Overview of the SORCE Mission and its Future

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Talk Outline

• Overview of SORCE Measurements
  – Total Solar Irradiance (TSI)
  – Solar Spectral Irradiance (SSI)

• Status of SORCE Instruments
  – TIM, SIM, SOLSTICE, XPS

• Future of SORCE
  – Extended mission opportunity for 2008-2012
Solar Spectral Irradiance (SSI)

- Spectral irradiance is the solar radiance integrated over the solar disk
  - Sometimes called the full-disk radiation
  - Energy units of $\text{W} / \text{m}^2 / \text{nm}$
  - Often normalized to a distance of 1.0 AU

$$
\text{TSI} = \int_0^\infty SSI \cdot d\lambda
$$

<table>
<thead>
<tr>
<th>Range</th>
<th>Min - Max (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard X-ray</td>
<td>0.001-0.1</td>
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<tr>
<td>XUV</td>
<td>0.1 - 10</td>
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<tr>
<td>EUV</td>
<td>10 - 120</td>
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<tr>
<td>FUV</td>
<td>120 - 200</td>
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<tr>
<td>MUV</td>
<td>200 - 300</td>
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<tr>
<td>NUV</td>
<td>300 - 400</td>
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<tr>
<td>Visible</td>
<td>400 - 760</td>
</tr>
<tr>
<td>NIR</td>
<td>760 - 1400</td>
</tr>
<tr>
<td>MIR</td>
<td>1400 - 3000</td>
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<tr>
<td>FIR</td>
<td>3000 nm - 1 mm</td>
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</tbody>
</table>
The Earth's Radiation and Energy Balance

Satellite measurements required to accurately measure the top of the atmosphere (TOA) solar irradiance.

Note this solar energy is averaged over Earth’s surface

\[ E = I \frac{\pi R_E^2}{4 \pi R_E^2} = \frac{1}{4} I \]

For \( I = 1368 \frac{W}{m^2} \)

\[ \therefore E = 342 \frac{W}{m^2} \]
Absorption Has Wavelength Dependence

- Solar radiation drives heating, chemistry, and dynamics in the atmosphere.
  - Atomic and molecular species dominate absorption in the ultraviolet
  - Water (clouds) and aerosols dominate the absorption and scattering in the visible and near infrared

from P. Pilewskie (Solar Physics, 2005)
Estimated Climate Forcings: 1850 to present

From Hansen et al. (Proc. Nat. Acad. Sci., 1998)
SOPOE Measures TSI and SSI

SOPOE spacecraft was launched on 25 January 2003, and its mission is through 2008.

http://lasp.colorado.edu/sorce/

<table>
<thead>
<tr>
<th>Instrument</th>
<th>λ Range (nm)</th>
<th>Δλ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIM: Total Irradiance Monitor</td>
<td>TSI (all)</td>
<td>-</td>
</tr>
<tr>
<td>SIM: Spectral Irradiance Monitor</td>
<td>200-2700</td>
<td>1-30</td>
</tr>
<tr>
<td>SOLSTICE: Solar Stellar Irradiance Comparison Experiment</td>
<td>115-320</td>
<td>0.1</td>
</tr>
<tr>
<td>XPS: XUV Photometer System</td>
<td>0.1-27, 121.6</td>
<td>7-10</td>
</tr>
<tr>
<td>SORCE Instrument</td>
<td>Instrument Scientists</td>
<td>Public Data Products</td>
</tr>
<tr>
<td>------------------</td>
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<tr>
<td>TIM</td>
<td>Greg Kopp</td>
<td>TSI</td>
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<tr>
<td></td>
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<td>TIM L3 Version 7</td>
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<tr>
<td>SIM</td>
<td>Jerry Harder, Juan Fontenla,</td>
<td>SSI: 200-2700 nm</td>
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<tr>
<td></td>
<td>Erik Richard, Peter Pilewskie</td>
<td>SIM L2 Version 10</td>
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<td>SORCE L3 Version 10</td>
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<tr>
<td>SOLSTICE</td>
<td>Bill McClintock, Marty Snow</td>
<td>SSI: 115-320 nm</td>
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<td>SOLSTICE L2 Version 6</td>
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<td>SORCE L3 Version 10</td>
</tr>
<tr>
<td>XPS</td>
<td>Tom Woods</td>
<td>SSI: 0-27 nm</td>
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<td></td>
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<td>XPS L3 Version 7</td>
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<td>XPS L4 Version 7</td>
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</tbody>
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http://lasp.colorado.edu/sorce/
TIM Status

- TIM is functioning nominally
  - Degradation of primary cavity with solar exposure remains small
    - Degradation is corrected in released data
- Data are updated daily with releases 7 days after acquisition

SORCE/TIM TSI record is very stable
No problems
No anomalies

Greg Kopp’s TIM talk
TSI at 1361 W/m²
TSI variability

TIM Total Solar Irradiance (TSI)
TIM Primary Cavity Degradation Following An Exponential

TIM Inter-Cavity Comparisons

B - A Offset
C - A Offset
B - D Offset

Cavity Offsets [ppm]

09 Jun 2003
26 Dec 2003
13 Jul 2004
29 Jan 2005
17 Aug 2005
05 Mar 2006

Updated 26-Apr-2006

TIM Cavity B Degradation

(B-A) Relative Variation
Cavity B Est. Degradation

B-A Initial Offset = 246.62 ppm
Net Degradation to Date = 121.22 ppm
Ultimate Degradation = 142.58 ppm
Degradation Time = 605.79 days
RSS Differences = 8.724 ppm

B-A Relative Variation [ppm]

TIM Degradation 120 ppm

Cumulative Cavity Exposure Times

Cavity A (x20)
Cavity B
Cavity C (x50)
Cavity D (x50)

Net Exposure Times
B (99.5%): 393.4 days
A (1.0%): 6.2 days
C (0.5%): 41.6 hours
D (0.2%): 20.7 hours

Days of Solar Exposure

09 Jun 2003
26 Dec 2003
13 Jul 2004
29 Jan 2005
17 Aug 2005
05 Mar 2006

Updated 23-Aug-2006
SIM Status

SIM Irradiance Spectrum April 21, 2004

- SIM is operating nominally
  - Degradation is strongest in the UV and minimal in the IR
    - SIM A / SIM B redundant channel calibrations and direct prism transmission measurements
- Several improvements for SIM data products are in progress
  - Refined degradation corrections, ESR calibration at NIST, extension of SSI into IR

SORCE/SIM’s newer data products have improved corrections for degradation, wavelength shift, and radiometric calibrations

No problems
No anomalies

Jerry Harder’s SIM talk
NUV-Vis-NIR validation
SSI variability
SIM has Prism and Diode Degradation

- Degradation correction has a wavelength and time component
  - $\kappa(\lambda)$
    - From comparisons of ESR and diodes
    - UV has largest degradation
  - $C(t)$
    - From prism transmission experiments and SIM-A and SIM-B comparisons

- ESR calibrates diodes
  - Measure weekly 60 discrete wavelengths from 250-2700 nm
  - ESR detector does not degrade
  - Degradation rate is from a fit to the ratio of diode to ESR
  - VIS2 diode has largest degradation
SOLSTICE Status

- SOLSTICE is functioning nominally except for SOLSTICE-A entrance slit mechanism
  - SOLSTICE-A: making only solar measurements since January 2006
  - SOLSTICE-B: no anomalies, so performing both solar and stellar observations
    - Transfer SOL-B stellar calibrations to SOL-A using concurrent solar measurements

SORCE/SOLSTICE has little degradation

SOLSTICE-A had entrance slit anomaly in January 2006

Bill McClintock’s talk
FUV-MUV validation
UV variability
Marty Snow’s talk
Mg II C/W index

Solar Spectrum from SORCE SOLSTICE

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Irradiance (W/m²/nm)</th>
</tr>
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<tbody>
<tr>
<td>150</td>
<td>10^{-14}</td>
</tr>
<tr>
<td>200</td>
<td>10^{-13}</td>
</tr>
<tr>
<td>250</td>
<td>10^{-12}</td>
</tr>
<tr>
<td>300</td>
<td>10^{-11}</td>
</tr>
</tbody>
</table>

FUV: 115-180 nm  \( \Delta \lambda = 0.1 \) nm
MUV: 180-320 nm  \( \Delta \lambda = 0.1 \) nm
SOLSTICE Has Little Degradation

Changes in the mean irradiance from an ensemble of stars is due to changes in the instrument.

Degradation rates are less than 3% per year in both channels.

Current Data Availability (Version 6):

FUV data have degradation correction from launch to present time.

MUV data are available from launch to January 2006, but with no degradation correction yet applied.
SOLSTICE-A Entrance Slit Mechanism Anomaly

- SOLSTICE A had an anomaly with its entrance slit mechanism. On 27 January 2006, the mechanism to switch from the entrance stellar aperture to the solar aperture did not respond to a command. Luckily, the operational plan had additional commands within a few minutes, and it finally did move. We have opted to leave SOLSTICE-A in solar mode for duration of mission due to reliability concerns for this mechanism.
- SOLSTICE B has no anomalies.

Both instruments continue to take daily solar measurements. The degradation of SOLSTICE A is tracked by cross calibration with SOLSTICE B. The aperture is displaced from its previous position, which has slightly changed the FOV correction. The effect on the data is being studied and will be applied in next data product version.
XPS Status

- XPS detectors are functioning nominally, but limit the filter wheel movement since its anomaly in December 2005
- Improved algorithm for deriving spectral irradiance in the 0.1-40 nm range (new XPS Level 4 data product)
  - Daily components: quiet Sun and active region
  - Flare component: also uses 1-min GOES X-rays for solar plasma temperature

SORCE/XPS has no degradation for XUV channels

XPS had filter wheel anomaly in Dec. 2005

Factor of 10 variation in XUV over SORCE mission
New Operations for XPS

- Filter wheel anomaly on 9 December 2005
  - Filter wheel (FW) stopped moving for 41 hours, but FW is functional now

- New operations for XPS
  - Leave filter wheel in position 6 to maximize spectral coverage
    - Lose 17-23 nm band and H I Lyman-α (121.6 nm) daily measurement from XPS
    - But still have Lyman-α measurements from SOLSTICE
  - Low risk solution for extended mission
  - Perform a calibration once a month by moving FW to position 4

Suspect debri in the planetary gears of the motor
New XPS Algorithm Has Less Flare Variability

Flare variations are much less and agree better now with other measurements.

Spectral shape is very different - much less irradiance in the 4-14 nm range.

But NOT measured spectral shape! (Chianti spectral model for 0-40 nm)
Solar Irradiance Satellite Programs at LASP University of Colorado at Boulder

<table>
<thead>
<tr>
<th>Satellite Instrument</th>
<th>Years Operating</th>
<th>Wavelength Range</th>
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</thead>
<tbody>
<tr>
<td>Past</td>
<td></td>
<td></td>
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<tr>
<td>Rockets</td>
<td>1950-2004</td>
<td>0-320 nm</td>
</tr>
<tr>
<td>SME</td>
<td>1981-1989</td>
<td>115-320 nm</td>
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<tr>
<td>UARS SOLSTICE</td>
<td>1991-2005</td>
<td>119-420 nm</td>
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<tr>
<td>TIMED SEE</td>
<td>2001-2010</td>
<td>27-195 nm</td>
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<tr>
<td>EGS</td>
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<td>0-27 nm</td>
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<tr>
<td>XPS</td>
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<tr>
<td>SORCE</td>
<td>2003-2008</td>
<td>TSI</td>
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<tr>
<td>TIM</td>
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<td>200-2000 nm</td>
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<tr>
<td>SIM</td>
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<td>115-320 nm</td>
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<tr>
<td>XPS</td>
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<tr>
<td>Glory TIM</td>
<td>2007-2013</td>
<td>TSI</td>
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<tr>
<td>NPOESS</td>
<td>??? 2013-2023</td>
<td>TSI</td>
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<tr>
<td>TIM</td>
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<td>200-2000 nm</td>
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<td>SIM</td>
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</table>

Current

Future

data web site
lasp.colorado.edu/lisird/
SORCE Future

• SORCE mission is currently funded for operations until January 2008

• NASA Earth science mission senior review in spring 2007 will consider a 4-year extension for SORCE: 2008-2012
  – Critical for continuity of TSI and SSI records
  – Measure full range of solar cycle conditions
    • 2003: near solar maximum (SC-23 max in 2000-2002)
    • 2006-2007: solar minimum
    • 2010-2012: expected to be SC-24 maximum
Satellite measurements of TSI have been made since 1978.

Current TSI measurements are from SOHO VIRGO, ACRIMSAT, and SORCE TIM.

from G. Kopp
Continuity Also Important for SSI Measurements

- Same issues for spectral time series in combining data sets
  - Calibration differences
  - Instrument degradation issues
- Factor of 2 difference is sometimes found in the UV range

Example is composite Lyman-α (121.6 nm) time series from T. Woods (JGR, 2000)
• The photospheric visible radiation (500 nm) is usually out of phase with chromospheric UV radiation (Mg II).

• Occasionally, the visible and UV radiations are in phase when sunspots do not dominate the variability.
• Variability ratio of 2004/280 to 2004/268 from SORCE is in good agreement with REF2002 (Woods & Rottman, 2002) solar cycle variability shortward of 420 nm.
• Variability ratio of 2004/280 to 2004/268 from SORCE is in good agreement with REF2002 (Woods & Rottman, 2002) solar cycle variability shortward of 420 nm.

• Variability in the near ultraviolet, visible, and near infrared is consistent with variability predicted by changing the mean (disk-averaged) photospheric temperature by 0.4 K.
Summary

• SORCE spacecraft and instruments are healthy
  – All instruments are making daily, routine measurements

• Couple anomalies during 3\(\frac{1}{2}\) years of operations
  – XPS filter wheel anomaly in December 2005
    • Limited filter wheel operations as low risk for extended mission for XPS solar observations
  – SOLSTICE-A entrance slit anomaly in January 2006
    • Limit SOL-A to solar observations
    • Transfer SOL-B stellar calibrations to SOL-A

• Extended SORCE mission needed for continuity of TSI and SSI time series
  – Opportunity to extend SORCE to 2012
  – Glory, PICARD launch in 2008 - new TSI measurements
  – NOAA funding cut for NPOESS TSIS (TSI + SSI)