TIMED Solar EUV Experiment: Phase E Annual Report for 2006

SEE Science Team

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Report Outline

- ◆ SEE Instrument Operations and Instrument Status
- ◆ SEE Data Products
- ◆ SEE Science Overview
- ◆ Summary of SEE Results
  - • Flare measurements and modeling and their impact on the upper atmosphere
  - • Solar influences on thermosphere's neutral density and improved modeling on satellite drag
  - • Results from SEE Solar - GUVI QEUV workshop in Aug 2006
- ◆ Summary of SEE Related Talks and Papers
- ◆ Summary of SEE Solar Observations
- ◆ Future Plans for SEE Team

Overview of Operations
and Data Processing

SEE Measures the Solar VUV Irradiance
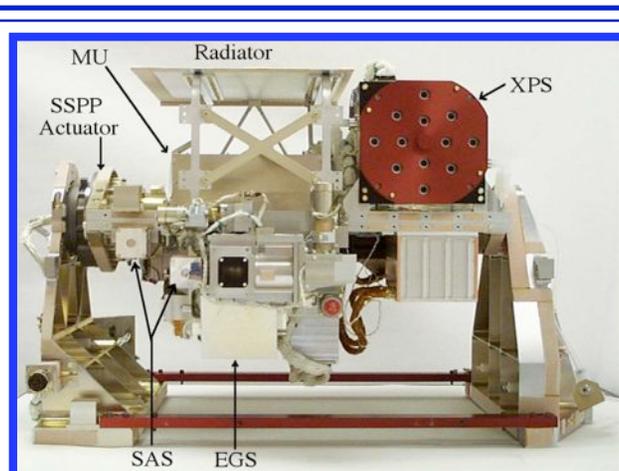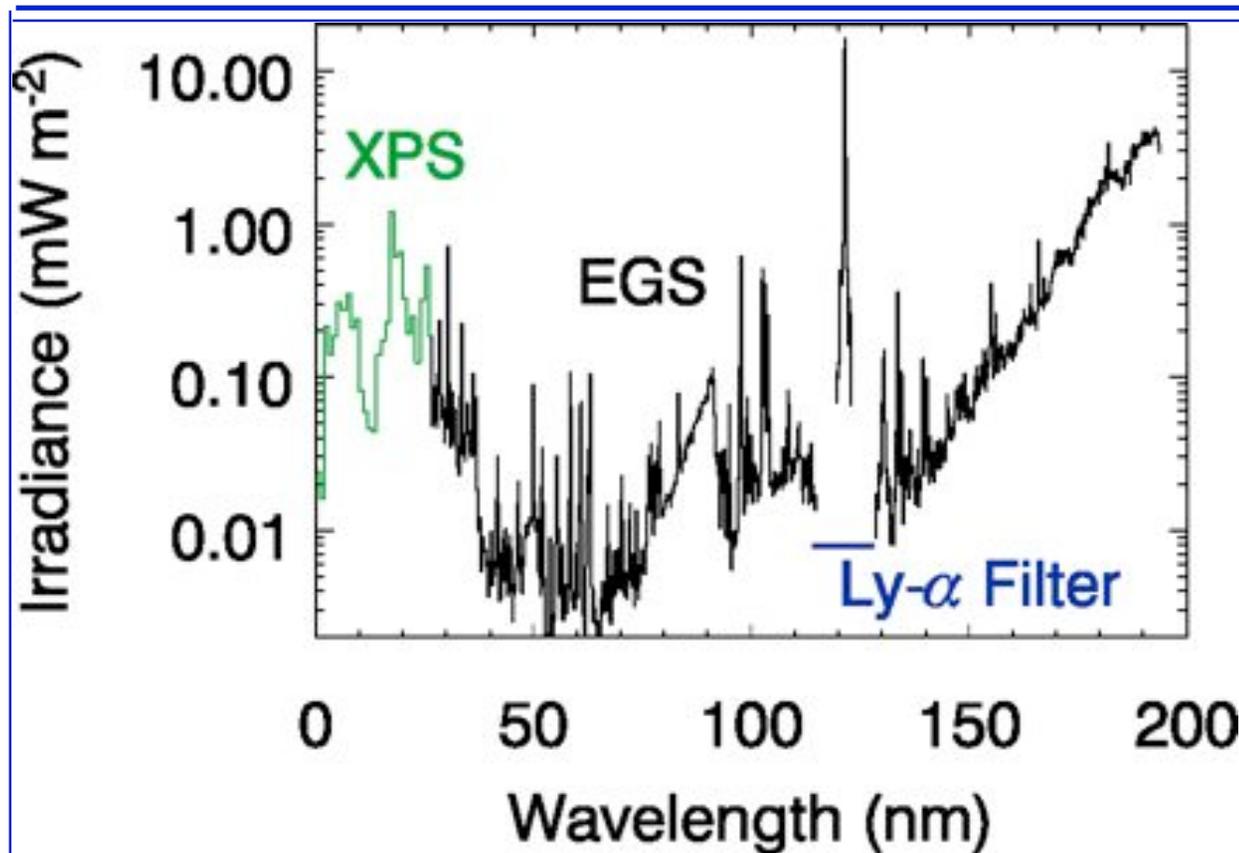
EGS = EUV Grating Spectrograph
Rowland-circle grating spectrograph with
64x1024 CODACON (MCP-based) detector

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

XUV	EUV	FUV

EGS 27-194 nm with Δλ=0.4 nm

XPS 0.1-34 nm with Δλ=7-10 nm
and Ly-α (121.6 nm) with Δλ=2 nm

FUV = Far UltraViolet: 115-200 nm
EUV = Extreme UltraViolet: 30-115 nm
XUV = X-ray UltraViolet: 0-30 nm

EGS = EUV Grating Spectrograph
XPS = XUV Photometer System

TIMED SEE

Summary of SEE Flight Operations

- ◆ Planned Experiments (through Dec 31, 2006)
  - • Number of normal solar experiments = 25,844

- ◆ Actual Experiments (through Dec 31, 2006)
  - • Number of normal solar experiments = 25,104 (97.1%)

- ◆ Calibration rockets provide degradation rates for SEE
  - • 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 incorporated into Version 7 data
  - • NASA 36.217 launched on Oct. 15, 2004, complete success
    - – Rocket results incorporated into Version 8 data
  - • NASA 36.233 launched on Oct. 28, 2006
    - – Partial success (only 0.1-36 nm and 121.6 nm irradiance measured)
    - – Reflight being considered by NASA HQ for 2007

List of SEE Data Gaps

Date	State	Sensor(s)	Science Data Affected
March 1, 2002	Safe Mode	Both	Part day
March 2, 2002	Safe Mode	Both	All day
March 4, 2002	Ground SW Anomaly	EGS	All day
March 5, 2002	Ground SW Anomaly	EGS	Part day
March 19, 2002	Safe Mode	Both	Part day
March 29, 2002	Safe Mode	Both	Part day
July 24 - 30, 2002	XPS Filter Wheel Anomaly	XPS	All days
Nov. 18-19, 2002	Leonid Safing	Both	Part day
Sept. 16 - 21, 2004	TIMED Flight Software Load	Both	Sept. 16,21: Part day Sept. 17-20: All day
Sept. 29 - Oct. 1, 2004	TIMED Flight Software Load	Both	Sept. 29, Oct. 1: Part day Sept. 30: All day
May 4, 2005	Lost data due to HK rate being at 5 sec (normally 15 sec)	Both	Part day (after SSR allocation reached)

TIMED SEE

Status of SEE Instruments

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, SORCE, and XPS comparisons

- **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 providing solar measurements
  - SORCE, with almost identical XPS, launched on Jan. 25, 2003
    - SORCE XPS data are incorporated into SEE version 7 (and later) Level 3 data products in the 0.1-27 nm range

- **Microprocessor Unit (MU) - fully functional**
- **SEE Solar Pointing Platform (SSPP) - fully functional**

SEE Version 8 Data Products

- SEE Version 8 data products - released June 2005
  - SEE Level 2, 2A, 3, and 3A data products are available on public FTP site and are updated daily
  - EGS improvements
    - Improved flat-field corrections, wavelength scale algorithm, and field of view correction
    - Incorporate first three rocket calibration results
  - XPS improvements
    - Incorporate first three rocket calibration results
    - Improved solar irradiance model for the Level 3 and 3A data products using SORCE XPS data
  - SEE space weather data product - Level 2A SpWx
    - Producing observation averaged solar UV irradiances for select wavelengths that are useful proxies for space weather operations used by NOAA Space Environment Center (SEC)
      - XPS: 0.1-7 nm
      - EGS: He II 30.4 nm, Fe XVI 33.5 nm, Mg IX 36.8 nm, H I 121.6 nm, C II 133.5 nm
      - EGS broadbands: 27-34 nm, 145-165 nm

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

Future Plans for SEE Data Products

- Plans for SEE Version 9 data products - release to be in early 2007
  - EGS revisions
    - Improved flagging of data affected by energetic particles (in polar regions)
    - Updated FUV degradation rates from comparison to SORCE
    - If reflight of calibration rocket, then can update EUV degradation rates
  - XPS revisions
    - Updated radiometric calibrations and updated XUV degradation rates
    - New Level 4 algorithm using GOES XRS for flare temperature and CHIANTI model
      - Also improves Level 3A 0-27 nm irradiance results for flares
  - **New SEE occultation data product**
    - Produce atmospheric transmission / density from EGS occultation measurements (100-500 km range)
      - New product will be called EGS L2occ

- **LASP Interactive Solar IRradiance Datacenter (LISIRD)**
  - Relatively new data center at LASP for its solar irradiance data products
    - SME, UARS SOLSTICE, TIMED SEE, SORCE, rocket experiments
    - Future missions: Glory TIM, SDO EVE
  - http://lasp.colorado.edu/LISIRD/

SEE Science Overview

SEE Science Plans

Solar UV Irradiance Measurements
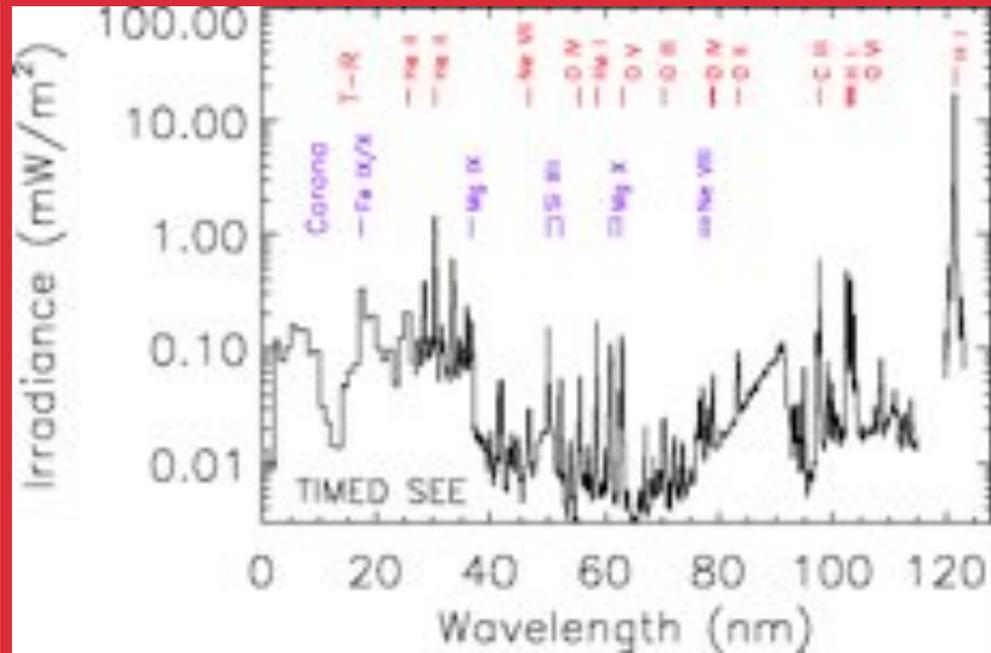
Obj. #1

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

Eparvier, Woods, Bailey, Rottman

Obj. #2

All

Solar UV Variability
Function of wavelength
Over time scales of minutes to years

Obj. #4

Obj. #3

Obj. #5

Solomon, Roble, Bailey, Eparvier

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

Lean, Tobiska, Chamberlin, Woods

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

TIMED SEE

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 - 1

- **Objective 1: solar VUV spectral irradiance measurements**
  - Daily measurements since Jan. 22, 2002 with very few gaps
  - SEE solar EUV irradiance and GUVI QEUV have much less differences with recent improvements / calibrations for GUVI QEUV and for new XPS algorithm for the 0.1-27 nm range [Woods, Meier, Lean]
- **Objective 2: solar variability**
  - Updated results on solar rotation and solar cycle variations [Woods et al.]
  - Updated results on flare variability as SEE has observed >500 flares
    - Contribution of XUV-EUV to flare's total photon energy ranges from 30% to 100% and is sensitive to flare location on Sun [Woods, Kopp, Chamberlin]
- **Objective 3: model solar response in Earth's atmosphere**
  - Use of SEE solar data and FAST photoelectron data [Peterson, Richards]
  - Use of HAO TIME-GCM for atmospheric response to SEE's solar input [Solomon, Roble, Qian, Lu]
  - New satellite drag modeling / analysis indicating importance of solar EUV and FUV
    - Air Force now using EUV and FUV data for operational satellite drag model based on new satellite drag analysis with SEE data [Bowman, Tobiska]
    - Use of TIME-GCM with SEE data input to study thermospheric neutral density [Qian, Solomon]
    - Use of SEE solar data and TIMED S/C orbit to study solar influence on TIMED orbit decay [Woodraska]
    - Study of satellite drag following flare showing < 2 hour response [Sutton, Forbes]

Summary of SEE Results - 2

- **Objective 4: solar irradiance modeling**
  - SOLAR2000 (S2K) model improvements [Tobiska]
    - Upgraded S2K to v2.27, v2.28, 2.30,
    - Updated XPS algorithm using Mewe spectrum in SFLR v1.01
    - Provided backup to creation of S10 for JB2006 thermospheric density model
  - NRLEUV model improvements [Lean, Warren]
  - HEUVAC model improvements [Richards]
  - New Flare Irradiance Spectral Model (FISM) developed at LASP [Chamberlin]
    - SEE data used to parameterize FISM - daily components and 1-min flare components
- **Objective 5: atmospheric density from solar occultations**
  - SEE version 9 data products will include results from solar occultations [Eparvier]

Flare Results with SEE Data

♦ **Flare Irradiance Spectral Model (FISM)**

- New flare model developed using SEE data
  - 2 daily components (long-term and short-term)
  - 2 1-min flare components (impulsive & gradual phase)
- Chamberlin *et al.*, ILWS Workshop Proceedings, submitted, Feb 2006
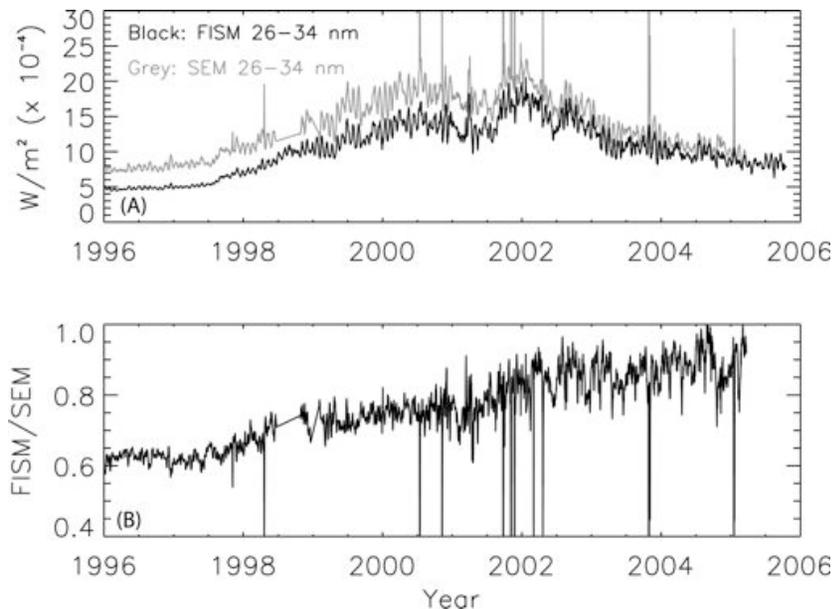
Fig. 1. (A) Time series of the FISM integrated results from 26-34 nm and the SEM 26-34 nm channel over the time of the SEM mission. (B) The ratio of the FISM estimates to the SEM measurements
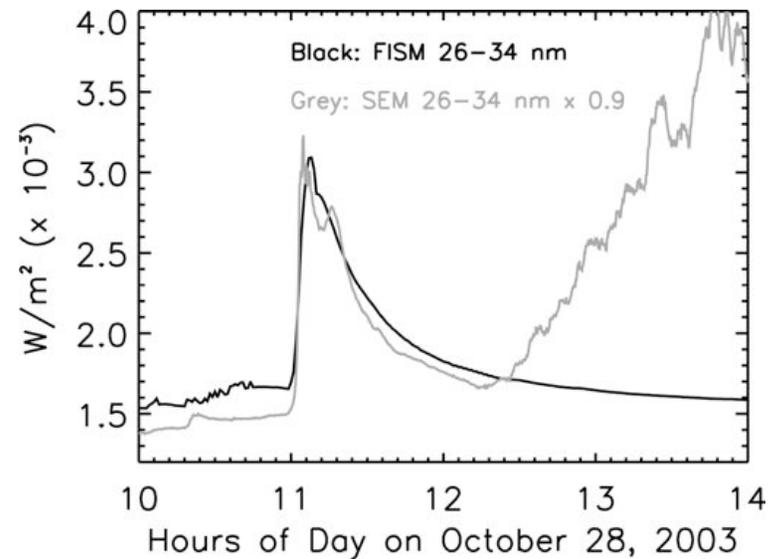
Fig. 2. The FISM 26-34 nm estimates (Black, 60 sec temporal resolution) and the similar SEM measurements (Grey, 15 sec temporal resolution) during the X17 flare that occurred on 28 October 2003.

Thermospheric NO Density Response due to Solar Flares - 1

Observations from the TIMED–SEE XPS are used to determine the solar irradiance during a solar flare. Observations from the Student Nitric Oxide Explorer (SNOE) are analyzed to determine how the solar flare soft X-ray irradiance affects the Earth's lower thermosphere.
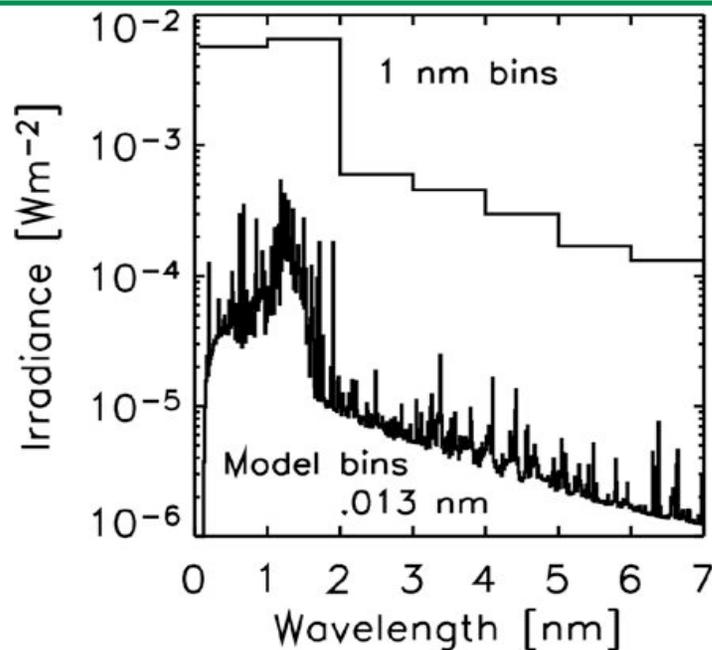
The 28 October 2003 X18 solar flare spectrum. [3]
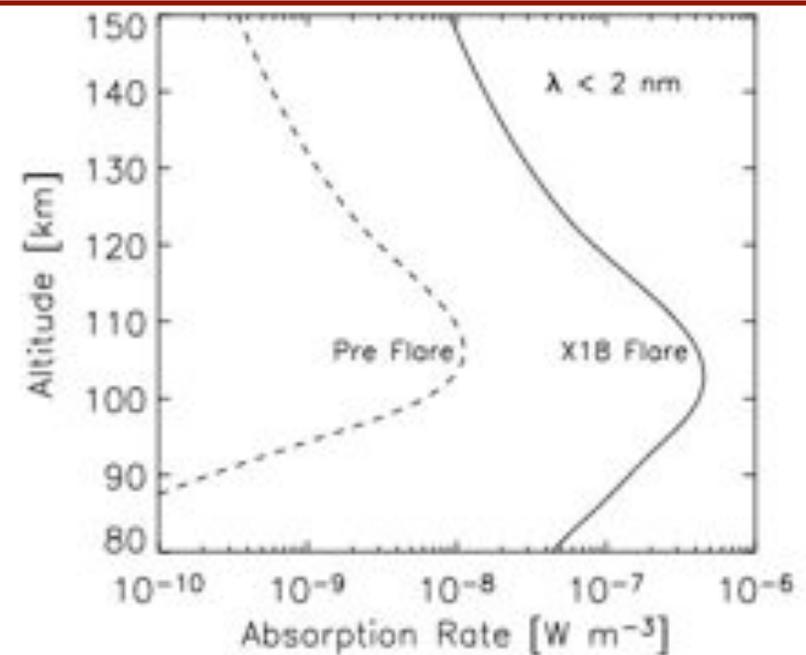
- The XPS observations are used to infer a solar flare spectrum. [3]
- The overall soft X-ray irradiance between 0.1–7 nm is increased with most of the increase between 0.1–2 nm.

- The energy from solar flare enhanced soft X-ray irradiance is absorbed and produces photoelectrons in the same thermospheric altitude region where peak NO production occurs. [1,2,3]

1. Bailey, S. M. et al., *J. Geophys. Res.*, 107, SIA 22–1, 2002.　　**2.** Barth, C. A. and S. M. Bailey, *J. Geophys. Res.*, 109, A03304, 2004.

3. Rodgers, E. M. et al., *J. Geophys. Res.*, 111, A10S13, 2006.

Thermospheric NO Density Response due to Solar Flares - 2
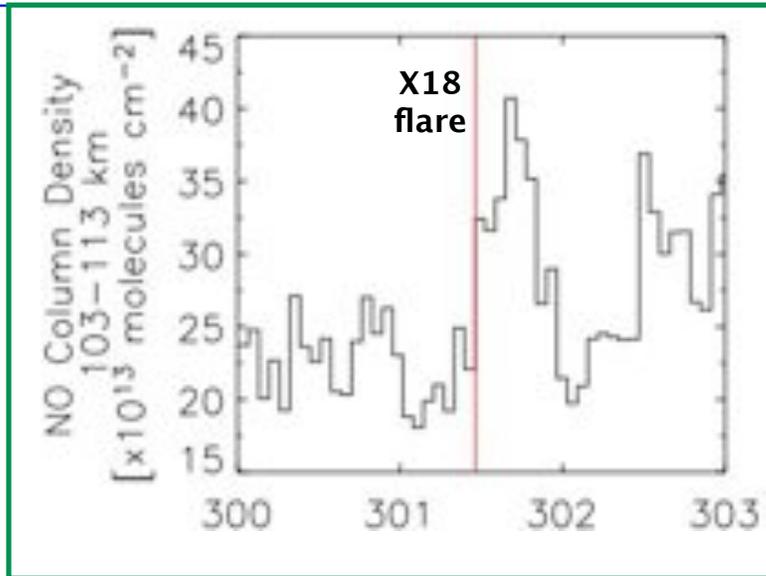
NO column density doubles after the 28 October 2003 X18 solar flare (day 301) at the subsolar latitude.

- The NO column density enhancement of altitudes between 103–113 km show an increase between latitudes of 70°S to 70°N following the X18 flare.

- Observations indicate a symmetry of increased NO density about the flare subsolar point (✳) near 15°S.

- The integrated NO density during the nine hours following the flare is equivalent between the subsolar latitude and 50° to the north and south.
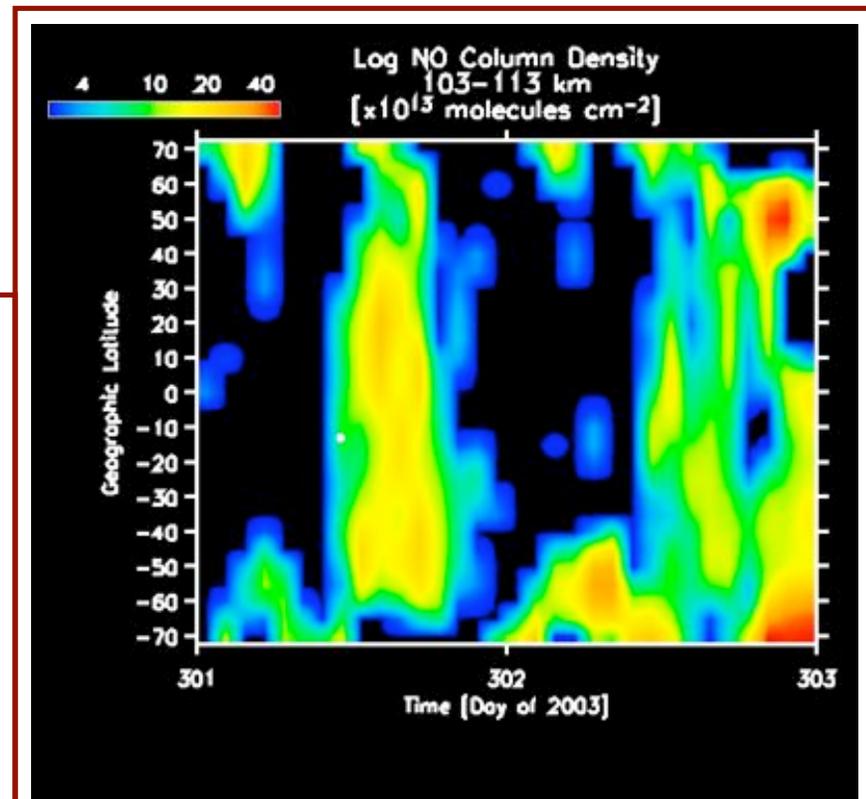
TIMED SEE

Neutral Density & Satellite Drag Results - 1

- Bowman, Tobiska, & Bouwer have developed new Air Force operational model of the thermospheric neutral density using TIMED SEE data for analysis
    - Uses EUV and FUV solar proxies instead of just F10.7
    - Significant improvement from previous models
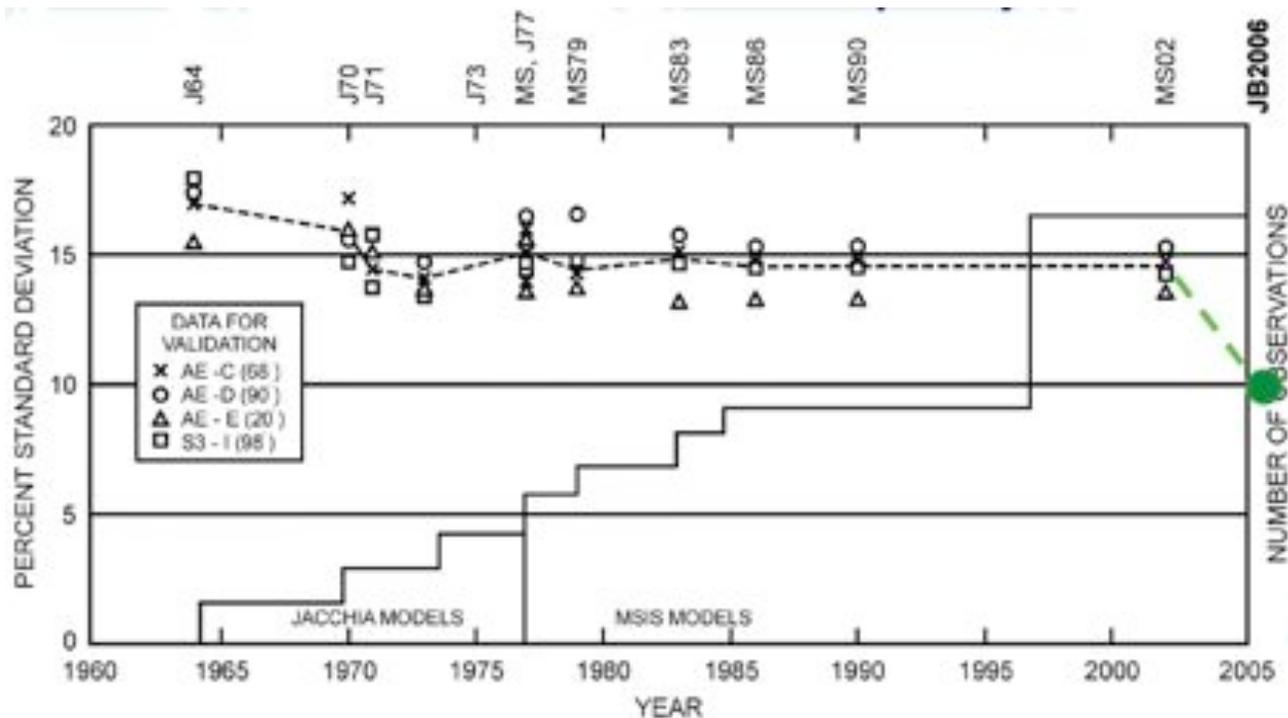
TIMED SEE

Neutral Density & Satellite Drag Results - 2

♦ Woodraska *et al.* (AIAA, 2006) empirically models TIMED spacecraft orbit decay using TIMED SEE data

- Model of drag rate uses EUV and FUV solar measurements and with 1-day lag of the FUV

Decay Rate (m/day)
EUV+FUV Model

Difference (Actual-Model) (m/day)

EUV+FUV Model is significantly better than F10.7 Model

Decay Rate (m/day)
F10.7 Model

TIMED SEE
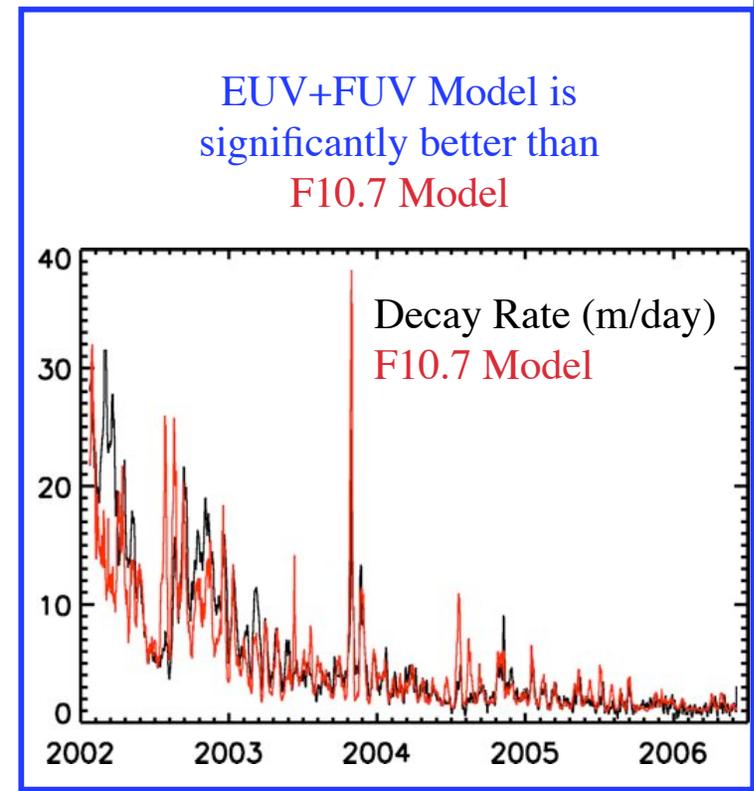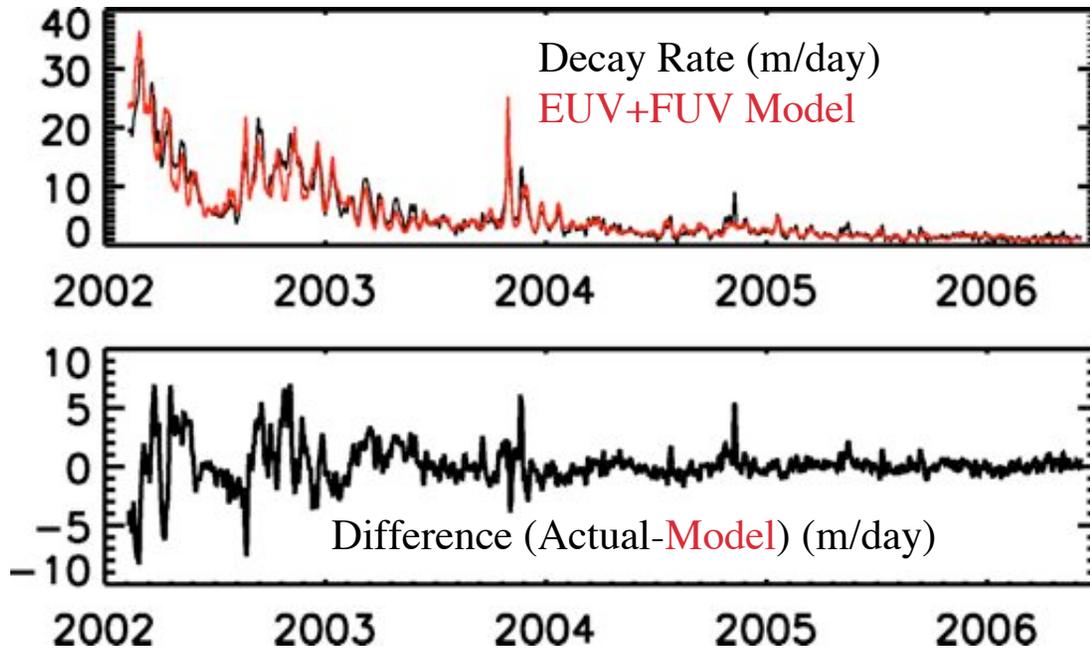
Neutral Density & Satellite Drag Results - 3

♦ Sutton et al. (GRL, 2006) shows thermospheric neutral density responds to large X17 flare within 2 hours

- Surprising result as had not expected this rapid response
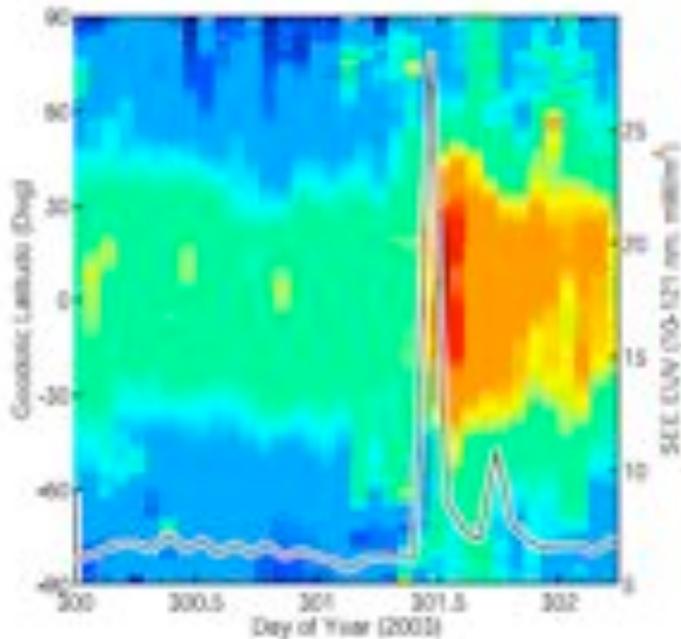
GRACE S/C   CHAMP S/C
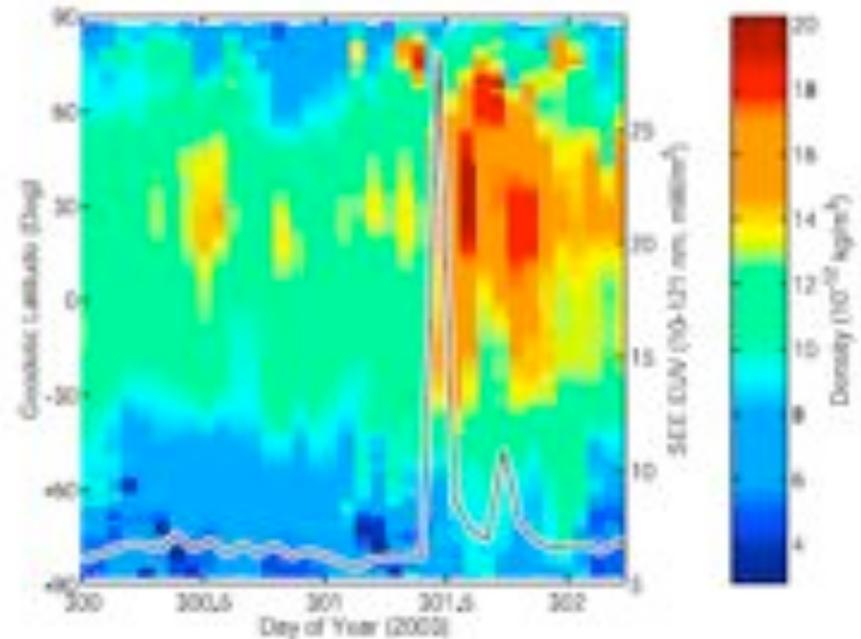
Results from SEE-GUVI QEUV Workshop

- SEE solar EUV irradiance and GUVI QEUV (0-45 nm) differences remain at about 30% but are more consistent with each other. Changes include:
  - GUVI has updated calibrations
  - SEE Version 9 has new algorithm for XPS data processing
    - Uses GOES X-ray measurements (ratio of XRS-B to XRS-A) to obtain coronal plasma temperature
    - Spectral model (at 0.01 nm resolution) is calculated at that temperature
    - Spectral model prediction is scaled to match the XPS measured current
    - SEE Level 3 uses new XPS results in the 0.1-27 nm range
- Algorithms that use CHIANTI spectral model (with plasma temperature) for XPS data analysis improve the XPS flare irradiances significantly
  - Rodgers & Bailey technique using multiple XPS measurements
  - Woods technique for SEE XPS Version 9 data processing (GOES X-rays provide plasma temperature)
  - SEE flare irradiances are much lower, primarily in the 4-14 nm range

SEE-GUVI QEUV Workshop Goal - Agenda

♦ Aug 10, 2005 Workshop Overview / Goal

  • There have been outstanding issues in the magnitude and variability, especially for flares, of the solar extreme ultraviolet (EUV) irradiance. The TIMED Solar EUV Experiment (SEE) measures the solar EUV irradiance from 0.1 to 194 nm with 0.4 nm spectral resolution longward of 27 nm but only with 7-10 nm bands shortward of 27 nm (XUV range). The TIMED Global Ultraviolet Imager (GUVI) measures the ultraviolet airglow and derives (infers) solar EUV irradiance in the 0-45 nm band. This one-day workshop is an opportunity to discuss the comparison between the SEE and GUVI results of the solar EUV irradiance and to work towards resolving the differences, primarily in the XUV range where only broadband measurements are available.

♦ Workshop Agenda - Discussion Topics

Bob Meier (NRL)	GUVI Daily Airglow Results
Stan Solomon (NCAR)	Solar Flare Effects on the Thermosphere and Ionosphere
Dave Pawlowski (UM)	Modeling the IT System during Flares
Bill Peterson (LASP)	Variations of the Solar flux in the 1 to 50 nm range over a solar rotation inferred from observations of photoelectrons with energies from 0.01 to 1 keV from the FAST satellite
Judith Lean (NRL)	SEE EUV Irradiances: Measurements, Models and Validation
Tom Woods (LASP)	New Calibrations and Algorithms for XPS
Don McMullin (Praxis)	New Calibrations and Algorithms for SOHO SEM
Bob Meier (NRL)	High Resolution Oxygen Cross-Sections

TIMED SEE

GUVI QEUV is lower than SEE Version 8 Irradiances

From B. Meier's Airglow Talk : prior to GUVI calibration changes and new SEE XPS algorithm change

Daily Averages 2002.2–2005.3

SEE Version 8

Average = 0.764

+++ < 10 pts in average
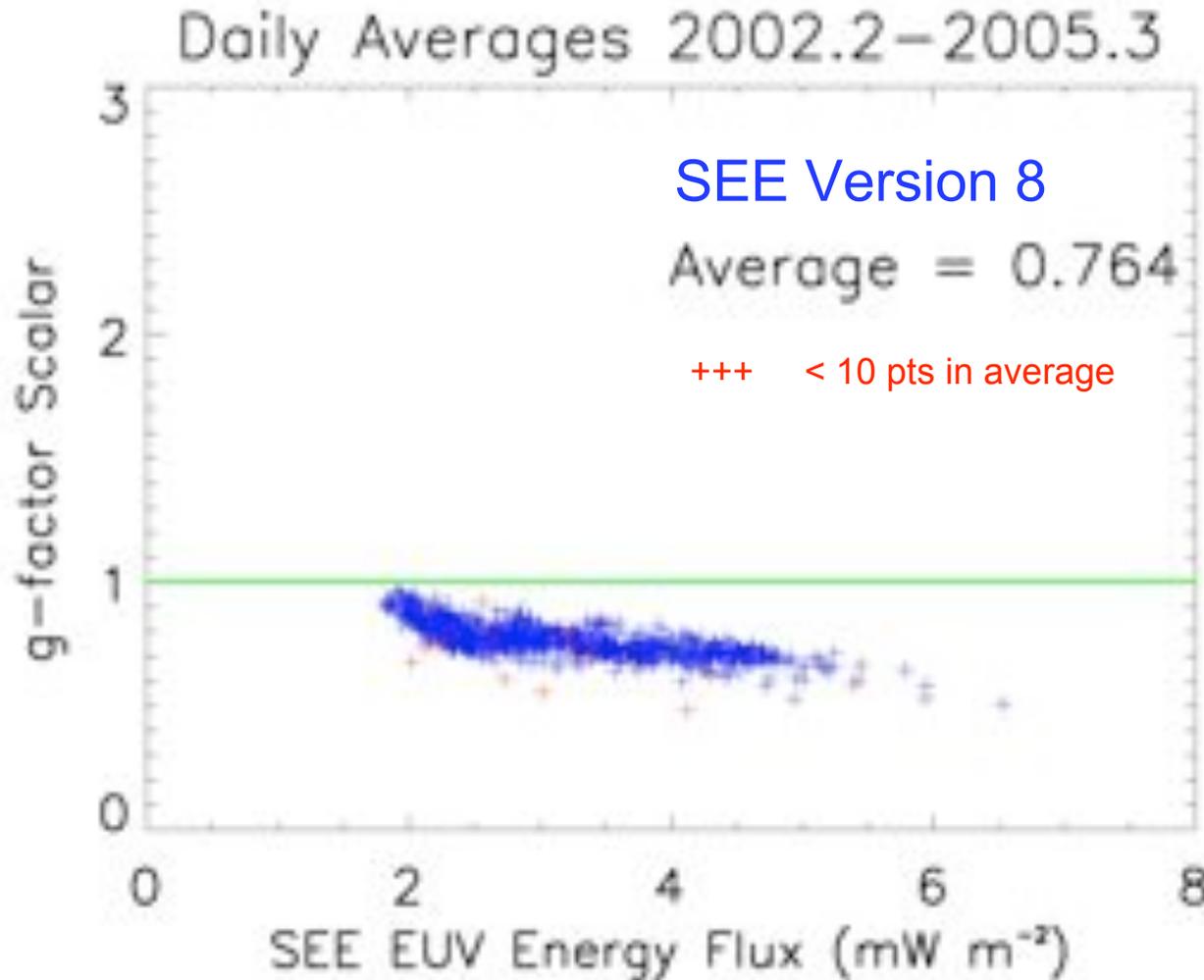
Offset of 0.76
OK as within calibration uncertainty

Trend with solar activity
BAD - expect constant g-factor

TIMED SEE

No Solar Cycle Trend for Latest GUVI & SEE Data

From B. Meier's Airglow Talk : with new GUVI calibration changes and
with new SEE XPS algorithm change (SEE Version 9)
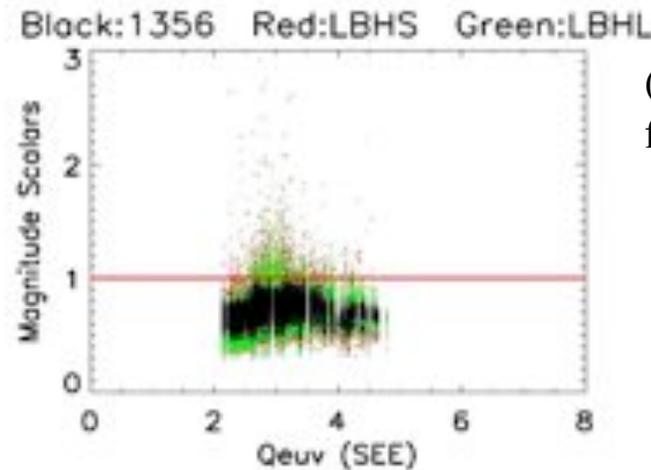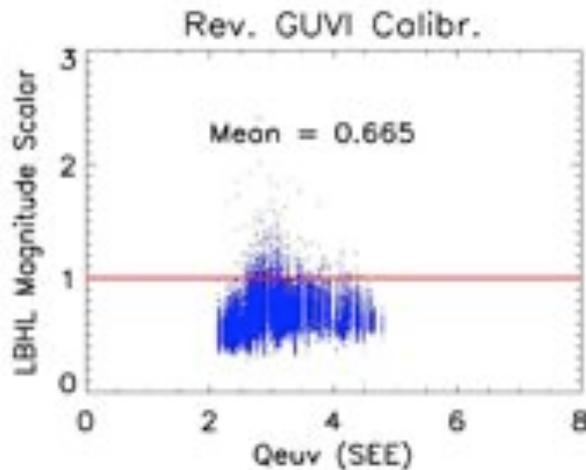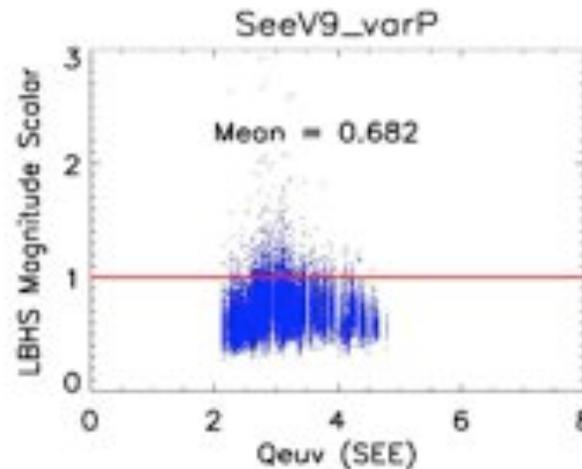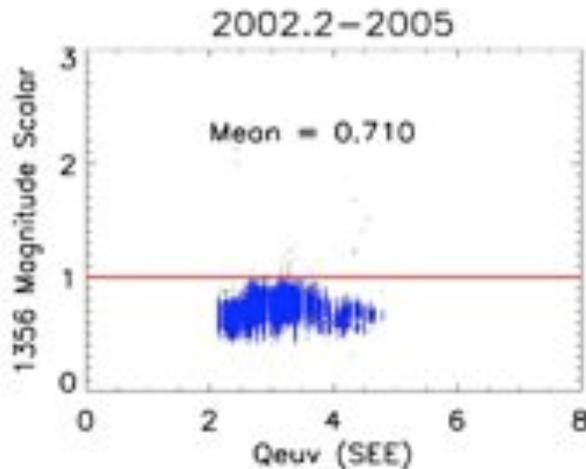
<u>Avg. Offset of 0.69</u>
OK as within calibration
uncertainty
(new GUVI calibration
makes difference worse)

<u>No Trend</u>
GOOD as expect
constant scalar
(new XPS algorithm
fixed the trend)

New XPS Level 4 Algorithm (July 2006)

♦ Changed spectral model for XPS Level 4 processing

    • Use Chianti spectra model results scaled to XPS#1 & 2 signal (current)

        - Daily Component

          • Quiet Sun (QS), Coronal Hole (CH), and Active Region (AR) DEM

          • MIN_REF = (QS + CH) / 2   based on GOES XRS analysis ($SF_{QS} \leq 1.0$)

          • Daily Variability = Scale Factor (fractional area) of AR spectrum

             - based on minimum signal of XPS#1-2 for each day ($SF_{AR} \sim 0 - 0.1$)

        - Flare Component

          • GOES XRS-B / XRS-A ratio defines plasma temperature for flare

          • Chianti iso-thermal spectrum used at this temperature (1-min cadence)

          • Residual XPS#1 & 2 signal provides magnitude for flare spectrum ($SF_{Flare} \sim 0 - 100$)
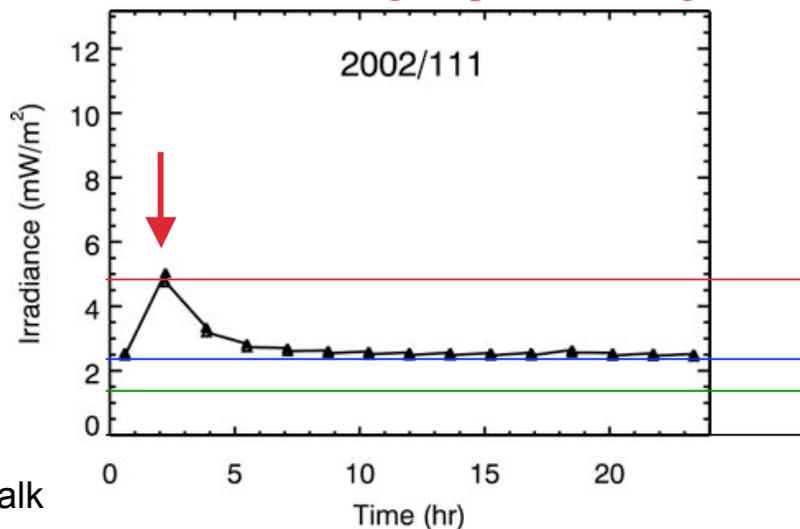
From T. Woods Talk

TIMED SEE

Example Plasma Temperature for 2002/111

GOES XRS-B

GOES XRS-A

Ratio gives plasma
Temperature with
1-min cadence
(H. Garcia)

2002111

TIMED SEE
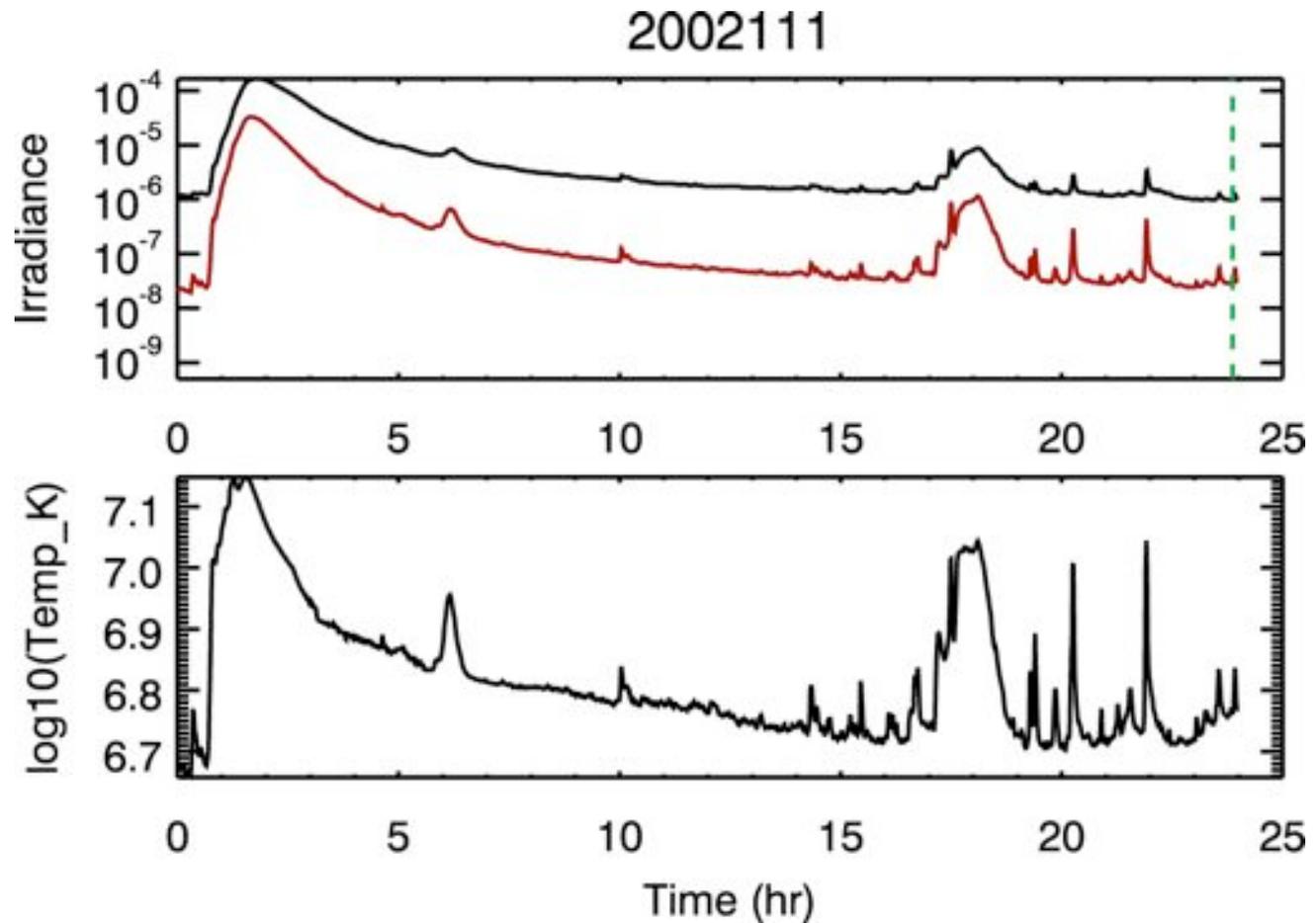
New XPS Version 9 Has Less Flare Variability

Flare variations are much less in the 4-14 nm range for XPS Version 9.

Spectral shape is very different - larger 2 nm peak for new version in addition to 4-14 nm changes

But **NOT** measured spectral shape !
(Chianti spectral model for 0-40 nm)

2003/308: 5-40 nm

S-XPS L4 (Version 9)

SEE L3A V8

2003/308 13:07

S-XPS L4
SEE L3A V8

2003/308 19:41

S-XPS L4
SEE L3A V8
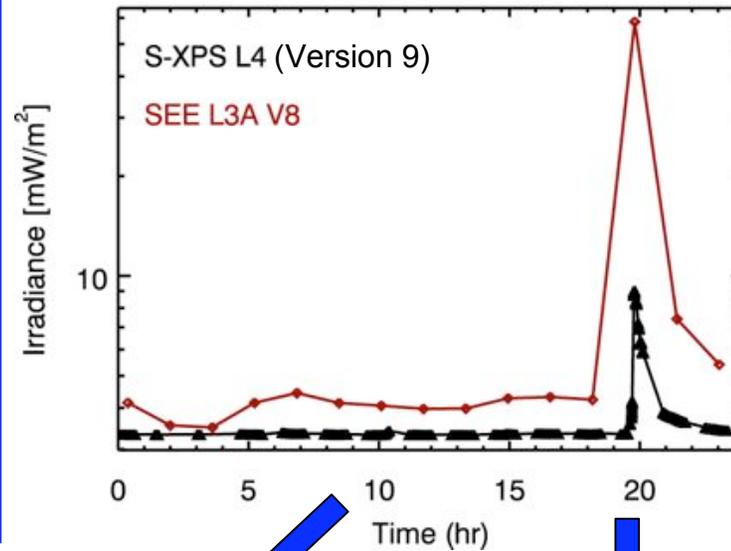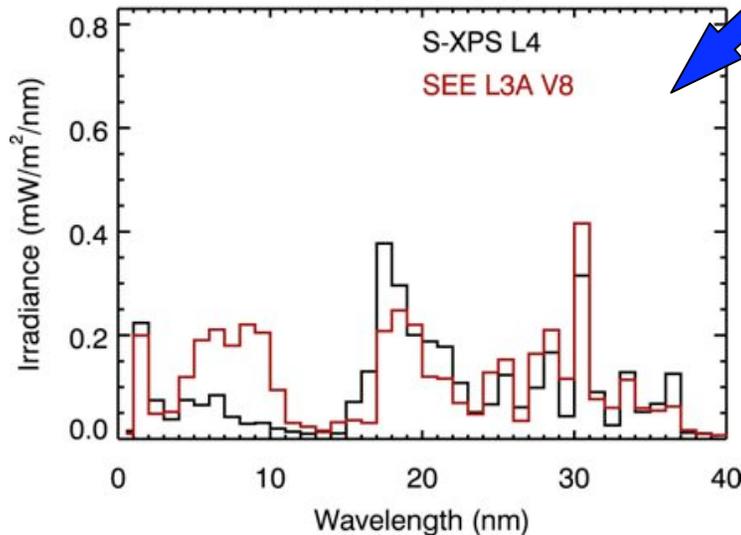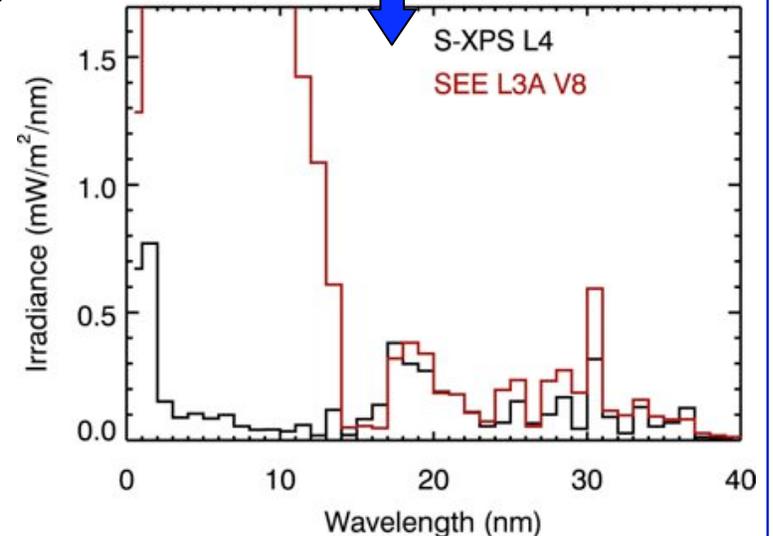
TIMED SEE

SEE Version 9 agrees much better with SOHO SEM

0-26 nm peak flux

	V8		V9
28Oct03 X17	83	→	17
4Nov03 X28	101	→	27

0-26 nm

XPS V8
XPS V9

SEM and SEE: 5-50 nm

— SEM energy
— SEE V8
— XPS V9 + EGS V8
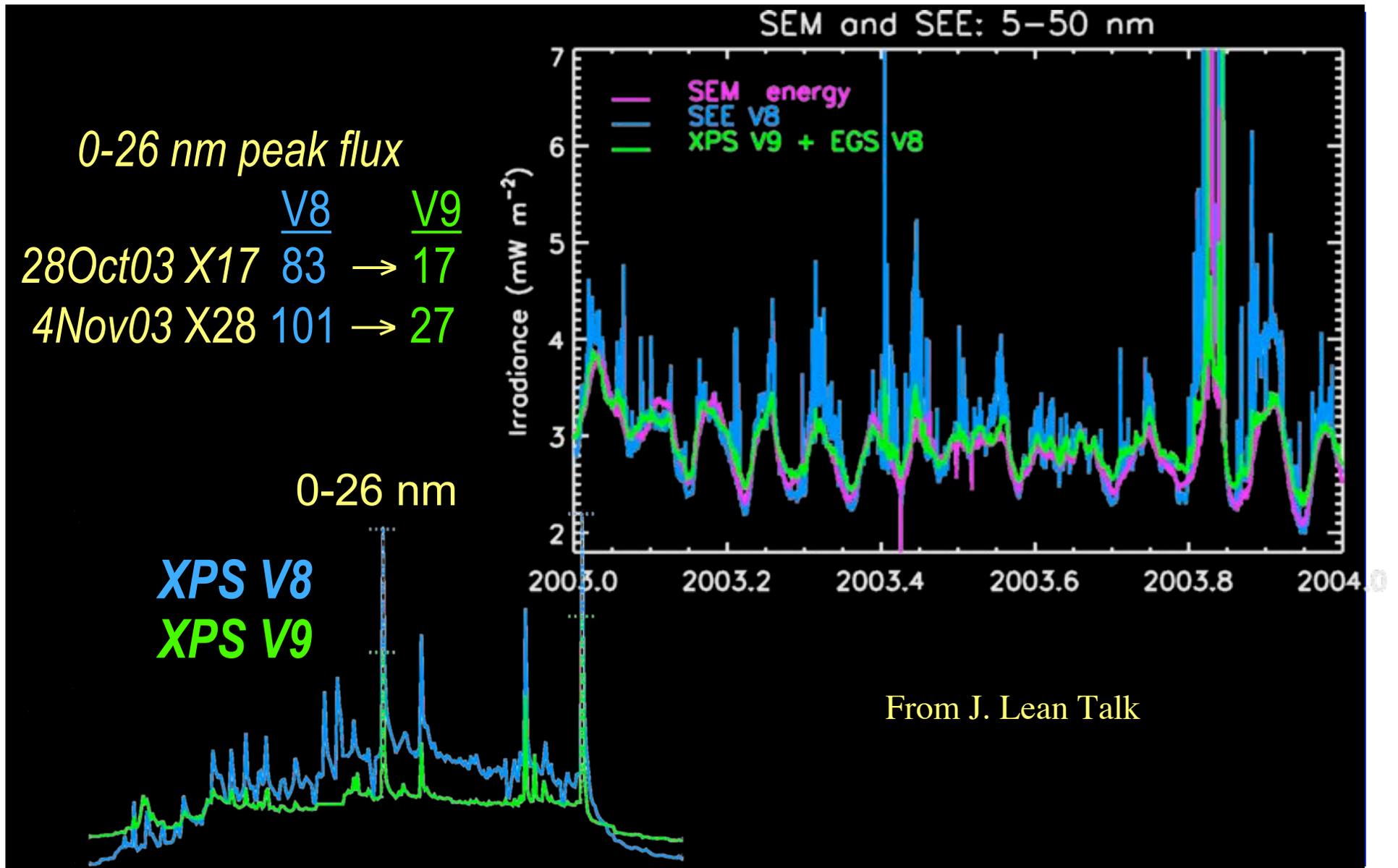
From J. Lean Talk

TIMED SEE

SEE Flare Spectra — Version 8 vs. R&B Method

From S. Solomon Talk: TIMED SEE Version 8 has "too much" solar irradiance during large flares in the 3-14 nm range as compared to the Rodgers & Bailey (R&B) method that uses CHIANTI spectral model for the XPS data analysis. (note that R&B Method and new XPS Version 9 algorithm are similar concepts)

TIMED SEE
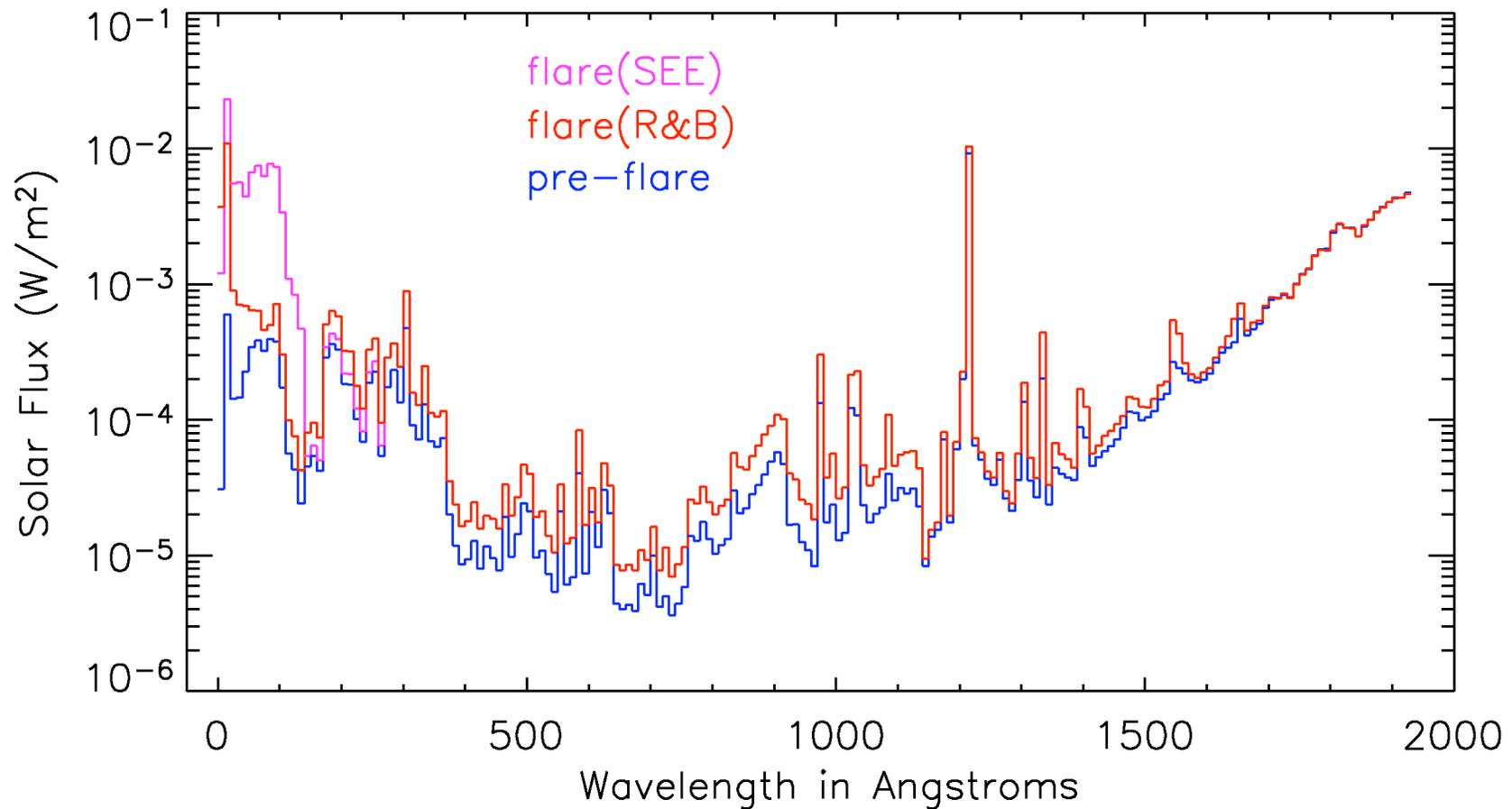
Electron Density Enhancement during Flare

From S. Solomon Talk: GLOW model simulations of *E*-region electron density for the X17 flare on 10/28/03 agree best with measurements (factor of 2) using the R&B solar input. SEE Version 8 flare irradiances over estimate electron density.

TIMED SEE
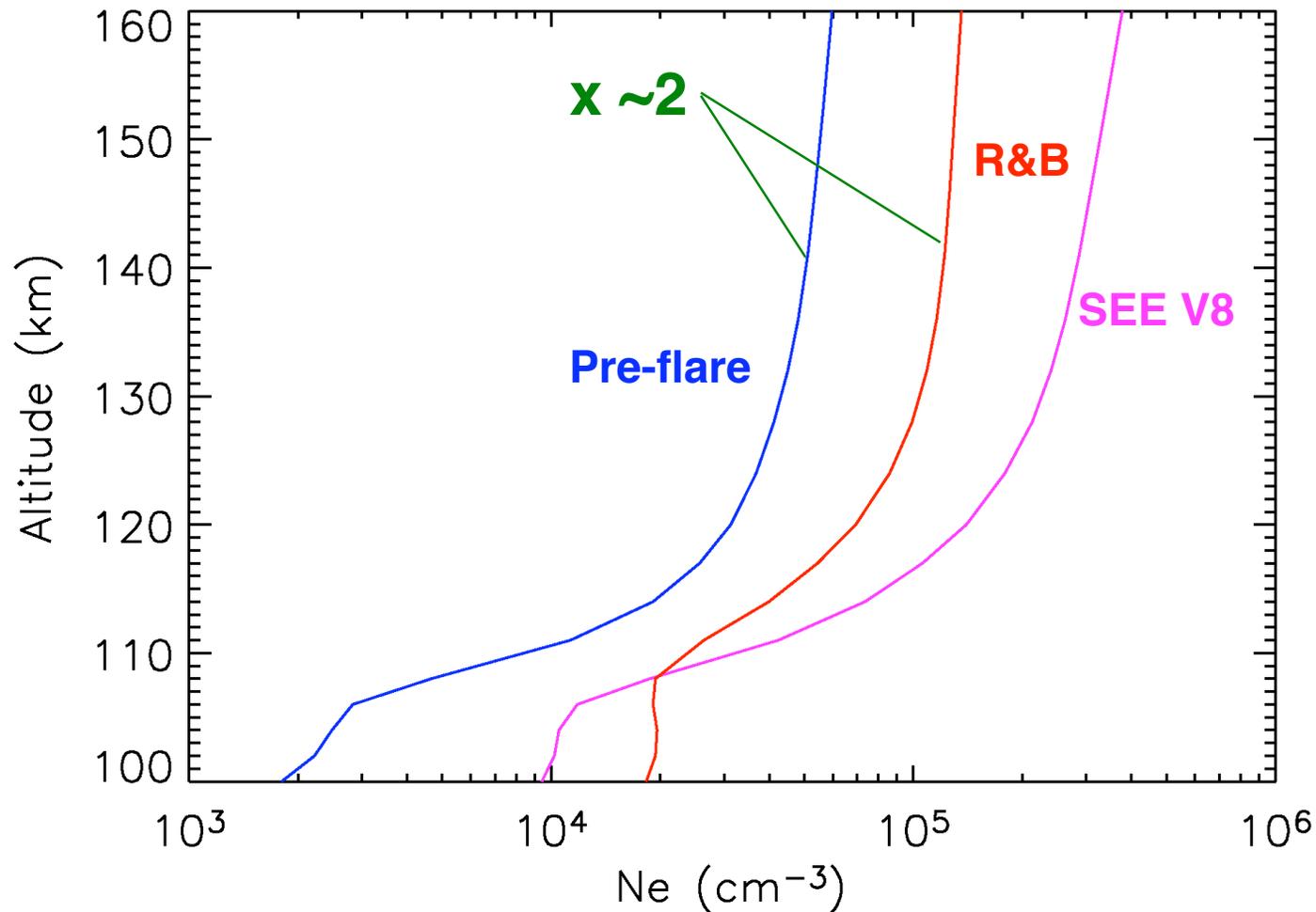
SEE Related Talks and Papers

SEE Related Talks in 2006

- ◆ ILWS Workshop - India: Feb. 06, 3 talks
- ◆ SCOSTEP STP Meeting - Brazil: Mar. 06, 1 talk
- ◆ Boulder Solar Day: Mar. 06, 1 talk
- ◆ AGU Spring Meeting: May 06, 2 talks / posters
- ◆ SEE-GUVI QEUV Workshop: Aug. 06, 8 talks
- ◆ COSPAR Meeting - China: July 06, 7 talks
- ◆ SOLARIS Workshop: Oct 06, 1 talk
- ◆ AGU Fall Meeting: Dec. 06, 4 talks / posters

SEE Related Papers in 2006 - 1

- Woods, T. N., G. Kopp, and P. C. Chamberlin, Contributions of the solar ultraviolet irradiance to the total solar irradiance during large flares, *J. Geophys. Res.*, **111**, A10S14, doi:10.1029/2005JA011507, 2006.
- Rodgers, E. M., S. M. Bailey, H. P. Warren, T. N. Woods, and F. G. Eparvier, Soft X-ray irradiances during a solar flare observed by TIMED-SEE, *J. Geophys. Res.*, **111**, A10S13, doi: 10.1029/2005JA011505, 2006.
- Sutton, E. K., J. M. Forbes, R. S. Nerem, and T. N. Woods, Neutral density response to the solar flares on October and November 2003, *Geophys. Res. Lett.*, **33**, L22101, doi:10.1029/2006GL027737, 2006.
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Conclusions and Future Plans

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 500 flares have been observed by SEE
  - Extreme flare periods are April 2002, July 2002, May-June 2003, Oct.-Nov. 2003, July 2004, Jan. 2005, Sept. 2005, and Dec. 2006
  - Large flares vary as much as 11-year solar cycle variations
  - New flare models have been developed with SEE observations
- More than 65 solar rotations have been observed by SEE
  - Variability of 5-70% observed (wavelength dependent)
- TIMED mission has observed solar maximum and low solar activity during solar cycle 23
  - Extended TIMED mission should observe solar cycle minimum conditions that are predicted in late 2007

TIMED SEE

SEE Plans for 2007

- Daily mission operations and data processing for SEE
  - Release of Version 9 data products is primary new effort
- Possible reflight of SEE calibration rocket in 2007
  - No measurements in the 27-105 nm range due to instrument anomaly on the Oct. 2006 flight
  - Future, additional underflight calibrations will be by SDO EVE calibration rockets that should start on an annual basis in late 2008
- Provide SEE data and model products for space weather operations
  - Already providing SEE Space Weather data product to Air Force and NOAA SEC for daily space weather operations
  - Phil Chamberlin plans to make FISM output available near real-time for space weather operations using SEE's daily Space Weather product and the 1-min cadence GOES X-ray measurements
- Detailed modeling of Earth's response to solar irradiance changes
  - Composition, dynamics, temperature using TIME-GCM for solar cycle variations
  - More detailed comparison to FAST photoelectron measurements to estimated photoelectron flux from the *glow* model that uses SEE solar measurements
- Occultation data analysis