



Belgian Institute for Space Aeronomy (BIRA-IASB)  
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Belgisch Instituut voor Ruimte-Aeronomie (BIRA)

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

# *Solar Spectral Irradiance observations from the PICARD/PREMOS radiometer*

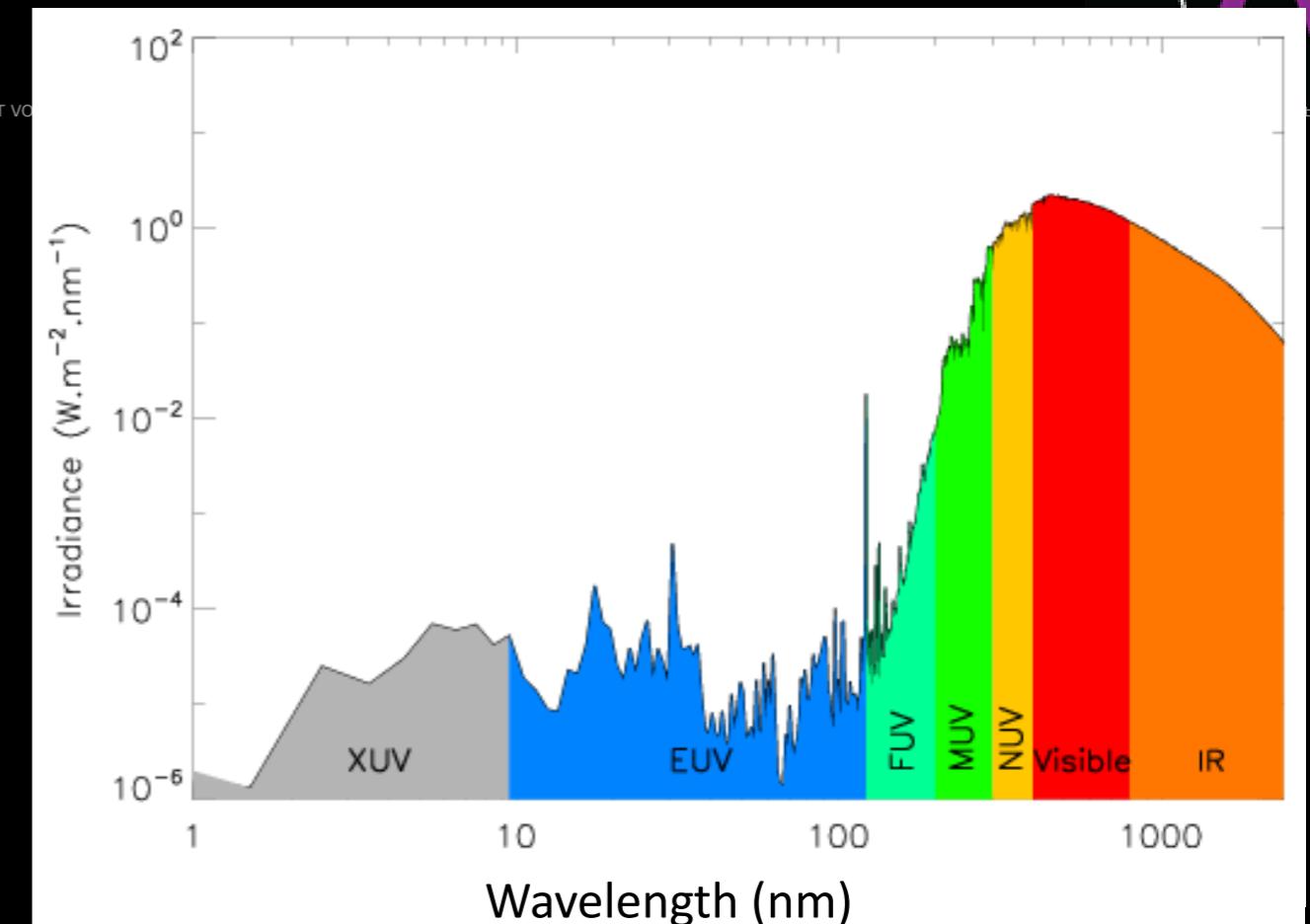
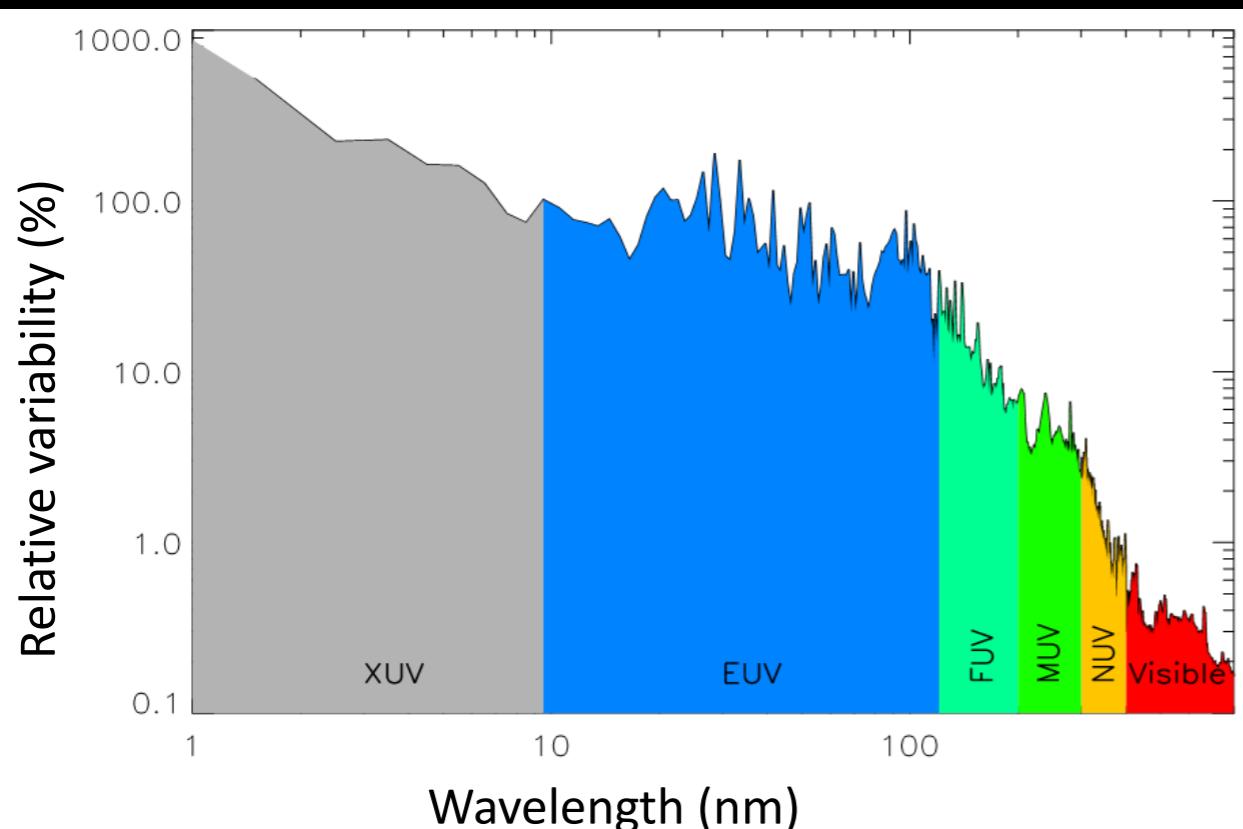
*Gaël Cessateur, Werner Schmutz, A. Shapiro  
and the PREMOS team*

# The Solar Spectrum



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- ✓ Black body at 5777 K
- ✓ Absorption and Emission lines
- ✓ Plasma between  $10^4$ K and  $10^6$ K



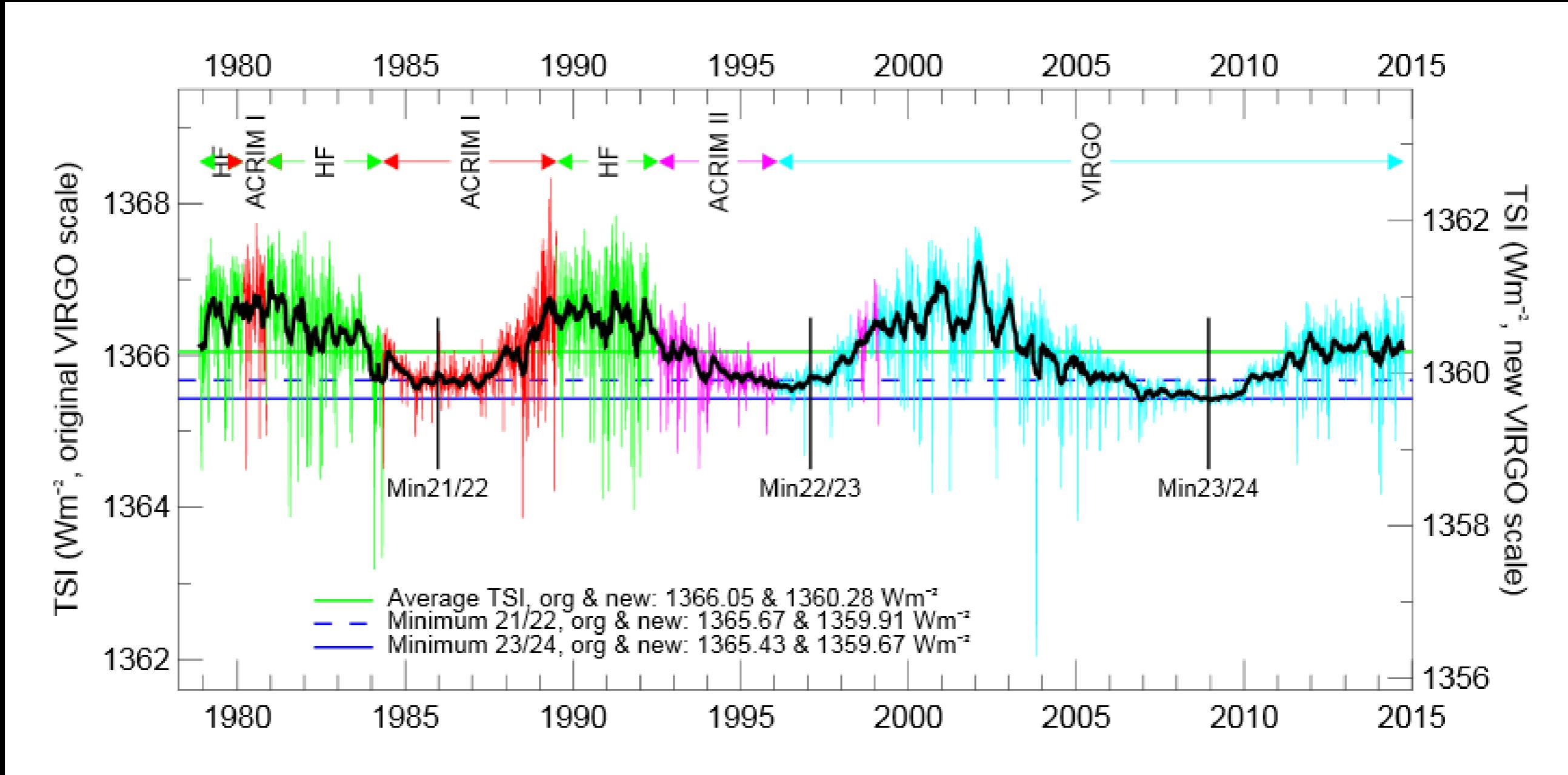
Solar variability is irregular

- ✓ Wavelength dependent
- ✓ Different timescales
  - 27-days solar rotation
  - 13.5-days: CLV modulation
  - Schwabe cycle (10-12 years)
  - Transient events

# Solar 11-year cycle & TSI



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# SSI variability observations with PREMOS

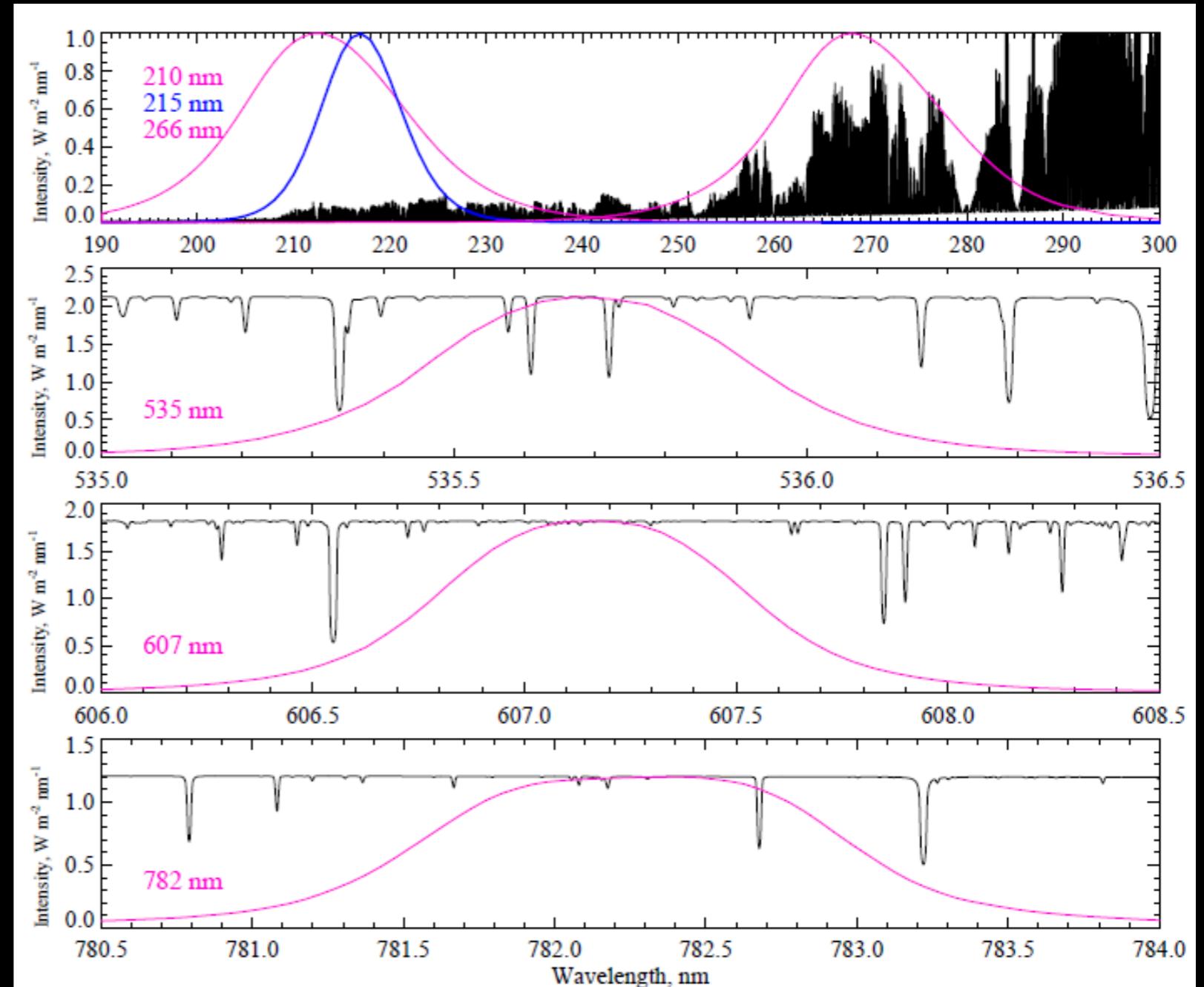


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## PREMOS/PICARD



- ✓ September 2010 – April 2014
- ✓ Strong degradation...
- ✓ Long term variability for the UV
- ✓ Rotational modulation visible and IR



# PREMOS paper, soon submitted !



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## The PREMOS radiometer aboard PICARD: In-flight performance and data release

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# PREMOS First light



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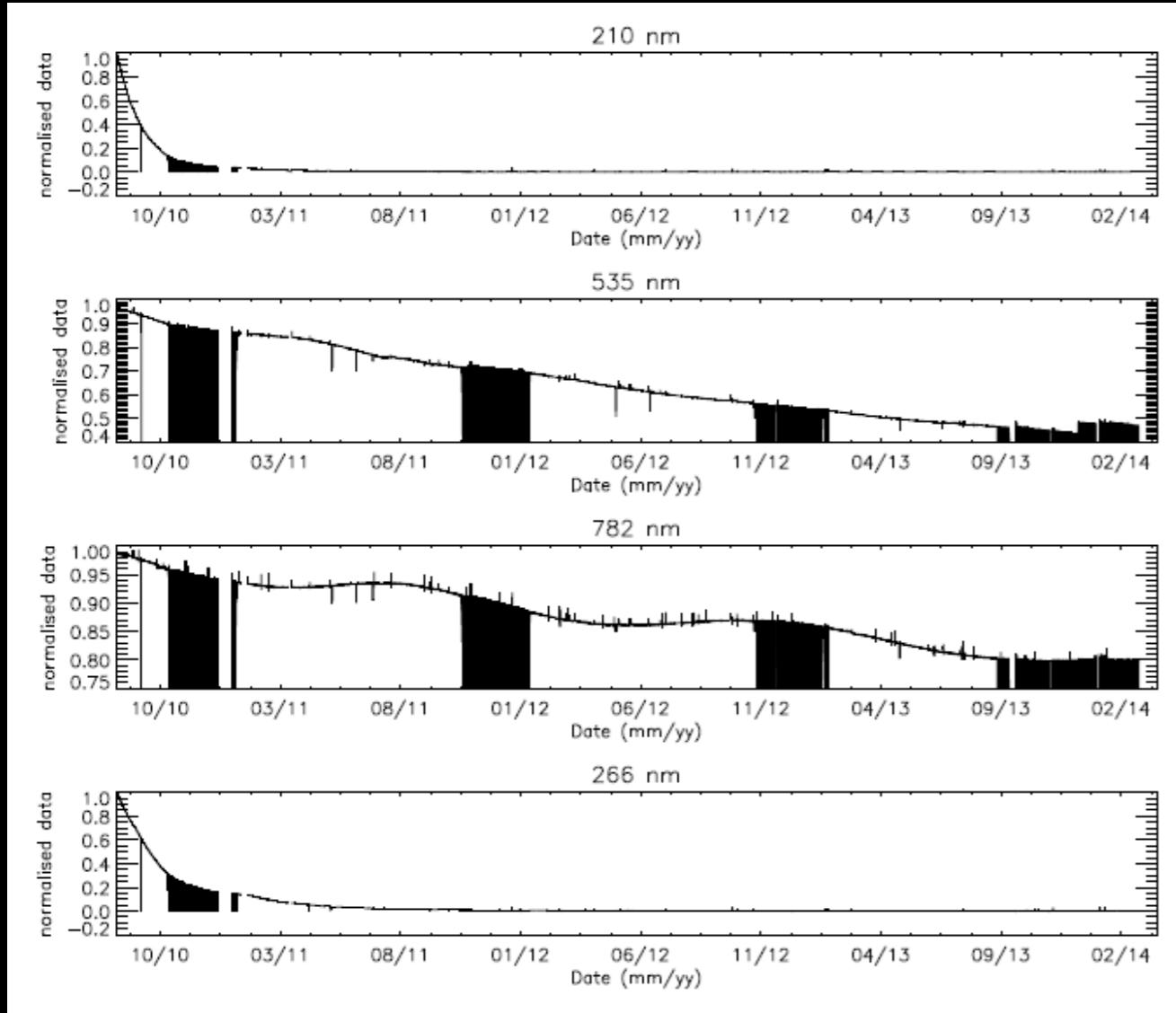
PREMOS	210 nm	215 nm	266 nm	535.69 nm	607.16 nm	782.26 nm
Head A	$2.49 \cdot 10^{-2}$ (-14 %)		0.198 (+5.8 %)	1.856 (-4.8 %)		1.138 (-4.6 %)
Head C	$2.33 \cdot 10^{-2}$ (-20 %)		0.189 (+1.2 %)	1.883 (-1.7 %)		1.121 (-3.7 %)
Head B (Channels 1 & 2)		$2.64 \cdot 10^{-2}$ (-28.6 %)			1.806 (+4.3 %)	
Head B (Channels 3 & 4)		$3.05 \cdot 10^{-2}$ (-17.5 %)			1.824 (+5.3 %)	

- ✓ 210 and 215 nm: Irradiance decrease compared to Sorce (-15%): degradation prior to the launch which was already foreseen (Schmutz et al. 2009)
- ✓ 266 nm: Irradiance increases up to 6 %: heat problems ? Transmittance ?
- ✓ 535 and 782 nm : also an important decrease, from 1 to 5%. Degradation of the filter prior to the launch....
- ✓ 607 nm: irradiance excess of about 2-4%, ground calibration issues

# Degradation problems PREMOS

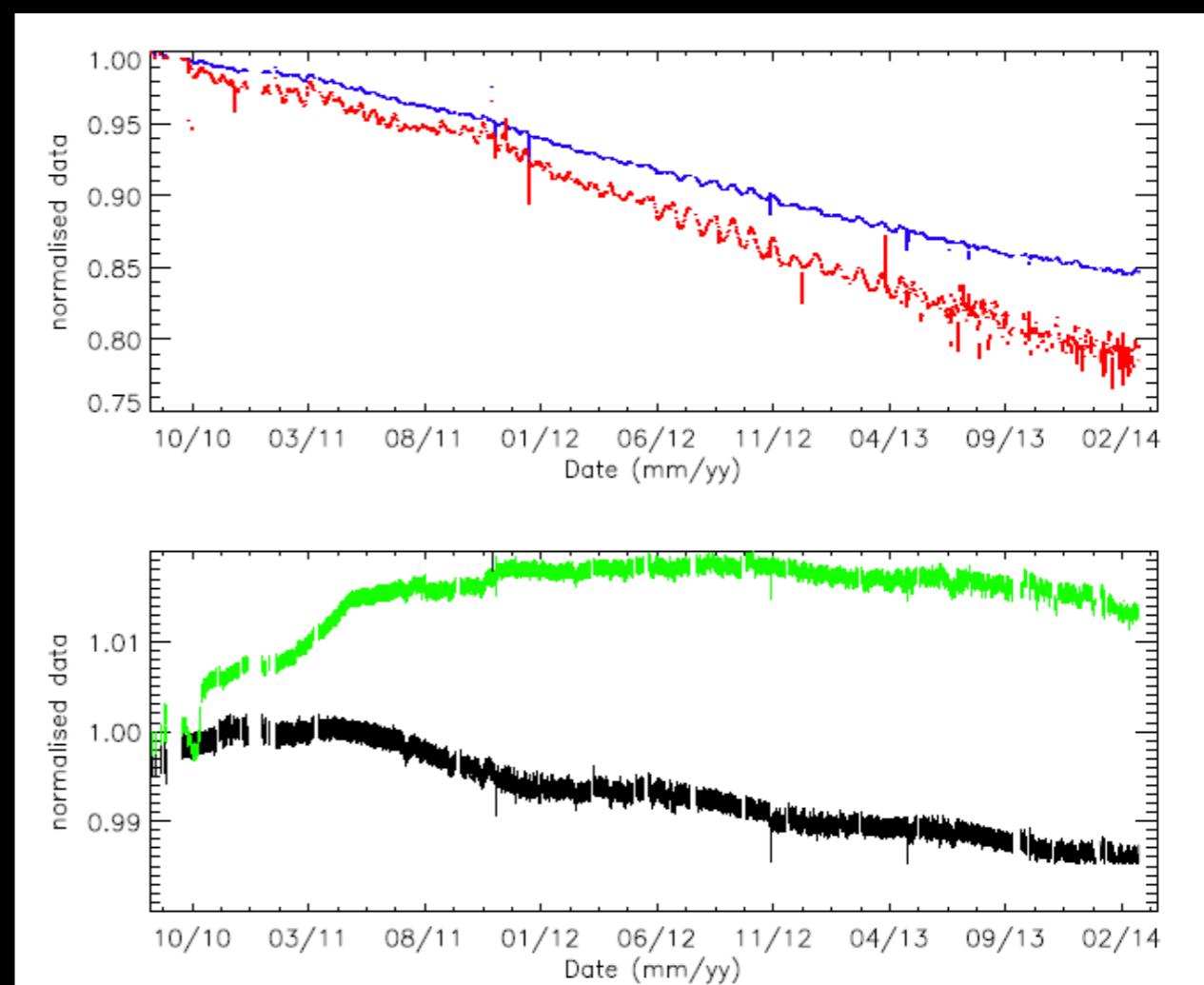


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## ✓ Head C

- 210 and 266 nm: 20 and 14 %
- 535 nm: ~ -1.1%
- 782 nm: ~ +1.5 %



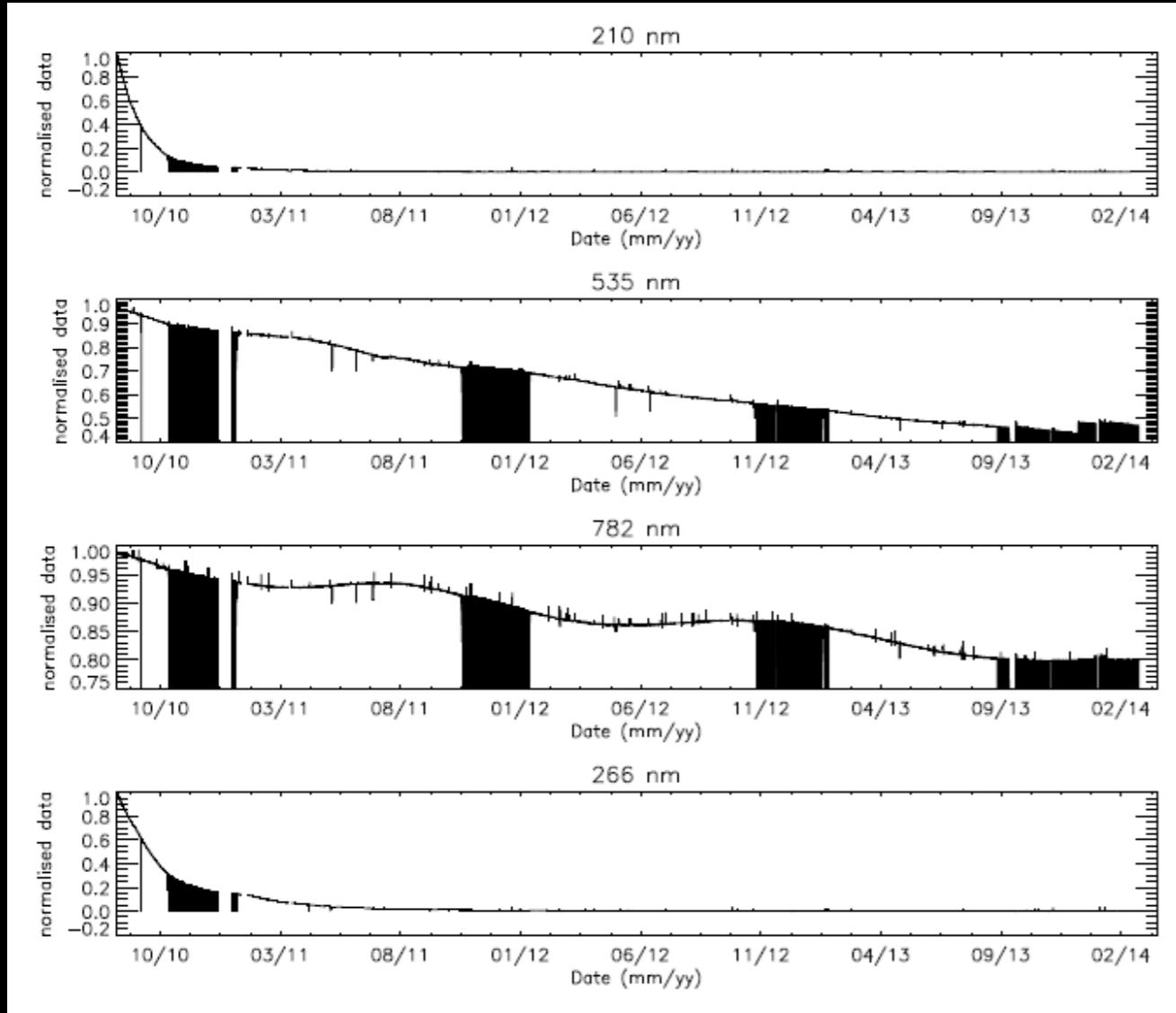
## ✓ Head A

- 210 and 266 nm: more than 99%
- 535 nm: ~ 50%
- 782 nm: ~ 20 %

# Degradation problems PREMOS

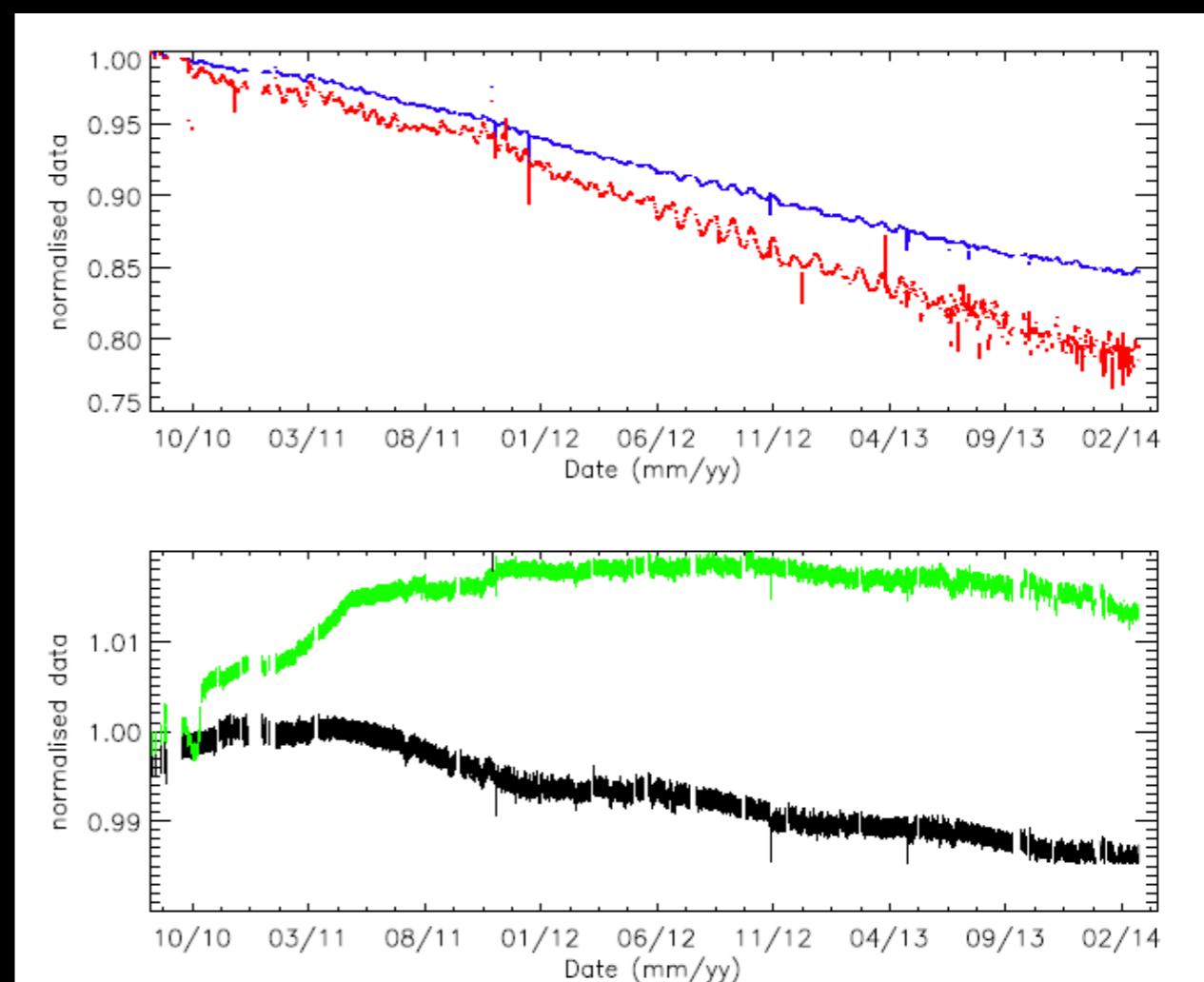


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- ✓ Head A (High Cadence)
  - 210 and 266 nm: more than 99%
  - 535 nm: ~ 50%
  - 782 nm: ~ 20 %

- ✓ Head C (Once per day)
  - 210 and 266 nm: 20 and 14 %
  - 535 nm: ~ -1.1%
  - 782 nm: ~ +1.5 %

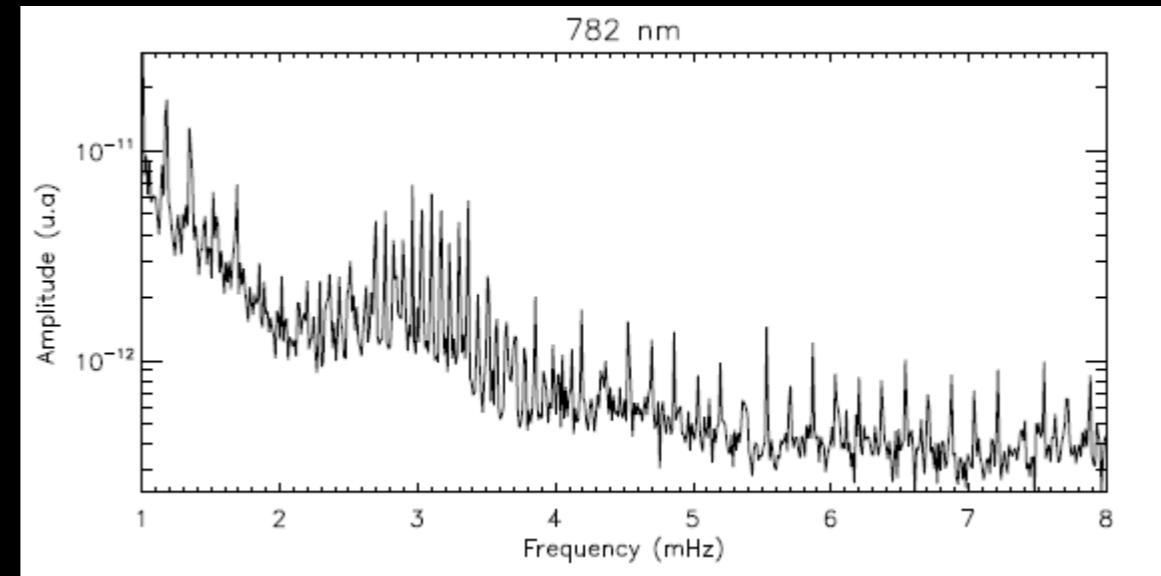


# What can we do with Head A ?



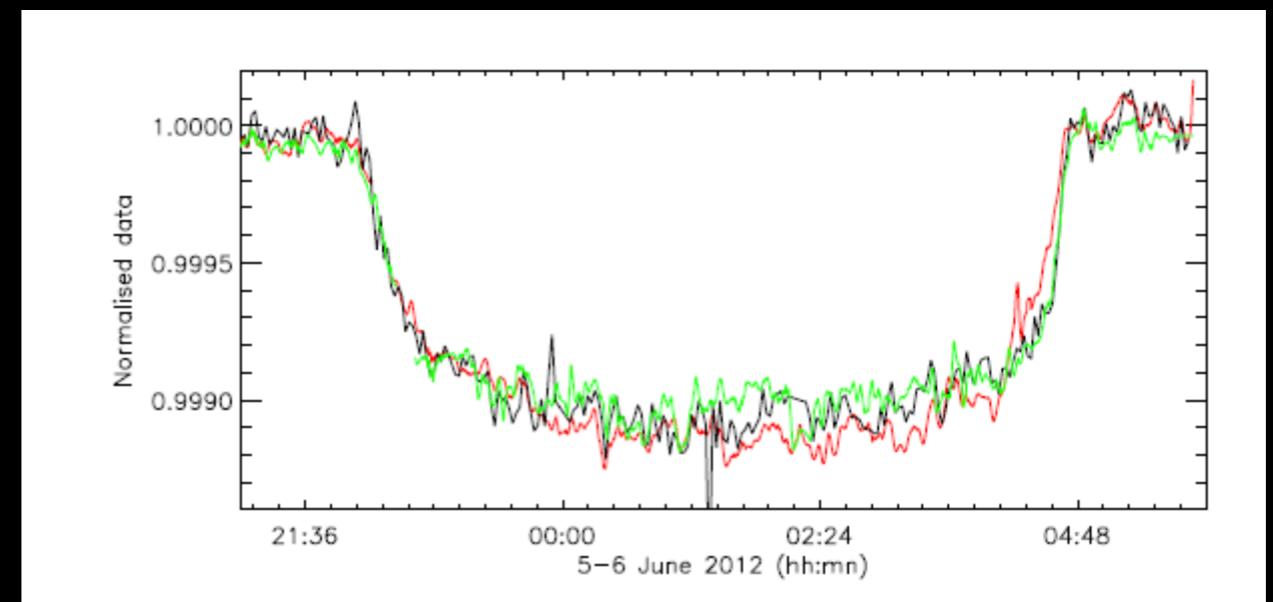
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- ✓ Helioseismology



- ✓ Flare detection ? No flare signature has been found, either directly or using statistical methods...

- ✓ Venus transit

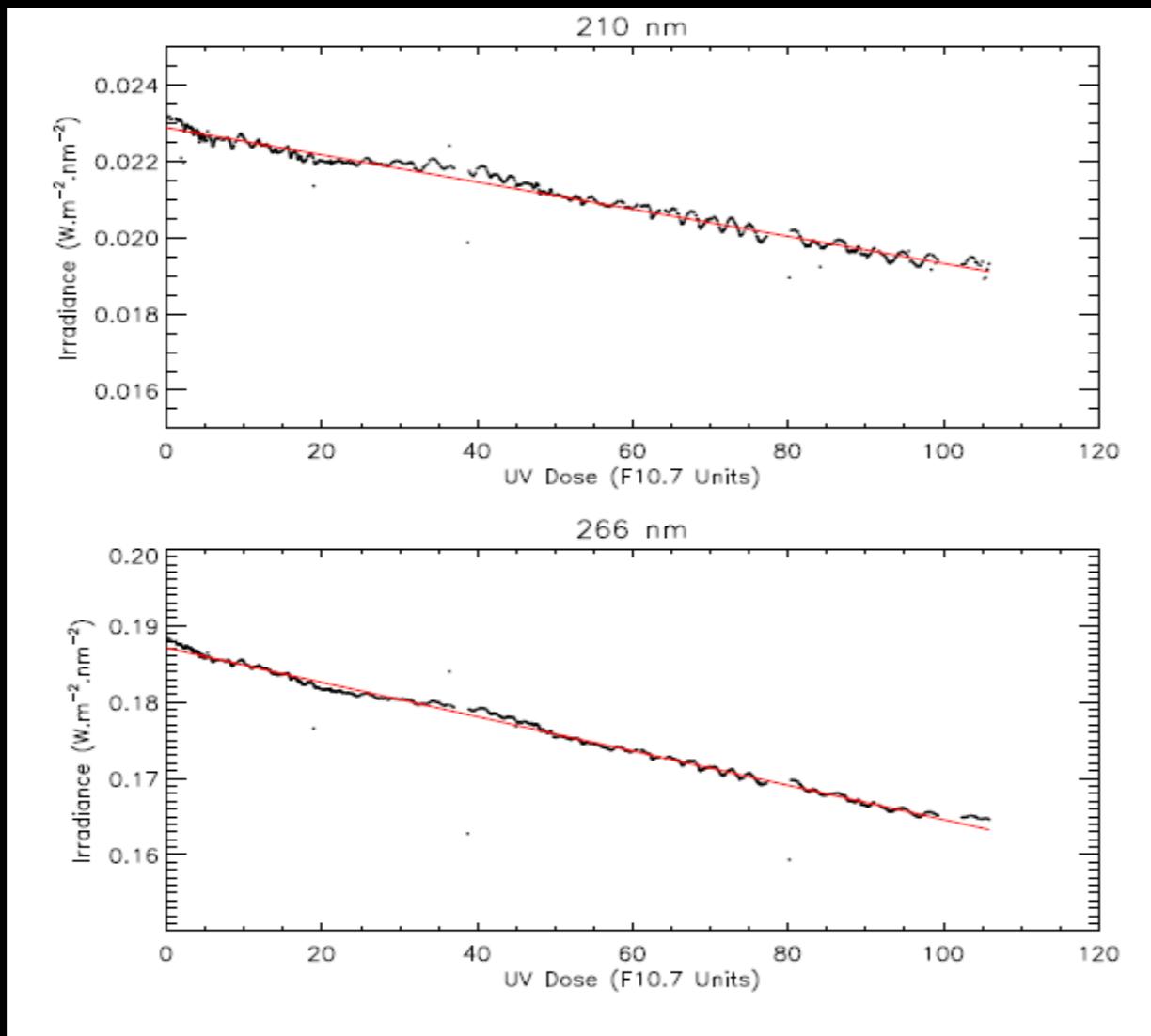


# What can we do with Head C ?



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- ✓ UV channels :degradation correction using a UV dose function. We do not consider the exposure time, but the amount of UV received by the system  $A T_{UV} + B$

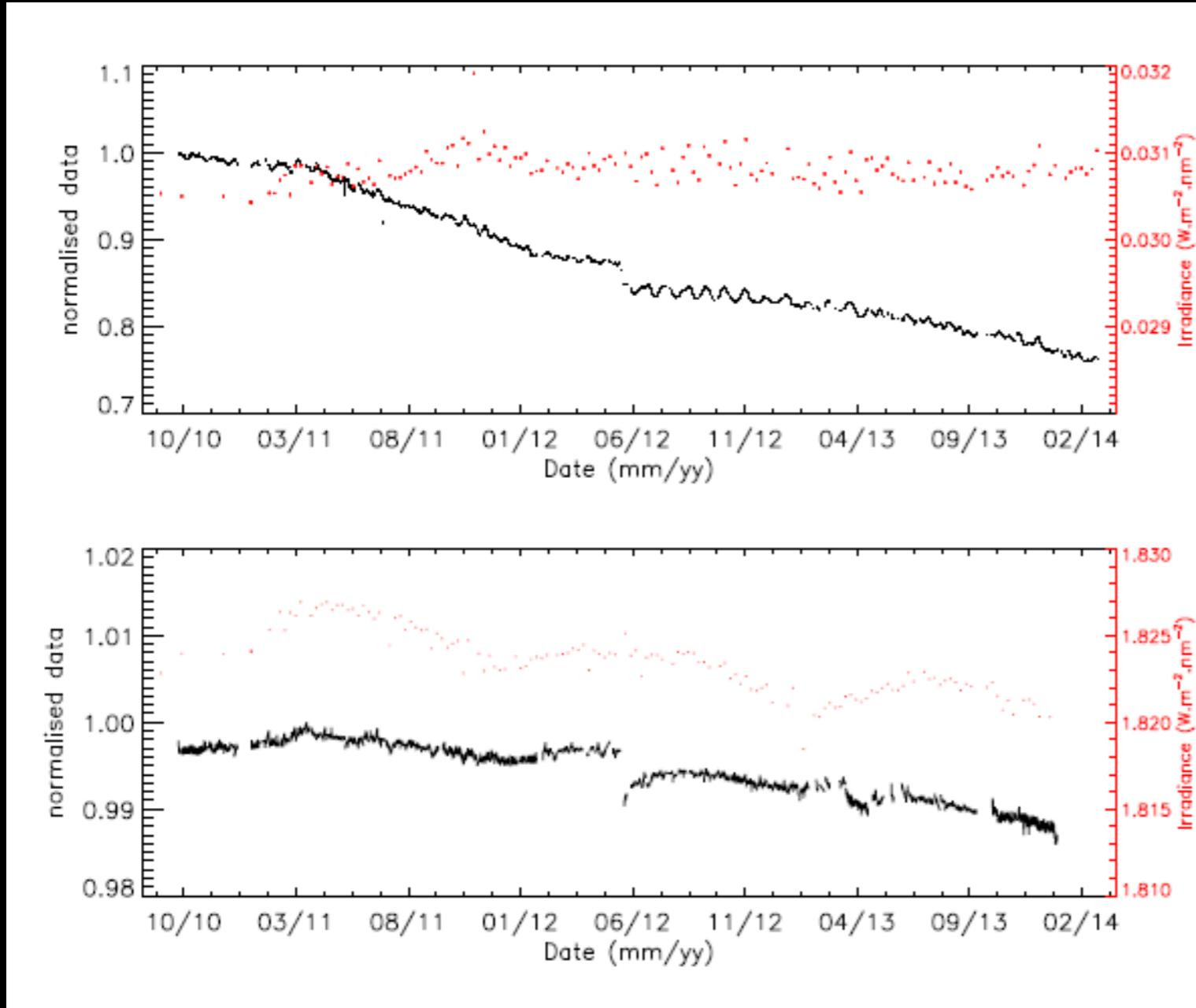


- ✓ F10.7, Mg II or Lyman  $\alpha$  as UV proxies
- ✓ Linear or quadratic regression
- ✓ Visible and near-IR channels ? Degradation oscillations are difficult to correct without any further information. Comparison with SODISM and LYRA in progress. 27- day modulation only available so far.

# Head B



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➤ 215 nm  
25% for channel 1  
no degradation for channel 3  
(once a week)  
Possibility here to correct directly  
the irradiance at 215 nm

➤ 607nm  
1% for channel 2  
0.3 % for channel 4 (once a week)  
Oscillations patterns for 607 nm no  
yet understood. Only the 27-day  
solar modulation.

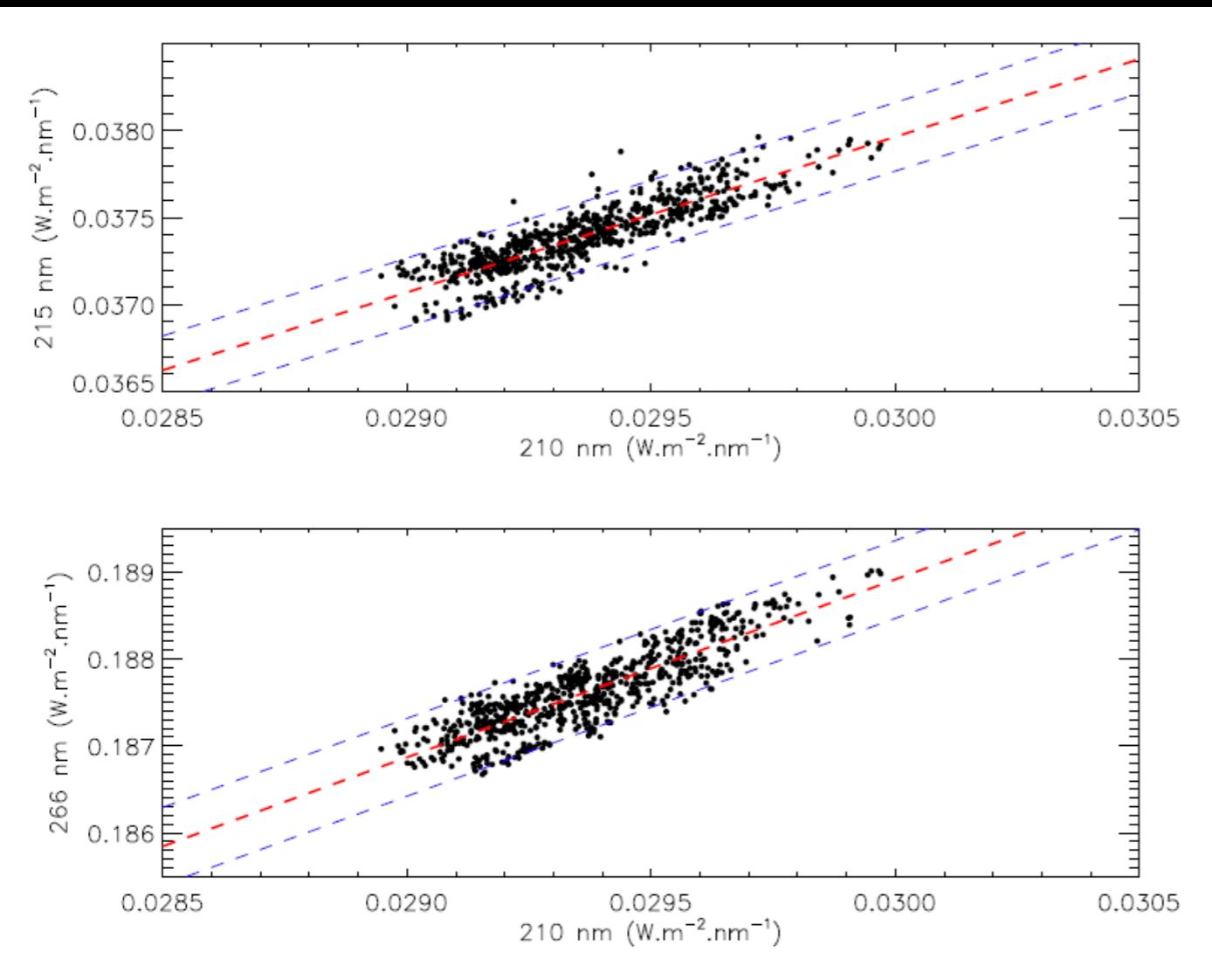
# Validation of the PREMOS data



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- ✓ Solar variability in the UV

Cross comparison between 210, 215 and 266 nm



$a + b \times I_{210}$	R	$R^2$	$\sigma_{\text{err}}$
$I_{215} = 0.011 + 0.893 \times I_{210}$	0.867	0.753	$1 \cdot 10^{-4}$
$I_{266} = 0.127 + 2.04 \times I_{210}$	0.869	0.756	$2.2 \cdot 10^{-4}$

- ✓ Good correlation between all PREMOS UV channels, which outlines the variability coherence.
- ✓ Once channels is enough to reconstruct the variability in the UV (200-300 nm)

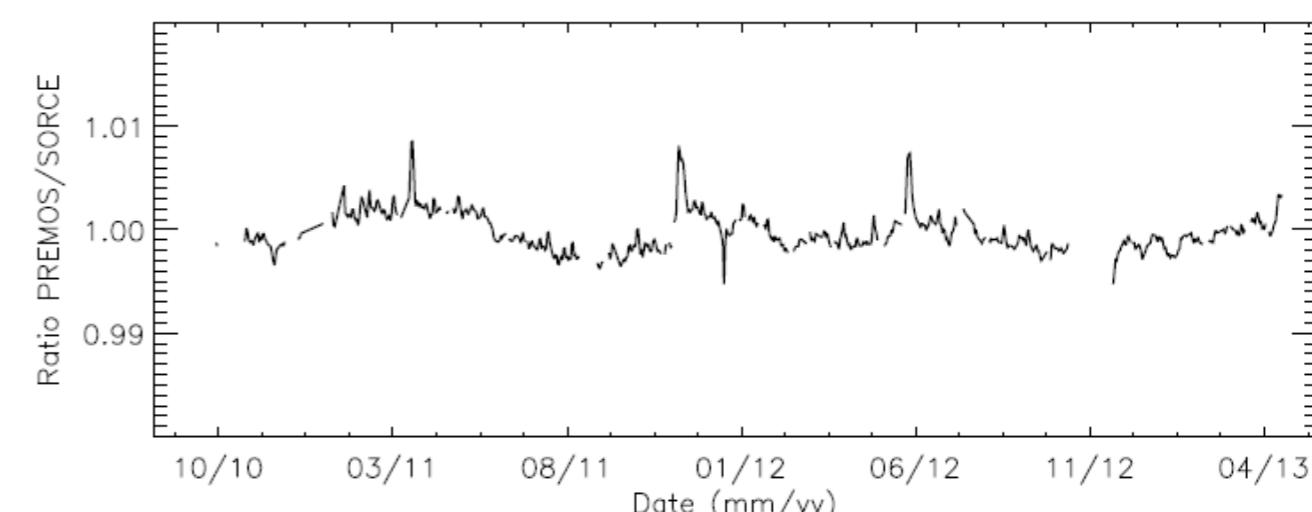
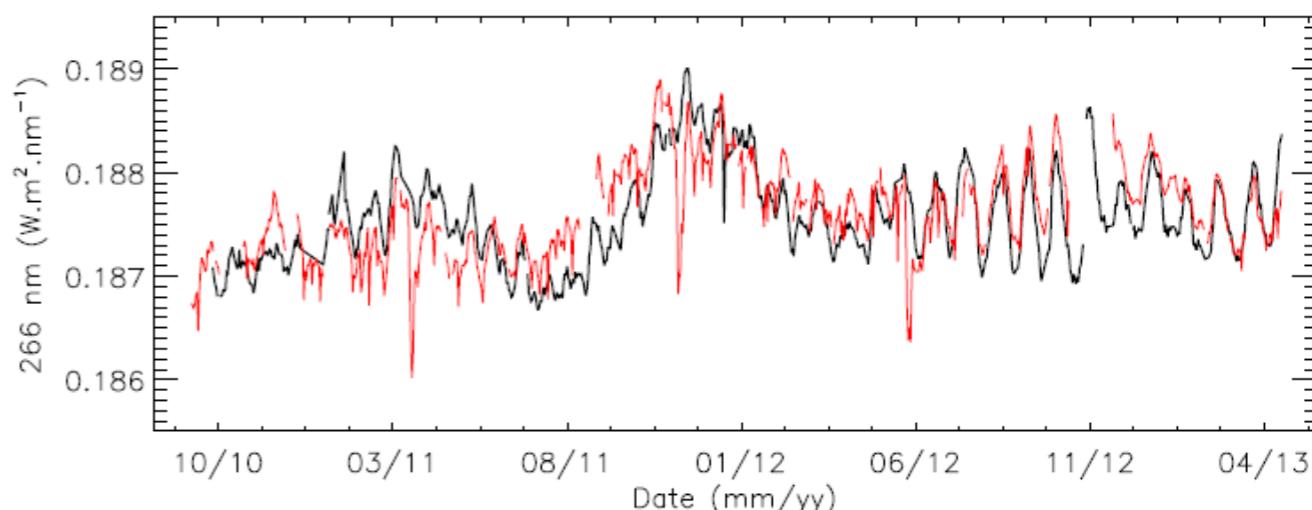
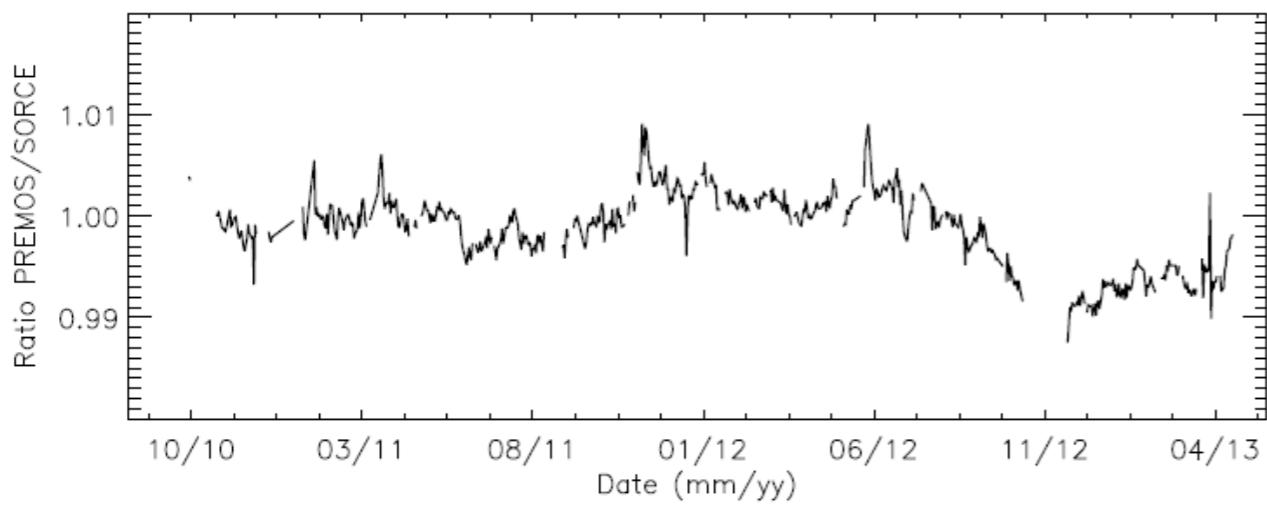
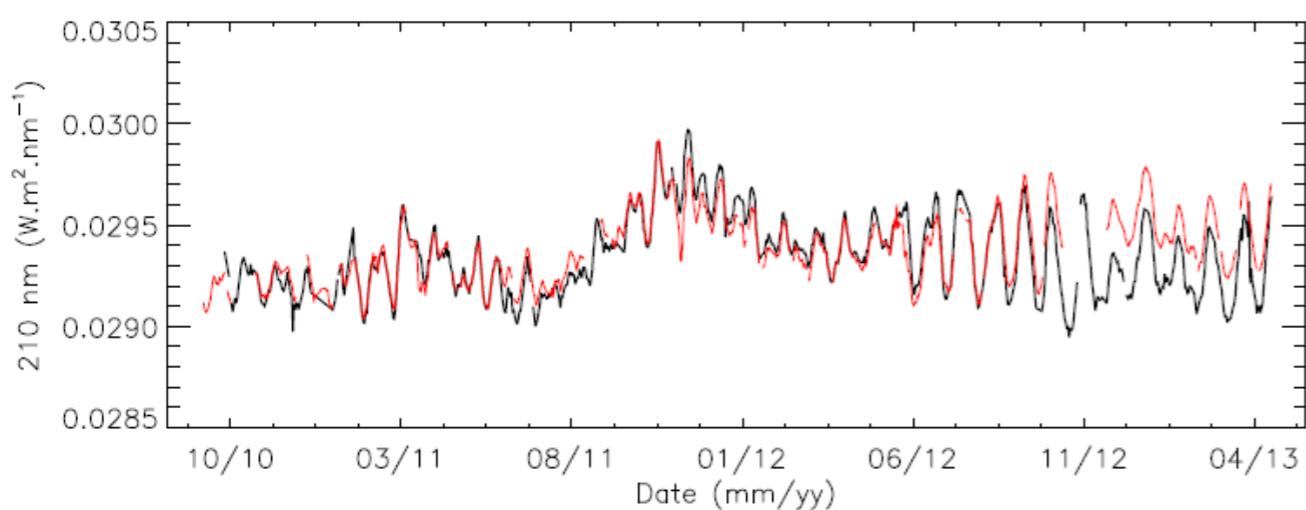
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- ✓ Solar variability in the UV

Comparison with SORCE/SOLSTICE data sets (level 3, version 12)



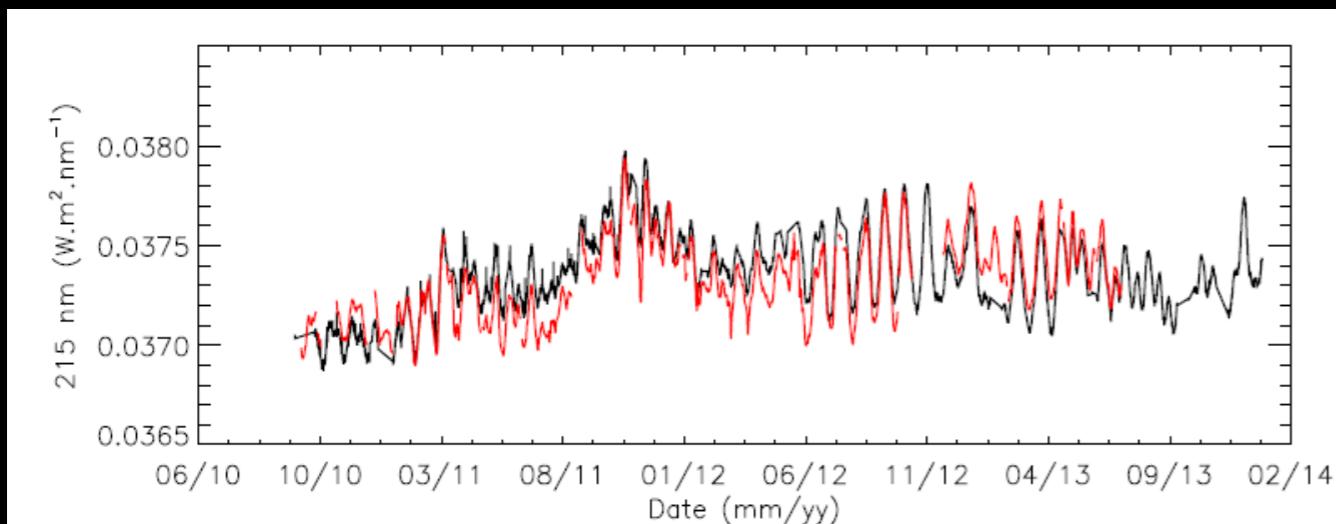
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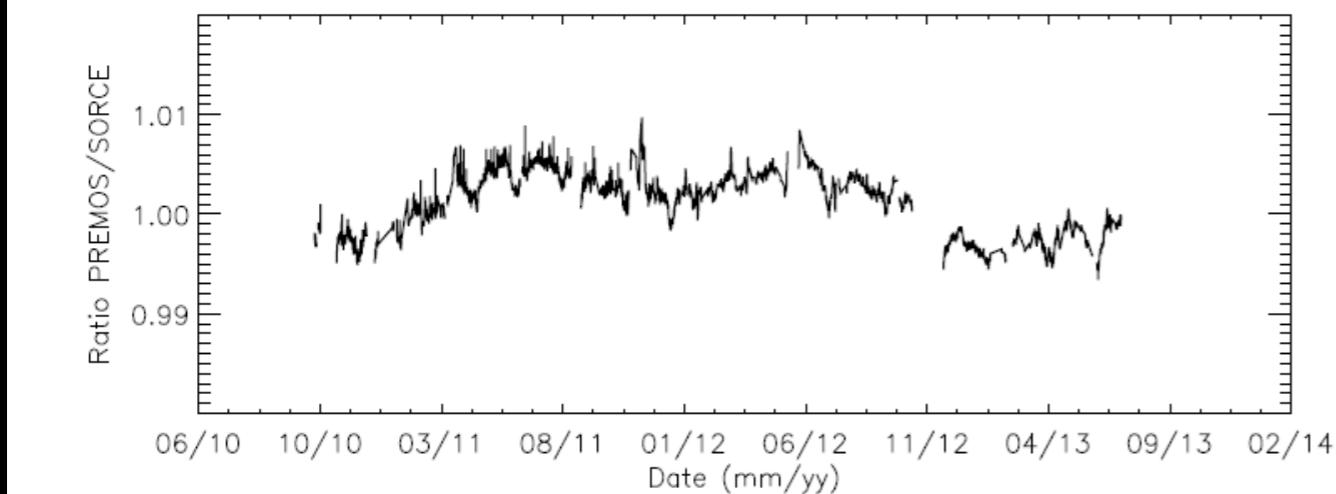
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- ✓ Solar variability in the UV

Comparison with SORCE/SOLSTICE data sets (level 3, version 12)



	210 nm	215 nm	266 nm
PREMOS vs SORCE	0.83 (0.69)	0.85 (0.72)	0.67 (0.42)



- ✓ Good correlation between PREMOS UV channels and SORCE/SOLSTICE data
- ✓ Possibility to use the 215 channel for filling the SORCE gap between July 2013 and Feb. 2014

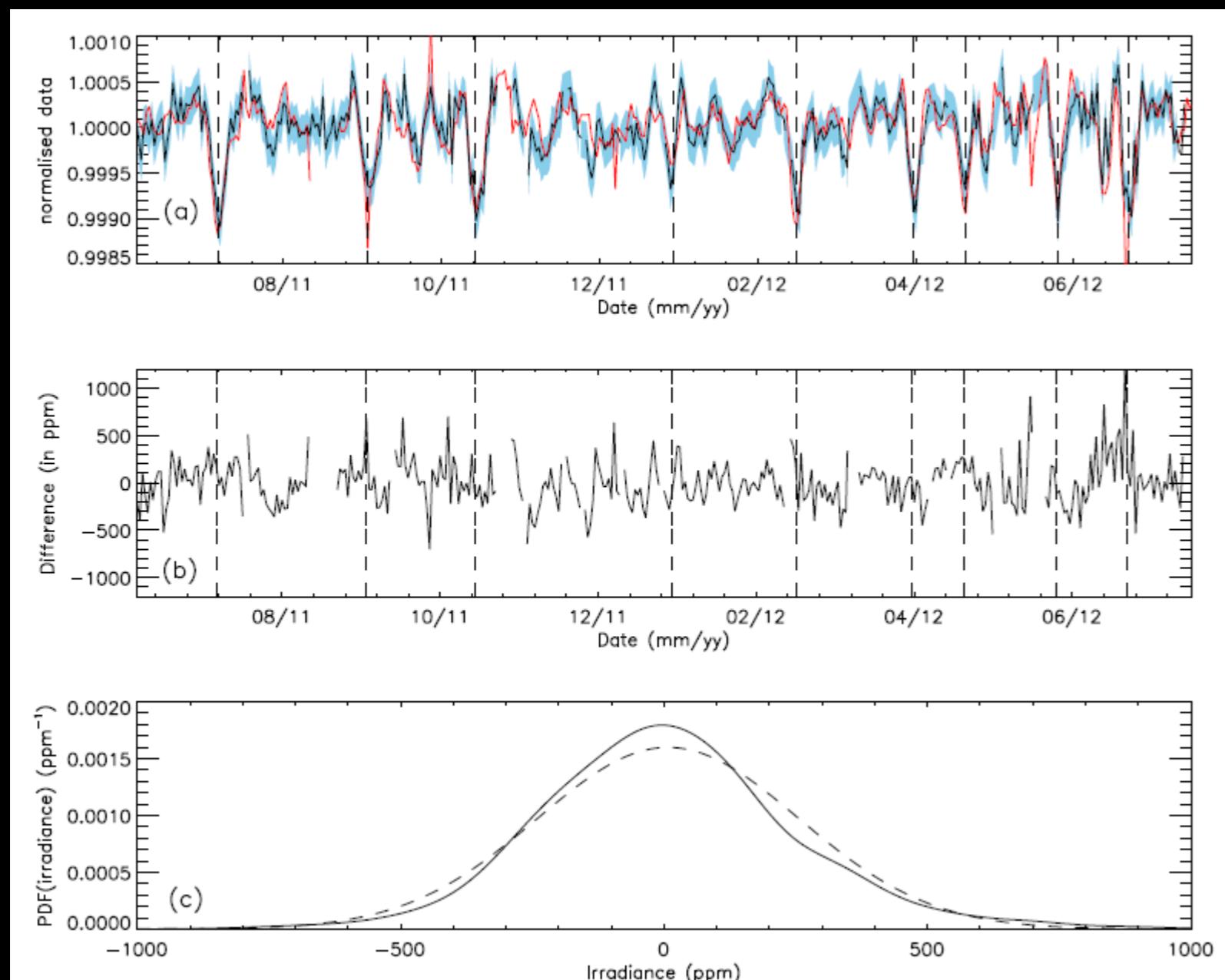
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- ✓ Solar variability in the visible and near-IR (27-day modulation)

Comparison with SORCE/SIM data sets (level 3, version 21)



- ✓ Sunspot passages in very good agreement
- ✓ Noise distribution not gaussian
- ✓ Noise estimation for PREMOS

$$\sigma_{\text{PREMOS}} = \sqrt{\sigma_{\text{Total}}^2 - \sigma_{\text{SIM}}^2}$$

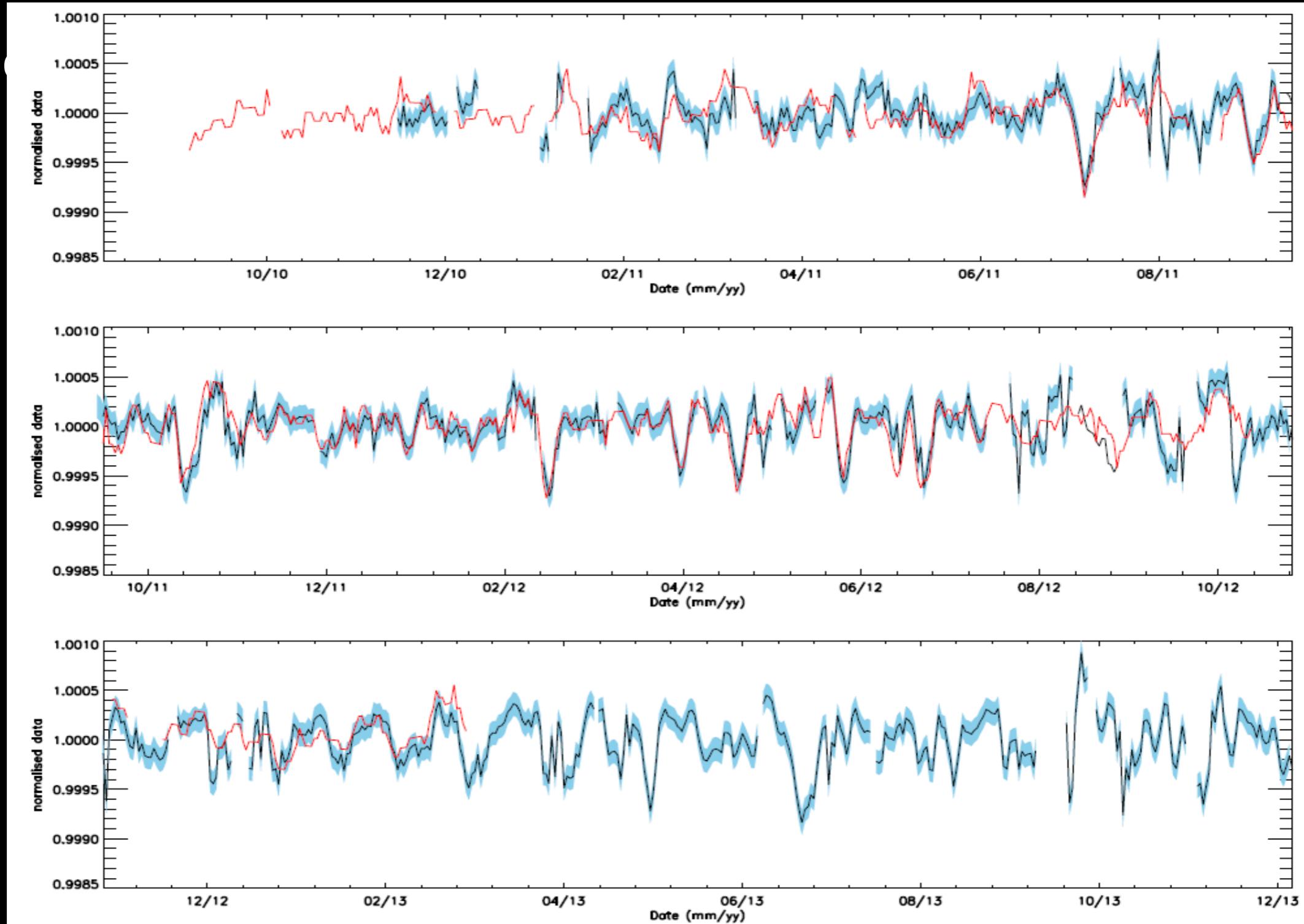
	N	R ( $R^2$ )	$\sigma$ (in ppm)
535 nm	740	0.63 (0.4)	205
607 nm	559	0.58 (0.34)	242
782 nm	717	0.61 (0.37)	120

# Validation of the PREMOS data



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- ✓ Solar variability in the visible and near-IR (27-day modulation)



# PREMOS: first conclusions



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- ✓ PREMOS was a success !
- ✓ Degradation correction for the UV channels: long term variability (2010-2014), with the rising phase of the 24 solar cycle
- ✓ PREMOS data are in excellent agreement with SORCE/SOLSTICE
- ✓ PREMOS data are in good agreement with SORCE/SIM in the visible and near-IR, where the variability is very (tiny) small
- ✓ PREMOS data (level 3) will be soon available through the SOLID and MEDOC databases.
- ✓ PREMOS Data are useful for modeling the solar irradiance variability

# Conclusions



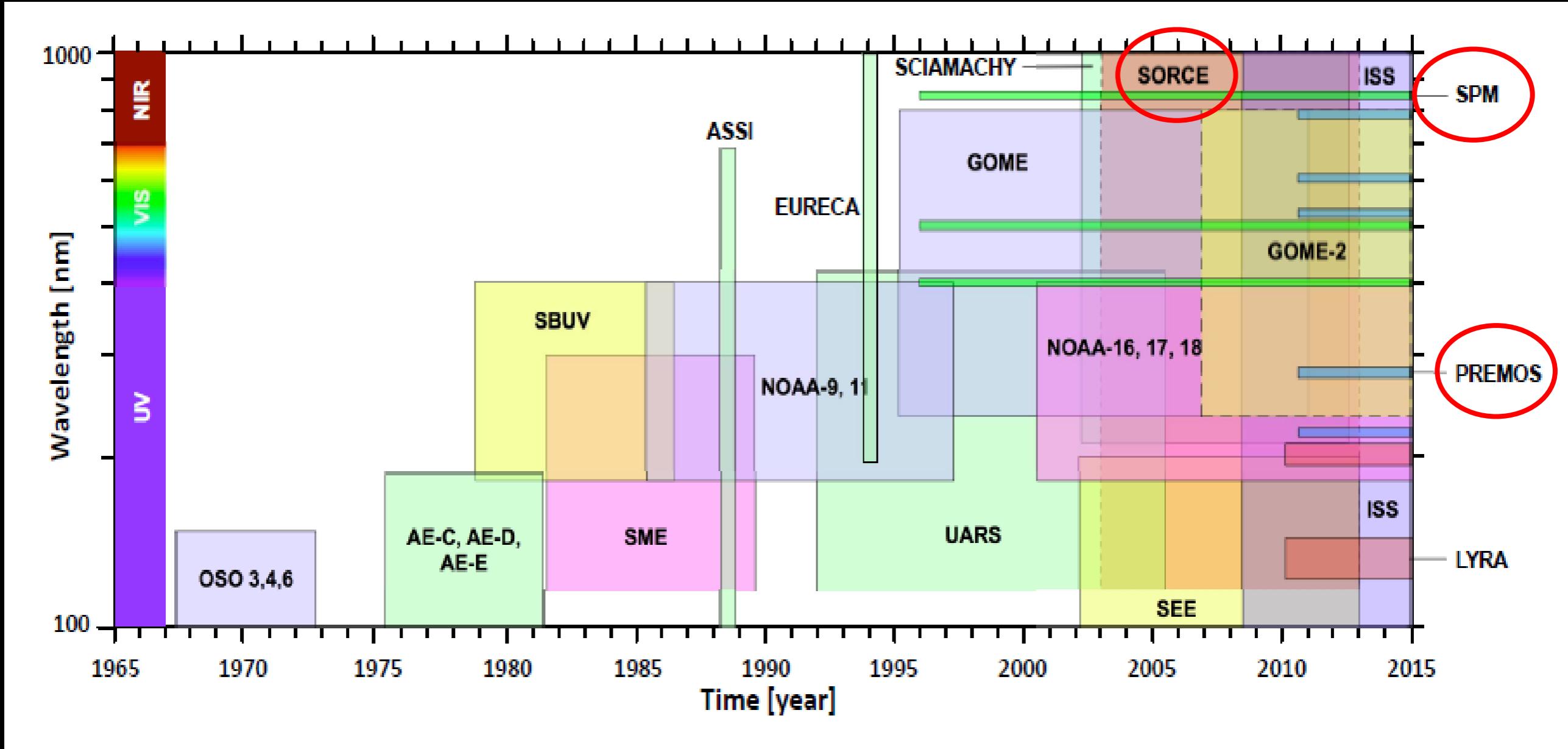
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- ✓ COSIR model: Irradiance variability is induced by the evolution of surface magnetism
- ✓ 5-th component model is enough to reproduce a very large fraction of the variability
- ✓ Comparison between the COSIR model and observations with SPM and PREMOS are in very good agreement !
- ✓ SORCE observations suffer from a high disturbance by instrumental noise. Good correlation however in the UV (< 250 nm and 500-800 nm)
- ✓ COSIR synthetic variations are the better estimate for SSI variability when noise of the observations is as large as solar variations
- ✓ The COSIR Model should now be tested for long term trends

# SSI variability observations



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Ermolli et al, 2013

# SSI variability observations



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SPM/VIRGO



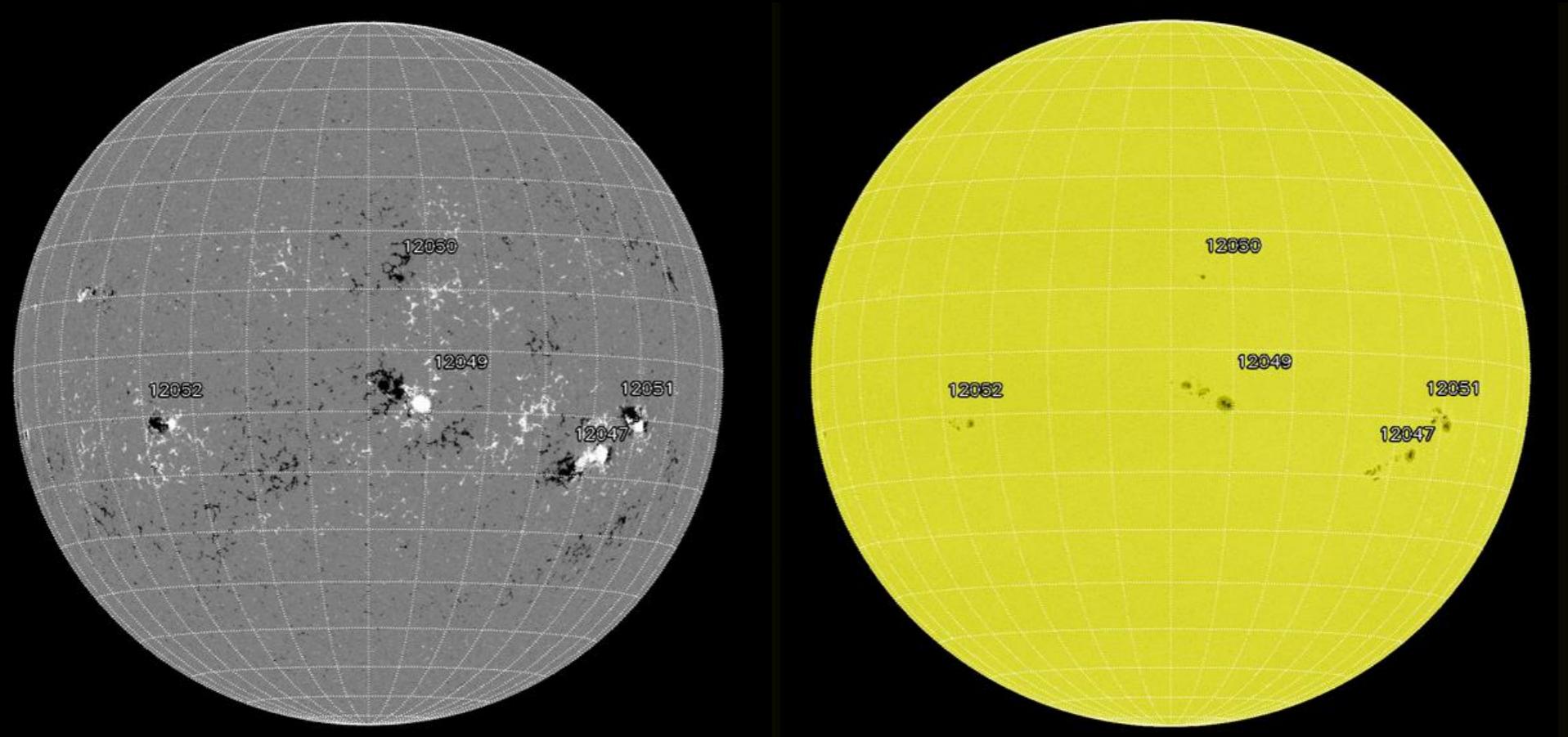
- ✓ Interference filter radiometer with 3 channels centered at 862nm, 500nm and 402nm (R,G,B); FWHM bandwidths 5nm
- ✓ SPM-B: exposed rarely for solar spectral irradiance measurements ( $\approx$  3 days), gives us access to rotational modulations

# Solar Modeling



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Main assumption: Variations in the solar irradiance are directly related to the evolution of surface magnetic flux



Sunspot umbrae (U)  
Sunspot Penumbrae (P)  
Faculae (F)  
Network (AN)  
Quiet Sun (QS)

$$\begin{aligned} F(\lambda, t) = & \sum_k (\alpha_{QS}(\mu_k, t) I_{QS}(\lambda, \mu_k) + \alpha_U(\mu_k, t) I_U(\lambda, \mu_k) \\ & + \alpha_P(\mu_k, t) I_P(\lambda, \mu_k) + \alpha_{AN}(\mu_k, t) I_{AN}(\lambda, \mu_k) \\ & + \alpha_F(\mu_k, t) I_F(\lambda, \mu_k)), \end{aligned}$$

# Solar Modeling



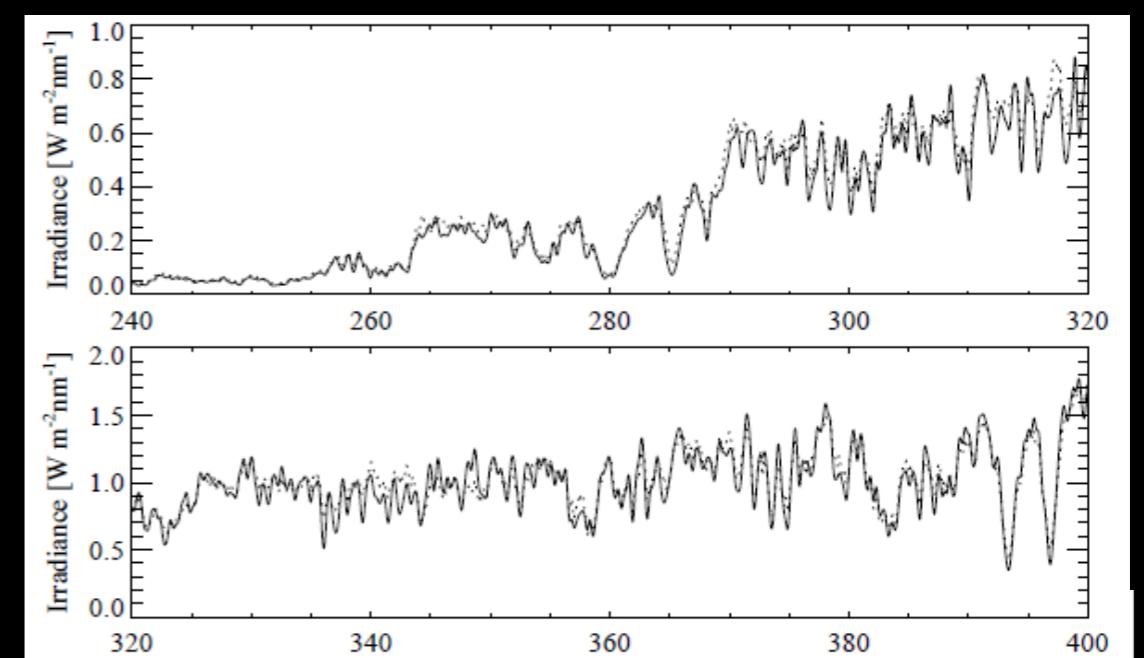
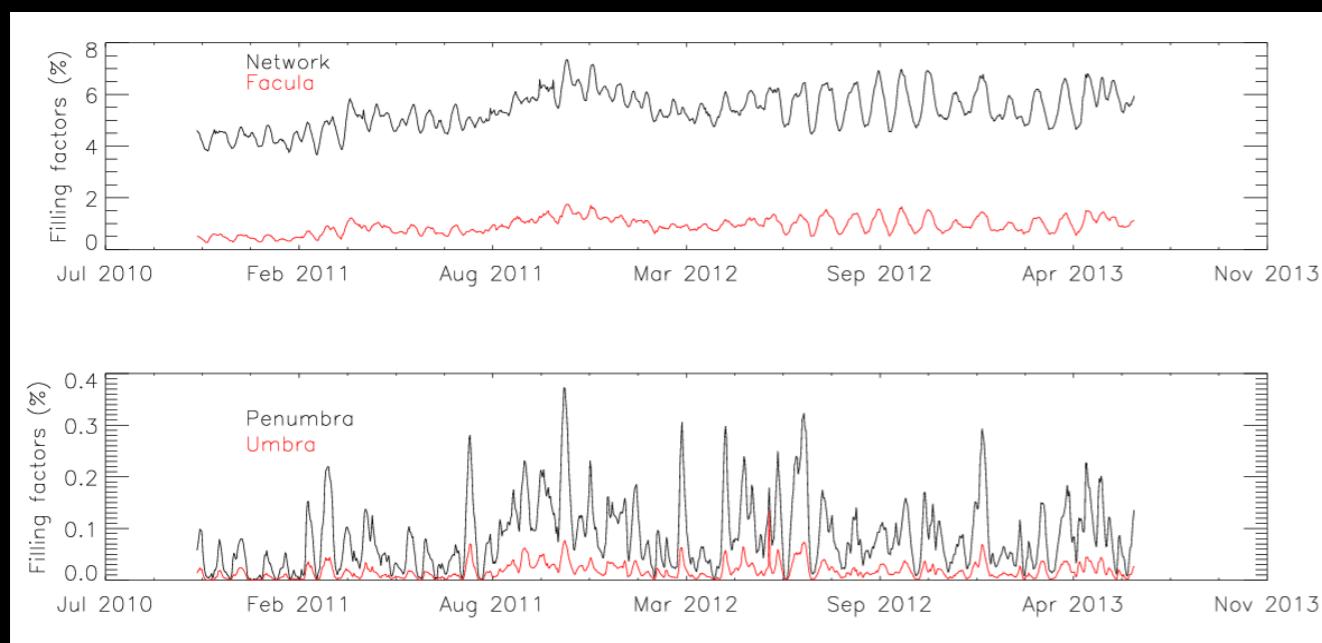
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## COSIR: Code Of Solar Irradiance Reconstruction

$$F(\lambda, t) = \sum_k \omega^k (\alpha_{QS}^k(t) I_{QS}(\lambda, \mu_k) + \alpha_U^k(t) I_U(\lambda, \mu_k) + \alpha_P^k(t) I_P(\lambda, \mu_k) + \alpha_{AN}^k(t) I_{AN}(\lambda, \mu_k) + \alpha_F^k(t) I_F(\lambda, \mu_k)).$$

Filling factors deduced from HMI/SDO images (Yeo et al., 2013)

COSI code for the radiance for each magnetic feature (Shapiro et al., 2010)

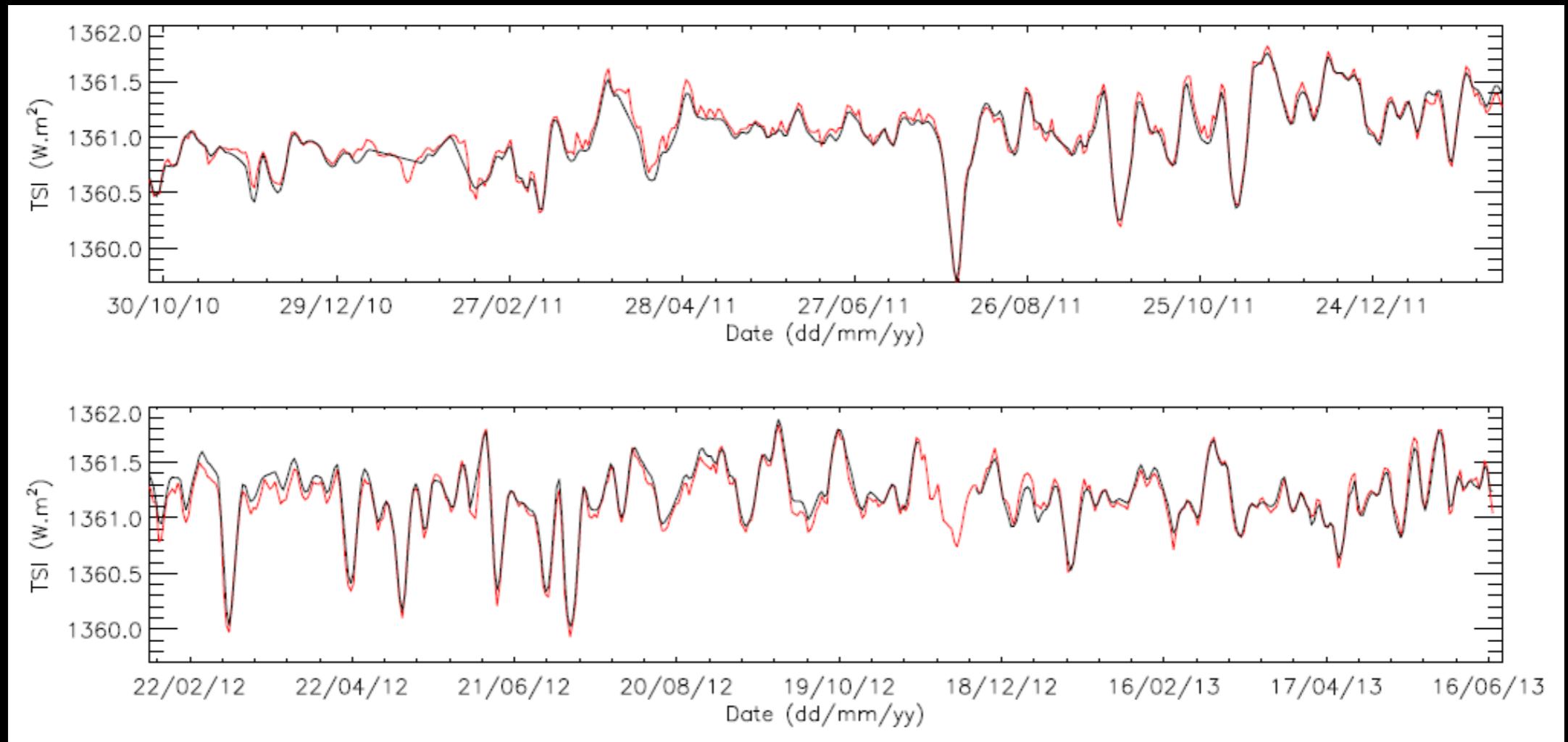


# Magnetic Threshold



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Free parameter  $B_{\text{thr}}$ : magnetic threshold between faculae and network regions



Relative error minimization  
on TSI measurements to  
obtain  $B_{\text{thr}}$

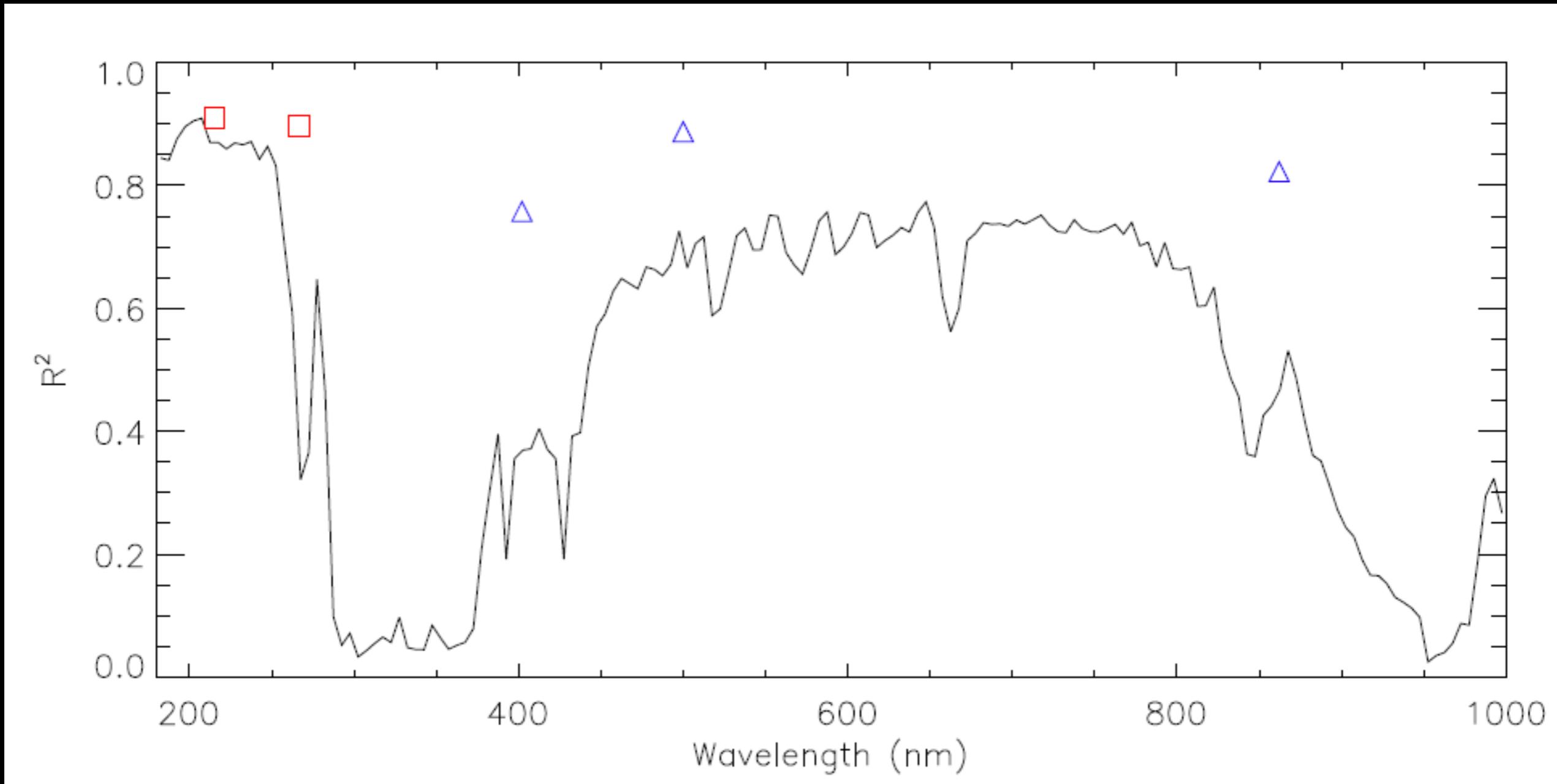
$$\epsilon(\lambda) = \frac{\langle |I_{\text{measured}}(\lambda, t) - I_{\text{fitted}}(\lambda, t)| \rangle_t}{\sigma_\lambda}$$

$$B_{\text{thr}} = 165 \text{ G}$$

# Comparison between SORCE and COSIR



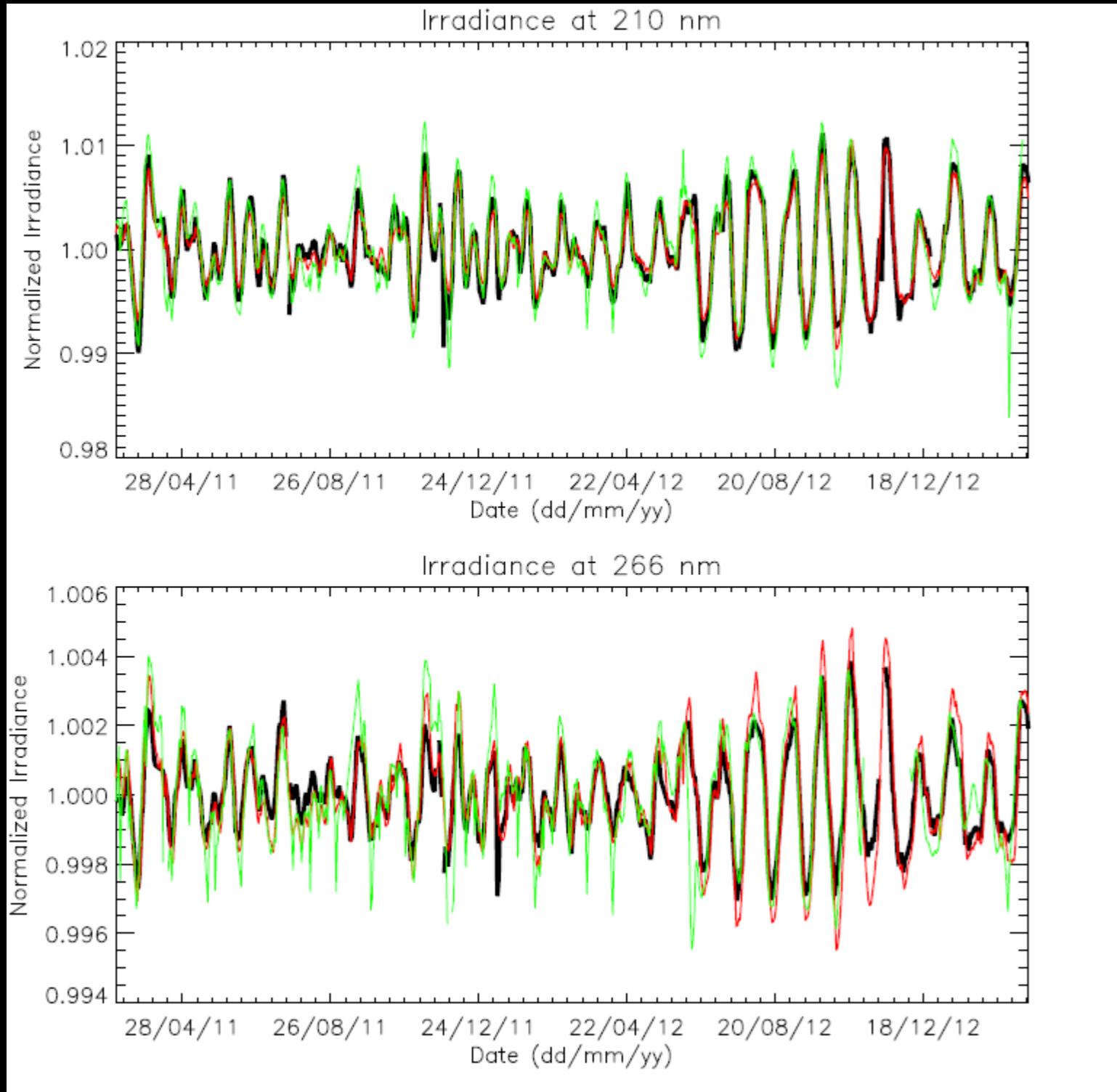
BELGISH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO



# Comparison in the UV



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

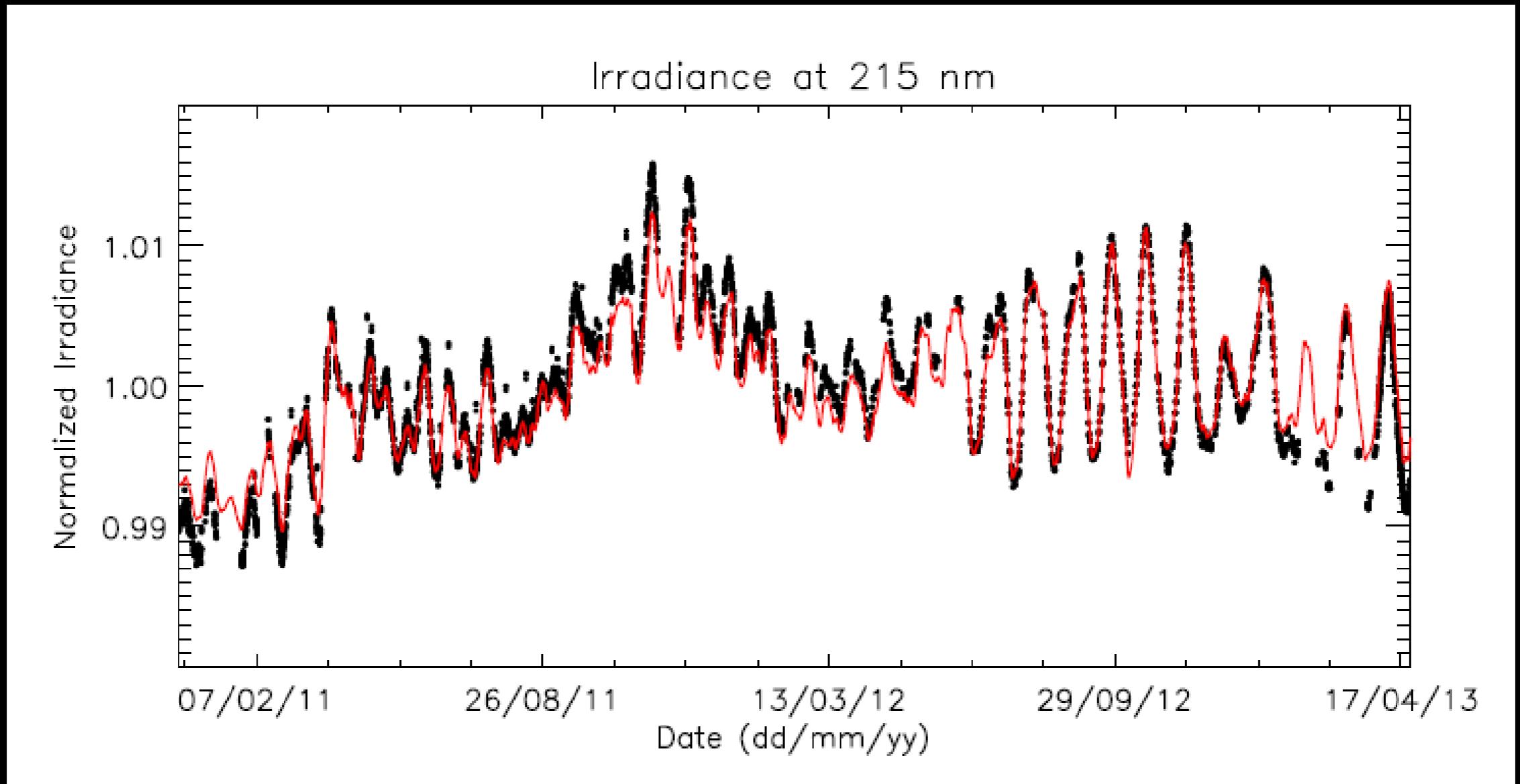


- ✓ Good correlation between model and PREMOS ( $R^2=0.91$   $R^2=0.89$ )
- ✓ Less good correlation with SORCE ( $R^2=0.89$ ,  $R^2=0.60$ )
- ✓ SORCE data quite noisy at 266 nm, for which reasons ?

# Variability over PREMOS lifetime mission

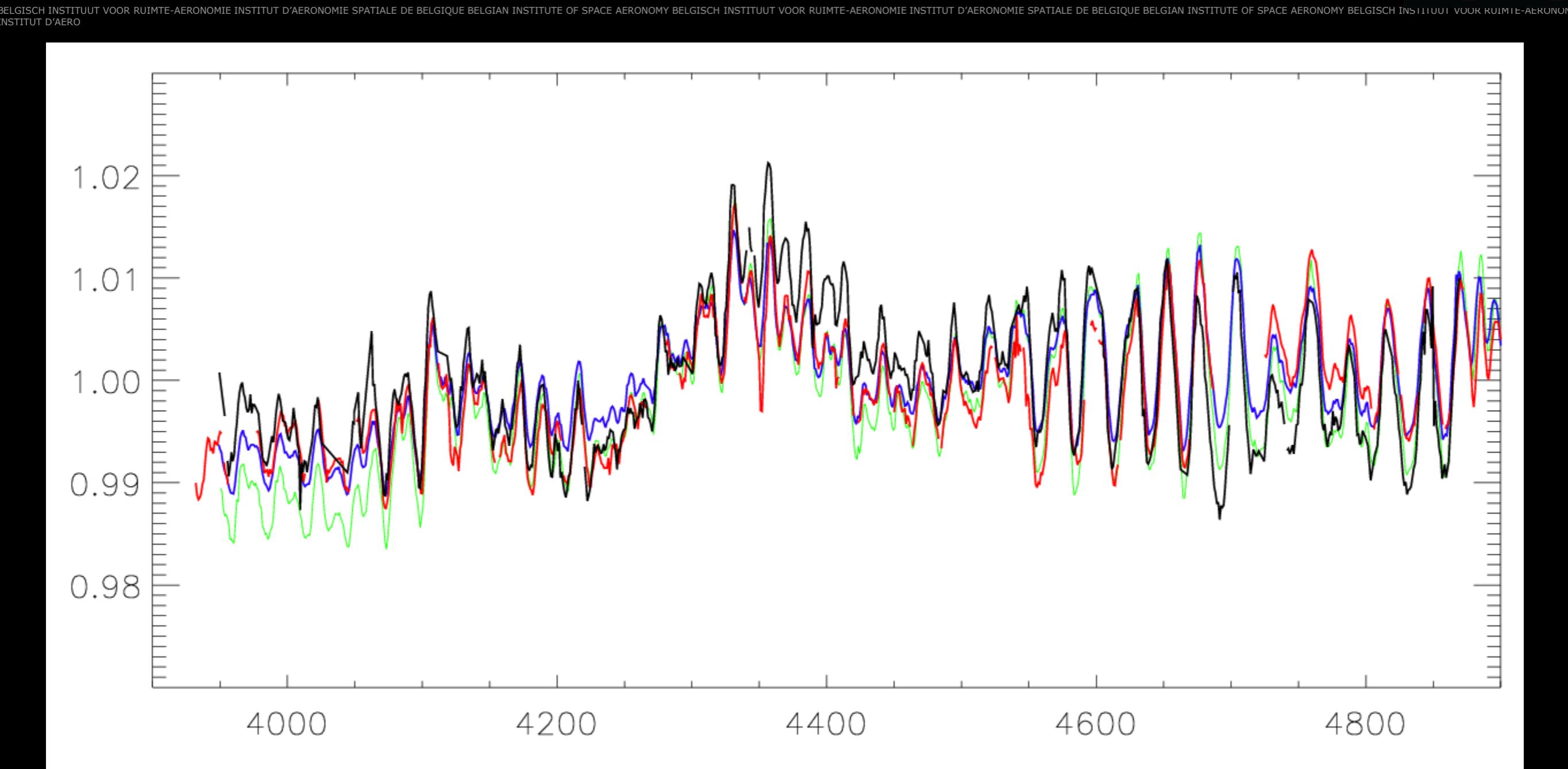


BELGISCHE INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCHE INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCHE INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO



- ✓ Excellent correlation between COSIR and PREMOS observations ( $R^2=0.94$ )
- ✓ More than 94% of the variability is reconstructed over more than 2 years

# Variability over PREMOS lifetime mission

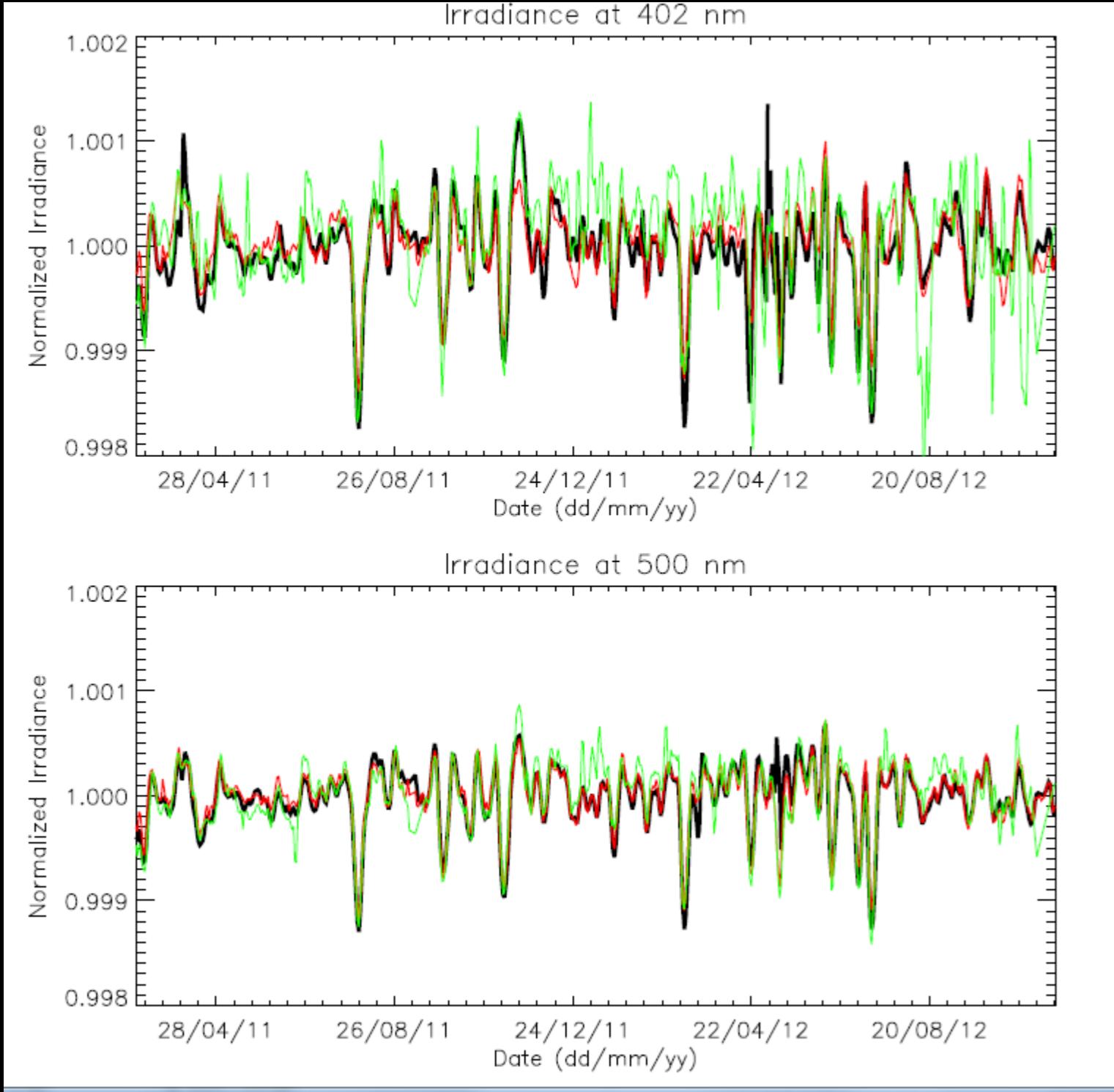


Color code: Black for PREMOS, red for SORCE, Blue for COSIR and green for SATIRE  
All models and observational data are in excellent agreement !

# Comparison in the visible



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

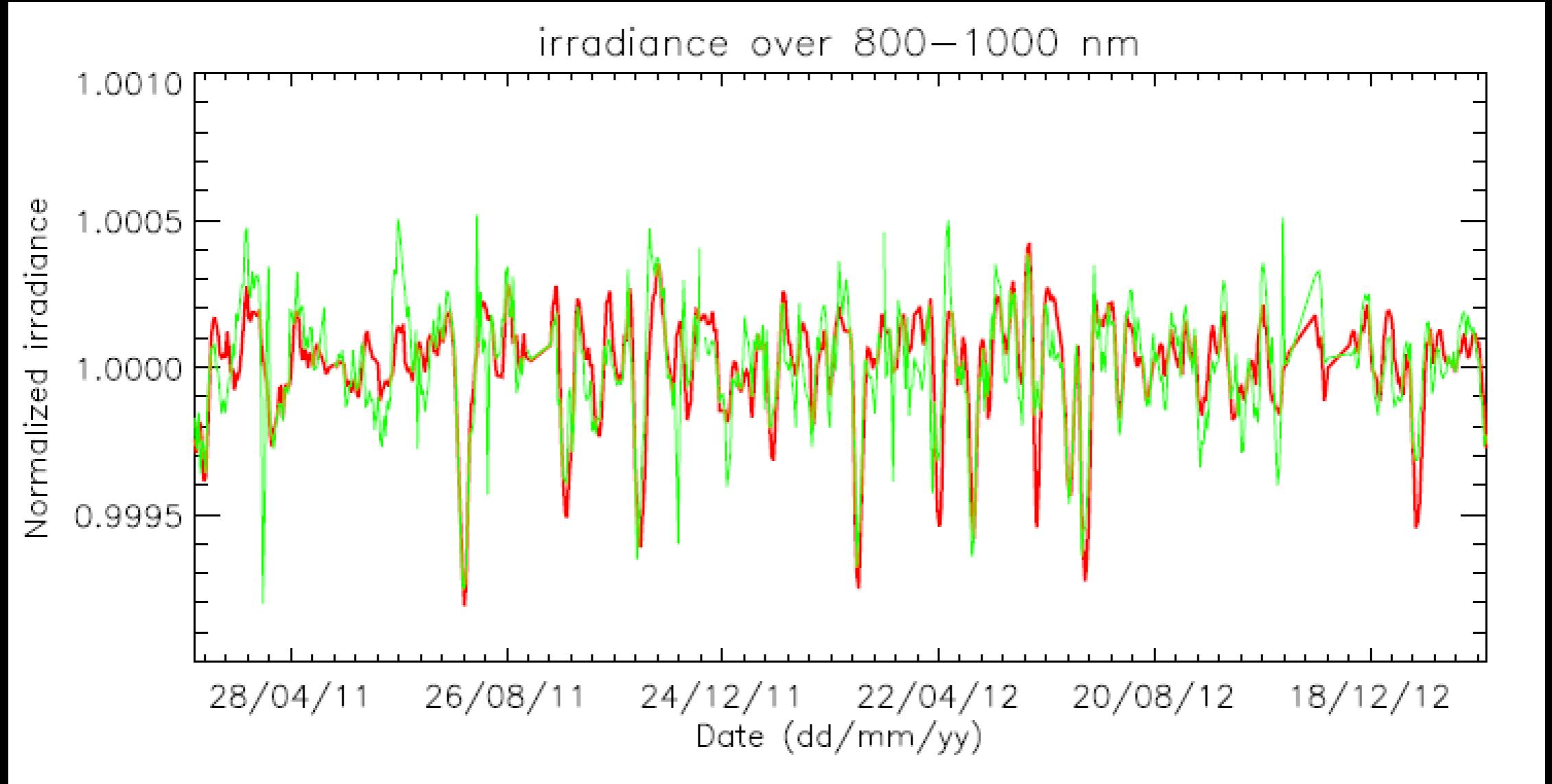


- ✓ Good correlation between model and SPM ( $R^2=0.76$ ,  $R^2=0.87$ )
- ✓ Less good correlation with SORCE ( $R^2=0.44$ ,  $R^2=0.77$ )
- ✓ Facular brightening and sunspots darkening effects underestimated at 400 nm

# Comparison in the infrared



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

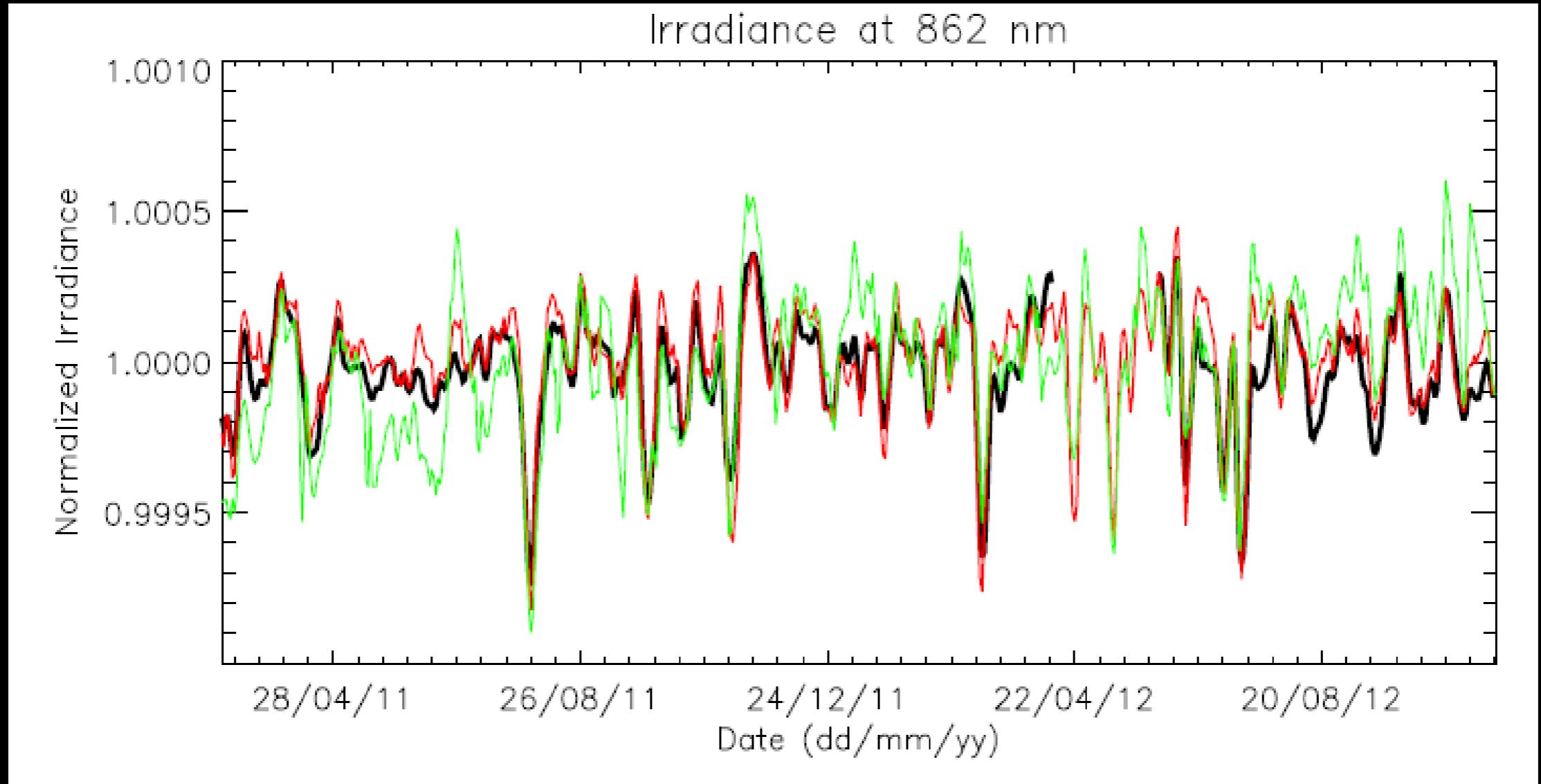


- ✓ Bad correlation between model and SORCE observations ( $R^2=0.55$ )
- ✓ Sunspots darkening effects well estimated
- ✓ But SORCE/SIM observations very noisy in the infrared

# Comparison in the infrared



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



- ✓ Good correlation between model and SPM observations ( $R^2=0.82$ )
- ✓ But SORCE/SIM observations very noisy in the infrared ( $R^2=0.46$ )



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Thank you for your attention!