Automating The Characterization Of Solar Flares

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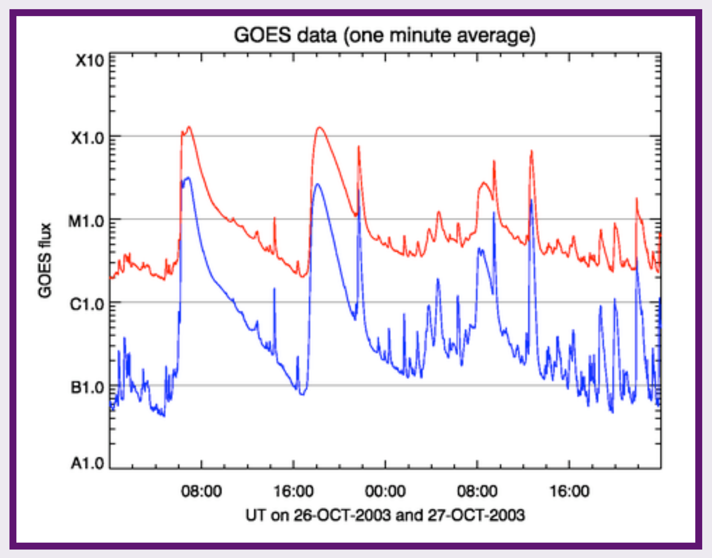
Abstract

The future Geostationary Operational Environmental Satellite (GOES) EUV and X-Ray Irradiance Sensors (EXIS) will continue the more than 30-year record of solar X-Ray measurements. Unlike previous GOES X-Ray Sensors (XRS) instruments the EXIS-XRS will use silicon detectors and by using a quadrant photodiode will be able to locate solar flares on the disk of the Sun. A similar photodiode on Solar Dynamics Observatory's (SDO) Extreme ultraviolet Experiment (EVE) EUV SpectroPhotometer (ESP) instrument was launched in February of 2010, monitoring the Sun in the soft X-Ray 0.1 – 7 nm (0-order) band. I have created a database of recent flares, as recorded by the current GOES satellites and found the corresponding flare in ESP's zeroth order channel. ESP's significantly higher time cadence data provide a more detailed view of the evolution of a solar flare. This allowed me to examine the relationship between the magnitude and rise time of a flare. Using this correlation I developed a flare finding algorithm that automates the flare detection process, providing information on both flare location and magnitude.

Introduction

- Solar flares are sudden release of energy from the Sun in nearly all wavelengths.
  - – Earth-directed solar flares pose a threat to astronauts and disrupt both ground and satellite based communications.
  - – Solar laboratory closest look at accelerated particles and plasmas.
- GOES has been monitoring both Earth and Space weather for > 30 yrs.
- GOES XRS monitors solar X-Ray irradiance to detect solar flares and characterize their magnitude.



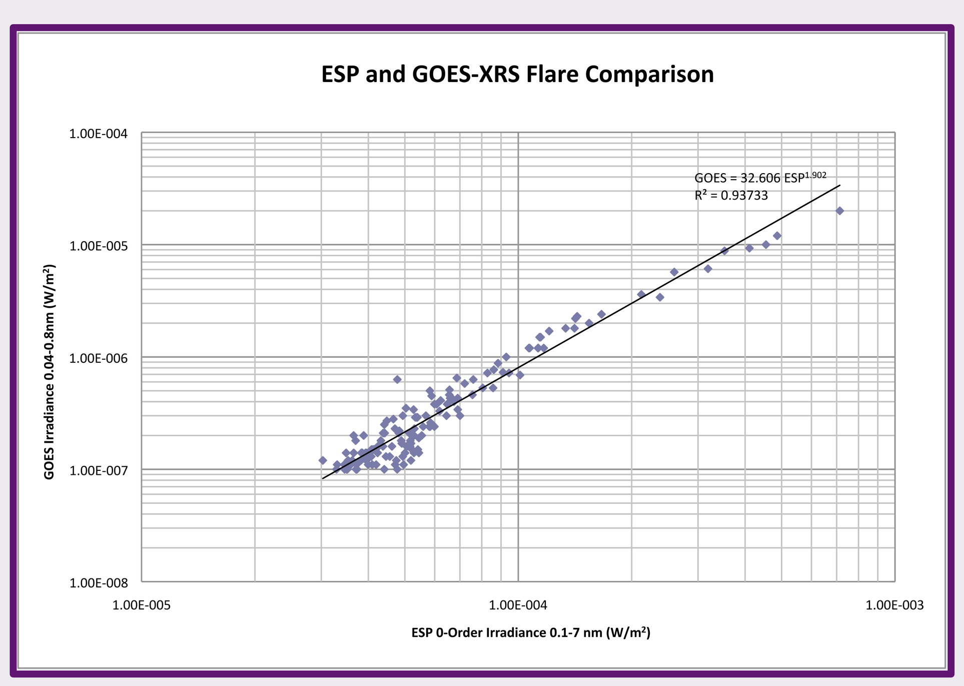
The GOES scale, is logarithmic with the smallest flares classified as A Class flares, going up to ten thousand times in irradiance to X – class flares.

GOES–R EXIS

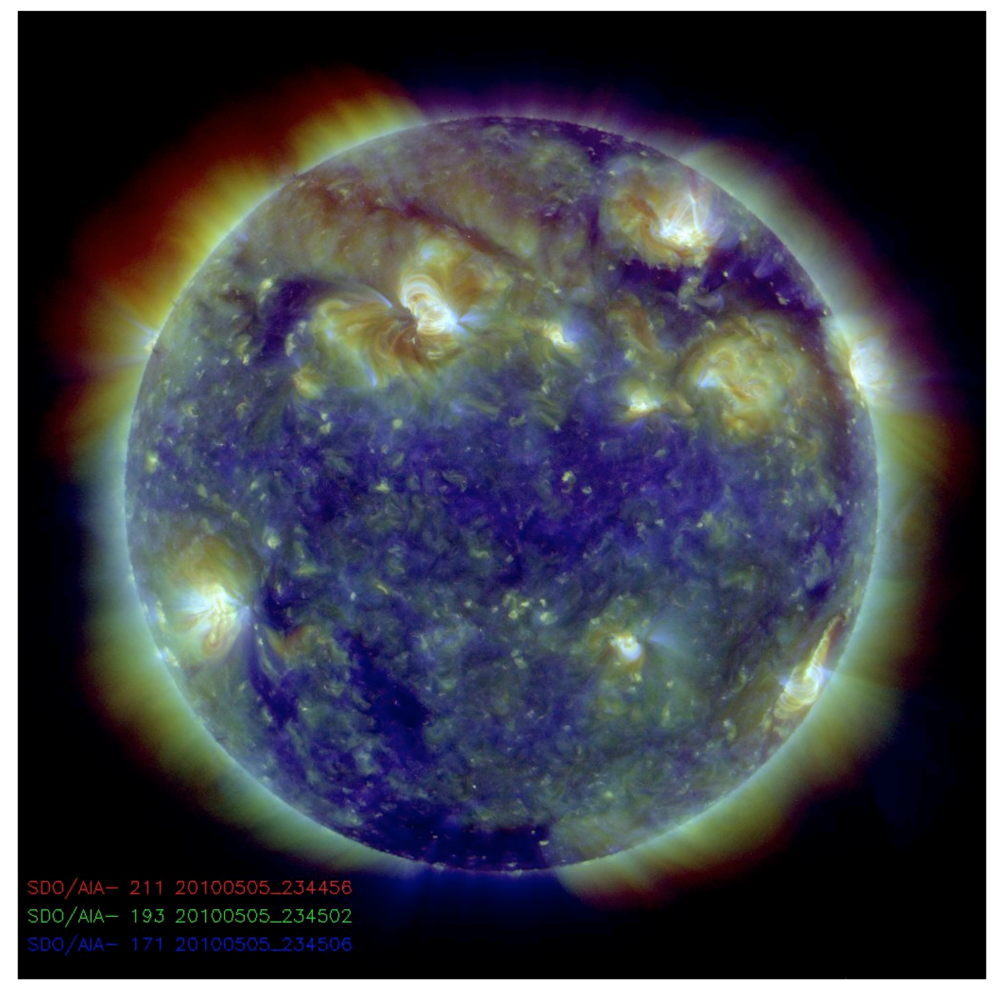
- GOES – R, will not only detect solar flares – but also locate them on the solar disk using quadrant photodiode.
- The GOES – R will be launched in 2015, however there is currently a similar quadrant photodiode on SDO-EVE-ESP instrument.

SDO's EUV SpectroPhotometer

- The quadrant photodiode on ESP measures solar irradiance from 0.1 to 7 nm, at a cadence of a quarter second.
  - – Unprecedented time cadence for solar observations with potential for early flare detection and location.
- The ESP and GOES irradiances correspond to a power fit, as seen below.
- This fit matches a previous fit of SORCE XPS, also 0.1 – 7 nm, to GOES irradiance.



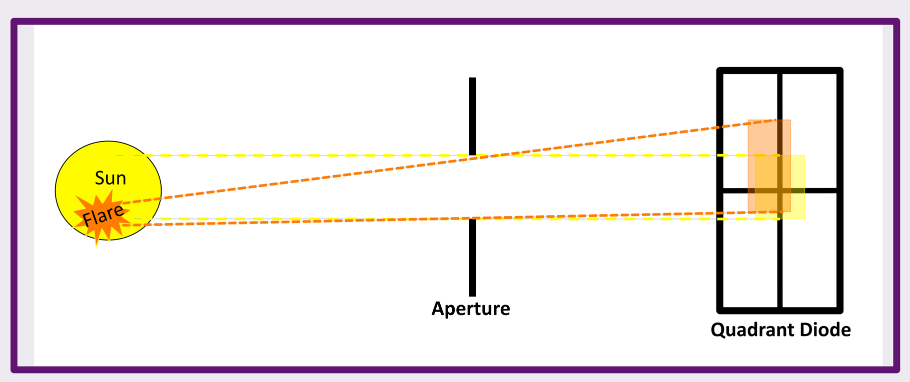
Calibrate the two measurements using flares already identified and classified through GOES were located and recorded by hand in the ESP irradiance data, as well as other relevant flare characteristics



SDO's Atmospheric Imaging Assembly (AIA) image of the Sun on June 5, 2010

Quadrant Detector

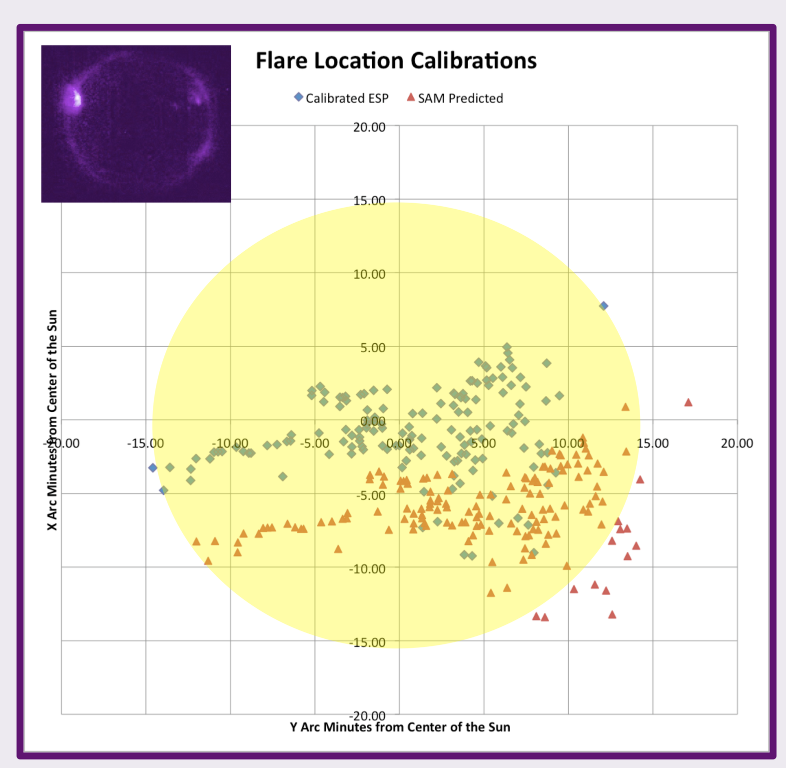
- Measure the solar irradiance on four separate channels in the quadrants of the detector.
  - – Sum of channels gives Irradiance
  - – Channel differences give position
- Can provide near real-time flare location and magnitude for any given event.



This simplified diagram explains how a flare can be detected using a Quadrant photodiode. Detection is based on the angle of the light.

Image Calibration

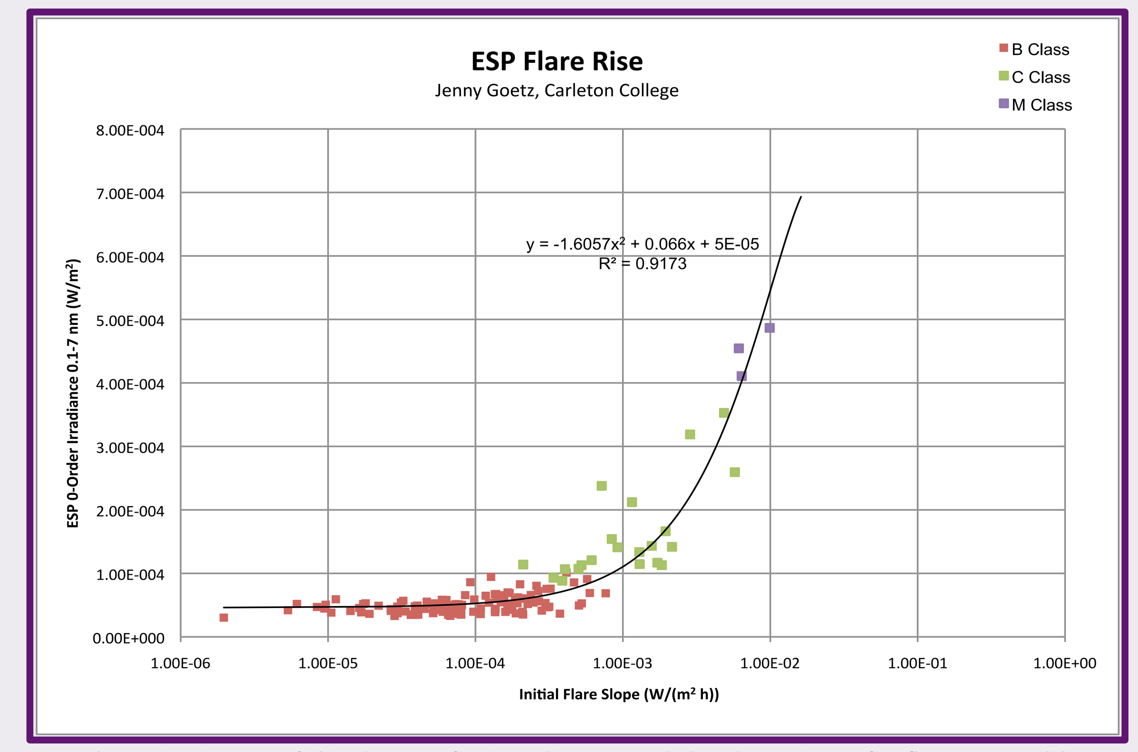
- The relative x-y coordinates returned by the program need to be calibrated to fit the disk of the Sun.
- Images were calibrated using image flare location from SAM, a pin hole camera on EVE.
- All flares, even those too small to be seen by SAM, could then be located on the solar disk.
- SDO preformed calibrations, changing the angle pointed towards the sun.
  - – ESP calibrations were then determined so flares could be fully located.
- The ESP calibrated and the SAM predicted flare points follow a very similar trend, however there is a clear off set between the two.



ESP flare location is offset from the SAM calibration, however the two are very similar in location. A SAM flare image is shown above.

How to Detect a Flare

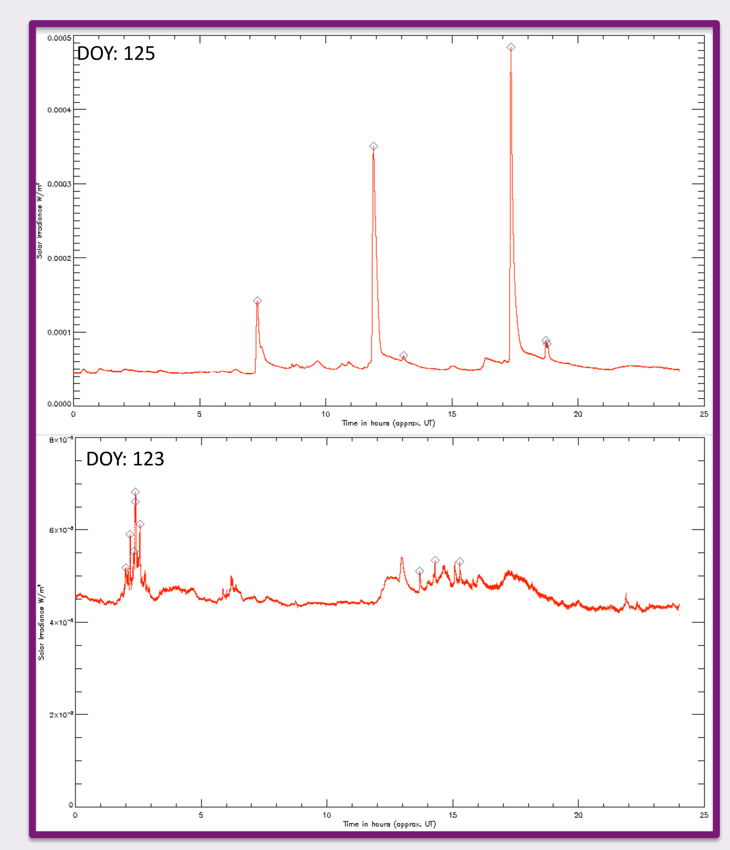
- Flares are difficult if not impossible to predict.
- However, once they start the rise of the irradiance allows the irradiance of flare to be predicted, providing a basis for automated flare detection.



Flare rise is a useful indicator for irradiance and the detection of a flare. Notably there have not been any flares larger than M2 observed by ESP.

Automated Flare Finder

- Solar flare detection is currently done with a human interface, however this leads to a lack of standardization and very slow data collection.
- The FlareFinder algorithm uses a threshold slope, on a linear fit, to determine whether a flare has begun.
  - – Locates the peak using the time derivative.
  - – Can record any measurable flare statistics.
- FlareFinder is particularly effective on higher magnitude fast rising flares.
- All flares above C level recorded by GOES since the launch of SDO were found.



Two days of solar irradiance measured by ESP found by FlareFinder. Flares detected have diamonds at their peaks.

For day 125, the program identified nearly all of the flares throughout the day. However for day 123 the program identifies many small sharp flares without catching larger flares.

Conclusions & Future Work

- I have created a flare detection algorithm that is accurate for most C and up class flares.
- ESP provides high time cadence flare location and …
- Quadrant diode flare location method works
  - – further calibration needed.
  - – Expansion and improvements, including slow rising flares, B class events, HEK and real time applications.

References

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