Solar Spectral Irradiance observations from the PICARD/PREMOS radiometer

Gaël Cessateur, Werner Schmutz, A. Shapiro
and the PREMOS team
The Solar Spectrum

- 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

![Graph showing the solar 11-year cycle and Total Solar Irradiance (TSI). The graph displays data from 1980 to 2015, with peaks and troughs indicating solar activity changes over time. The graph includes markers for ACRIM I, ACRIM II, and VIRGO, along with TSI values in Wm^-2.](image)
SSI variability observations with PREMOS

PREMOS/PICARD

- September 2010 – April 2014
- Strong degradation...
- Long term variability for the UV
- Rotational modulation visible and IR
PREMOS paper, soon submitted!

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

G. Cessateur\textsuperscript{1,2}, W. Schmutz\textsuperscript{1}, C. Wehrli\textsuperscript{1}, J. Gröbner\textsuperscript{1}, M. Haberreiter\textsuperscript{1}, M. Kretzschmar\textsuperscript{3}, M. Schöll\textsuperscript{1}, A. Shapiro\textsuperscript{4}, G. Thuillier\textsuperscript{5}, W. Finsterle\textsuperscript{1}, N. Fox\textsuperscript{6}, J.-F. Hochederz\textsuperscript{5,7}, S. Koller\textsuperscript{1}, M. Meftahi\textsuperscript{5}, P. Meindl\textsuperscript{8}, S. Nyeki\textsuperscript{1}, D. Pfiiffer\textsuperscript{1}, H. Roth\textsuperscript{1}, M. Rouze\textsuperscript{9}, M. Spescha\textsuperscript{1}, R. Tagirov\textsuperscript{1}, L. Werner\textsuperscript{8}, J.-U. Wyss\textsuperscript{1}

\textsuperscript{1} Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center (PMOD/WRC), Dorfstrasse 33, 7260 Davos Dorf, Switzerland
\textsuperscript{2} Space Physics Division, Belgian Institute for Space Aeronomy (BIRA-IASB), Ringlaan 3, B-1180 Brussels, Belgium
\textsuperscript{3} Laboratoire de Physique et de Chimie de l’Environnement et de l’Espace (LPC2E), UMR 6115 CNRS and University of Orléans, 3a av. de la recherche scientifique, 45071 Orléans,
\textsuperscript{4} Max-Planck-Institut für Sonnensystemforschung, 37077 Göttingen, Germany
\textsuperscript{5} Laboratoire Atmospheres, Milieux, Observations Spatiales (LATMOS), CNRS - Université Paris VI & Université de Versailles Saint-Quentin-en-Yvelines, 78280 Guyancourt, France
\textsuperscript{6} National Physical Laboratory (NPL), Hampton Road, Teddington, Middlesex, TW11 0LW, UK
\textsuperscript{7} Observatoire Royal de Belgique Koninklijke Sterrenwacht van België (ORB-KSB), Ringlaan 3, B-1180 Brussels, Belgium
\textsuperscript{8} Physikalisch-Technische Bundesanstalt (PTB), Berlin, Germany
\textsuperscript{9} French Space Agency (CNES), 18, Avenue Edouard Belin, 31401 Toulouse CEDEX 9 - France
PREMOS First light

<table>
<thead>
<tr>
<th>PREMOS</th>
<th>210 nm</th>
<th>215 nm</th>
<th>266 nm</th>
<th>535.69 nm</th>
<th>607.16 nm</th>
<th>782.26 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head A</td>
<td>2.49 \times 10^{-2} (-14%)</td>
<td>0.198 (+5.8%)</td>
<td>1.856 (-4.8%)</td>
<td>1.138 (-4.6%)</td>
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</tr>
<tr>
<td>Head C</td>
<td>2.33 \times 10^{-2} (-20%)</td>
<td>0.189 (+1.2%)</td>
<td>1.883 (-1.7%)</td>
<td>1.121 (-3.7%)</td>
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<td></td>
</tr>
<tr>
<td>Head B (Channels 1 &amp; 2)</td>
<td>2.64 \times 10^{-2} (-28.6%)</td>
<td>1.806 (+4.3%)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Head B (Channels 3 &amp; 4)</td>
<td>3.05 \times 10^{-2} (-17.5%)</td>
<td>1.824 (+5.3%)</td>
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</tbody>
</table>

- 210 and 215 nm: Irradiance decrease compared to Sorce (-15\%): degradation prior to the launch which was already forseen (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

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

- **Head C**
  - 210 and 266 nm: 20 and 14%
  - 535 nm: ~ -1.1%
  - 782 nm: ~ +1.5%
Degradation problems PREMOS

- **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?

- Helioseismology

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

- Venus transit
What can we do with Head C?

- 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

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

- 607 nm
  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

✓ Solar variability in the UV

Cross comparison between 210, 215 and 266 nm

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)
Validation of the PREMOS data

- Solar variability in the UV

Comparison with SORCE/SOLSTICE data sets (level 3, version 12)
Validation of the PREMOS data

✓ Solar variability in the UV

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

- 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
Validation of the PREMOS data

- 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

\[
\sigma_{\text{PREMOS}} = \sqrt{\sigma^2_{\text{Total}} - \sigma^2_{\text{SIM}}}
\]

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>N</th>
<th>R (R^2)</th>
<th>( \sigma ) (in ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>535</td>
<td>740</td>
<td>0.63 (0.4)</td>
<td>205</td>
</tr>
<tr>
<td>607</td>
<td>559</td>
<td>0.58 (0.34)</td>
<td>242</td>
</tr>
<tr>
<td>782</td>
<td>717</td>
<td>0.61 (0.37)</td>
<td>120</td>
</tr>
</tbody>
</table>
Validation of the PREMOS data

☑️ Solar variability in the visible and near-IR (27-day modulation)
PREMOS: first conclusions

✓ 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

✓ 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

Ermolli et al, 2013
SSI variability observations

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 (~3 days), gives us access to rotational modulations
Solar Modeling

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

\[
F(\lambda, t) = \sum_k (\alpha_{QS}(\mu_k, t)I_{QS}(\lambda, \mu_k) + \alpha_U(\mu_k, t)I_U(\lambda, \mu_k) + \alpha_P(\mu_k, t)I_P(\lambda, \mu_k) + \alpha_{AN}(\mu_k, t)I_{AN}(\lambda, \mu_k) + \alpha_F(\mu_k, t)I_F(\lambda, \mu_k)),
\]

Sunspot umbrae (U)
Sunspot Penumbrae (P)
Faculae (F)
Network (AN)
Quiet Sun (QS)
COSIR: Code Of Solar Irradiance Reconstruction

\[
F(\lambda, t) = \sum_k \omega^k \left( a_{QS}^k(t) I_{QS}(\lambda, \mu_k) + a_U^k(t) I_U(\lambda, \mu_k)ight.
+ a_P^k(t) I_P(\lambda, \mu_k) + a_N^k(t) I_N(\lambda, \mu_k)
+ a_F^k(t) I_F(\lambda, \mu_k) \right)
\]

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

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
Comparison in the UV

- 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

- 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

- 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

✓ 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

- Good correlation between model and SPM observations ($R^2=0.82$)
- But SORCE/SIM observations very noisy in the infrared ($R^2=0.46$)
Thank you for your attention!