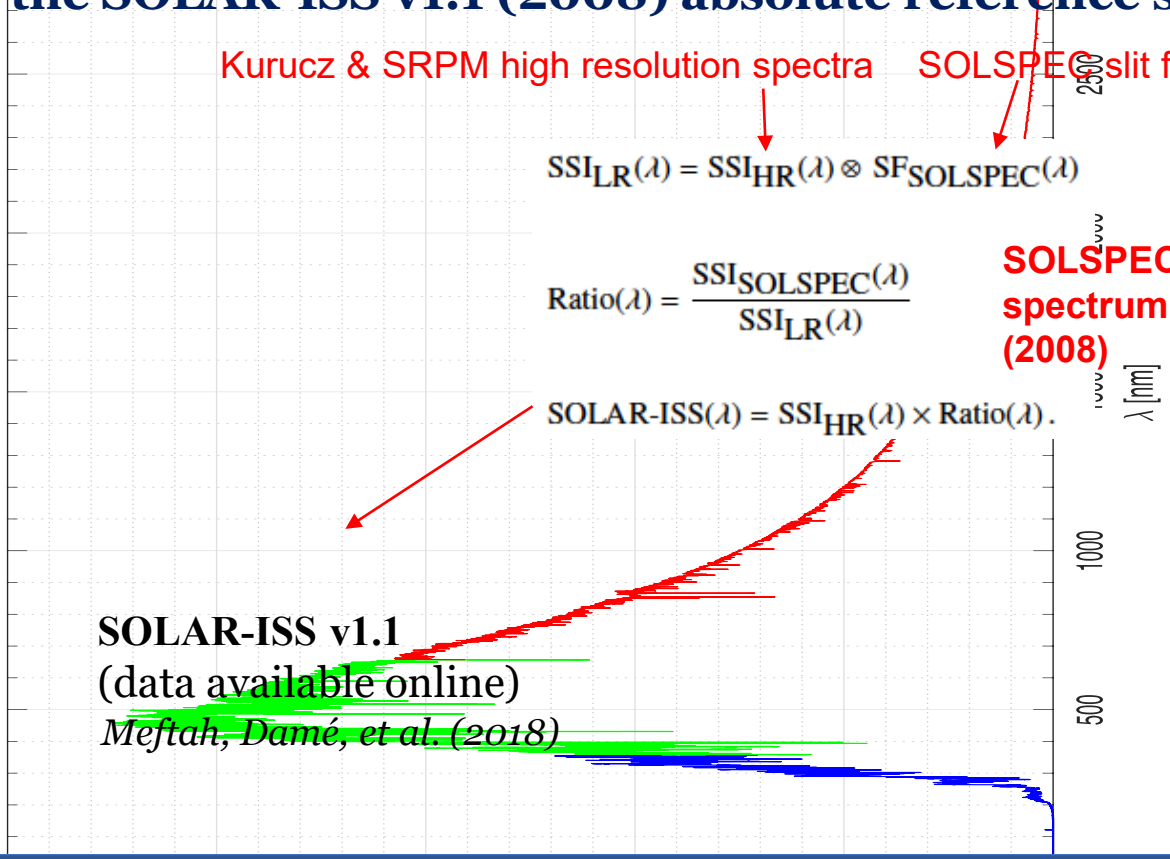
SOLSPEC slit functions

$$SSI_{LR}(\lambda) = SSI_{HR}(\lambda) \otimes SF_{SOLSPEC}(\lambda)$$

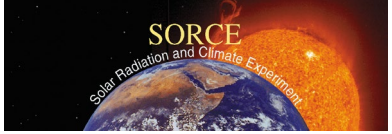
$$Ratio(\lambda) = \frac{SSI_{SOLSPEC}(\lambda)}{SSI_{LR}(\lambda)}$$

$$SOLAR\text{-}ISS(\lambda) = SSI_{HR}(\lambda) \times Ratio(\lambda).$$

SOLSPEC spectrum (2008)



SOLAR-ISS v1.1
(data available online)
Meftah, Damé, et al. (2018)



Step 1: improving the SOLAR-ISS Absolute Reference Spectrum

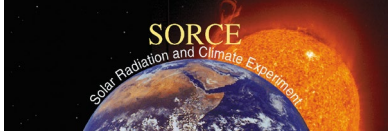
We updated the SOLAR-ISS (low resolution) spectrum along 4 directions:

① **Revision of the SOLAR/SOLSPEC calibration between 165 and 180 nm in order to revise the SOLSPEC/SOLSTICE ratio slightly diverging in this wavelength range;**

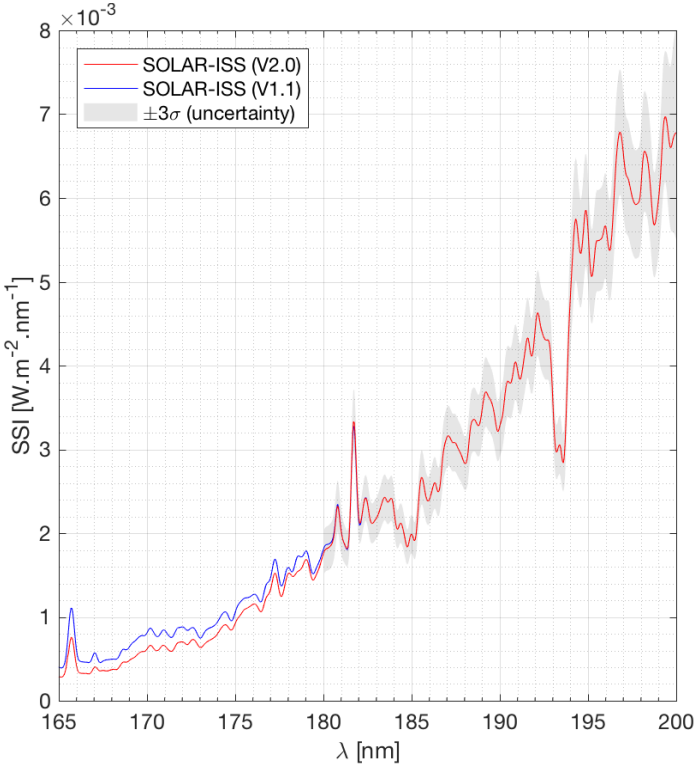
② **Correction of the UV double monochromator channel of the SOLAR/SOLSPEC between 216 and 230 nm (Herzberg continuum band). In this region, measurement's incertitude is important and mainly due to a change of filter in this channel since of the rapid change of flux with wavelength;**

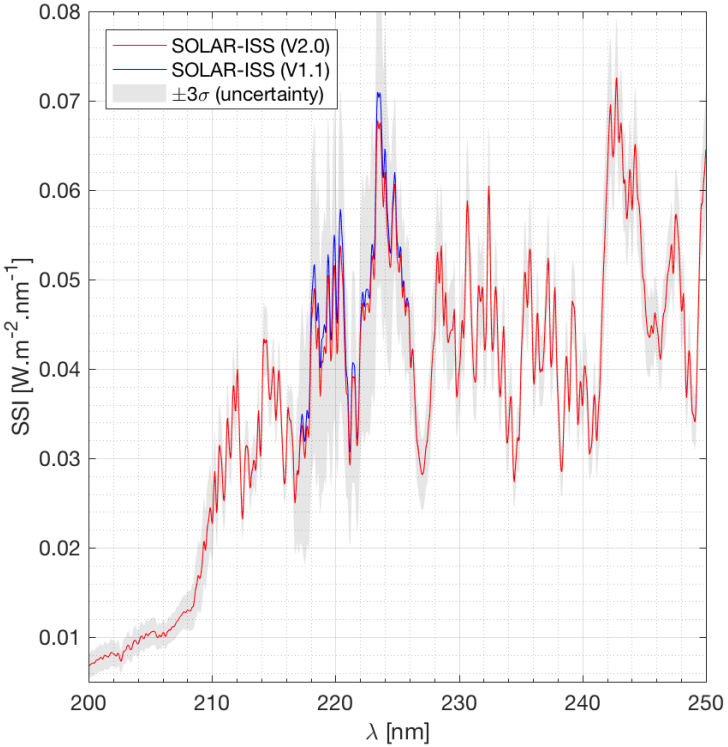
③ **Need of a non-regular sampling in wavelength in order to better account for the discontinuities introduced by Fraunhofer lines;**

④ **Between 2400 and 3000 nm, the SRPM model was used for the SOLAR-ISS spectrum. In this region, however, there is a clear disagreement between SOLAR-ISS and NESSY and SRPM models. It is therefore necessary to update the SOLAR-ISS spectrum between 2400 and 3000 nm using Kurucz instead of NESSY or SRPM.**

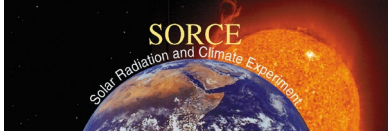


Reference Solar Spectrum (2008) SOLAR-ISS2 (v2.0) vs SOLAR-ISS (v1.1)

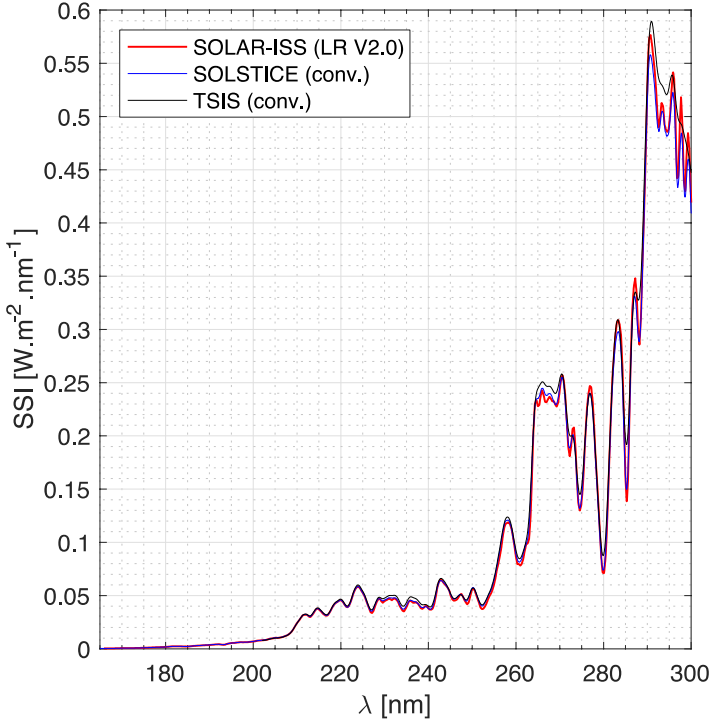


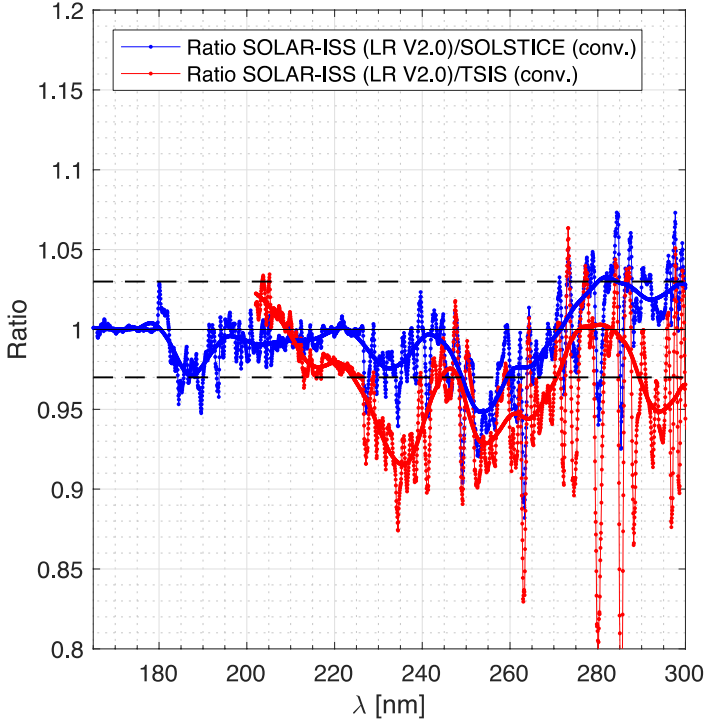


Meftah, Damé, et al. (2020)

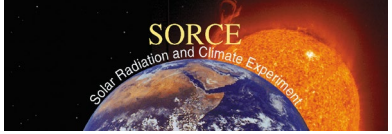


Comparison SOLAR-ISS2 (v2.0), SOLSTICE (2008) and TSIS-1 (2018)

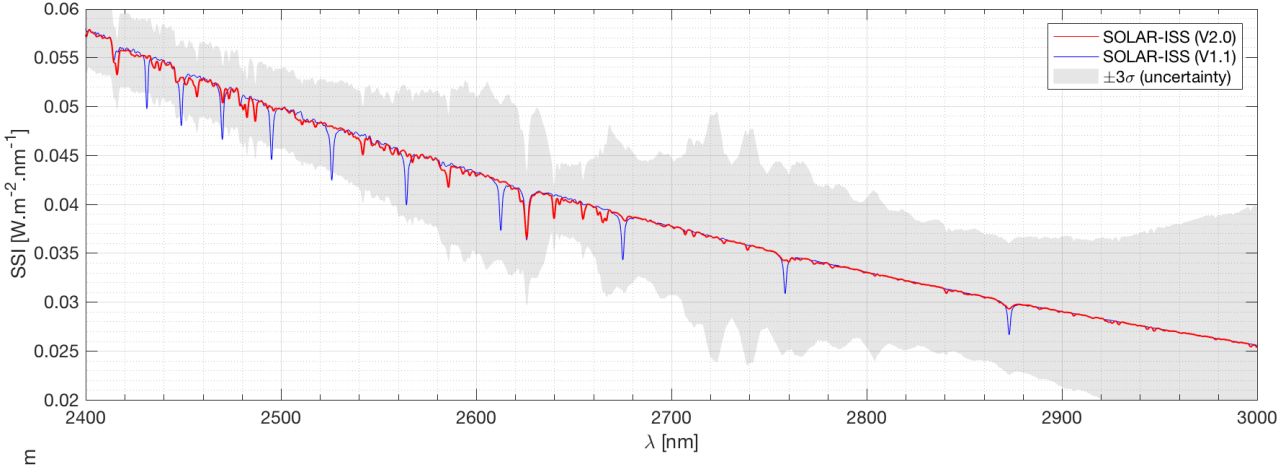


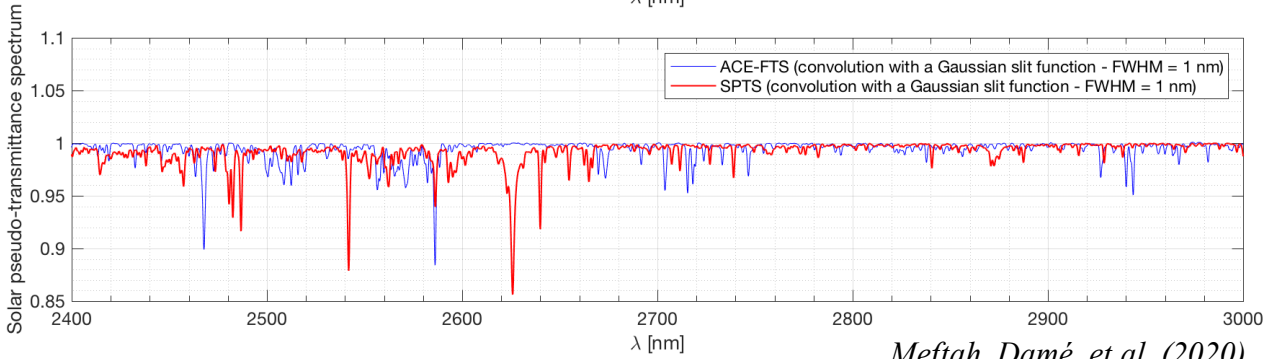


Meftah, Damé, et al. (2020)



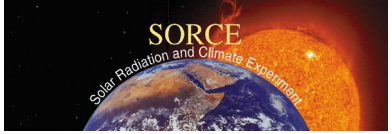
Improving SOLAR-ISS in the NIR



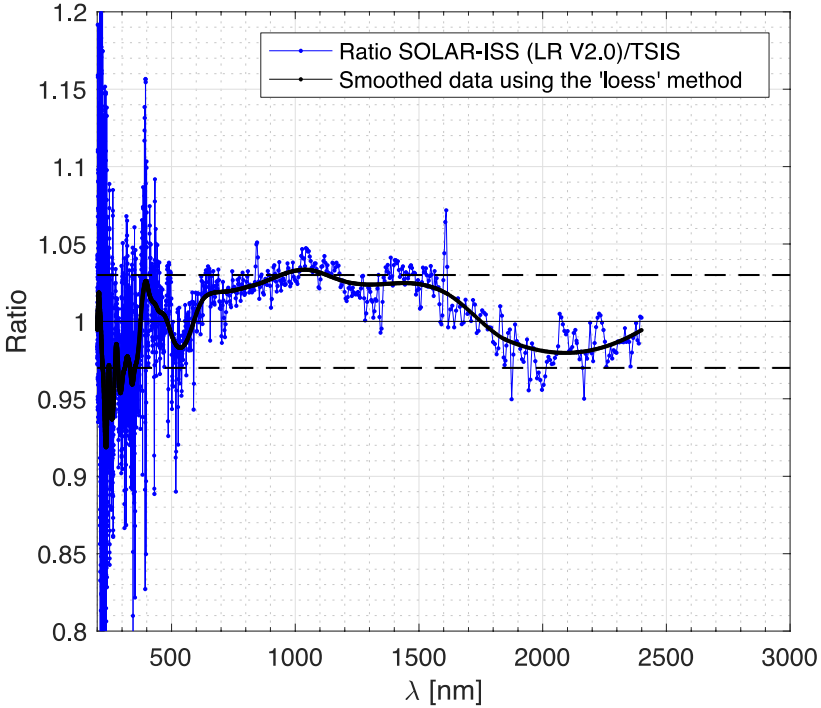


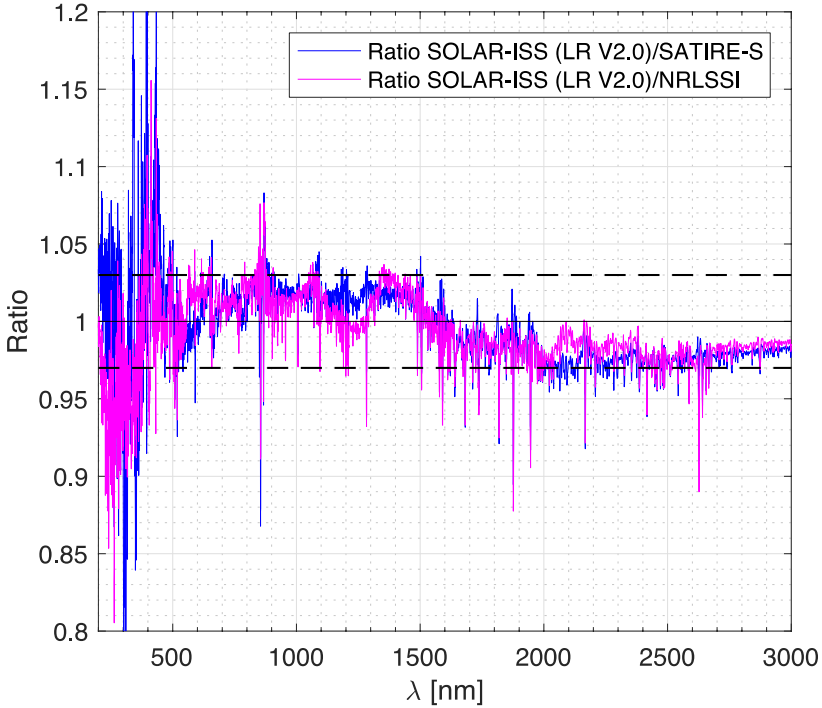
Meftah, Damé, et al. (2020)

Between 2400 and 3000 nm, abnormal solar lines appear in SOLAR-ISS (V1.1). They are derived from the Solar Radiation Physical Modeling (SRPM) theoretical model of Fontenla et al. (2015). To improve SOLAR-ISS and to check the existence of these lines, a comparison is made with the solar pseudo-transmissions obtained with the ACE-FTS with a high spectral resolution (0.02 cm^{-1}) and with the Solar Pseudo-Transmittance Spectrum (SPTS) obtained by Toon (2017) and computed using various recent versions of HITRAN solar line-list.

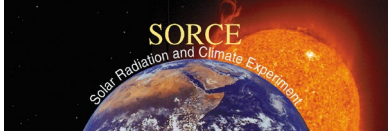


Comparison SOLAR-ISS2, TSIS-1 and models: SATIRE-S & NRLSSI

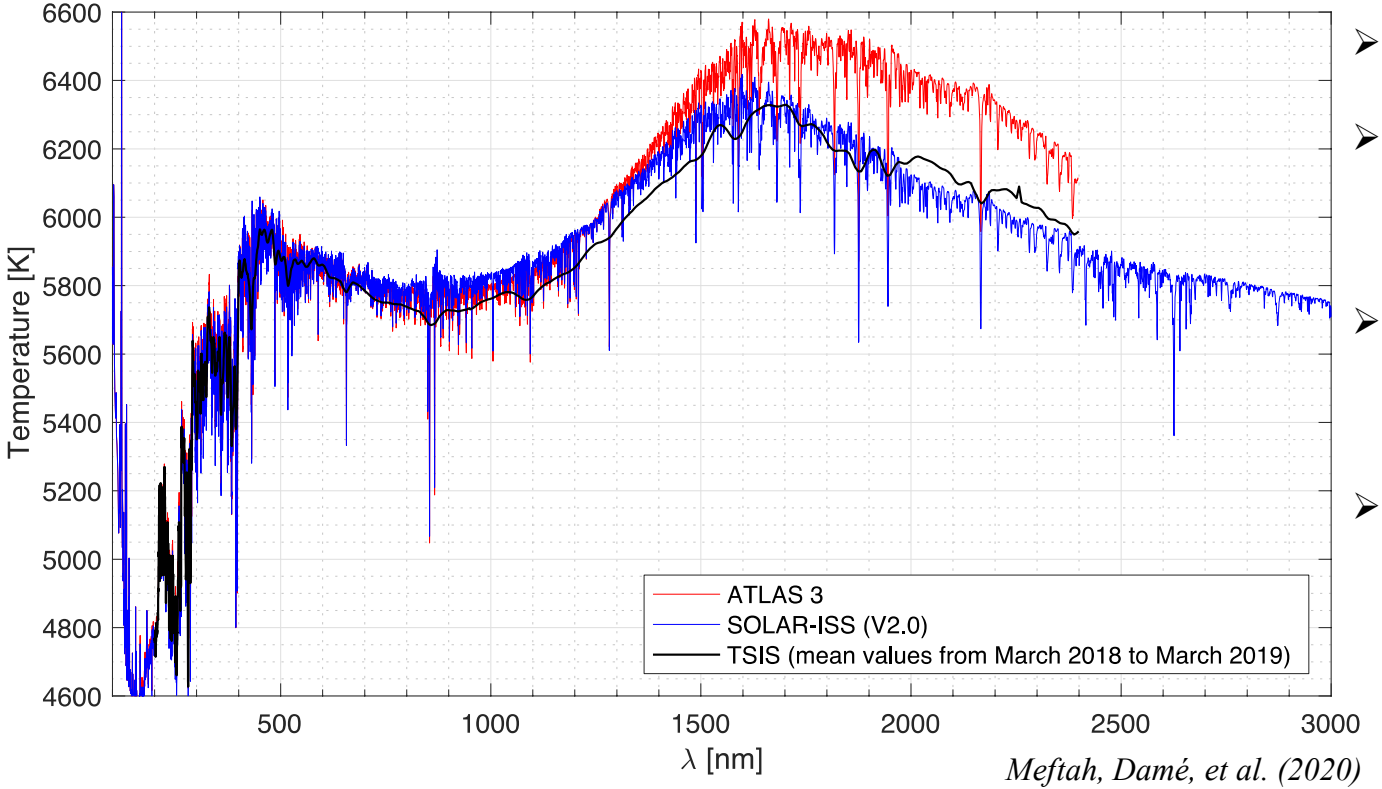




Meftah, Damé, et al. (2020)

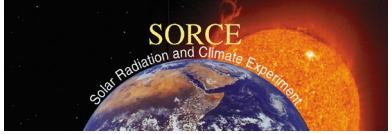


Comparison SOLAR-ISS2 (v2.0), TSIS (2018-2019) and ATLAS 3



Meftah, Damé, et al. (2020)

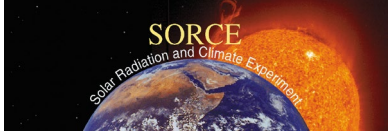
- **ATLAS 3 out of scale above 1.3 µm**
- **TSIS lower than SOLAR-ISS2 between 0.75 and 1.6 µm**
- **Good agreement TSIS and SOLAR-ISS2 between 1.6 and 2 µm**
- **TSIS slightly over SOLAR-ISS2 between 2 and 2.4 µm and presenting unrealistic 2 bumps**



Towards a High Resolution Reference Solar Spectrum

The MicroCarb space-based mission (launch expected in 2021), measuring O2 and CO2, requires an absolute solar spectrum as close as possible of the "true" solar spectrum, **and at very high resolution (0.01 nm)** to disantangle O2, CO2 and airglow from the solar reflected spectrum. MicroCarb aims to measure with precision the carbon dioxide exchange present in the Earth's atmosphere over all regions of the globe.

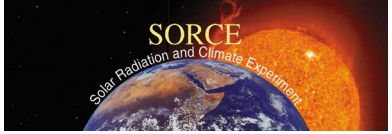
Knowledge of the absolute solar spectrum is expected/required to be better, **< ± 1%**, to validate models/measurements while presently global uncertainty on solar spectrum (@1♦) is around **± 1.26%** [Requirement similar for planetary atmospheres' missions].



Step 2: a high resolution solar spectrum SOLAR-ISS2-HR

Objective: provide a new Solar Reference Spectrum at very high resolution → SOLAR-ISS2-HR with a resolution better than **0.01 nm**

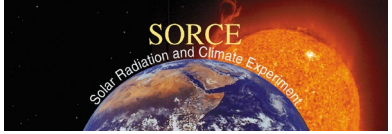
Method: there are four methods to determine the solar spectrum: theoretical, exo-atmospheric, zero airmass extrapolation, and **telluric subtraction**. Based on the telluric subtraction approach, an empirical solar linelist has been generated by simultaneous fitting of ATMOS, MkIV, Kitt Peak, Denver U, TCCON spectra (Toon et al., 2014) and measurements of ACE-FTS instrument. The telluric absorptions were fitted using the HITRAN linelist and any remaining airmass-independent absorptions were attributed to the Sun. Together, with a simple lineshape function, this linelist allows the computation of a solar pseudo-transmittance spectra for disk-integrated. From this solar pseudo-transmittance spectra (high resolution) and from the SOLAR-ISS2 spectrum (absolute determination at lower resolution), we determine a new reference spectrum at very high resolution (better than 0.01 nm).



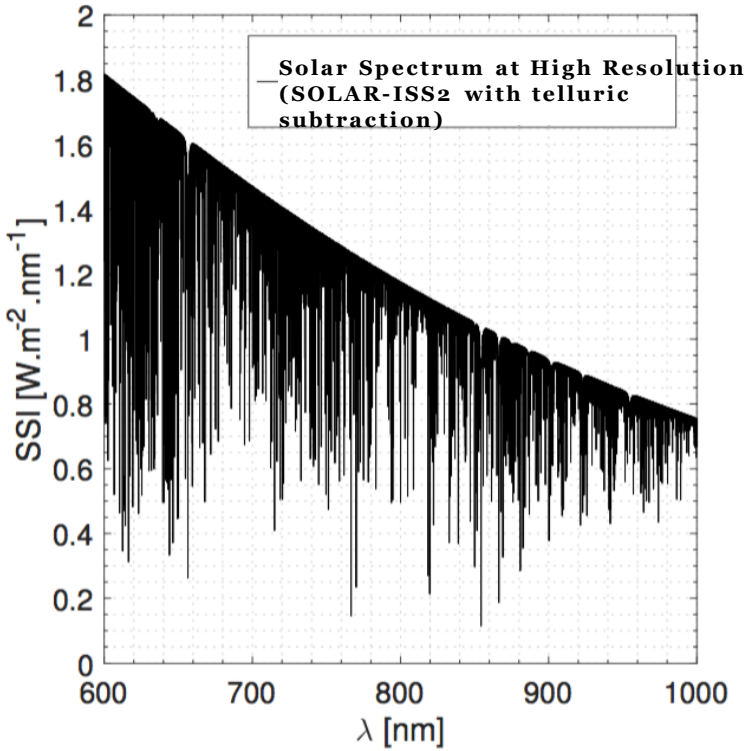
Step 2: a high resolution solar spectrum SOLAR-ISS2-HR (cont'd)

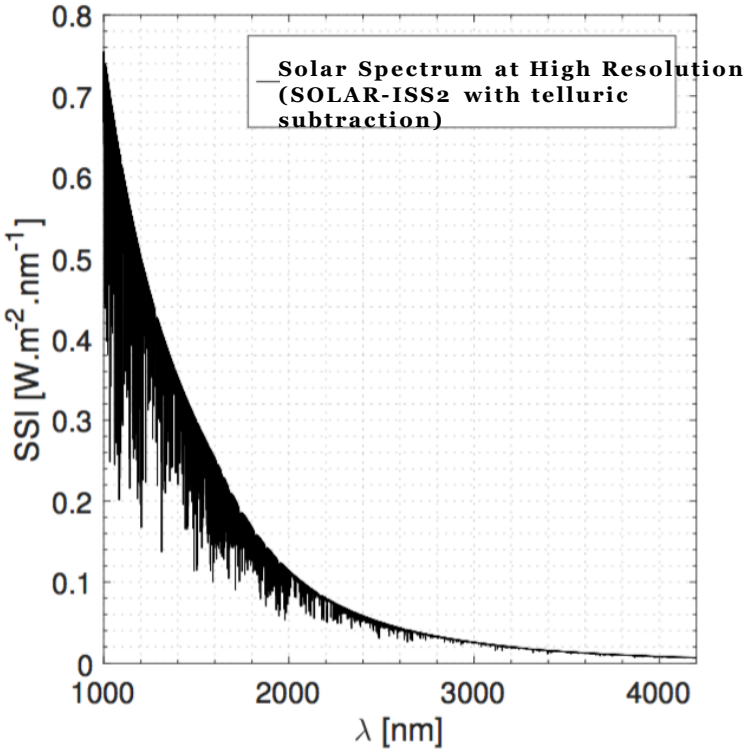
Application: MicroCarb measures atmospheric spectra corresponding to oxygen (O2) in two wavelength bands (around 0.76 µm and 1.27 µm) in order to reconstruct the surface pressure and to control the measurement of carbon dioxide (CO2) concentration – mixing ratio of CO2 to dry air – in normalizing it in 2 bands (around 1.6 µm and 2 µm). Thus, the importance of a good determination of the solar spectrum (back scattered solar spectrum reflected imprinted with CO2 and O2 signatures), especially in the MicroCarb measurement bands.

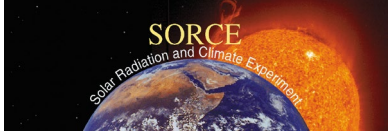
Extension: we provide a solar spectrum over an extended wavelength range (600 to 4200 nm presently) with the will to extend it down to 500 nm. We compare with models (NESSY, COSI, SRPM) or high resolution measurements (ACE-FTS, CAVIAR, QASUME) in given spectral domains of interest.



A new high resolution solar spectrum: SOLAR-ISS2-HR

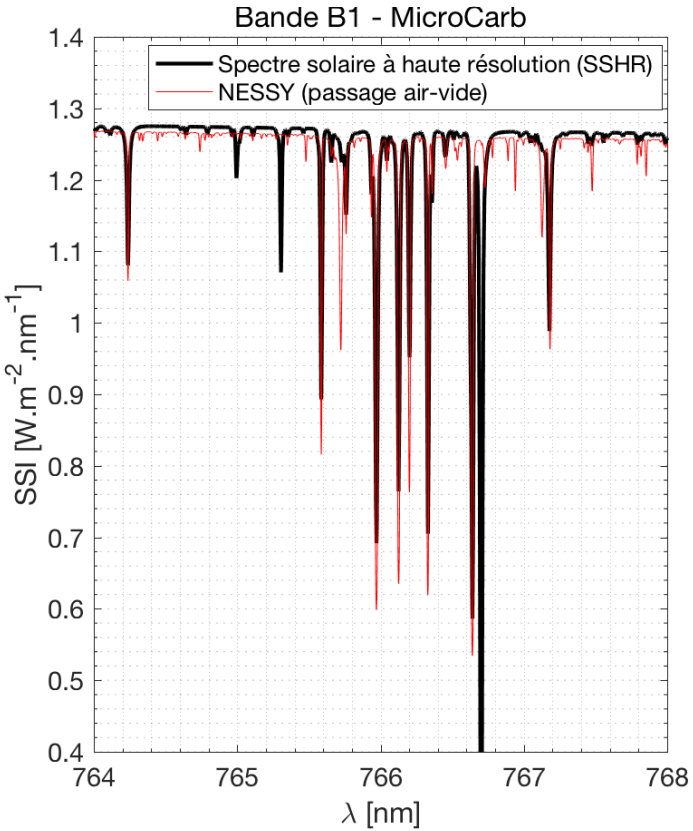


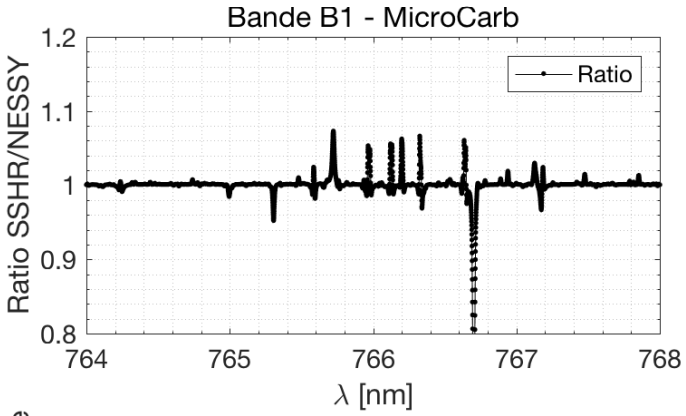


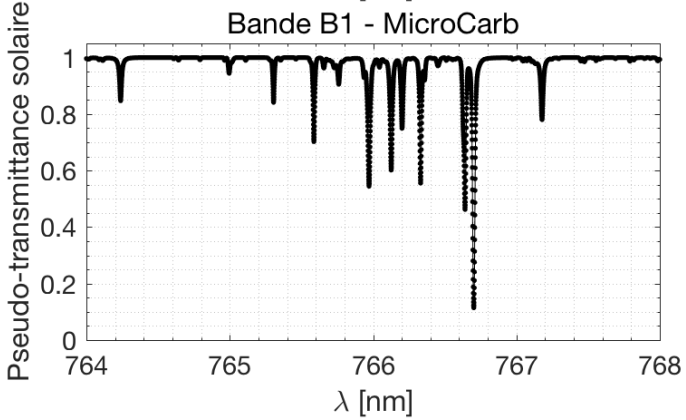
SOLAR/SOLSPEC

SORCE
Solar Radiation and Climate Experiment

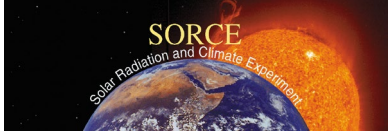
TSIS

O2
760 nm


Bande B1 - MicroCarb
Spectre solaire à haute résolution (SSHR)
NESSY (passage air-vide)
SSI [W.m-2.nm-1]
λ [nm]
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
764
765
766
767
768

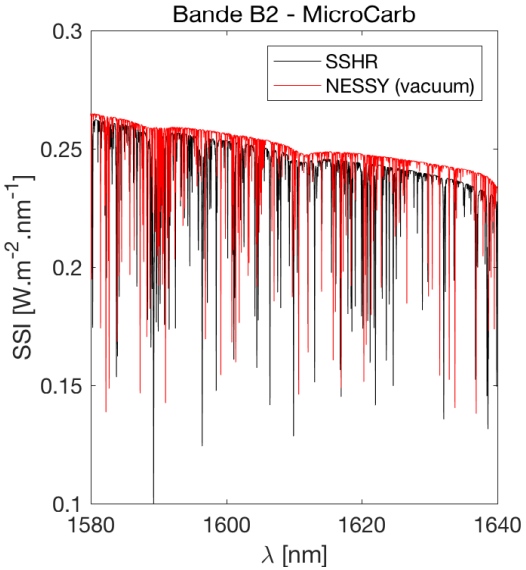

Bande B1 - MicroCarb
Ratio
Ratio SSHR/NESSY
λ [nm]
1.2
1.1
1
0.9
0.8
764
765
766
767
768

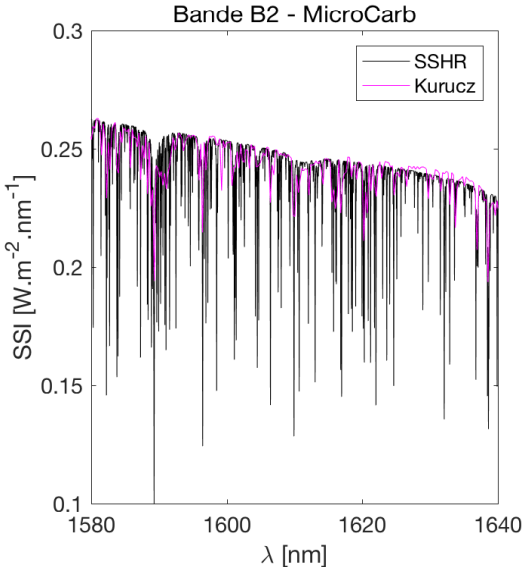

Bande B1 - MicroCarb
Pseudo-transmittance solaire
λ [nm]
1
0.8
0.6
0.4
0.2
0
764
765
766
767
768

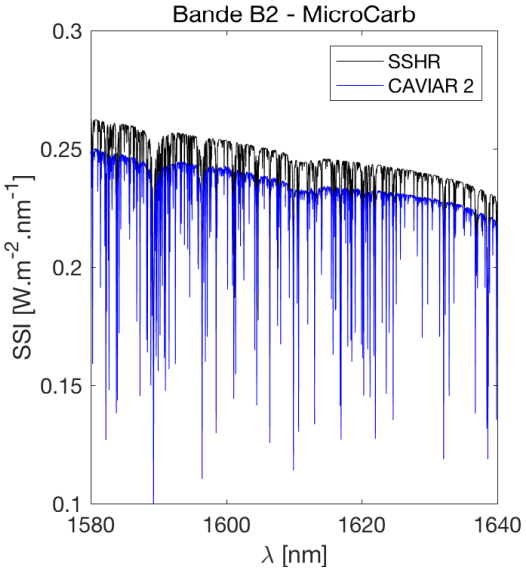
SOLAR/SOLSPEC

SORCE
Solar Radiation and Climate Experiment

TSIS

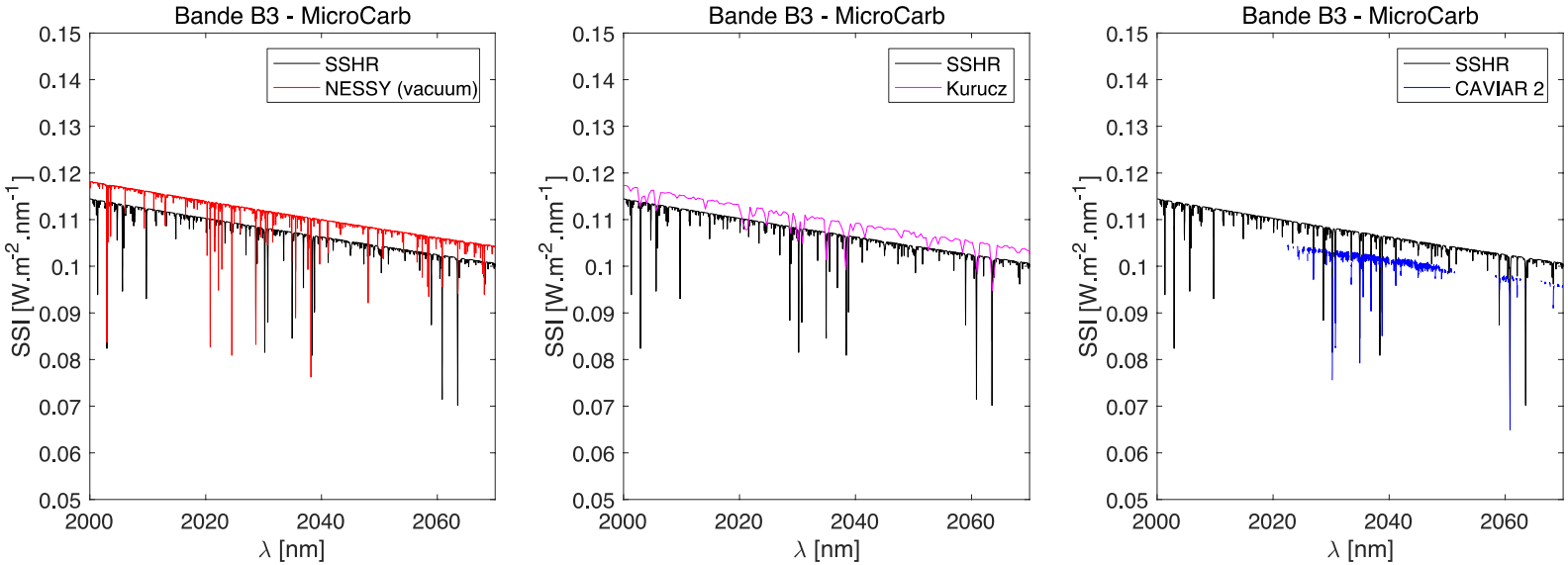
CO2
1600 nm

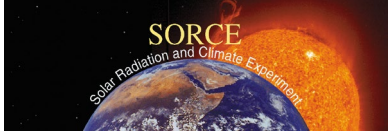

Bande B2 - MicroCarb
SSHR
NESSY (vacuum)
SSI [W.m-2.nm-1]
λ [nm]
0.3
0.25
0.2
0.15
0.1
1580
1600
1620
1640


Bande B2 - MicroCarb
SSHR
Kurucz
SSI [W.m-2.nm-1]
λ [nm]
0.3
0.25
0.2
0.15
0.1
1580
1600
1620
1640


Bande B2 - MicroCarb
SSHR
CAVIAR 2
SSI [W.m-2.nm-1]
λ [nm]
0.3
0.25
0.2
0.15
0.1
1580
1600
1620
1640

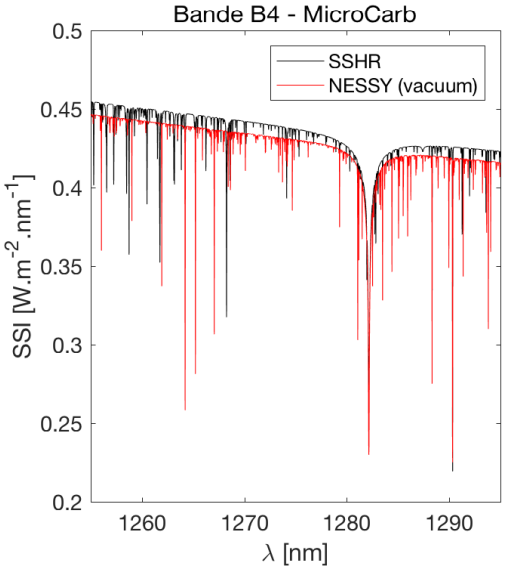
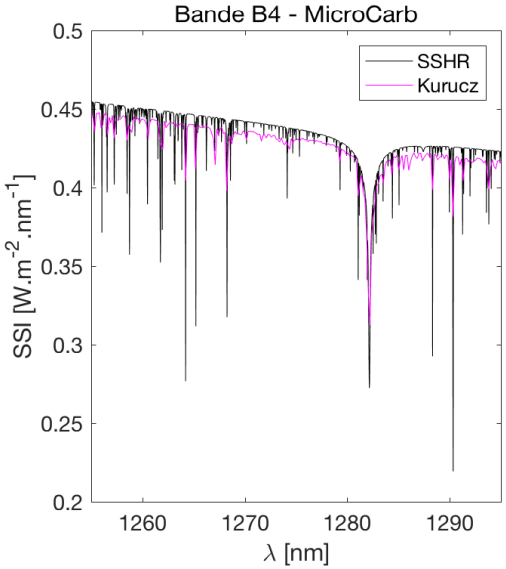
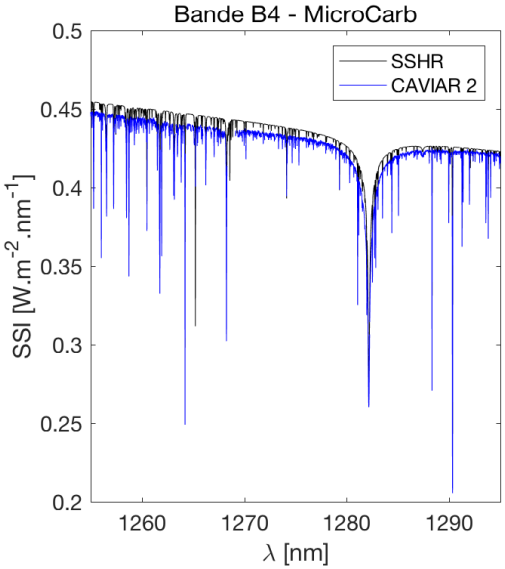
CO2
2000 nm

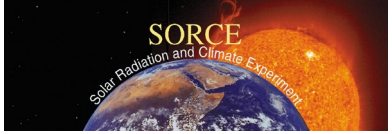

Bande B3 - MicroCarb
SSHR
NESSY (vacuum)
Kurucz
CAVIAR 2
SSI [W.m-2.nm-1]
λ [nm]
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
2000
2020
2040
2060

SOLAR/SOLSPEC

SORCE
Solar Radiation and Climate Experiment

TSIS

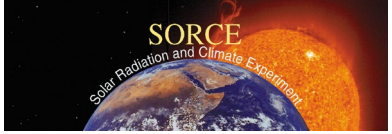
O2
1270 nm


Bande B4 - MicroCarb
SSHR
NESSY (vacuum)
SSI [W.m-2.nm-1]
λ [nm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
1260
1270
1280
1290

Bande B4 - MicroCarb
SSHR
Kurucz
SSI [W.m-2.nm-1]
λ [nm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
1260
1270
1280
1290

Bande B4 - MicroCarb
SSHR
CAVIAR 2
SSI [W.m-2.nm-1]
λ [nm]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
1260
1270
1280
1290



Conclusions and Perspectives

- The SOLAR-ISS Absolute Reference Spectrum was revised/improved in version 2.0 (FUV, Herzberg MUV and NIR corrections)
- SOLAR-ISS2 (2008), extending from 165 to 3000 nm, is the more comprehensive absolute reference spectrum [uncertainties evaluated]
- SOLAR-ISS2 is in agreement [± 5%] with the early results of the Space Station TSIS spectrum (extending from 200 to 2400 nm)
- SOLAR-ISS2 is developed in a high resolution version (SOLAR-ISS2-HR, 0.01 nm resolution) to serve as a reference for atmosphere (MicroCarb O2, CO2) and planetary atmospheres' measurements from 600 to 4200 nm
- Based on the proven SOLAR-ISS2 absolute reference spectrum of 2008, we are now studying solar variability, in particular UV one



Thank you!

luc.dame@latmos.ipsl.fr, mustapha.meftah@latmos.ipsl.fr, alain.hauchecorne@latmos.ipsl.fr

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Data available online (CDS Strasbourg) for v1.1 and v2.0

(and soon the HR version)