# GOES Extreme UltraViolet Sensors (EUVS) calibrations with SDO EVE

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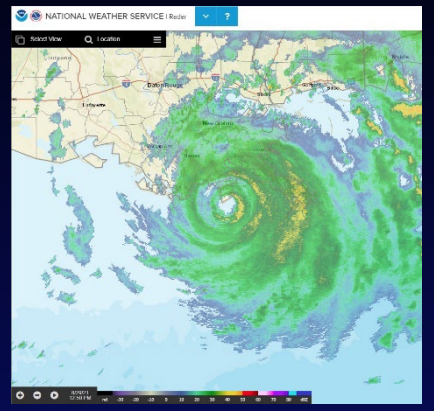
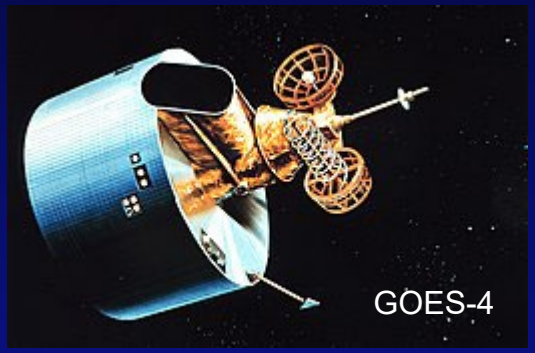
[4] NOAA/SWPC

# 48 Years of GOES Measurements

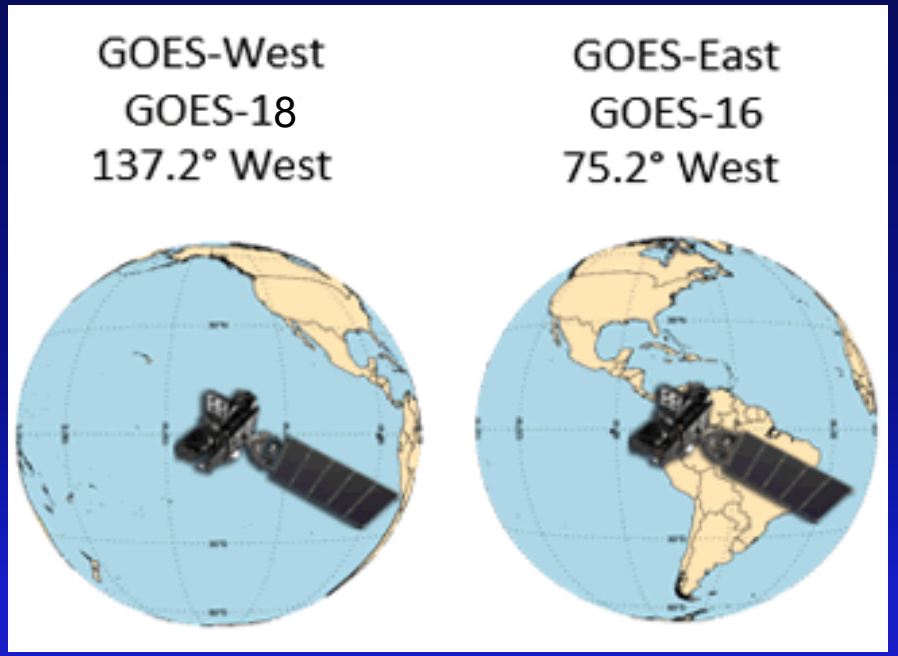
- Geostationary Operational Environmental Satellites
  - Earth imagery and space weather monitoring
  - At GEO: 36,000 km altitude, at 6.6 $R_E$
  - Always two satellites in operations
- GOES-1 through -15 (1975-2020)
  - Space Environment Monitor (SEM)
    - particles, MAG, XRS, EUVS (GOES 13+)
- GOES-R (-16 through- 19; 2017- )
  - EUV and X-Ray Irradiance Sensors (EXIS)




# GOES-R

- EXIS designed and built by the Laboratory for Atmospheric and Space Physics (LASP) at CU Boulder
- GOES-16 2016 launch
- GOES-17 2018
- GOES-18 2022
- GOES-19 2024

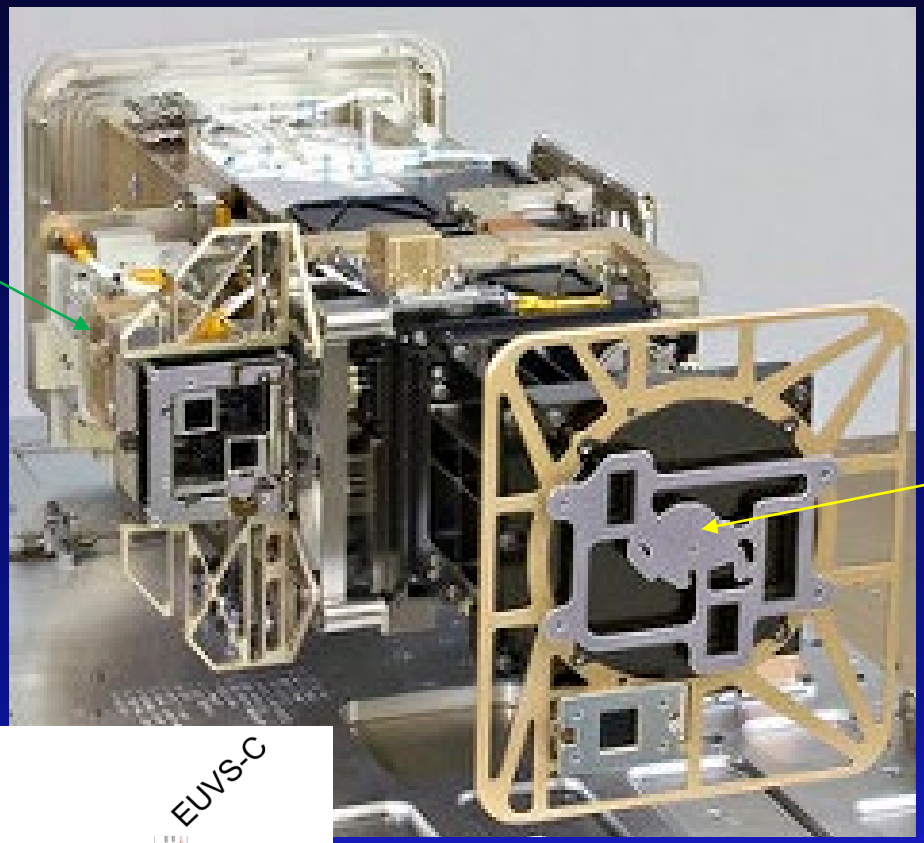


# GOES-R EUVS

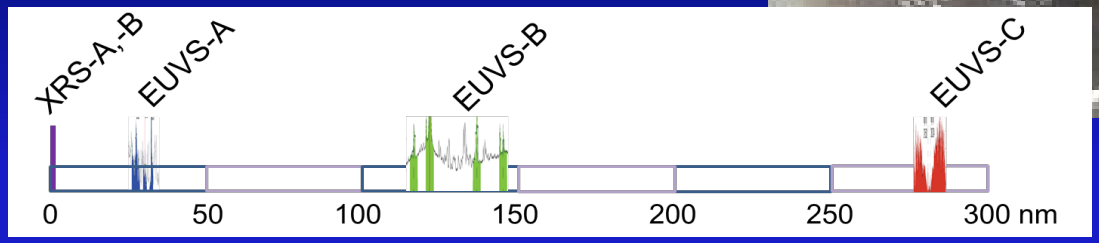
# EUV and X-Ray Irradiance Sensors (EXIS)

Extreme Ultraviolet Sensor (EUVS)

X-Ray Sensor (XRS)



CU buffalo (bison)



# GOES-R EUVS

*Very different measurements between generations*

- GOES 13-15: 5 broadband channels
- GOES-R: higher resolution spectral measurements

3 grating spectrographs

EUVS-A: 24-diode array

EUVS-B: 24-diode array

EUVS-C: 512-diode array

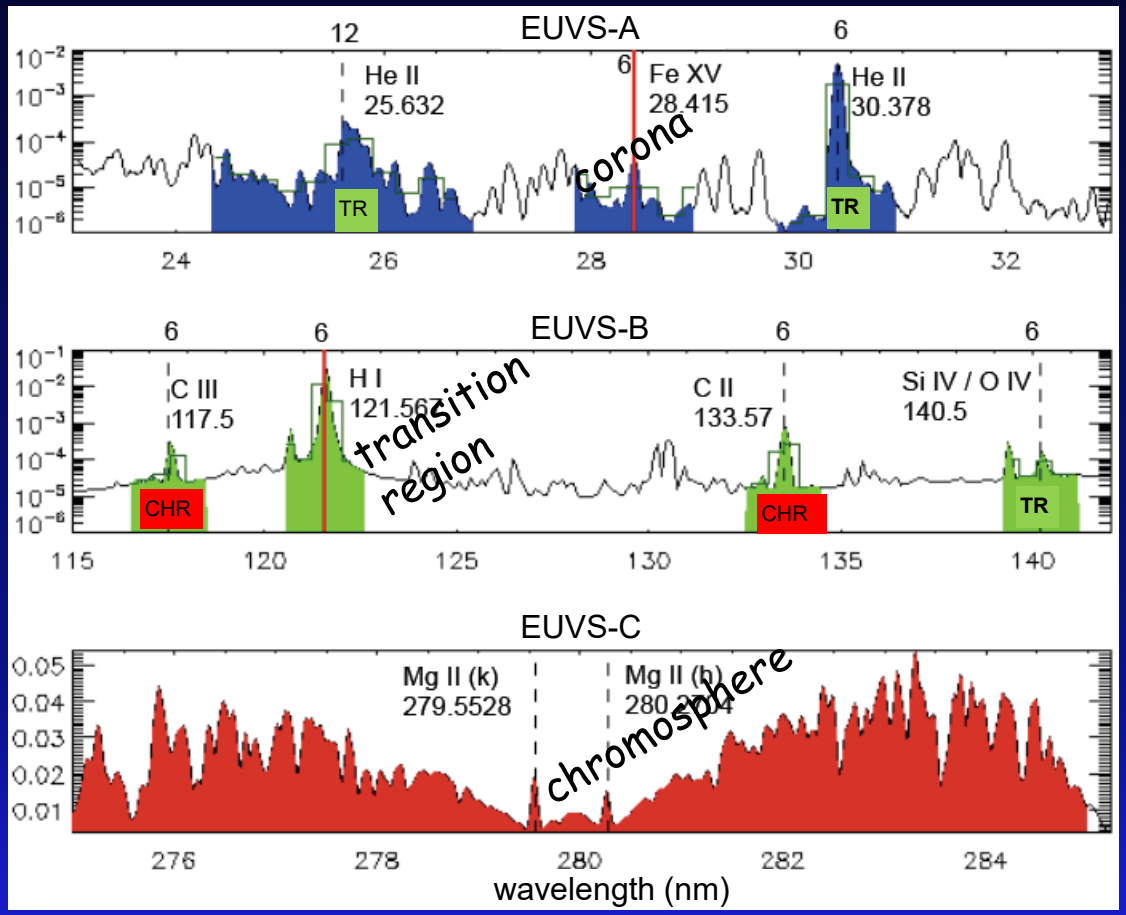
Key measurements

7 spectral lines

Mg II index

Spectral model (5-127 nm)

- uses representative emissions from solar layers



# Mg II Index

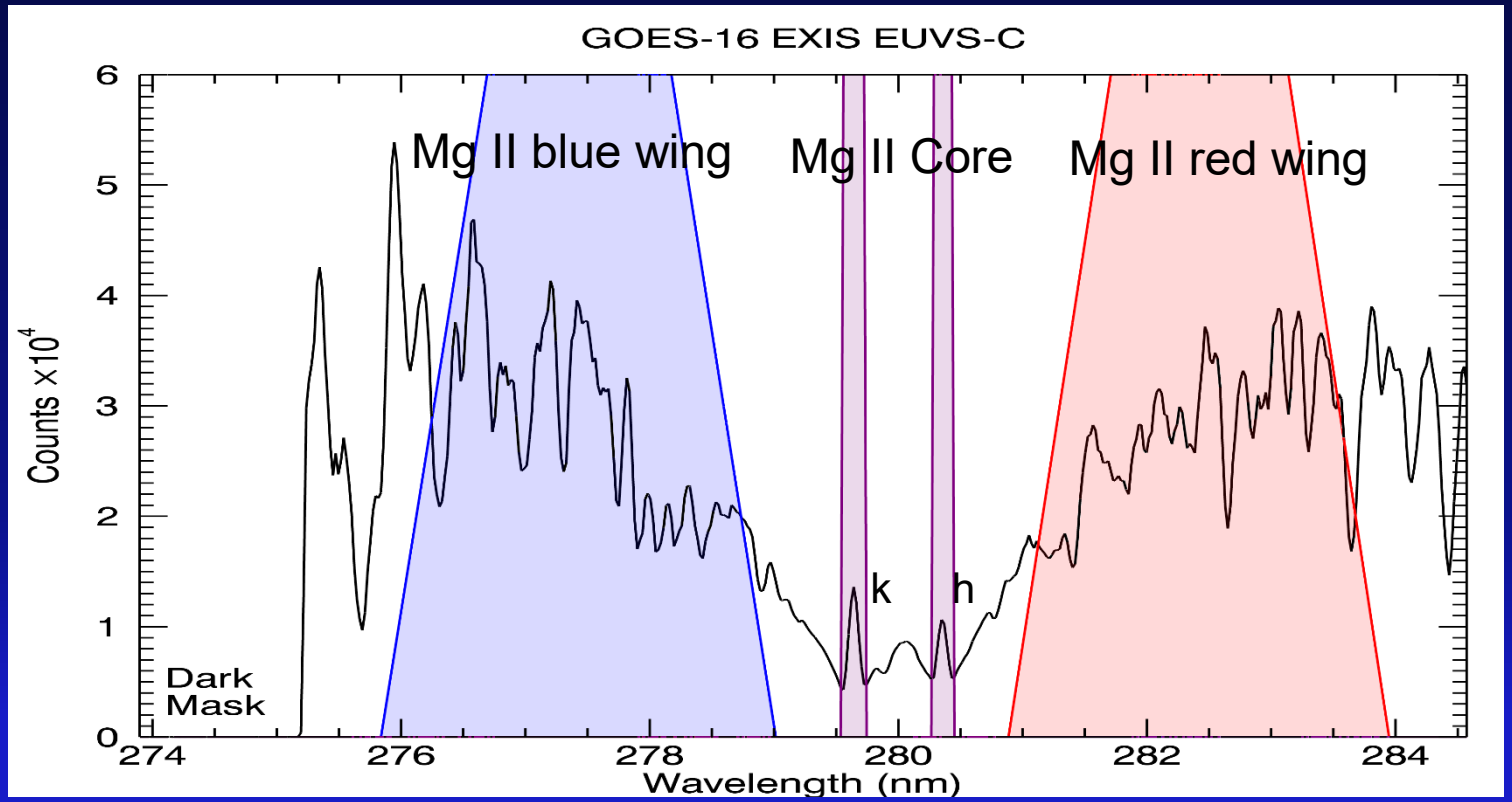
- Mg II core-to-wing ratio (Mg II index) is a proxy for UV solar spectral irradiance

$$Mg\ II\ index = \frac{I_h + I_k}{I_{blue\ wing} + I_{red\ wing}}$$

chromospheric

photospheric

- No degradation correction needed (to first order)



# On-orbit Absolute Calibration of EUVS-A

EUVS-A scaled to SDO EVE Calibration Rocket measurements.

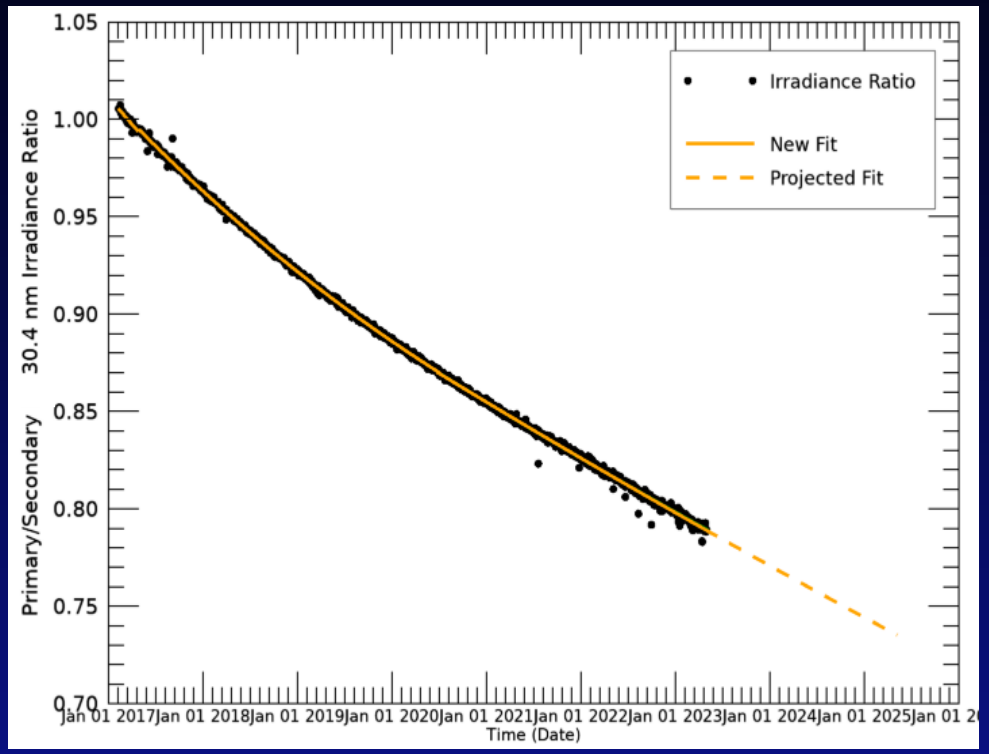
- GOES-16 and -17: 2018 EVE rocket flight
- GOES-18: scaled to GOES-16
- GOES-16 and -18: will use 2023 rocket flight

| GOES-17 EUVS-A line | EVE rocket scaling factor | |
|---|---|---|
| | GOES-16 | GOES-17 |
| 25.6 nm | 0.89 | 0.92 |
| 28.4 nm | 0.82 | 0.85 |
| 30.4 nm | 0.98 | 1.02 |

# Degradation of EUVS-A, -B

EUVS-A degradation
- Uses primary to secondary filter ratio

EUVS-B calibration + degradation
- Use ratio of daily average to...
  - SORCE SOLSTICE (into 2019)
  - proxy for each wavelength based on GOES-R Mg II (now)



# GOES-16 Degradation

## EUVS-A

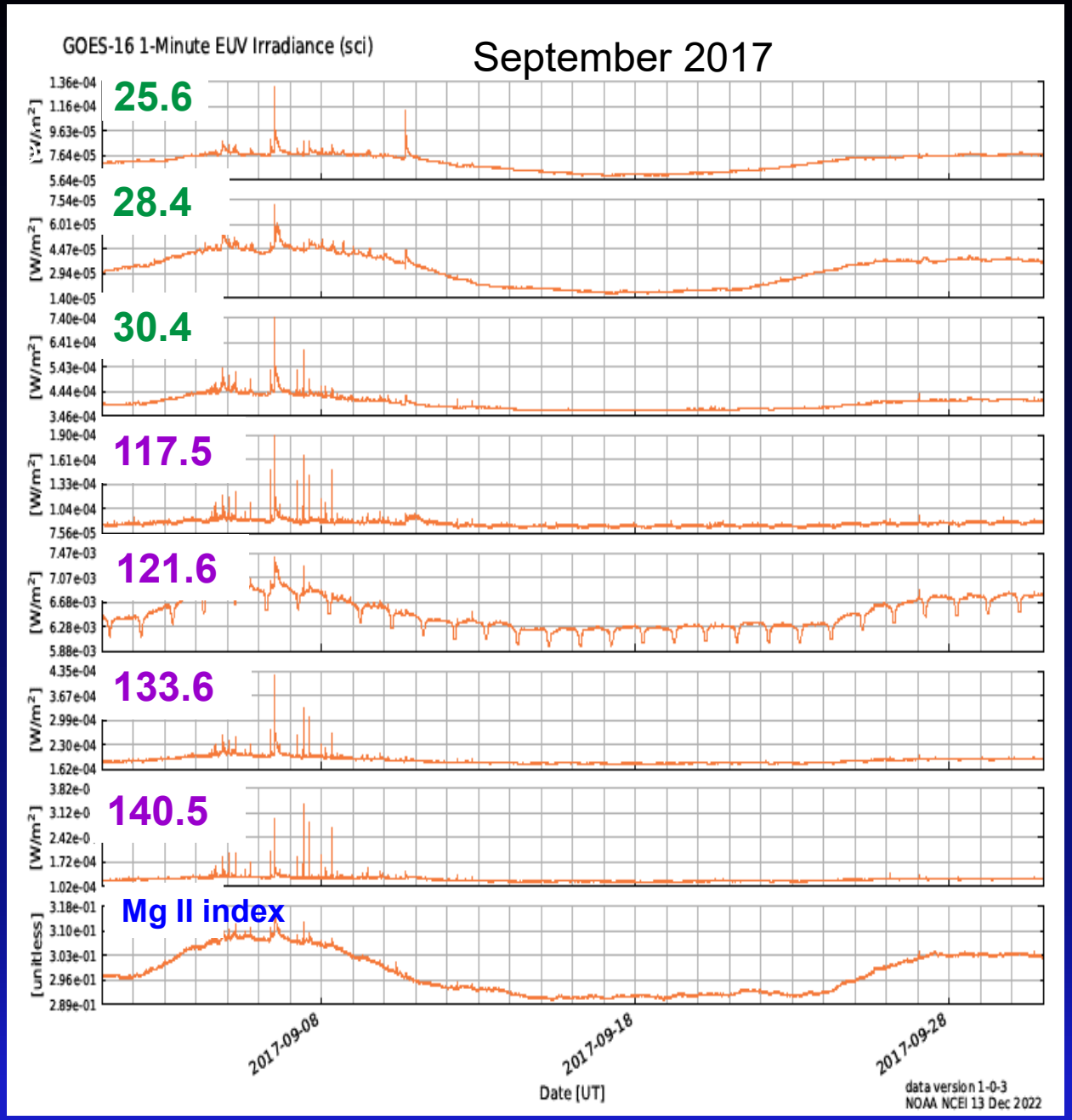
| λ[nm] | Degradation May 2023 | Degradation after 20 years |
|---|---|---|
| 25.6 | 0.86 | 0.54* |
| 28.4 | 0.82 | 0.59 |
| 30.4 | 0.79 | 0.48 |

## EUVS-B

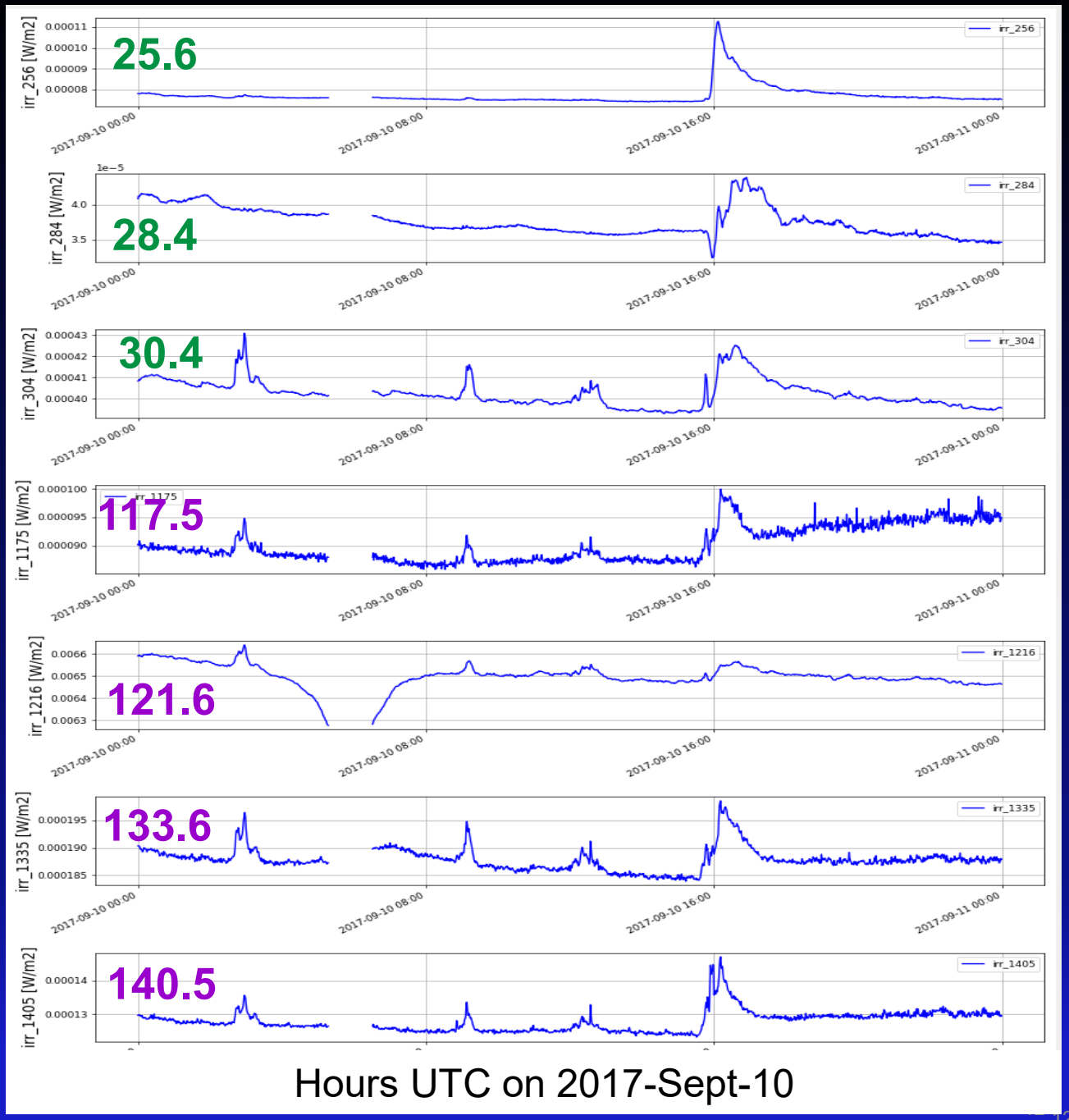
| λ[nm] | Degradation May 2023 | Degradation after 20 years |
|---|---|---|
| 117 | 0.85 | 0.34* |
| 121 | 0.58 | 0.42 |
| 133 | 0.95 | 0.42* |
| 140 | 0.90 | 0.76* |

* Upper bounds based on linear (instead of exponential) fits.

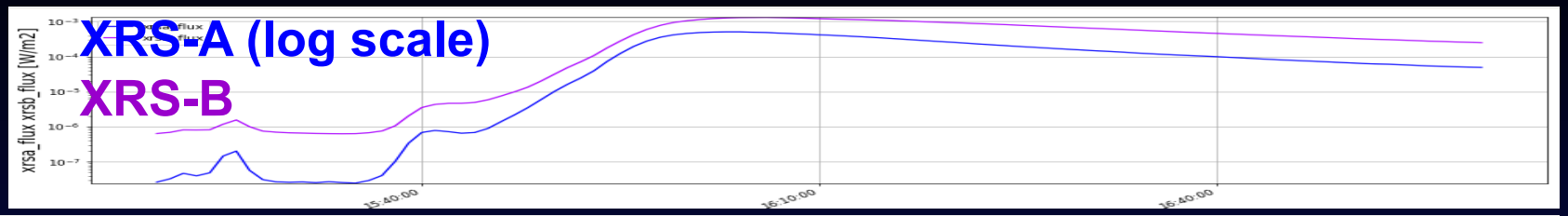
# EUVS Line Measurements

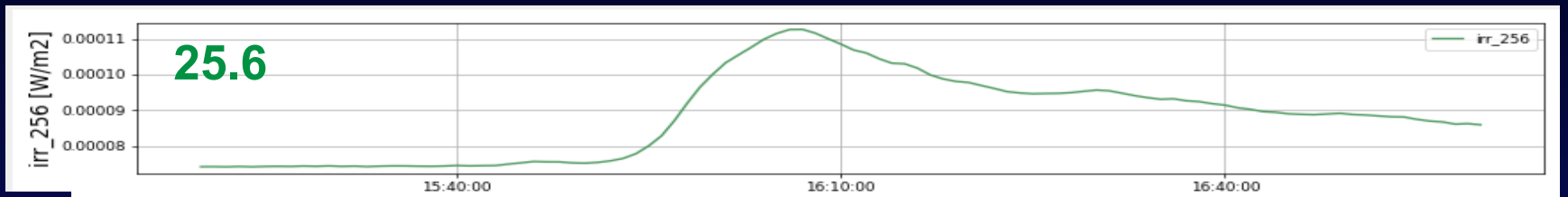


# EUVS Line Irradiances

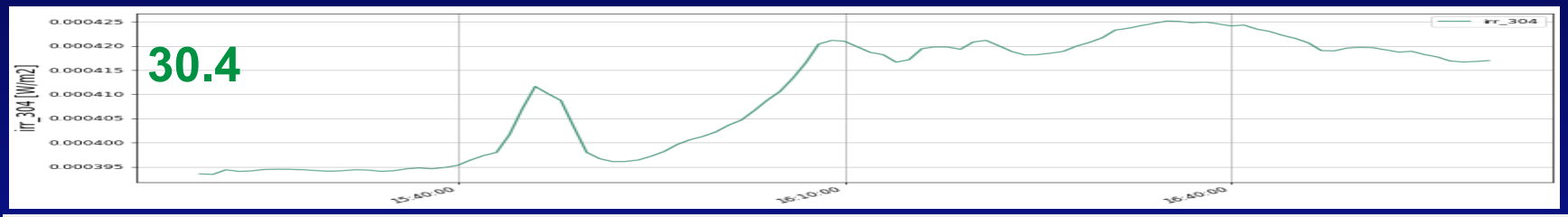


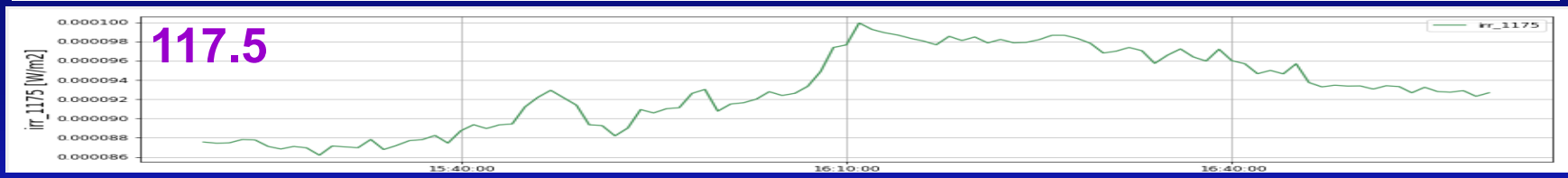
# 2017-09-10 Flares

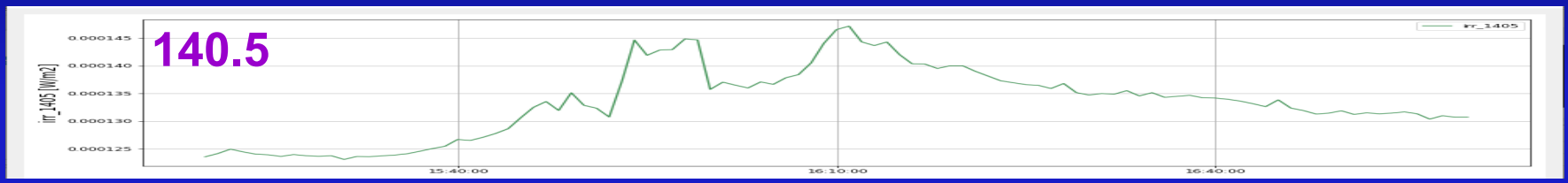




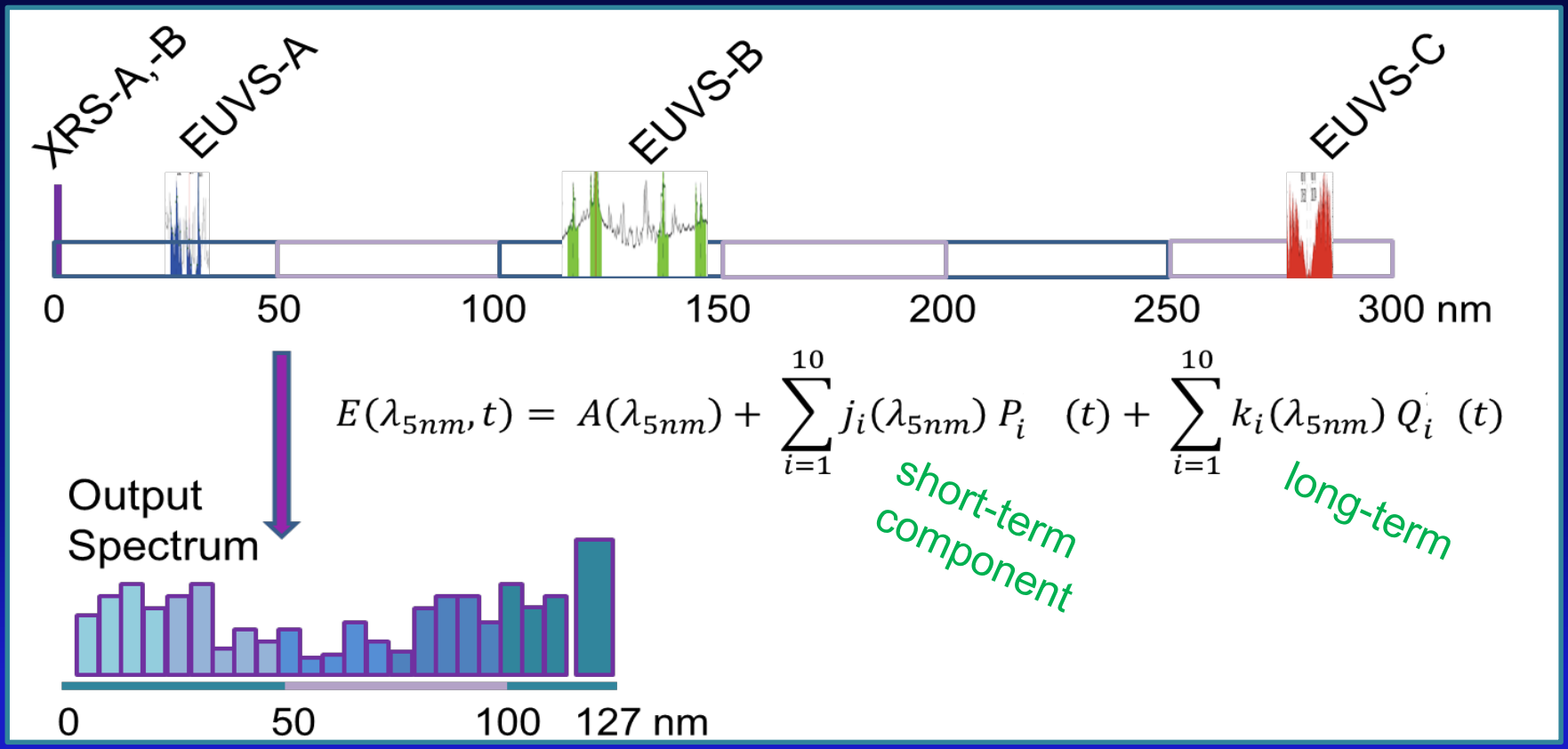


# EUVS Spectral Model

- 24 bins from 5 - 127 nm
  - Thiemann, E.M.B, et al. (2019), J. Space Weather and Space Clim.
  - uncertainties: 2-20% long term, short-term: 6-80%
- EUVS lines can be input to other models or serve as proxies for missing data



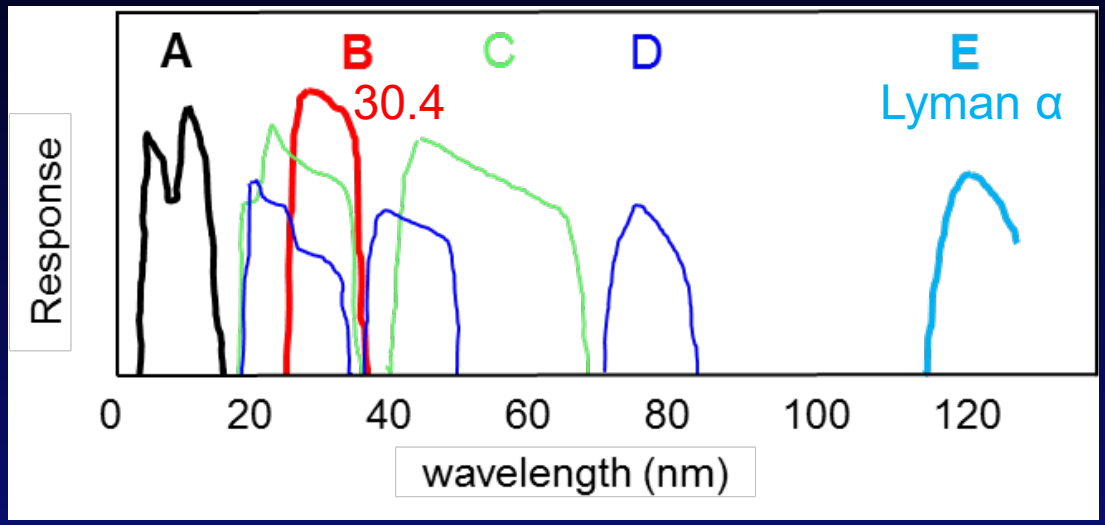
# GOES 13-15 EUVS

# GOES 13-15 EUV Irradiance

5 broadband measurements

Sporadic measurements for GOES-13 and -14

Cadence: 10 sec

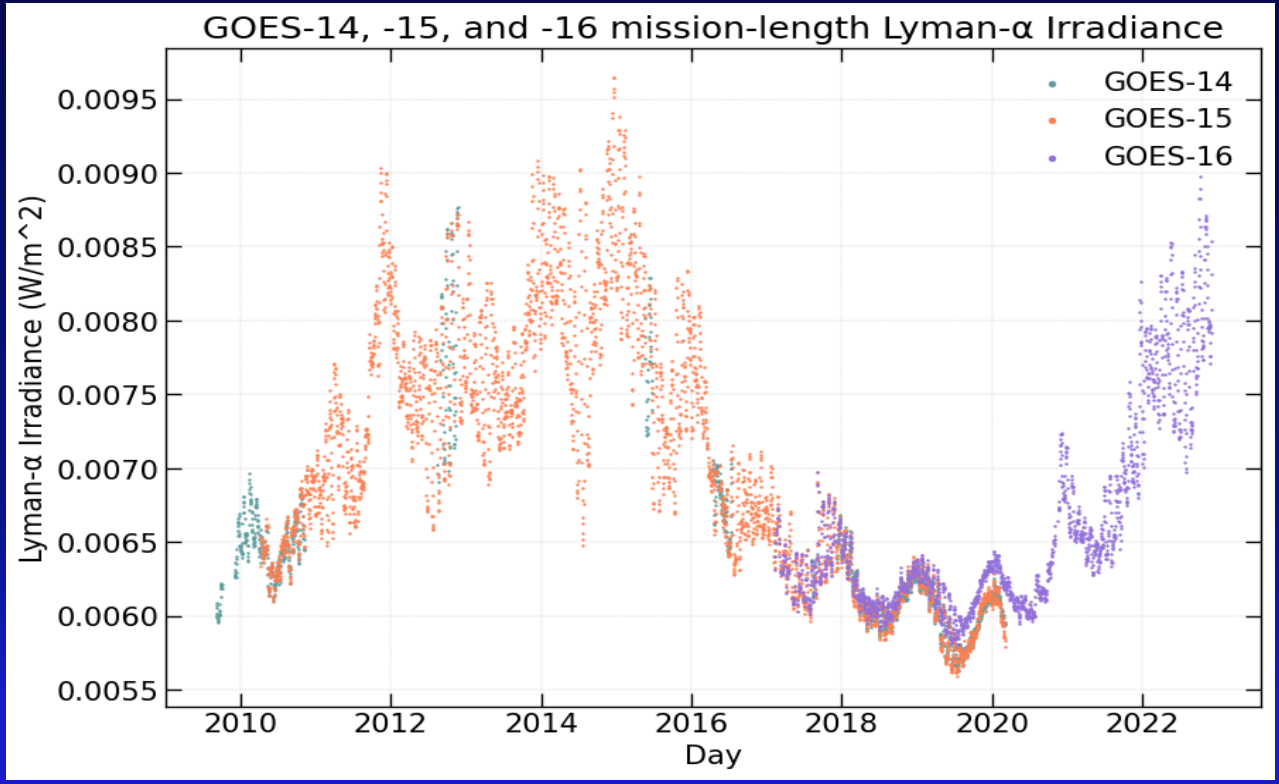



| GOES | Years of Operation |
|---|---|
| 13 | 2006 - 2017 |
| 14 | 2009 - 2020 |
| 15 | 2010 - 2020 |

# Science-Quality GOES 13-15 Lyman α

EUVS-E (121 nm; Lyman alpha)

- Degradation and calibration with SORCE SOLSTICE Lyman alpha
- Science-quality
  - G14 and -15: 2010-2020, version 5
  - G13: 2006-2016, version 4

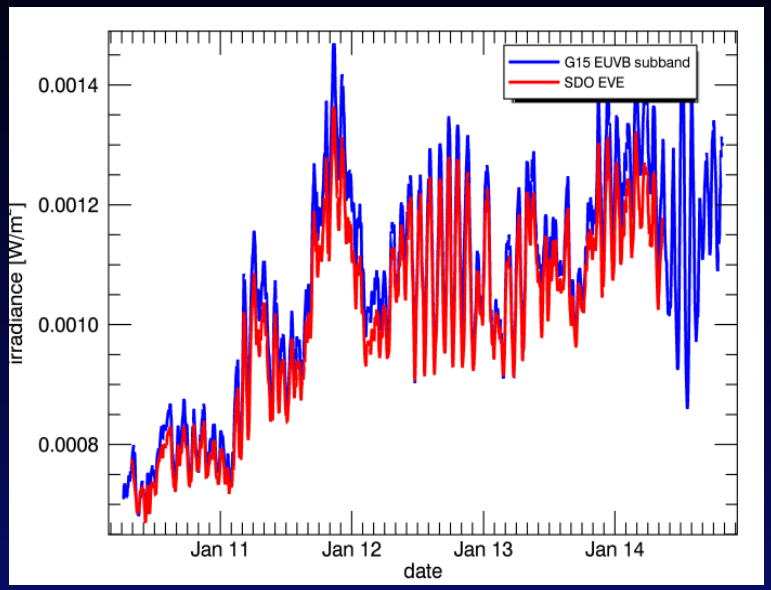


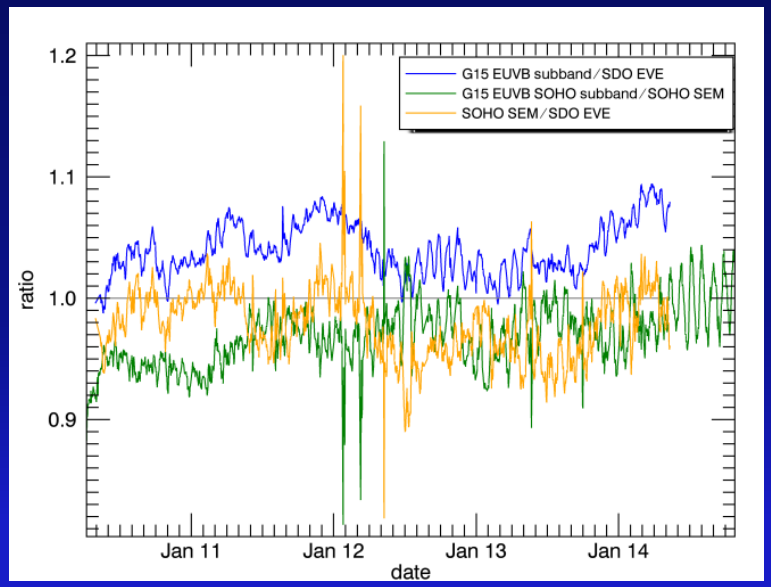
# Science-Quality GOES 13-15 EUVS-A, B

EUVS-A (15 nm)
EUVS–B (30.4 nm, He II)

- validated against EVE/MEGS-A
- Science-quality data at Version2 through 2014,
- Redo EUVS-B next year to Version 5
  - Challenge would be to extract 30.4 nm line
    - Use MEGS-A

https://www.ngdc.noaa.gov/stp/satellite/goes/doc/GOES_NOP_EUV_readme.pdf



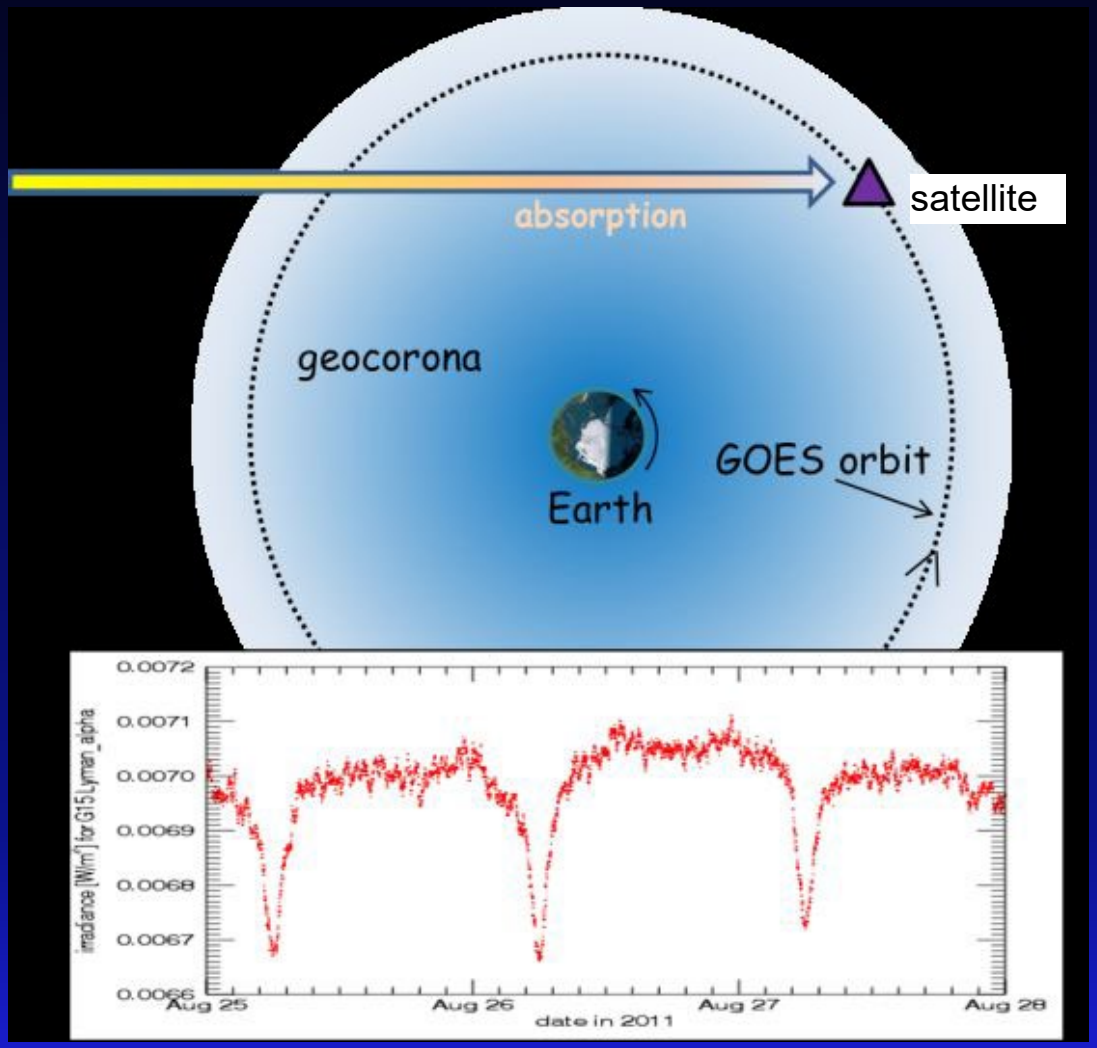
# Some applications of EUVS

# EUV for Satellite Drag Model

- High Accuracy Satellite Drag Model (HASDM)
  - Run operationally by the US Air Force.
  - Calculate and predict neutral density and satellite position for collision avoidance
  - Customers:  DOD, NASA, NOAA, satellite operators
  - The output used to revise NORAD catalogue of satellite 2 line elements every 8 hours.
  - Uses solar indices as inputs.

- solar indices
  - Produced by Space Environment Technologies (SET)
  - Use 28.4, 30.4 and 121.6 nm from GOES
  - Use measurements from other satellites also.

# Exospheric Neutral Hydrogen Densities




Use solar occultations to determine neutral hydrogen densities

Challenges

- Need proxy for top-of-atmosphere Lyman alpha during dip
  - Tried proxies. Use scaled second satellite.
- Multiple scattering in optically thick region (<3 $R_E$)
  - Determine line-of-sight velocity distributions and associated cross section

# NOAA/NCEI GOES Irradiance Data

# Operational vs Science-quality Data

## Operational data (real time)

Calibrations changes delayed & abrupt

Algorithm updates

Data gaps

Original file format & products

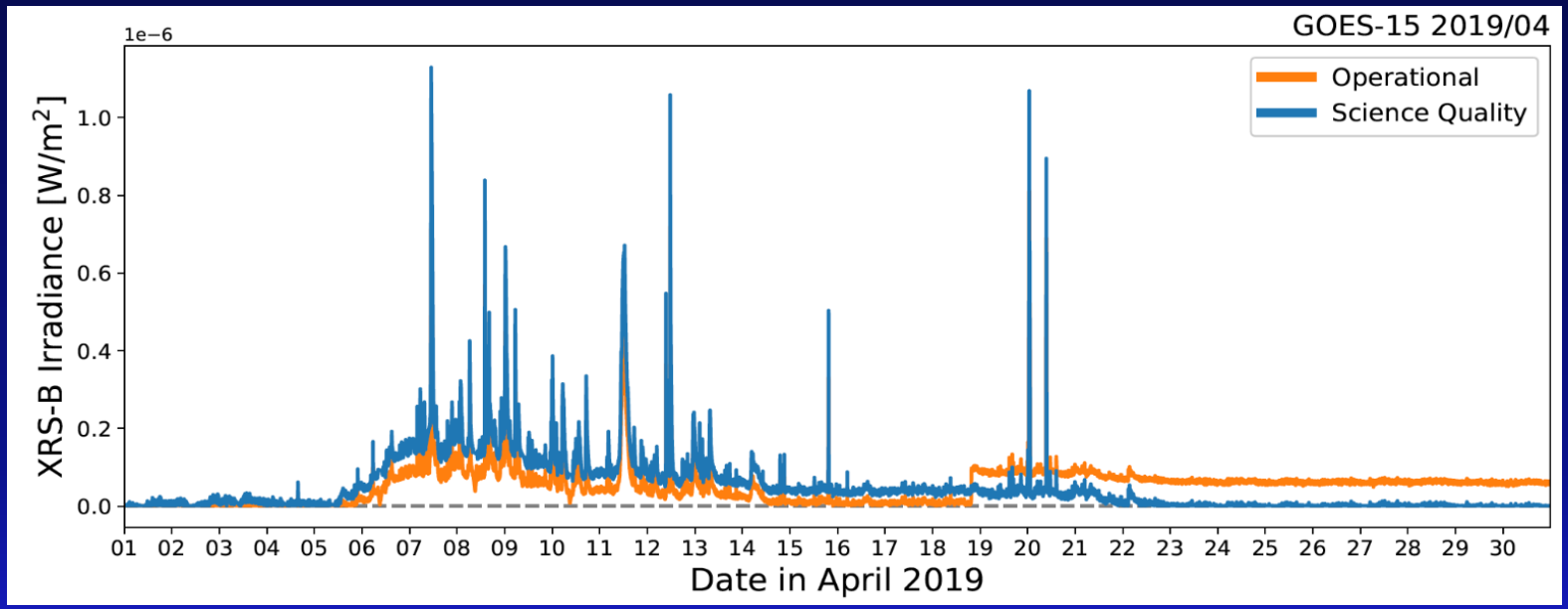
## Science-quality

Cal changes are smooth

Reprocessed from mission start

Gaps filled

GOES-R format & product types



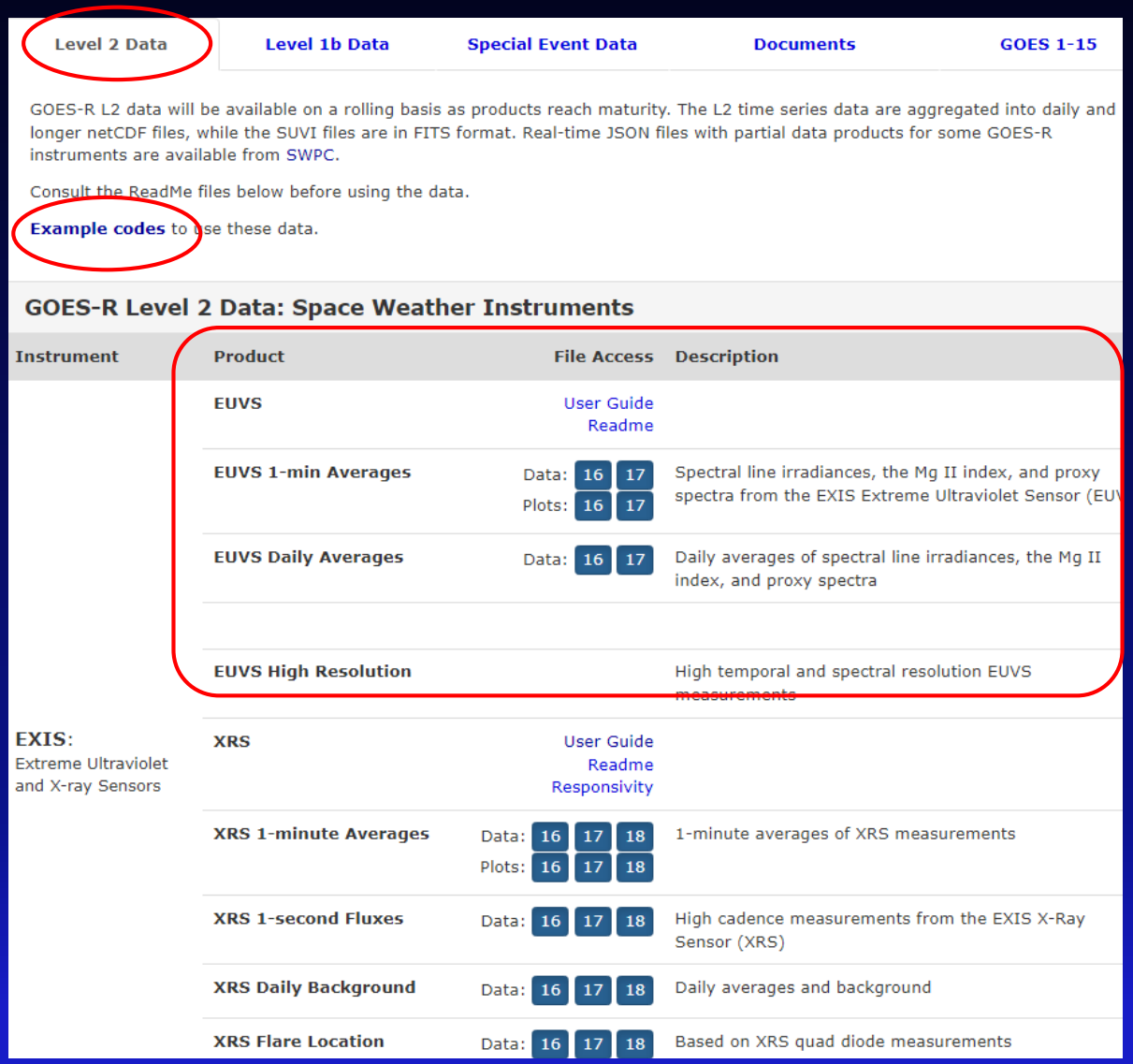
# EUVS Data

## NOAA/NCEI EUVS

- Science quality and Operational
- Includes aggregations
- GOES-18 August
- Future: high resolution, composites, GOES-19

## NOAA/SWPC

- Real-time, but limited info
- No EUVS yet



Level 2 Data | Level 1b Data | Special Event Data | Documents | GOES 1-15

GOES-R L2 data will be available on a rolling basis as products reach maturity. The L2 time series data are aggregated into daily and longer netCDF files, while the SUVI files are in FITS format. Real-time JSON files with partial data products for some GOES-R instruments are available from SWPC.

Consult the ReadMe files below before using the data.

Example codes to use these data.

**GOES-R Level 2 Data: Space Weather Instruments**

| Instrument | Product | File Access | Description |
|---|---|---|---|
| | EUVS | User Guide<br>Readme | |
| | EUVS 1-min Averages | Data: 16 17<br>Plots: 16 17 | Spectral line irradiances, the Mg II index, and proxy spectra from the EXIS Extreme Ultraviolet Sensor (EUV |
| | EUVS Daily Averages | Data: 16 17 | Daily averages of spectral line irradiances, the Mg II index, and proxy spectra |
| | EUVS High Resolution | | High temporal and spectral resolution EUVS measurements |
| EXIS: Extreme Ultraviolet and X-ray Sensors | XRS | User Guide<br>Readme<br>Responsivity | |
| | XRS 1-minute Averages | Data: 16 17 18<br>Plots: 16 17 18 | 1-minute averages of XRS measurements |
| | XRS 1-second Fluxes | Data: 16 17 18 | High cadence measurements from the EXIS X-Ray Sensor (XRS) |
| | XRS Daily Background | Data: 16 17 18 | Daily averages and background |
| | XRS Flare Location | Data: 16 17 18 | Based on XRS quad diode measurements |

# Future

EUVS
- Continued degradation tracking
- Improved artifact corrections
  - temperature impacts: ~1% annual oscillations, post-eclipse
  - Mg II second order corrections
- New GOES-R products: high resolution (spectral & time), other spectral models, composites, event detection
- Version 5 for 30.4 (GOES 13-15) and 121 (GOES-13)

XRS
- Improved electron contamination correction
- Improved flare location algorithm
- New products: flare report and composite
- Science-quality GOES 1-12 XRS

Science fun!

GOES-U (-> GOES-19) launch in April 2024!


GOES-S launch, 1 March 2018

# Questions?

https://www.ngdc.noaa.gov/stp/satellite/goes-r.html

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# Backup

# Solar X-ray and EUV Variability

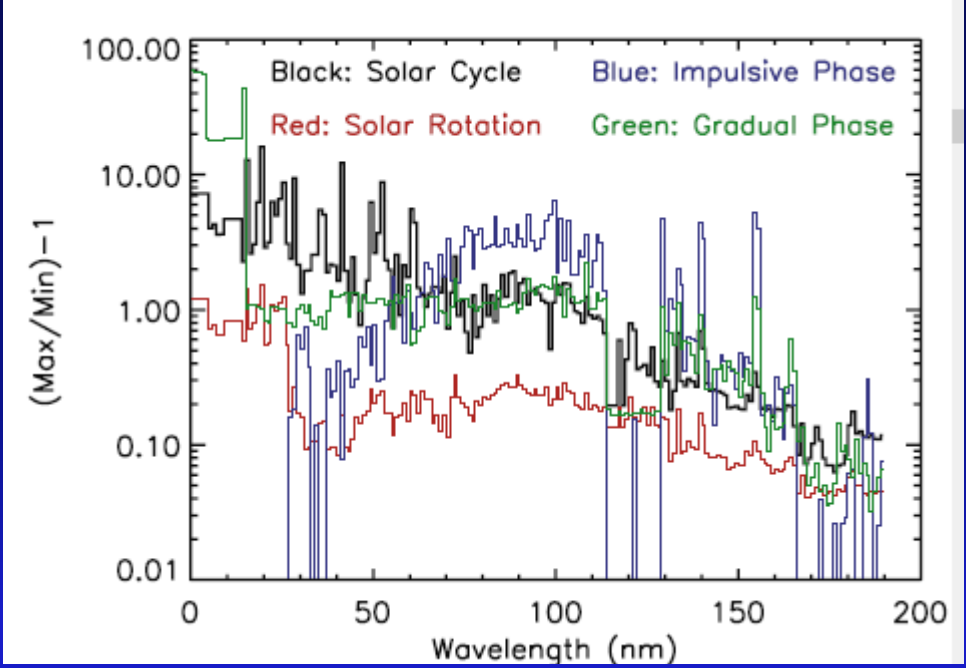
**EUV** (10-120 nm) and **soft X-ray** irradiance

create the ionosphere and heat the thermosphere.

EUV / X-ray irradiances have the **highest variability**

< 0.01% of total solar irradiance (TSI)

TSI varies by 0.1% while EUV varies by <2, X-rays by $<10^5$




Woods et al., 2006, JGR,
doi:10.1029/2005JA011507

# Operational Uses of EUV measurements

With an increase in solar EUV irradiance...

The thermosphere heats up and expands.

Satellite drag increases by up to a factor of 10.

Satellite operators must correct orbit calculations.

Ionospheric changes impact radio communications and GPS navigation.

EUV irradiance is key input to thermospheric/ ionospheric models

Flares emit at some EUV wavelengths before X-rays

>> faster flare detection

Image Credit: ESA

# EXIS Calibrations

- Nominal Weekly - 90 s comparison with secondary
  - EUVS - A, -B — Measure and trend darks and gain.
  - EUVS-A — Measure and trend primary filter changes.
  - EUVS - A, -B, -C — Measure and trend flatfield.
  - EUVS -C — Measure and trend primary channel offset.
- Quarterly cruciform
  - XRS, EUVS-A, -B, -C — Measure and trend FOV map
  - XRS, SPS — Measure and trend internal gain, dark
- Quarterly other
  - XRS, EUVS-A, -B — Measure radiation k factors
  - SPS — Check for radiation sensitivity
  - EUVS-C — Check radiation filtering, Mg II scaling.
  - XRS — Find cross-over thresholds for A1-A2 and B1-B2. Check impact on ratios.
  - XRS — Determine NOAA scaling, L1b uncertainties.
  - EUVS — L1b model baseline and uncertainties.
  - EUVS — Check for bootstrap relationships and degradations.
- Longterm comparisons
  - XRS — Compare flare locations from XRS and SUVI
  - XRS, EUVS — Compare measurements with other satellites