The Flare Irradiance Spectral Model - Version 2 (FISM2)

An improved model of the solar spectral irradiance at ultraviolet wavelengths

Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) Program 2021
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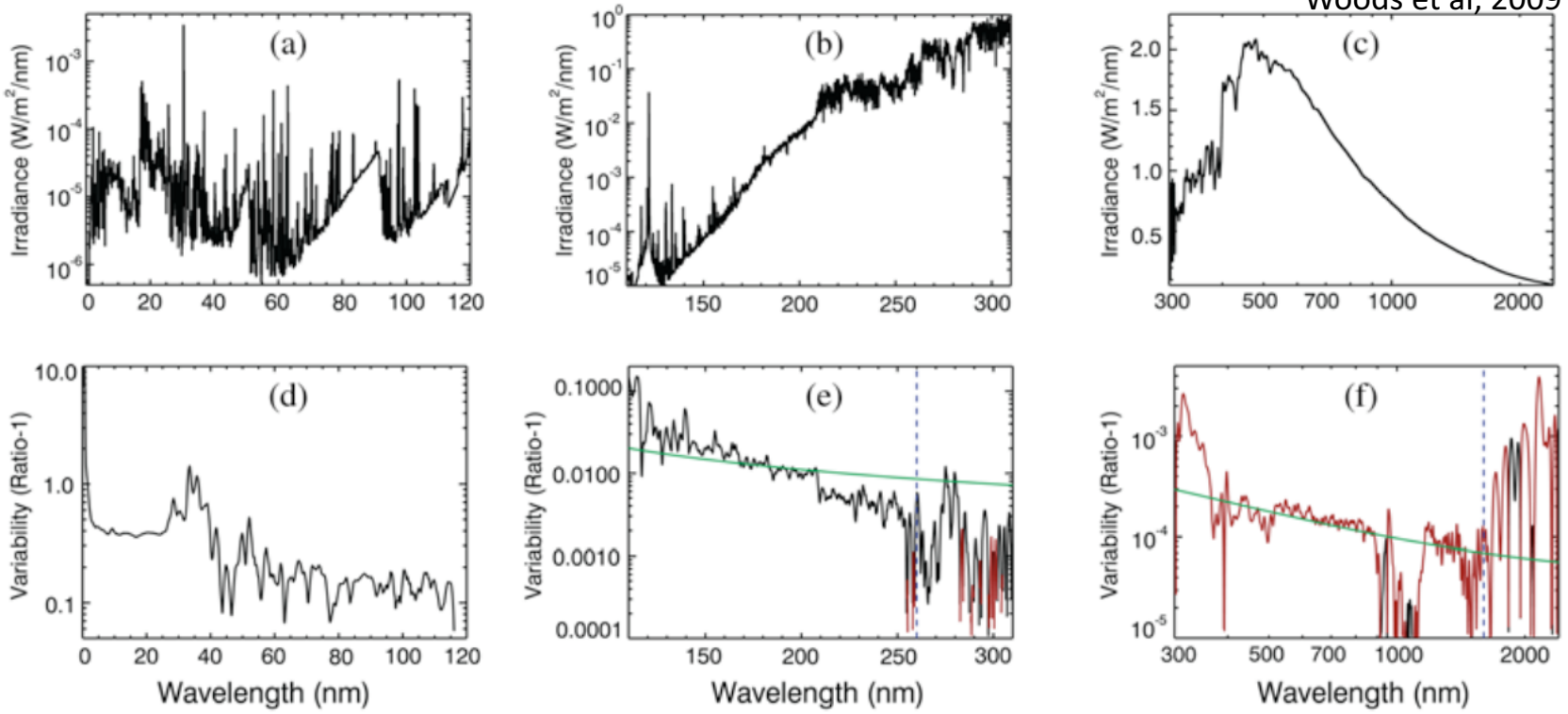
Introduction/Outline

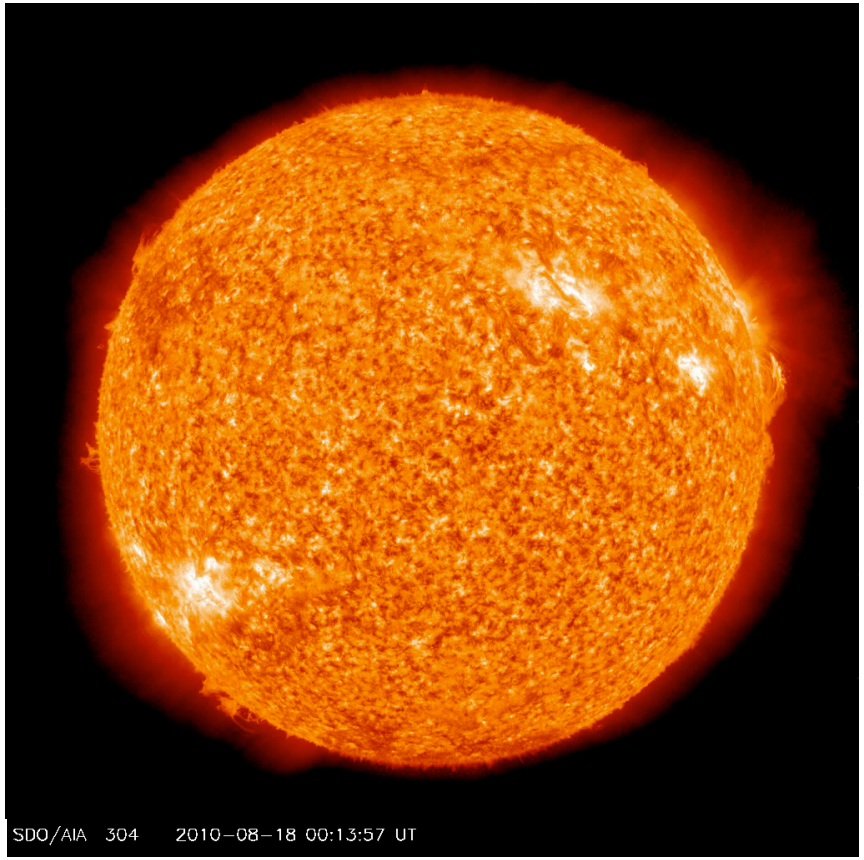
- Solar EUV spectral Irradiance: The solar irradiance varies on all time scales, and these variations are different for all wavelengths.
- Measurements: There have been many new measurements and models of the solar irradiance over the past decade to quantify this variability.
- Space Weather Effects: Solar UV irradiance drives the Ionosphere and Thermosphere
- **FISM2: Empirical model to fill the measurement gaps, both spectrally, temporally, and spatially.**
- LISIRD: Data access for solar irradiance data has been centralized.
- Conclusions/The Future: Future instruments will improve the measurement accuracy.

Solar Irradiance – “Sun as a Star”

- Solar Spectral Irradiance is the amount of light from the Sun incident on the Earth
  - Units of $W/m^2/nm$
- Total Solar Irradiance is then summed over all wavelengths

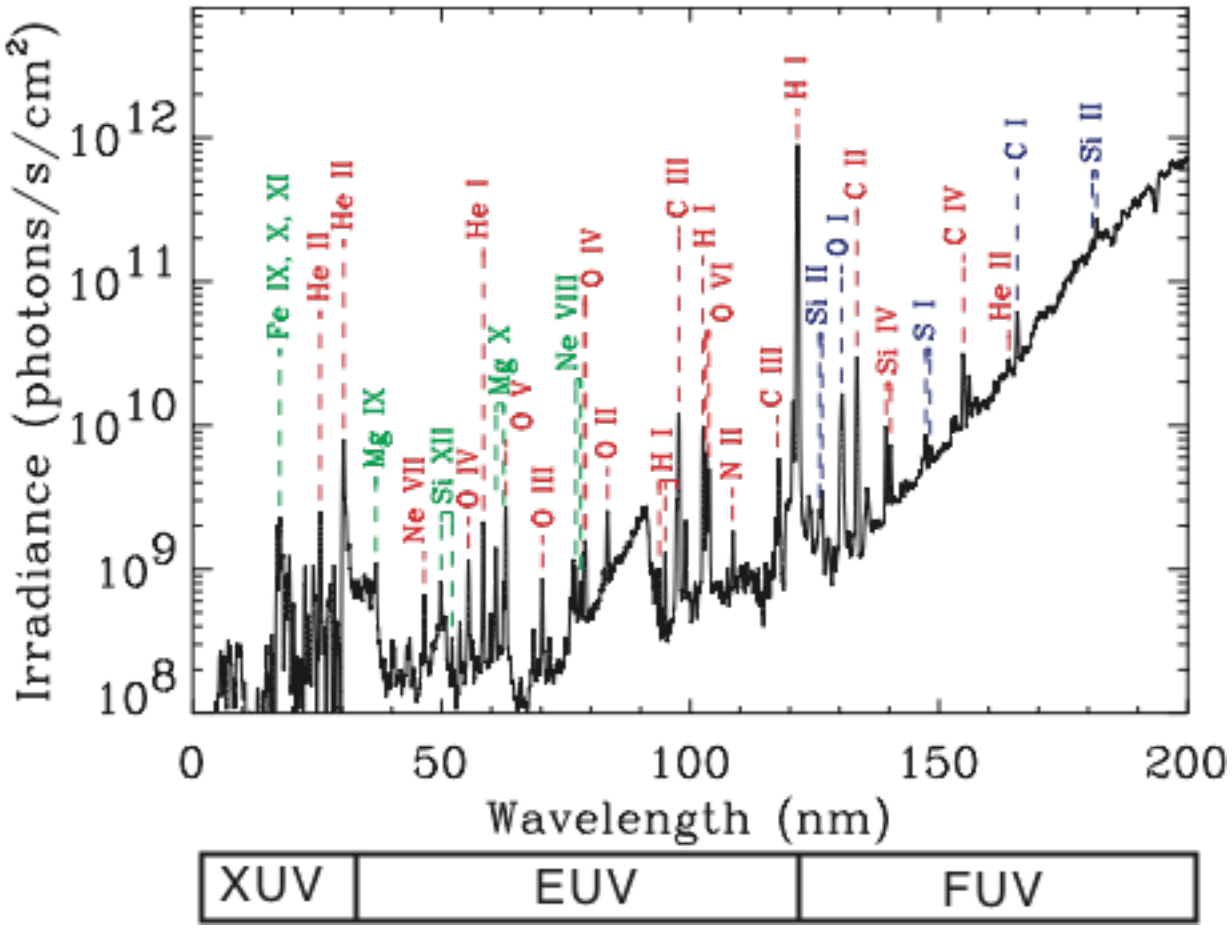
Woods et al, 2009





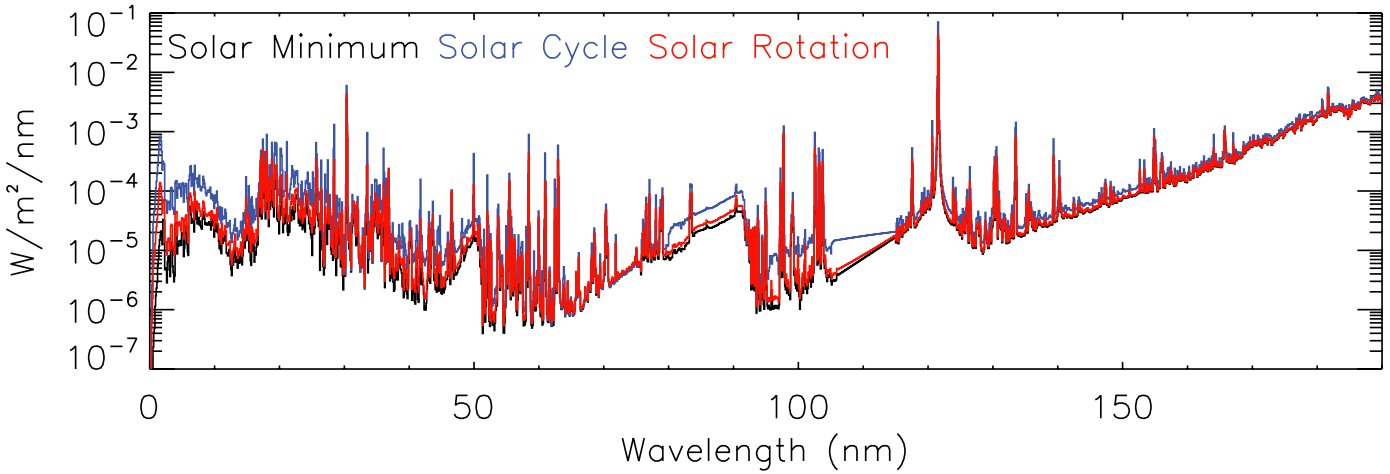
Ultraviolet Wavelengths

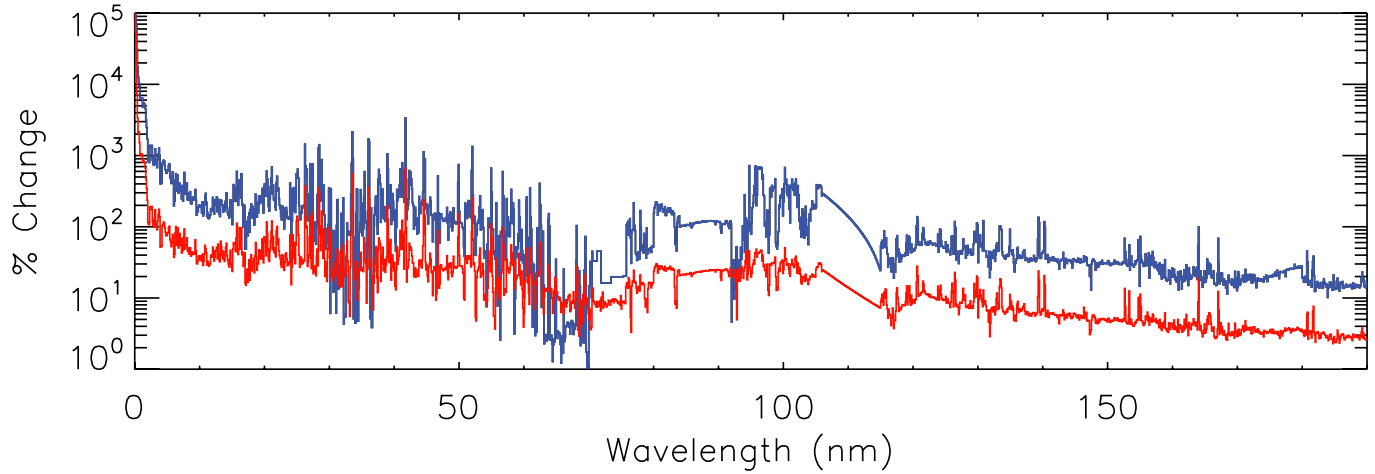
- Ultraviolet Wavelengths are key to Space Weather and Solar Flare variations
  - 0.1-10 nm, X-ray Ultraviolet or Soft X-ray, XUV
  - 10-120 nm, Extreme Ultraviolet, EUV
  - 121-200 nm, Far Ultraviolet, FUV
- UV contains emissions from many continua
  - Free-Free, Free-Bound, and Blackbody
- UV also contains bound emission lines
  - Formation temperatures spanning entire solar atmosphere from chromosphere, transition region, corona and flare lines
- Many ultraviolet emissions are optically thick.



Solar Ultraviolet Variability

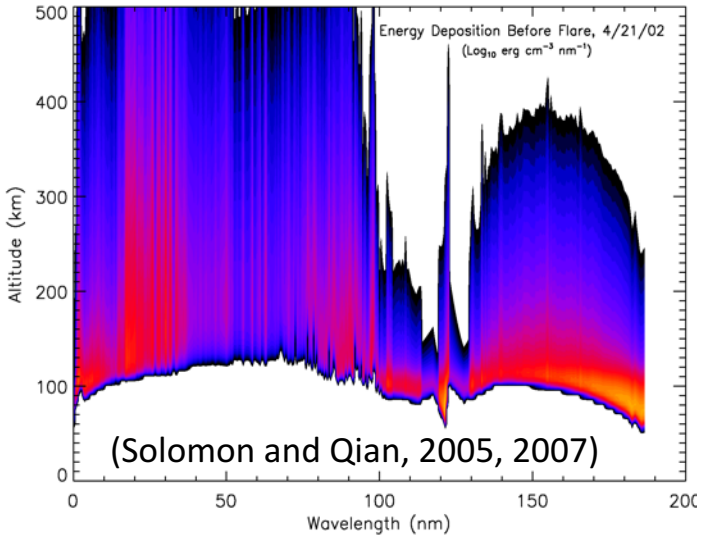
- Solar irradiance changes over timescales:
  - Seconds to hours due to solar flares and CMEs
  - Days to weeks due to active regions and solar rotation
  - Years and decades due to solar cycle
- Solar irradiance variation magnitude is wavelength and time scale dependent
  - I/T response is therefore altitude and time dependent

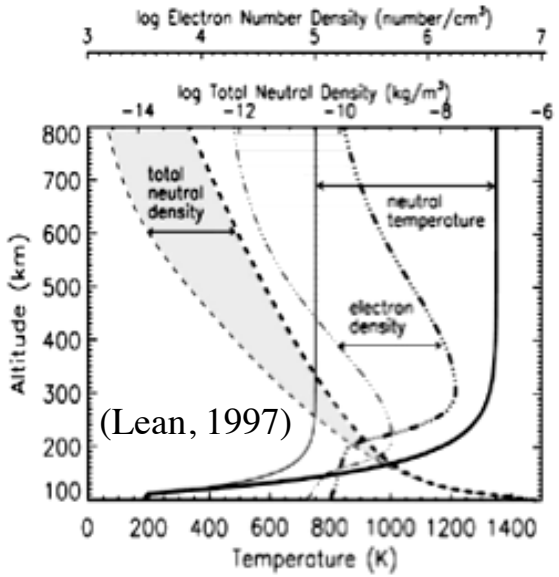


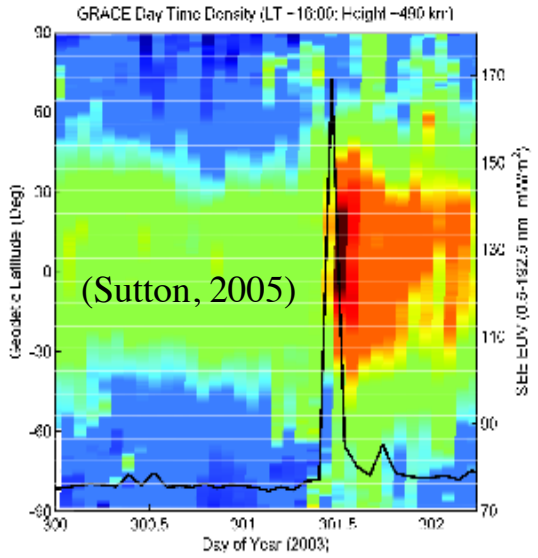


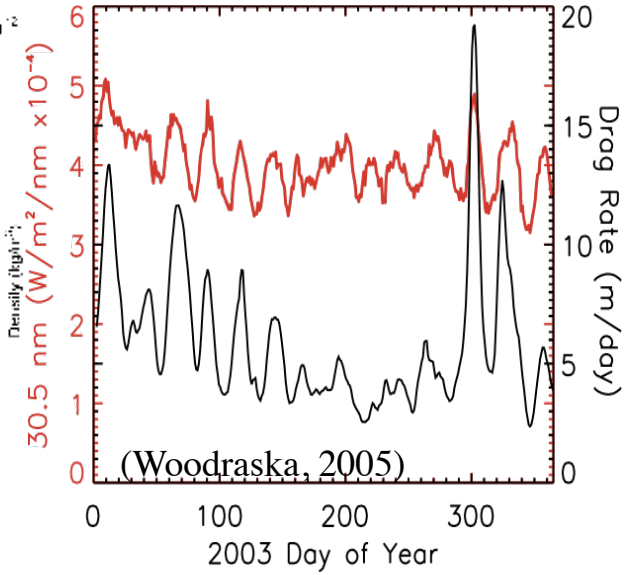
Ionosphere/Thermosphere Effects

- Solar ultraviolet irradiance is absorbed in the Earth's atmosphere, heating the Thermosphere and creating the Ionosphere initiating complex photochemistry.
- Immediate response and effects are significant in the lower latitudes.
- I/T changes affect technological systems that we are increasingly dependent on.
- Also drives changes in planetary atmospheres and lunar dust.



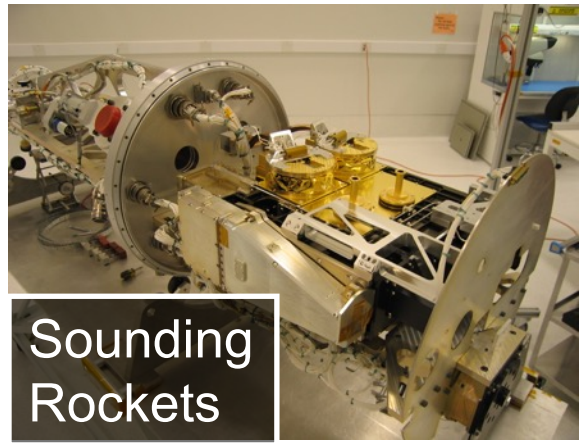






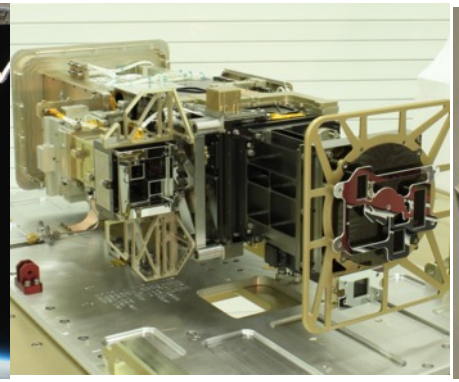
Measuring Solar Irradiance

- Solar spectral irradiance measurements are being made and continue to fill gaps
  - Temporally: Gaps between instruments/missions, higher time cadence
  - Spectrally: Missing wavelength ranges, higher spectral resolution
  - Full Sun: Throughout the Heliosphere (planetary, prediction)
- Future missions are looking to utilize CubeSat Platforms
  - CSIM (Launched Dec 2018), CSOL, CTIM, SunCET (proposal)
- Sounding Rockets have been critical in the development and calibration

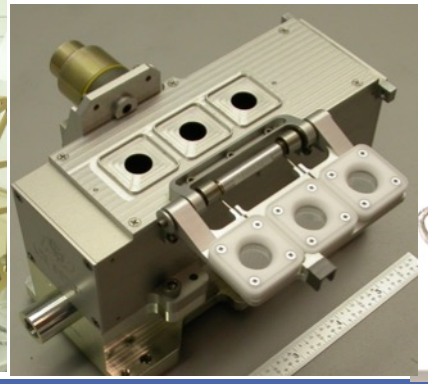


MinXSS

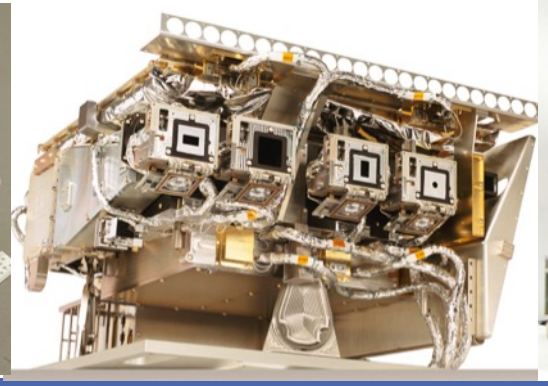
GOES R+ EXIS



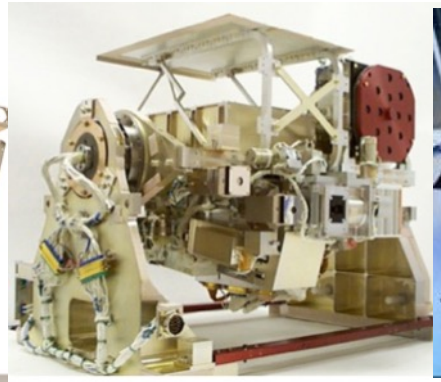
MAVEN EUV



SDO EVE



TIMED SEE



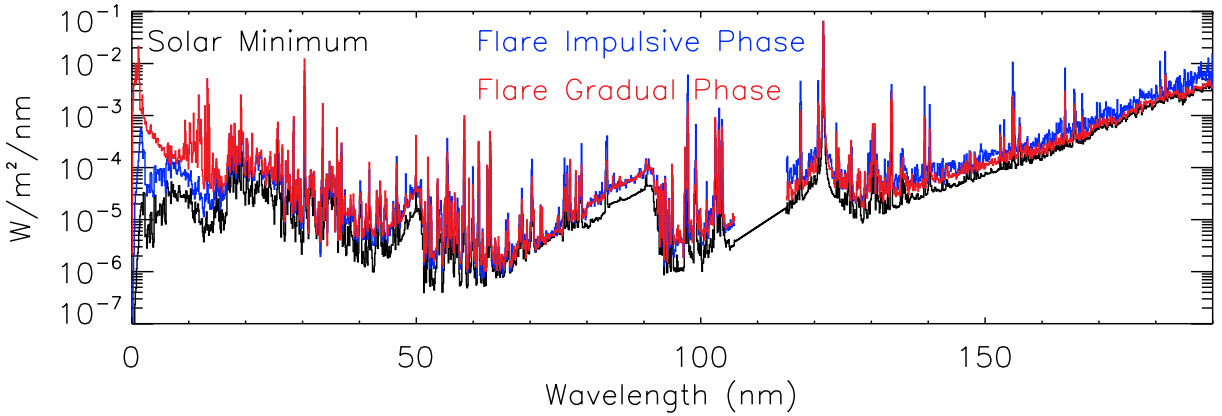
SORCE

FISM Version 2 (FISM2) – Now Available

- Many new measurements and studies have improved our knowledge of the Solar ultraviolet irradiance in the past 15 years

Chamberlin et al., *Space Weather*, 2020

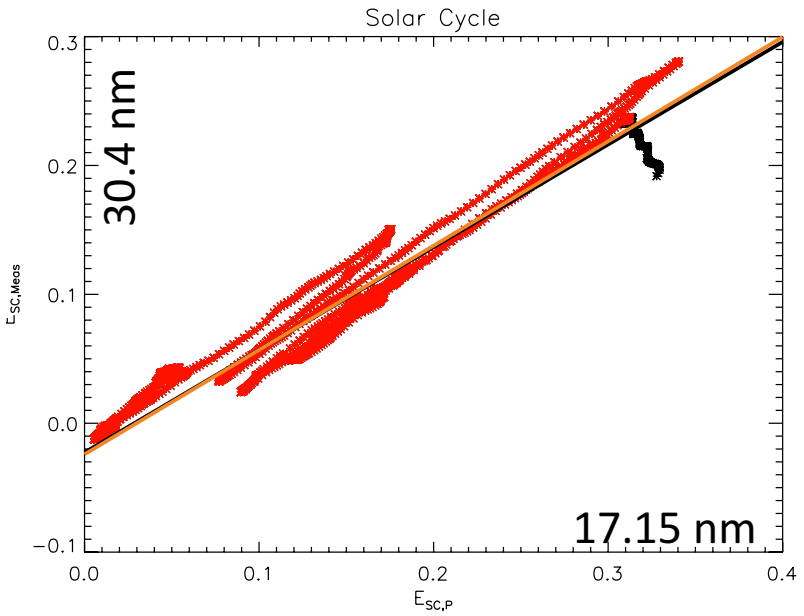
- Biggest improvement is new measurements and proxies (*: Not in initial FISM2 release)
  - MinXSS* (0-2.5 nm)
  - SORCE XPS (L4: 0-40 nm)
  - SORCE SOLSTICE (119-300+nm)
  - SDO EVE (6-105 nm, and ESP)
  - GOES EXIS* (XRS and EUVS)
  - MAVEN EUVM (0-7 nm, 17.1 nm, 121.6 nm) – FISM-M (Thiemann et al., 2018)

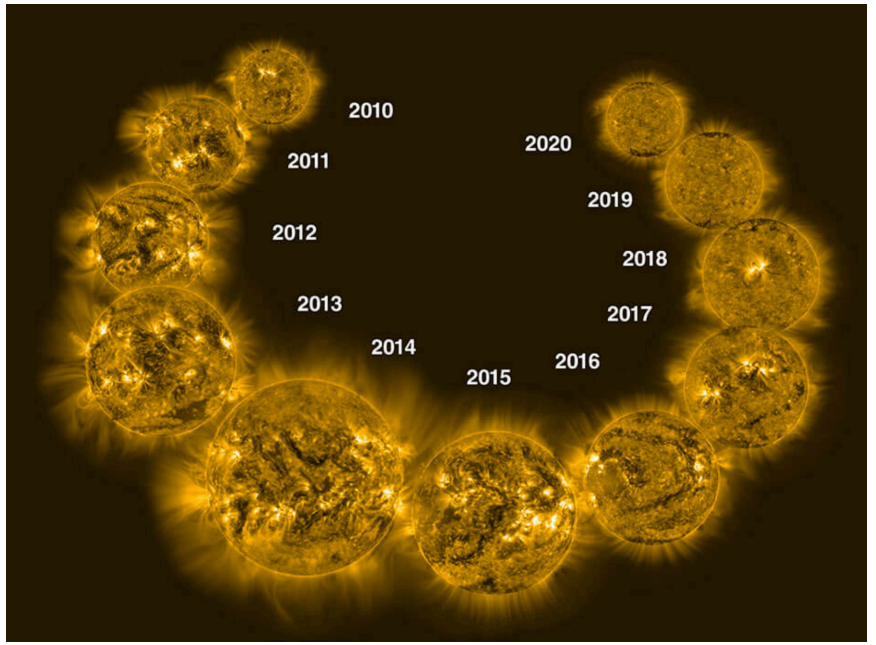


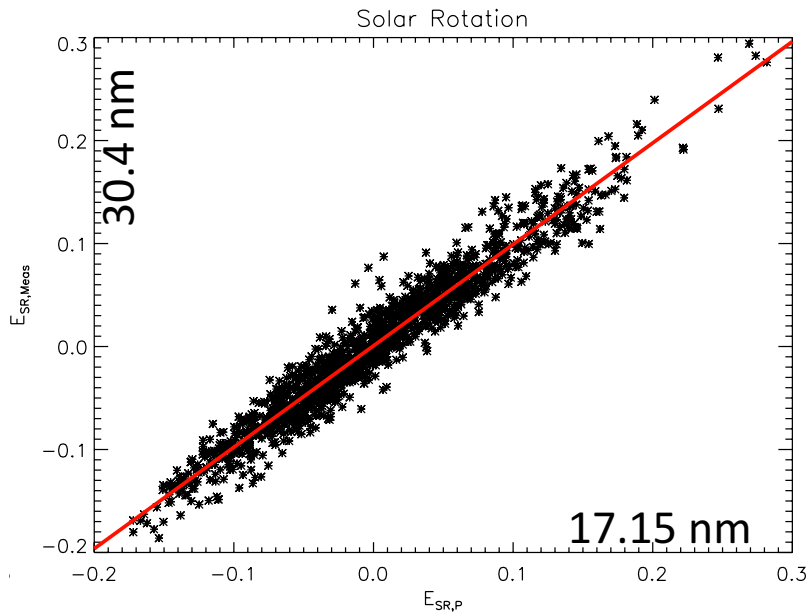
- All measurements are at 0.1. nm or better and much better temporal cadence than TIMED SEE
  - FISM2 has been improved to 0.1 nm bins
  - SDO EVE has observed well over 1000 flares and SORCE SOLSTICE ”hundreds”

FISM2 Empirical Model – SC and SR

- FISM2 relates measurements, when available, to the co-temporal proxies.
- Whenever the proxy is available, the estimated measurement value can then be modeled.
- Full details can be found in: *Chamberlin et al., Space Weather, 2020*

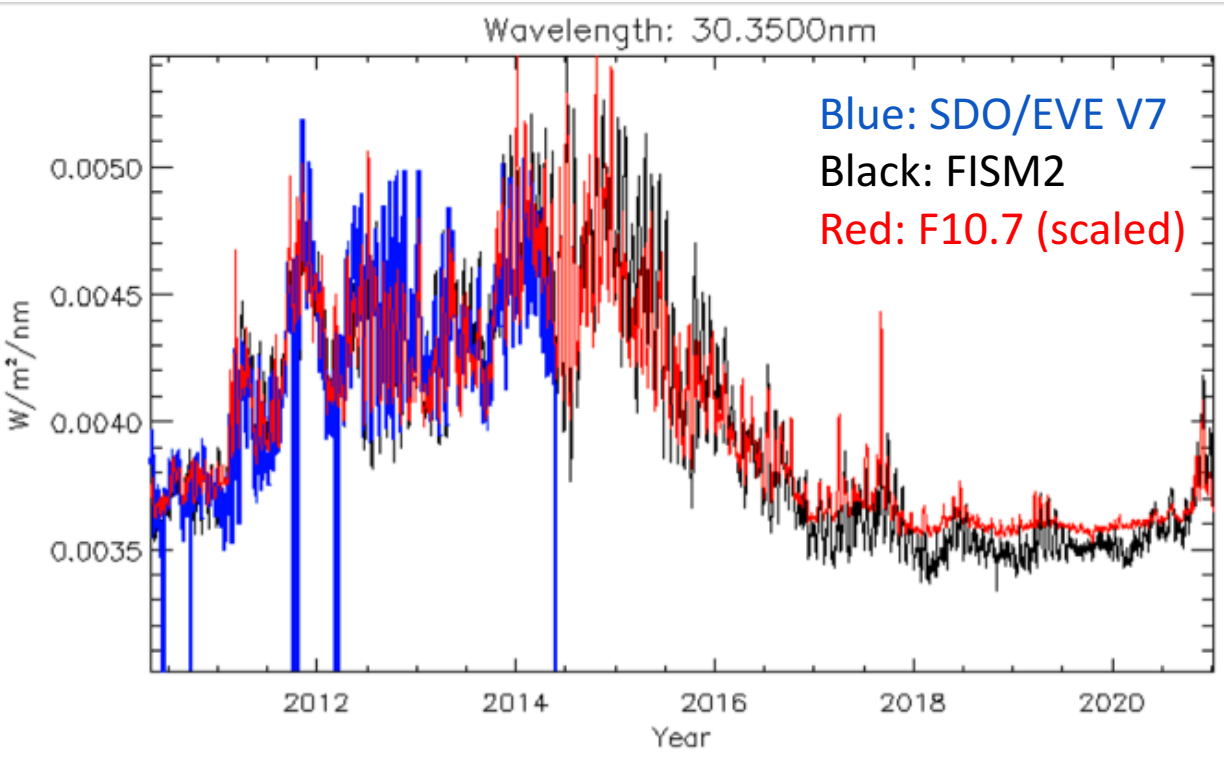


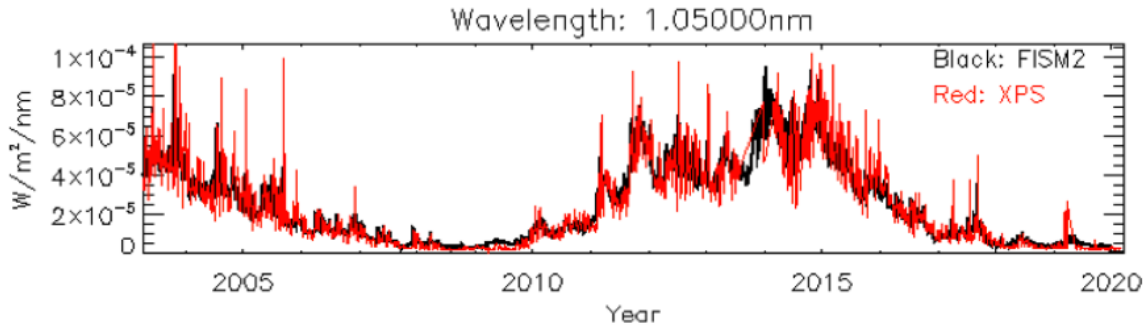


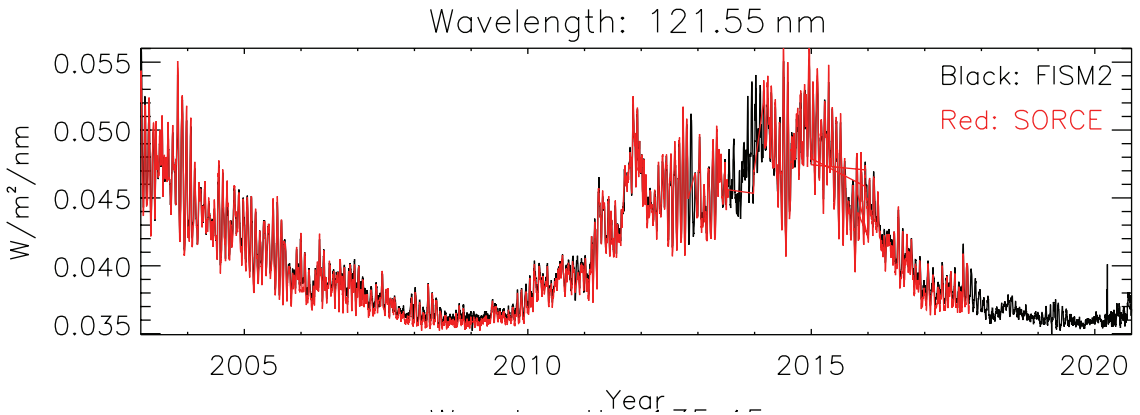


FISM2 vs Measurement Comparison

- EVE and SORCE lack full temporal coverage
- F10.7 does not fully represent the solar cycle variability, especially the solar minimum.
- Using multiple, representative proxies more accurately models the irradiance variability

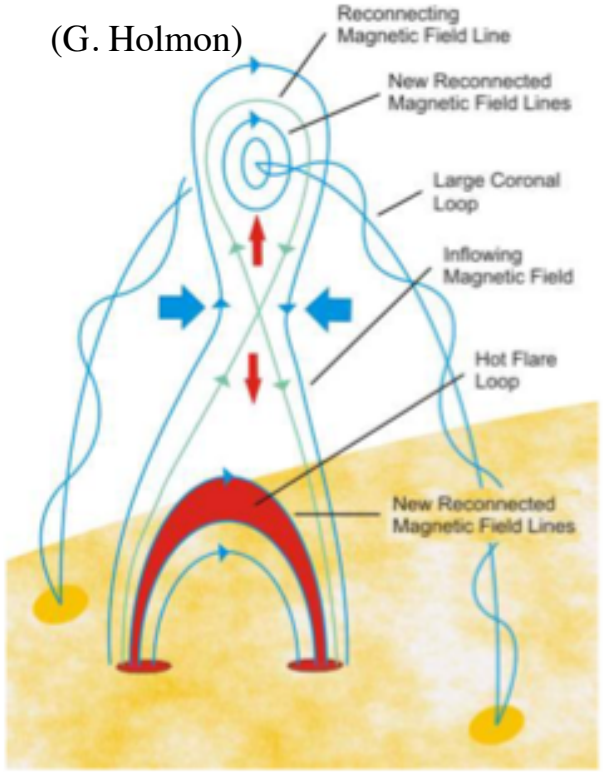


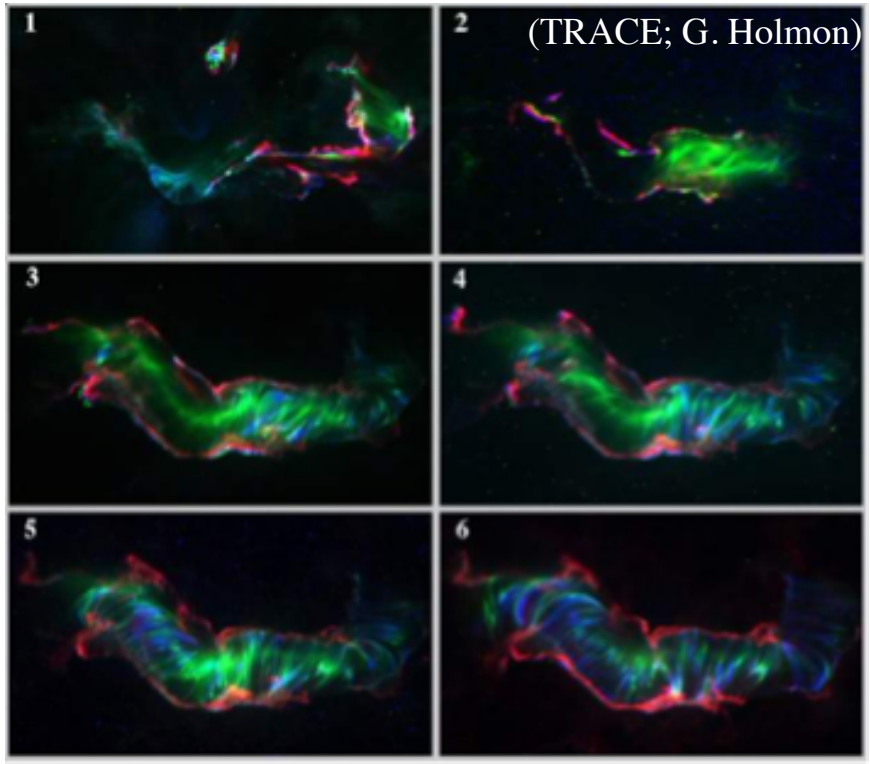


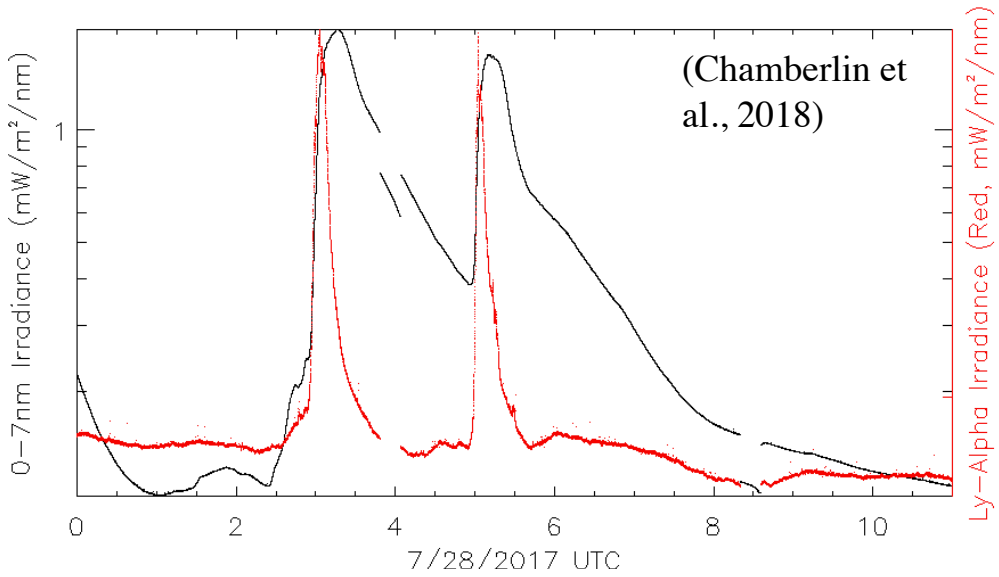


Solar Flares and UV Irradiance

- Measurements of UV irradiance can tell us about where and when energy is being deposited.
- Compute the total radiated energy from flares for Solar Physics and Space Weather studies







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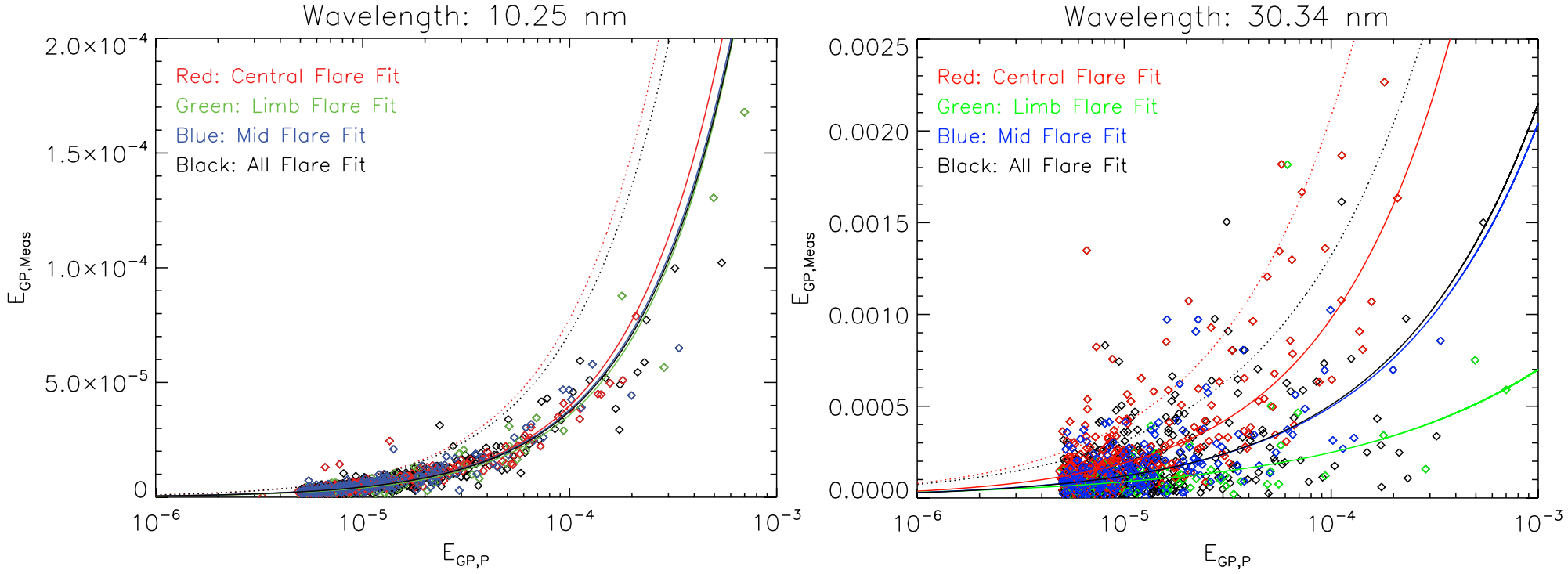
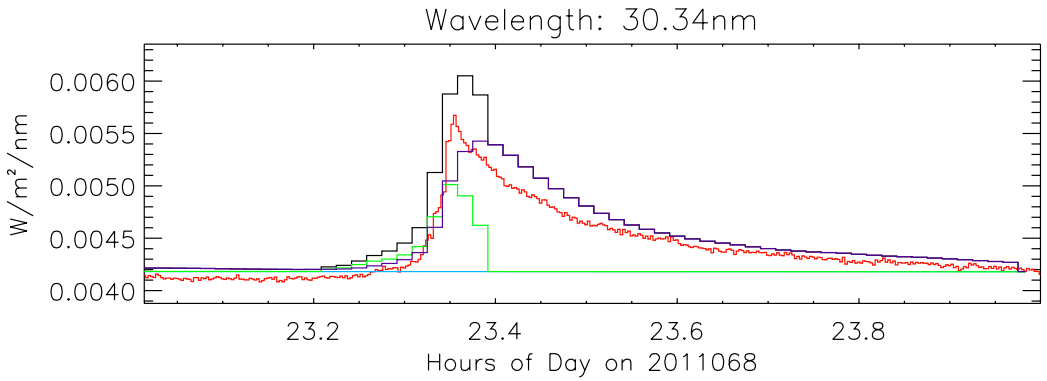
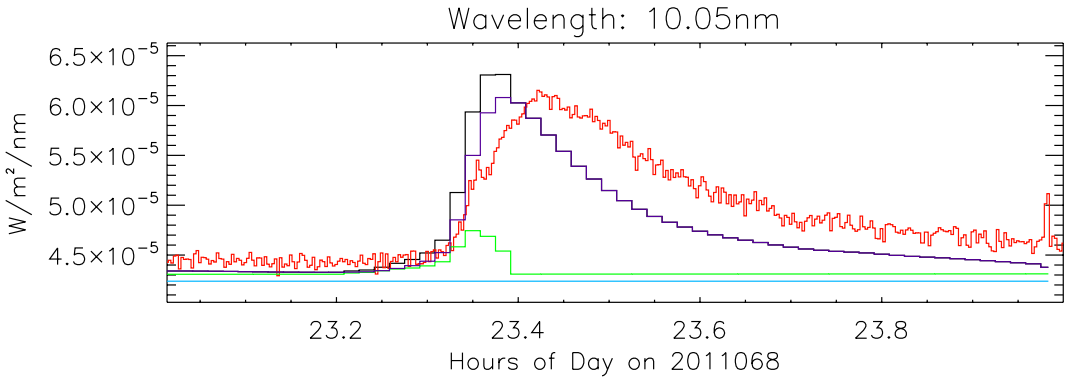


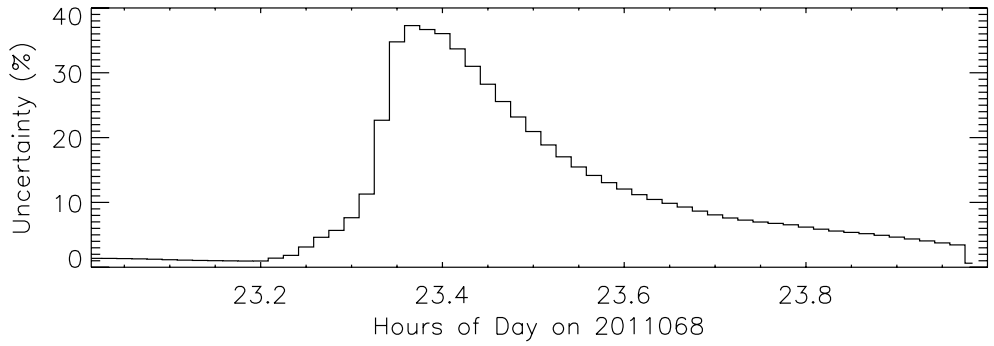
FISM2 vs Measurement Comparison

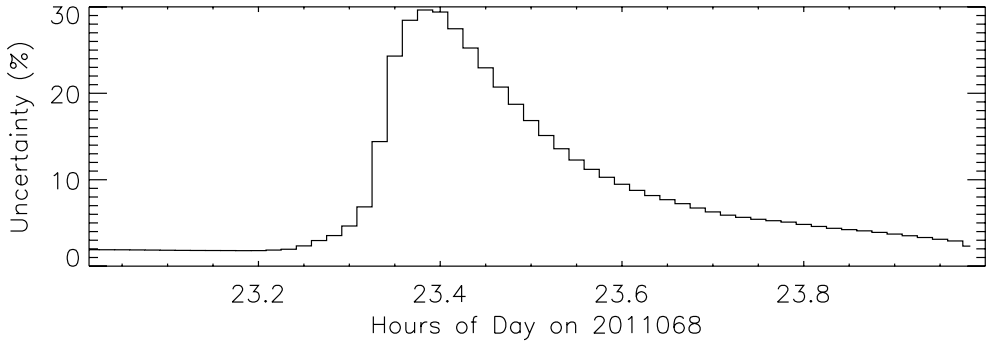
- FISM2 accurately fills in measurement gaps at 60 second cadence
- FISM2 estimates the irradiance changes due to both the impulsive and gradual phases of the solar flare.





Red: FISM2
Purple: FISM2 GP
Green: FISM2 IP
Blue: FISM2 Daily
Black: SDO/EVE





Solar Ultraviolet Variability - Flares

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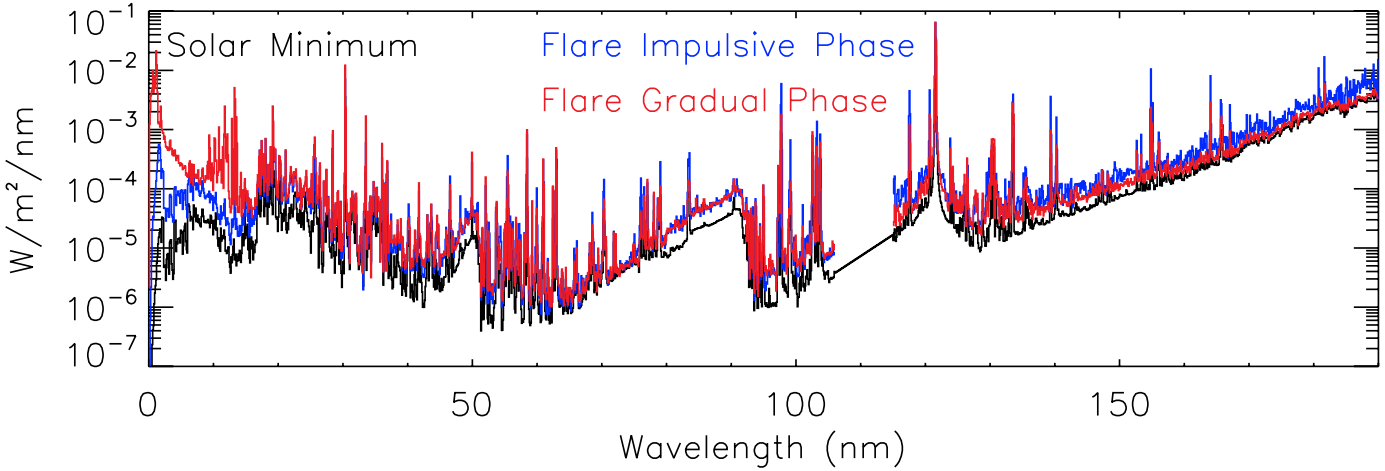
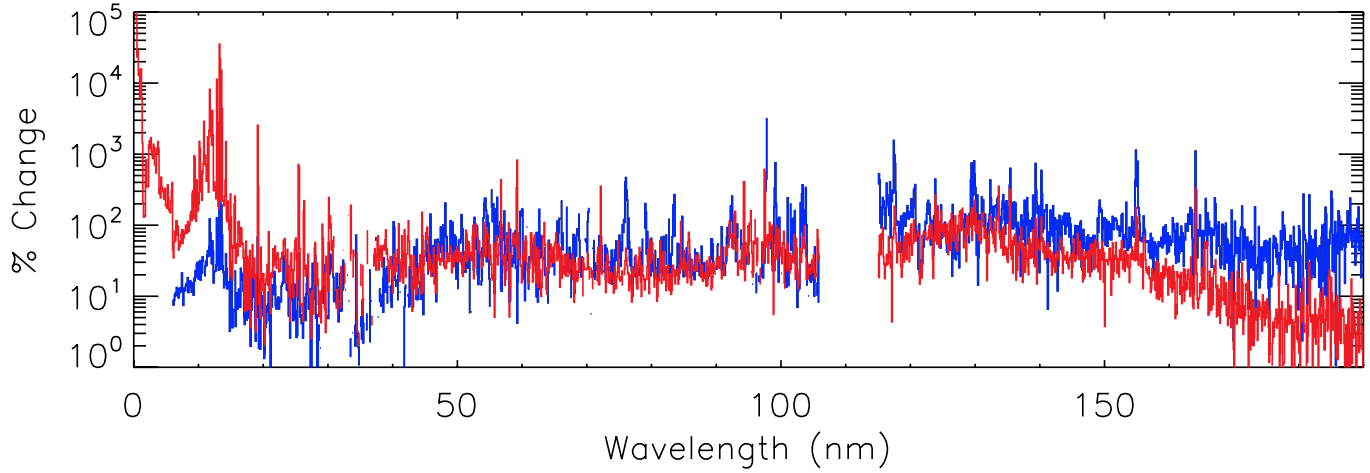
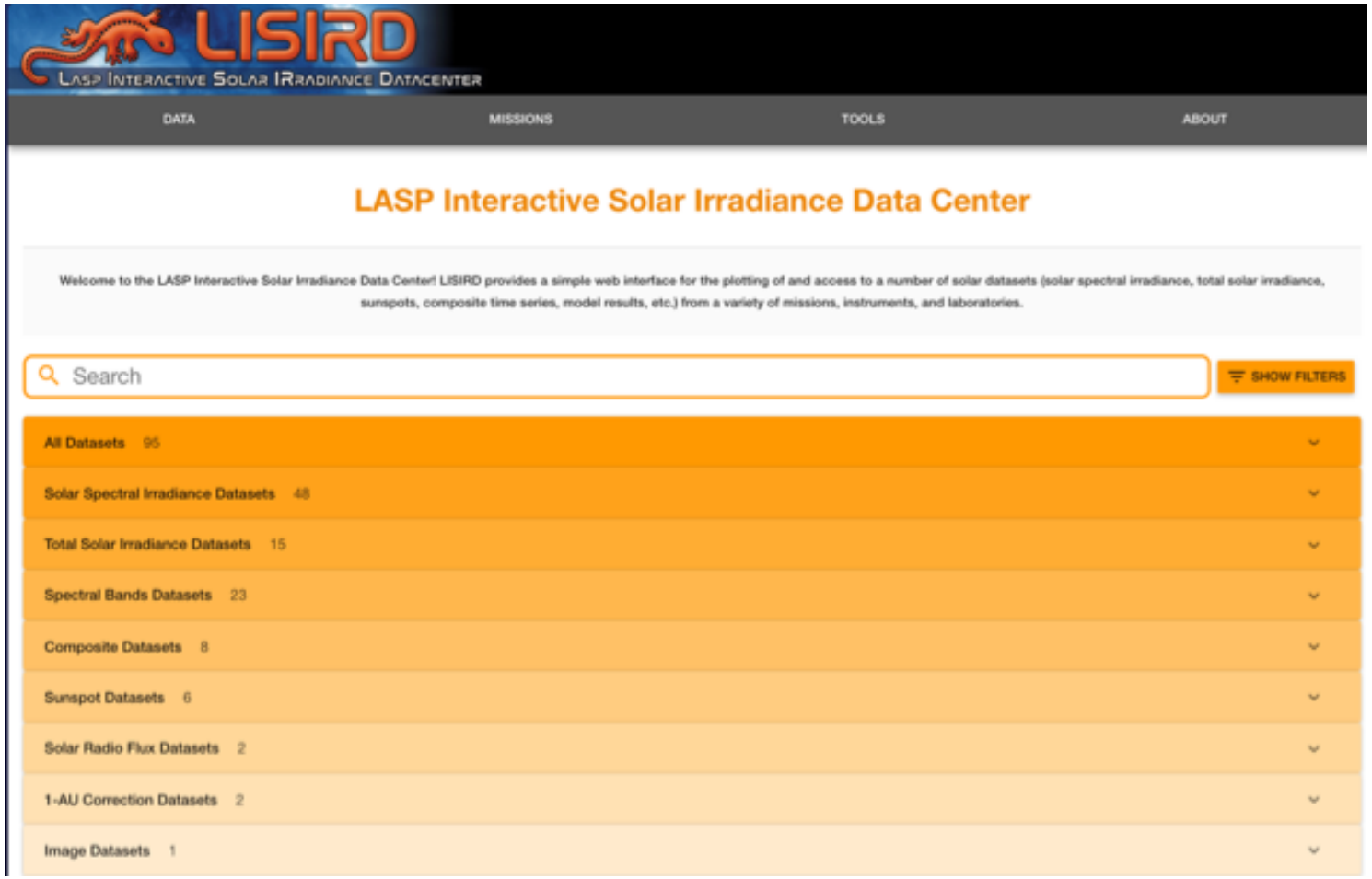
- Solar irradiance variation magnitude is wavelength and time scale dependent





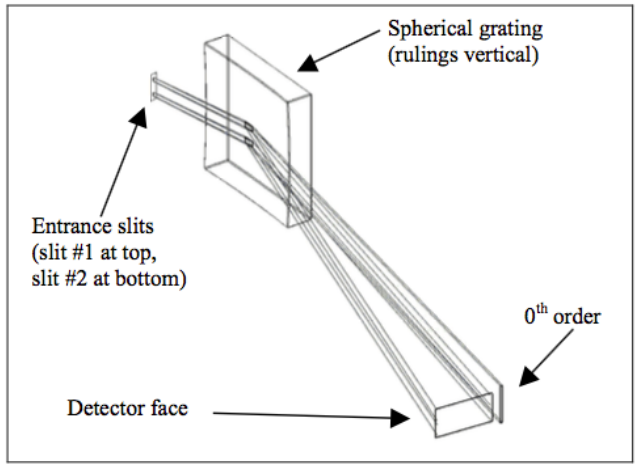
Solar Irradiance one-stop access

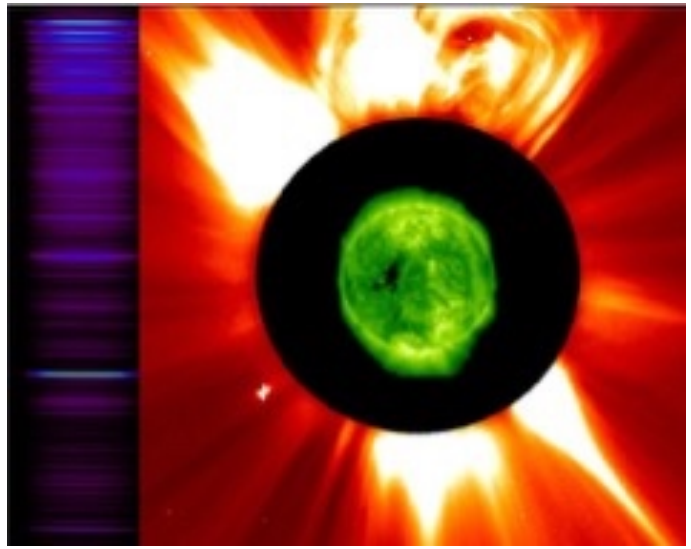
LASP Interactive Solar Irradiance Data Center (LISIRD): https://lasp.colorado.edu/lisird/



Conclusions

- There is a large dataset of solar irradiance measurements, both temporal and spectral
- Where gaps exist, empirical models are also improving to estimate energy inputs into Space Weather studies of the Ionosphere and Thermosphere, such as FISM2.
  - Use multiple, representative proxies : **F10.7 is insufficient**
  - Also semi-empirical models that utilize CHIANTI (e.g. Woods et al, 2005)
- New and future instruments will continue and improve upon these measurements
  - New: GOES-16+ EXIS, Chandrayaan-2 XSM
  - Planned: INSPIRESAT/DAXSS
  - Proposed: SunCET, CUBIXSS
  - Replace the lost SDO/EVE/MEGS-A channel
  - Desire multi-vantage point observations
  - Take advantage of small instruments
    - CubeSats and “instruments of opportunity”





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