Calibration Methodology: TIMED-SEE EGS

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Irradiance Measurement Essentials

- **Understand the Measurement Equation:**
  - Know all the parameters that go into the measurement to irradiance conversion and assess how to best quantify each
  - Do a thorough error analysis and budget
- **Calibrate pre-flight:**
  - Use a standard radiometric source
  - Primary standards, such as synchrotrons (e.g. NIST SURF-III) are preferred
- **Track in-flight:**
  - Any instrument changes that will affect results
  - E.g. detector flat fields, gain changes, temperature effects, background signals, …
- **Re-Calibrate in-flight:**
  - As close after launch as possible (changes since pre-flight calib.)
  - On a regular basis thereafter in order to track absolute changes
  - E.g. redundant channels, on-board sources, rocket underflights, proxy models
- **Validate:**
  - With measurements made with other instrumentation
  - Comparisons with models

Calibration is a lifetime commitment

EGS Calibration Plan

- Pre-Flight Calibrations at NIST-SURF-II BL-2
  - Responsivity (quantum throughput, photons/counts)
  - FOV maps
  - Second Order (with filters in beamline)
  - Gain and Linearity
  - Scattered light fitting
- In-Flight Calibrations/Tracking
  - Weekly detector flatfields with built-in lamp
  - Wavelength scale fit by solar spectrum
  - FOV maps on-orbit
  - Weekly comparisons with redundant (cal) channel
  - Regular dark measurements
  - Scattered light fitting
  - Sounding Rocket underflights
  - Comparisons with other instruments

EGS Irradiance Algorithm: Level 1

$$I_{L1} = \frac{\left[\left(C/\Delta t\right) \cdot FF \cdot DEG_1 \cdot LIN - D\right] \cdot G - SL}{R_C \cdot f_{FOV} \cdot A_{Slit} \cdot \Delta\lambda} \cdot \left(\frac{hc}{\lambda}\right)$$

I_{L1} = Level 1 irradiance (Watts/m^2/nm) at instrument resolution
C = Raw counts (cnts)
Δt = Integration time for individual spectrum (sec)
FF = Flatfield correction (preflight and inflight FFs)
DEG_1 = Degradation correction from weekly FFs
LIN = Linearity correction (preflight)
D = Dark correction (cts/sec) (inflight)
G = Gain correction (preflight, with inflight fit to temp dep)
SL = Scattered light correction (cts/sec) (inflight)
R_C = Responsivity (QT) for nominal pointing (cts/photon) (preflight)
f_{FOV} = Correction for responsivity FOV variations (preflight and inflight maps)
A_{Slit} = Area of slit (m^2)
$\Delta\lambda$ = channel width in wavelength units (nm)
hc/λ = Energy per photon of wavelength λ (Watts/photon)

EGS Irradiance Algorithm: Levels 2 & 3

Level 2:

$$I_{L2} = \left[\sum_{\substack{\text{good L1} \\ \text{in day}}} \text{Regrid}(I_{L1}) \cdot f_{1AU} \cdot DEG_2 \cdot f_{LongTerm} \right] - OS$$

I_{L2} = Level 2 irradiance (Watts/m2/nm) on a 0.1 nm wavelength grid
Regrid() = Regrids spectra from individual wavelength scales to common grid (0.1 nm)
f_{1AU} = Correction to normalize to 1 AU from Sun
DEG_2 = Degradation correction from fit to weekly calibration/normal slit comparisons
$f_{LongTerm}$ = Long-term Degradation Correction (Rocket cals for EUV, SOLSTICE cals for FUV)
OS = Order sorting correction (currently removing only isolated lines in higher orders)

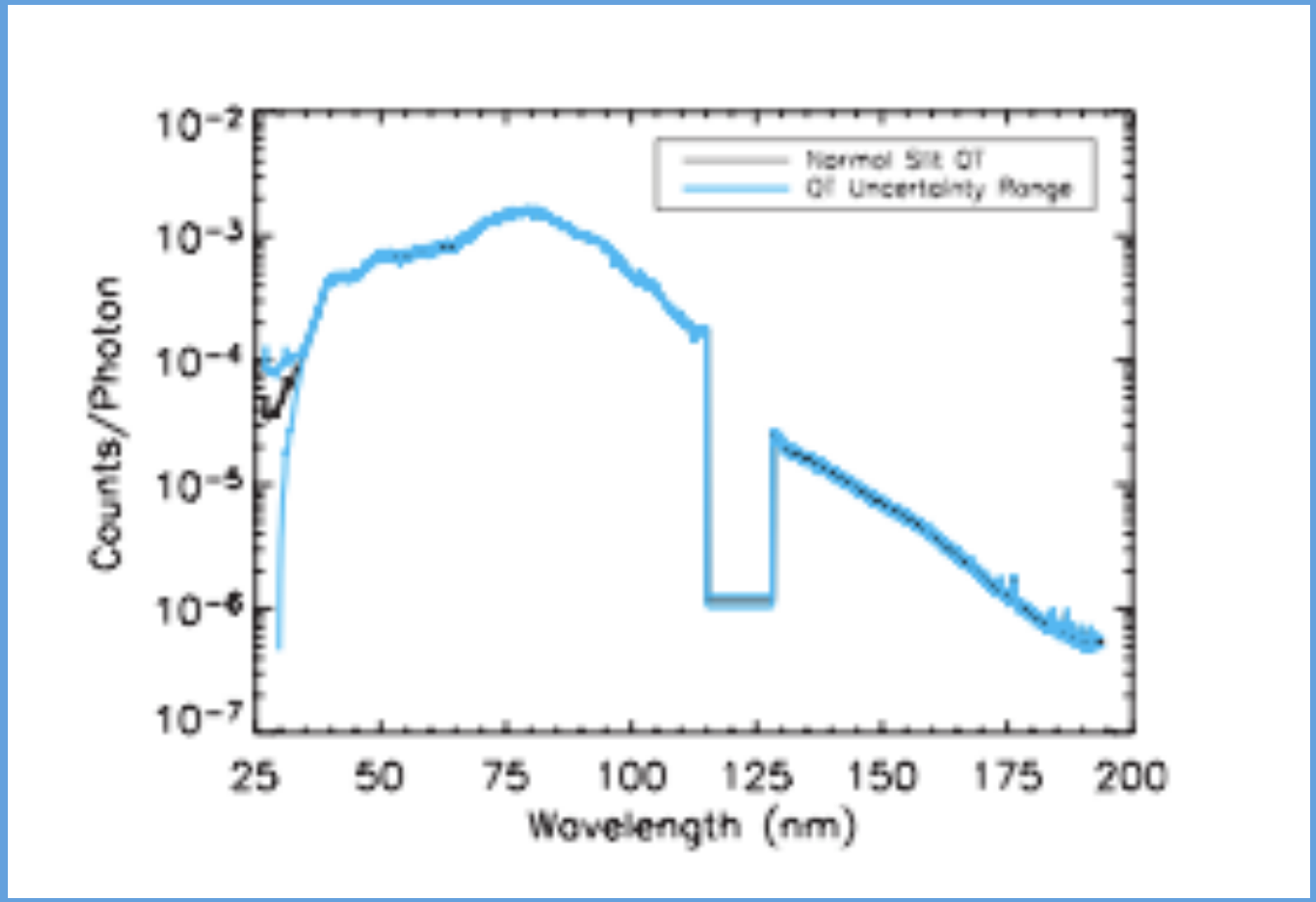
Level 3:

Lines: L2 spectra analyzed and specific lines are extracted, with background removed to give just the flux in the line itself

Spectra: L2 EGS spectra are put into 1 nm bins and combined with XPS irradiances to give spectra from 0-195 nm on 0.5 nm centers. EGS contributes for λ>27 nm. L3 has two spectra: flux_meas and flux_filled. Latter uses models to fill spectral gaps where no flux is measured (eg. Ly-α).

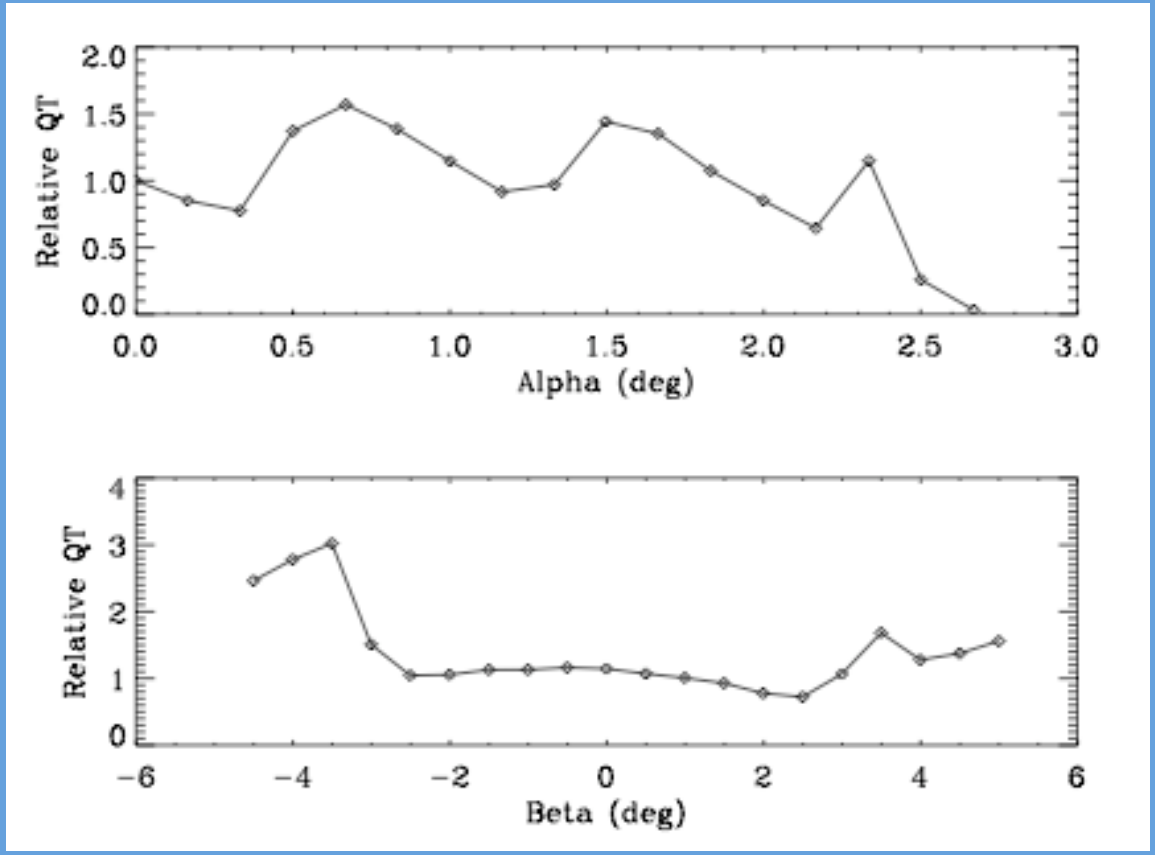
EGS Responsivity

Responsivity is determined at NIST-SURF. It is the inversion of the measurement equation with the light into the slit as a “known”.



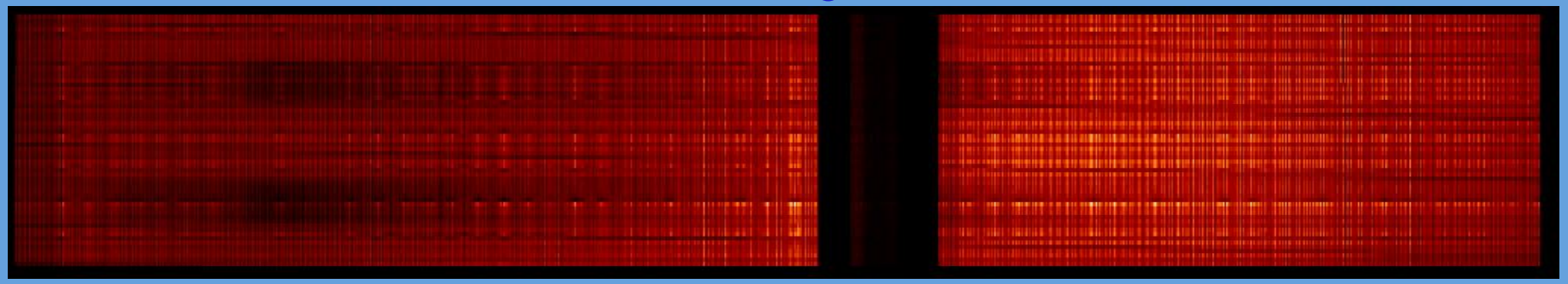
Preflight FOV Variations

Mechanically ruled, 5-partition blazed grating results in fairly significant FOV variations in responsivity.

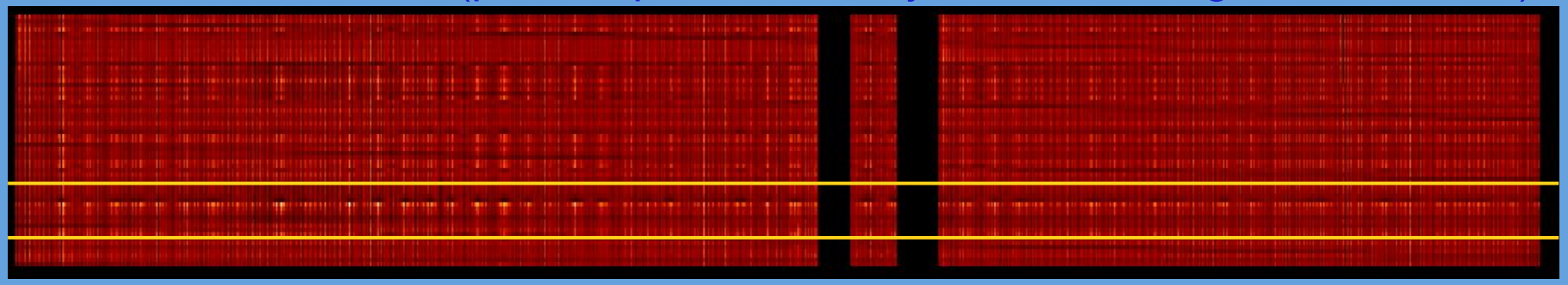


Preflight Flatfield Example

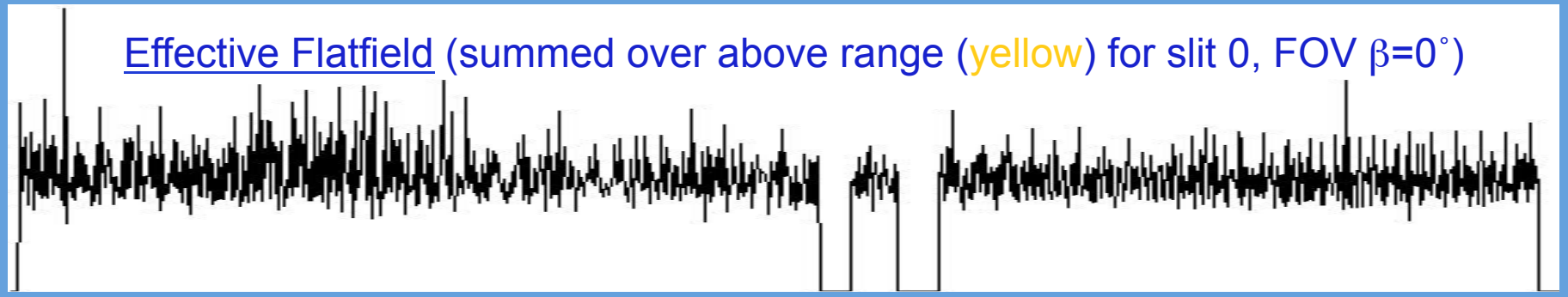
Raw Flatfield Image for HV Level 5



Processed Flatfield (pixel-to-pixel variability after removing slow variation)

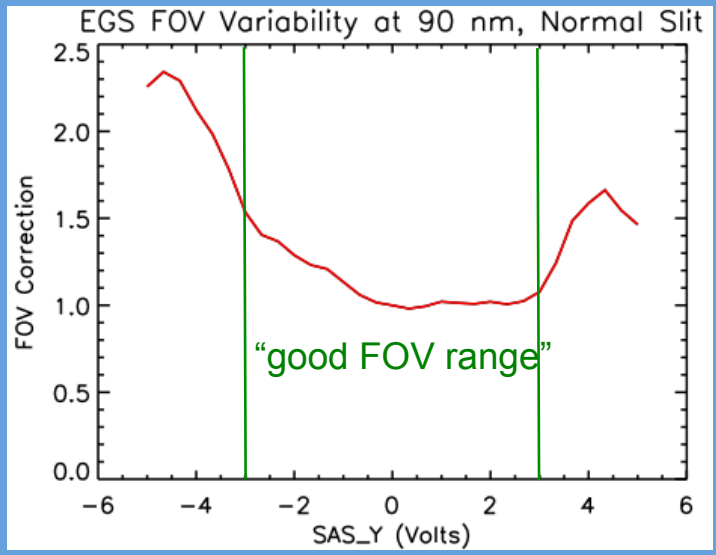


Effective Flatfield (summed over above range (yellow) for slit 0, FOV β=0˚)



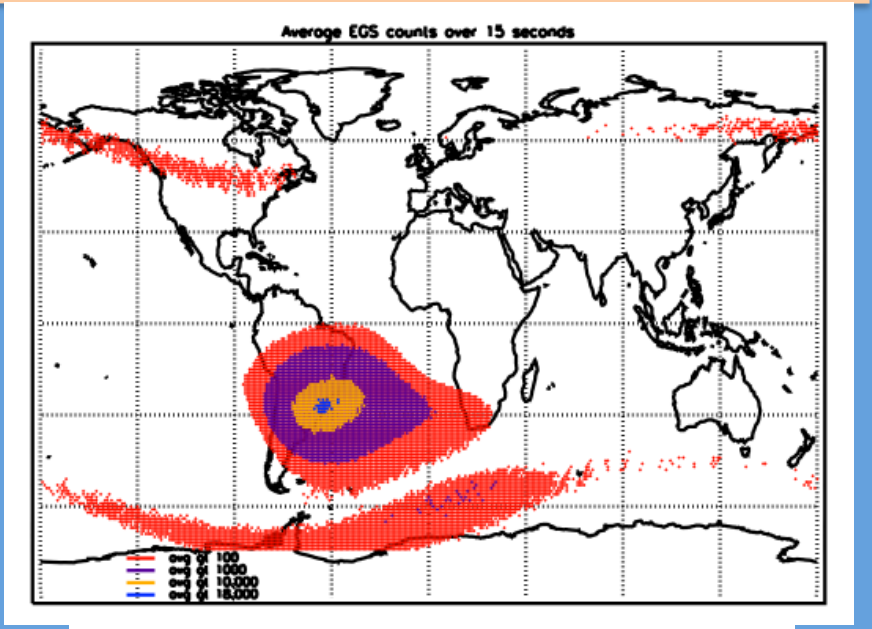
EGS Correction Factors

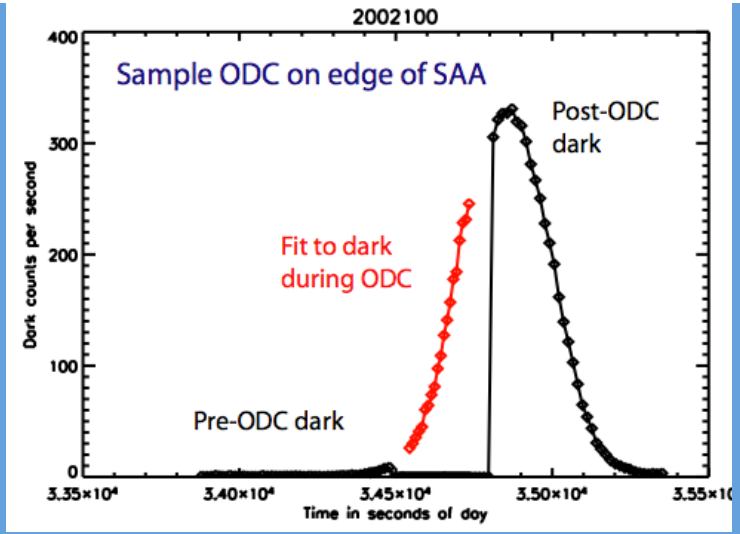
- Linearity and Gain: Based on pre-flight calibrations
- Scattered Light: removal and addition back into correct wavelengths based on scaled “background” spectra
- Order Sorting: removal of 2nd and 3rd order lines based on actual measured line ratios, also removal of “artifact” at 134.5 nm and 136.5 nm (“lines” at fixed columns on detector in both cal and norm spectra, but not in flatfield, not a solar line)
- Field of View: Variations in sensitivity along SAS_Y (dimension that SSPP does not track in) removed by using map built up with EGS measurements themselves (ratio to nominal SAS_Y=0 spectra), limit FOV range used in L2 to ±3 Volts (~ ±3˚).



Dark Corrections

- Version 6 has significant improvement in Dark corrections.
  - EGS detector is very quiet, normally a few counts/sec on whole detector
  - Get enhanced dark counts from energetic particle hits, primarily in SAA (can be thousands of counts/sec on whole detector) and some in polar zones
  - New “map” of average dark counts compiled from 15-sec “idle” (non-ODC) dark rates
  - Use idle dark rates before and after ODC and scale map to get dark during ODC

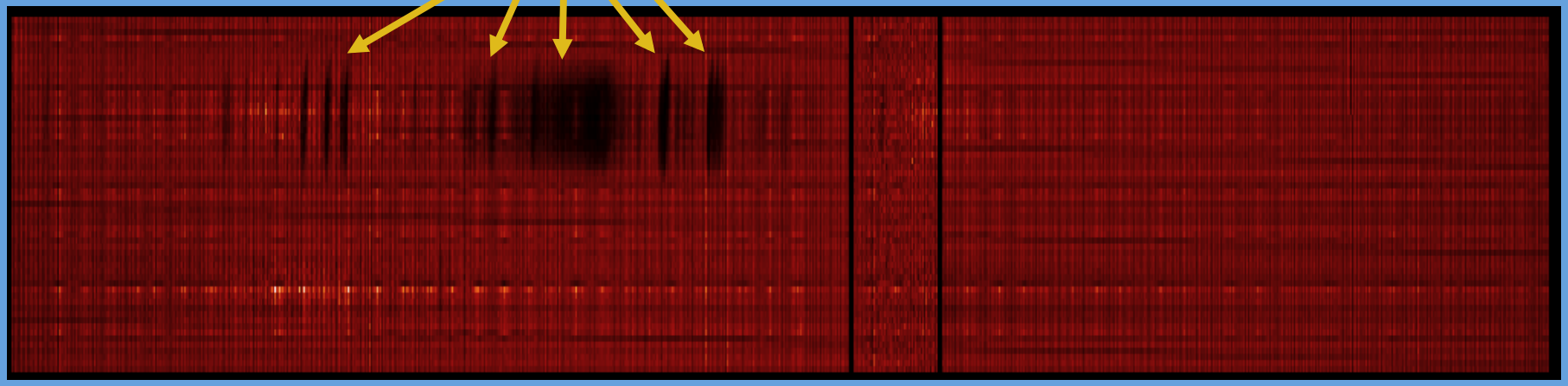




Flatfield and L1 Degradation

Degradation on MCP is a function of charge extracted.

spectral features with large count rates degrade most



- Three flatfield images are made each week during non-solar observing times
- A time series fit of FF degradation corrections (DEG_1) is made from ratios of the weekly FFs (extrapolated where degradation is so great that FF signal is below 1 DN)
- DEG_1 is applied when FF correction is applied in Level 1
- Assumes FF at 185 nm (from lamp) is same at all wavelengths, but this isn't true, which is on reason why we have the DEG_2 in Level 2.

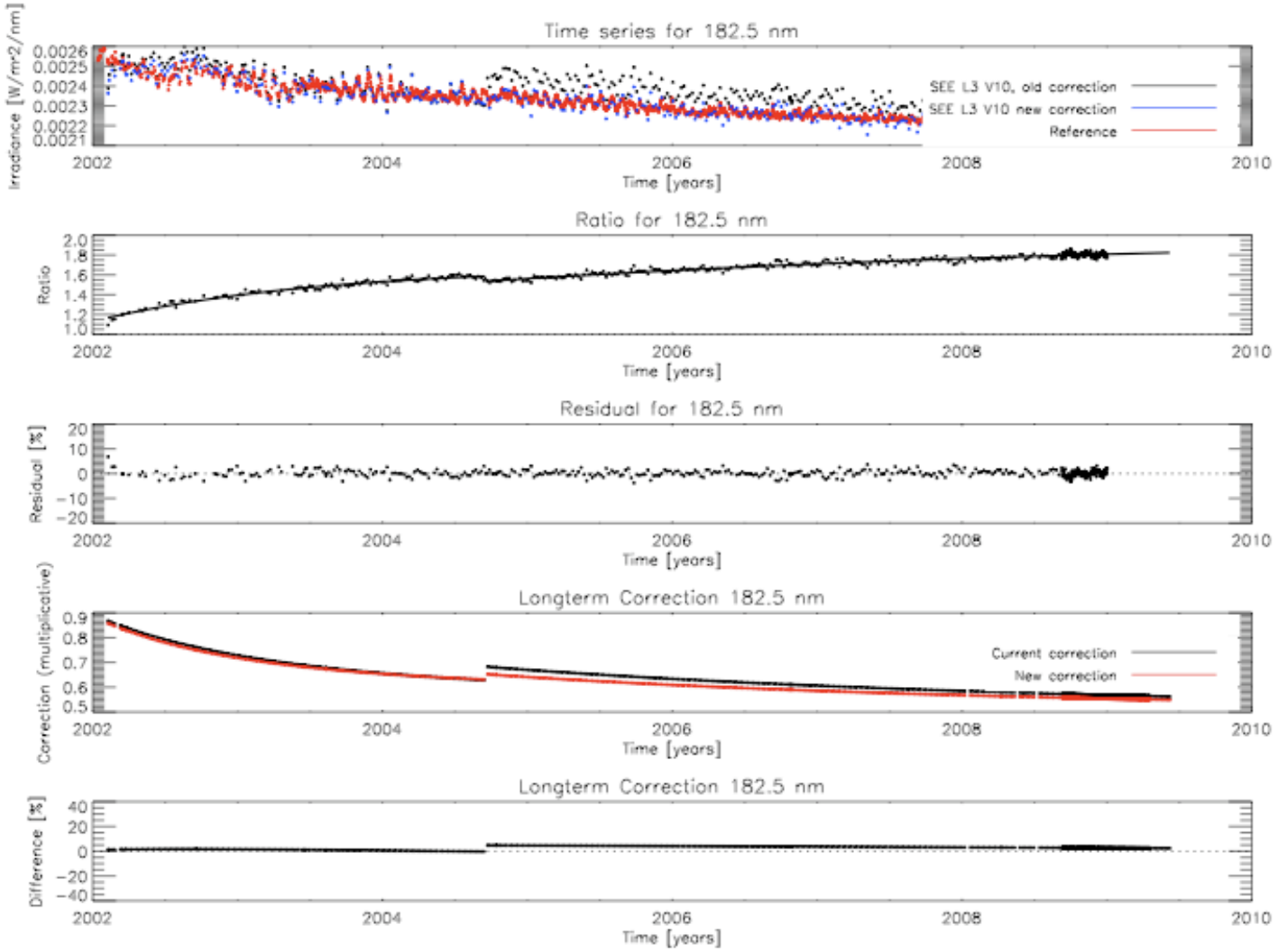
L2 Degradation (DEG_2)

- ~12-15 solar observations are made each day with the normal slit
- 2 solar observations are made per week (on Mondays) with the calibration slit
- Ratios of normal to calibration L2 irradiances are made and a time- and wavelength-dependent degradation correction (DEG_2) is determined and applied in Level 2 processing
- DEG_2 corrects for any degradation that is occurring in the normal channel but not the calibration channel and that is not captured by DEG_1

L2 Degradation ($f_{LongTerm}$): FUV

- FUV: Ly-alpha and longward
- Noted early on that non-degraded parts of detector were in sensitivity over time
  - Theory is that as degraded portions can carry less current, the non-degraded portions must carry more (think of MCP as set of parallel resistors).
- “Correct” FUV to match time change of composite UARS-SUSIM, UARS-SOLSTICE and SORCE SOLSTICE time series.

L2 Degradation ($f_{LongTerm}$): FUV



L2 Degradation ($f_{LongTerm}$): EUV

- Use wavelength and time-series fit to rocke comparisons to correct long-term EUV drift not captured elsewhere.
- Underflight rocket calibrations
  - 08-Feb-2002 18:41:00 UT (SEE)
  - 12-Aug-2003 18:23:30 UT (SEE)
  - 15-Oct-2004 17:28:34 UT (SEE)
  - 28-Oct-2006 17:58:00 UT (EVE, instrument noise problem, no EUV)
  - 14-Apr-2008 16:58:00 UT (EVE)
  - 03-May-2010 18:32:00 UT (EVE)
  - 23-Mar-2011 17:50:00 UT (EVE)

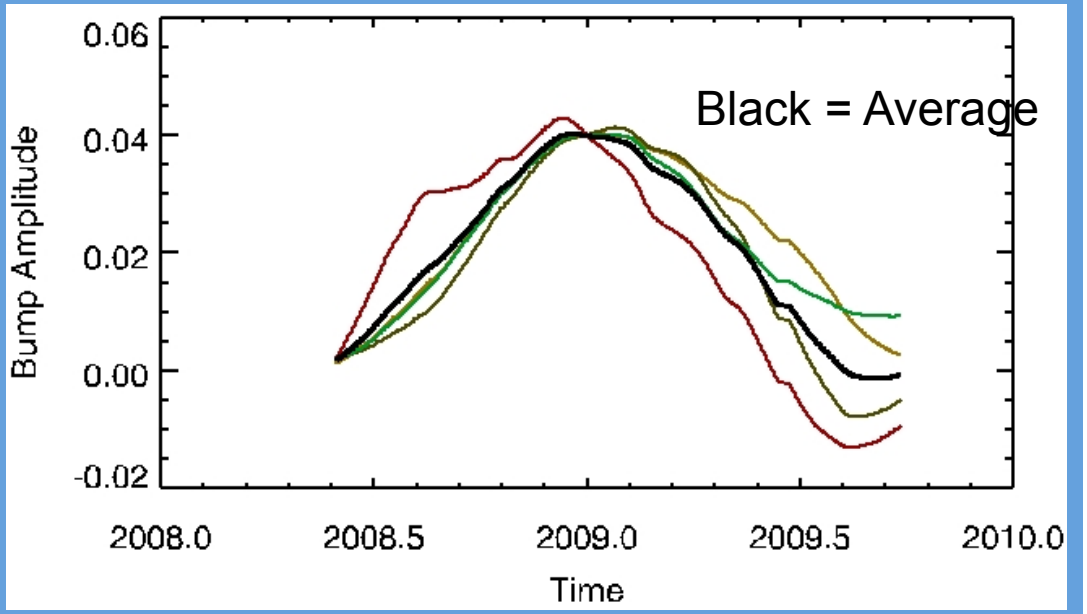
“Other” Corrections

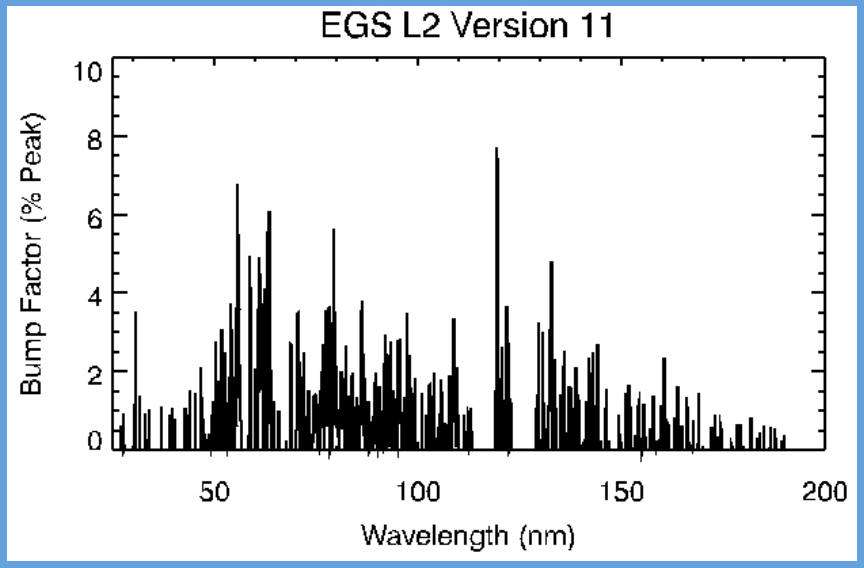
New with Version 11 are some specific corrections:

- Fix “bump” in 2008-2009 time series
  - Caused by over-use (bad decision) of cal channel resulting in degradation of cal channel and “screwing up” of cal-norm ratio correction
- Fix 27-45 nm scattered light and responsivity
  - Noted by CDS team and others, our 30.4 is too low, but the neighboring wavelengths were too high (compensating in broadband)

Correcting the Bump

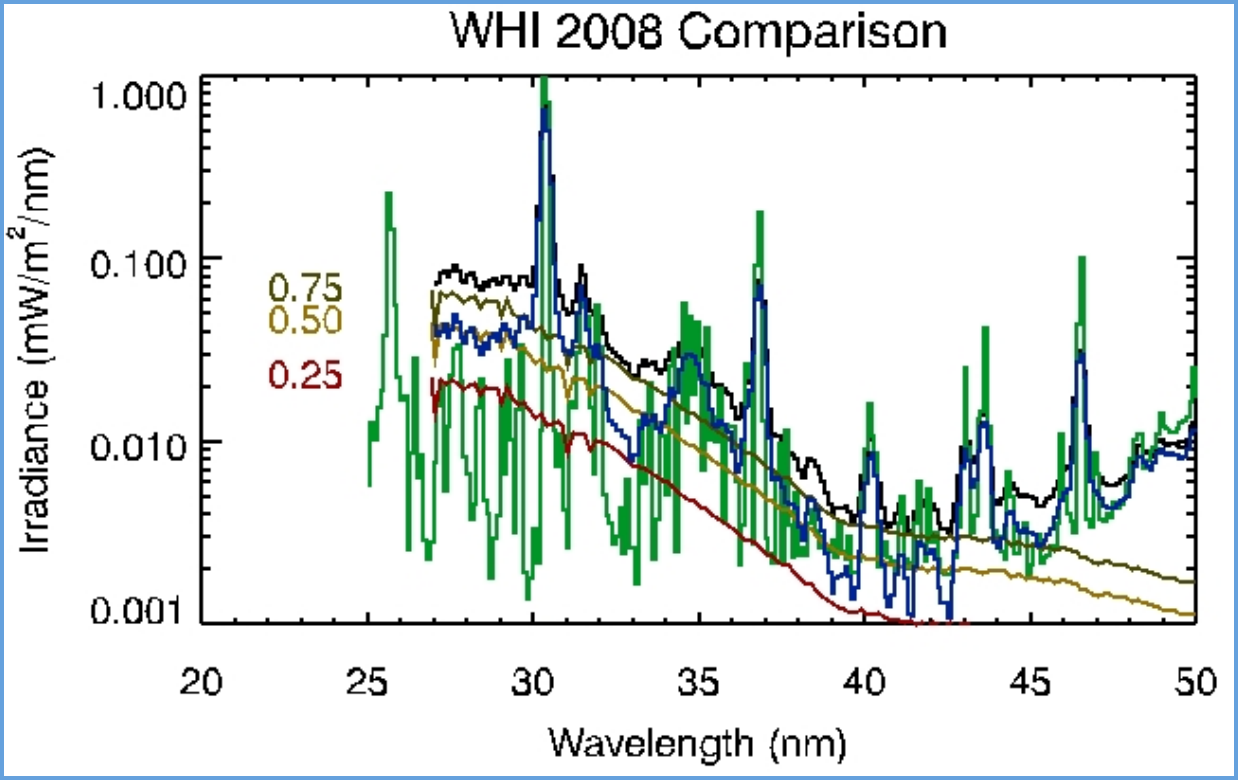
- Highly saturated emission lines have larger bumps during 2008-2009. Use them to get average bump time series.
- Correct the Bump using the 2009/001 irradiance as reference
- Not all wavelengths need this bump correction.
- Bump corrections are mostly < 1%. Largest is 8% at the peak.





Correcting 27-34 nm

- Scattered Light (SL): only need 0.5 counts removed to get EGS to agree better with rocket EVE spectrum
- Responsivity: the He II 304 emission remains low after the SL correction.
  - Concept: most of the SL could be from He II 304 and thus has too small irradiance.



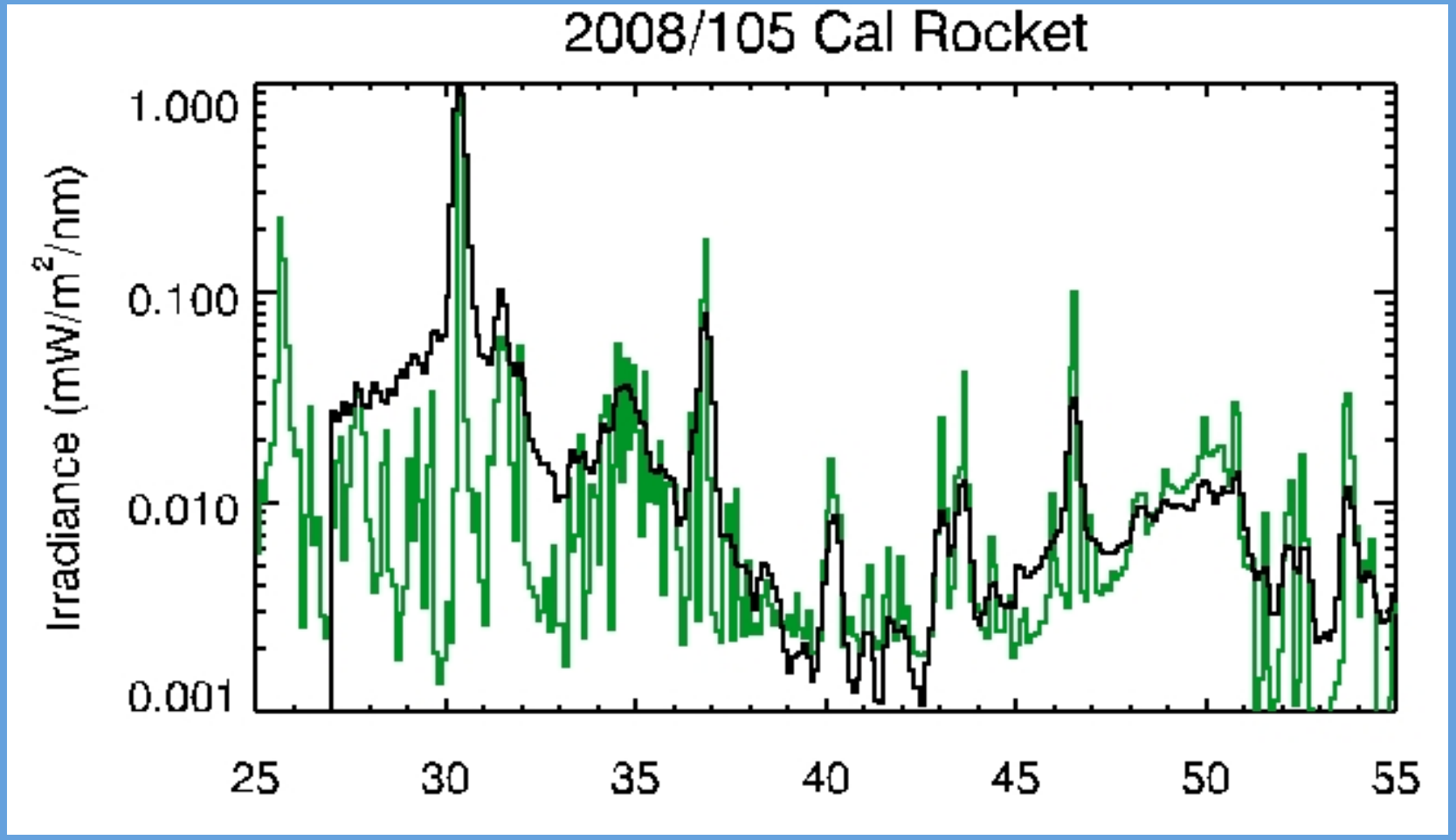
Counts / QT => Flux

Black = EGS L2

Blue = SL correction applied for 0.5 counts

Green = Rocket EVE (WHI SIRS, 4/14/08)

27-35 nm after Correcting in V11



Summary

- We do a lot of corrections, but they are all designed to make the product better
- We think a lot about each of them