EUV Variability Experiment

Multiple EUV Grating Spectrographs (MEGS)

Tom Woods

Instrument Overview
- MEGS-A 6-38 nm, 0.1-nm resolution
- MEGS-B 35-105 nm, 0.1-nm resolution
- MEGS-P Photometer for HI 121.6 nm
- MEGS-SAM 0.1-7 nm pinhole camera
- Measurement Technique
- Data Products

Calibrations
- Pre-flight calibrations
- In-flight calibrations
- MEGS degradation

Comparisons to SDO EVE
- MEGS-P Lyman alpha
- MEGS-A and –B to TIMED SEE

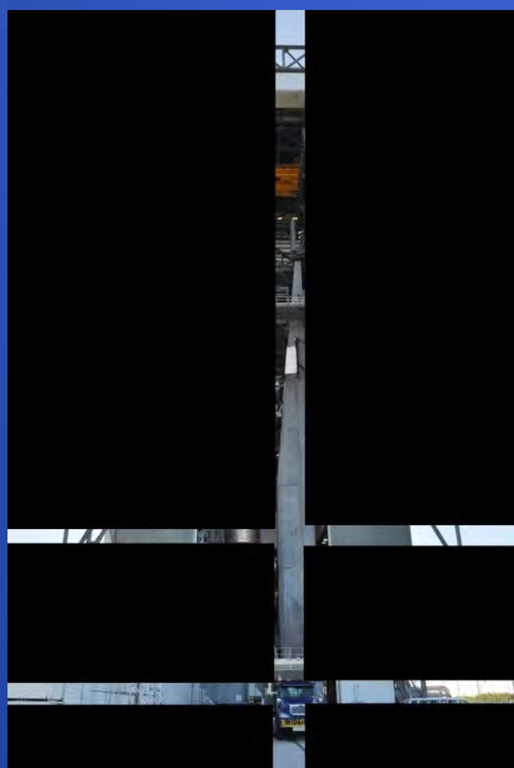
MEGS Instrument Overview

4 Things to Know about EVE

1. LASP / MIT-LL / USC / SI built excellent solar EUV irradiance instrument with significant improvements in spectral resolution and time coverage

Analogy with Photograph

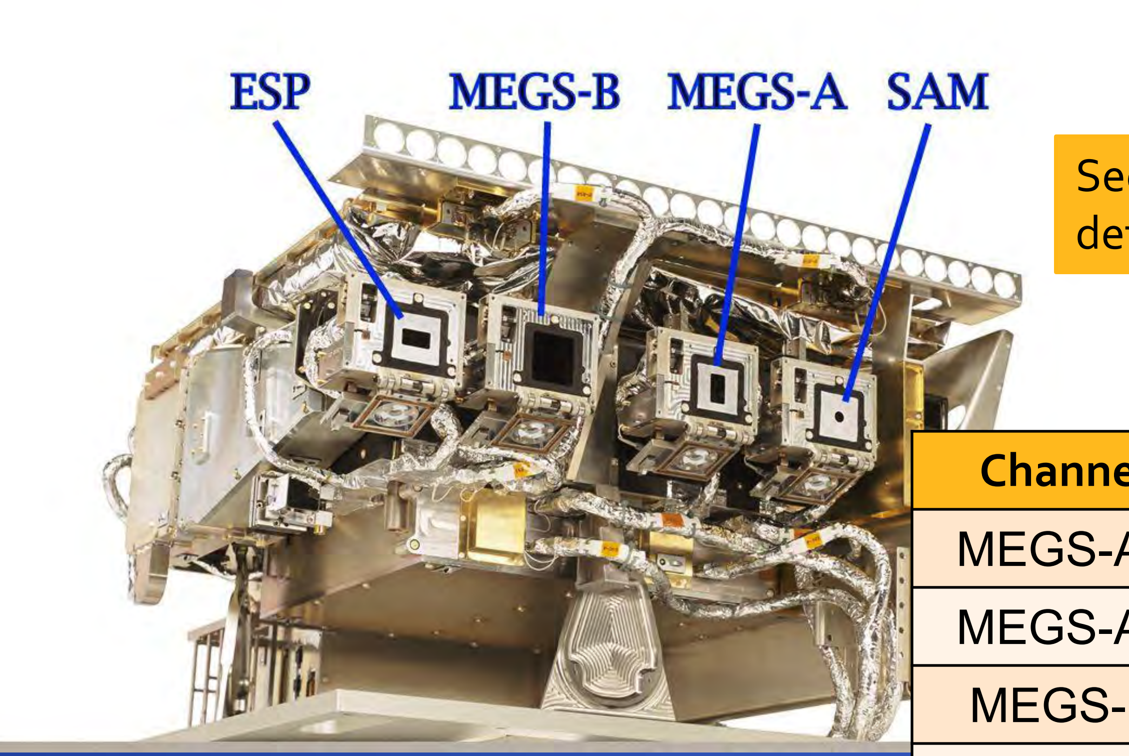
Prior to SDO



With SDO

4 Things to Know about EVE

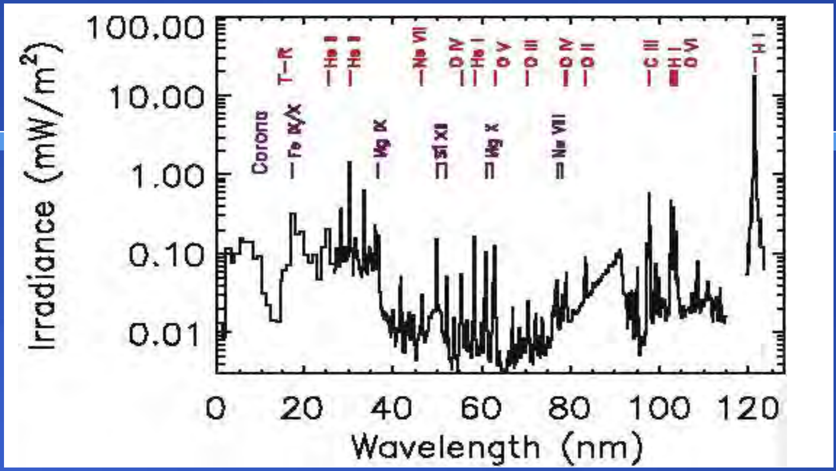
1. LASP / MIT-LL / USC / SI built excellent solar EUV irradiance instrument with significant improvements in spectral resolution and time coverage



See the EVE overview paper for more details: Woods *et al.*, *Solar Physics*, 2010

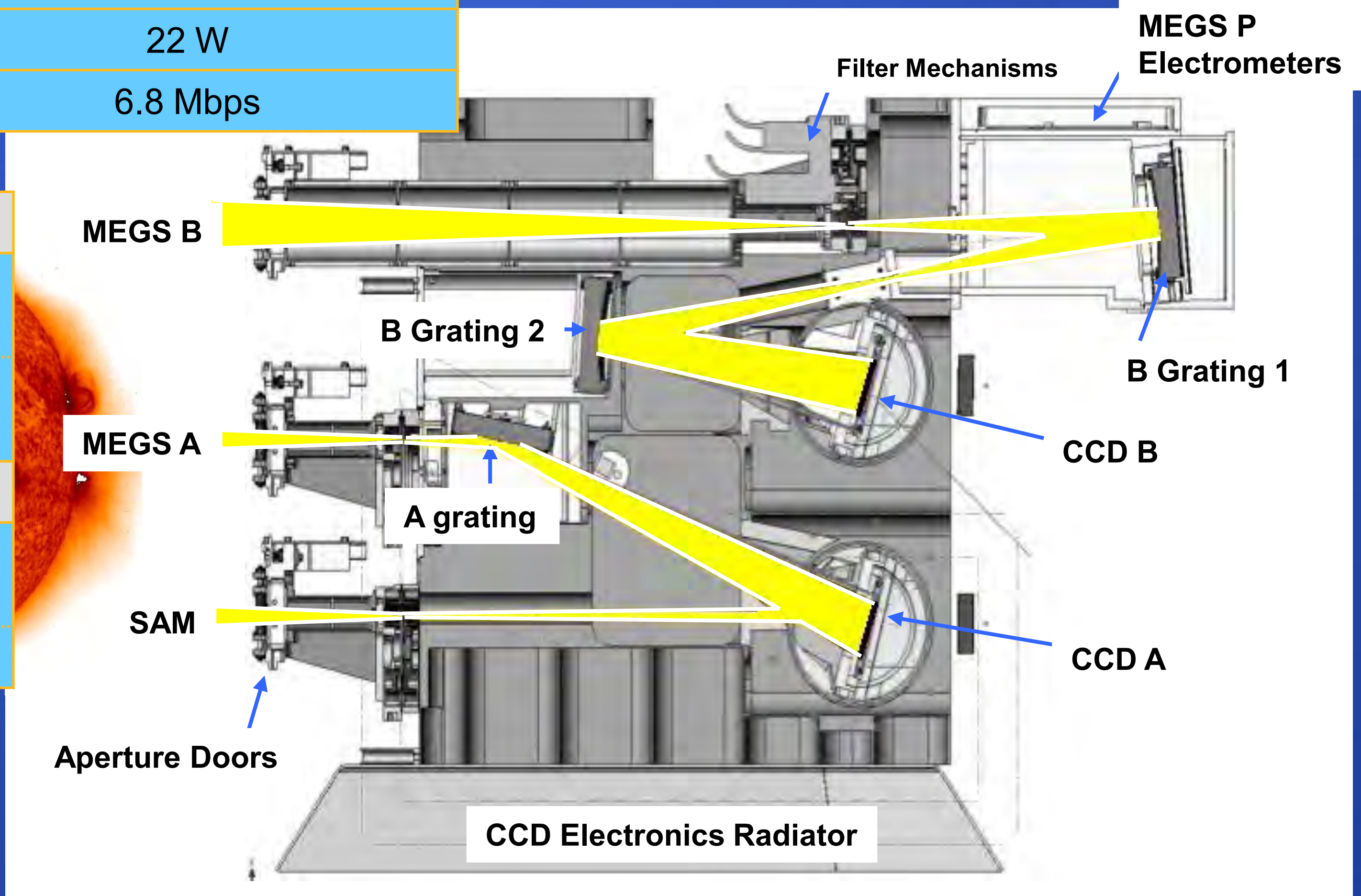
Channel	λ Range	Δλ	Δt
MEGS-A1	6-18 nm	0.1 nm	10 sec
MEGS-A2	18-37 nm	0.1 nm	10 sec
MEGS-B	37-106 nm	0.1 nm	10 sec
MEGS-SAM	0.1-7 nm	(1 nm)	10 sec
MEGS-P	121.6 nm	1 nm	0.25 s
ESP	0.1-38 nm	4 nm	0.25 s

Multiple EUV Grating Spectrograph (MEGS) Optical Overview



λ Range	A: 5-37 nm, B: 34-105 nm, SAM: 0.1-7 nm, P: 121.6 nm
Δλ Resolution	A & B: 0.1 nm, SAM & P: 1 nm
Time Cadence	A,B,SAM: 10 sec, P: 0.25 sec
Field of View	±2°
Power	22 W
Data	6.8 Mbps

Mechanisms
One-shot Aperture Door (3)
Five-position Filter Wheel (3)
Detectors
1024 x 2048 CCDs (2)
Si Photodiodes (2)

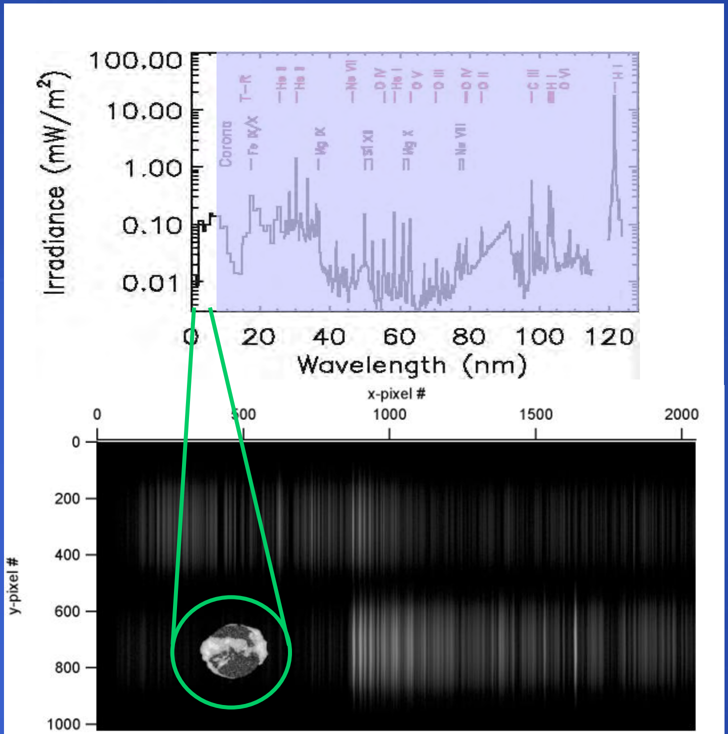


Solar Aspect Monitor (SAM)

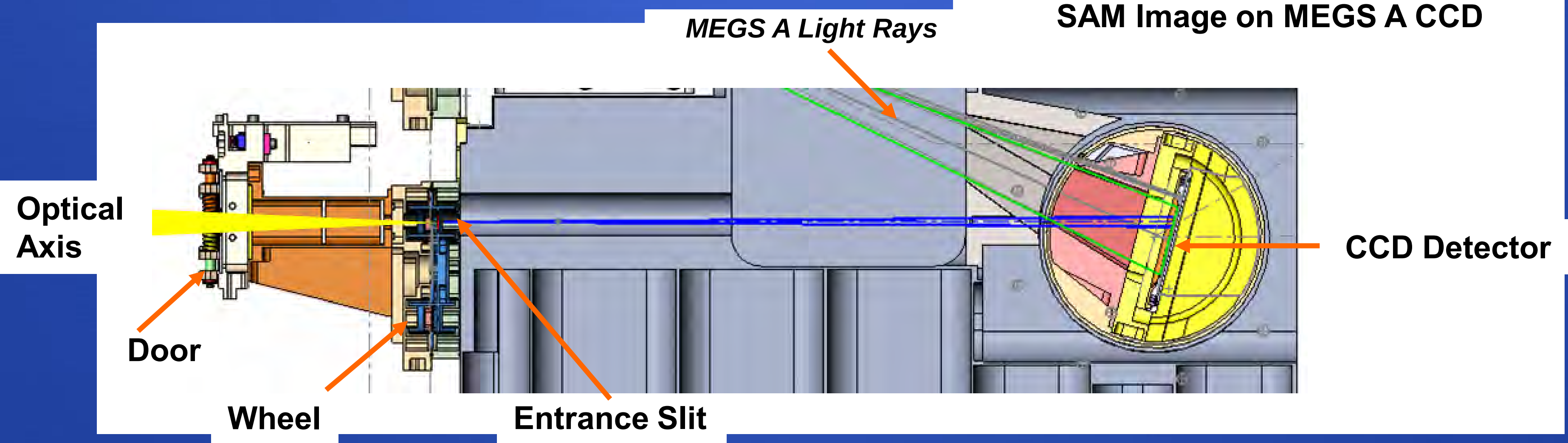
λ Range	0.1 - 7 nm
Δλ Resolution	0.01 - 1 nm
Time Cadence	10 sec
Field of View	± 2°
Aperture Door	One-shot
Filter Wheel	5 positions
CCD Detector	*
Average Power	*
Data	*

SAM is a pinhole camera with photon-counting technique for X-rays: SPECTRA and IMAGES

** Power, CCD, and detector are accounted for in the MEGS A budgets*



SAM Image on MEGS A CCD



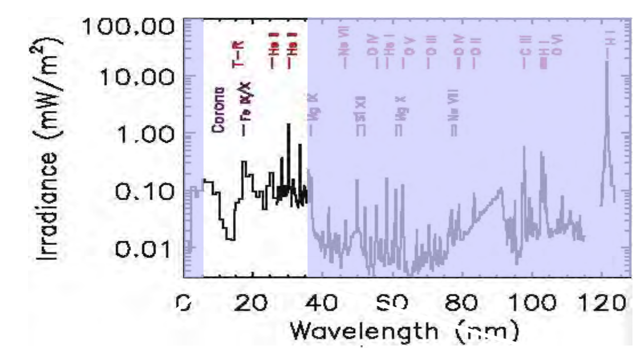
MEGS A Overview

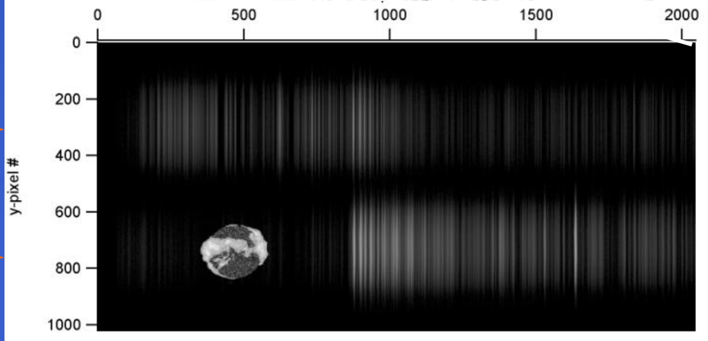
λ Range	5 - 37 nm
Δλ Resolution	0.1 nm
Time Cadence	10 sec
Field of View	±2°
Aperture Door	One-shot
Filter Wheel	5 positions
CCD Detector	1024 x 2048
Power	11 W
Data	3.4 Mbps

SAM images have 10 arc-sec pixels

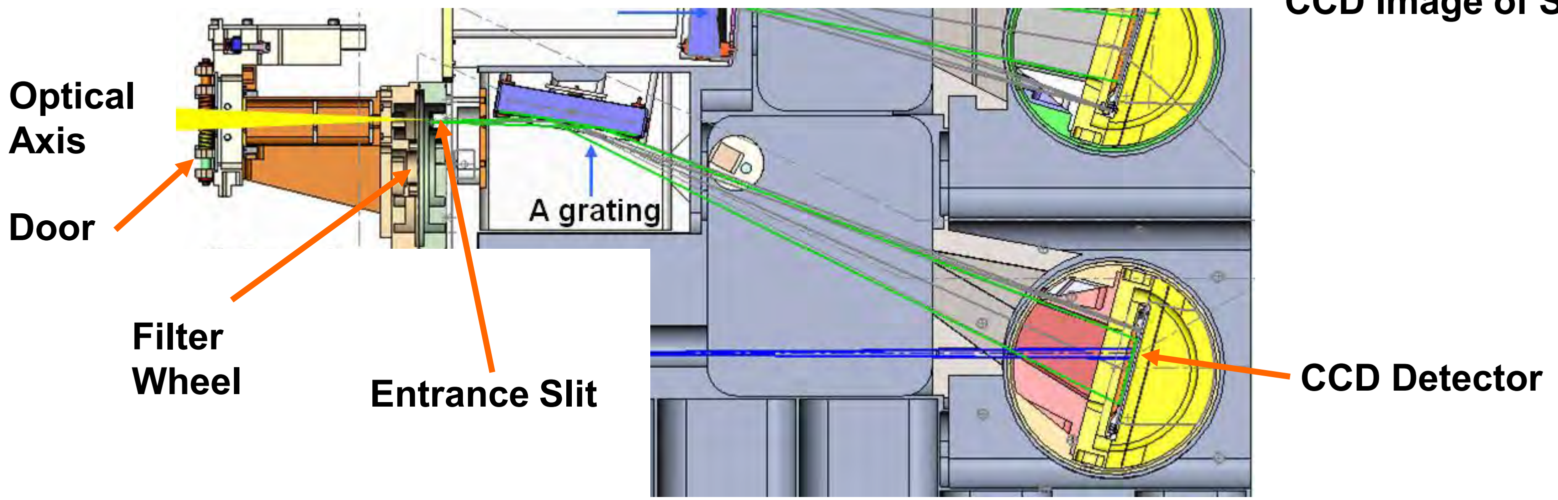
Slit 1
5-20 nm

Slit 2
17-37 nm



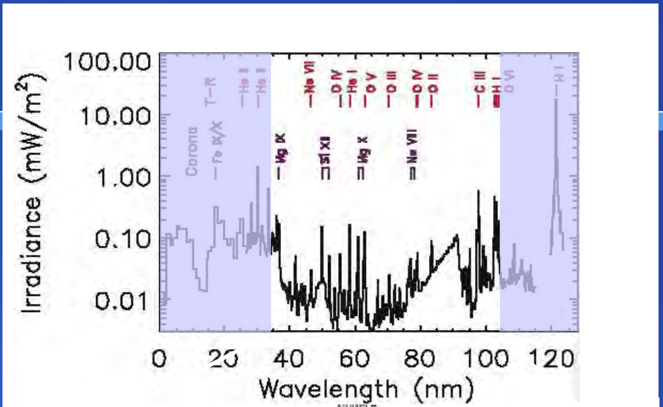


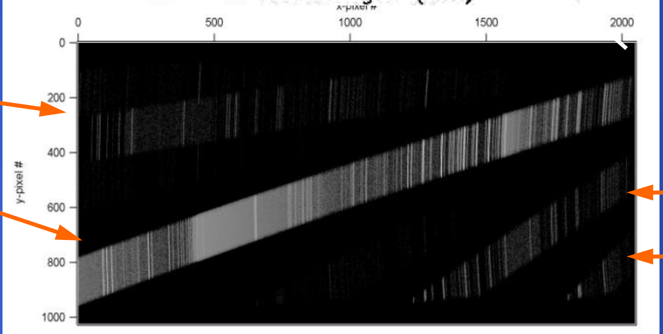
CCD Image of Solar Spectrum

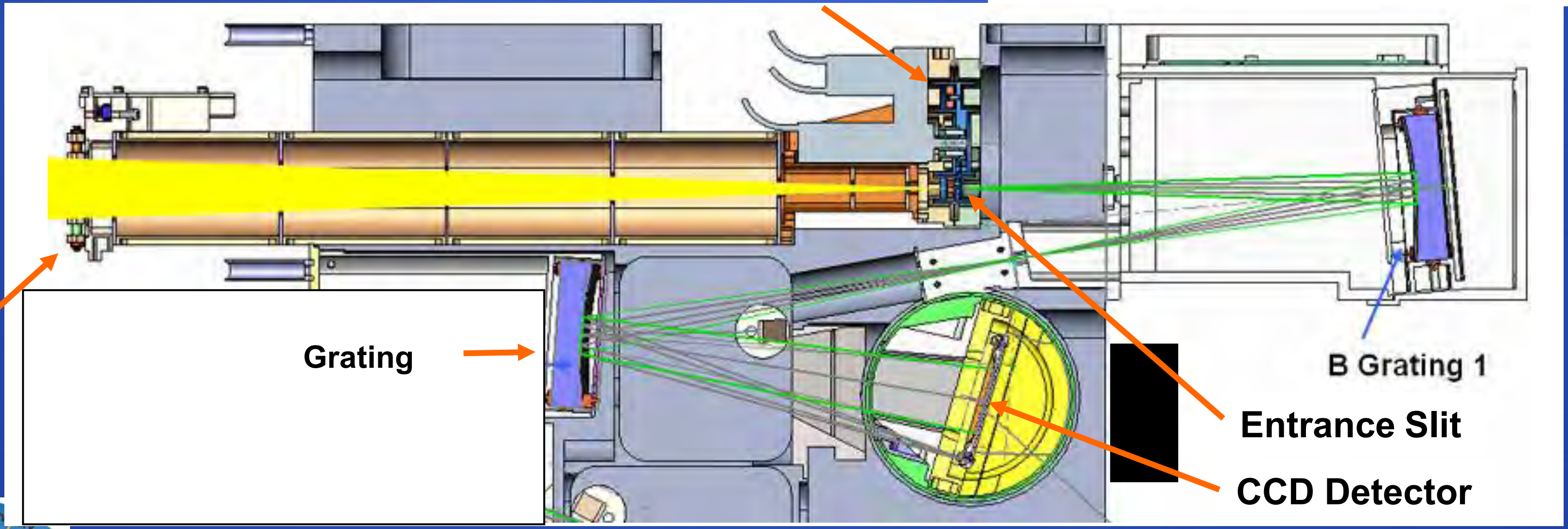


MEGS B Overview

λ Range	34 - 105 nm
Δλ Resolution	0.1 nm
Time Cadence	10 sec
Field of View	±2°
Aperture Door	One-shot
Filter Wheel	5 positions
CCD Detector	1024 x 2048
Power	11 W
Data	3.4 Mbps



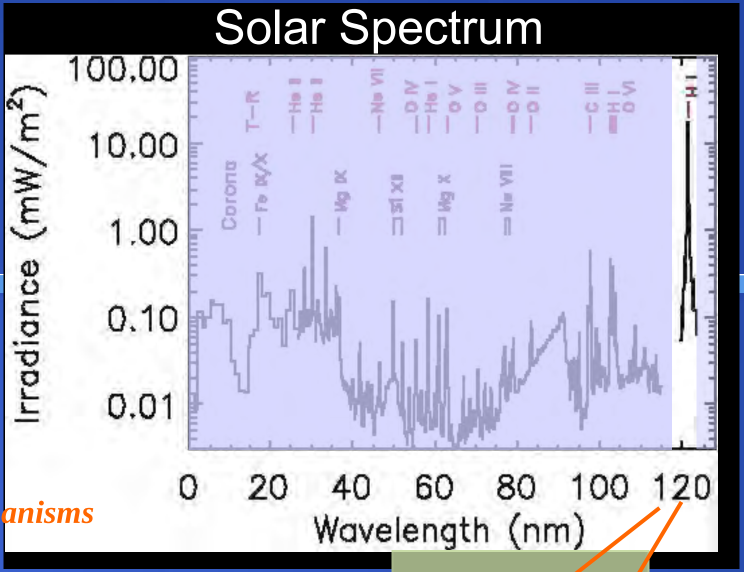




MEGS P Overview

λ Range	121.6 nm
Δλ Resolution	1 nm
Time Cadence	0.25 sec
Field of View	±2°
Aperture Door	*
Filter Wheel	*
Si Photodiode	1 cm x 1 cm
Power	0.2 W
Data	0.001 Mbps

** Behind MEGS B mechanisms*



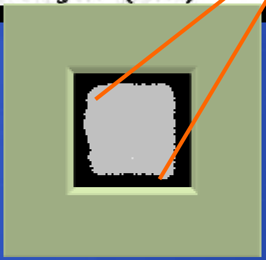
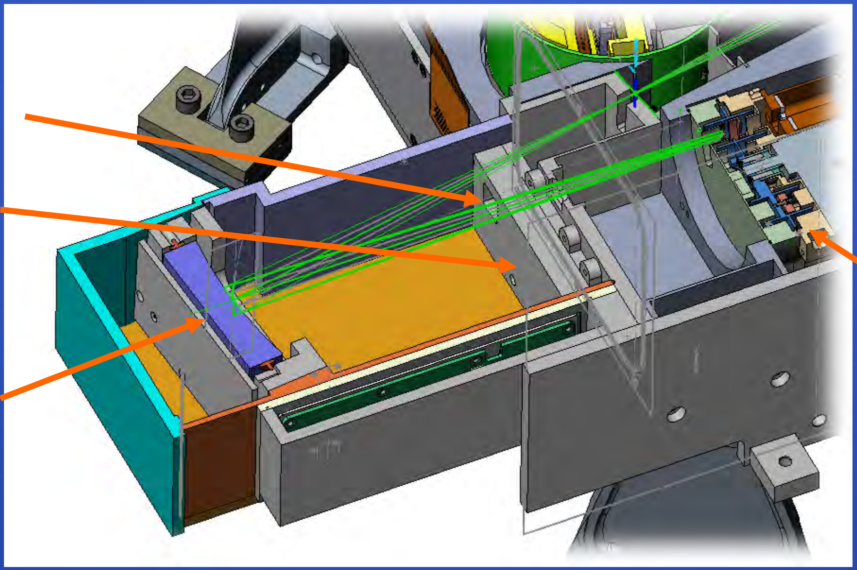
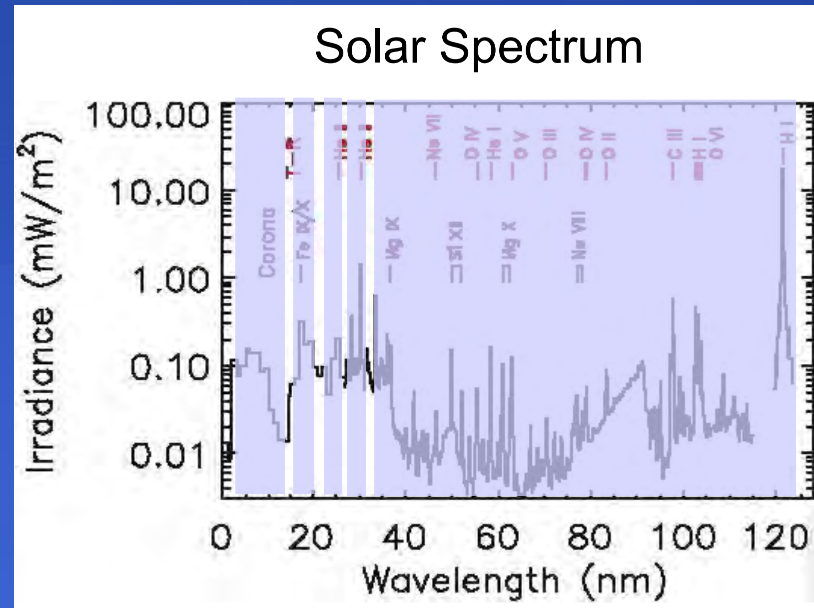


Image on MEGS P Detector

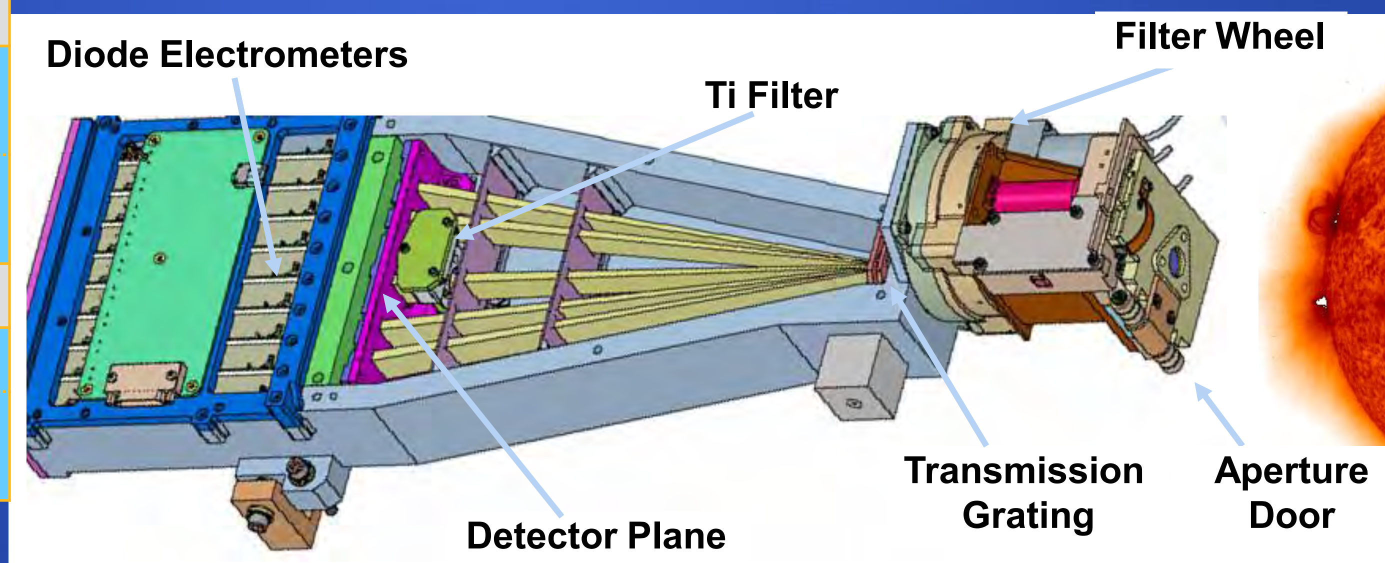


EUV SpectroPhotometer (ESP) Optical Overview

λ Range	1st: 18.4, 25.5, 30.4, 35.5 nm 0th order: 0.1-7 nm
Δλ Resolution	1st: 4 nm 0th: 7 nm
Time Cadence	0.25 sec
Field of View	±2°
Power	1.9 W
Data	0.007 Mbps



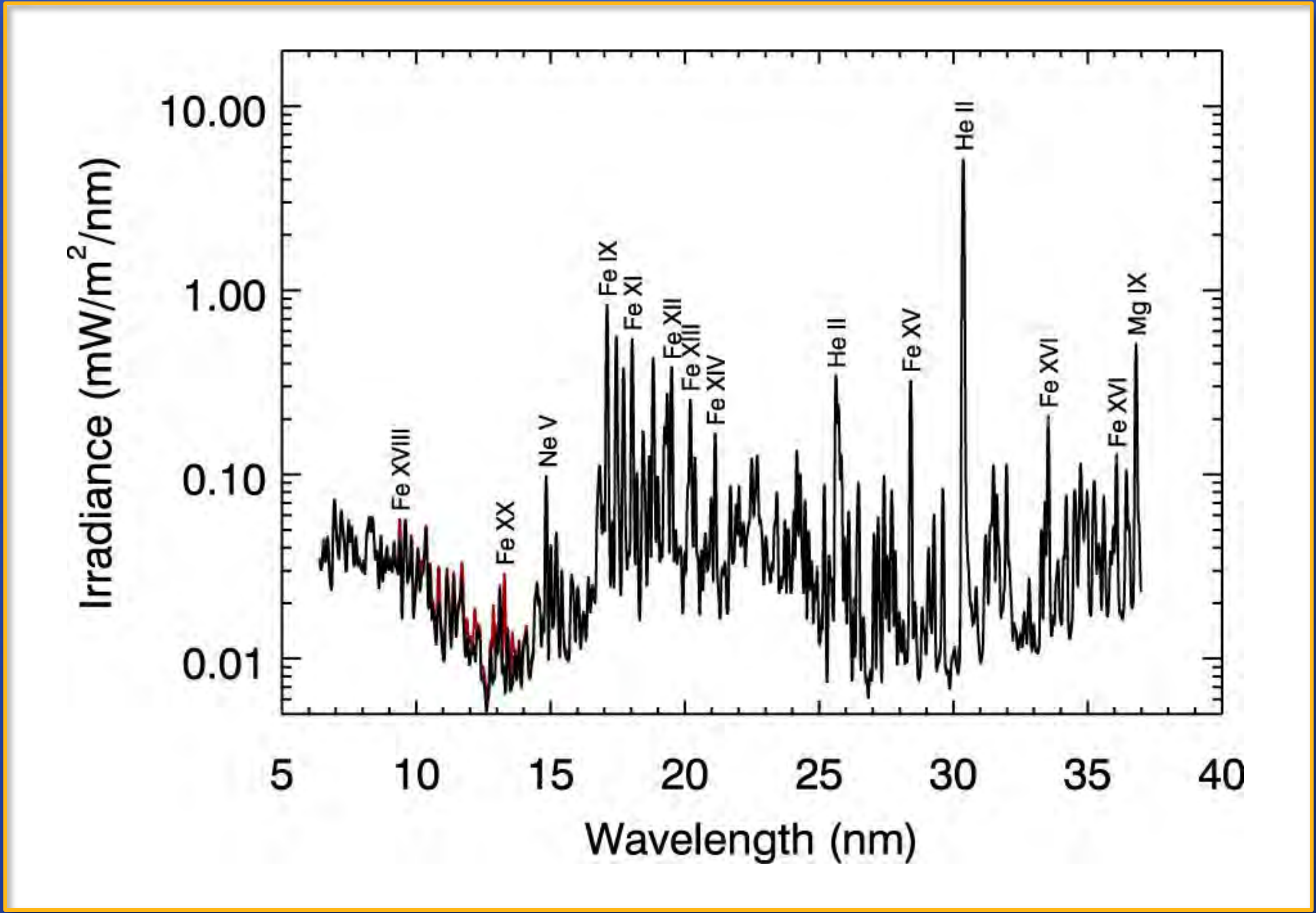
Mechanisms
One-shot Aperture Door (1)
Five-position Filter Wheel (1)
Detectors
Si Photodiodes (5)
Quad Si Photodiode (1 - 0th order)



USC's ESP instrument is similar to SOHO SEM

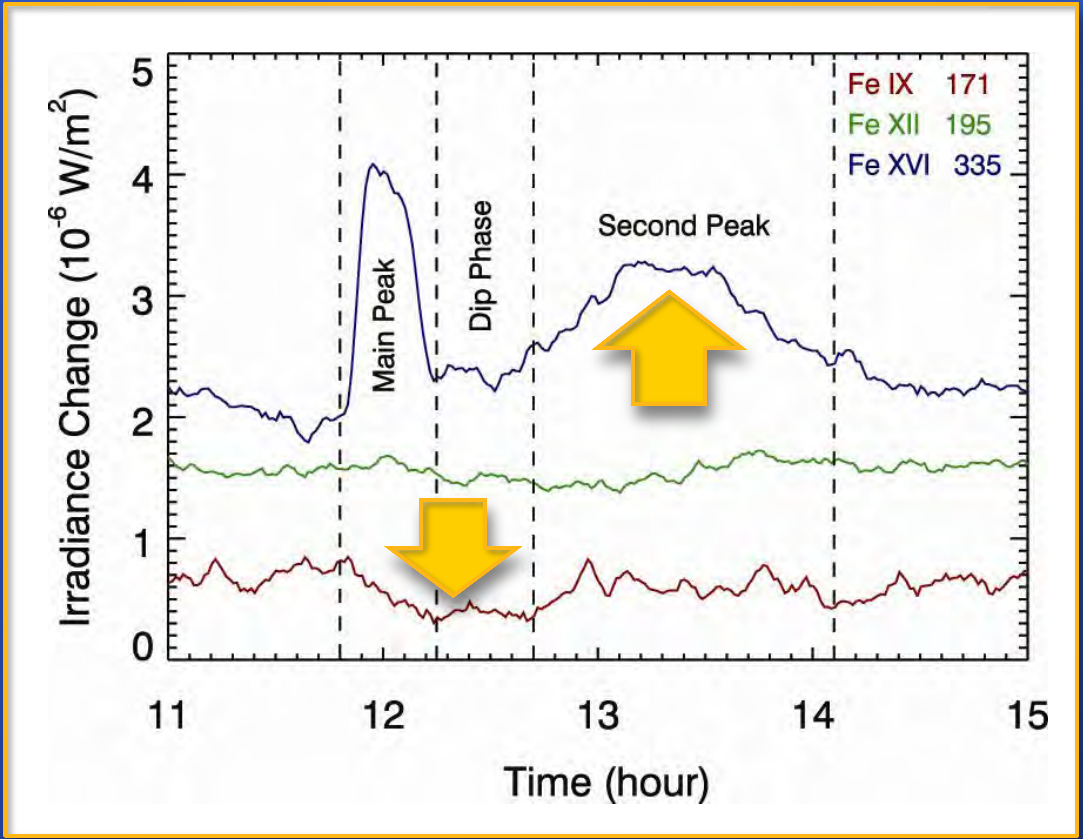
4 Things to Know about EVE

2. EVE MEGS provides spectrum every 10 seconds of dozens of bright coronal emissions in the extreme ultraviolet range (EUV: 5-105 nm)



4 Things to Know about EVE

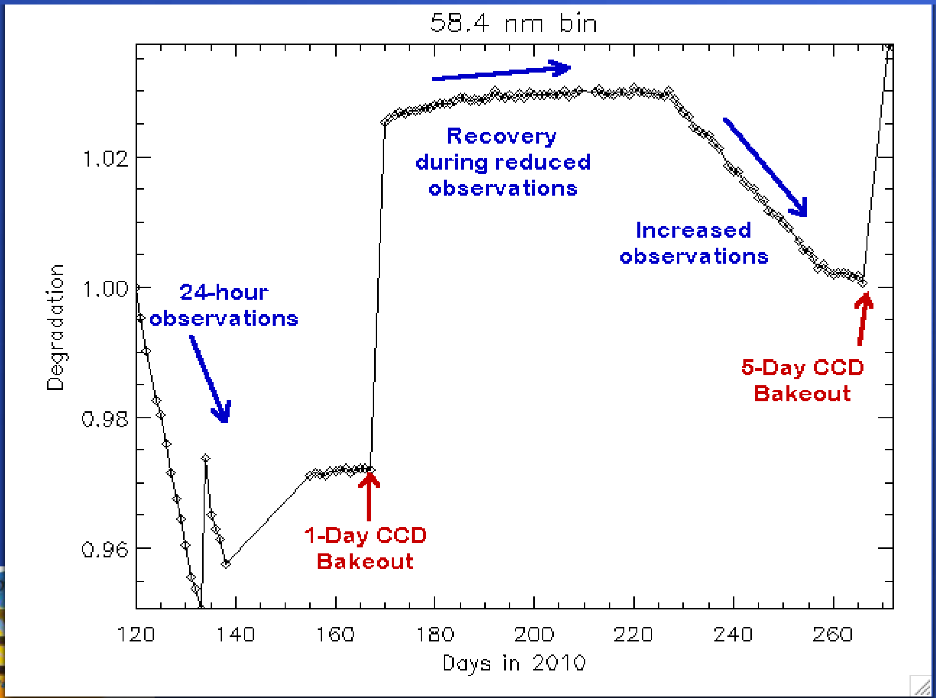
3. EVE observations are providing new insights on short-term solar variability
   - Cool coronal emissions dim during solar flare – could possibly be used to forecast CME mass and velocity
   - Some coronal emissions have large, delayed second peak that we refer to as the Late Phase. Flare models need to be updated.



4 Things to Know about EVE

4. EVE has some degradation - more on this in next MEGS talk
   - CCD charging of its SiOx top layer – on MEGS-B
   - External contamination on Al foil filter – on MEGS-A2 & ESP

- Daily calibrations and annual calibration rocket flight are working well to provide corrections for EVE degradation
  - First calibration rocket flight was on May 3, 2010 and second was on March 23, 2011.



Exposure to solar EUV radiation is causing charging on CCD; this creates extra Si dead-layer that absorps the EUV photons more.

CCD bakeout and less exposure provides recovery from the CCD charging effect.

MEGS-B Limitations in Operations

- MEGS-B degradation worst above 65 nm, so have MEGS-B campaigns instead of 24-7 observations that MEGS-A and ESP have
- Daily Plan
  - 3-hour observation (routinely observe some flares)
  - 5-minutes every hour (contribute to daily averaged irradiance)
- Flare Campaign
  - 24-hour observation for special flare observations / campaigns
  - Want to limit the flare campaigns to one per month. With a weak solar cycle, we have not had a MEGS-B flare campaign every month.

EVE Measurement Equation

Simple Form

R_{SURF} includes all of the gain, linearity, aperture area, spectral bandpass, higher order, and field of view corrections from the SURF calibrations

$$I = \frac{\left(C - C_{dark}\right) / \Delta t}{R_{SURF}} \cdot f_{\mathrm{degrade}} \cdot f_{\mathrm{1AU}}$$

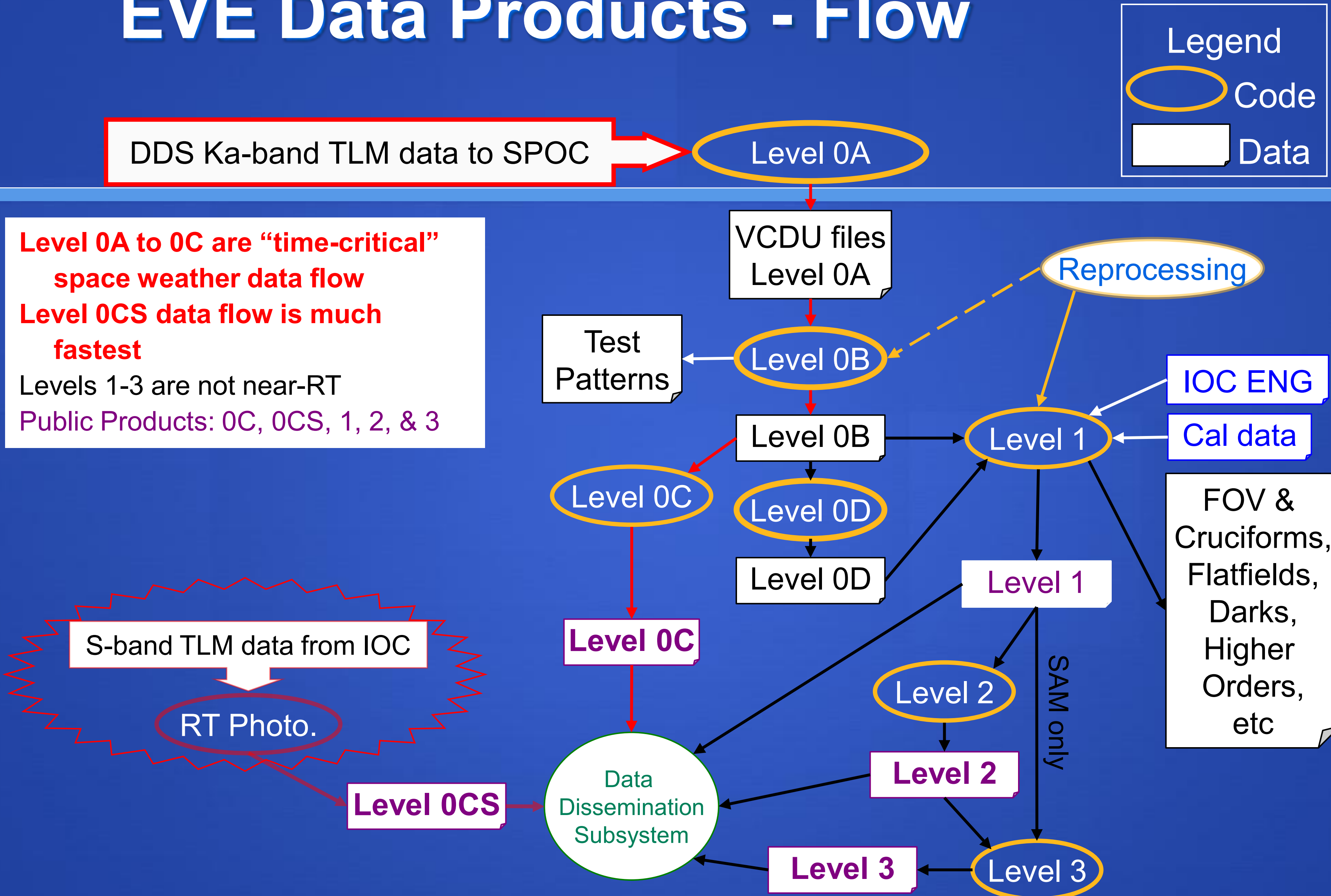
Actual Processing

- Identify particle hits (set mask array values for “bad” pixels)
- Remove dark and apply responsivity at the pixel level
- Determine the wavelength scale for each row and then collapse image into a spectrum after interpolating across “bad” pixels
- Apply the other corrections to the spectrum

See the MEGS paper for more details: Hock *et al.*, *Solar Physics*, 2010

EVE Data Products - Flow

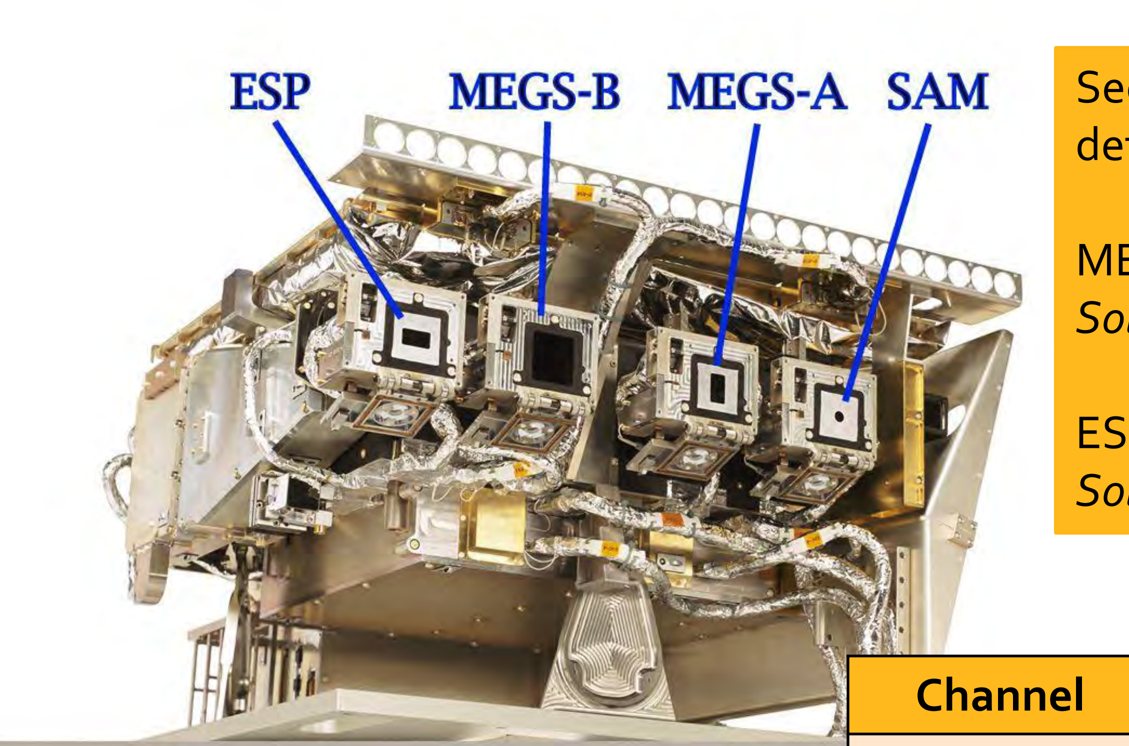
Level 0A to 0C are "time-critical" space weather data flow
Level 0CS data flow is much fastest
Levels 1-3 are not near-RT
Public Products: 0C, 0CS, 1, 2, & 3



EVE Data Products - Listing

Level	Description	Span	Type
0A (TLM)	Unprocessed VCDUs (packets) – files received from DDS	~1 min	binary
0B	Assembled/merged integrations separated by channel	~1 min	FITS
0C	Space weather (Ka-band) – all channels available in Latest and Daily files	15 min & 1 day	ASCII
0CS	Space weather (S-band) – lowest latency, only diodes and proxies	Same	ASCII
0D	Daily merged 0B data with duplicates removed	1 day	FITS
1	Irradiance for each channel (no degradation applied to spectra)	1 hour	FITS
~~1A~~	~~SAM only, event list~~	~~1 day~~	~~FITS~~
~~1B~~	~~SAM only, spectrum (cadence is TBD)~~	~~Same~~	~~FITS~~
2-EVS	Merged, degradation corrected MEGS-A and B level 1 spectra with MEGS-B sampling (.02 nm)	1 hour	FITS
2-EVL	Extracted lines and bands, averaged diodes to match spectrum timestamp, proxies (same as 0C)	Same	FITS
3	Daily average spectrum at 0.02 nm	1 day	FITS
3	Daily average 0.1 nm spectrum	1 year	FITS / SAV
3	Daily average 1 nm spectrum	Mission	

Summary of EVE Channels



See the EVE overview paper for more details: Woods *et al.*, *Solar Physics*, 2010

MEGS Calibration Paper: Hock *et al.*, *Solar Physics*, 2010

ESP Calibration Paper: Didkovsky *et al.*, *Solar Physics*, 2010

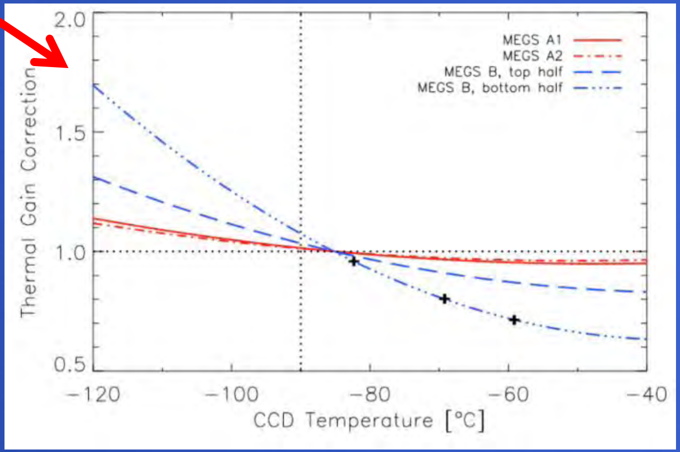
Limited to 4.75 hours/day and a 24-hour flare campaign / month

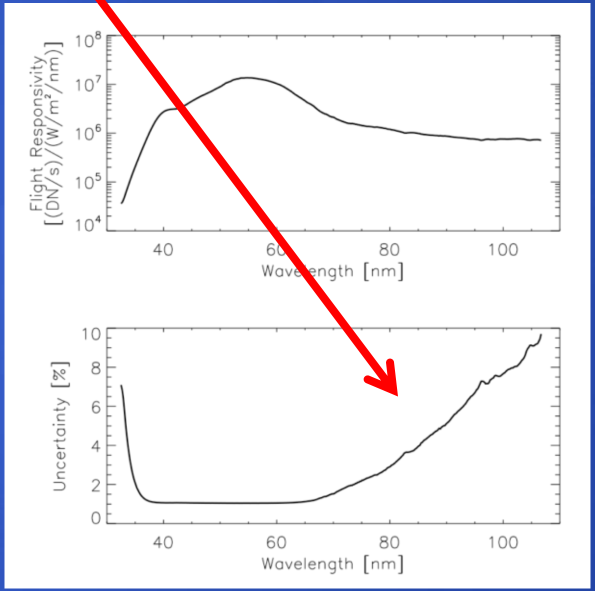
Channel	λ Range	Δλ	Δt
MEGS-A1	6-18 nm	0.1 nm	10 sec
MEGS-A2	18-37 nm	0.1 nm	10 sec
MEGS-B	37-106 nm	0.1 nm	10 sec
MEGS-SAM	0.1-7 nm	(1 nm)	10 sec
MEGS-P	121.6 nm	1 nm	0.25 s
ESP	0.1-38 nm	4 nm	0.25 s

MEGS Calibration

MEGS Calibration Overview

- Pre-flight Calibrations
  - Selection of filters, gratings, and CCDs
  - Responsivity calibrations at NIST SURF-III with 2-10% accuracy
  - Gain and dark as function of temperature

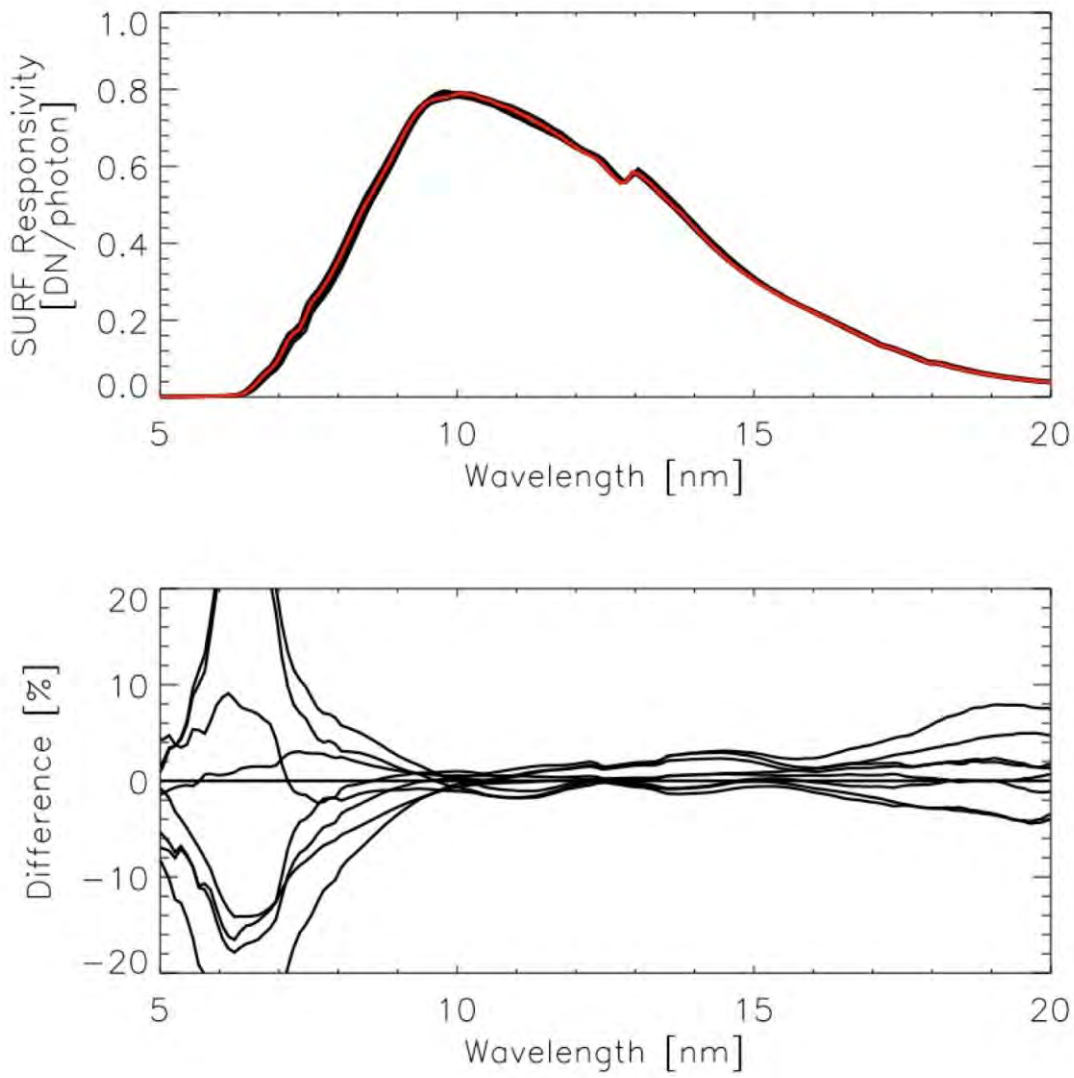




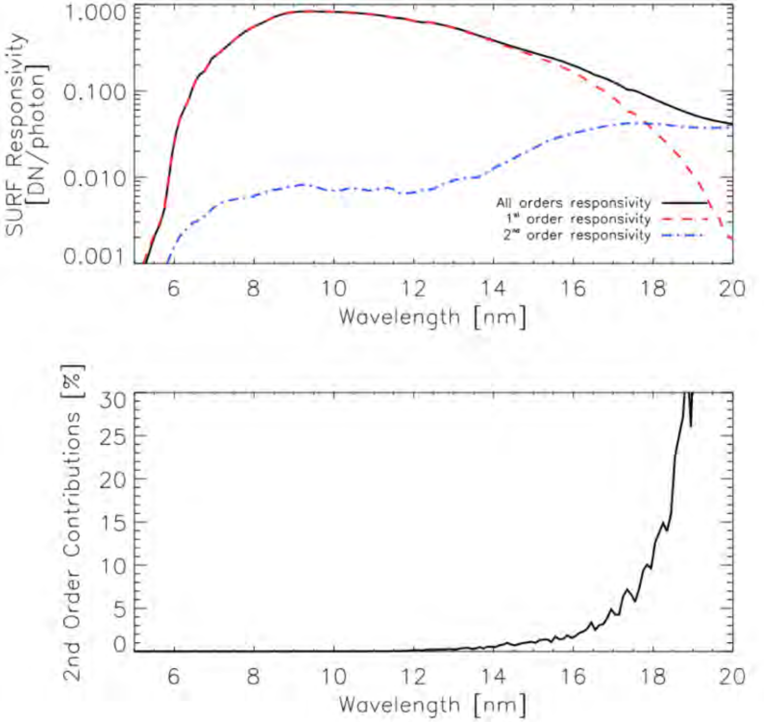
- In-flight Calibrations
  - Rocket underflight calibrations using prototype EVE (about once per year)
    - NIST SURF-III used for the rocket EVE calibrations
  - Redundant filters, flatfield lamps (LEDs), & dark calibrations are done daily
  - FOV maps and cruciform scans are done once a quarter

MEGS-A1 Responsivity – FOV Map Data

- MEGS-A1 is for 6-18 nm measurements

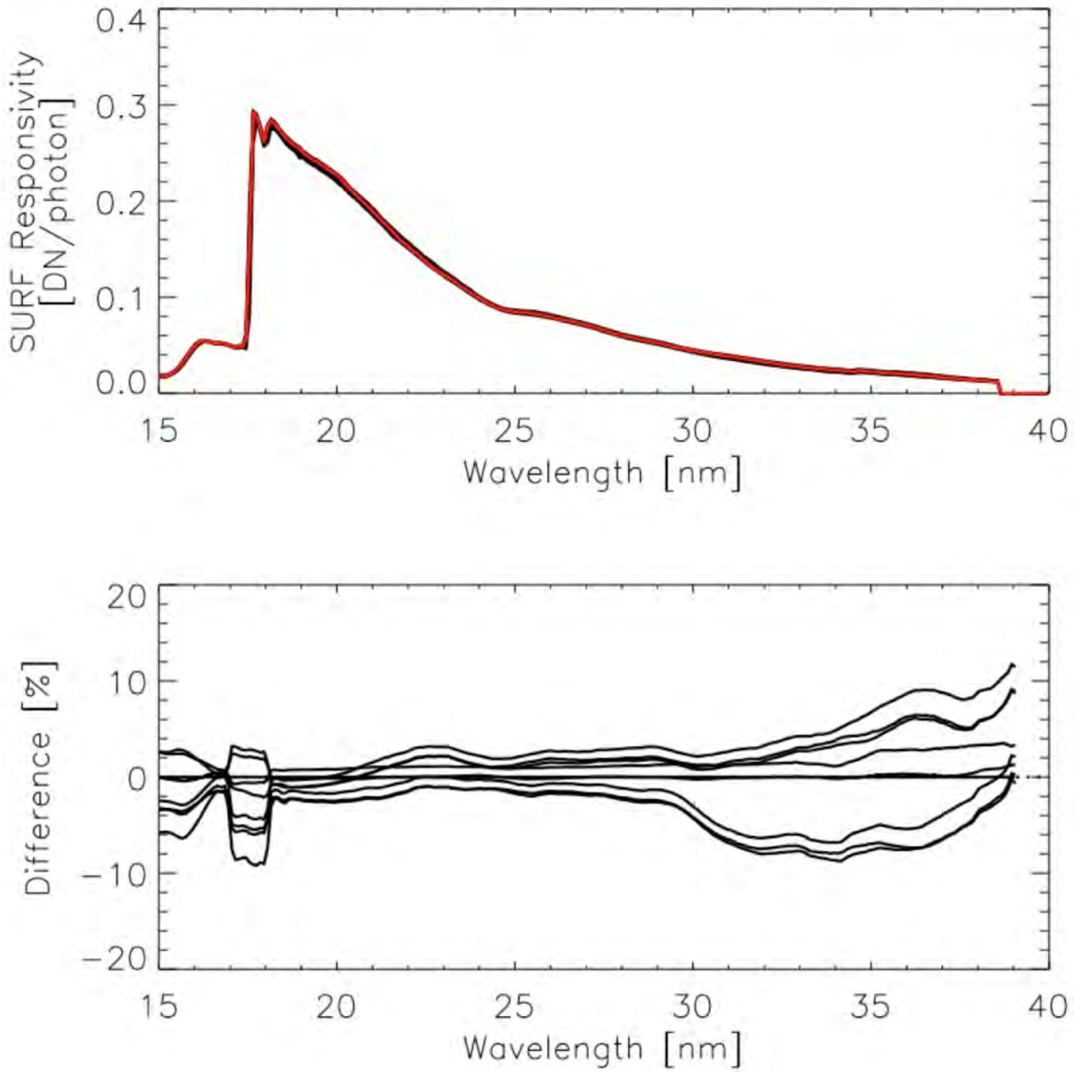


2nd Order Contribution is small

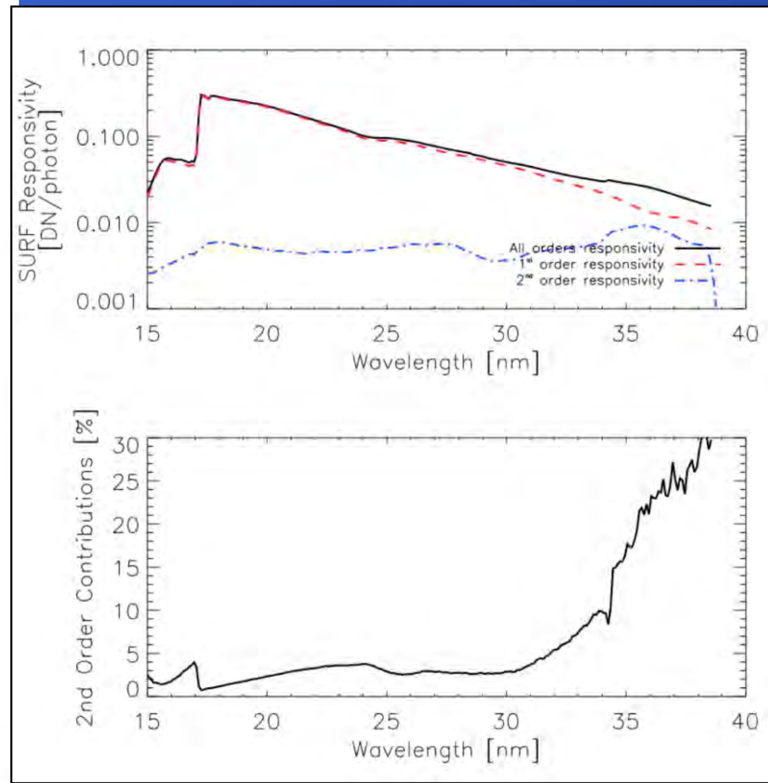


MEGS-A2 Responsivity – FOV Map Data

- MEGS-A2 is for 18-37 nm measurements

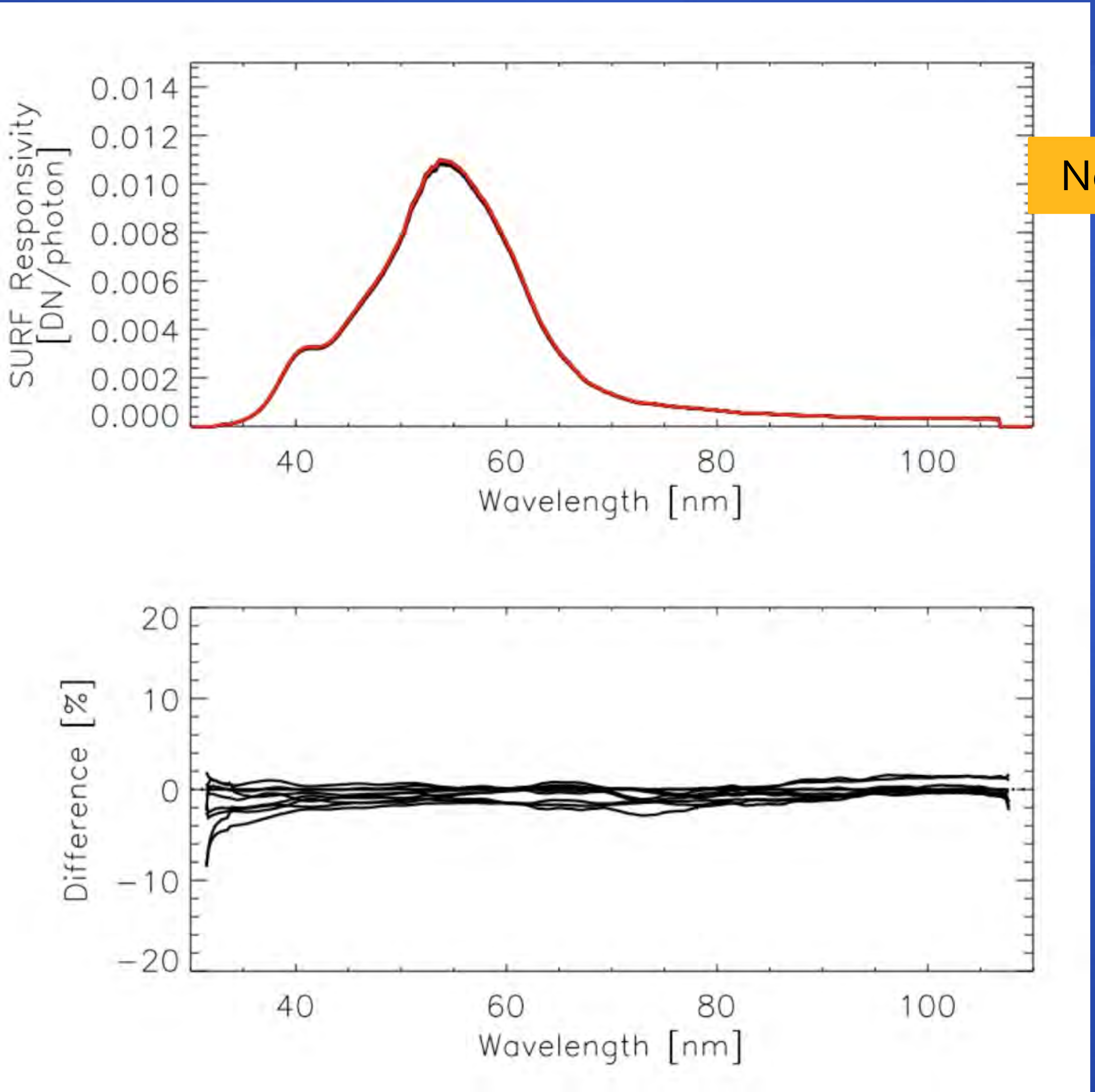


2nd Order Contribution is small



MEGS-B Responsivity – FOV Map Data

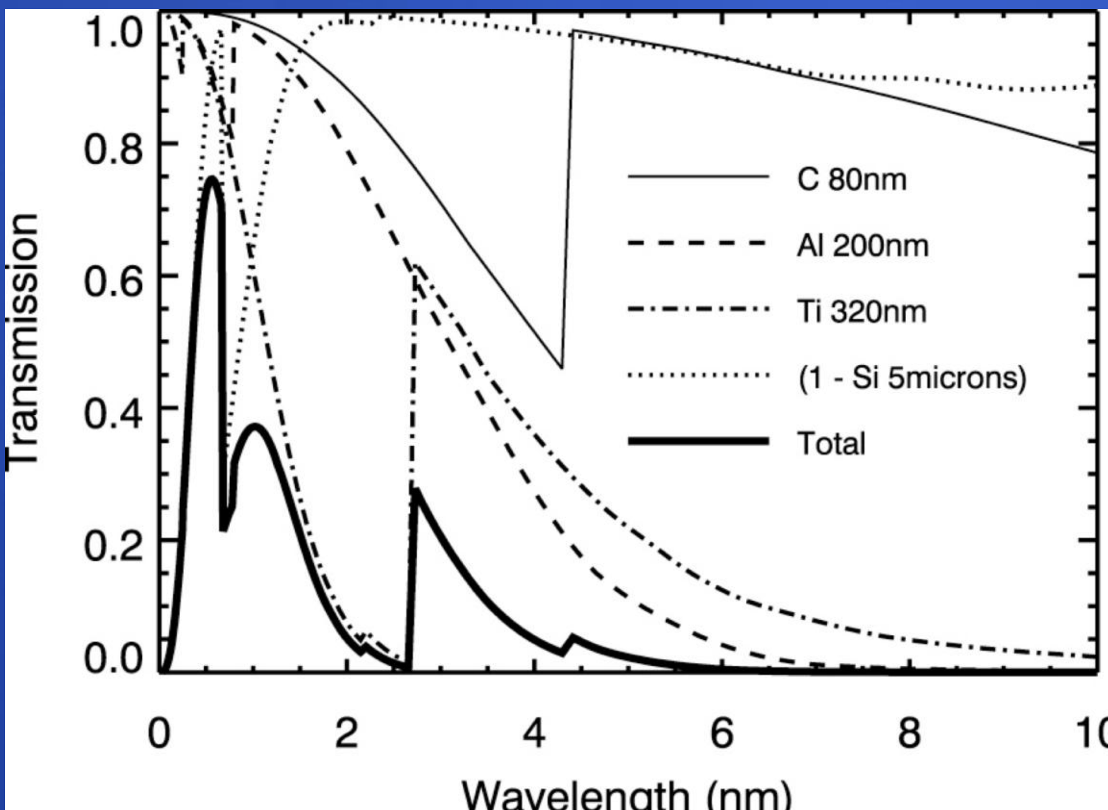
- MEGS-B is for 37-105 nm measurements

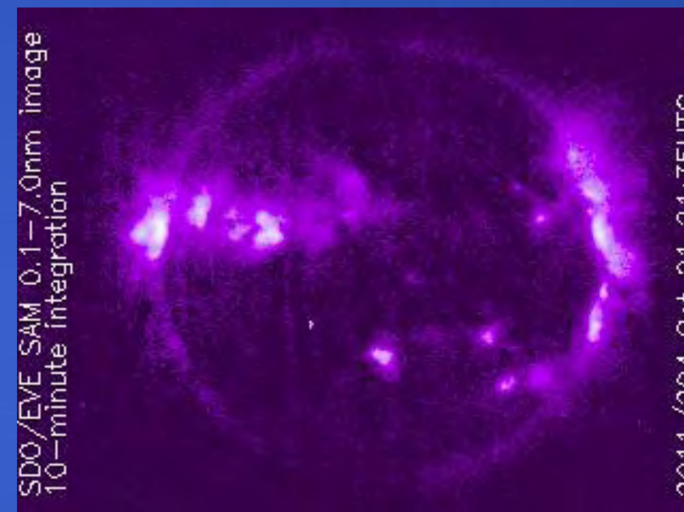


No 2nd Order Contribution

MEGS-SAM – Filter Transmission

- Ti/Al/C filter is in front of pinhole aperture





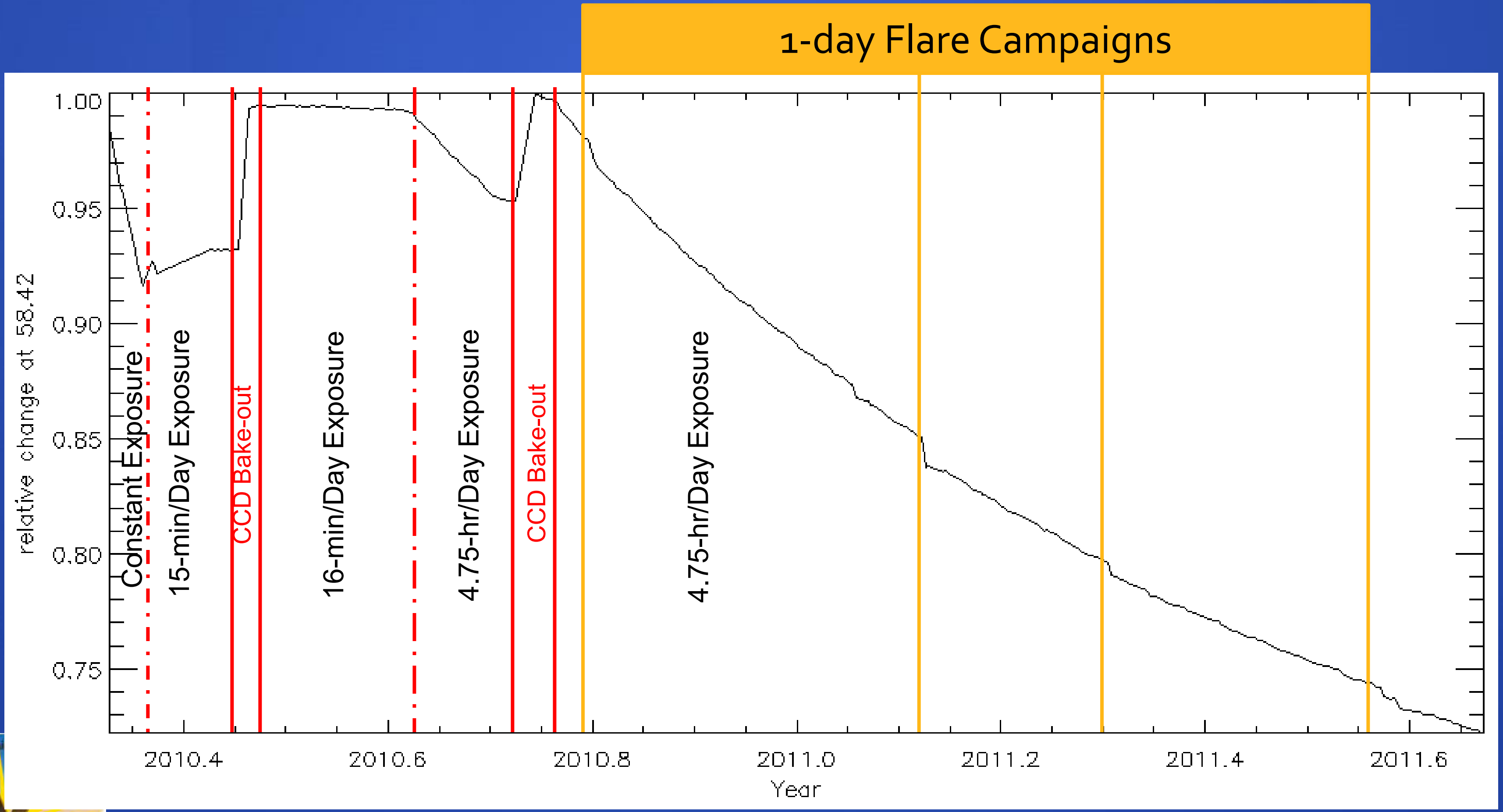
MEGS
In-flight
Degradation

MEGS Degradation Overview

- CCD Degradation
  - Initial degradation seen for MEGS-B: worst for > 70 nm
  - Burn-in of bright lines for both MEGS-A and MEGS-B
  - Rocket underflight calibrations and daily flatfield lamp calibrations are best at tracking the CCD degradation rate
- Filter (Contamination) Degradation
  - MEGS-A2 (and ESP) filters (Al/Ge/C) are degrading with exposure
    - Thought to be related to contamination on S/C and charging effect of the filter
  - MEGS-A1 filters (Zr/C) are not degrading. No filters on MEGS-B.
  - Daily redundant filter calibrations are best at tracking filter degradation

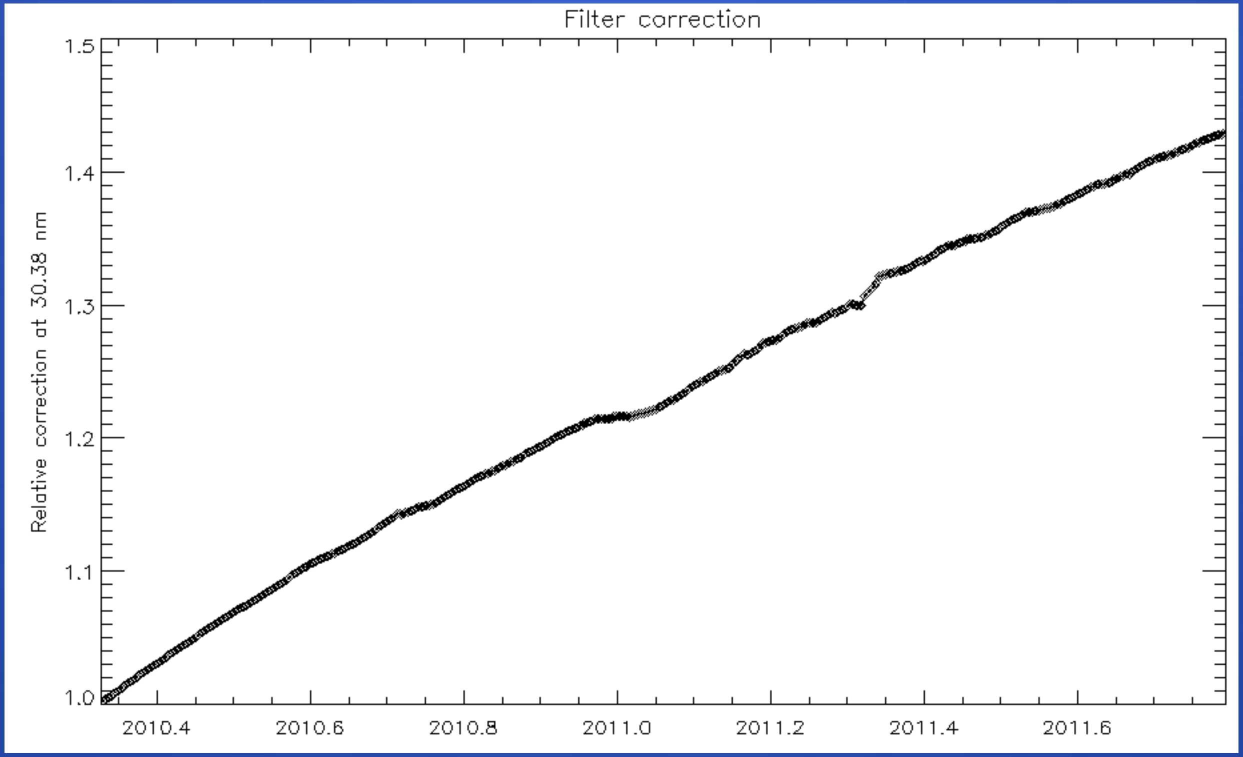
MEGS-B CCD Degradation Trend over Mission

- MEGS-B CCD is degrading faster than expected with exposure, so MEGS-B observations are now limited to about 5 hours per day (instead of 24/7).



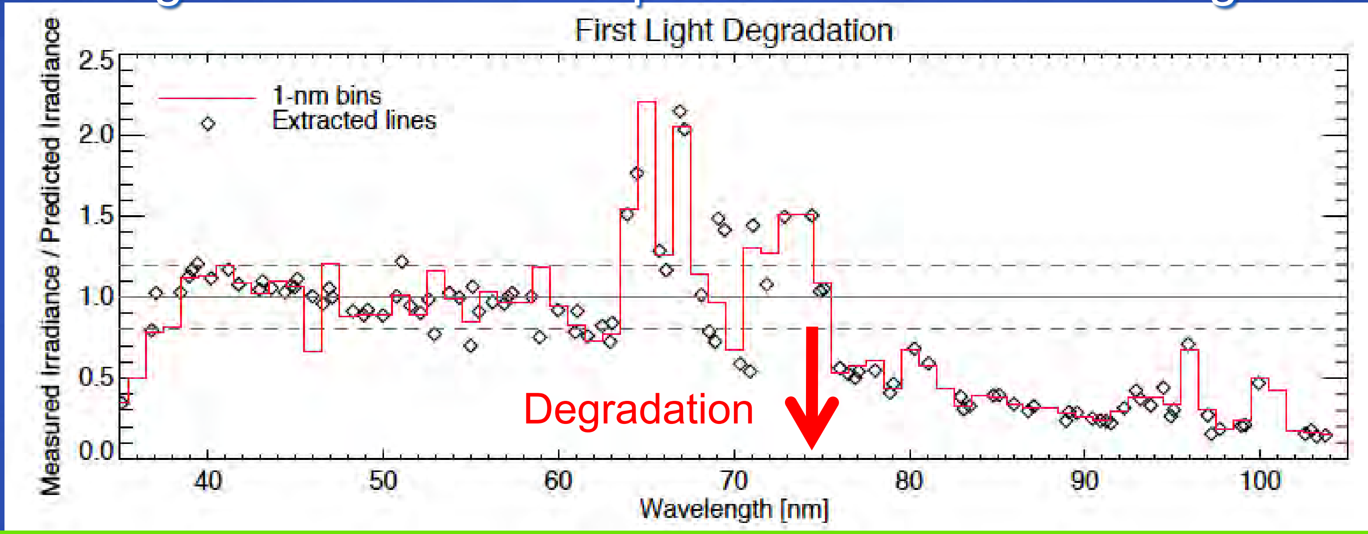
MEGS-A2 Filter Degradation Trend over Mission

- MEGS-A (and ESP & SAM) is used 24/7.
- MEGS-A2 and ESP show a steady degradation that appears to be related to contamination / charging on their foil filters.
- MEGS-A1 filter is not degrading.

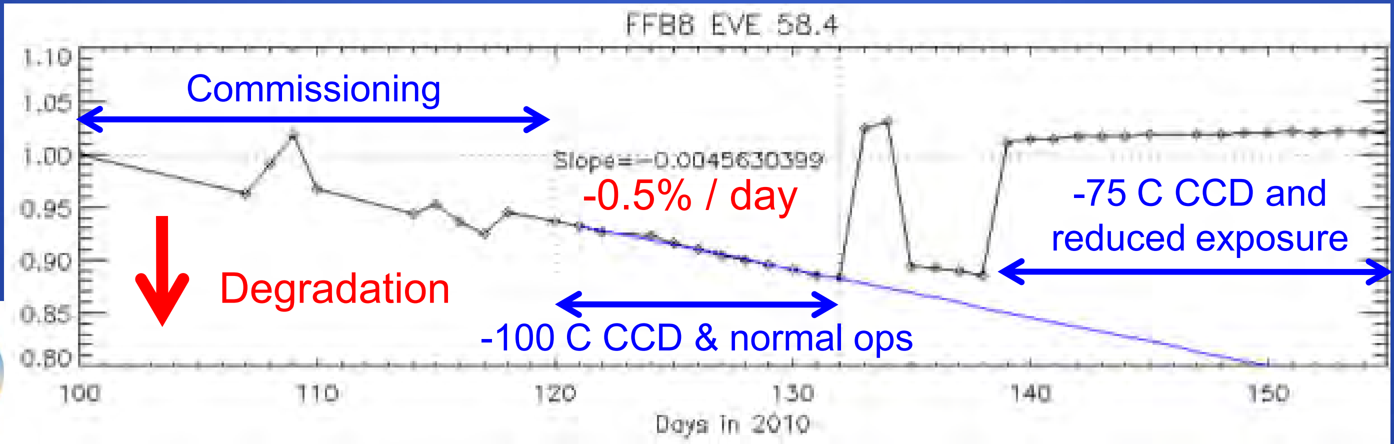


Two Phases of MEGS-B Degradation

- First Light Degradation
  - Solar signal smaller than expected in 70-105 nm range



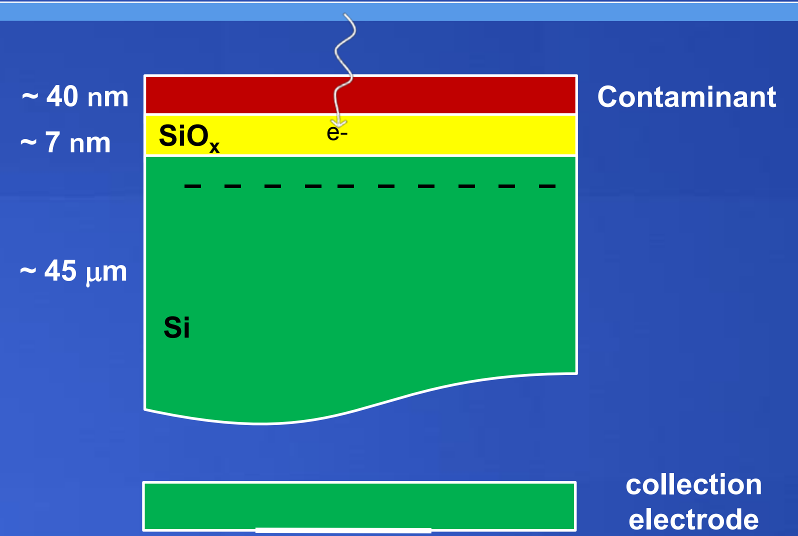
- **Burn-in of bright solar lines into CCD since first light**
  - Burn-in seen in both flat-field (FF) LED images and for solar observations

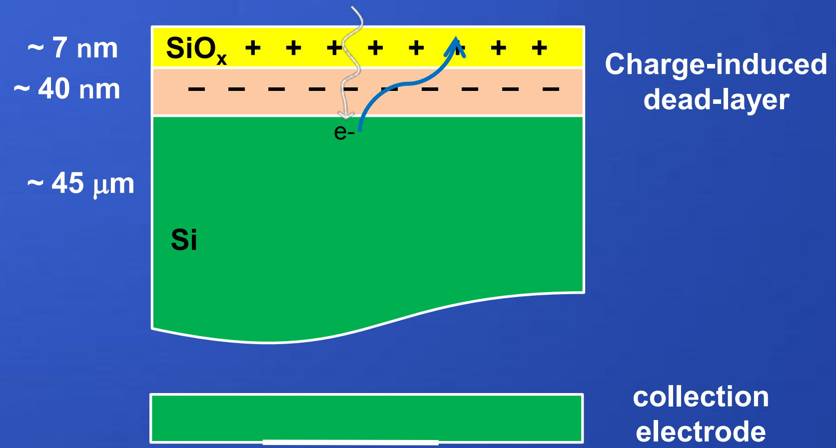


Step up is gain change due to temperature change

Possible Degradation Scenarios

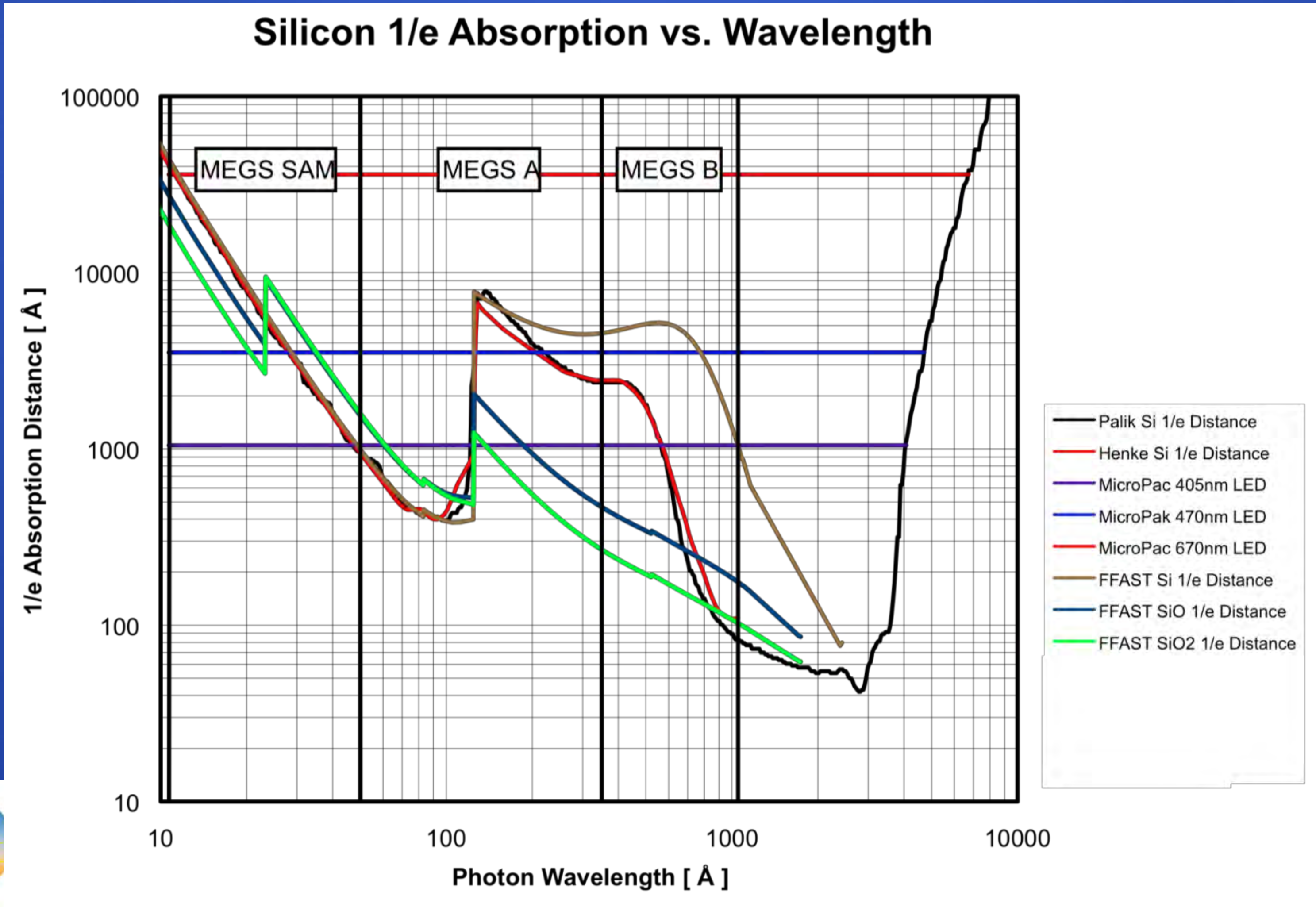
- Contamination Since Calibration
  - Degradation amount suggests about 20 nm of contaminant on CCD or gratings. Pre-flight monitoring indicates less than 10 nm.
  - Possible sources from EVE itself, purge gas, propulsion.
  - Mitigation: bake-out CCD
- CCD Charging
  - Top layer (SiOx and/or contaminant) can charge up and create Si dead layer inside CCD.
  - Possible sources for charging by protons during GTO and by solar EUV. Could also be charging from purge gas, but unlikely.
  - Mitigation: apply higher voltage across CCD (not option for MEGS)
- Combination of Both Options





CCD (Si) Absorption Curve

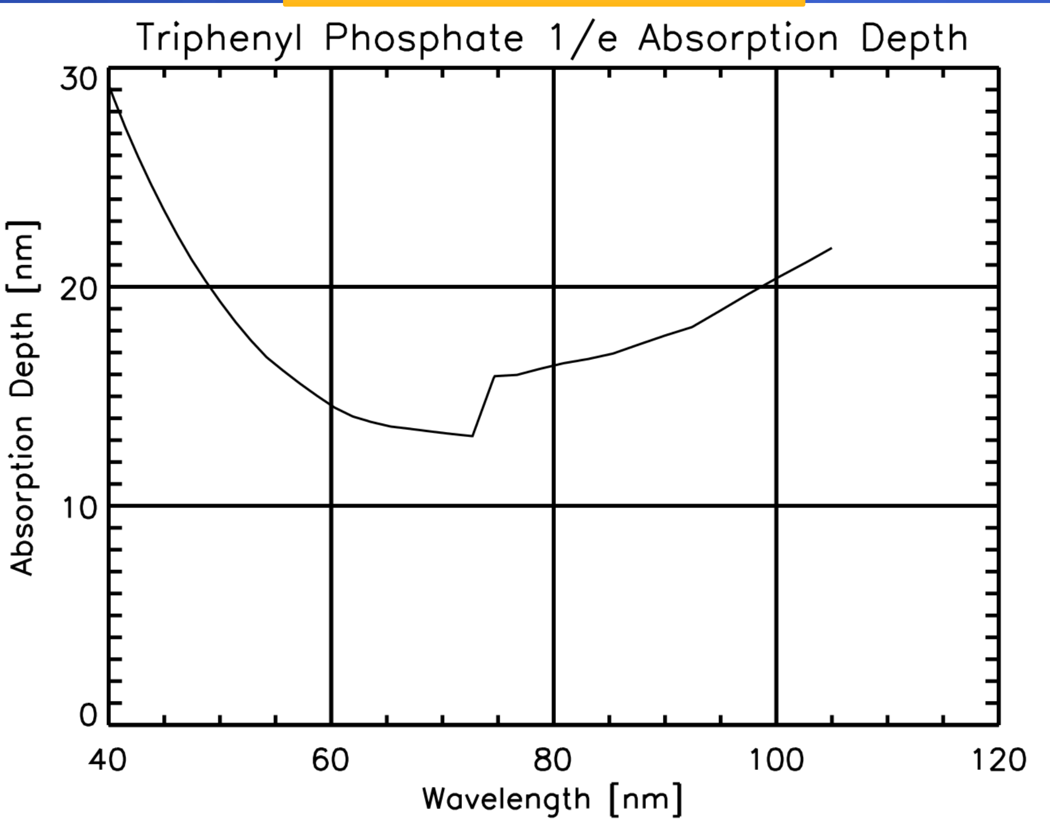
- Blue LED is intended for MEGS-A CCD comparisons
- Violet LED is intended for MEGS-B CCD comparisons

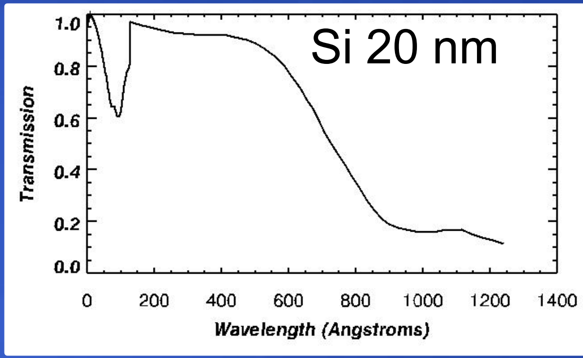


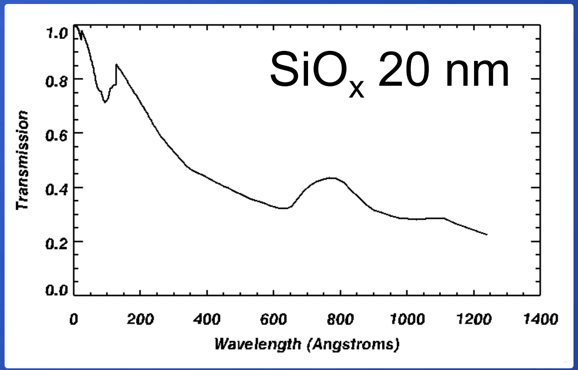
Contaminant Absorption Curves

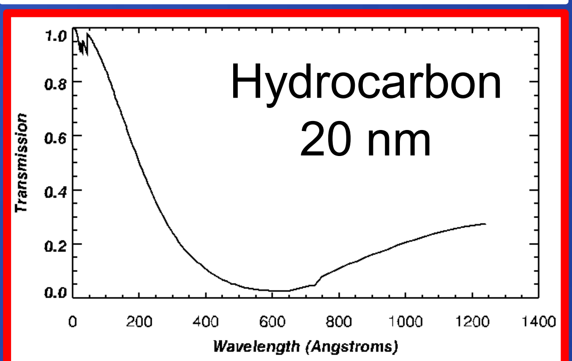
- First Light Degradation curve looks more like Si
  - however, don't see 5-12 nm (50-120 Å) notch for MEGS-A
  - so other type of contaminant is also considered
  - or MEGS-A CCD might not be charged as much

Hydrocarbon Example



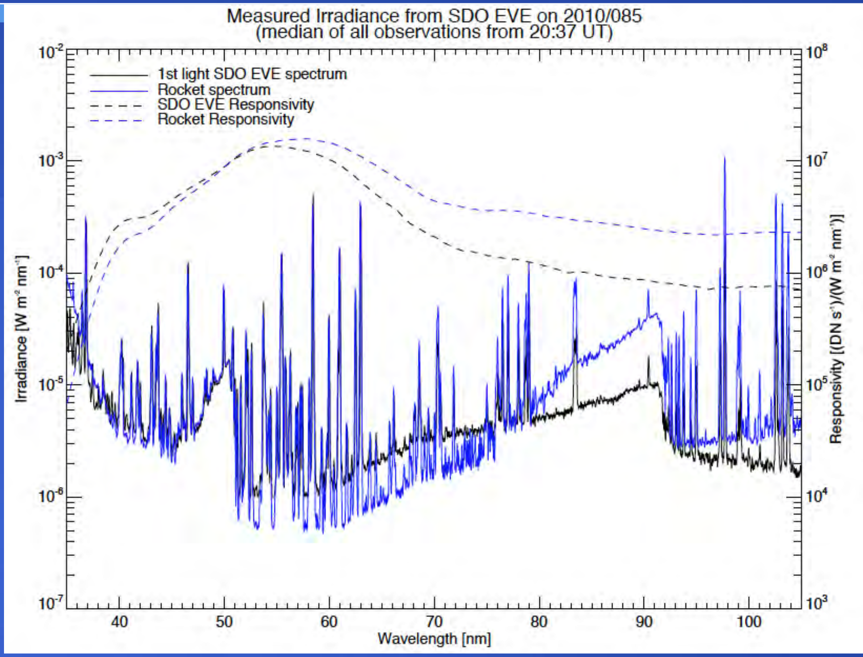


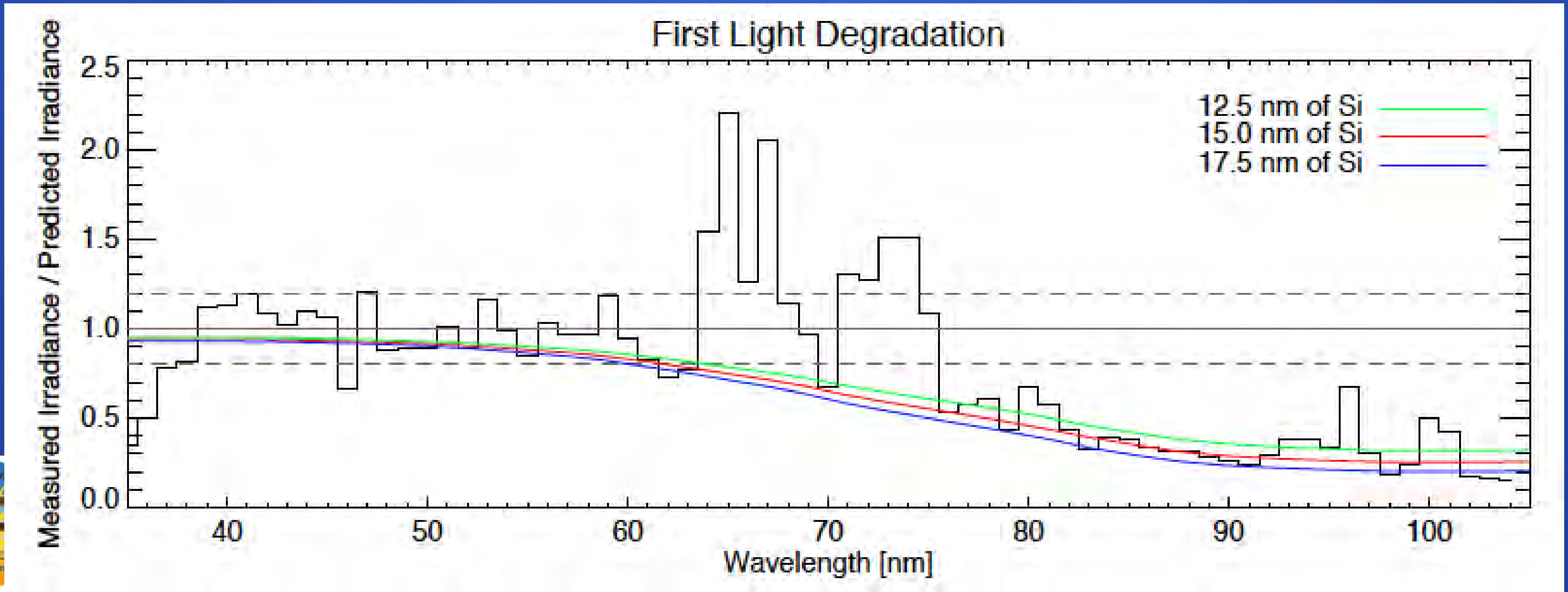




Degradation Seen in First Light Spectrum

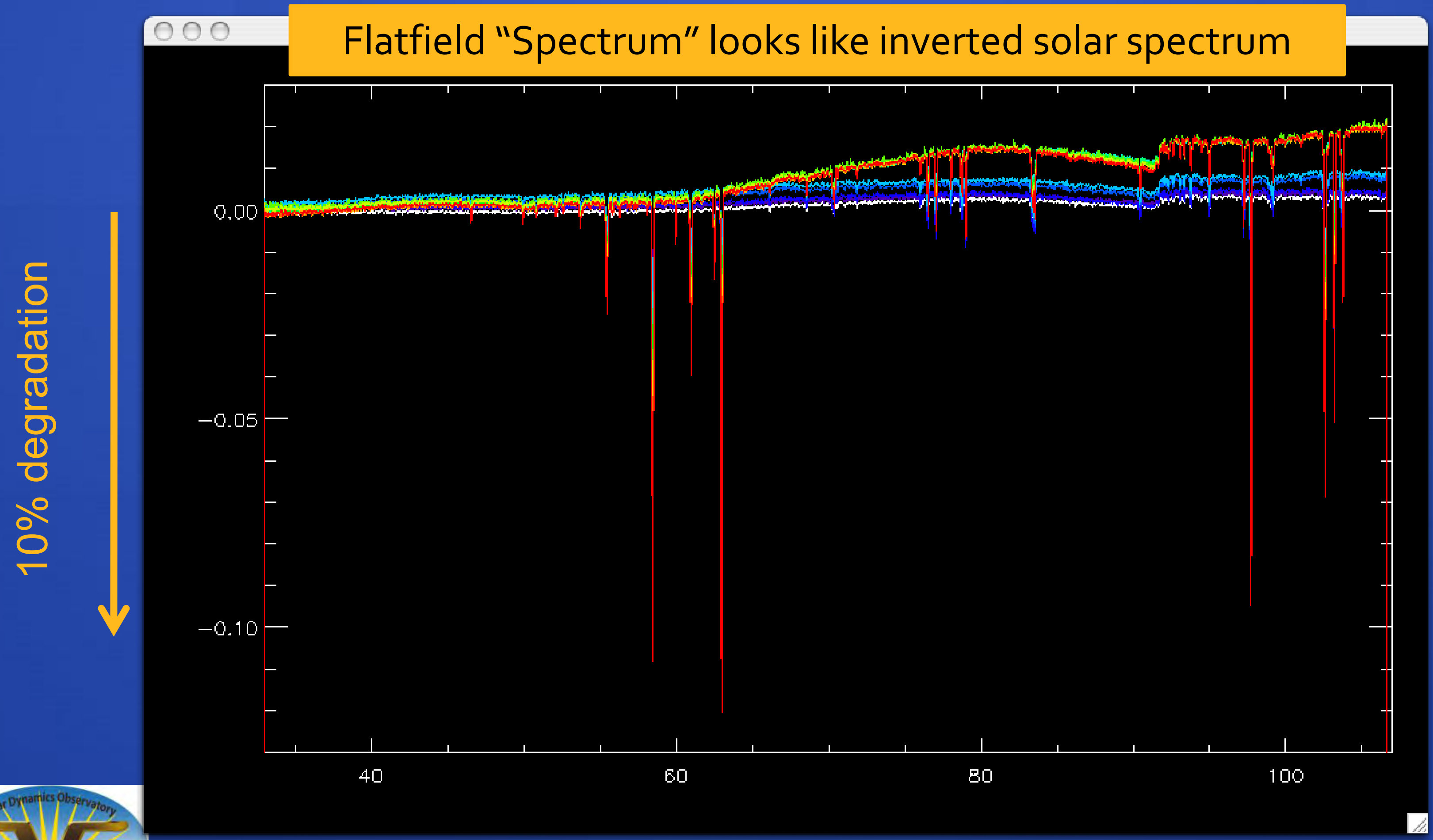
- First minute of solar observations indicate significant decrease in sensitivity from what was expected with SURF calibrations
- Ratio includes correction for solar variability from DOY 085 to 123 (rocket day) by using TIMED SEE data
  - Subtracting dark level impacts background so ratio is better where bright lines are
  - Si dead-layer model suggests charging equivalent to 15 nm Si





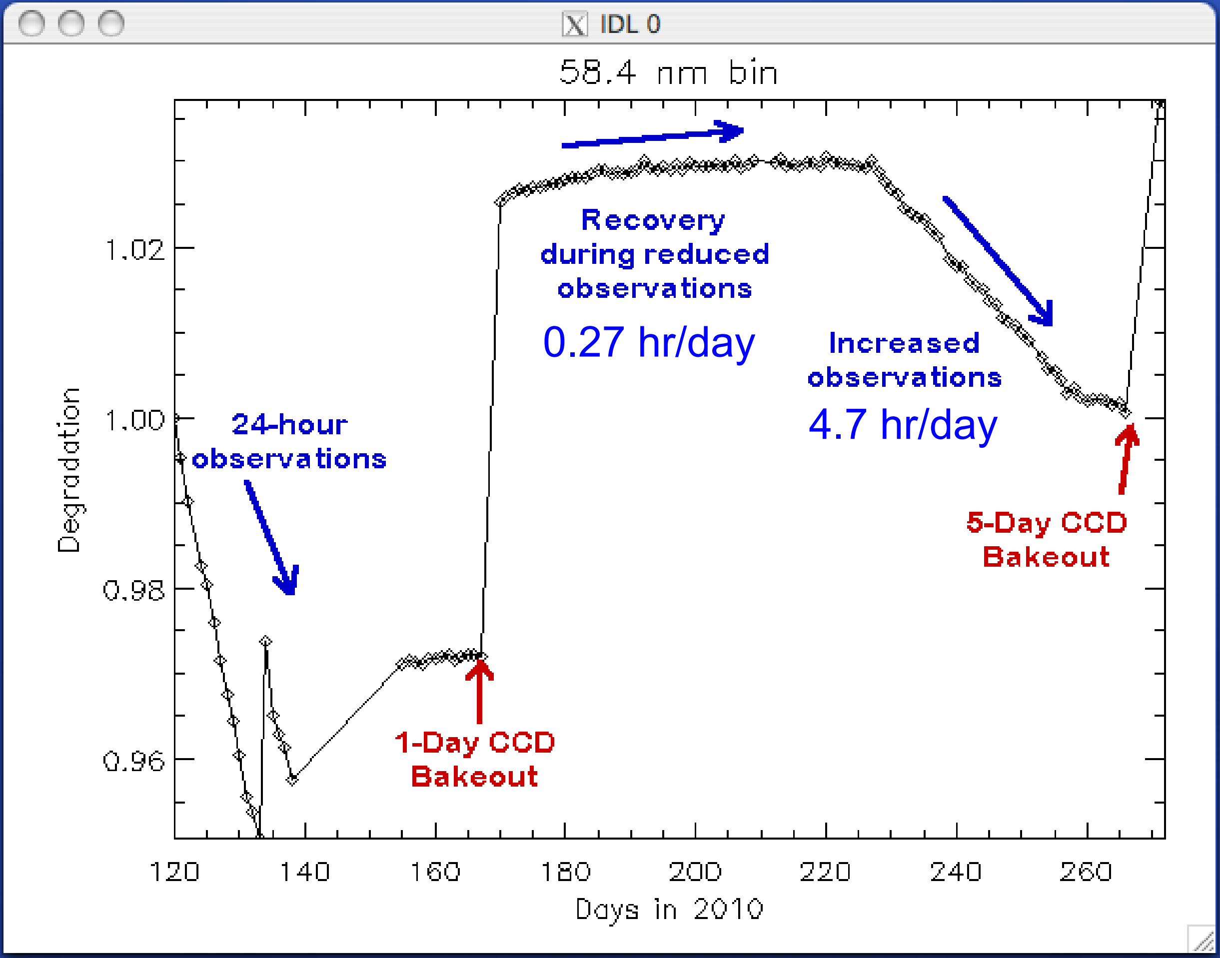
CCD Burn-in Seen for Bright Solar Lines

- CCD Burn-in is best seen in the flatfield LED images that show darker regions where there are bright solar lines



CCD Bake-outs Help to Mitigate Degradation

- Bake-out of CCD helped remove burn-in effects.
  - a 1-day bake appears as good as 5-day bake
- Plan to have CCD bake-outs 1-2 times per year (during eclipse season)



He I 58.4 nm line degrades the fastest

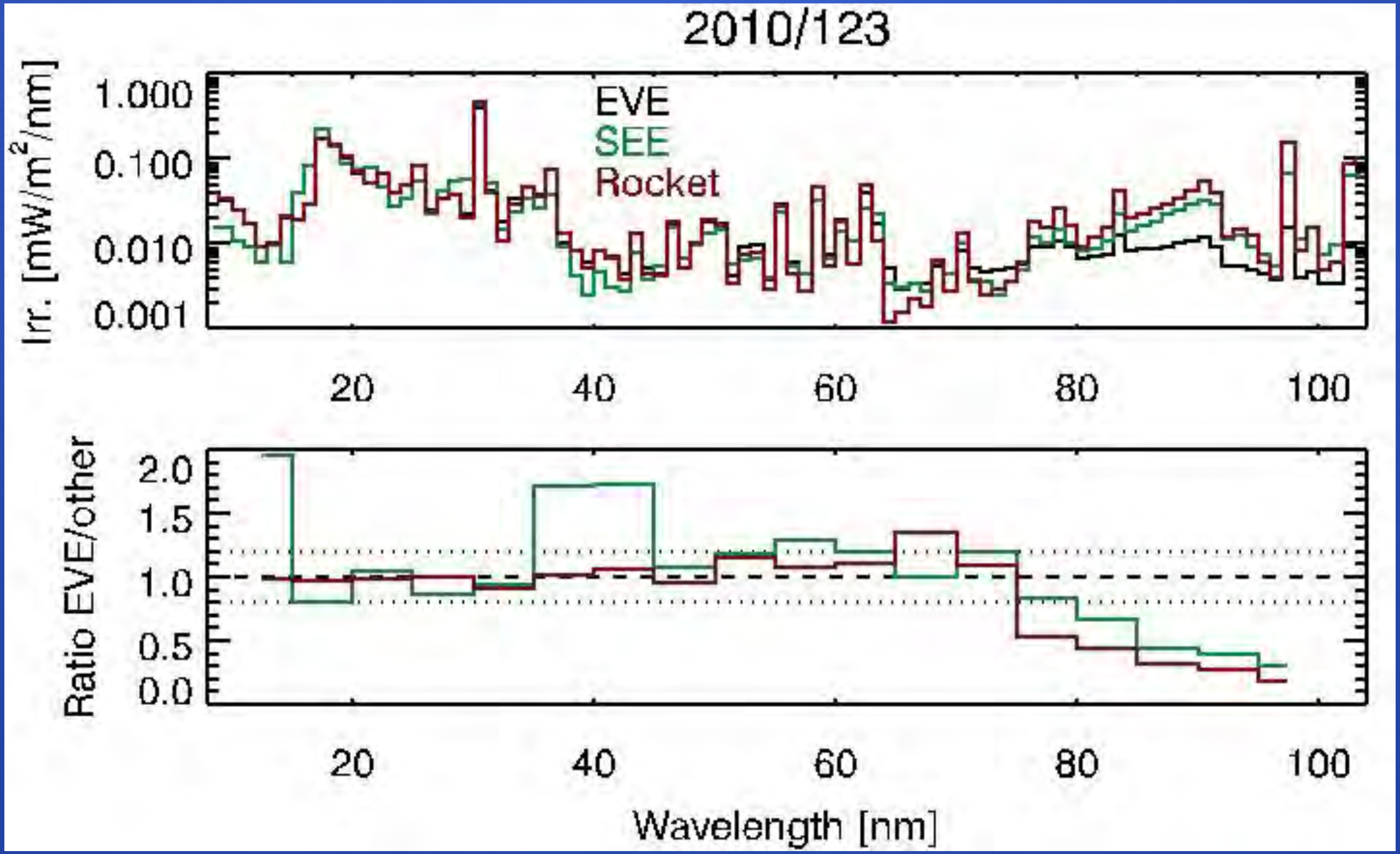
MEGS In-Flight Performance Summary

- MEGS-A1 and MEGS-SAM have very little degradation
  - short wavelengths are less sensitive to contamination and CCD exposure effects
- MEGS-A2 has steady degradation of its filter and the few bright lines (e.g. He II 30.4 nm) have burn-in
  - Daily use of redundant filter and flat field lamp does well at tracking most of this degradation; however, the second calibration rocket indicates additional degradation
- MEGS-B has strong initial degradation of CCD at longer wavelengths and additional burn-in for the bright lines
  - MEGS-B observations have been changed to 4.7 hours per day (3-hours campaign and 5-min every hour) and also allow for one 24-hour flare campaign per month
  - MEGS-B data are only released up to 65 nm in Version 2

MEGS Comparisons

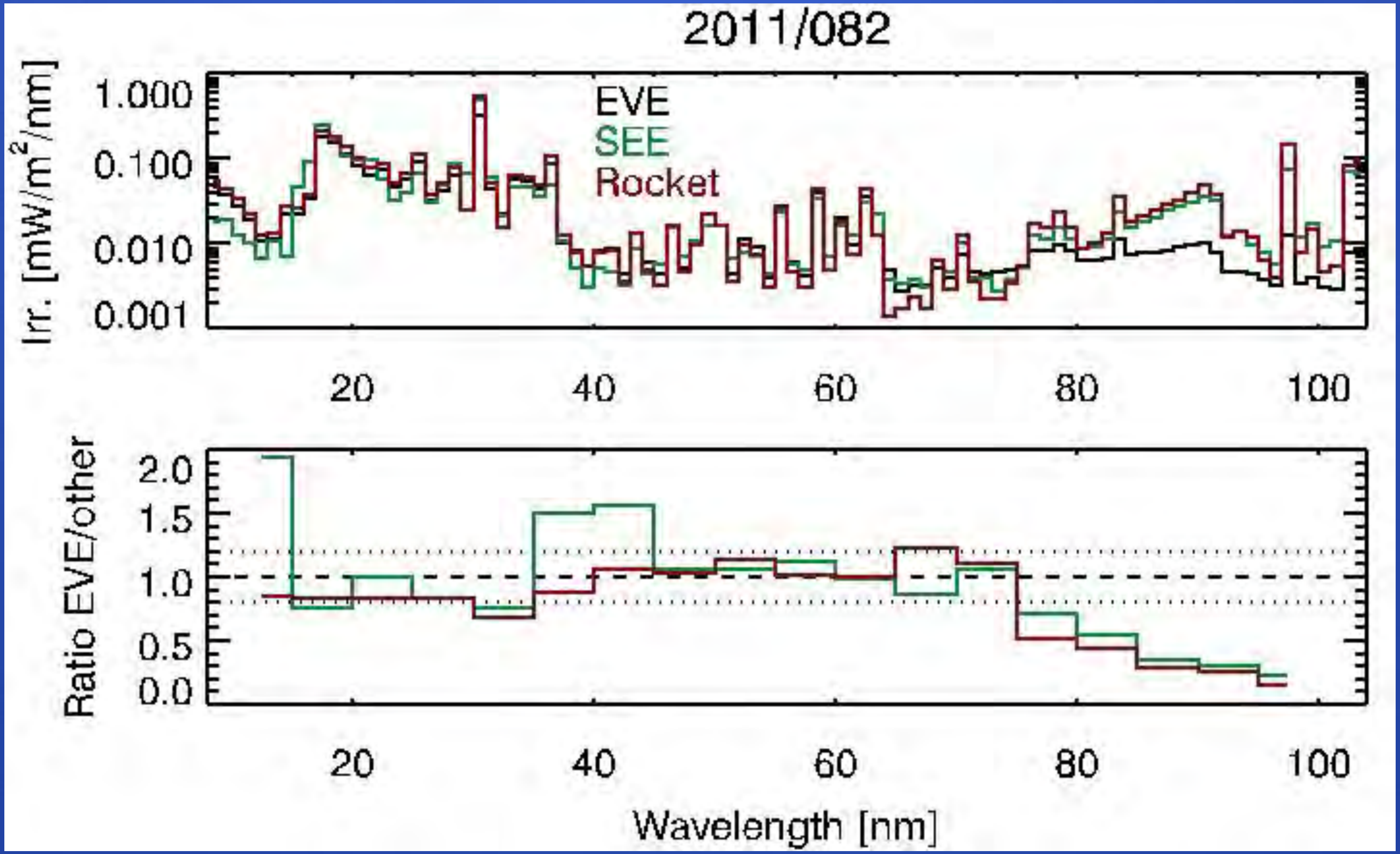
EVE Comparison for First Cal Rocket

- EVE version 3 uses the First Cal Rocket for MEGS-A processing and so good agreement < 38 nm.
- MEGS-B processing has not been updated yet…
- SEE version 11 compares much better to rocket (than SEE ver 10)



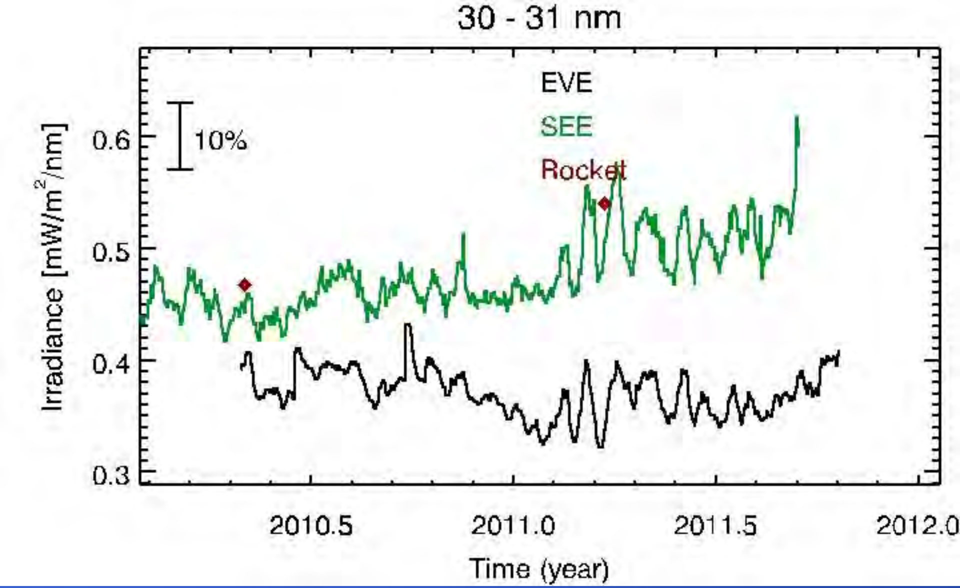
EVE Comparison for Second Cal Rocket

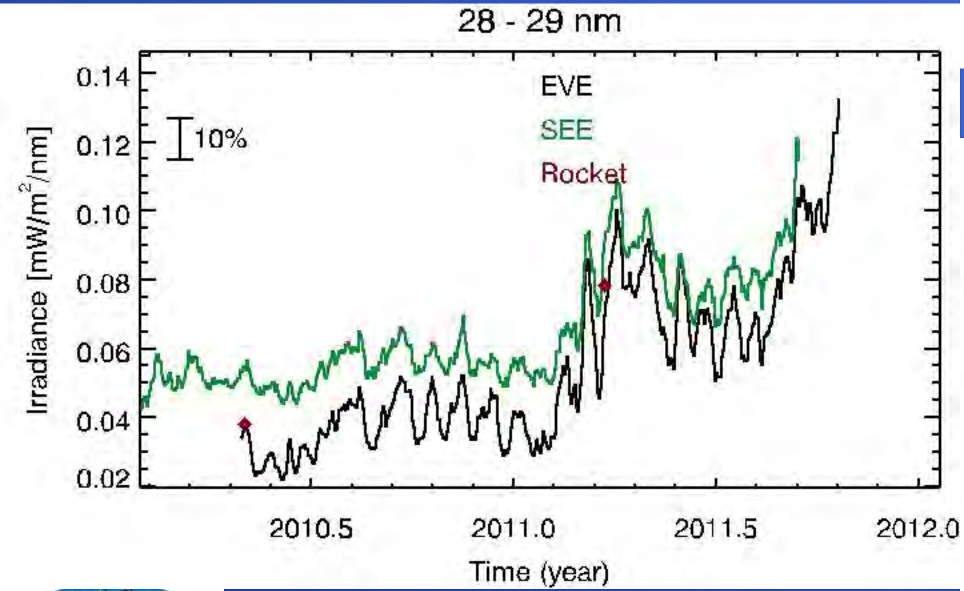
- EVE version 3 processing does not yet use the Second Cal Rocket
  - ~10% extra degradation for MEGS-A needs to be corrected
- SEE version 11 compares much better to rocket (than SEE ver 10)

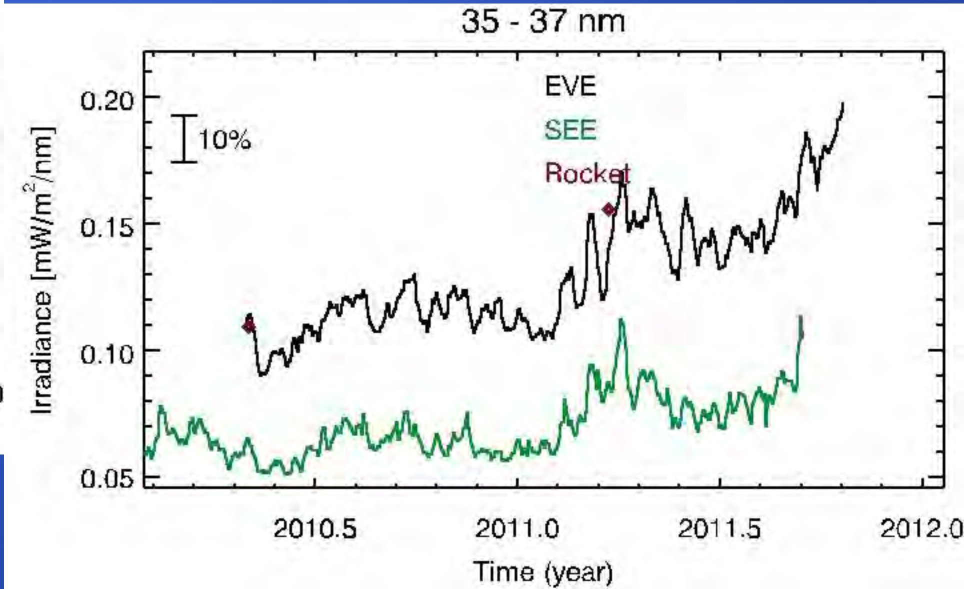


EVE MEGS-A2 Comparison to SEE EGS

- SEE Version 11 is improved over its old version 10
- EVE He II 30.4 nm has additional degradation

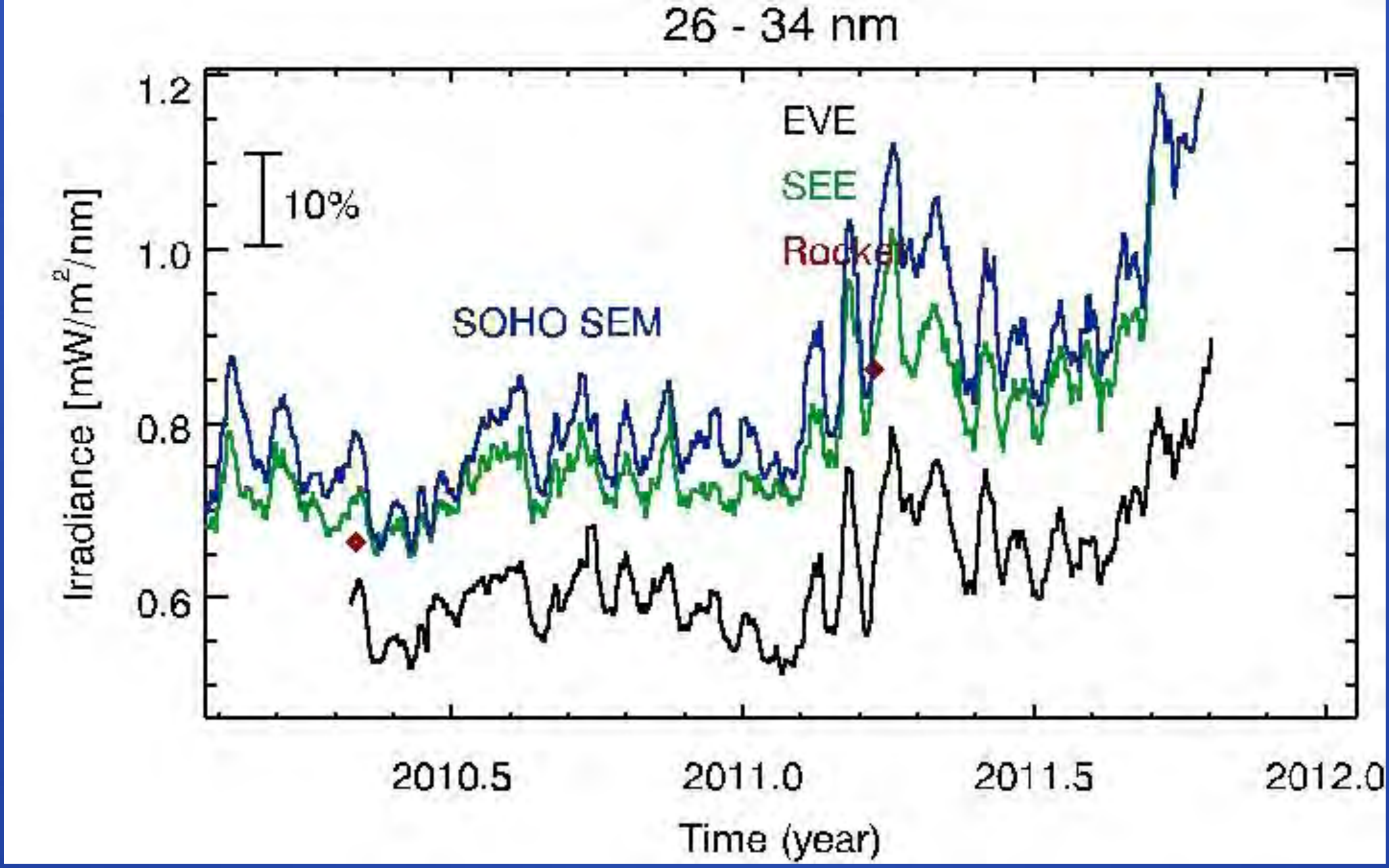






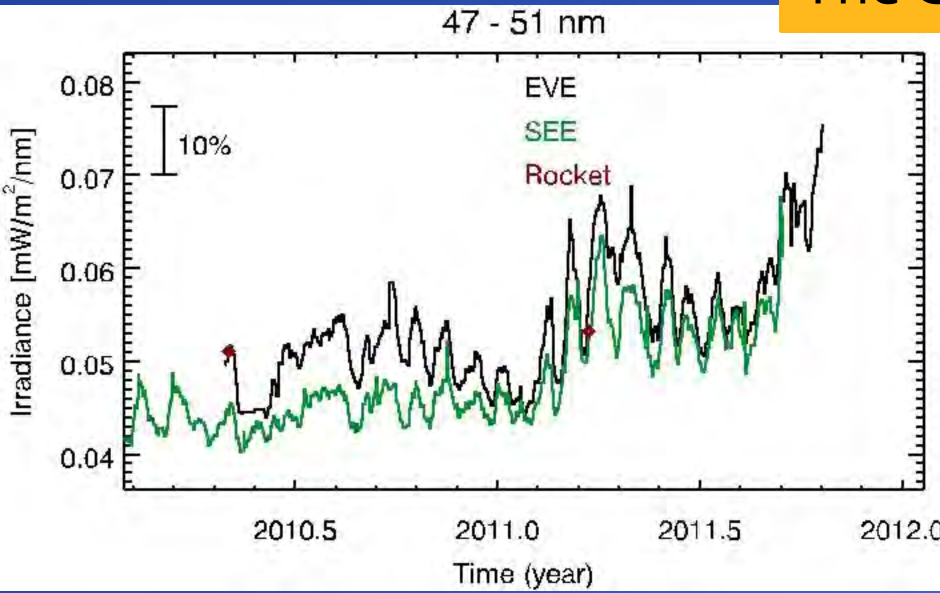
MEGS-A2 Compared to SOHO SEM

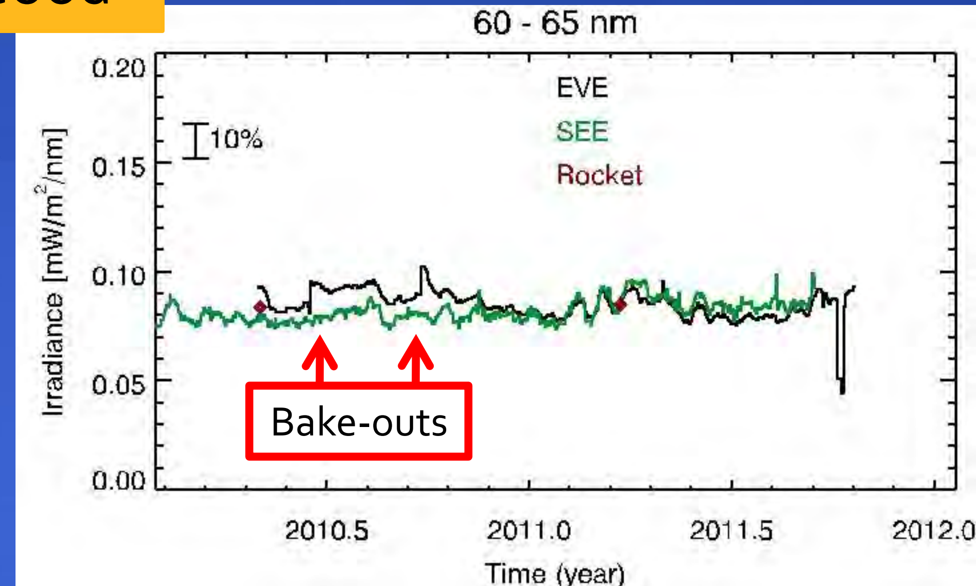
- MEGS-A2 is about 10% lower than rocket MEGS, SEE, and SOHO SEM at beginning of mission and is now about 20% lower. MEGS data processing has not included the second cal rocket result yet.



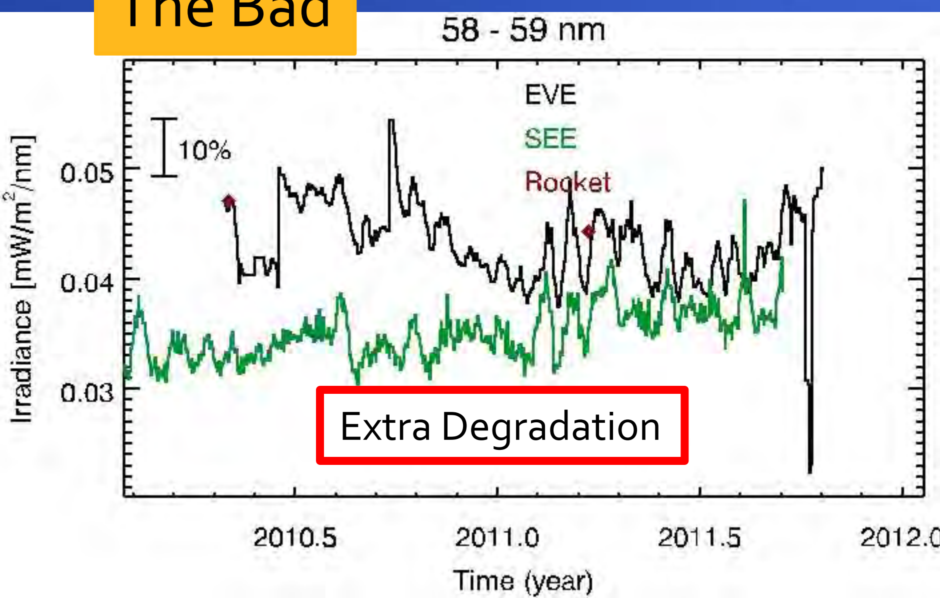
EVE MEGS-B Comparison for SEE EGS

The Good





The Bad



The Ugly