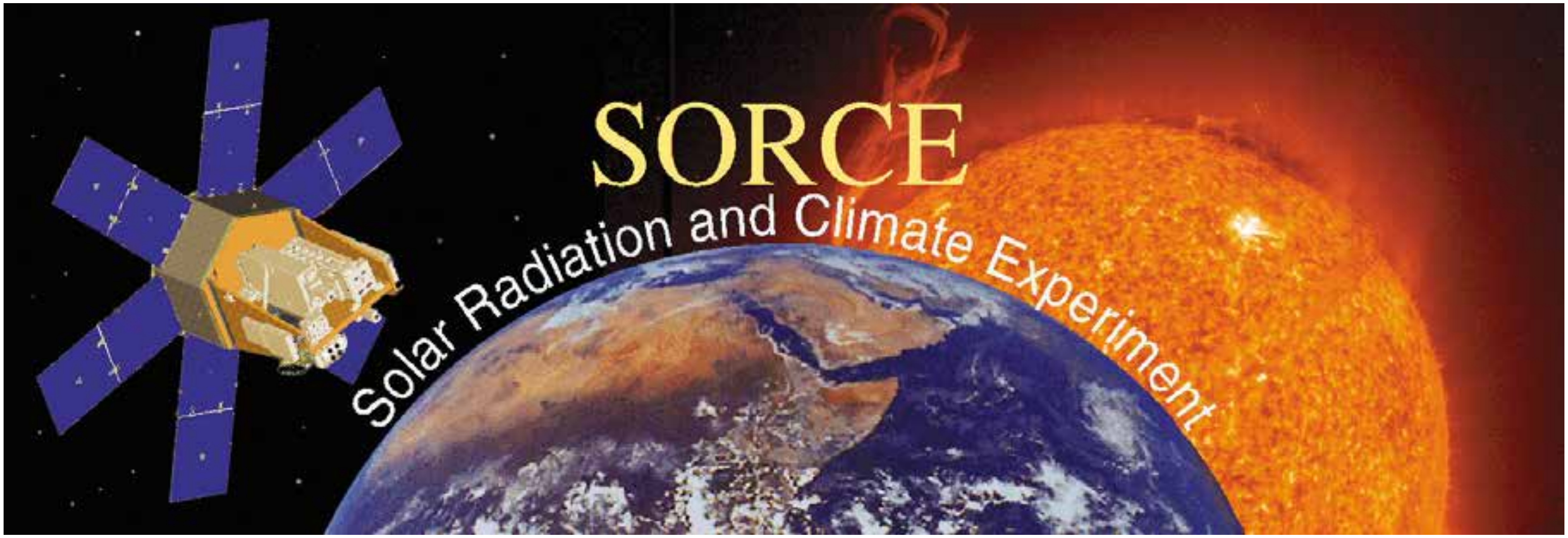
SORCE
XUV Photometer System - XPS



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SORCE XPS Overview Talk Outline

- XPS Science Motivation
- XPS Measurement Overview
  - Photometer Bandpasses
  - Observations
  - Calibrations
- XPS Science Highlights
  - Solar Cycle Variability
  - Secular Trend (2008 cycle minimum to 2019 cycle minimum)
  - Oct-Nov 2003 Large Flares

SORCE XPS Key Instrument and Algorithm References

Woods, T. N., G. Rottman, and R. Vest, XUV Photometer System (XPS): Overview and calibrations, ***Solar Physics***, **230**, 345-374, 2005.

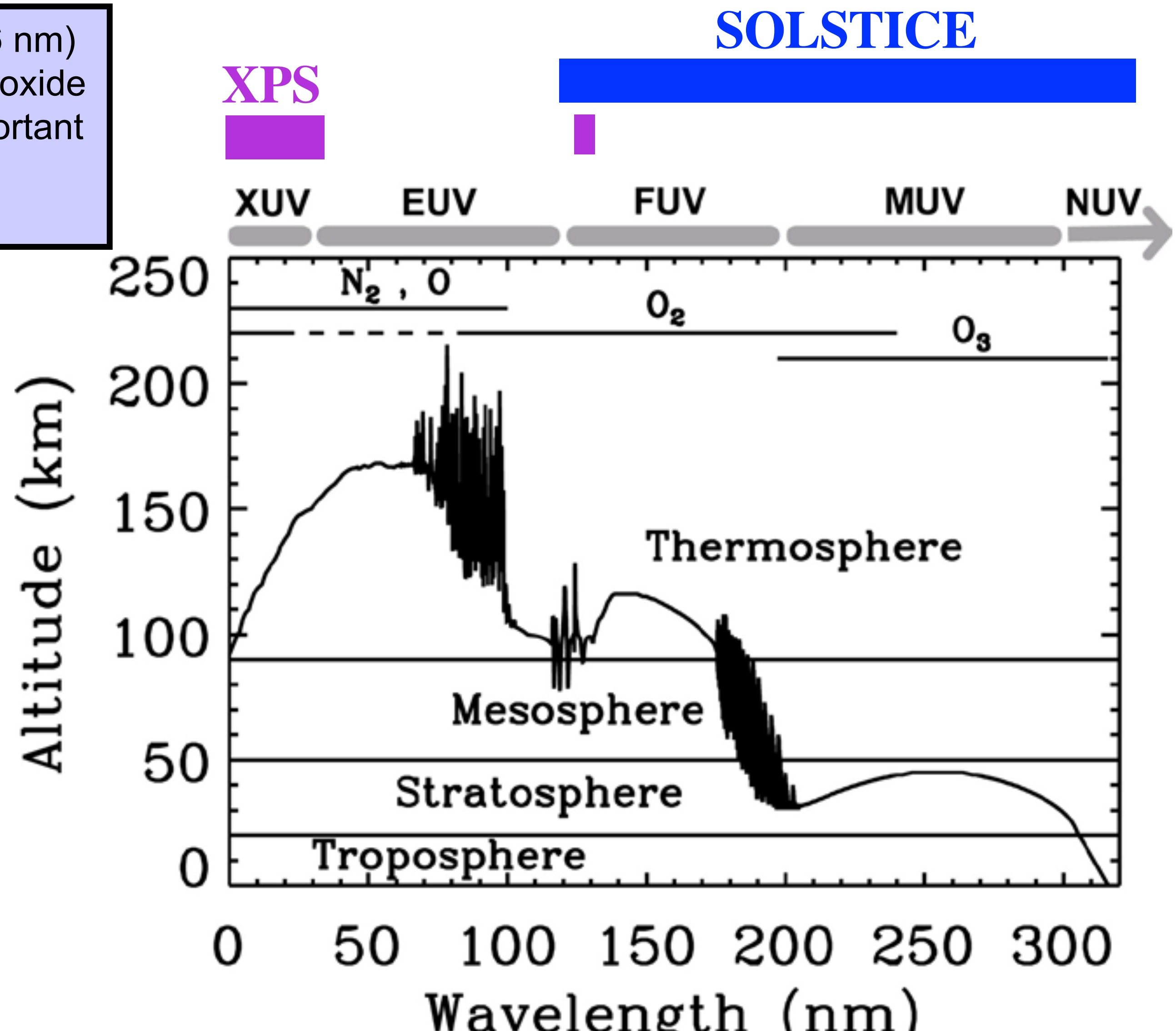
Woods, T. N., and G. Rottman, XUV Photometer System (XPS): Solar variations during the SORCE mission, ***Solar Physics***, **230**, 375-387, 2005.

Woods, T. N., P. C. Chamberlin, W. K. Peterson, R. R. Meier, P. G. Richards, D. J. Strickland, G. Lu, L. Qian, S. C. Solomon, B. A. Iijima, A. J. Mannucci, and B. T. Tsurutani, XUV Photometer System (XPS): Improved irradiance algorithm using CHIANTI spectral models, **Solar Physics, 249**, 235-267, 2008.

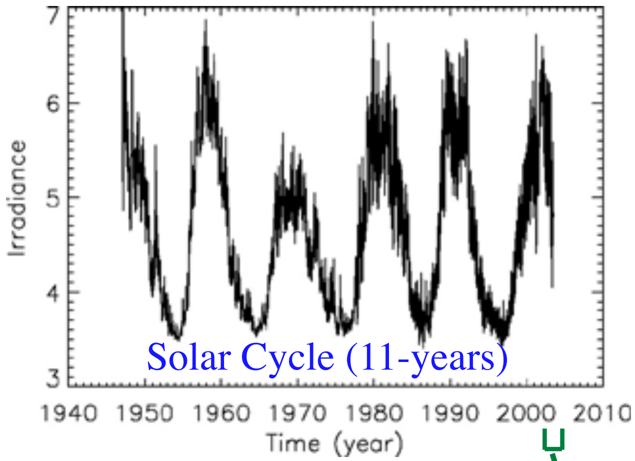
Earth's Atmosphere Absorbs the Solar Ultraviolet Radiation

The solar radiation shortward of 320 nm is completely absorbed in Earth's atmosphere. The altitude for the absorption is wavelength dependent.

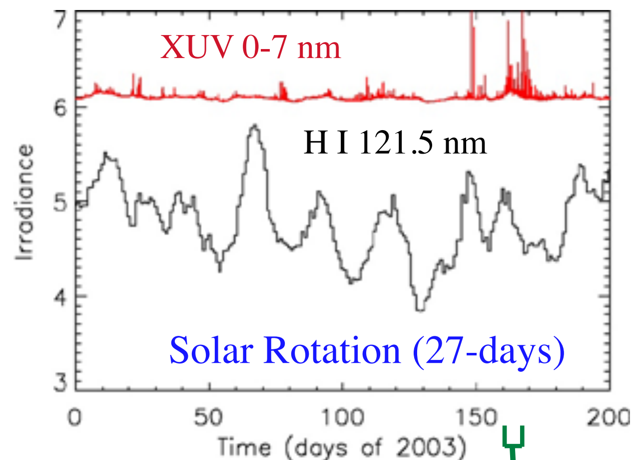
Solar XUV and H I Lyman-α (121.6 nm) emissions are key drivers for nitric oxide (NO) photochemistry, which is important component for water chemistry in Earth's upper atmosphere.



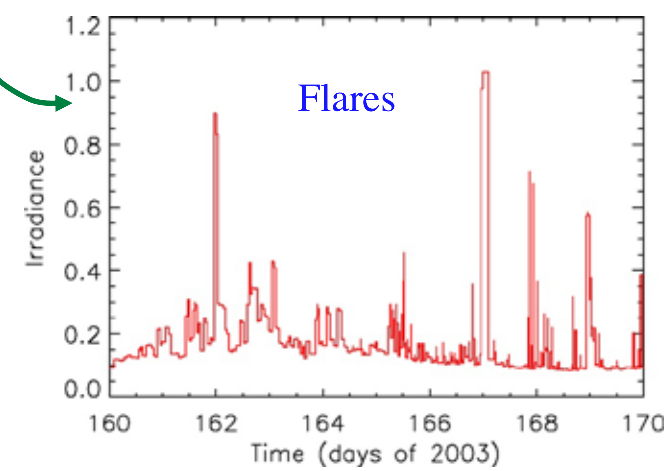
Solar Irradiance Varies on All Time Scales



- Solar Cycle - months to years
  - Evolution of solar dynamo with 22-year magnetic cycle, 11-year intensity (sunspot) cycle



- Solar Rotation - days to months
  - Beacon effect of active regions rotating with the Sun (27-days)

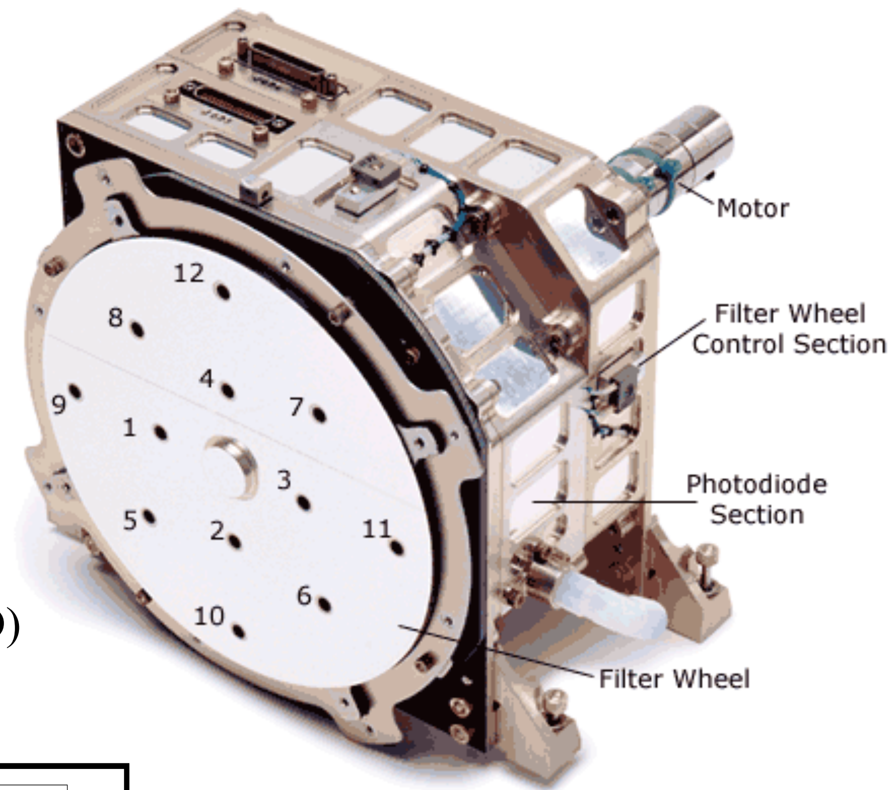


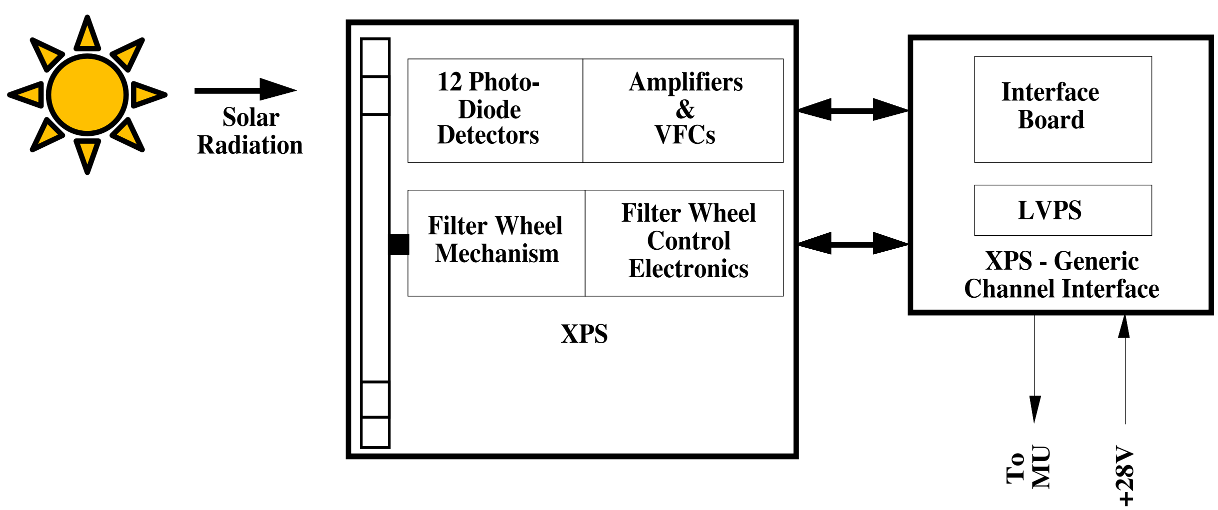
- Flares - seconds to hours
  - Related to solar storms (such as CMEs) due to the interaction of magnetic fields on Sun

SORCE XPS excels at detecting solar flares

XUV Photometer System (XPS) Design Overview

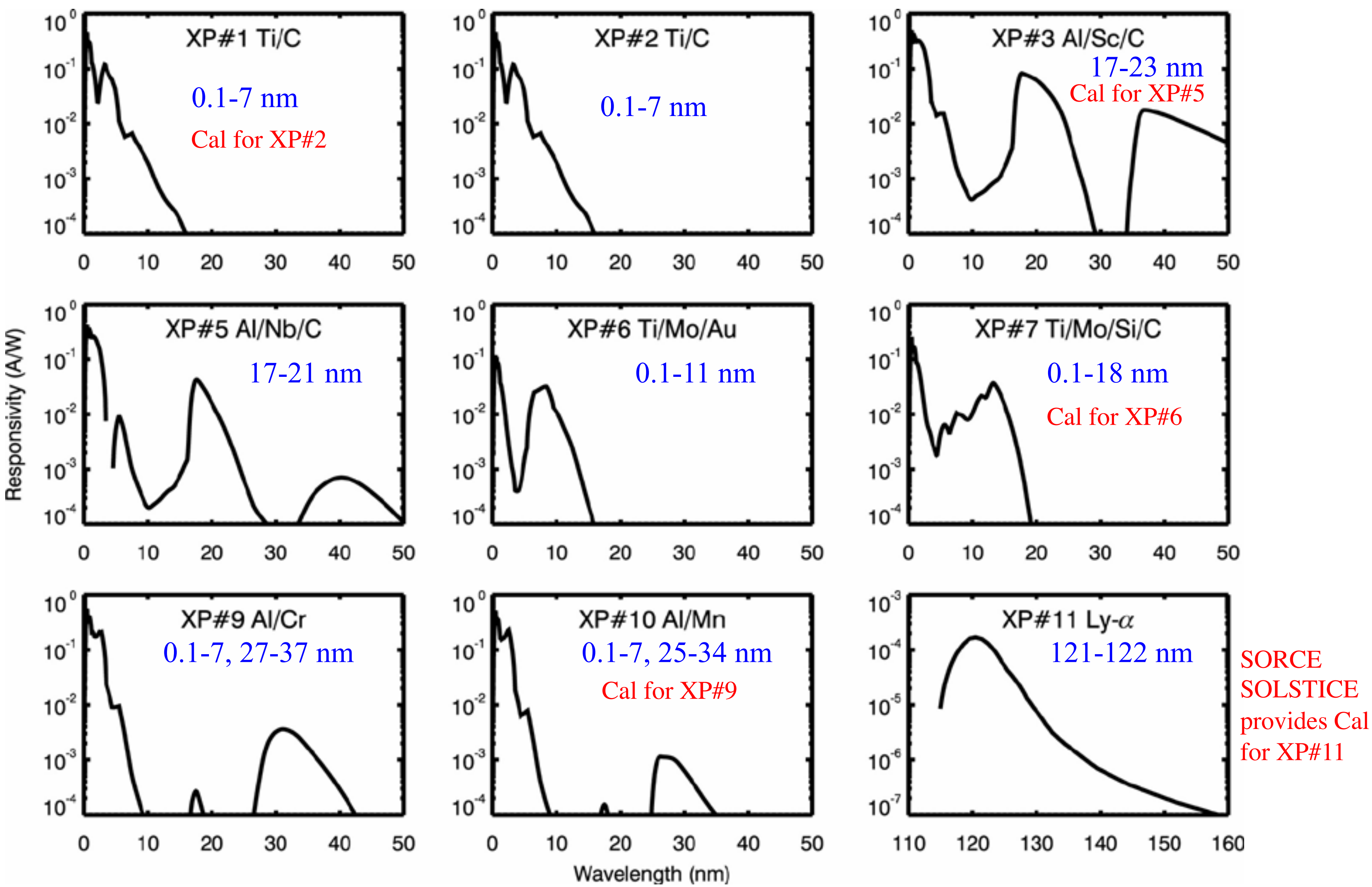
- Wavelength Range: 1-34 nm and 121.5 nm
- Wavelength Resolution: 1-10 nm
- Optics: Thin film filters (deposited on Si photodiodes)
- Detector: 12 Si photodiodes: 8 XUV, Ly-α, 3 bare
- Absolute Accuracy: 20% Long-term Stability: 4%
- Mass: 3.6 kg Power: 9 W Data Rate: 0.3 kbits/s
- Heritage: SORCE, TIMED SEE, SNOE, rocket (1992)
- Pre-flight Calibrations: NIST SURF
- In-flight Calibrations: Three redundant channels, Underflight rocket calibrations (NASA TIMED and SDO)





<u>One Flight Anomaly for XPS</u>
The filter wheel got stuck once in December 2005. The Filter Wheel has worked fine for rest of the mission.
XPS observations were changed in 2006 to reduce the use of the filter wheel to just a few times per month.
XPS started being power cycled for orbit eclipses in 2010 due to S/C battery issues.

XUV & Lyman-α Spectral Bands of XPS Channels

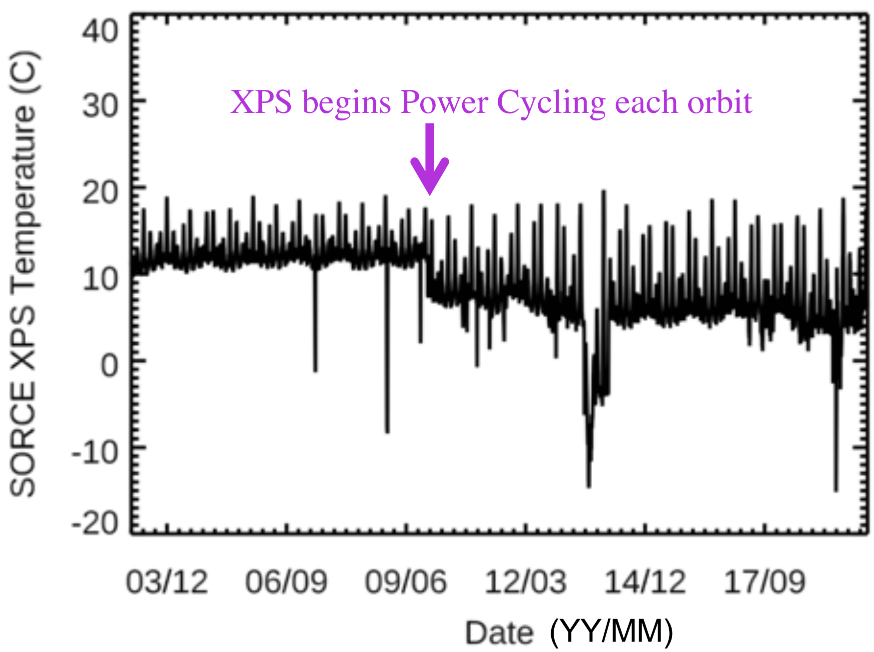


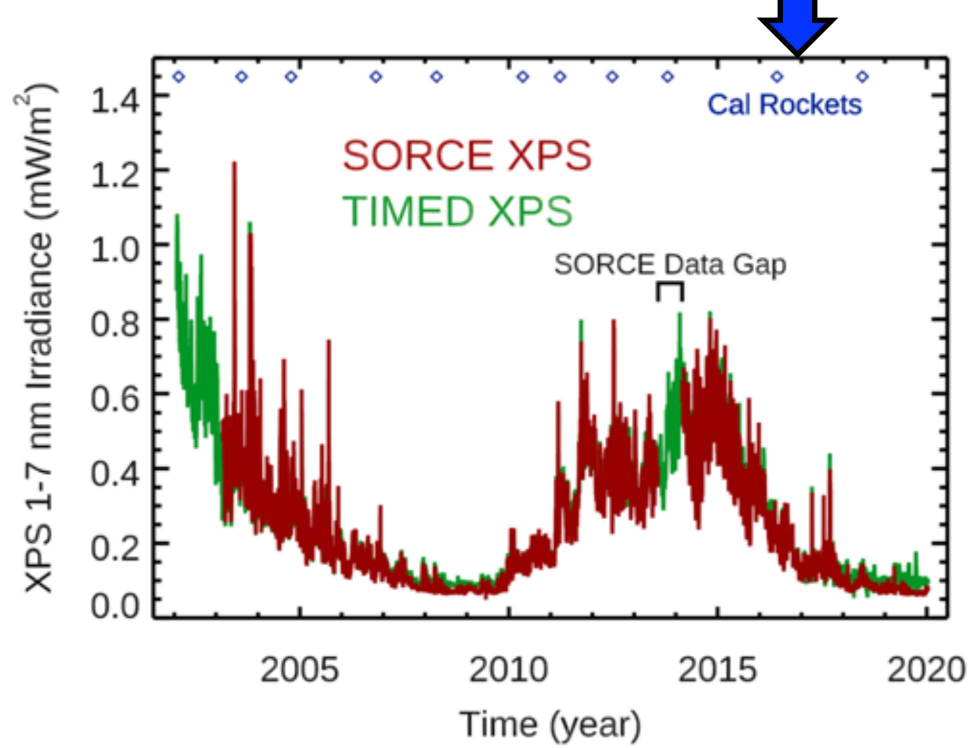
Channels 4, 8, and 12 are visible light channels to calibrate XPS calibration windows.

XPS In-flight Calibrations

- Redundant Channel calibration checks are done at least once per month
- TIMED XPS has almost identical measurements with 15 observations per day since January 2002 (year before SORCE launched)
- Underflight Rocket Calibrations are supported by NASA TIMED and SDO missions and occur about once per year
- XPS photometers are fairly stable with <1% degradation per year

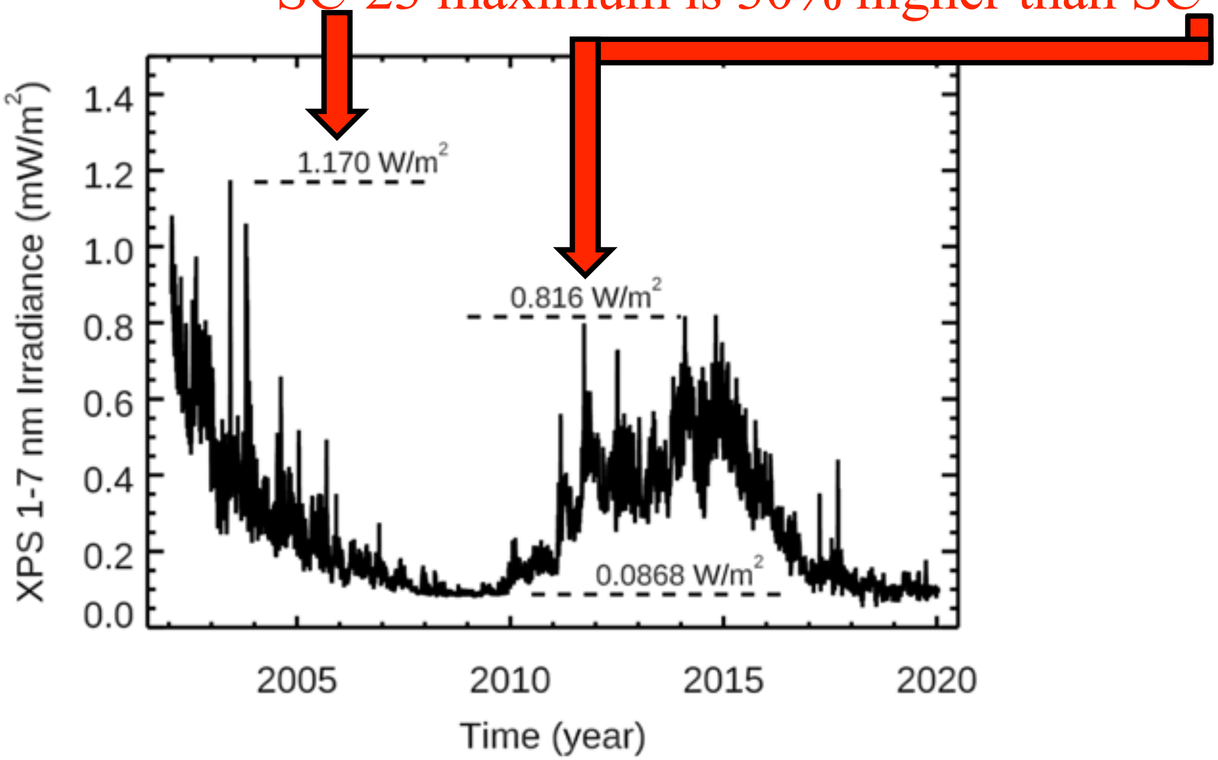
Without internal heater, XPS temperature varies by about 5 C over an orbit and is cooler once power cycling began.





SORCE Mission started near Maximum of Solar Cycle 23

- SORCE observed declining phase of solar cycle 23
- SORCE observed during the long and slightly low minimum in 2008-2009
- SORCE observed a lower maximum for cycle 24 relative to cycle 23
  - SC-23 maximum is 30% higher than SC-24 maximum



Solar Cycle Variability = (Max-Min)/Min
SC-23 Variability is x 12.5
SC-24 Variability is x 7.9

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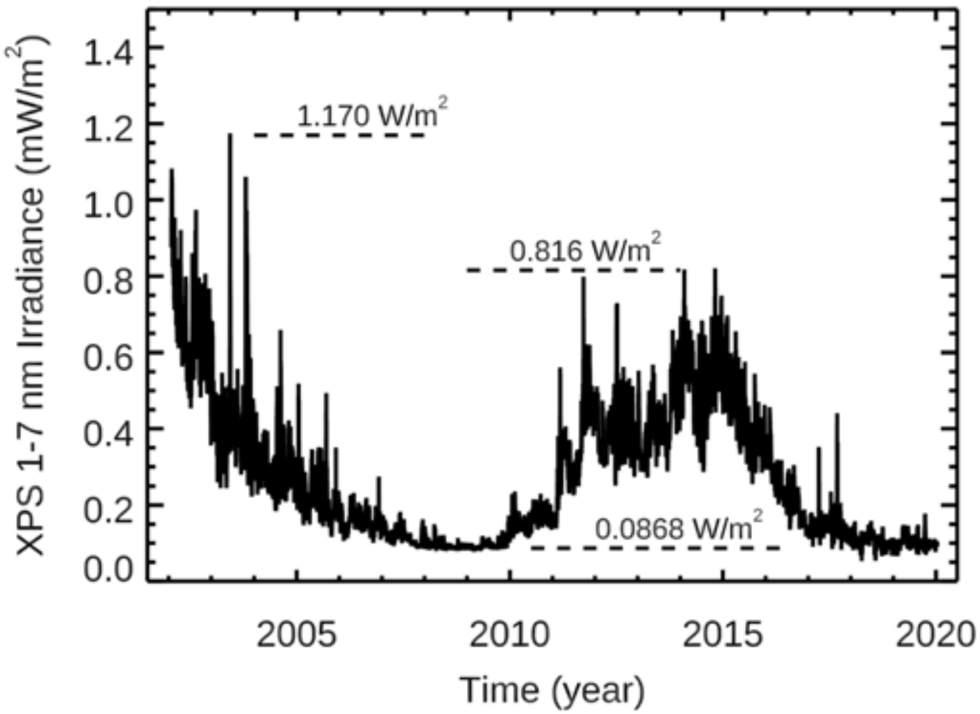
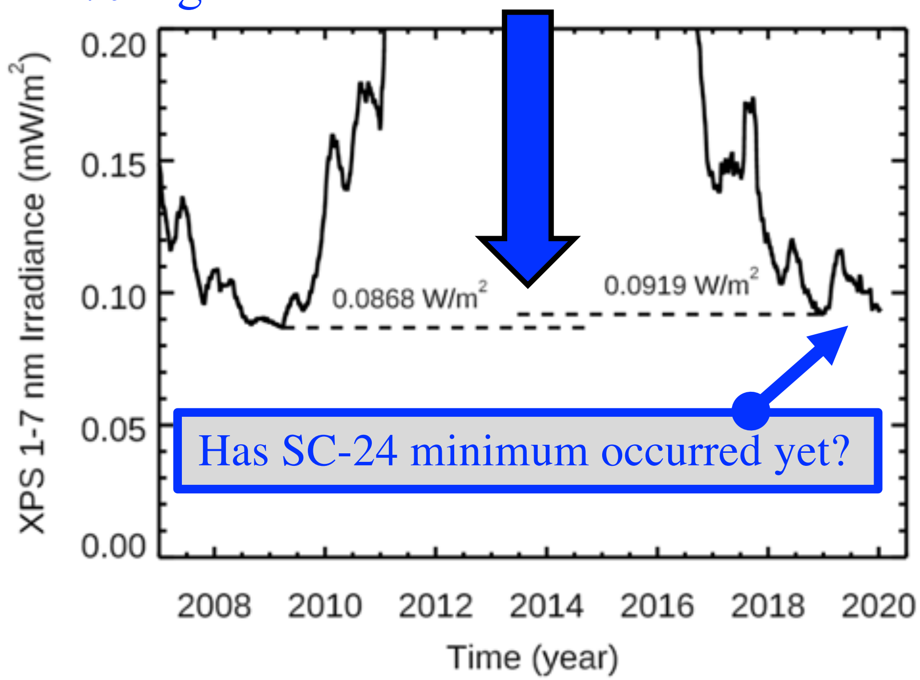
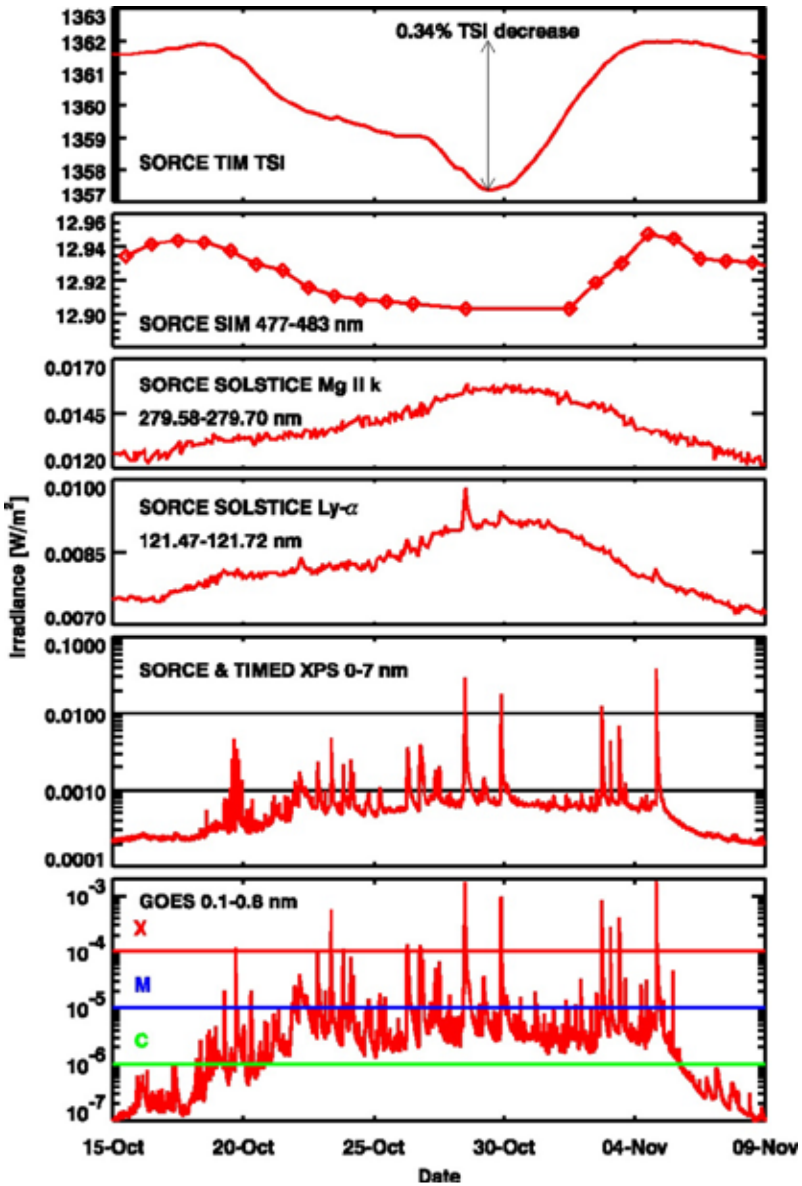


- SORCE is also observing the next cycle minimum in 2019-2020, which is currently 6% higher than 2008-2009 minimum.

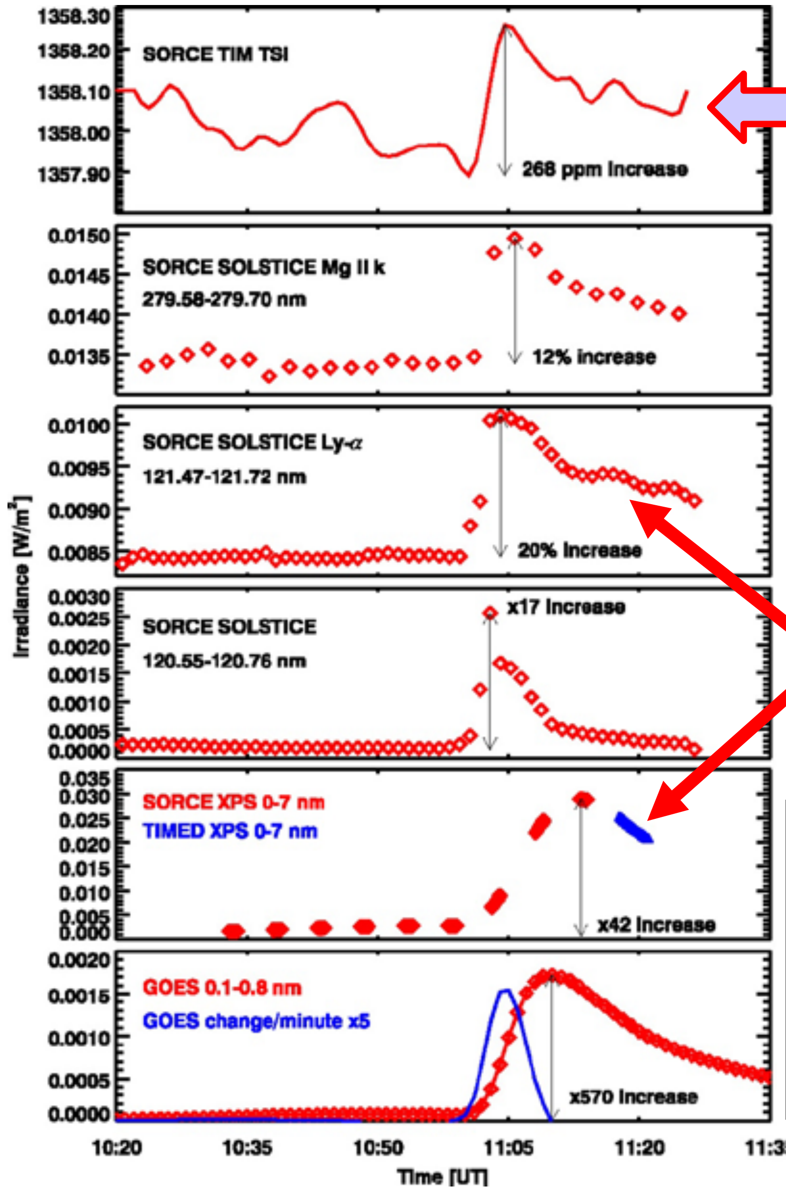


SORCE & TIMED Measure the Irradiance of the Large Flares

55 Large Flares in 2-week Period



X17 Flare on 28 Oct 2003



First Detection of a Flare in the TSI

55 Large Flares Observed During Period that Normally has Less Than 7 Large Flares

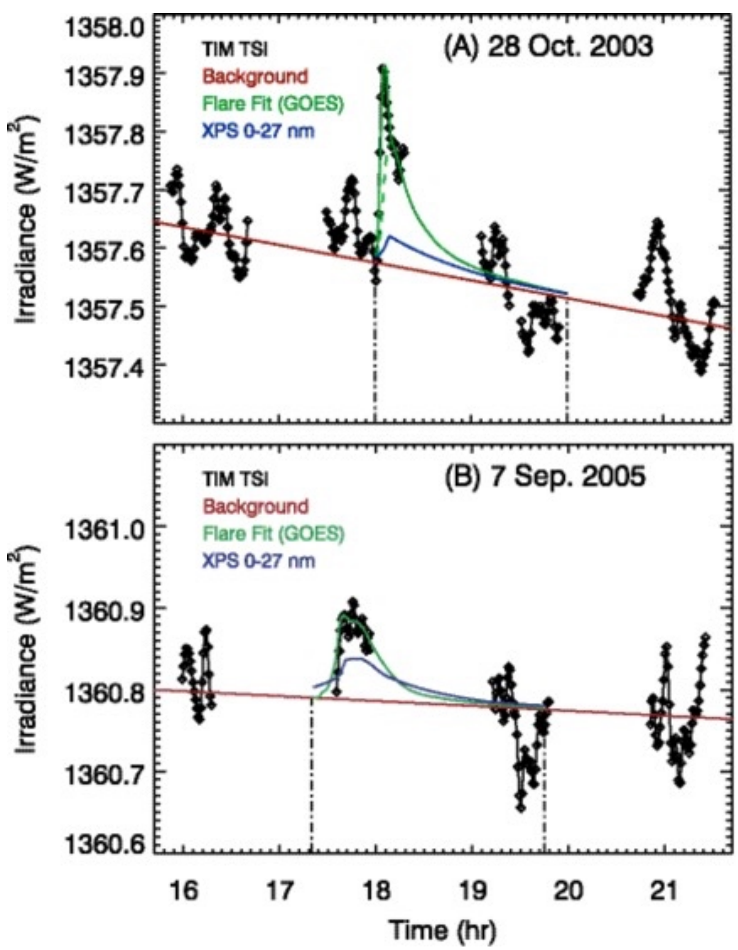
XUV 0-7 nm is x 3 times brighter than H I Lyman-α !

Full Spectral Coverage by TIMED and SORCE for the X17 Flare on Oct. 28

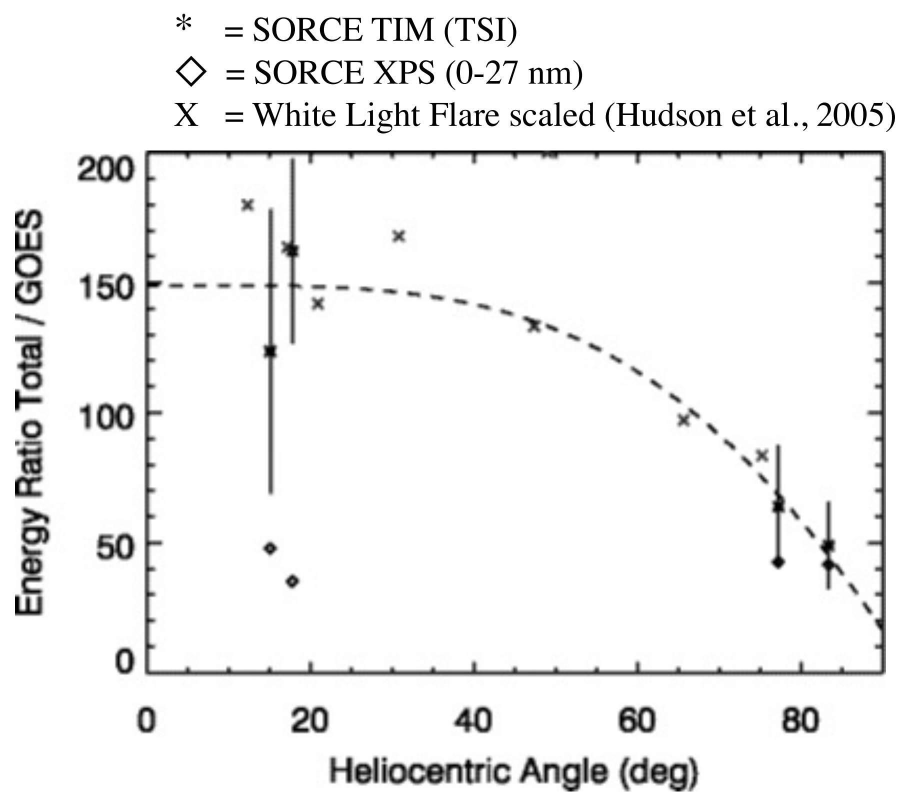
Woods *et al.*, ***GRL*, 31**, L10802, 2004

SORCE TIM & XPS Provide New Results about Flare Energetics

Total Flare Energy is > 10^{32} ergs for X10 class flares.
This is 10 times more energy than previous thought prior to SORCE flare observations.



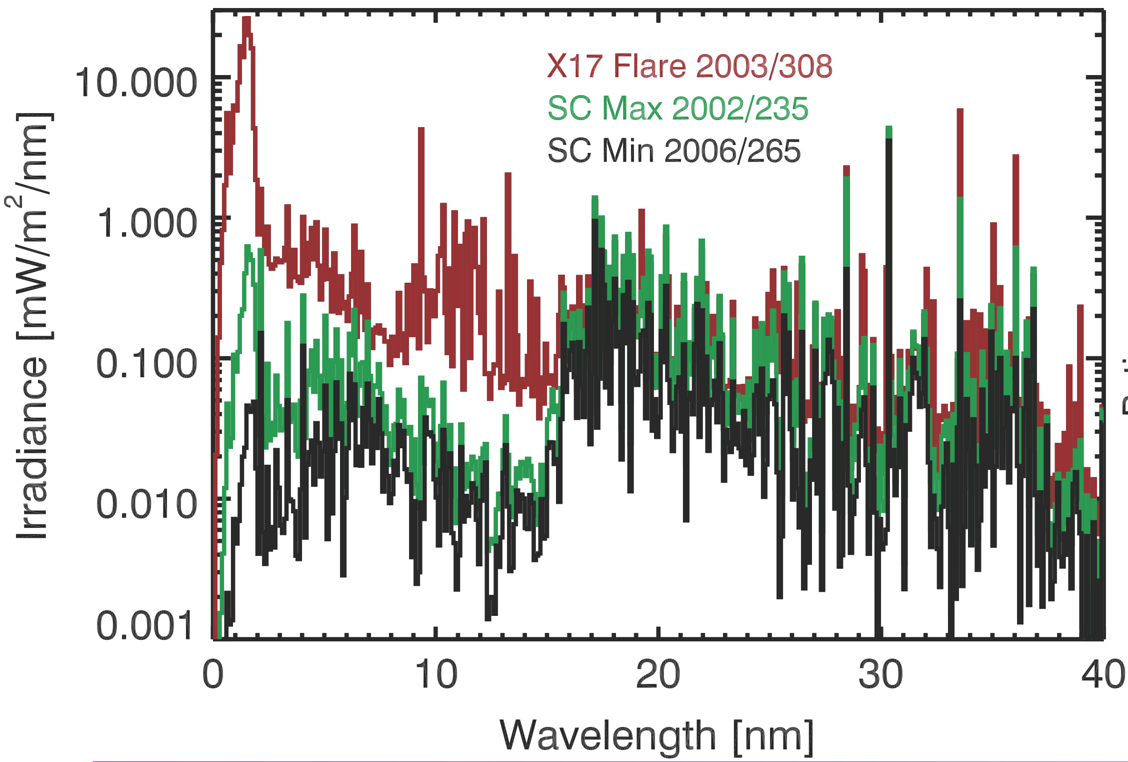
Flares on the solar limb are weaker by a factor of 3 and are dominated by XUV radiation.



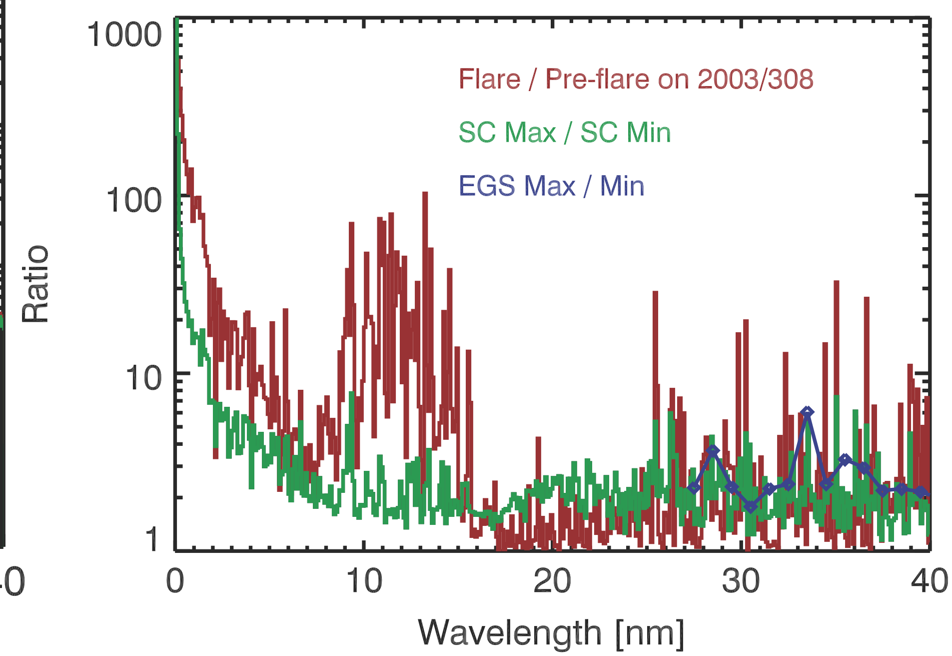
From Woods, Kopp, and Chamberlin, ***JGR***, **111**, A10S14, 2006

Solar X-ray Ultraviolet (UV) Variations with Temperature

- XPS Level 4 product is model of the solar XUV irradiance with three components:
  - Quiet Sun: solar cycle minimum
  - Active Region: daily variation (above Quiet Sun)
  - Flare: coronal iso-thermal spectrum using temperature from GOES XRS data
  - All three components are CHIANTI spectra



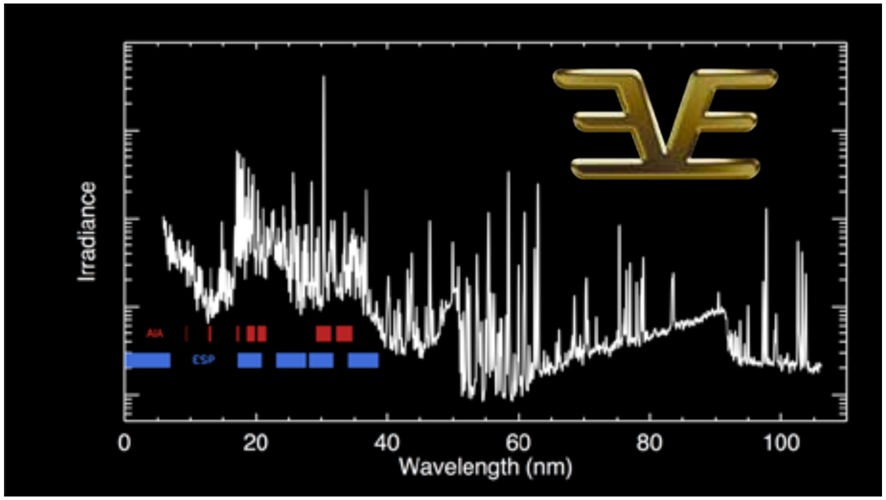
XPS Level 4 Solar Variability

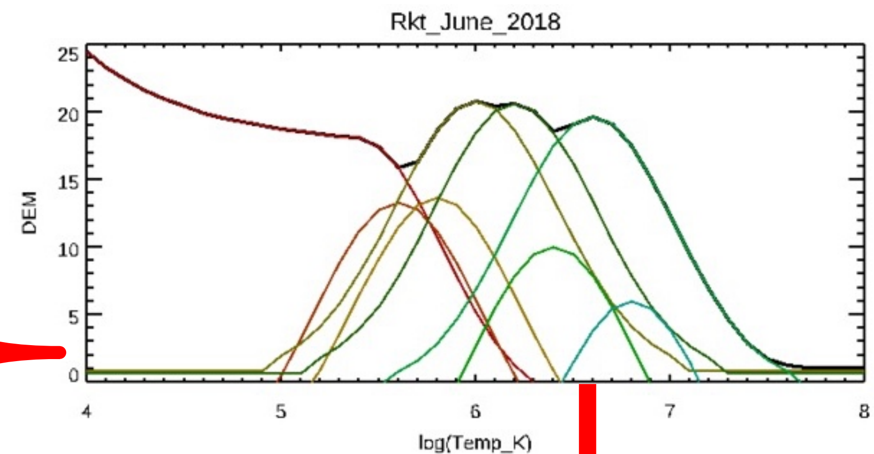


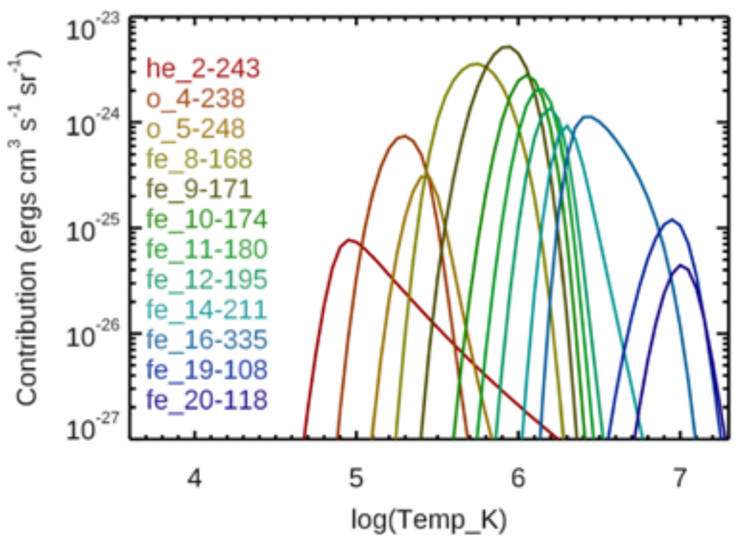
Figures from Woods *et al*., *Solar Phys*., 2008

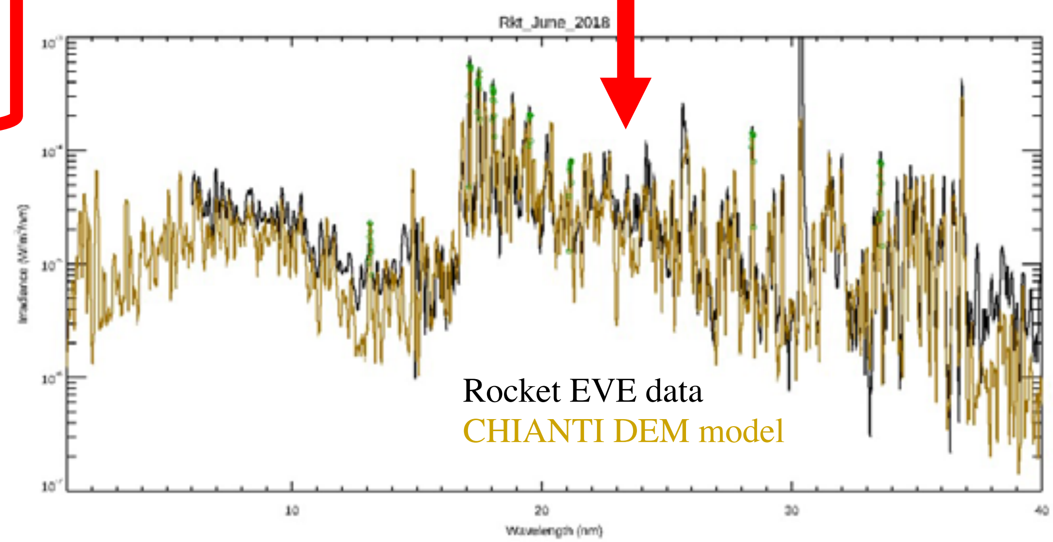
XPS Level 4 – Version 13 Development

- SDO EVE spectra down to 6 nm is being used to develop new CHIANTI reference spectra. Those will replace the XPS Level 4 Quiet Sun and Active Region reference spectra.









SORCE XPS Summary

- SORCE XPS has 17 years of observations of the X-ray Ultraviolet (XUV 1-34 nm) and H I Lyman-α (121.6 nm) solar irradiance. Some key results from XPS:
  - Solar Cycle Variability is more than a factor of 10 at the shorter wavelengths and is factor of 1.7 for H I Lyman-α.
  - Secular Trend from 2008 minimum to 2019 minimum is +6% for 1-7 nm irradiance, but new cycle minimum may not occur until sometime in 2020.
  - XPS has observed more than 3000 flares during the SORCE mission. The largest flares are in October-November 2003 for SC-23 and in September 2017 for SC-24.
  - Solar XUV 0-7 nm flare irradiance is brighter than H I Lyman-α for large (>X10) flares.

SORCE XPS Data Products
Version 11: current version
Version 12: February 2020
Version 13 (final): July 2020

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Woods, T. N., P. C. Chamberlin, W. K. Peterson, R. R. Meier, P. G. Richards, D. J. Strickland, G. Lu, L. Qian, S. C. Solomon, B. A. Iijima, A. J. Mannucci, and B. T. Tsurutani, XUV Photometer System (XPS): Improved irradiance algorithm using CHIANTI spectral models, **Solar Physics, 249**, 235-267, 2008.