Solar EUV inter-calibration workshop

LASP, University of Colorado, Boulder

October 25-27, 2011

# Solar EUV Monitor (SEM) instrument overview background and calibration

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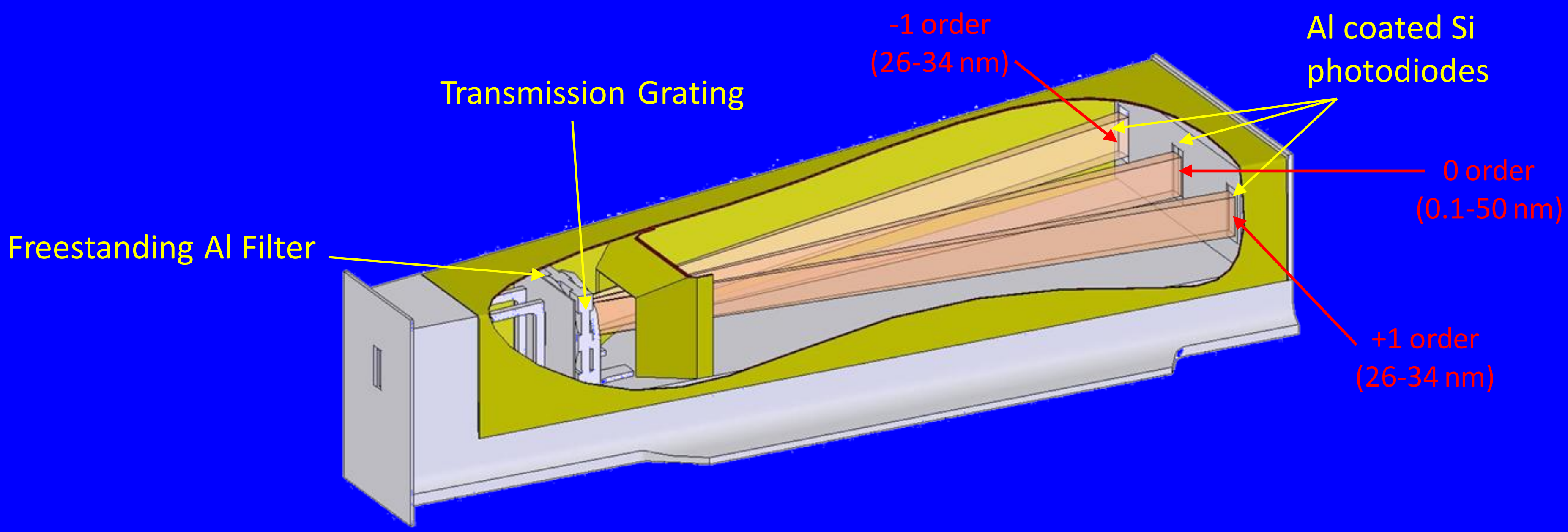
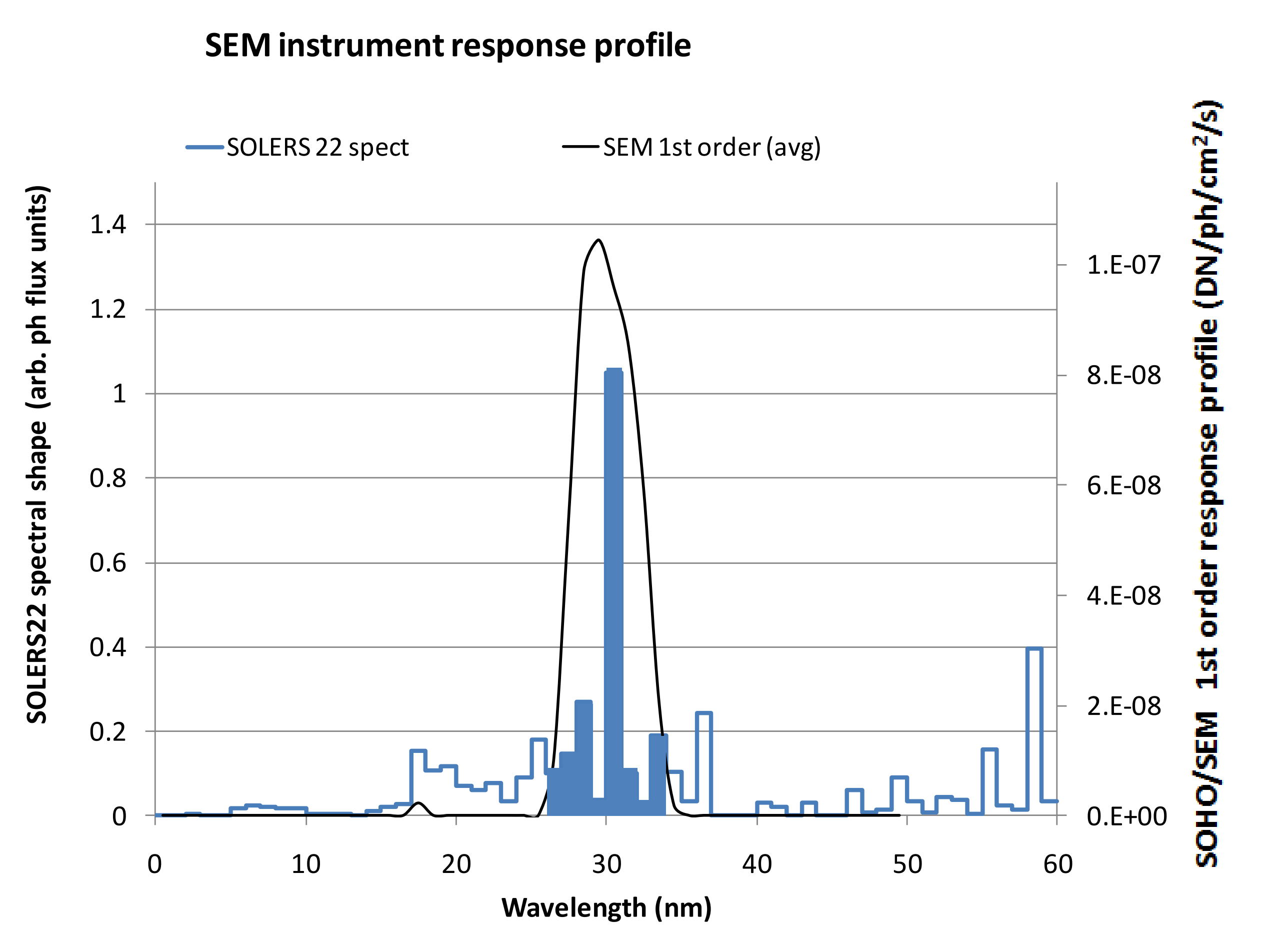
# Introduction

- SOHO/CELIAS/SEM has been providing nearly continuous (with the exception of the summer of 1998 when SOHO went offline) EUV irradiance measurements for all of the nearly 16 yrs. SOHO has been in operation
- It is a highly stable transmission grating spectrometer with high photometric accuracy
- Measures solar flux in two bandpasses: 26-34 nm(+/- 1st order) and 0.1-50 nm (0-order)
- Data used for researching the sun, interplanetary space, and earth/planetary atmospheres



# How irradiance is calculated




- NIST measured instrument efficiencies
- SOLERS22 composite reference spectrum [Woods, T., H. Ogawa, K. Tobiska, and F. Farnik, Solers 22 WG-4 and WG-5 Report for The 1996 Solers 22 Workshop, Solar Physics, 511, 1998]

# How irradiance is calculated

$$\textbf{SEM EUV flux} = k_1 \frac{DN_{SEMch} - bkgrd}{\left( \dfrac{A \int_{\lambda_1}^{\lambda_2} \eta \cdot \phi_{S22} \cdot f_{carbon-trans} \cdot d\lambda \cdot f_{1AU}}{\int_{\lambda_1}^{\lambda_2} \phi_{S22} \cdot d\lambda} \right)}$$

where:

$k_1$ = correction for SEM sensitivity band which extends slightly beyond 26-34 nm (including second order contributions from wavelengths near 17 nm)

$bkgrd$ = background signal due to diode/electrometer dark current and residual light leaks

$DN_{SEMch}$ = data channel raw count rate

$A$ = entrance aperture area

$$k_1 = \frac{\int_{26nm}^{34nm} \phi_{S22} \cdot d\lambda}{\int_{\lambda_1}^{\lambda_2} \phi_{S22} \cdot d\lambda}$$

$\eta$ = SEM channel efficiency from NIST calibration

$\phi_{S22}$ = Solar flux from SOLERS22 reference spectrum

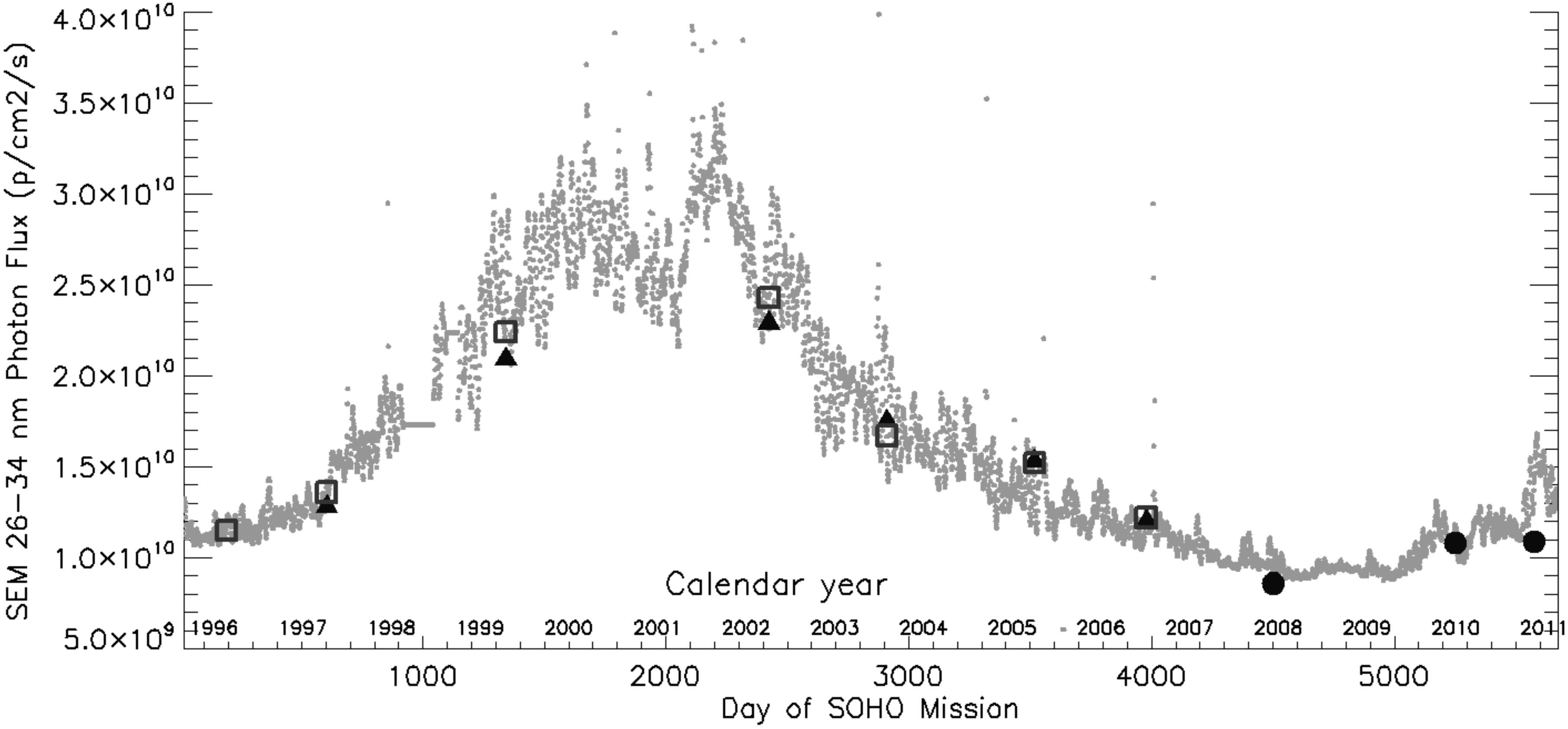
$f_{carbon-trans}$ = transmission through carbon contamination layer, f(time)

all functions of λ

$f_{1AU}$ = correction for 1 AU, and

$\lambda_1$ - $\lambda_2$ = range of wavelengths over which SEM the first order channel is sensitive

# SEM 26-34 nm irradiance



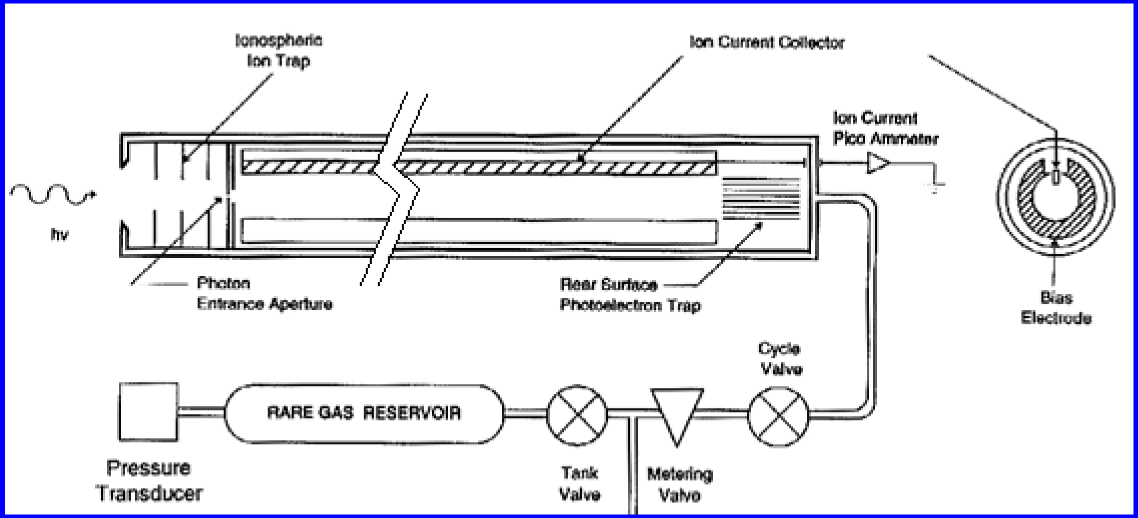

- Time series, January 1996 – Present. Black squares, triangles and circles represent sounding rocket measurements using a Rare Gas Ionization Cell (RGIC), the SEM clone instrument, and the SDO/EVE/ESP clone instrument, respectively

| Date | Rocket Flight | SOHO/SEM Daily avg. 26-34 nm flux (ph/cm$^2$/s) | SEM clone 26-34 nm flux (ph/cm$^2$/s) | 26-34 nm flux RGIC (ph/cm$^2$/s) | ESP Ch9 flux (SEM) 26-34nm (ph/cm$^2$/s) | SOHO/SEM to RGIC (26-34nm) ratio | SOHO/SEM to SEM clone (26-34nm) ratio | SOHO/SEM to ESP ratio |
|---|---|---|---|---|---|---|---|---|
| 6/26/96 | 36.147 | **1.21E+10** | **1.32E+10** | **1.15E+10** | | **0.95** | **0.92** | |
| 8/11/97 | 36.164 | **1.42E+10** | **1.28E+10** | **1.36E+10** | | **0.96** | **1.11** | |
| 8/18/99 | 36.181 | **2.22E+10** | **2.09E+10** | **2.24E+10** | | **1.01** | **1.06** | |
| 8/6/02 | 36.202 | **2.28E+10** | **2.29E+10** | **2.43E+10** | | **1.06** | **1.00** | |
| 12/5/03 | 36.211 | **1.78E+10** | **1.75E+10** | **1.67E+10** | | **0.94** | **1.02** | |
| 8/3/05 | 36.227 | **1.57E+10** | **1.53E+10** | **1.52E+10** | | **0.96** | **1.03** | |
| 11/7/06 | 36.236 | **1.26E+10** | **1.20E+10** | **1.22E+10** | | **0.97** | **1.05** | |
| 4/14/08 | 36.240 | **0.95E+10** | | | **0.86E+10** | | | **1.10** |
| 5/3/10 | 36.258 | **1.18E+10** | | | **1.08E+10** | | | **1.09** |
| 3/23/11 | 36.275 | **1.37E+10** | | | **1.09E+10** | | | **1.26** |

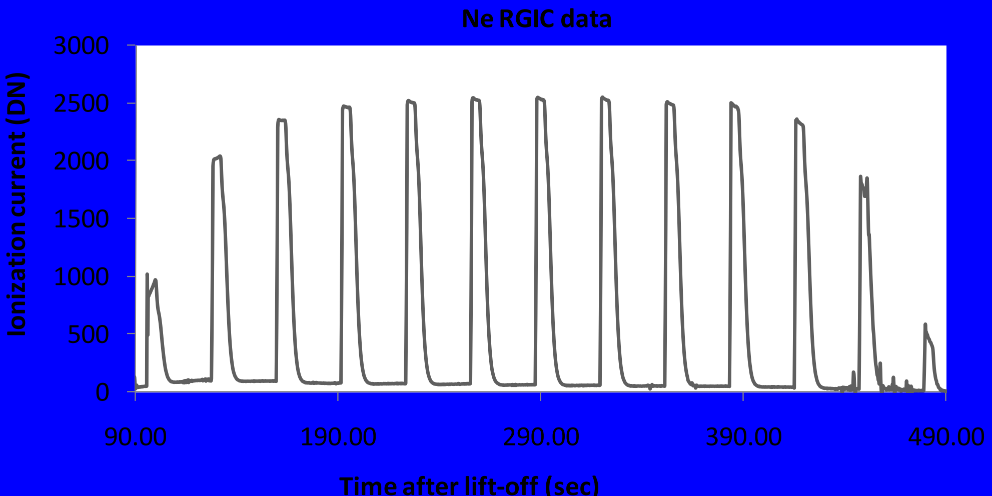
red text indicates SDO/EVE sounding rocket measurements

# Ne RGIC

- Operates optically **thick**
- Windowless; no optical surfaces to degrade
- Target gas is periodically cycled through the cell

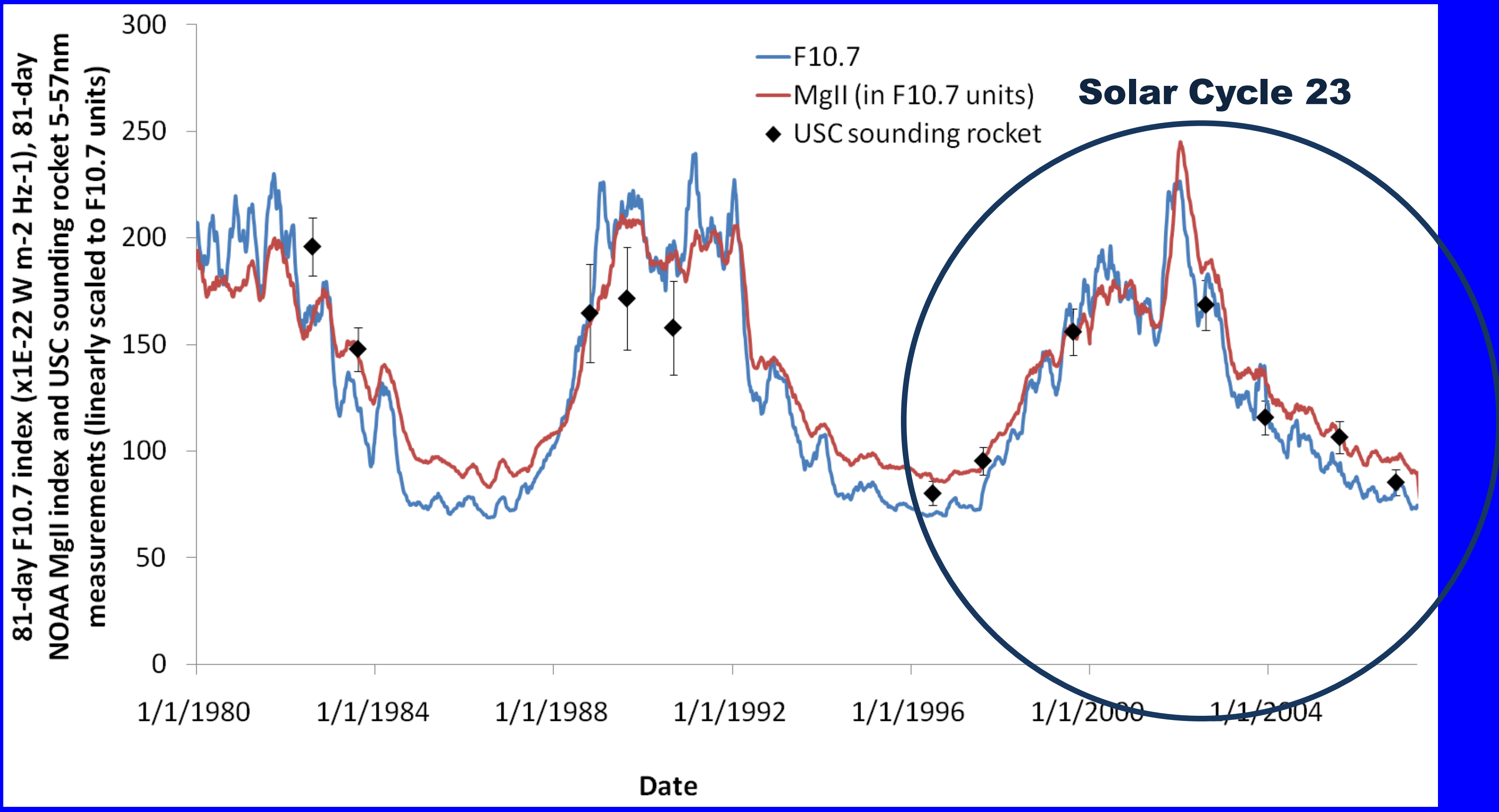



Schematic of the Ne rare gas ionization cell and gas supply system




Typical Ne RGIC sounding rocket data . Periodic gas pulses give rise to peaks in ionization current. Peaks are highest near flight apogee (~ 300 sec after lift-off) where atmospheric EUV absorption is at a minimum

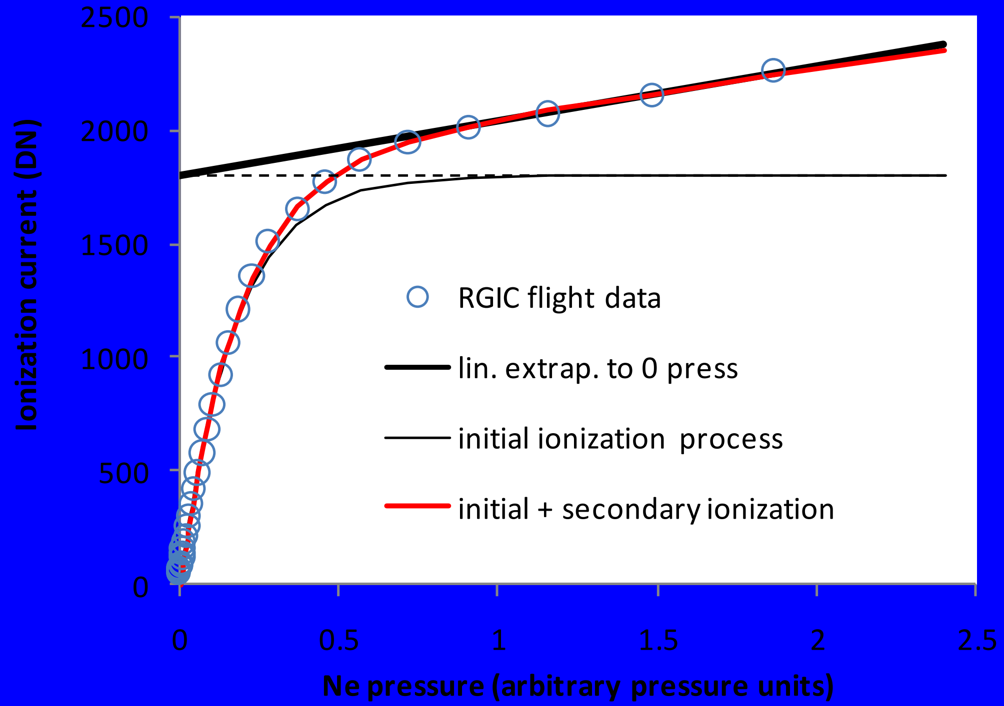
# USC sounding rocket absolute EUV irradiance measurements 1982 -2006

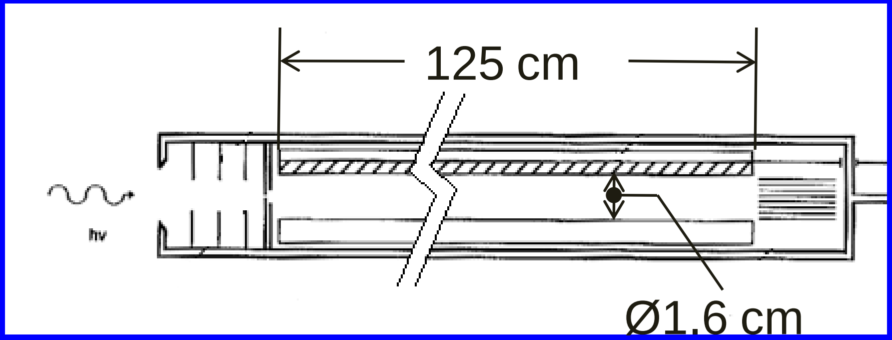



EUV variability based on scaled flux values (5-57 nm) from USC sounding rocket measurements are generally in good agreement with F10.7 and NOAA composite Mg-II solar activity indices

# Ne RGIC

- Solar flux is determined from ionization vs. pressure curve from each purge-fill cycle (linear portion of curve is extrapolated back to zero pressure current corresponding to current with no contribution from secondary ionization)
- Geometry of cell (long along optic axis with small radius) makes it optically thick for EUV but “optically thin” for ejected photoelectrons



# Part 2 - SEM calibration

## 2a) Alternative (variable) reference spectra

# How irradiance is calculated

$$\textbf{SEM EUV flux} = k_1 \frac{DN_{SEMch} - bkgrd}{\left( \dfrac{A\int_{\lambda_1}^{\lambda_2} \eta \cdot \phi_{S22} \cdot f_{carbon-trans} \cdot d\lambda \cdot f_{1AU}}{\int_{\lambda_1}^{\lambda_2} \phi_{S22} \cdot d\lambda} \right)}$$

where:

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$\phi_{S22}$ = Solar flux from SOLERS22 reference spectrum

$f_{carbon-trans}$ = transmission through carbon contamination layer, f(time)

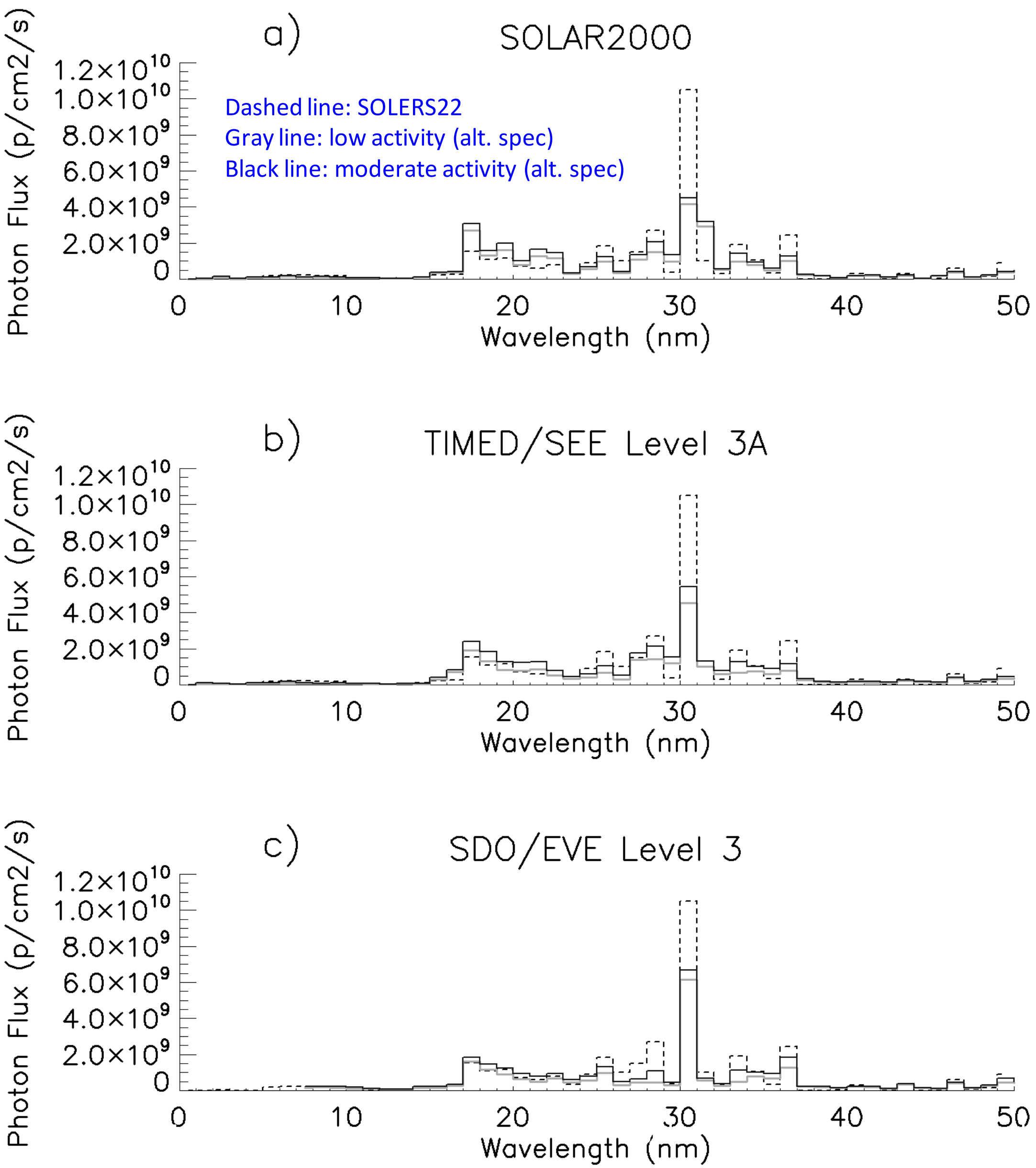
all functions of λ

$f_{1AU}$ = correction for 1 AU, and

$\lambda_1 - \lambda_2$ = range of wavelengths over which SEM the first order channel is sensitive

$$k_1 = \frac{\int_{26nm}^{34nm} \phi_{S22} \cdot d\lambda}{\int_{\lambda_1}^{\lambda_2} \phi_{S22} \cdot d\lambda}$$

# Alternate reference spectra

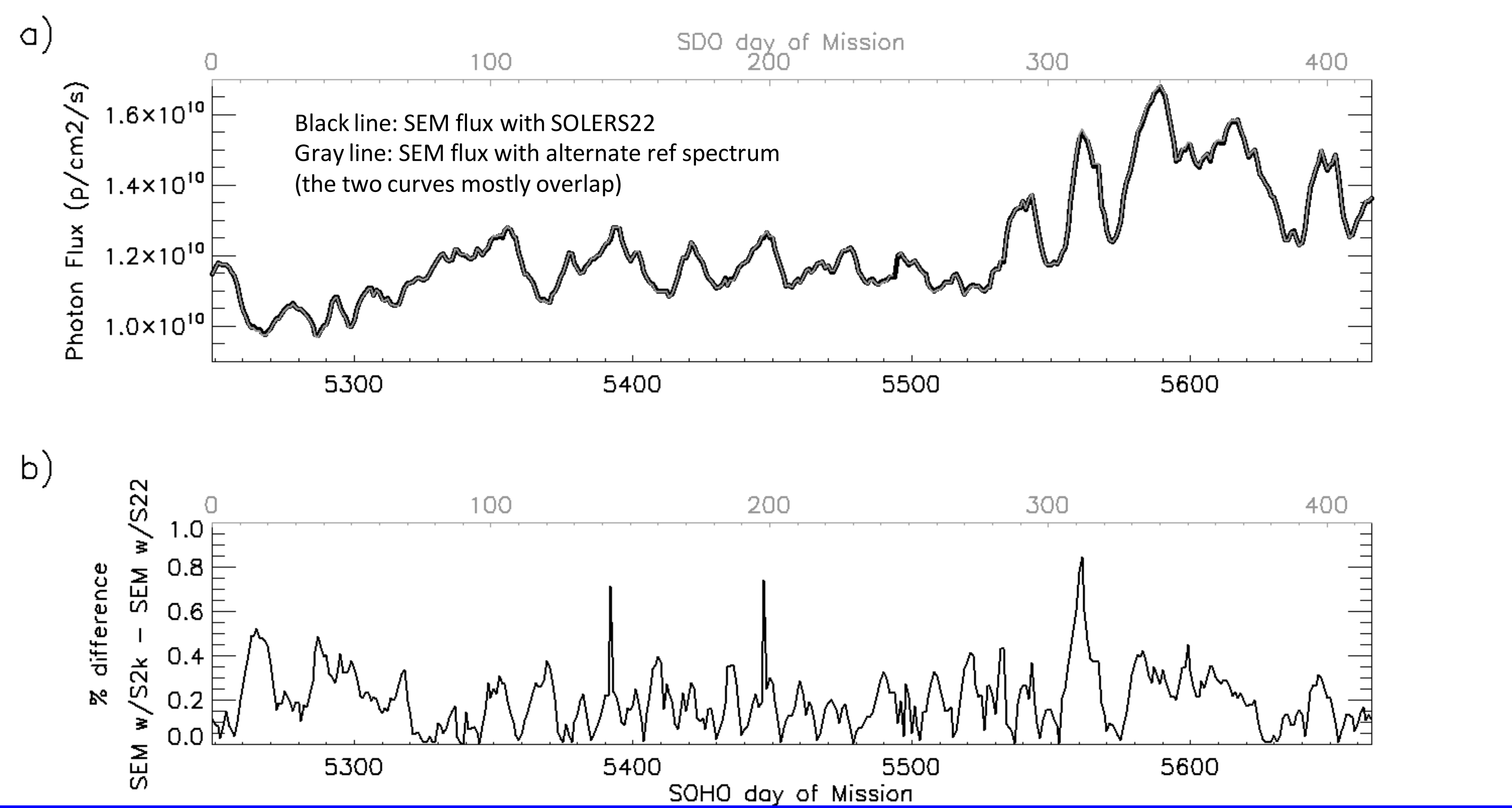



**Solar Irradiance Platform** historical irradiances are provided courtesy of W. Kent Tobiska and Space Environment Technologies. These historical irradiances have been developed with partial funding from the NASA UARS, TIMED, and SOHO missions.

Woods, T. N., F. G. Eparvier, S. M. Bailey, P. C. Chamberlin, J. Lean, G. J.Rottman, S. C. Solomon, W. K. Tobiska, and D. L. Woodraska, **The Solar EUV Experiment (SEE): Mission overview and first results**, J. Geophys. Res., 110, A01312, 2005.

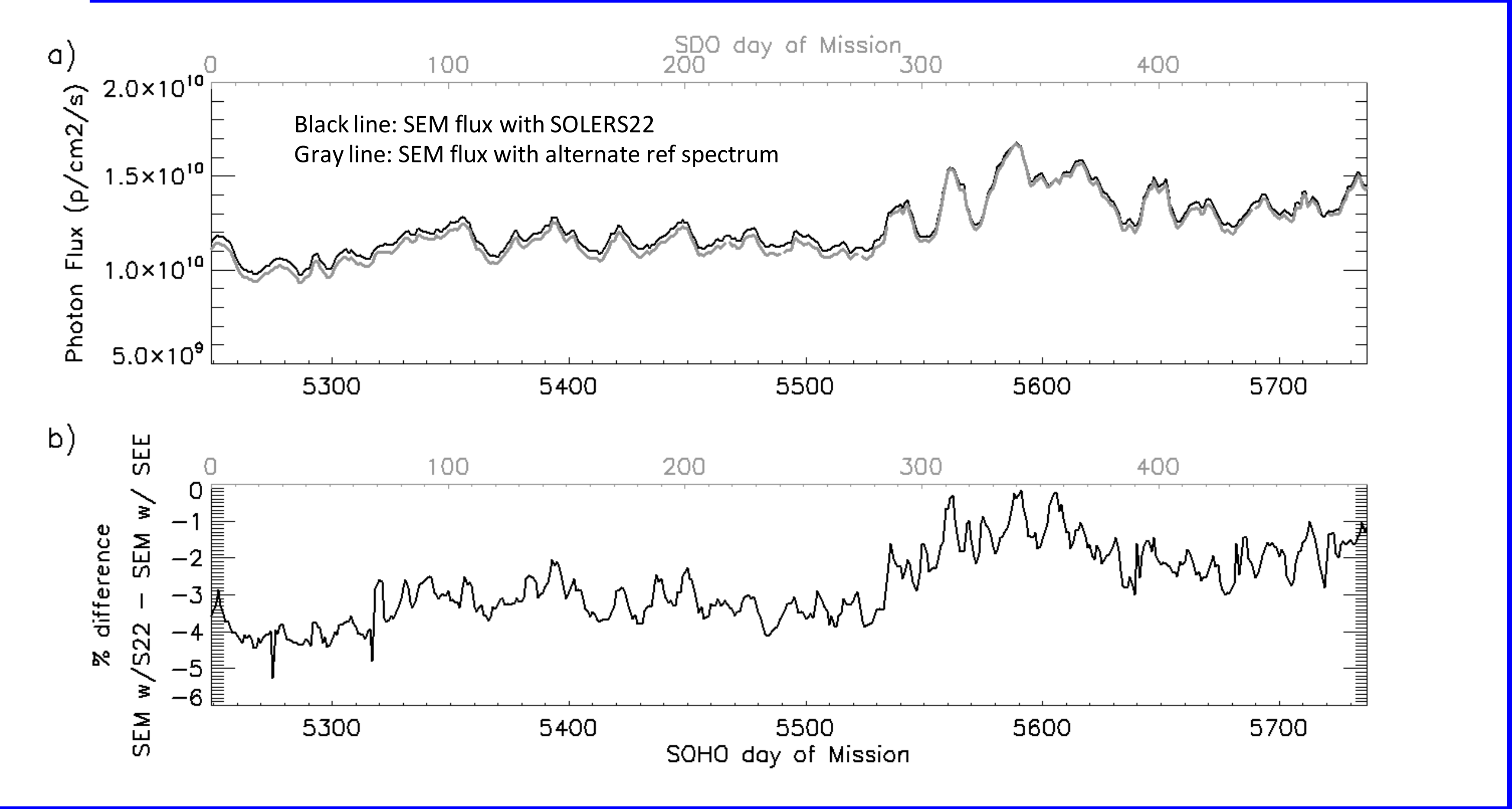
Woods, T. N., F. G. Eparvier, R. Hock, A. R. Jones, D. Woodraska, D. Judge, L. Didkovsky, J. Lean, J. Mariska,H. Warren, D. McMullin, P. Chamberlin, G. Berthiaume, S. Bailey, T. Fuller-Rowell, J. Sojka, W. K. Tobiska,and R. Viereck, **Extreme Ultraviolet Variability Experiment (EVE) on the Solar Dynamics Observatory(SDO): Overview of Science Objectives, Instrument Design, Data Products, and Model Developments**, Solar Physics, p. 3, Jan. 2010.

# SIP/SOLAR 2000 ref. spectra



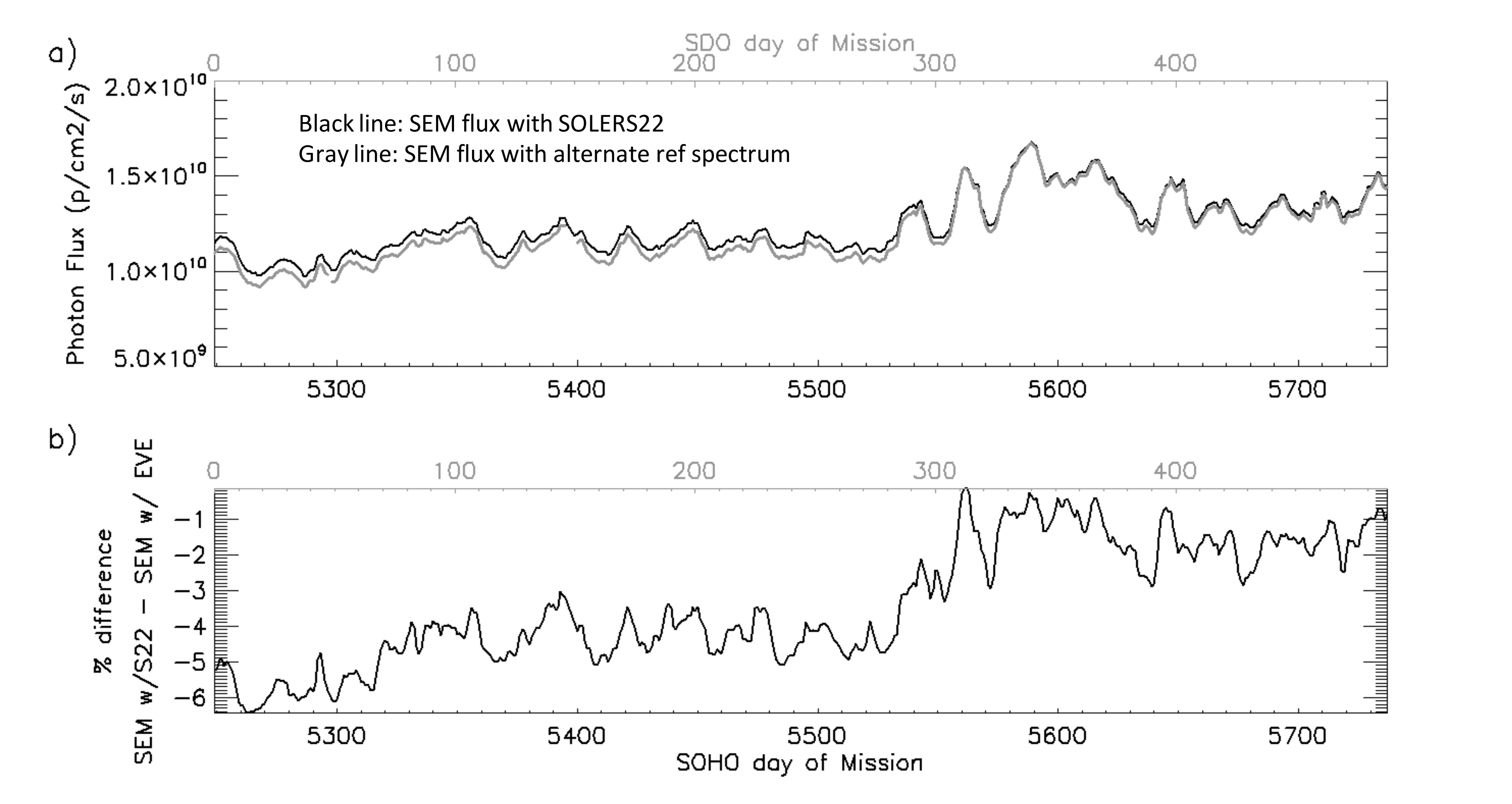

- SEM fluxes calculated with SOLAR2000 model agree well with those calculated using SOLERS22
- Relative spectral shape of SOLAR2000 doesn't change significantly with activity in SEM band

# TIMED/SEE Level 3A



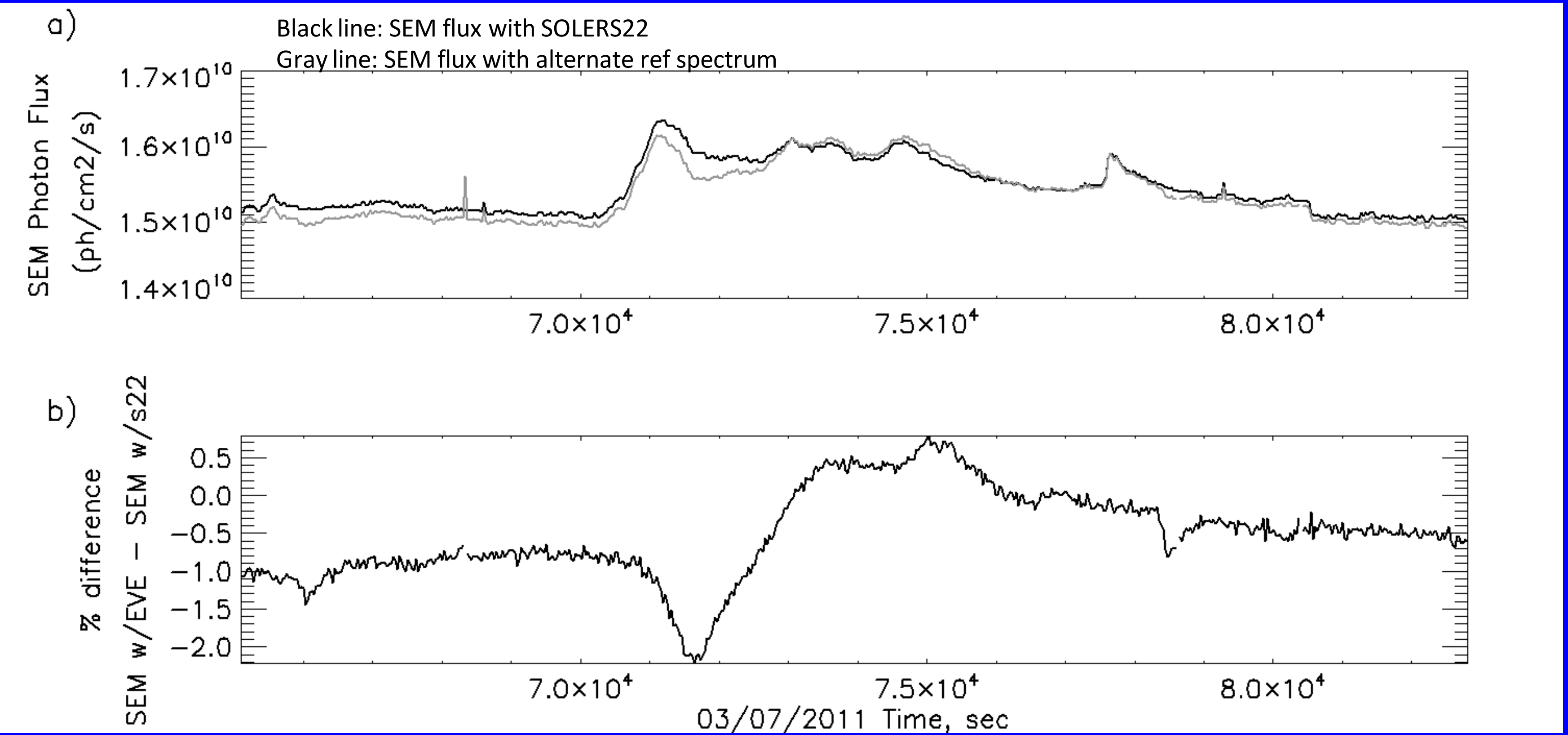

- The improved agreement observed with the transition from low to moderate activity is presumably related to the SOLERS22 spectrum better representing the solar spectral shape associated with mid levels of activity

# SDO/EVE Level 3




- Results for EVE ref. spectra are similar (i.e. decreasing discrepancy with increasing activity)to those obtained with TIMED/SEE

# SDO/EVE Level 2 during flare




- 30 sec average SDO/EVE reference spectra are used to calculate SEM flux

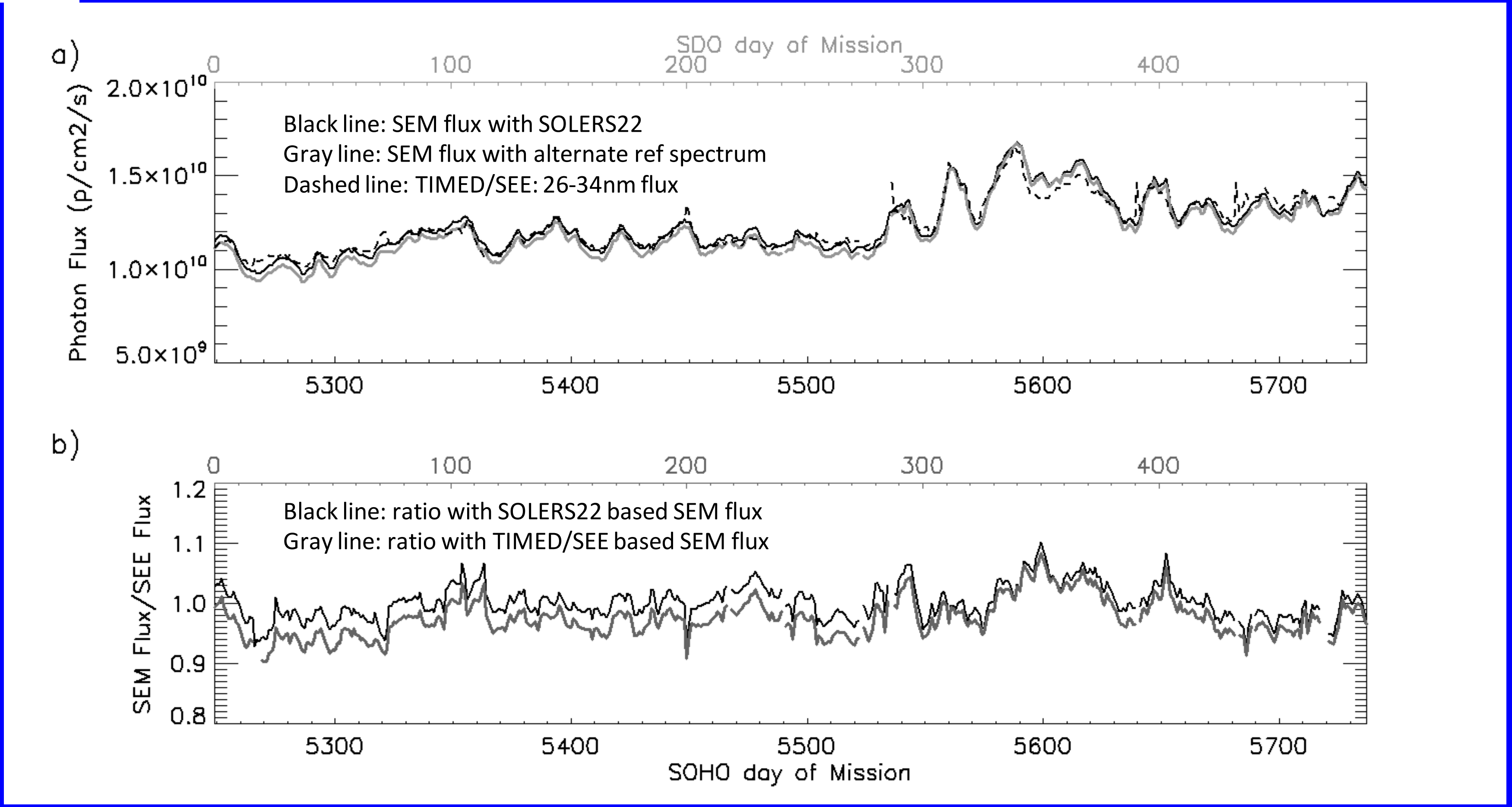
# Average discrepancy due to choice of reference spectrum

| Reference spectra | MAX abs(% difference) | MIN abs(% difference) | MEAN abs(% difference) |
|---|---|---|---|
| TIMED/SEE | 5.27 | 0.15 | 2.72 |
| SDO/EVE | 6.43 | 0.15 | 3.35 |
| SDO/EVE(flare) | 2.22 | 0.00 | 0.65 |

- Reference spectrum related discrepancies are averaged over the SDO mission
- For the flare (bottom row) discrepancies are averaged only over a 5-hr period on 3/7/2011 during which the flare occurred. Because the flare mean does not include the period of lower activity at the beginning of the SDO mission (i.e. the period for which reference spectrum related differences are the greatest) it is lower than the mission averaged discrepancies in the rows above.

# Absolute irradiance comparison

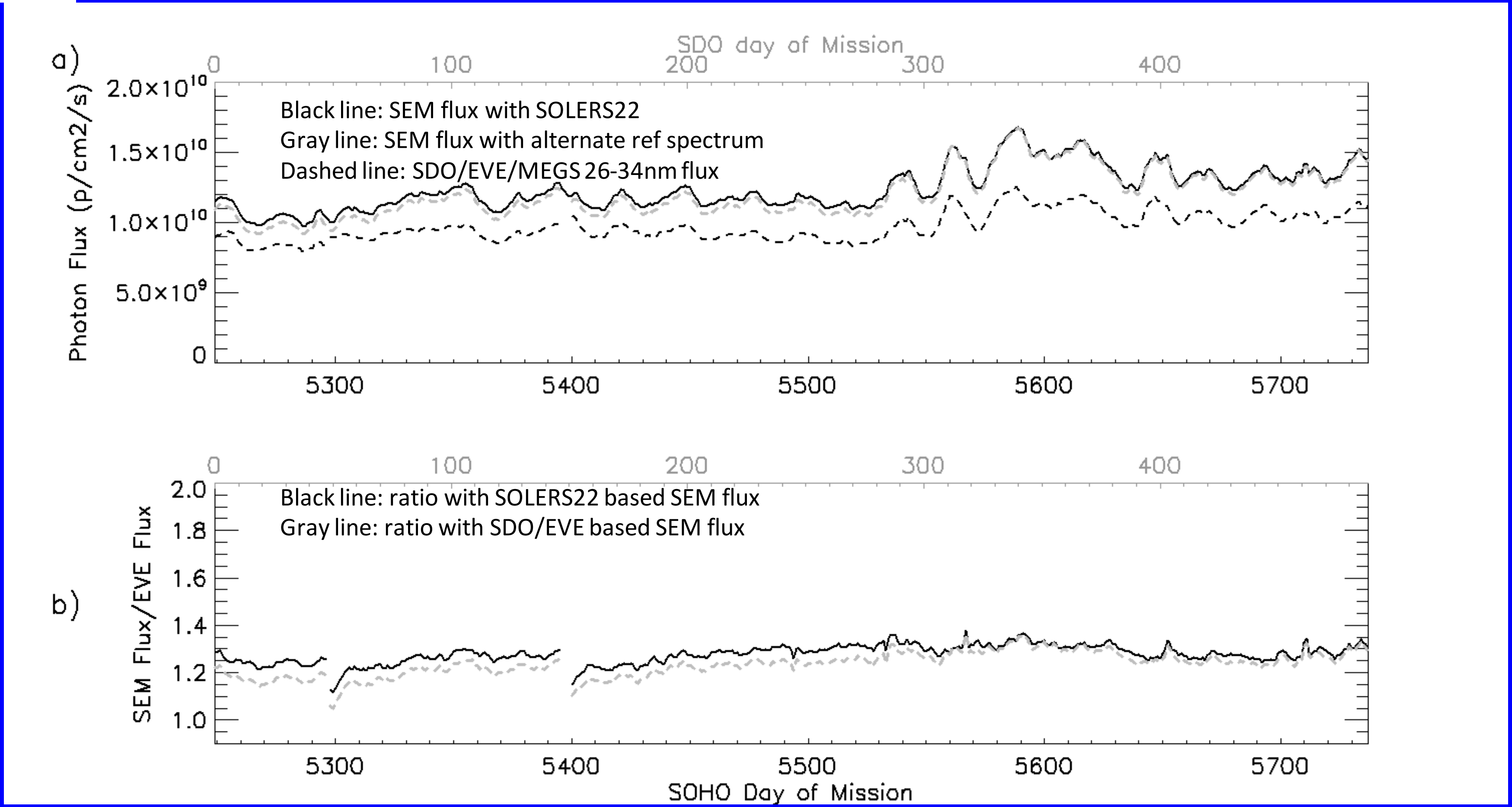
## SEM vs. TIMED/SEE




- Daily averaged TIMED/SEE level 3A spectra (dashed line in panel a) are integrated over 26-34 nm (i.e. SEM band) for this comparison

# Absolute irradiance comparison

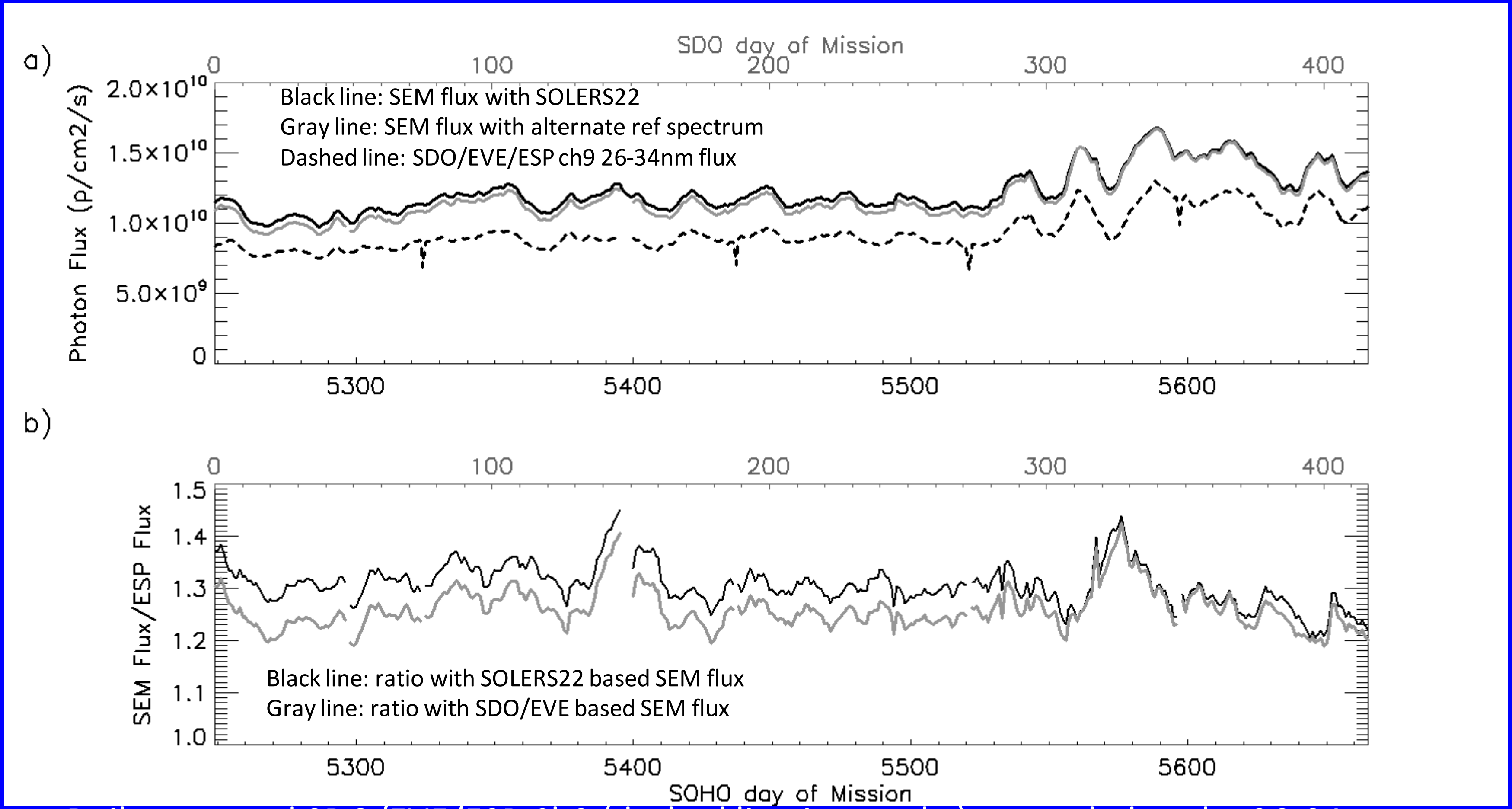
## SEM vs. SDO/EVE




- Daily averaged SDO/EVE level 3 spectra (dashed line in panel a) are integrated over 26-34 nm (i.e. SEM band) for this comparison

# Absolute irradiance comparison

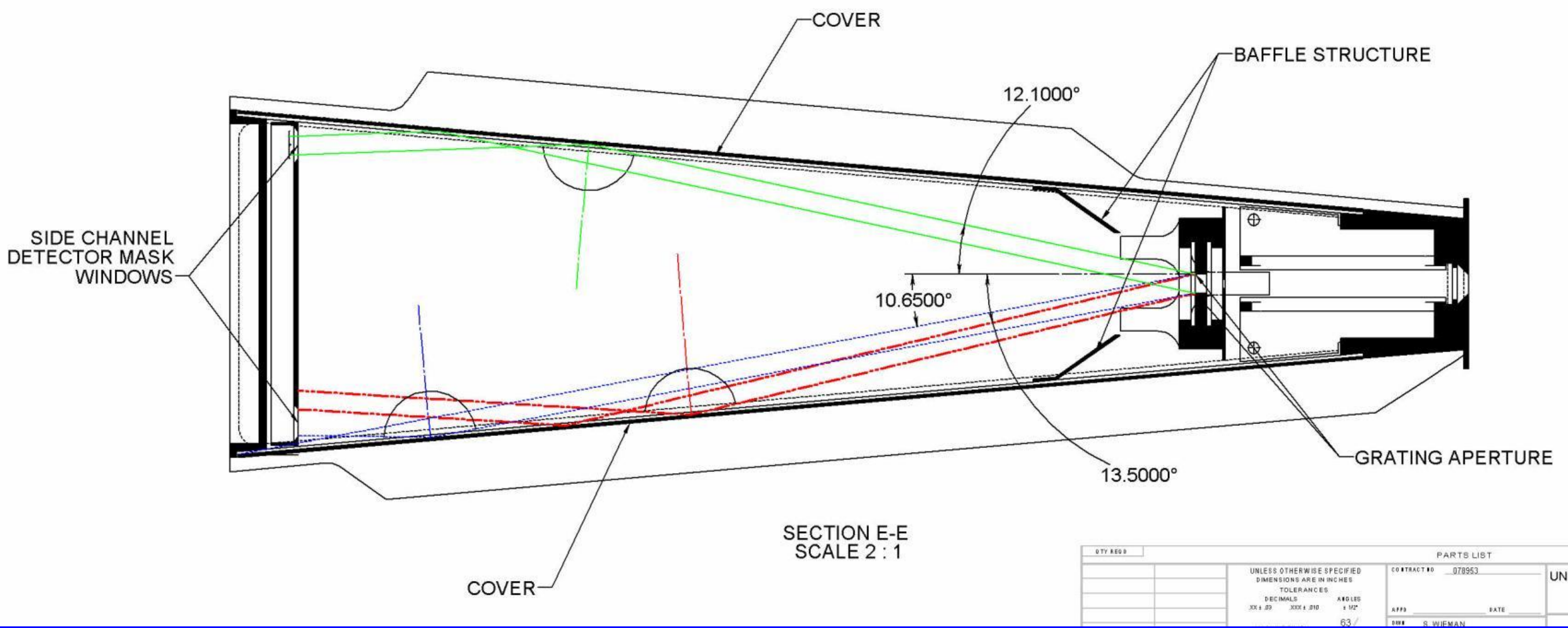
## SEM vs. SDO/EVE/ESP CH9




- Daily averaged SDO/EVE/ESP Ch9 (dashed line in panel a) are scaled to the 26-34 nm SEM band (based on the corresponding daily SDO/EVE spectra) for this comparison

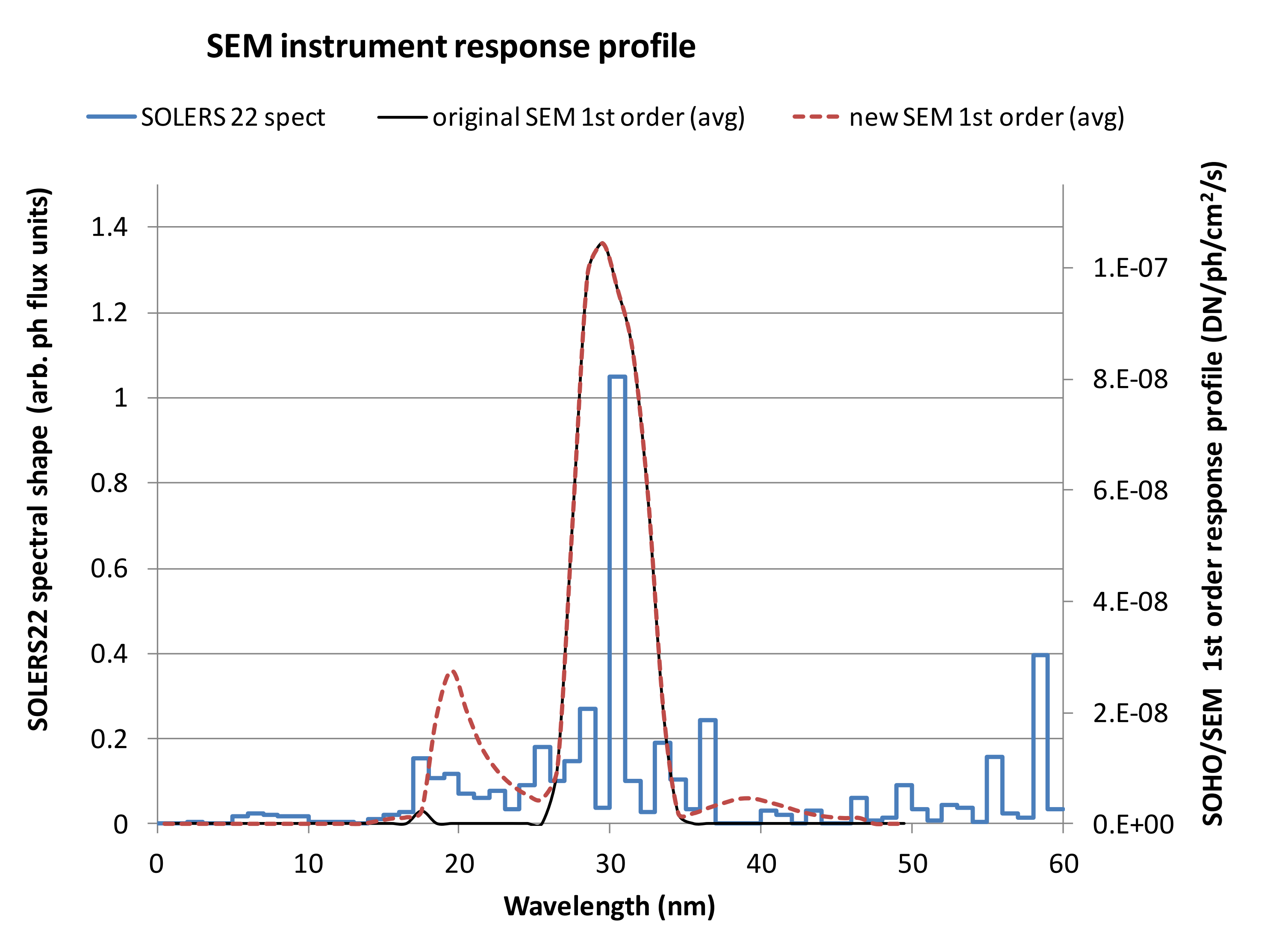
# b) Updated efficiency profiles

# Updated efficiency profile



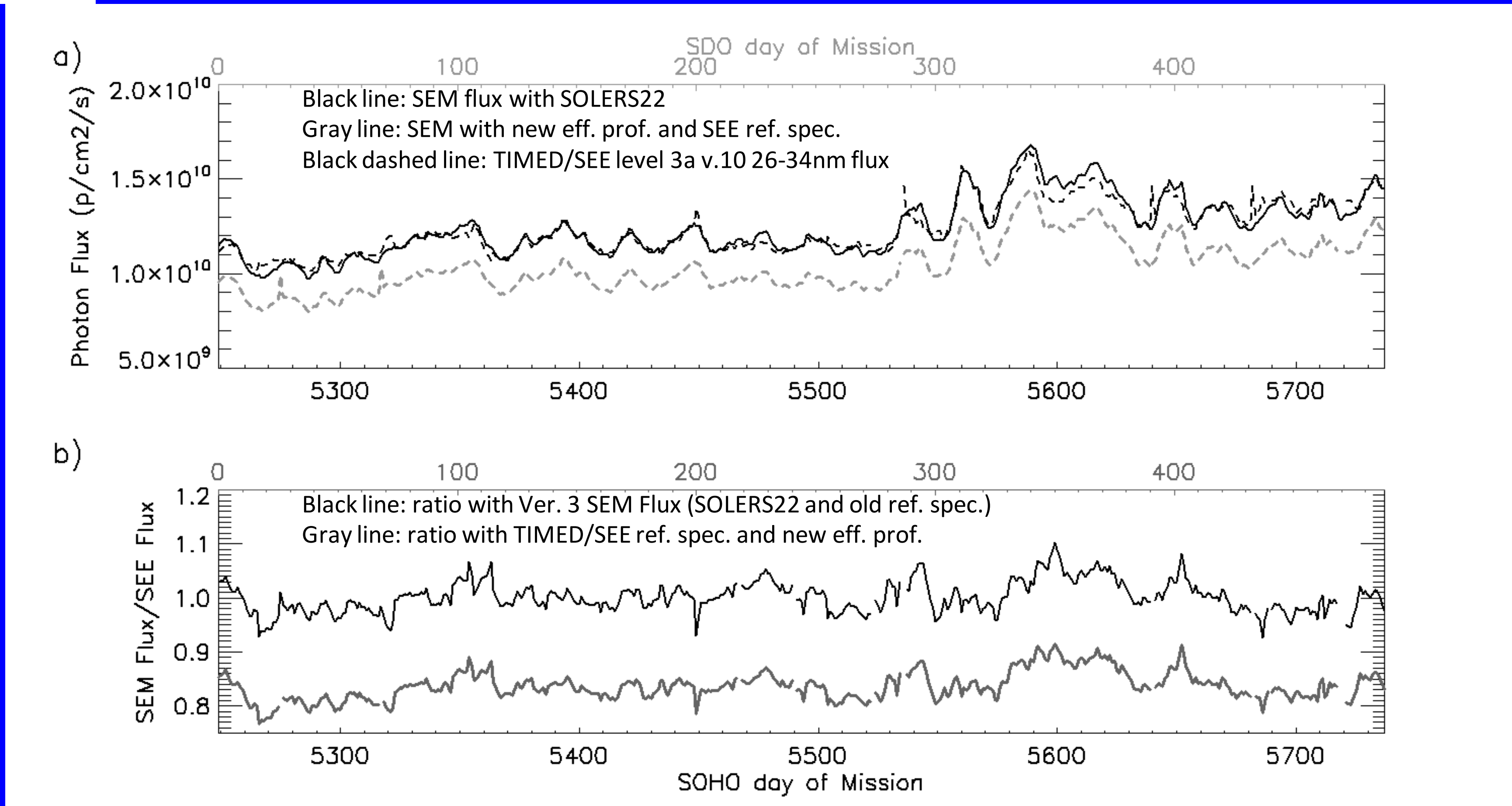

- Techniques for calibrating SEM at NIST BL-9 have improved over many years of calibrating the sounding rocket clone instrument
- Additional sensitivity around 39nm and 19.5nm due to grazing incidence reflection of the first and second diffraction orders respectively discovered when calibrating with SEM cover ON.

# Updated efficiency profile



# Absolute irradiance comparison

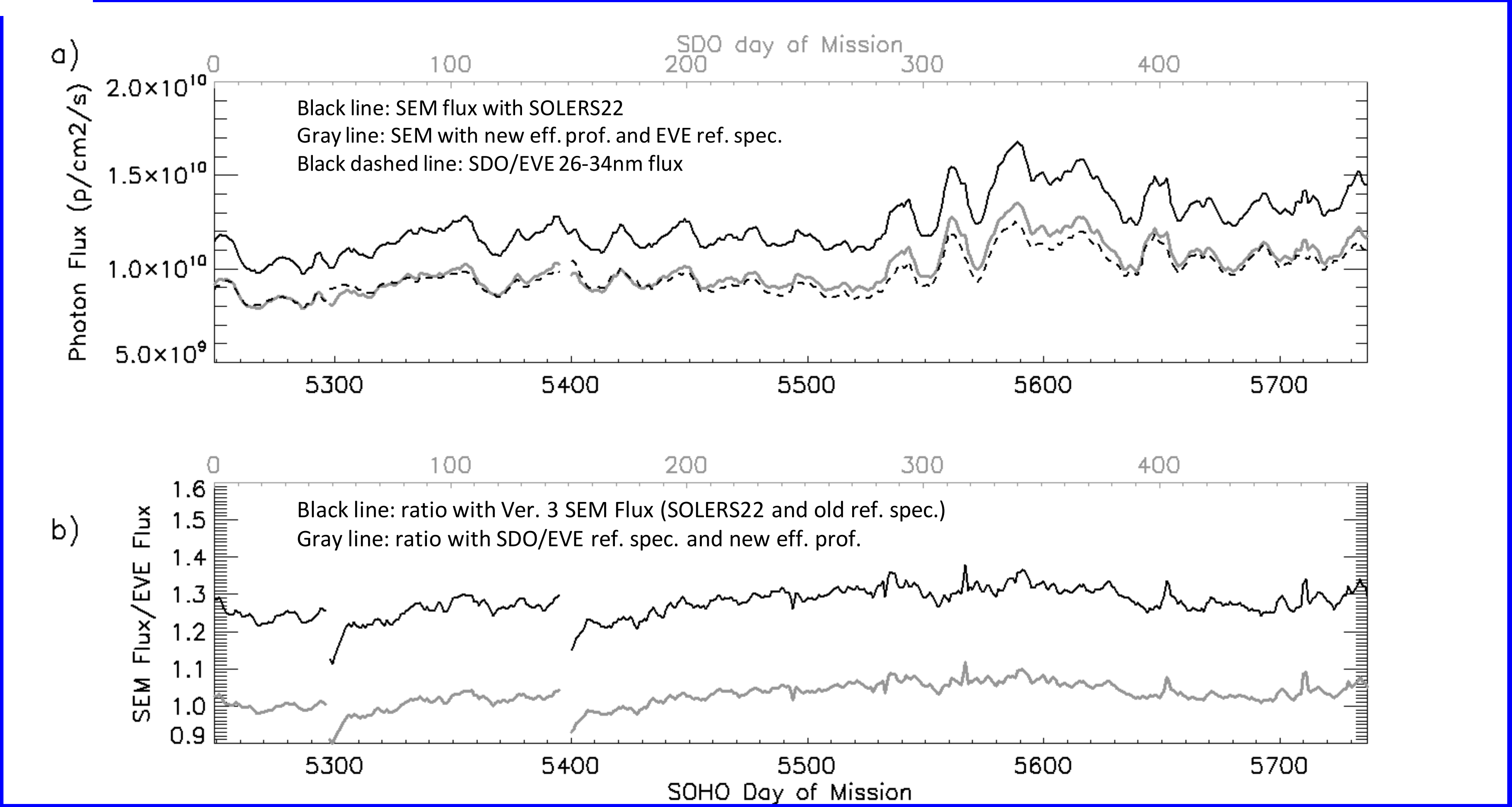
## SEM vs. TIMED/SEE




- Daily averaged TIMED/SEE level 3A spectra (dashed line in panel a) are integrated over 26-34 nm (i.e. SEM band) for this comparison

# Absolute irradiance comparison

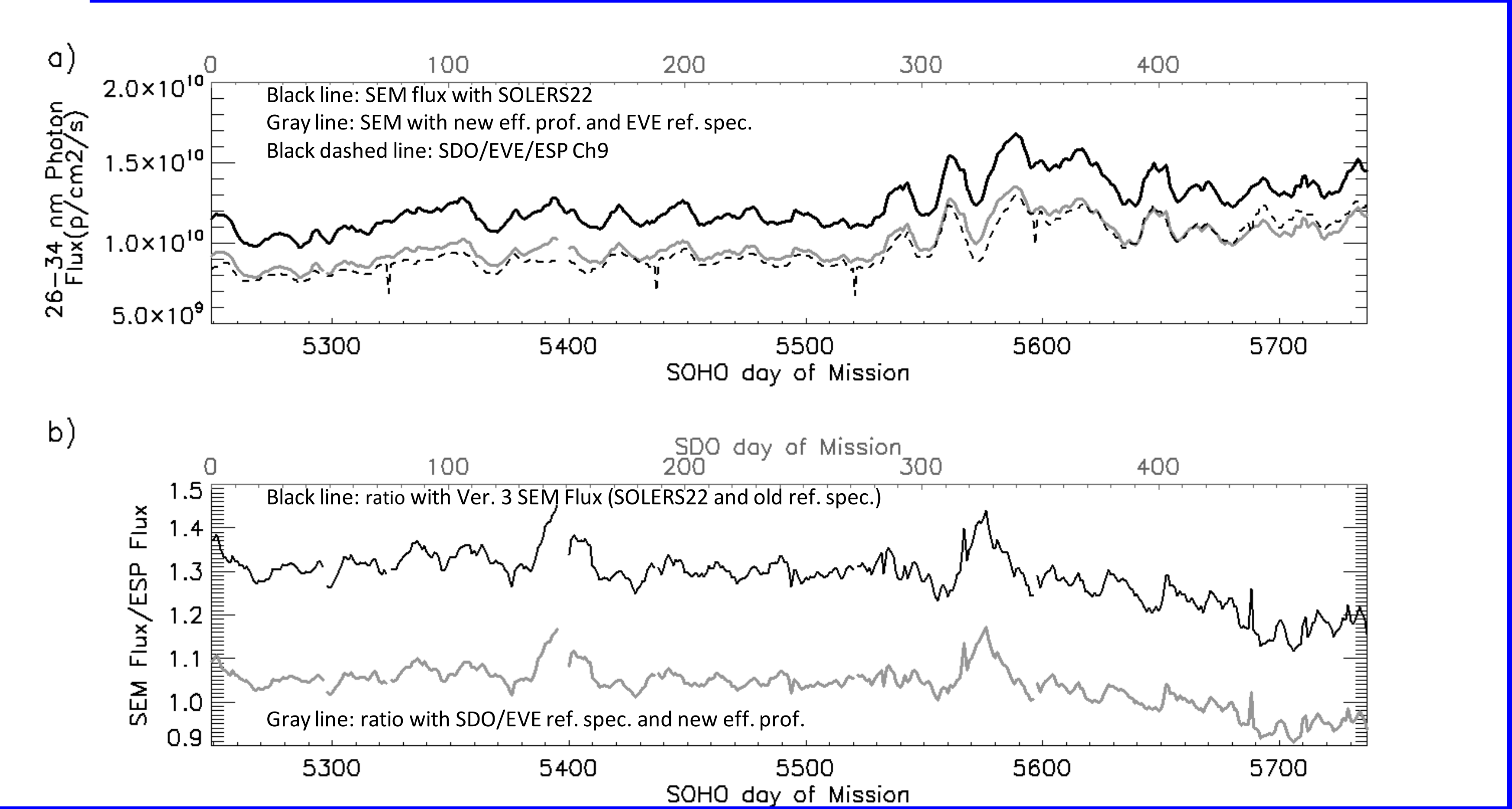
## SEM vs. SDO/EVE




- Daily averaged SDO/EVE level 3 spectra (dashed line in panel a) are integrated over 26-34 nm (i.e. SEM band) for this comparison

# Absolute irradiance comparison

## SEM vs. SDO/EVE/ESP CH9




- Daily averaged SDO/EVE/ESP Ch9 (dashed line in panel a) are scaled to the 26-34 nm SEM band (based on the corresponding daily SDO/EVE spectra) for this comparison

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# Conclusions

- Use of EVE/MEGS spectrum as a reference can affect calculated SEM absolute irradiance by approx. 7% (max. seen so far) versus fixed SOLERS22 spectrum
- Difference between SOLERS22 and EVE/MEGS calculated SEM irradiances is dependent on activity level (greater for low solar activity, lower for moderate activity)
- Revised efficiency profile results in a shift of SEM calculated irradiance. This shift is less dependent on activity level, and results in better agreement with EVE/MEGS and EVE/ESP but worse agreement with TIMED/SEE

# Acknowledgments


- The authors wish to thank W. Kent Tobiska and Dave Bouwer of Space Environment Technologies for their generous time and assistance with the Solar Irradiance Platform/SOLAR 2000 model.
- This work was supported in part by University of Colorado award 153-5979, and by NASA Grant NNX08AM94G.
- SOHO is a project of international cooperation between ESA and NASA

# Extra slides

# Part a) Conclusions

- Using the newly available time-varying reference spectra can change the calculated SEM irradiances by several percent
- Discrepancies are generally lower during conditions of moderate solar activity, corresponding to the period best represented by SOLERS22
- Using the varying reference spectra improves the agreement between SEM and SDO/EVE and between SEM and SDO/EVE/ESP Ch9

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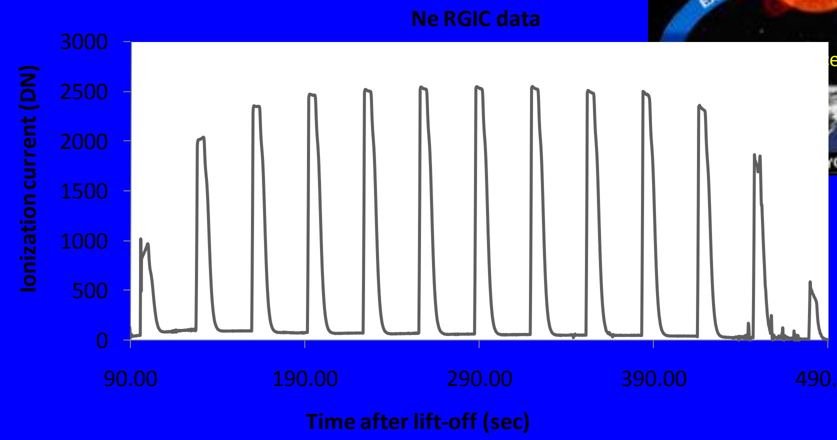
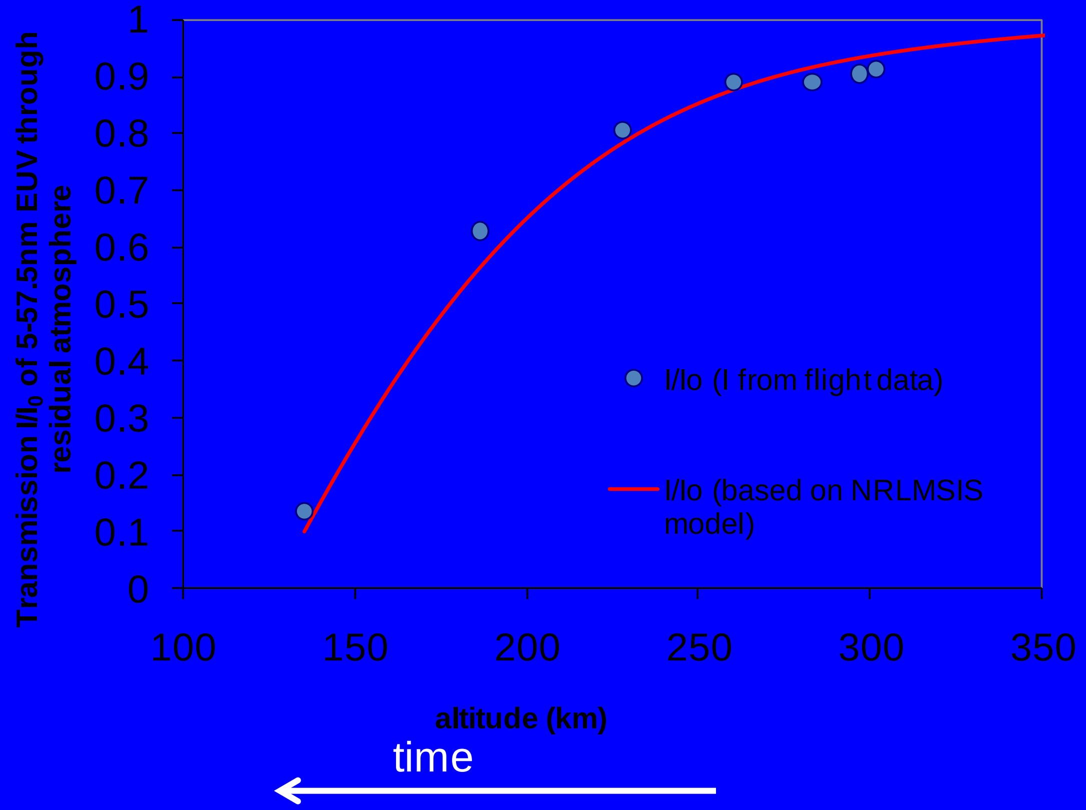
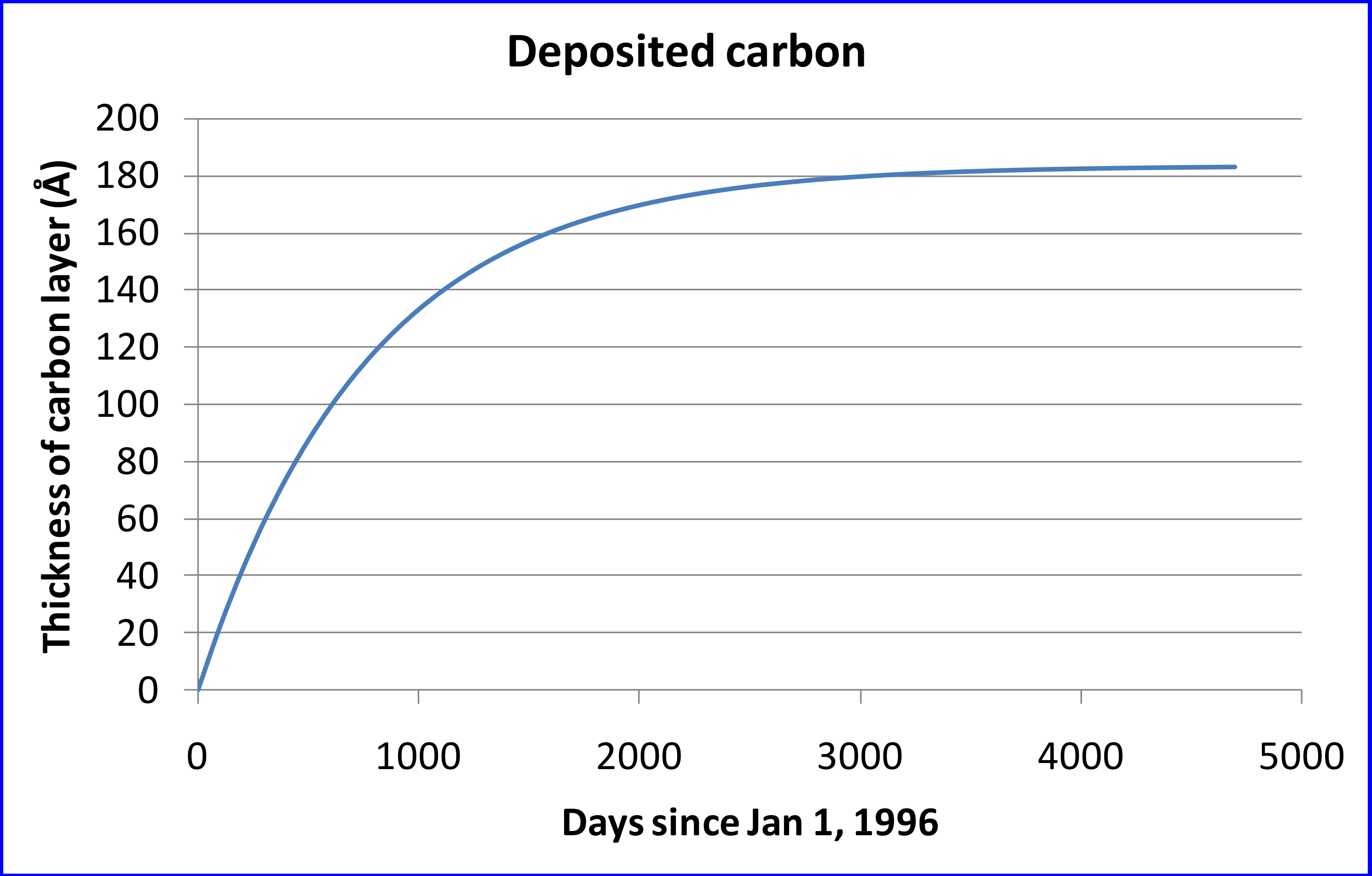
# Ne RGIC

- Flux values for the downward leg (lower background) measurements are fit to a modeled 5-57 nm atmospheric absorption profile based on NRLMSIS and $O_2$, $N_2$ and O cross sections.
- The above atmosphere flux (i.e. zero absorption flux, referred to as $I_0$ in plot at right) is the value which provides the best fit between RGIC measurements and the modeled profile




Deposited carbon
Thickness of carbon layer (Å)
200
180
160
140
120
100
80
60
40
20
0
0
1000
2000
3000
4000
5000
Days since Jan 1, 1996