TIMED Solar EUV Experiment: Phase E Annual Report for 2003

Submitted for NASA Grant NAG5-11408
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SEE Science Team

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NRL: Judith Lean

SpaceWx: Kent Tobiska

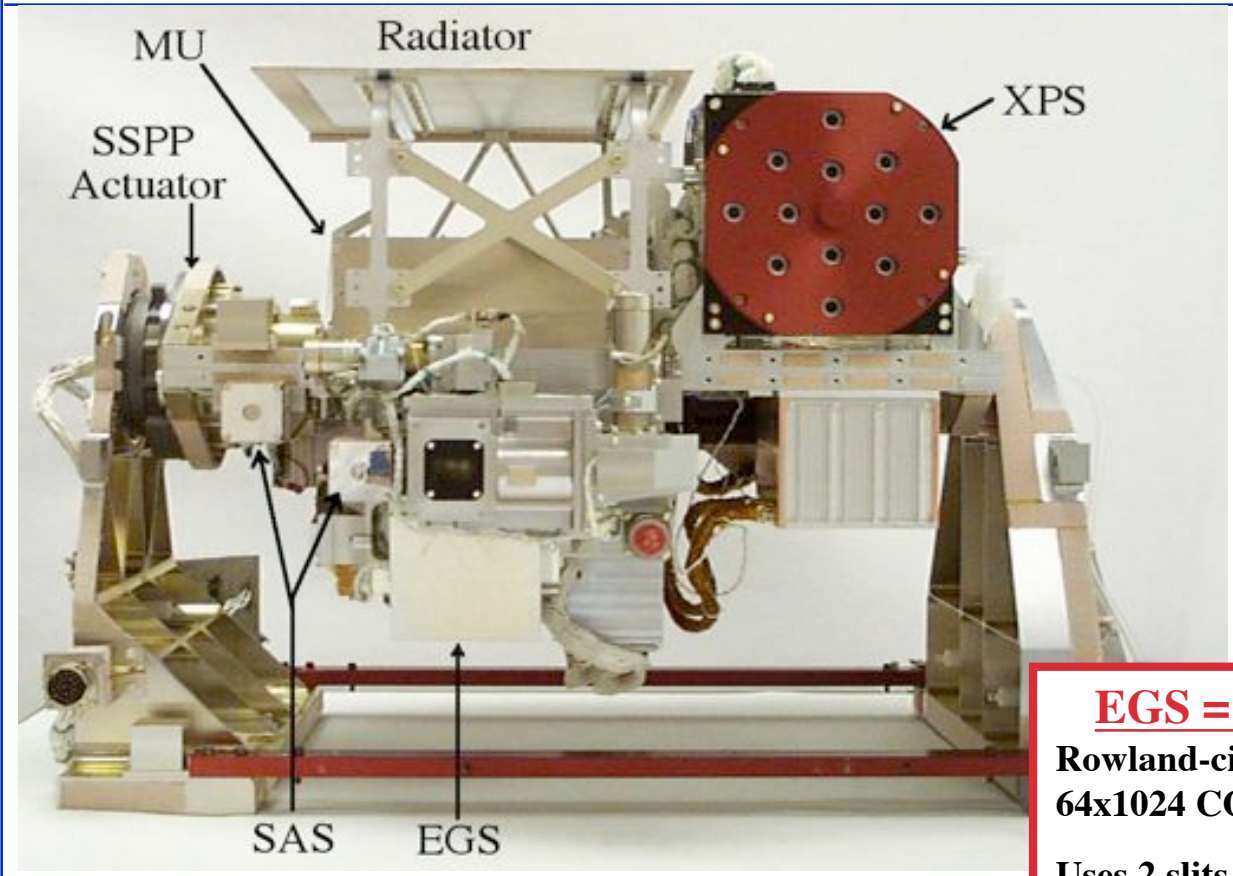
GI/UAF: Scott Bailey

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Aeronautics and Space Administration.

Report Outline

- SEE Instrument Overview, Operations, and Status
- SEE Data Products
- SEE Science Overview
- Summary of SEE Results
- Summary of SEE Related Talks and Papers
- Summary of SEE Solar Observations
- Future Plans for SEE Team

TIMED Solar EUV Experiment



Measures the solar vacuum ultraviolet (VUV) irradiance

Range:

0.1-194 nm

Resolution:

0.4 nm EGS (27-194 nm)

5-10 nm XPS (0.1-34 nm)

Frequency:

10-sec integrations, but only for 3 min per orbit (96 min)

MU = Microprocessor Unit
SSPP = SEE Solar Pointing Platform
SAS = Solar Aspect Sensor (2)

EGS = EUV Grating Spectrograph

Rowland-circle grating spectrograph with 64x1024 CODACON (MCP-based) detector

Uses 2 slits to provide redundant measurements

XPS = XUV Photometer System

Set of 12 Si photodiodes - 8 for XUV, 1 for Ly-α, and 3 for window calibrations

Includes 3 redundant photodiodes

Summary of SEE Flight Operations

- Daily solar observations began Jan. 22, 2002 and include:
  - 98% of orbits with solar observations
  - > 600 days (>99% of mission) with EGS and XPS observations
  - > 300 calibration (redundant channel) solar observations
  - > 300 EGS detector flat-field calibrations (Hg lamp)
  - > 200 solar occultation experiments (90-500 km tangent height range)
- There are no data gaps in 2003. The three data gaps in 2002 are:
  - March 2, 2002: gap for EGS and XPS, due to S/C safehold (yaw around error)
  - March 4, 2002: gap for EGS only, due to improper slit command (ground S/W error)
  - July 25-29, 2002: gap for XPS only, due to its filter wheel anomaly
- SEE calibration rockets have been successful:
  - NASA 36.192 launched on Feb. 8, 2002, complete success
    - Rocket results incorporated into Version 6 data
  - NASA 36.205 launched on Aug. 12, 2003, complete success
    - Rocket results will be incorporated into future SEE products

Status of SEE Instrument

No recent changes for SEE

- **EUV Grating Spectrograph (EGS) - fully functional**
  - The EUV ($\lambda < 115$ nm) has degradation mostly at the bright lines on the CODACON (MCP-based) detector, but it is being tracked with on-board redundant channel and flat-field detector lamp weekly experiments
  - The FUV (115-195 nm) has recovery that is corrected using UARS and XPS comparisons, but it is not fully understood at the longer wavelengths
    - need more UARS/SORCE data and next SEE rocket calibration (Aug 12, 2003)
- **XUV Photometer System (XPS) - 3 channels functional**
  - Fully functional until 2002/205 when there was a filter wheel anomaly (filter wheel stuck in position 6)
  - Three channels continue to make good solar measurements - fill spectral gap from 17-27 nm in SEE Level 3 using prediction of XP#7 with XP#1 measurement
  - No detectable degradation for most channels, but some degradation for 3 channels
  - SORCE, with almost identical XPS, launched on Jan. 25, 2003
    - SORCE XPS data are available now and will be incorporated into future SEE products
- **Microprocessor Unit (MU) - fully functional**
- **SEE Solar Pointing Platform (SSPP) - fully functional**

Status of SEE Data Processing

- SEE data products are being generated daily
  - Version 6 is latest version (released Mar. 2003)
- SEE XPS and EGS Level 2 data products are available
  - Daily average, instrument resolution, atmospheric absorption corrected, degradation corrected, normalized to 1 AU
  - NetCDF format: use IDL read_netcdf.pro to read SEE data products
  - Quick-look: use IDL plotxps_ts.pro or plotegs_ts.pro to plot time series
- SEE Level 3 data products are available
  - SEE Level 3 is the solar irradiance in 1 nm bins on 0.5 nm centers from 0-195 nm along with a list of the irradiances of 38 EGS emission lines and of 9 XPS results
  - EGS data is used above 27 nm and a solar model scaled to the XPS data is used below 27 nm.
- SEE Version 6 data are better validated
  - Version 5 data have several calibration issues related to X-ray sensitivity for XPS and order sorting for EGS.

http://lasp.colorado.edu/see/

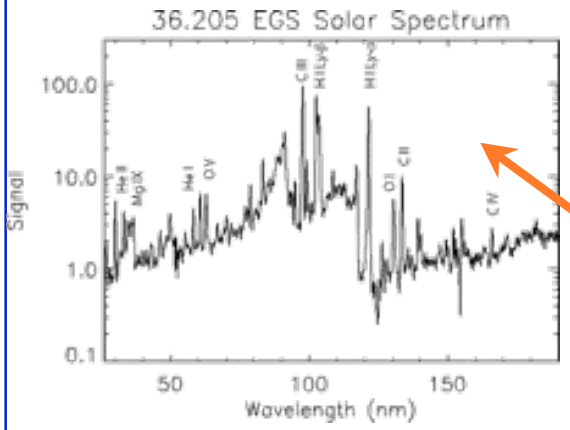
Improved web site released Sept. 2003

Future Plans for SEE Data Products

- SEE Version 7 data products - plan to release in Dec. 2003
  - EGS revisions
    - Incorporate latest rocket calibration results - address long-term FUV recovery
    - Improved field of view (FOV) maps
  - XPS revisions
    - Incorporate latest rocket calibration results - address long-term degradation
    - Improved field of view (FOV) maps
    - Improved dark and gain corrections (fix XP#5 negative irradiance issue)
  - New SEE observation average data products (3-min average every orbit)
    - Produce orbit average solar UV irradiances that are needed for solar storm / flare studies and useful for space weather studies by NOAA and Air Force
      - New products will be called EGS L2A, XPS L2A, and SEE L3A
      - Similar format as the daily average solar UV irradiance data products (EGS L2, XPS L2, SEE L3)

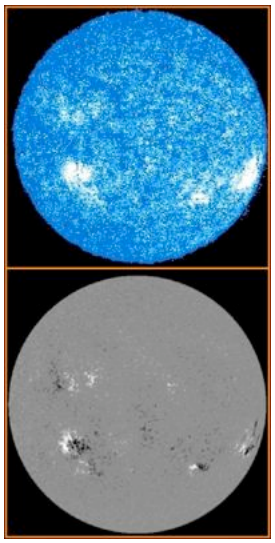
- Extended mission plans include additional SEE data products as requested from the community - planned release in 2004
  - New SEE occultation data product
    - Produce atmospheric transmission / density from EGS occultation measurements (100-500 km range)
      - New product will be called EGS L2occ
  - Improved spectral coverage for the XPS data product
    - Include SORCE XPS solar XUV irradiances in the TIMED SEE L3 data product
    - Improved algorithm for covering the full XUV range (fill XUV gap more accurately)

2003 Calibration Rocket Is Successful

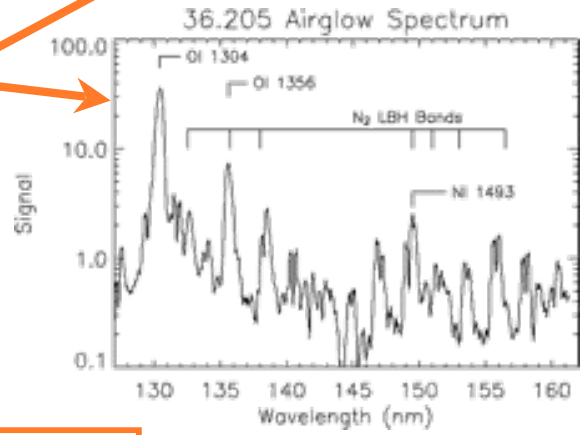


- SEE Calibration Flights
  - NASA 36.192: Feb. 8, 2002
  - NASA 36.205: Aug. 12, 2003
- Prototype EGS
  - 26-190 nm, $\Delta\lambda$=0.4 nm
- Prototype XPS
  - 0.1-35 nm, $\Delta\lambda$=~7 nm
- FUV Airglow
  - 128-160 nm
- Solar Imager
  - H I 1216

Rocket Ly-α Image



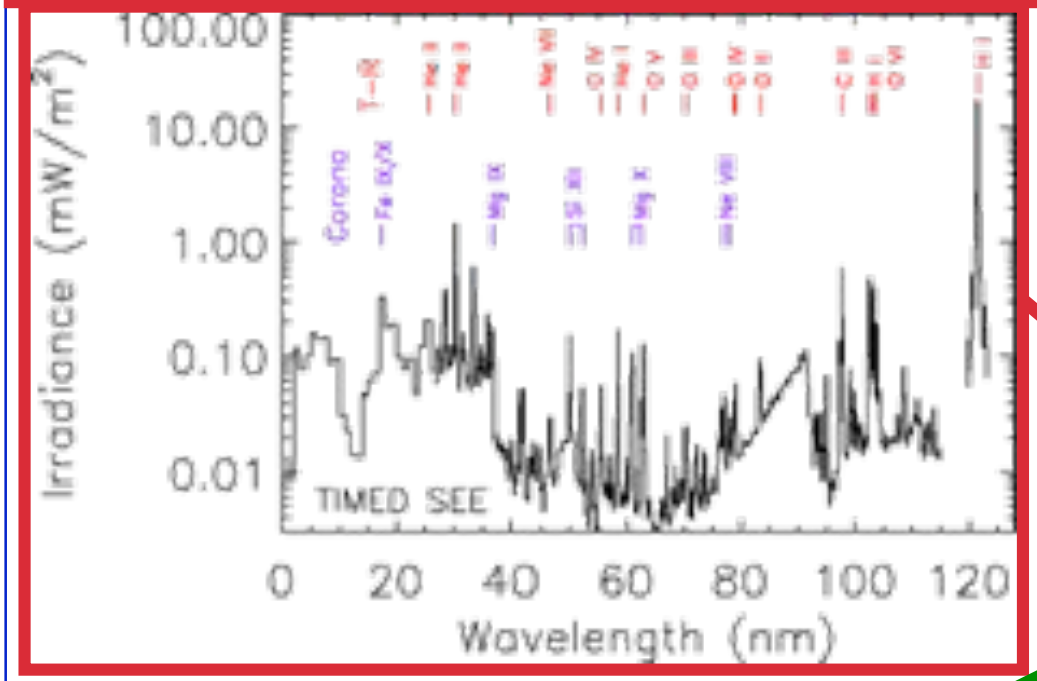
SOHO
Magnetogram



Also coordinated observations
with UARS, SOHO, TRACE, SORCE

SEE Science Plans

Solar UV Irradiance Measurements



Obj. #1

Validations

Internal Calibrations,
Underflight Calibrations
SOHO, SNOE,
UARS, SORCE

Eparvier, Woods, Bailey, Rottman

Obj. #2

Solar UV Variability

Function of wavelength
Over time scales of minutes to years

All

Obj. #4

Modeling Solar Variation

Study variations related to active region evolution derived from solar images
Improve the **NRLEUV, SOLAR2000,** and **SunRise** solar irradiance models

Lean, Tobiska, White, Fox, Woods

Obj. #3

Obj. #5

Study Earth's Response

Photoelectron analysis with FAST data and using the ***glow*** model
Atmospheric response studies using HAO's **TIM-GCM**

Solomon, Roble, Bailey, Eparvier

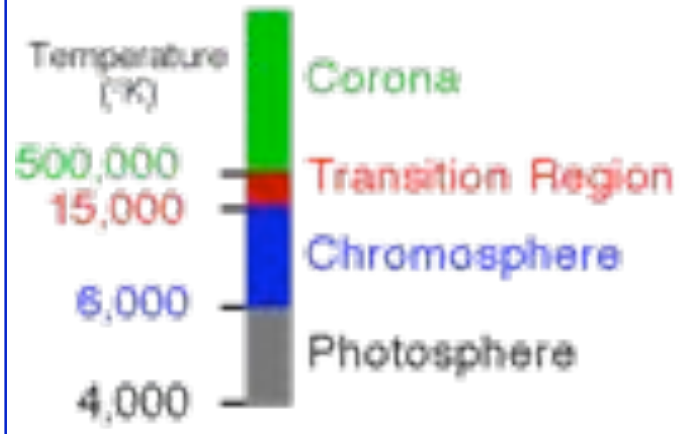
Overview of SEE Science Objectives

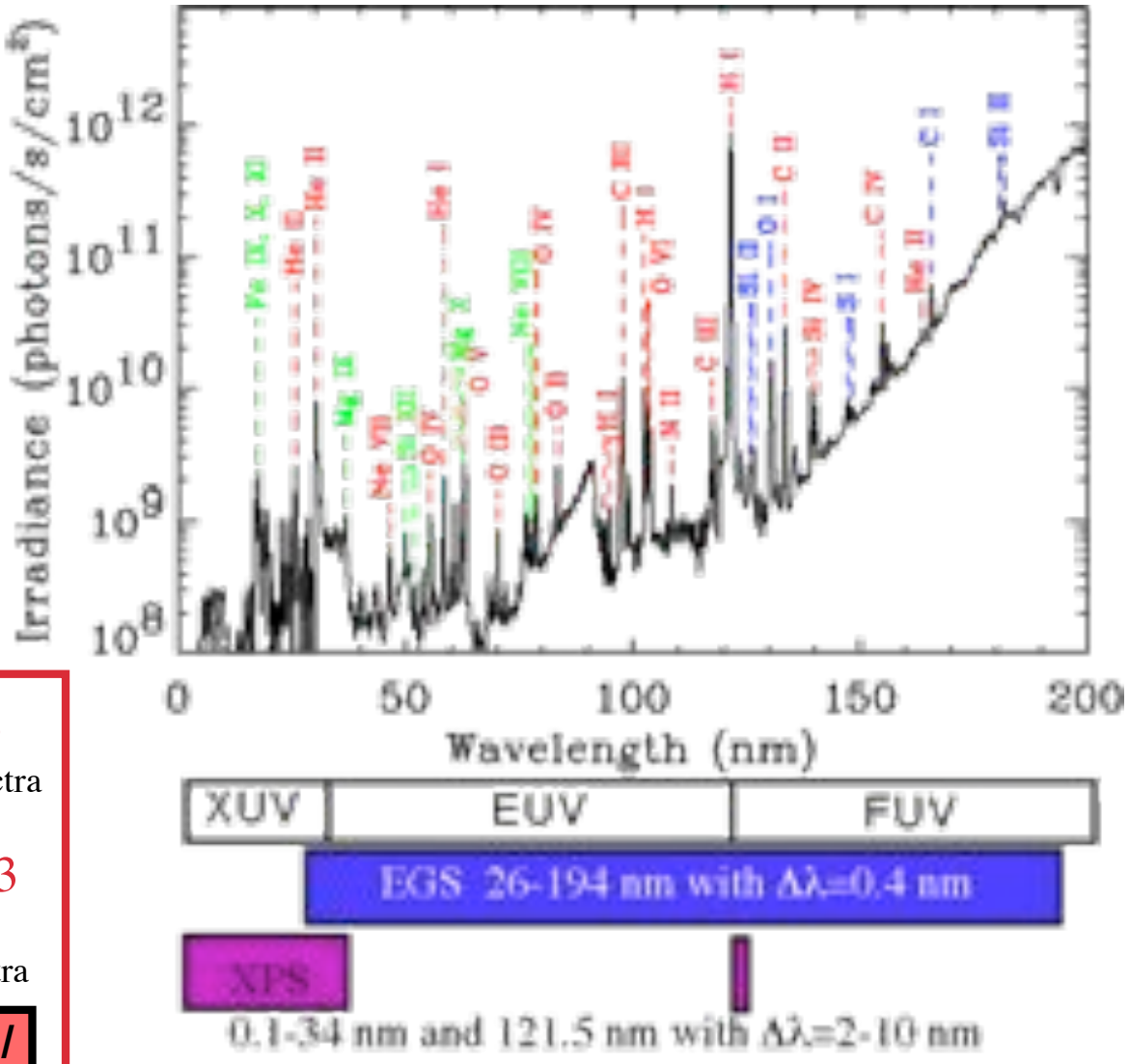
1. Accurately and precisely determine the time-dependent solar vacuum ultraviolet (VUV: below 200 nm) spectral irradiance
2. Study solar VUV variability (27-day rotations, solar cycle changes) and its sources
3. Study the solar-terrestrial relationships utilizing atmospheric models, primarily the TIME-GCM at HAO/NCAR
4. Improve proxy models of the solar VUV irradiance
5. Determine the thermospheric neutral densities (O_2, N_2 and O) from solar occultations

Summary of SEE Results

- **Objective 1: solar VUV spectral irradiance measurements**
  - Daily measurements since Jan. 22, 2002
  - On-going validation effort to verify 10-20% accuracy and 2-4% precision
- **Objective 2: solar variability**
  - Several solar rotations (23) observed during solar maximum conditions
  - Many flares (> 100) observed by SEE during TIMED mission
- **Objective 3: model solar response in Earth's atmosphere**
  - Use of *glow* model with SEE solar data and photoelectron data (FAST, GUVI)
  - Use of HAO TIME-GCM for atmospheric response to SEE's solar input
  - Comparison of GUVI Q_{EUV} and SEE solar irradiance measurements
- **Objective 4: solar irradiance modeling**
  - SOLAR2000 model improvements
  - NRLEUV model improvements
- ***Several new SEE results will be presented at Dec. 2003 AGU meeting***

Example Solar VUV (0-200 nm) Spectrum





SEE Data Products - Version 6

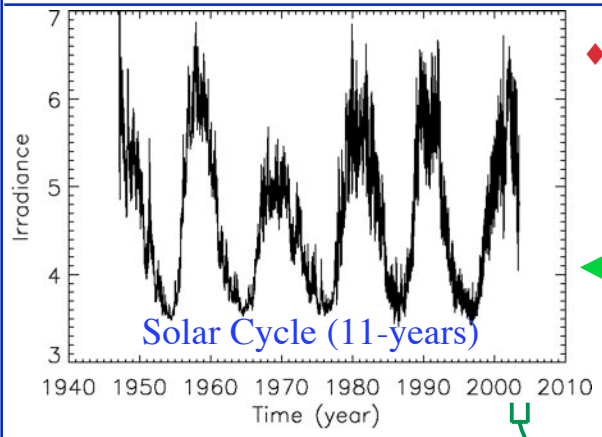
- Daily-averaged solar EUV irradiance spectra
- NetCDF files, IDL software available

Version 7 - Available Dec 2003

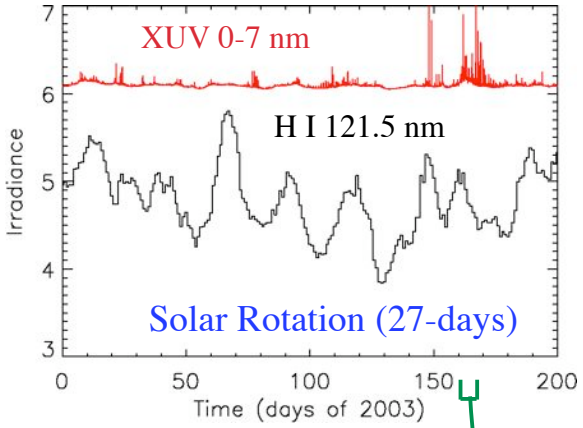
- Improved calibrations
- Orbit-averaged solar EUV irradiance spectra

http://lasp.colorado.edu/see/

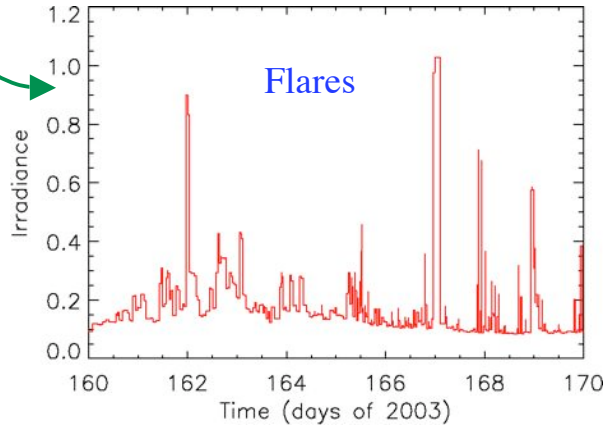
Examples of Solar Variations



- Solar Cycle - months to years
  - Evolution of solar dynamo with 22-year magnetic cycle, 11-year intensity (sunspot) cycle
  - Long-term H I Lyman-α time series has been extended with TIMED SEE measurements



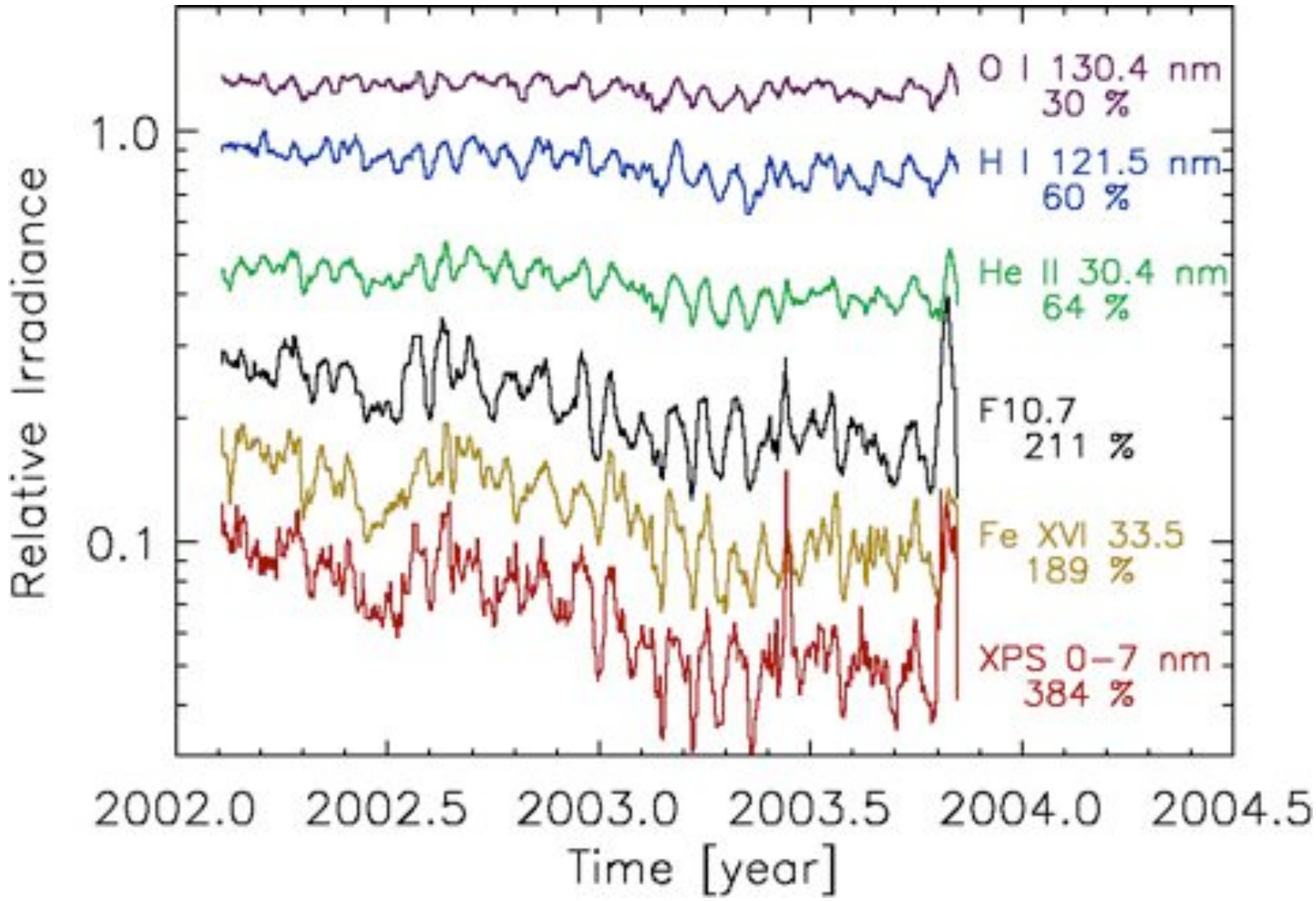
- Solar Rotation - days to months
  - Beacon effect of active regions rotating with the Sun (27-days)



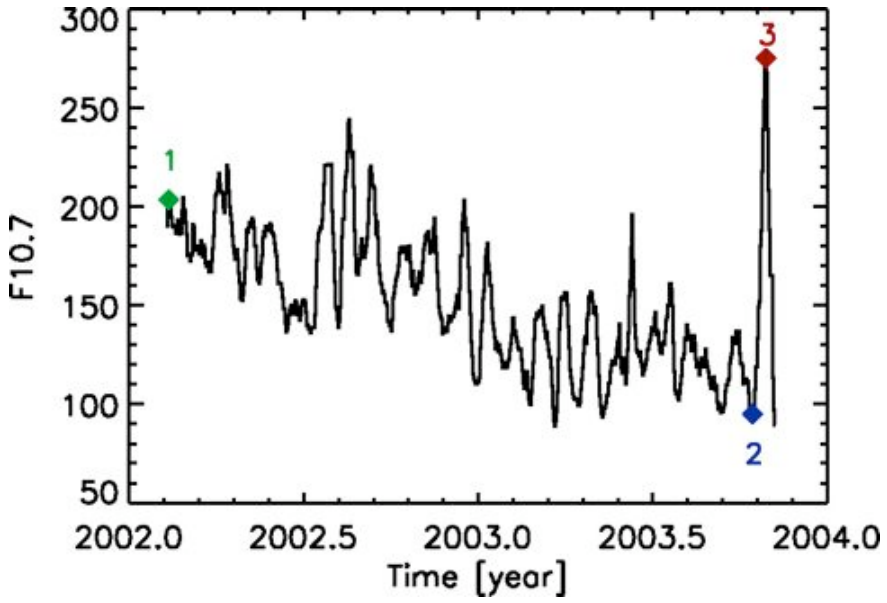
- Flares - seconds to hours
  - Related to solar storms (such as CMEs) due to the interaction of magnetic fields on Sun

SEE Has Made New Record of Solar EUV Variations

SEE has made daily measurements for 22 months (23 solar rotations).



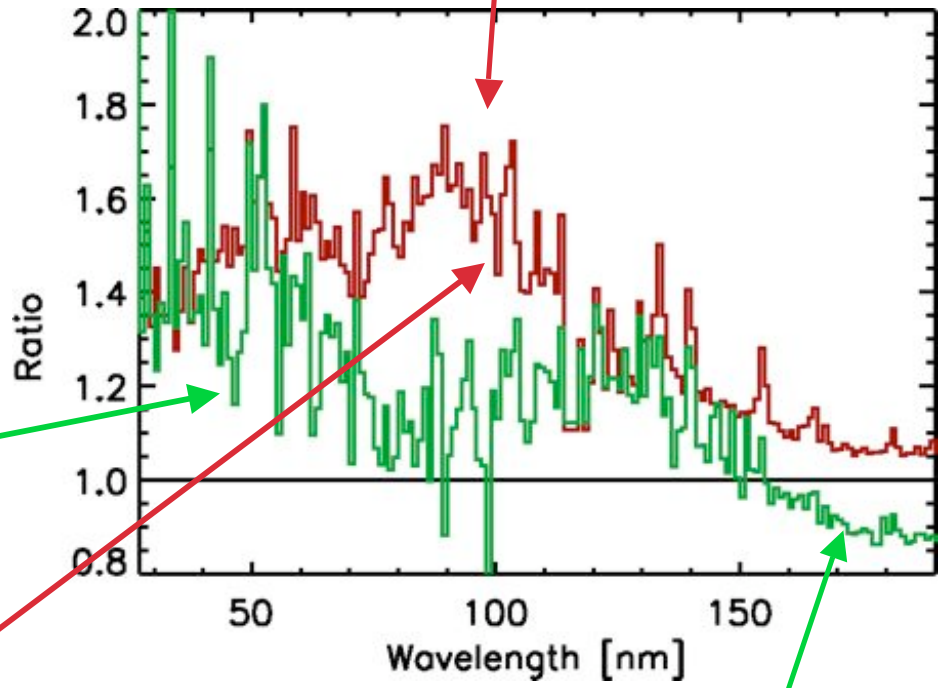
Solar Variations During TIMED Mission



$\frac{Day1}{Day2}$ = Variations over TIMED Mission and / or Instrument Degradation

$\frac{Day3}{Day2}$ = Largest Solar Rotation During TIMED Mission

Second and third order emissions are not fully removed from the flare data in the 70-110 nm range.

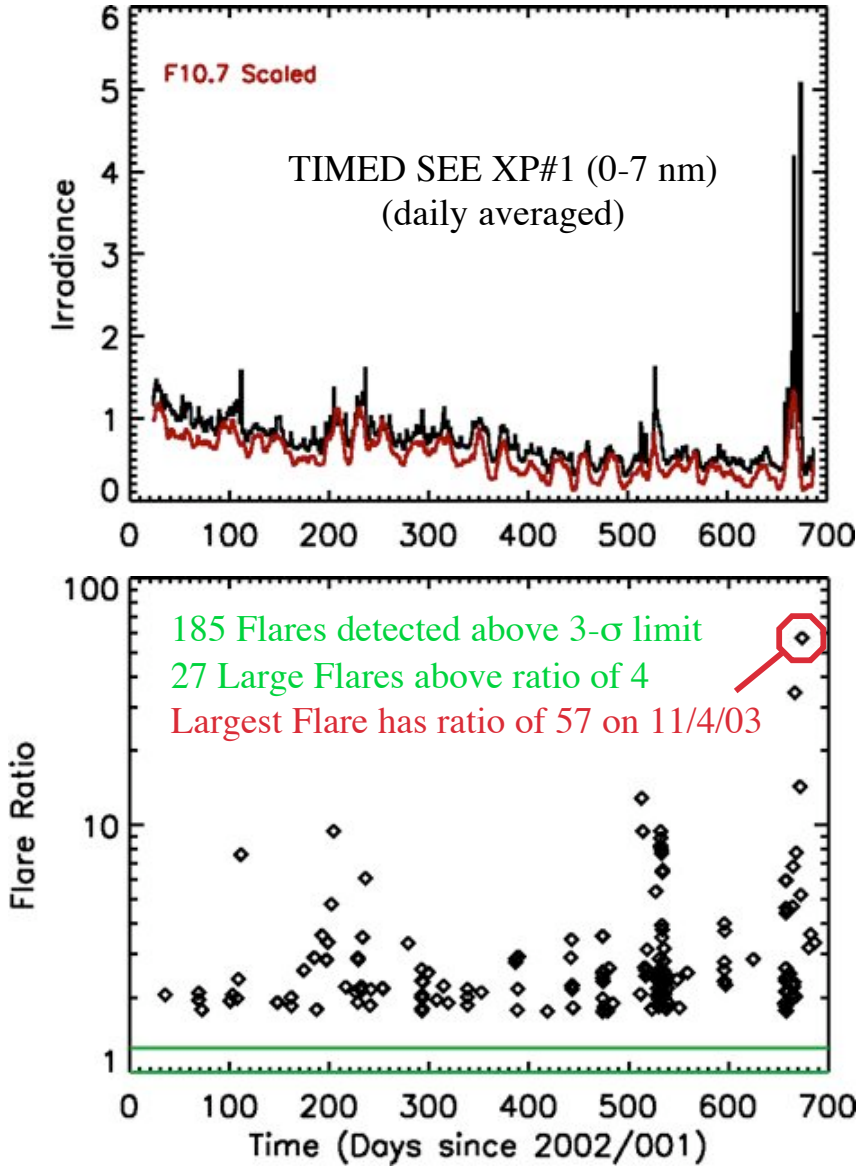


Recovery factor in the FUV will be corrected in future SEE products.

Over 180 Flares Detected By TIMED SEE

- Somewhat unexpected for TIMED SEE to observe flares because of its 3-min observations per orbit
- Expected frequency of flares:
  - ~1 X-class flare per month
  - ~15 M-class flares per month

  [Garcia, *Ap J Suppl, 127*, 189, 2000]
- 185 flares have been observed by TIMED SEE



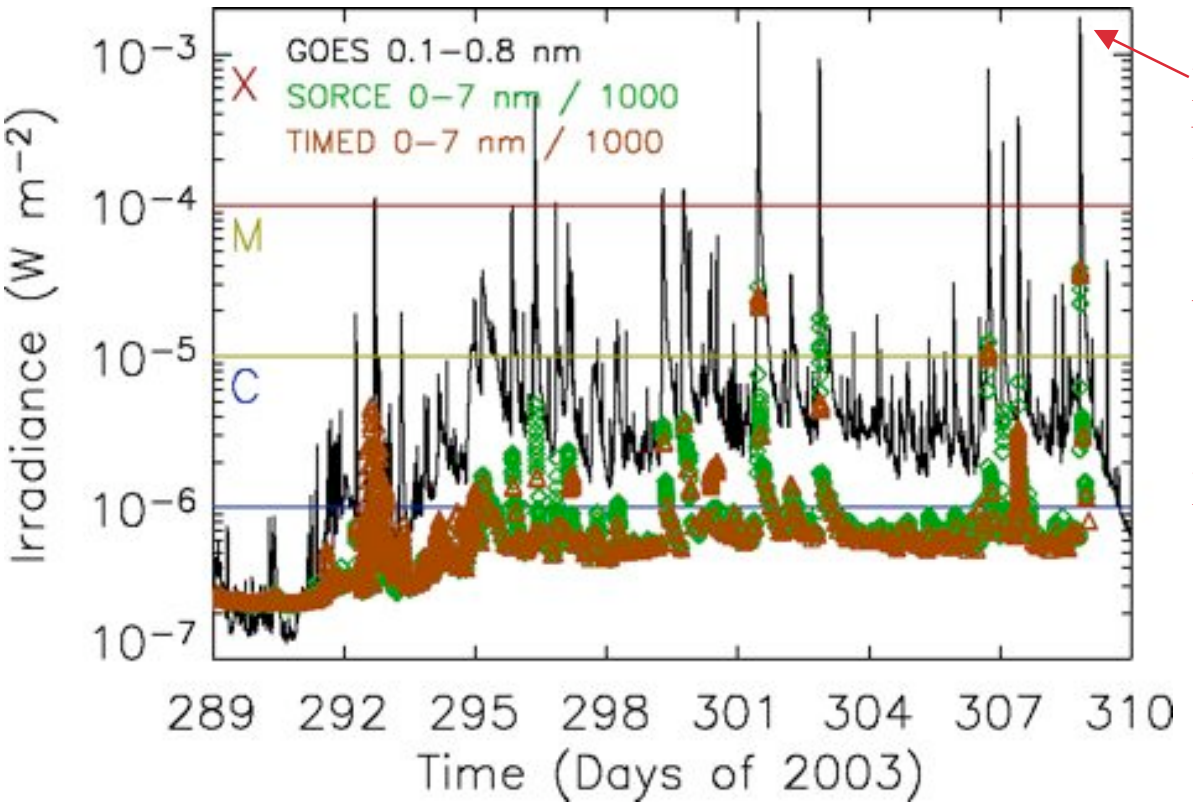
TIMED SEE Large Flare Summary

- Two concentrations
  - **100 flares** during May 26 - June 27, 2003
  - **54 flares** during Oct. 19 - Nov. 4, 2003
- Six peak observations
  - Marked with a "P"
- Two Monster Flares
  - Nov. 4, 2003 - X28
  - Oct. 28, 2003 - X17
    - EUV increase was larger for this flare than the X28 flare

SEE Observations Date - Time (UT)	GOES Class (Peak Time)	Flare / Pre-flare Ratio for 0-7 nm
4/21/02 02:13	X1.5 (01:51)	7.6
7/23/02 00:52	X4.8 (00:35)	9.5
8/24/02 01:38	X3.1 (01:12)	6.1
5/27/03 23:08 P	X1.3 (23:07)	12.6
5/29/03 01:06 P	X1.2 (01:05)	9.4
6/11/03 00:04 P	X1.3 (00:02)	5.4
6/15/03 23:58 P	X1.3 (23:56)	9.4
6/17/03 22:57 P	M6.8 (22:58)	6.6
10/26/03 07:27	X1.2 (06:54)	4.7
10/26/03 18:47	X1.2 (18:19)	6.8
10/28/03 11:17	X17.2 (11:10)	34.4
10/29/03 21:18	X10.0 (20:49)	7.7
11/02/03 17:36	X8.3 (17:25)	14.3
11/03/03 09:51	X3.9 (09:55)	5.2
11/04/03 19:48 P	X28 (19:48)	57.3

Major Solar Storms : Oct. 19 - Nov. 4

Large, complex active regions are sources for the solar events

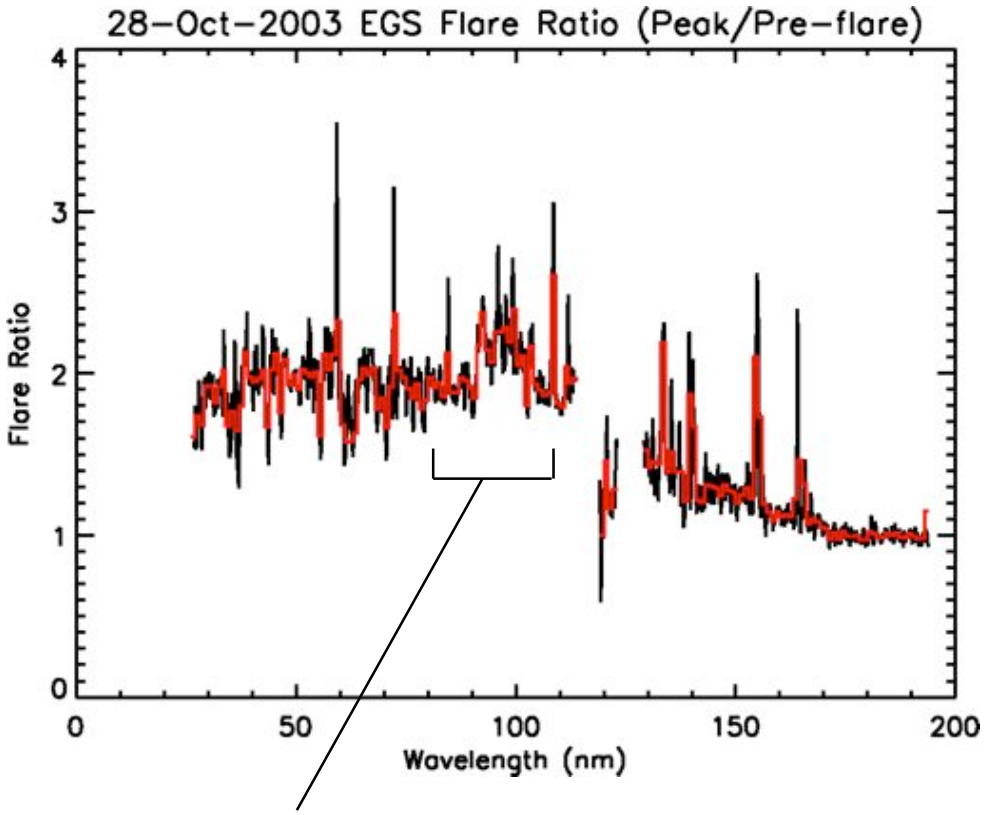


X-28 flare on Nov. 4 is largest flare ever measured by GOES (1976-present)

X-17 flare on Oct. 28 is 4th largest flare

- SEE observed 11 of the 12 large X-class flares during this storm period
  - Monster X-28 flare on Nov. 4 had x60 increase for 0-7 nm irradiance !
  - Solar EUV increases for the large flares are as large as solar cycle variations !
- SEE EGS (via detector background signal) also detected x100 increase of high energy protons on days 301-304 in the polar regions

Variability of the Solar UV Irradiance for X17 Flare



Some contamination of the spectrum by emissions from higher grating orders

- X17 class flare on Oct. 28, 2003

- X-ray increased by factor of 34
- EUV increased by factor of 2
- Longer wavelengths enhanced much less (10-40%)

Flare variations are larger than 11-year solar cycle variations !!!

Additional SEE flare measurements on April 21, 2002 and FAST photoelectron measurements are given in Woods et al. [Space Weather, 1001, 2003].

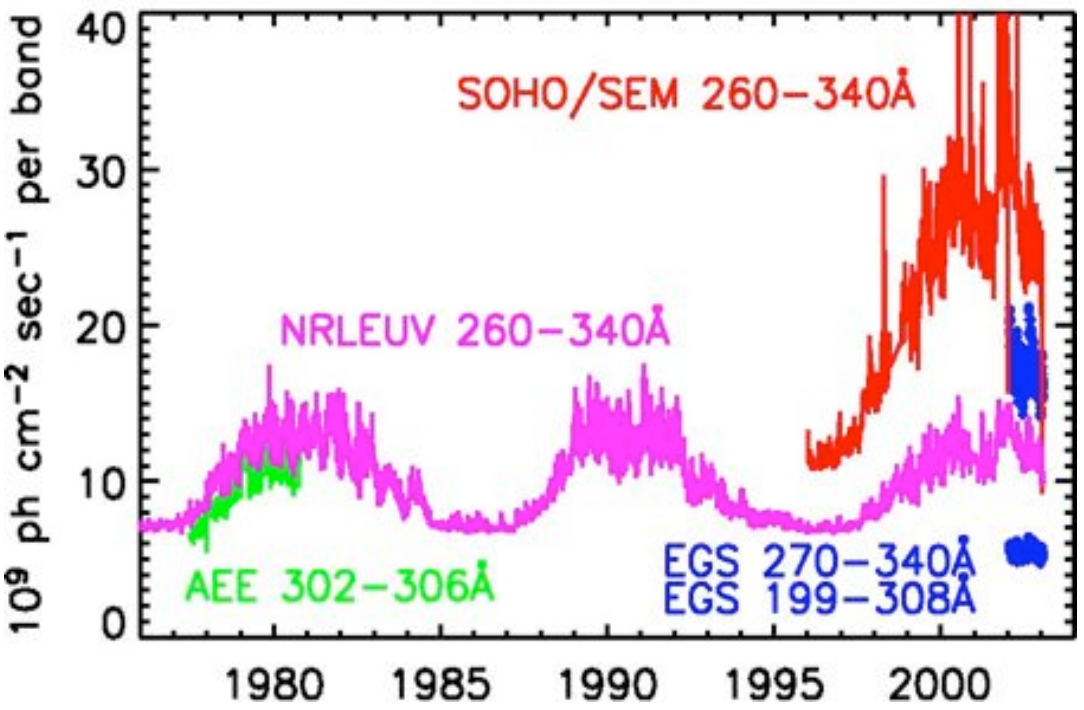
SOLAR2000 Model Improvements

- Version 2.21 (research grade) released May 03
  - SOLAR2000 model now has daily variability from 1 to 420 nm (extended to longer wavelengths)
  - Incorporates SEE Version 6 data (Level 3)
  - Also includes results from SNOE, SOHO SEM, YOHKOH, AE-E, SOLRAD, UARS, and sounding rockets
  - New E1_40 proxy : integrated irradiance 1-40 nm
  - GUI addition for different model sets
  - Improved exospheric temperature for Earth

NRLEUV Model Comparisons

- Comparisons of the NRLEUV model has focused on the important He II 30.4 nm emission, of which there are measurements from SOHO EIT, SOHO SEM, and TIMED SEE

Measurements and Models

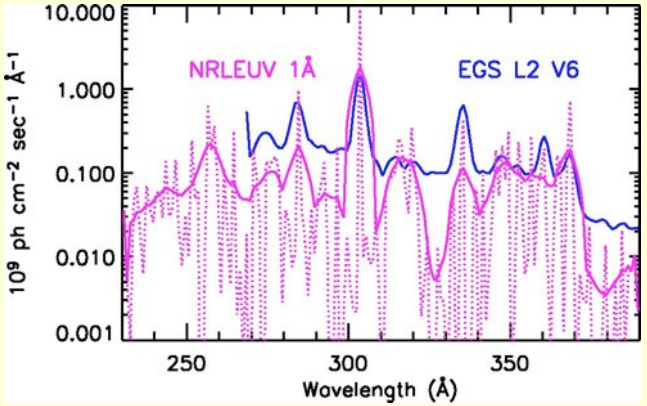


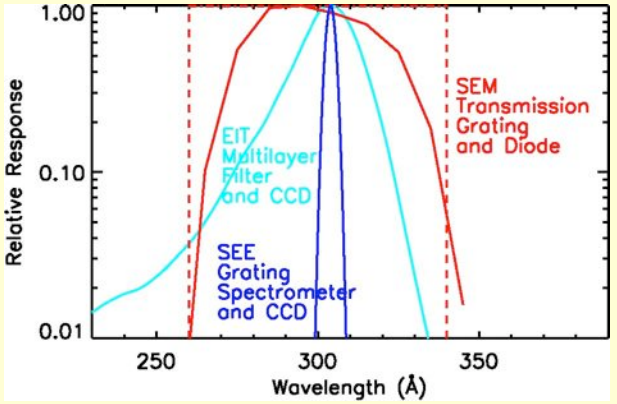
How and why does solar 304 Å irradiance vary?

- factors of two difference in absolute values and solar cycle variations

- relative changes during rotation modulation are better constrained

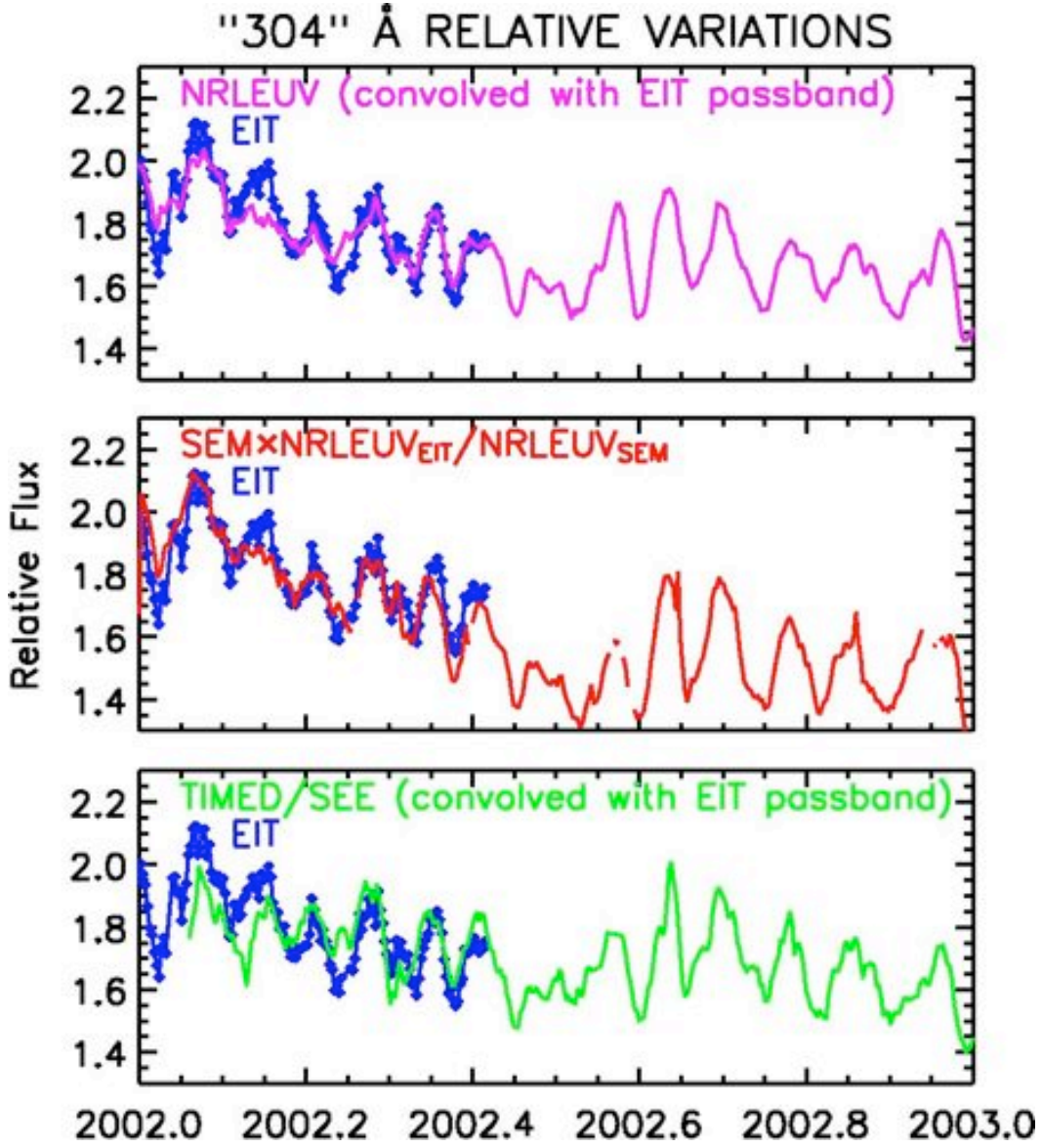
Solar Spectrum near 304Å





Instrument Passbands

NRLEUV Model Comparisons - 2



EIT
NRLEUV
SEM TIMED/SEE
Rotational
Modulation
in 2002

~ 20% rotational modulation near cycle max
- generally good agreement among EIT, NRLEUV, SEM and SEE
- NRLEUV underestimates some rotations
- SEM has larger trend
- SEE has smaller trend

SEE Team Held Feb. 2003 Workshop

SEE Workshop Agenda

8:00	Introduction / SEE Status	Tom Woods
8:30	SEE Data Processing	Don Woodraska
9:35	SEE Operations	Karen Turk
10:10	**break**	
10:20	SEE Rocket EGS Calibration	Phil Chamberlin
11:00	XPS Validation	Tom Woods
11:40	**lunch**	
12:40	EGS Validation	Frank Eparvier
1:40	NRLEUV Solar Model	Judith Lean
2:20	HAO TIME-GCM	Stan Solomon
3:00	**break**	
3:10	SOLAR2000 Model	Kent Tobiska
3:50	Photoelectron Analysis	Scott Bailey
4:30	Planning / publications	Tom Woods

February 10, 2003 at JHU/APL

SEE Related Talks in 2003

- TIMED Science Meeting: Feb 2003, 6 talks
- EGS Meeting: Apr 2003, 2 talks
- SORCE Validation Workshop: Apr 2003, 2 talks
- AGU Spring Meeting: May 2003, 1 talk
- AAS/SPD Meeting: May 2003, 1 talk
- Solar Cycle Symposium: June 2003, 1 talk
- IUGG Meeting: July 2003, 1 talk
- APL Storm Workshop: Aug 2003, 1 talk
- TIMED Science Meeting: Sept 2003, 3 talks
- AGU Fall Meeting: Dec 2003, 4 talks
- Public Seminars: LASP/CU, CSU, NOAA, NCAR

SEE Related Papers in 2003

- Woods, T. N., S. M. Bailey, W. K. Peterson, H. P. Warren, S. C. Solomon, F. G. Eparvier, H. Garcia, C. W. Carlson, and J. P. McFadden, Solar extreme ultraviolet variability of the X-class flare on April 21, 2002 and the terrestrial photoelectron response, *Space Weather*, **1**, 1001, doi:10.1029/2003SW000010, 2003.
- Tobiska, W.K., Forecast E10.7 for Improved LEO Satellite Operations, *J. Spacecraft Rock.,* **40** (3), 405-410, 2003.
- Eparvier, F. G., T. N. Woods, D.L. Woodraska, S.M. Bailey, and S.C. Solomon, Spectral irradiance measurements from the TIMED Solar EUV Experiment, *Advances in Space Research*, in press, 2003.
- Woods, T., L. W. Acton, S. Bailey, F. Eparvier, H. Garcia, D. Judge, J. Lean, D. McMullin, G. Schmidtke, S. C. Solomon, W. K. Tobiska, and H. P. Warren, Solar extreme ultraviolet and x-ray irradiance variations, in *Solar Variability and Its Effect on Earth's Atmospheric and Climate System,* eds. J. Pap, C. Fröhlich, H. Hudson, J. Kuhn, J. McCormack, G. North, W. Sprig, and S. T. Wu, Geophys. Monograph Series, Wash. DC, in press, 2003.
- Thuillier, G., T. N. Woods, L. E. Floyd, R. Cebula, M. Hersé, and D. Labs, Reference solar spectra during solar cycle 22, in *Solar Variability and Its Effect on Earth's Atmospheric and Climate System,* eds. J. Pap, C. Fröhlich, H. Hudson, J. Kuhn, J. McCormack, G. North, W. Sprig, and S. T. Wu, Geophys. Series, Wash. DC, in press, 2003.
- Tobiska, W. K. and A. A. Nusinov, Status of the ISO draft standard for determining solar irradiances, *Adv. Space Research*, in press, 2003.
- Tobiska, W.K., SOLAR2000 irradiances for climate change research, aeronomy, and space system engineering, *Adv. Space Research*, in press, 2003.
- Eparvier, F. G. and T. N. Woods, Solar EUV spectral irradiance: Measurements and variability, in *Proceedings of the International Solar Cycle Study 2003 Symposium*, ed. J. Pap, in press, 2003.
- Povich, M. S., J. C. Raymond, G. H. Jones, M. Uzzo, Y.-K. Ko, P. D. Feldman, P. L. Smith, B. G. Marsden, and T. N. Woods, Discovery of doubly ionized C in the ion tail of comet Kudo-Fujikawa, *Science*, in press, 2003.

Summary of SEE Observations

- TIMED SEE has been very successful in obtaining new, accurate measurements of the solar EUV irradiance
  - SEE data available from http: //lasp.colorado.edu/see/
- More than 180 flares have been observed by SEE
  - Extreme flare periods are May-June 2003 and Oct.-Nov. 2003
  - Large flares vary as much as 11-year solar cycle variations
- More than 23 solar rotations have been observed by SEE
  - Variability of 5-70% observed (wavelength dependent)
- TIMED mission has observed solar maximum and declining phase of solar cycle 23
  - Extended TIMED mission should observe solar cycle minimum conditions that is predicted in the 2006-2008 timeframe

SEE Plans for 2004

- Daily mission operations and data processing for SEE
  - New data products (L2A and L3A are orbit averages) are included in the SEE Version 7 data products
- Additional validations
  - Validate new SEE Version 7 data products
  - Next underflight rocket calibration planned for Oct. 2004
- Detailed solar variability studies
  - More complete analysis of the 23+ solar rotation and 100+ flare observations
  - Improve models of the solar UV irradiance
- Detailed modeling of Earth's response to solar irradiance changes
  - Composition, dynamics, temperature using TIME-GCM
  - Photoelectrons using *glow* model
- Occultation data analysis