Reference Solar Spectra for Earth Science Research

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Session 2: Solar Spectral Irradiance (SSI) Measurements

Session	**SORCE Top Ten Achievements** (*EOS*, **25**, Jan-Feb 2013)
Wed. S4	1. New TSI Level
Tue. S2	2. New SSI Record for 115-2400 nm range
Tue. S2	3. New SSI Reference Spectra
Tue. S1 & Wed. S3	4. Use of SORCE SSI & TSI in Climate Modeling
Fri. S6	5. Next-generation, highly-accurate Radiometers
Thur. S5	6. Extension of NOAA Mg II Solar Proxy
Tue. S2	7. Large Flare Measurements in SSI and TSI
Wed. S4 & Thur. S5	8. Advanced Models of the TSI and SSI
	9. Venus and Mercury Transit Observations
	10. Improved Calibrations for Stars and Lunar Reflectance

Key Papers for Top Ten #3 & #7

- WHI 2008 Reference Spectra for solar cycle minimum

GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L01101, doi:10.1029/2008GL036373, 2009

Solar Irradiance Reference Spectra (SIRS) for the 2008 Whole Heliosphere Interval (WHI)

Thomas N. Woods,[1] Phillip C. Chamberlin,[1] Jerald W. Harder,[1] Rachel A. Hock,[1] Martin Snow,[1] Francis G. Eparvier,[1] Juan Fontenla,[1] William E. McClintock,[1] and Erik C. Richard[1]

- Variations of large flares during Halloween Storm 2003

GEOPHYSICAL RESEARCH LETTERS, VOL. 31, L10802, doi:10.1029/2004GL019571, 2004

Solar irradiance variability during the October 2003 solar storm period

Thomas N. Woods, Francis G. Eparvier, Juan Fontenla, Jerald Harder, Greg Kopp, William E. McClintock, Gary Rottman, Byron Smiley, and Martin Snow

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, A10S14, doi:10.1029/2005JA011507, 2006

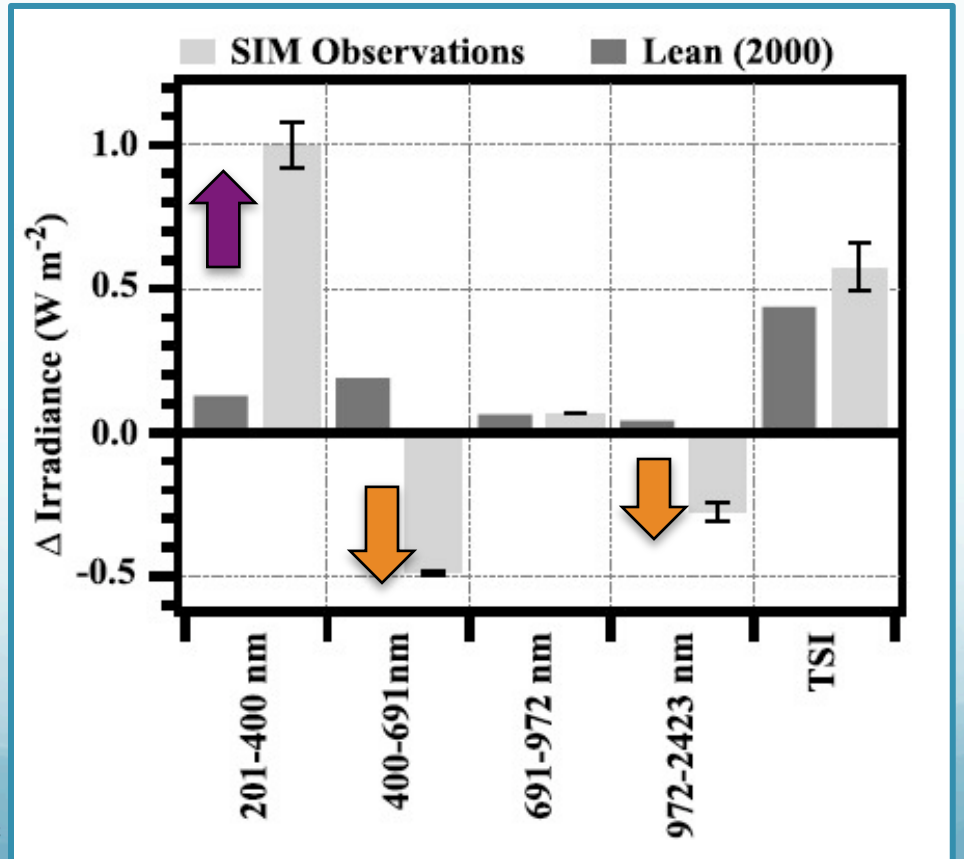
Contributions of the solar ultraviolet irradiance to the total solar irradiance during large flares

Thomas N. Woods,[1] Greg Kopp,[1] and Phillip C. Chamberlin[1]

Summary of those Findings and Recent Progress

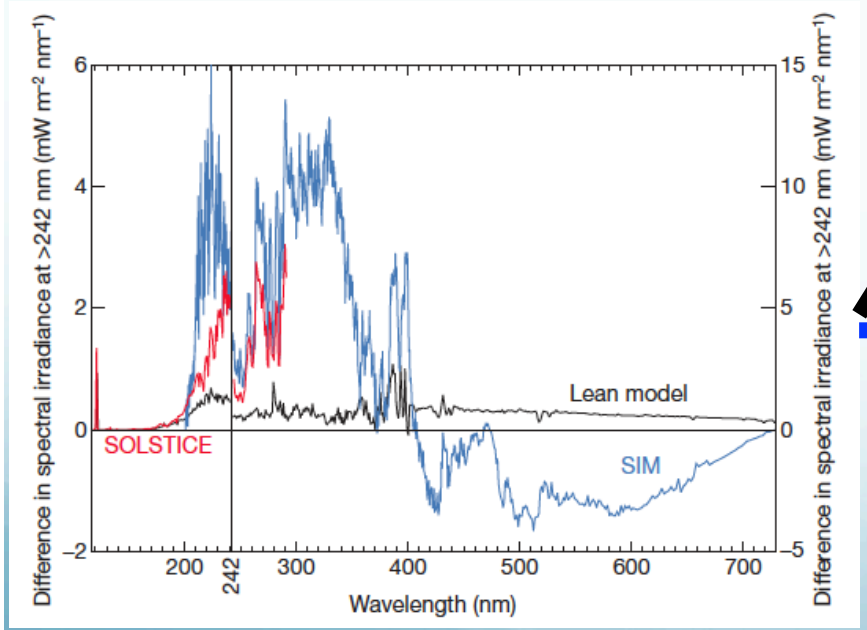
Solar Reference Spectra Importance

- Solar irradiance reference spectra are often used for modeling the solar forcing on Earth's atmosphere and for climate change.
- New SORCE results on solar cycle variability (Harder *et al.*, *GRL*, 2009) indicate **out-of-phase variations** for visible and near infrared and **larger ultraviolet variations**.



Solar Reference Spectra Importance

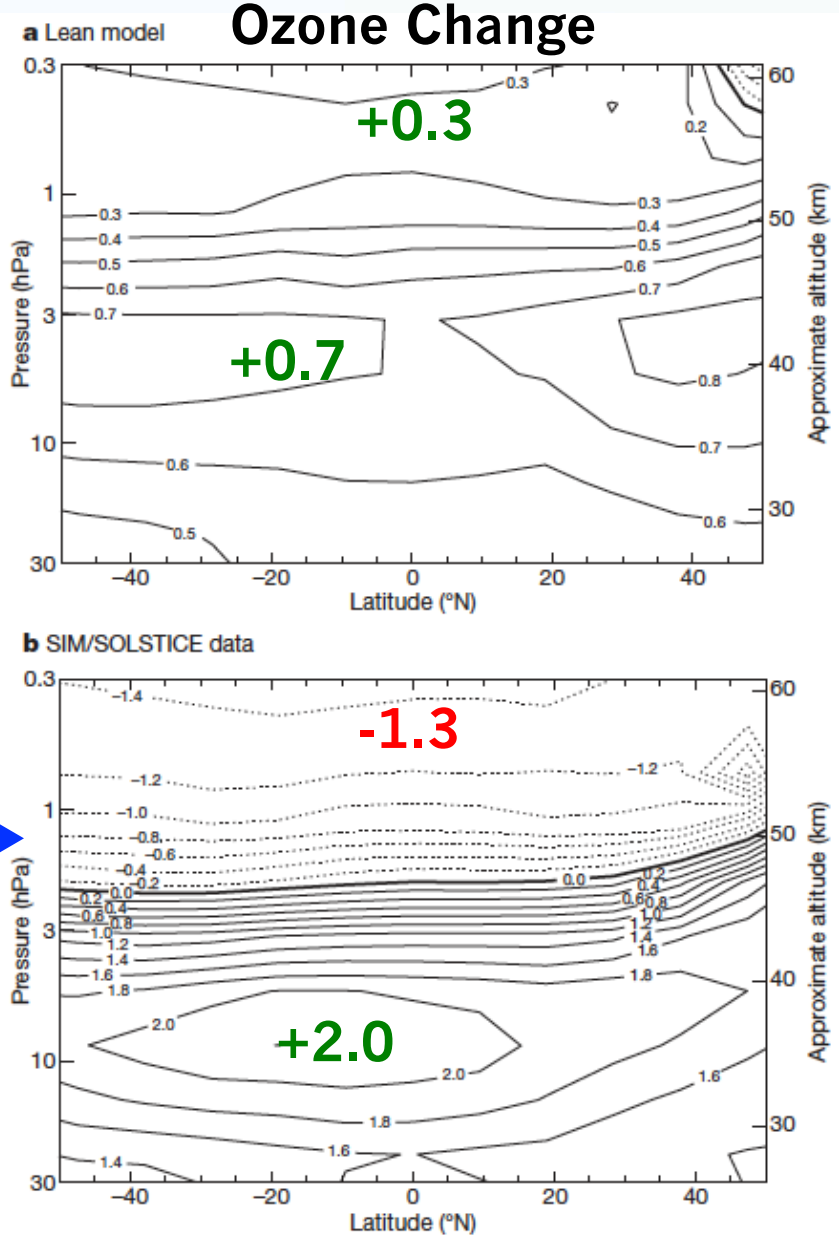
- These SORCE solar cycle variability results used in Earth atmospheric models give a new view of how solar variations might cause solar-induced changes in Earth's atmosphere.
  - More on this topic in Sessions 1, 2, and 3



NRLSSI

SIM

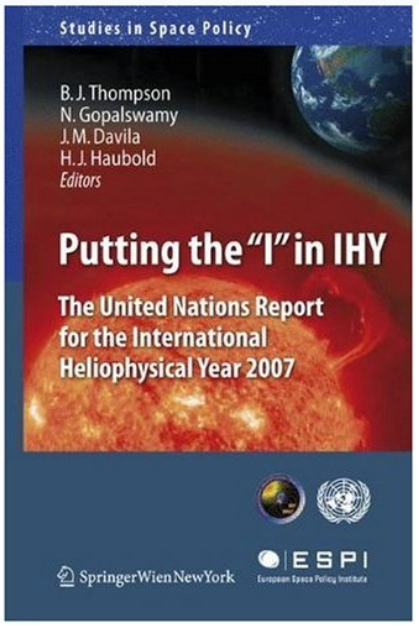
Ozone Change



Figures are from Haigh *et al.*, *Nature*, 2010

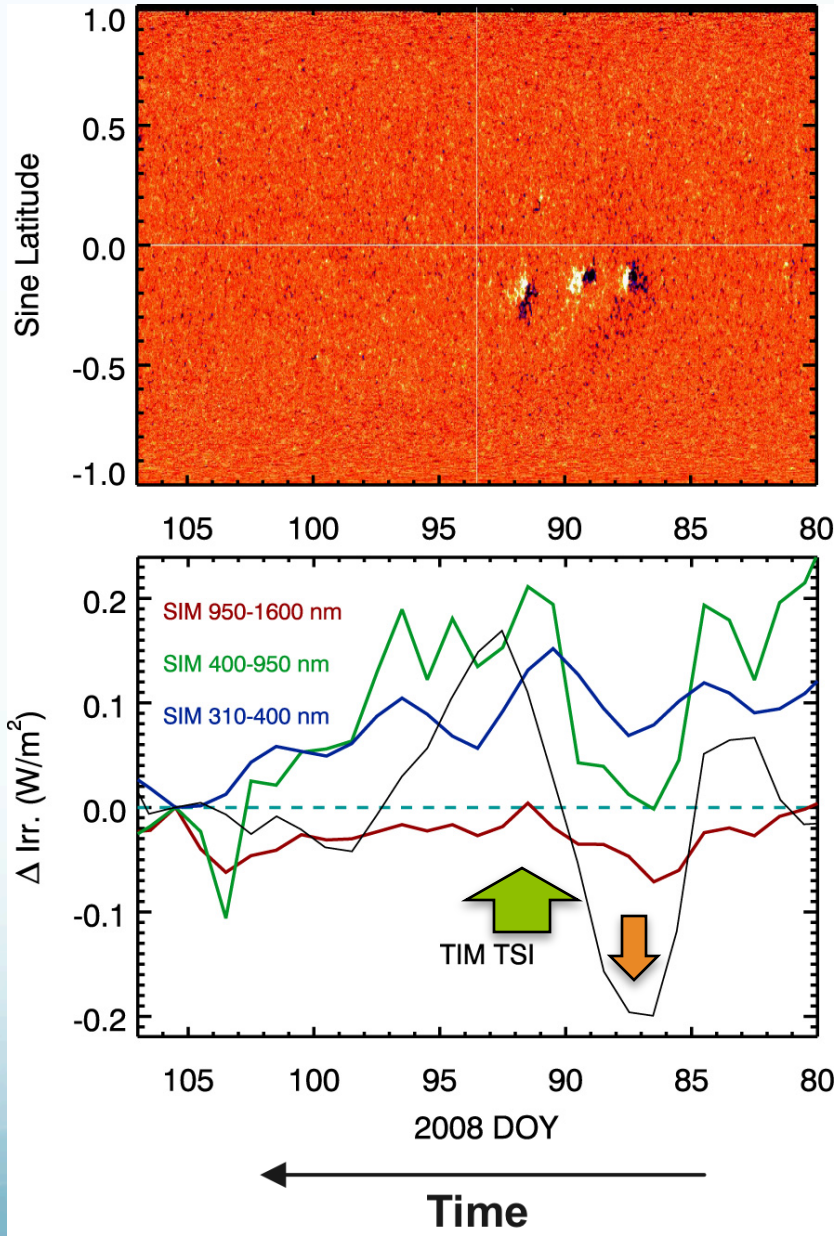
What is WHI 2008?

- The IHY 2007 Whole Heliosphere Interval (WHI) is international campaign to study the Sun and its influence on Earth during the solar Carrington Rotation 2068
  - CR 2068 = 20 March 2008 to 16 April 2008
- Web site: http://ihy2007.org
- IHY 2007 Report: http://www.amazon.com/Putting-IHY-Nations-International-Heliophysical/dp/3211991794



Solar Activity During WHI 2008

- March-April 2008 is during solar cycle 23/24 minimum
- Time runs backward for Carrington Rotation images
- Sunspot darkening has valley on DOY 86 = 25 March
- Bright faculae have peaks on DOY 90-92 = 29-31 March (dependent on wavelength)



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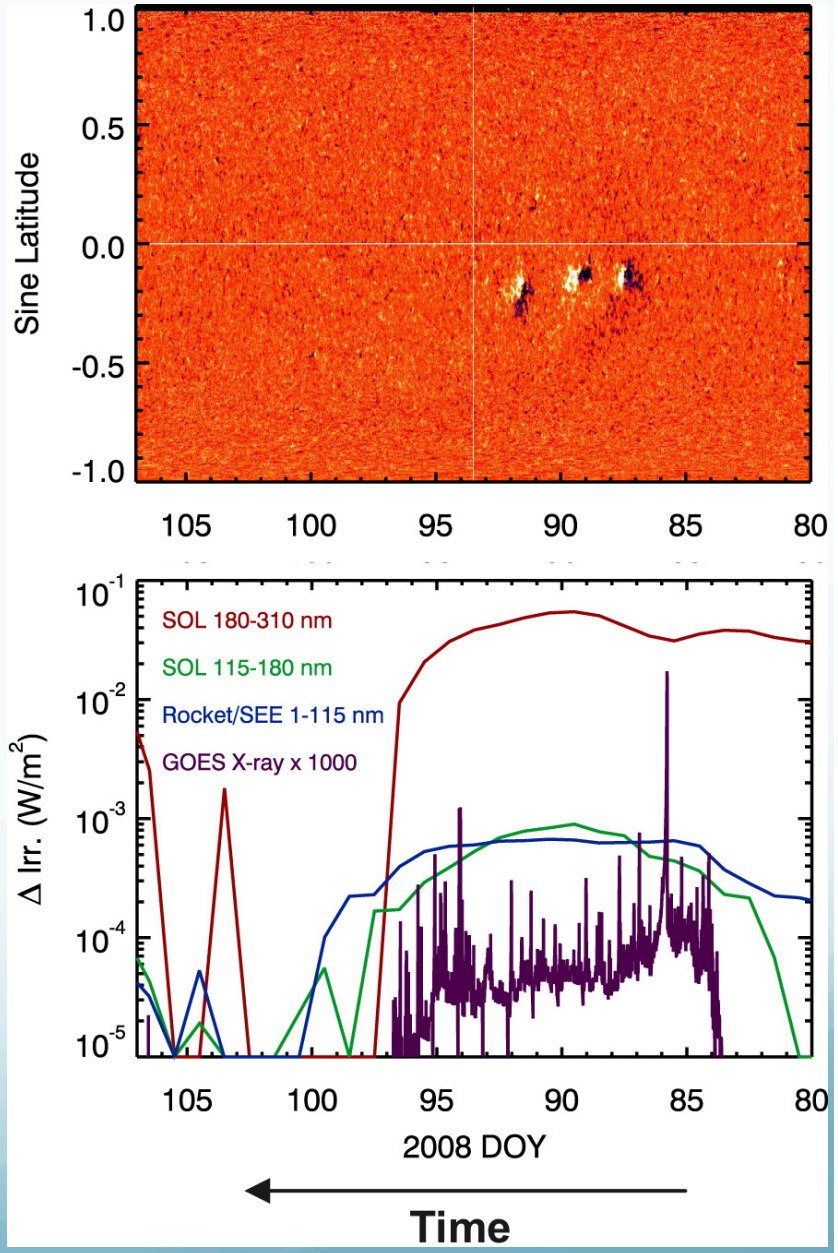
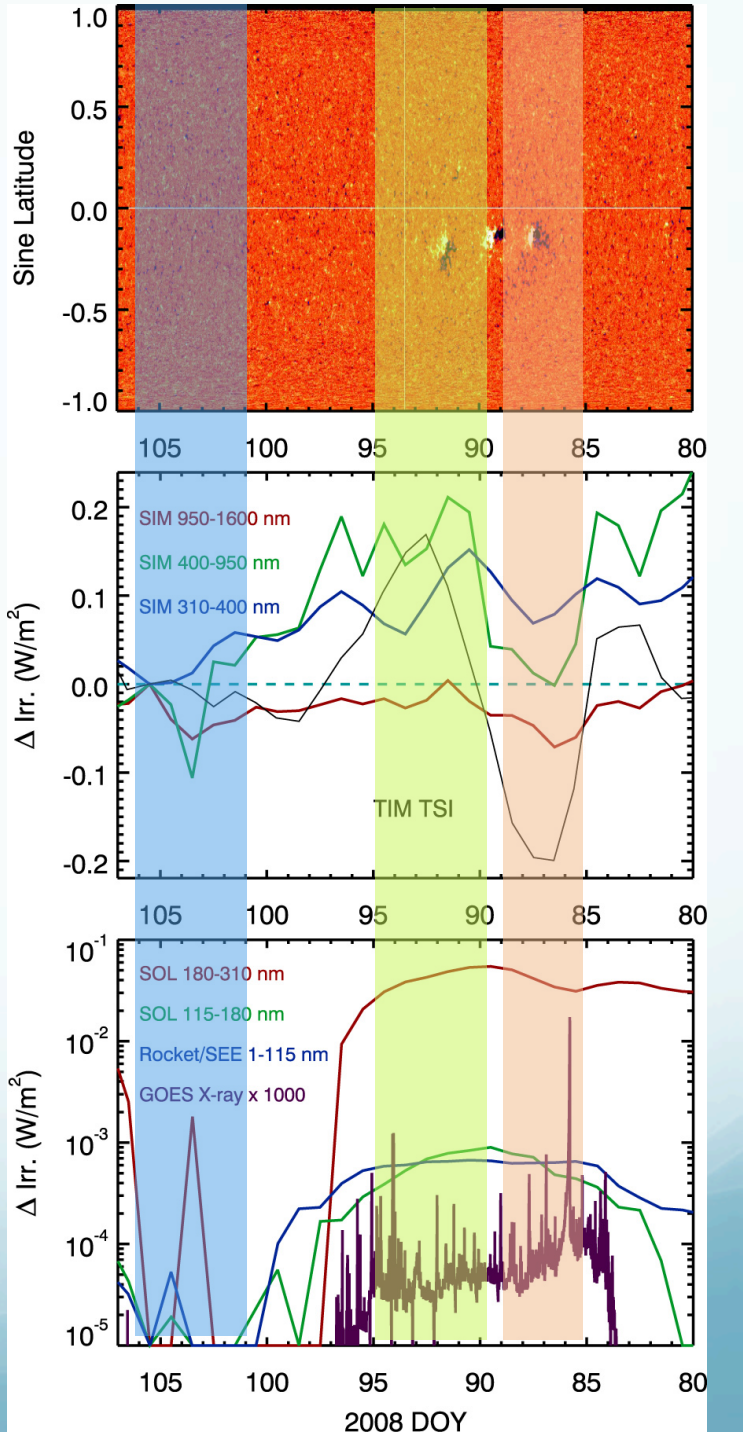


- UV valley is very broad between DOY 98 and 105 = 6 April and 13 April
- UV peak is very broad between DOY 82 and 96 = 21 March and 4 April

Measurements for Reference Spectra

- EUV range 0.1-116 nm
  - SDO EVE calibration rocket
  - TIMED SEE
- FUV-MUV range 116-310 nm
  - SORCE SOLSTICE
- NUV-Visible-NIR 310-2400 nm
  - SORCE SIM
- Reference Spectra Days
  - Solar Cycle Minimum = DOY 101-107
  - Sunspot Darkening = DOY 85-89
  - Faculae Brightening = DOY 90-95



WHI 2008 Reference Spectrum

- The EUV, FUV-MUV, and NUV-VIS-NIR ranges are shown for the solar cycle minimum reference spectrum
  - Average over 10-16 April 2008

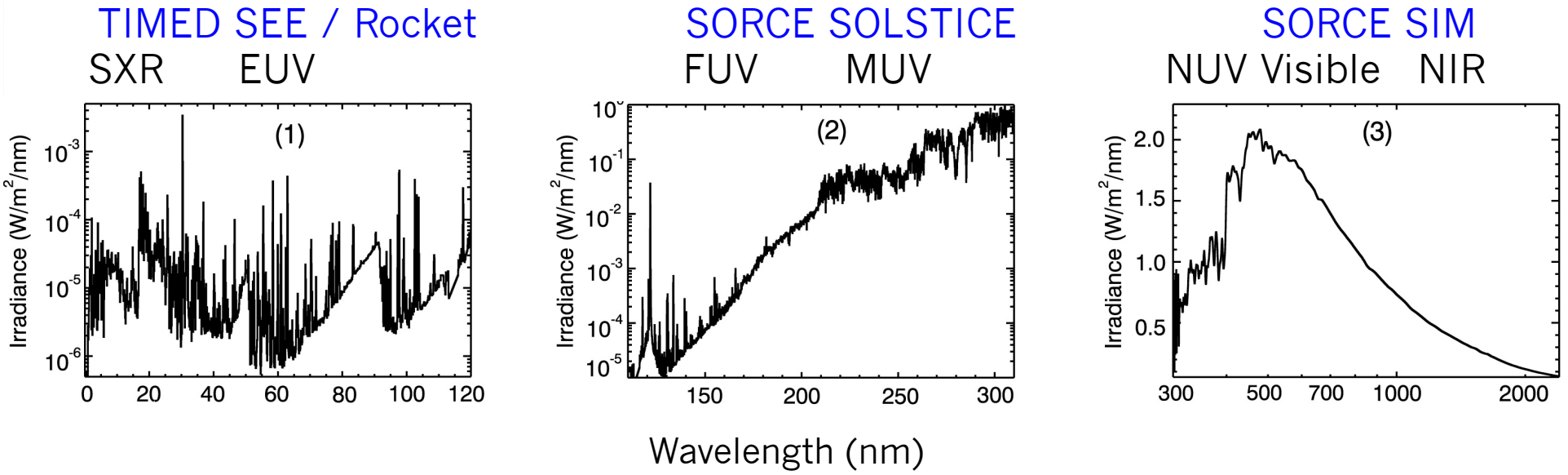


Figure 2 from Woods *et al.*, *GRL*, 2009

WHI 2008 Solar Variability

- Solar cycle variability ratio is

  [Average 25-29 March] / [Average 10-16 April] – 1.0

Red is negative variability (darkening)

Black is positive variability (brightening)

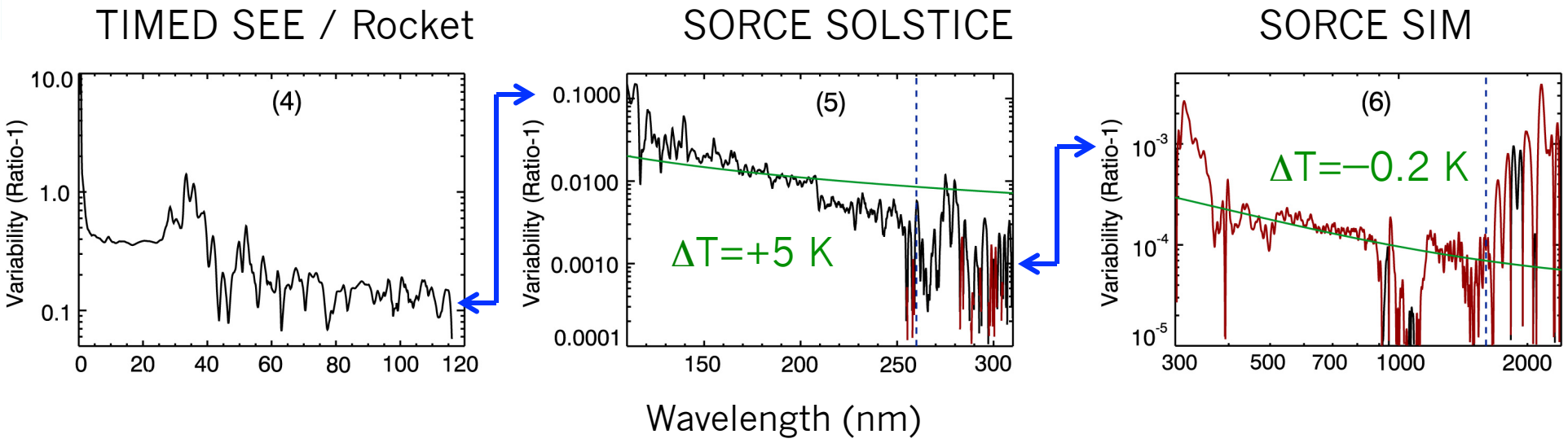


Figure 2 from Woods *et al.*, *GRL*, 2009

Comparison of WHI to ATLAS

- WHI 2008 is during solar cycle minimum (SSN=2, F10.7=69)
- ATLAS-3 [Thuillier *et al.*, 2004] is from 11 Nov 1994, which is during low solar activity (SSN=20, F10.7=77.5)
  - *Expect WHI/ATLAS ratio to be less than 1.0 for most wavelengths*
- Red error bar is ratio uncertainty that includes both WHI and ATLAS uncertainties

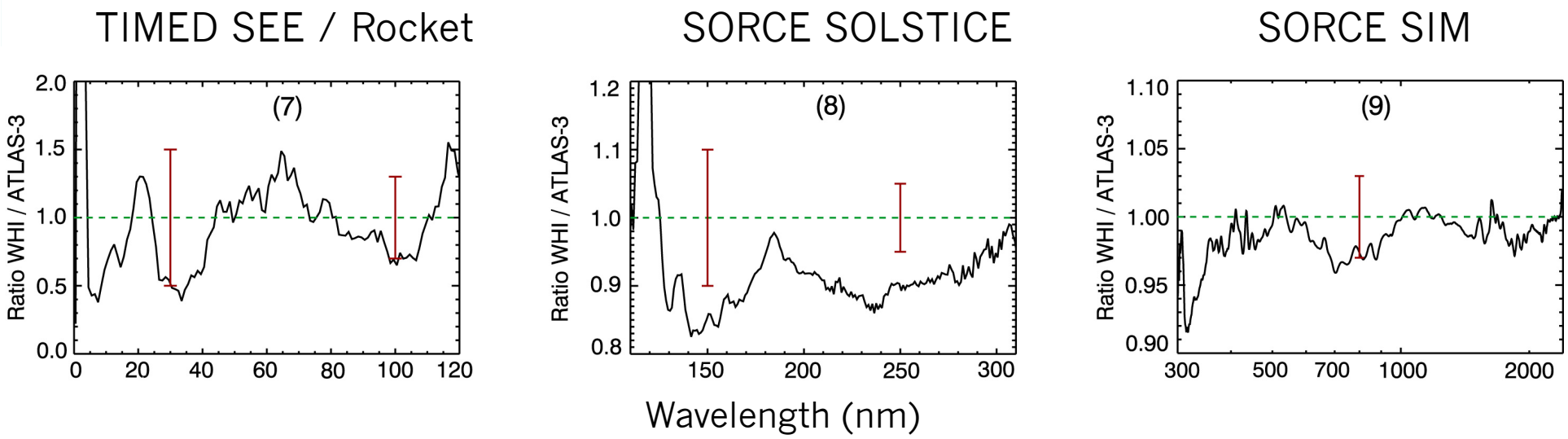


Figure 2 from Woods *et al.*, *GRL*, 2009

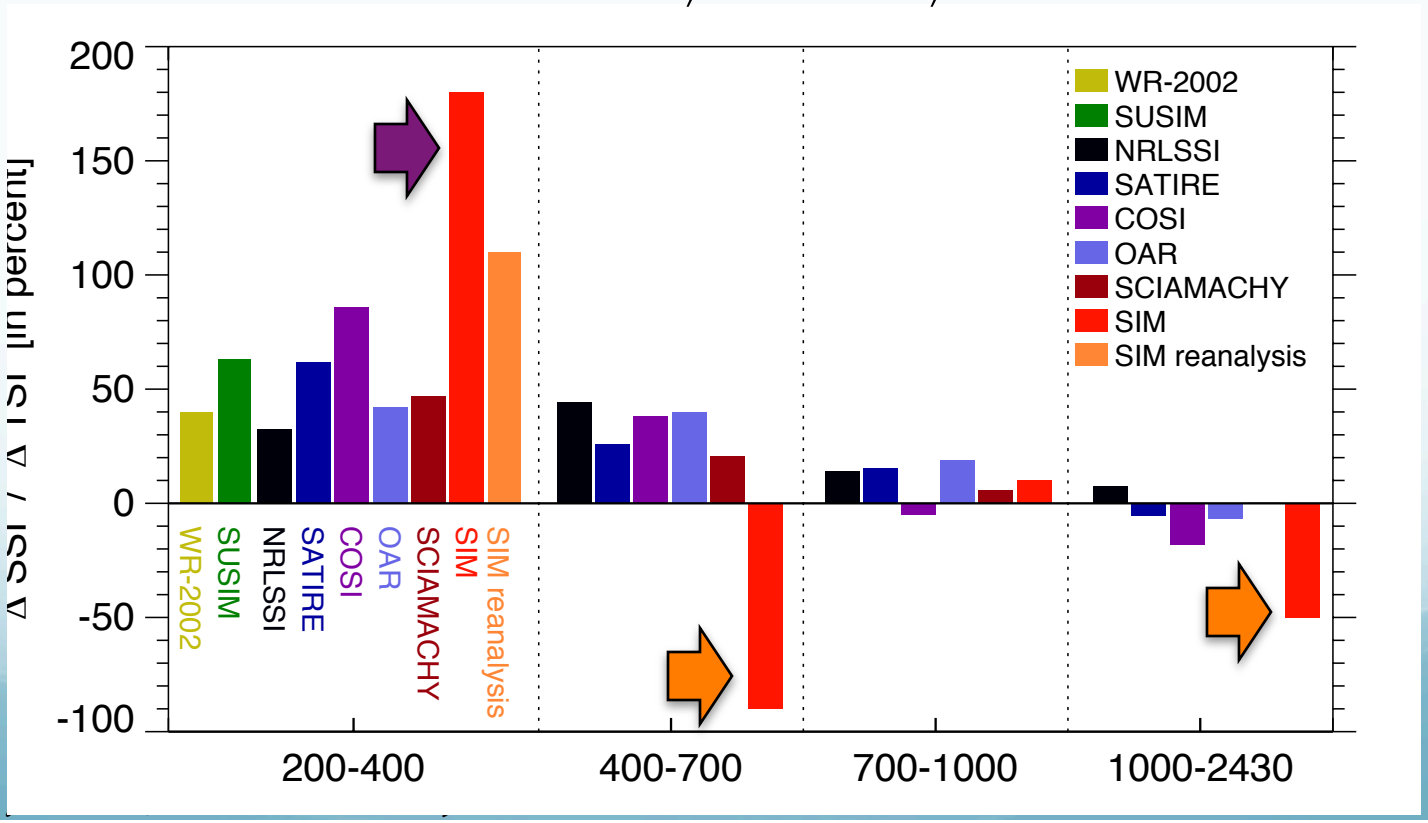
What's Next?

- Establish reference spectra for solar cycle maximum
  - In debate because of SORCE SIM results that show out-of-phase results for the solar cycle at some wavelengths
- Extend Earth atmospheric models and climate change studies to use daily values of the solar spectral irradiance (SSI) instead of reference spectra
- Improve spectral resolution (smaller spectral bands) for inclusion of the SSI into atmospheric and climate models

SORCE SIM Results for SC Variability

- New SORCE results on solar cycle variability (Harder *et al.*, *GRL*, 2009) indicate **out-of-phase variations** for visible and near infrared and **larger ultraviolet variations**.
- There are large differences between SORCE SIM and models.

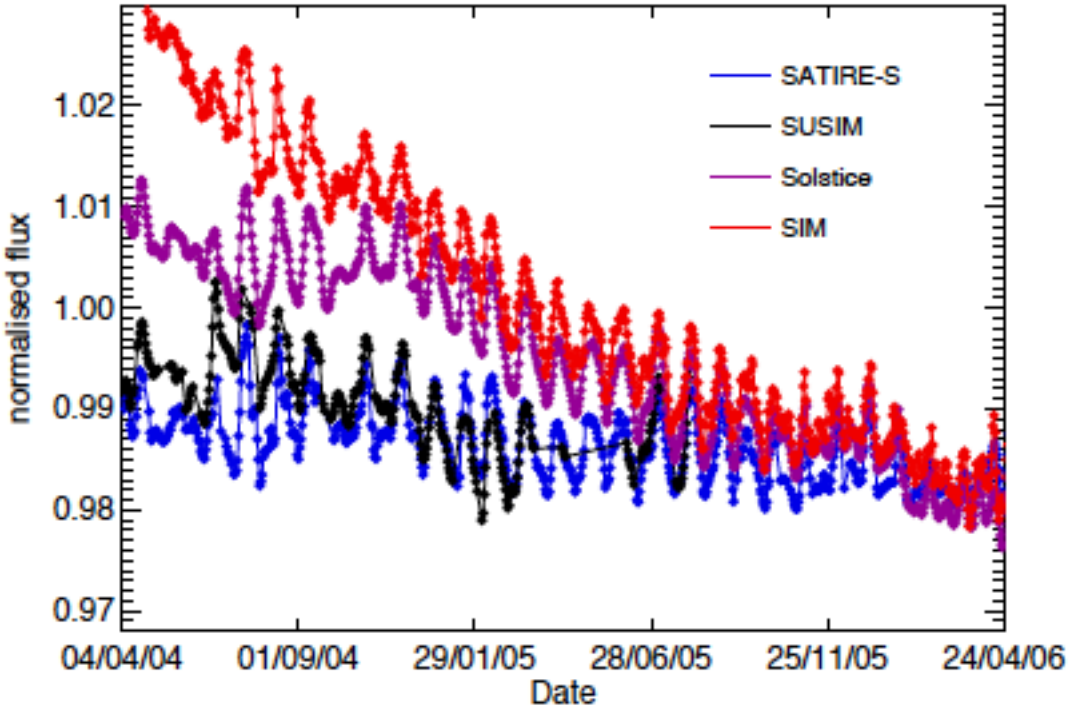
From Ermolli *et al.*, *A.C.P.D.*, 2012.



SSI Solar Cycle Variability Debate

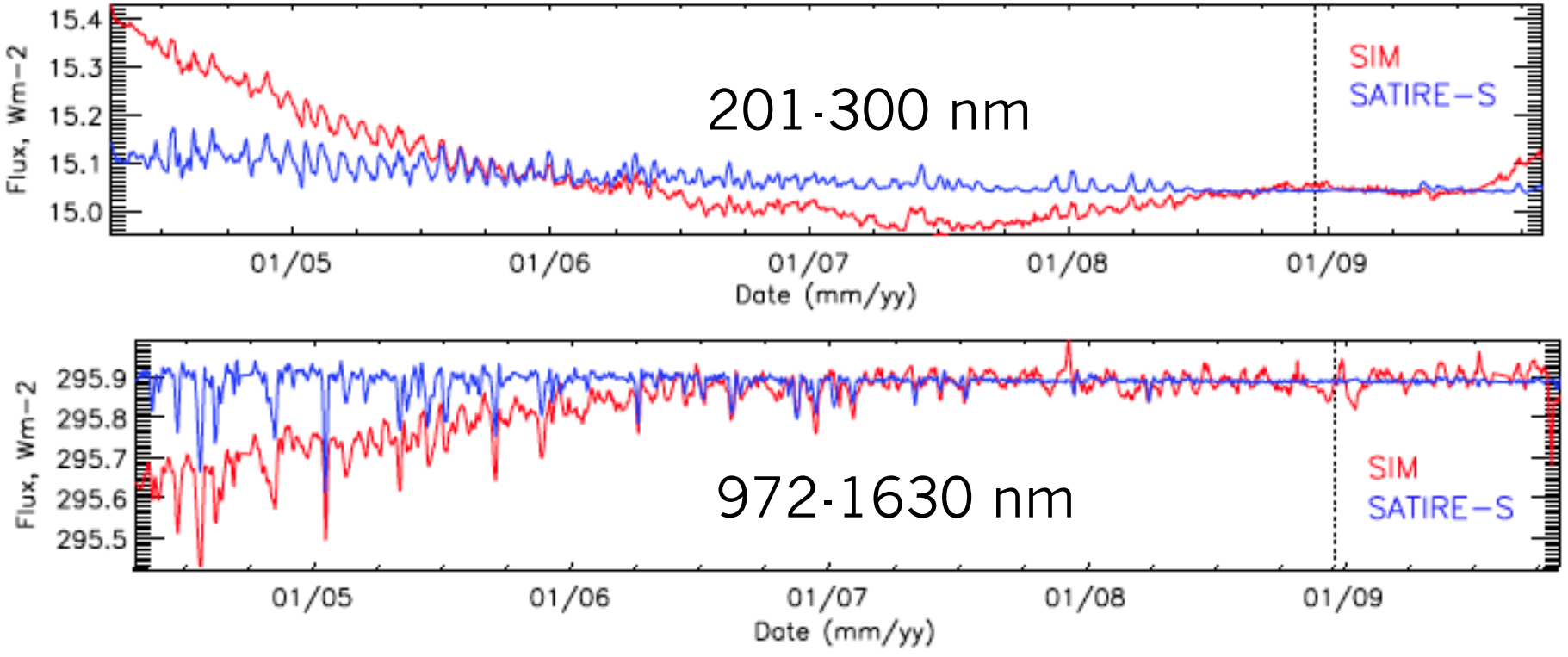
- DeLand & Cebula (*J.A.S.T.P.*, 2011): SIM versus earlier SBUV composite 170-400 nm (*but not concurrent measurements*) – concludes SORCE has uncorrected degradation based on NRLSSI model comparisons
- Unruh *et al*. (2011): Comparison of SATIRE, UARS, and SORCE for 220-240 nm shows 1% per year trend differences

220-240 nm



SSI Solar Cycle Variability Debate

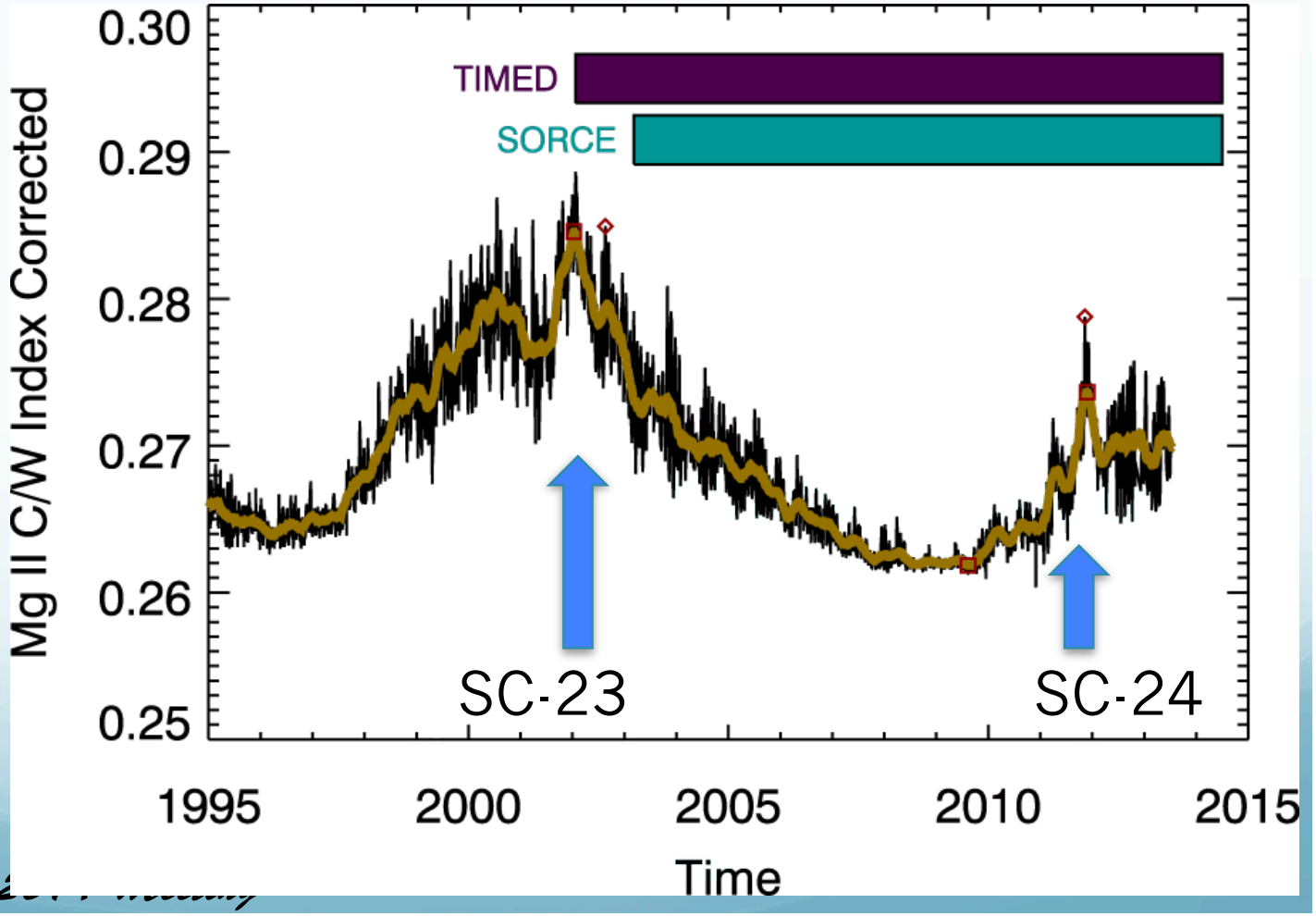
- Ball *et al.* (*Astron. & Astrophy.*, 2011): SATIRE model agrees with UARS results in UV but disagrees with SORCE SIM long-term variability (200-1600 nm)
  - Is SSI variability not entirely controlled by surface magnetism?
  - Are there uncorrected instrument trends in UARS or SORCE?



What about solar cycle (SC) 24?

- SC-23 Peak in 2002 SC-24 Peak in 2011
- SC-23 / SC-24 Variability Ratio is 1.9 for 81-day averages

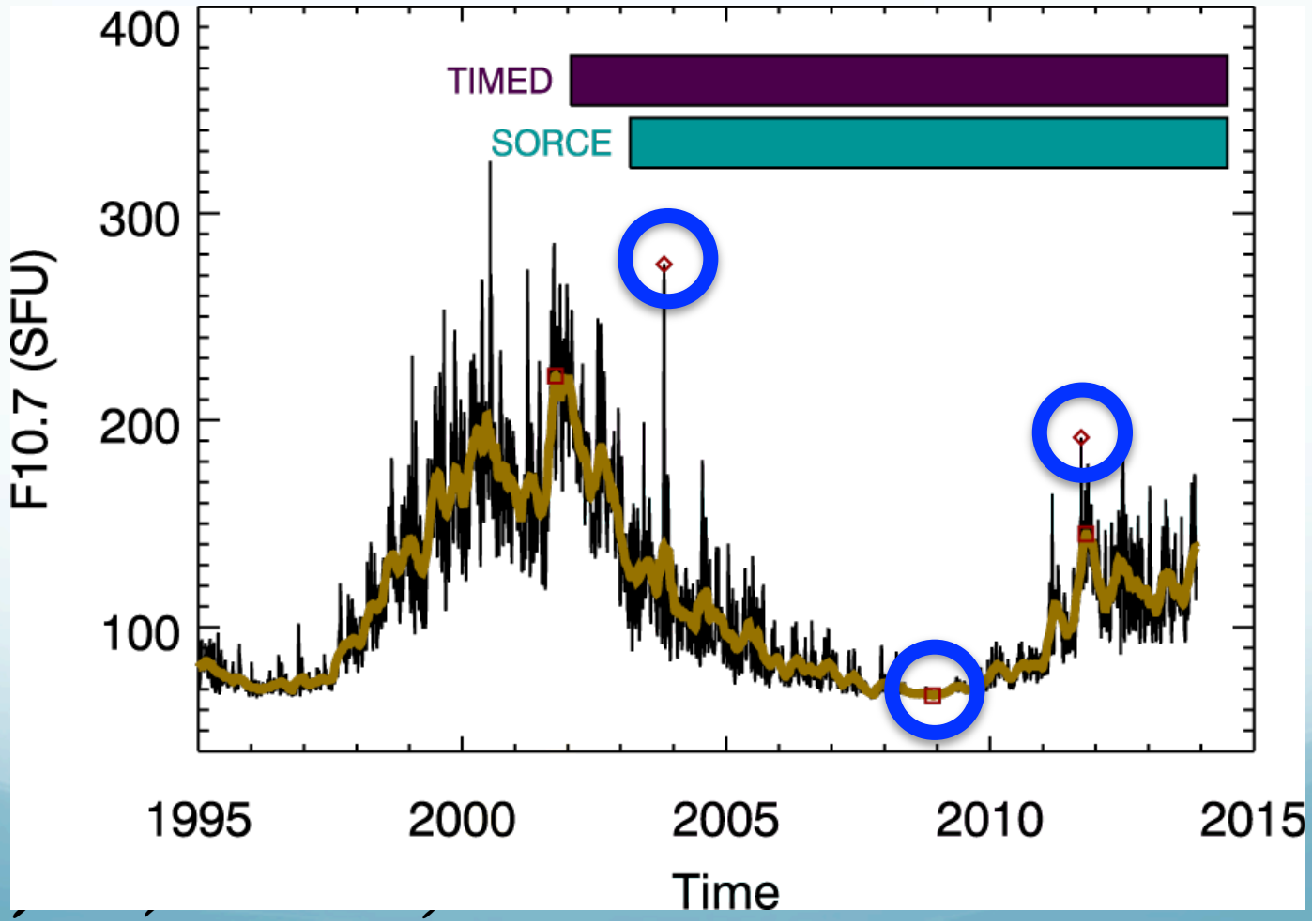
Definition
Variability =
$E / E_{min} - 1$



Days Selected for SORCE SSI Comparisons

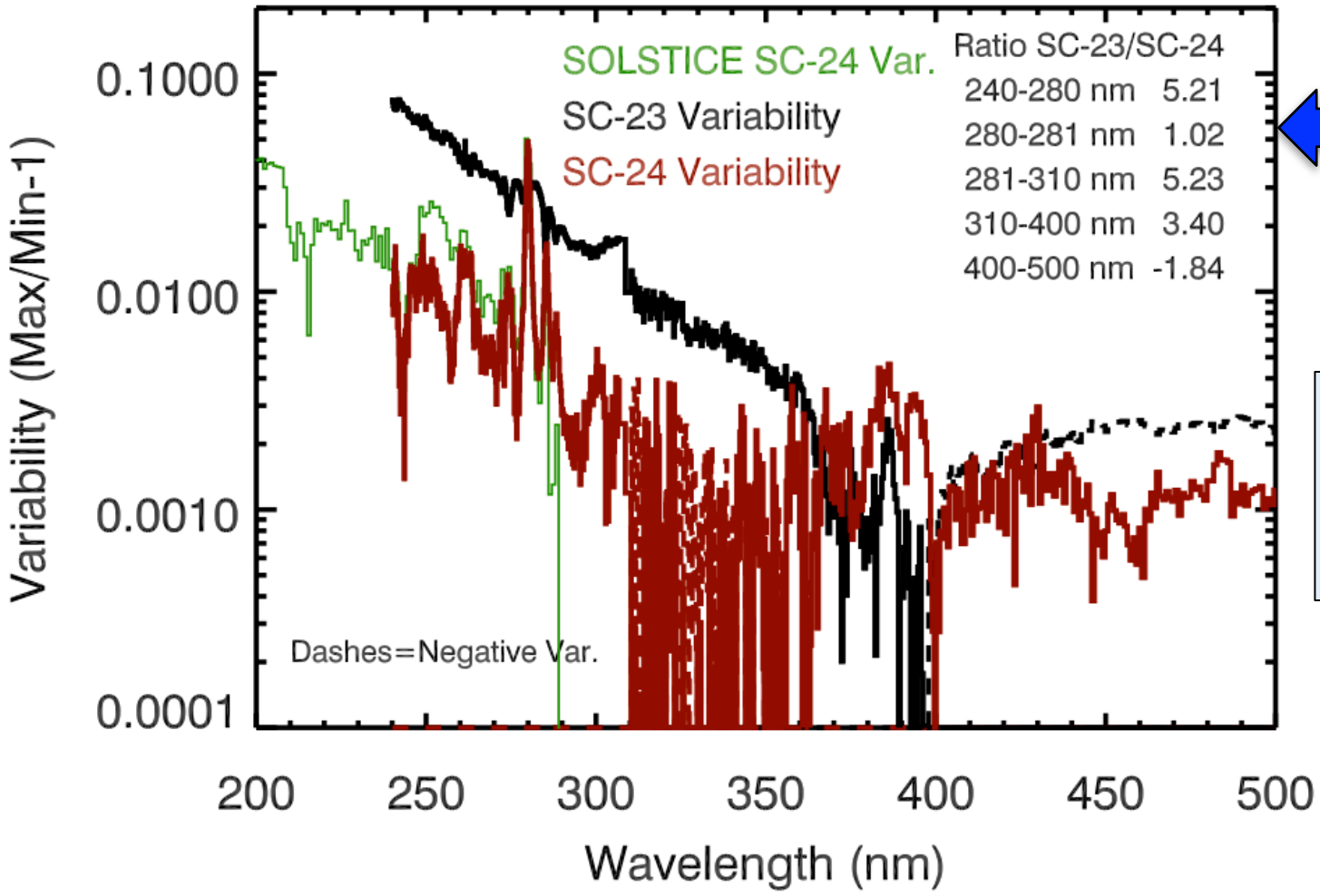
Minimum 2008/260
SC-23 Max 2003/302
SC-24 Max 2011/314

Use 27-day averages for SC variability comparison



Comparison of SC-23 to SC-24

- October 2003 period for the SC-23 maximum has large sunspot darkening effect that complicates the SC-23 variability comparison
- SIM Mg II 280 nm result agrees well with Mg proxy expectation of 1.0



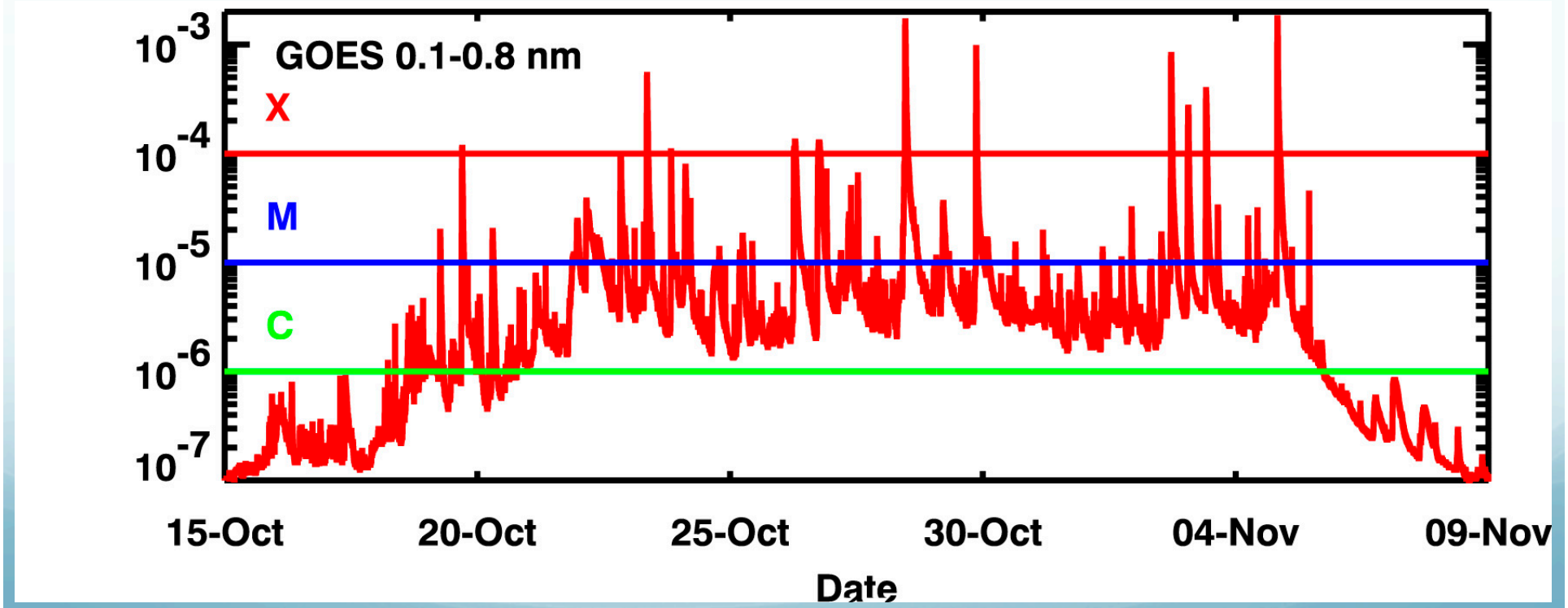
SIM SC-24 result is perhaps better for comparisons to others (UARS)

Summary and Future Plans

- WHI 2008 reference spectra are important results from the SORCE mission.
- Solar cycle variability is less in SC-24 than in SC-23. More analyses of SORCE SSI data and instrument trends over both cycles are planned to provide new reference spectra for solar cycle maximum conditions.
- SORCE SSI solar cycle variability results have been controversial and probably will remain so until new SSI observations are obtained for the NUV-VIS-NIR ranges
  - NOAA TSIS with TIM & SIM might fly in 2017
  - NASA IIP Mini-SIM development begins this year

Halloween Storm 2003

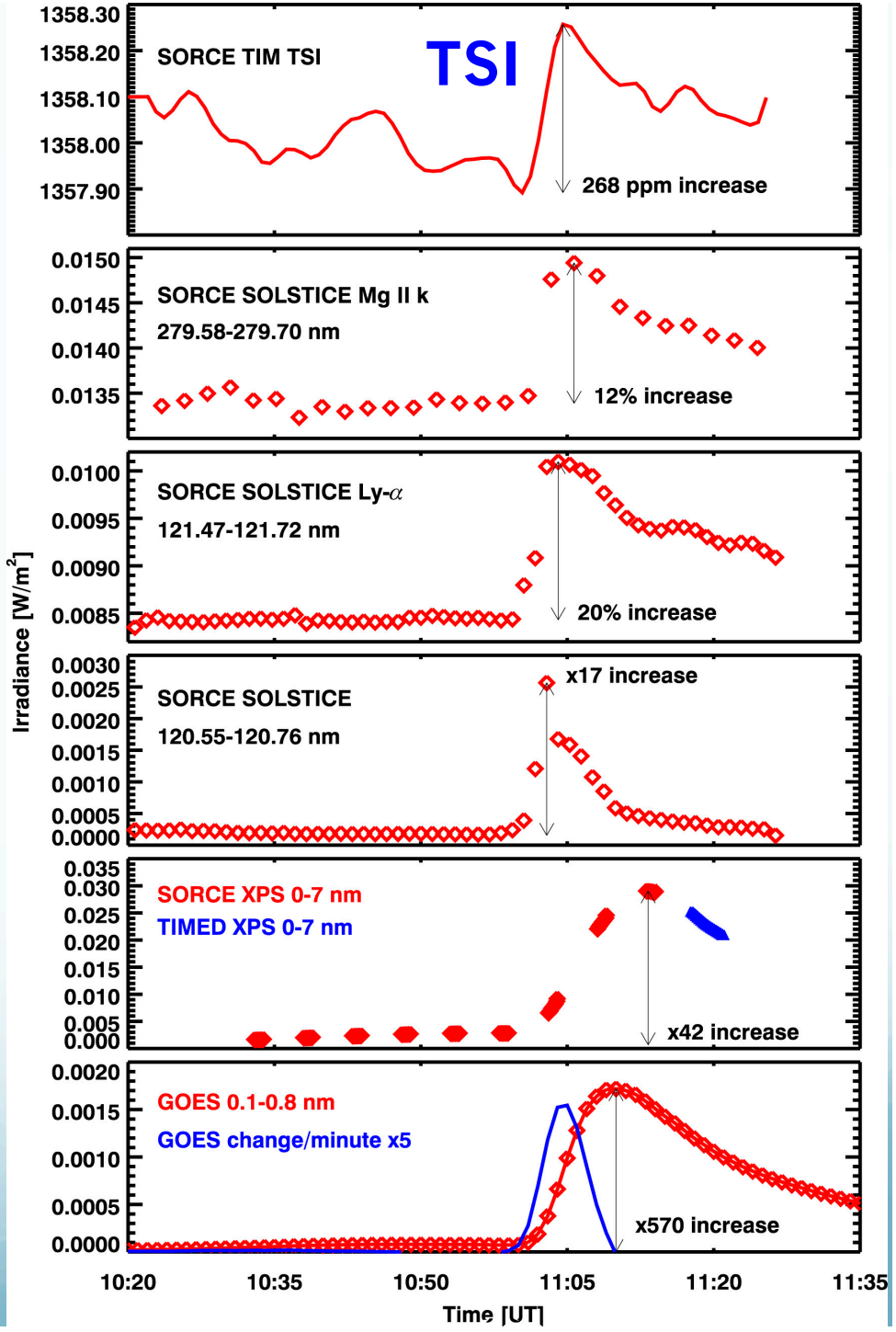
- There were many large solar flares over just 2 weeks in October 2003
  - 44 M-class flares
  - 11 X-class flares



Flare Results from SORCE

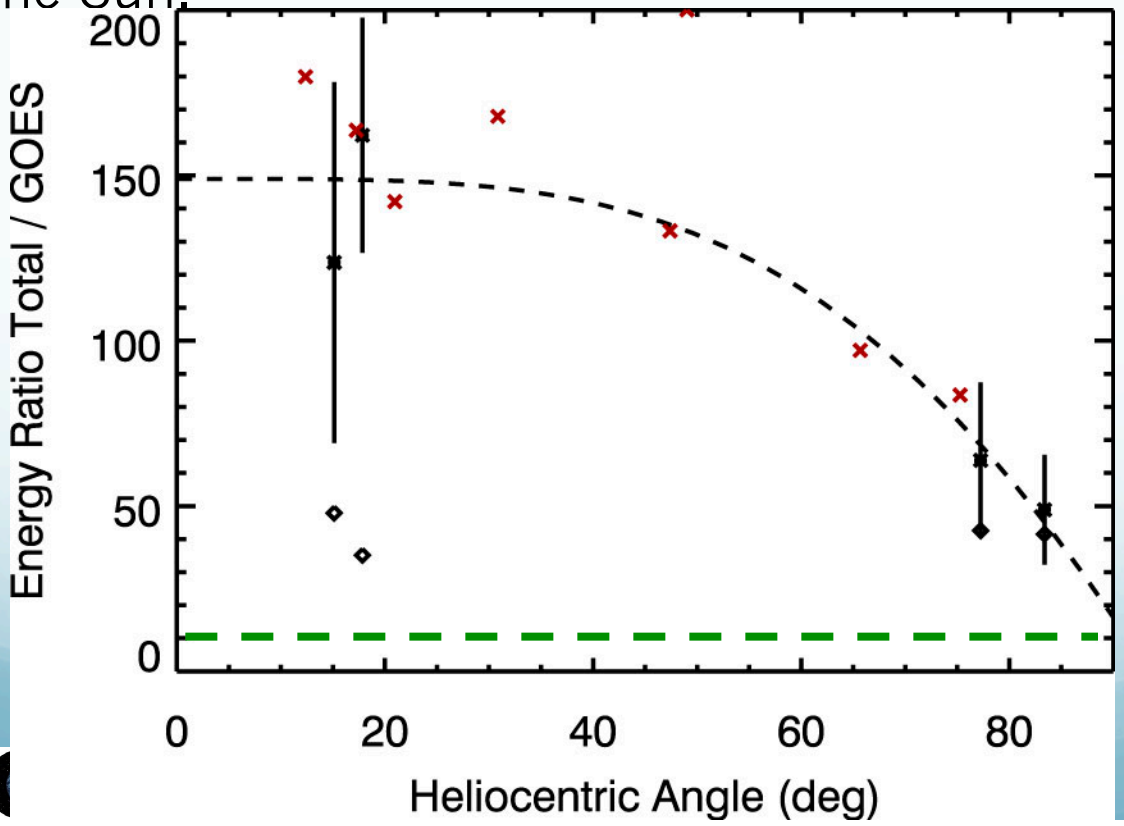
- SORCE was able to observe the X17 flare on 28 Oct 2003 the best
  - First accurate measurement of the flare variability in the TSI
  - Flare variability is as large as solar cycle variability at most EUV and UV wavelengths

From Woods *et al.*, *GRL*, 2004



More Flare Results from SORCE

- Because of the SORCE TIM measurements of several flares, it is now known that there is 15 times more energy in a flare than previously thought [Woods *et al*., *JGR*, 2006].
  - The flare energy is about the same as Coronal Mass Ejection (CME) kinetic energy.
  - The flare energy that arrives to Earth depends on flare location on the Sun.



* = TIM TSI
◆ = XPS 0-27 nm
X = WLF Vis. (scaled)

Previous Result
Hudson & Willson (1983)
Total / GOES = 10

Why are TSI flare results important?

- The flare total energy is much larger than previously thought. This result implies that there is much more heating in the chromosphere and photosphere from the energetic particles created from the magnetic reconnection process in the solar corona during flare events.

- These SORCE TSI flare results have sparked many new studies in flare energetics for the solar community.
  - Kretzschmar *et al.*, 2010: TSI flares from SOHO VIRGO
  - Kretzschmar *et al.*, *A&A*, 2011: TSI and visible spectral variations during flares using SOHO VIRGO and SPM
  - Emslie *et al.*, *Ap.J.*, 2012: energetics of flares and CMEs