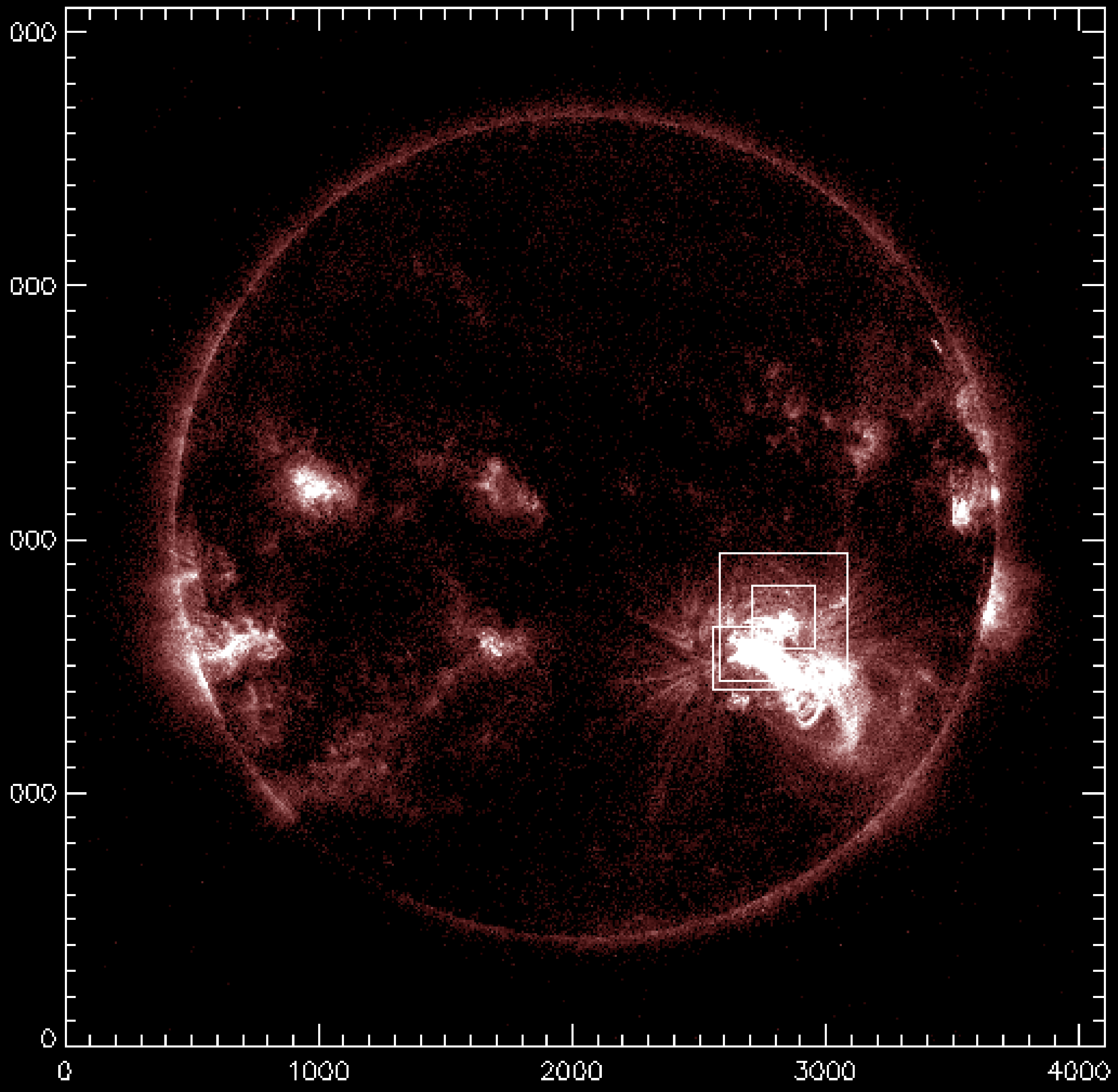
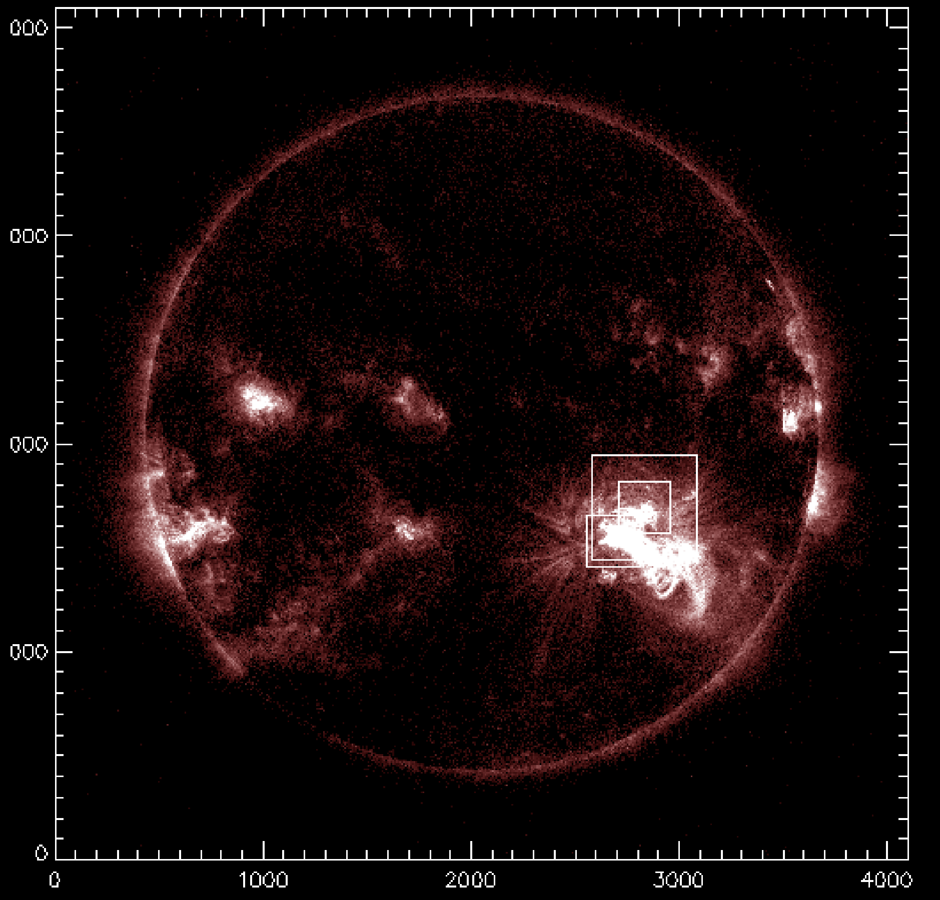


Using UV Event Localization to Constrain Magnetic Reconnection Geometry in Solar Flares

Research by Nathaniel Balmain

Goals

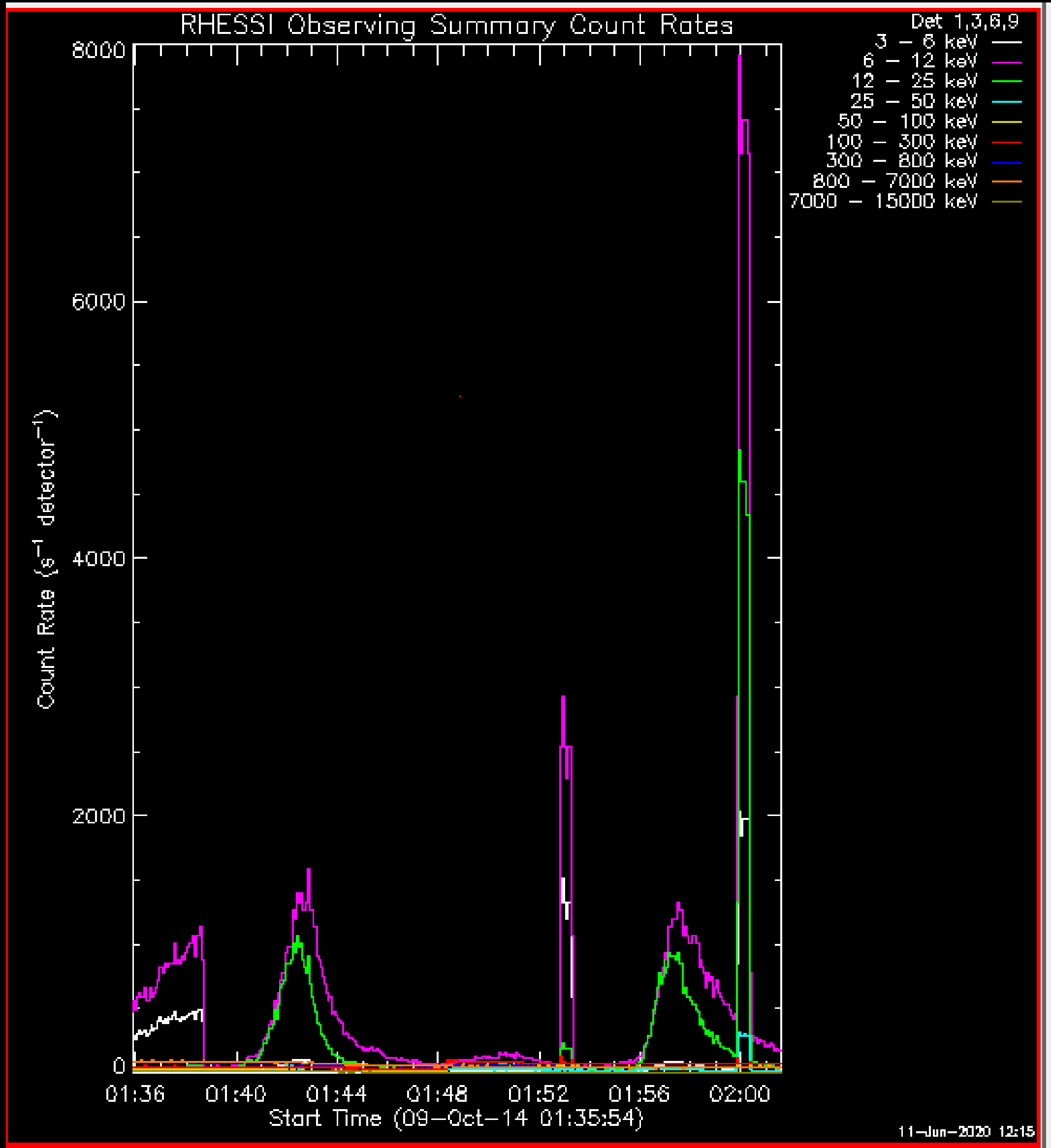


- Introduce our research and findings For a solar event
  - Date October 09, 2014
  - Time 01:35:52 – 02:00:54
- Explain how the created code extracts data from solar flares
- summarize results
- Importance of our source selection and the process behind it
  - no overlapping is important

Abstract

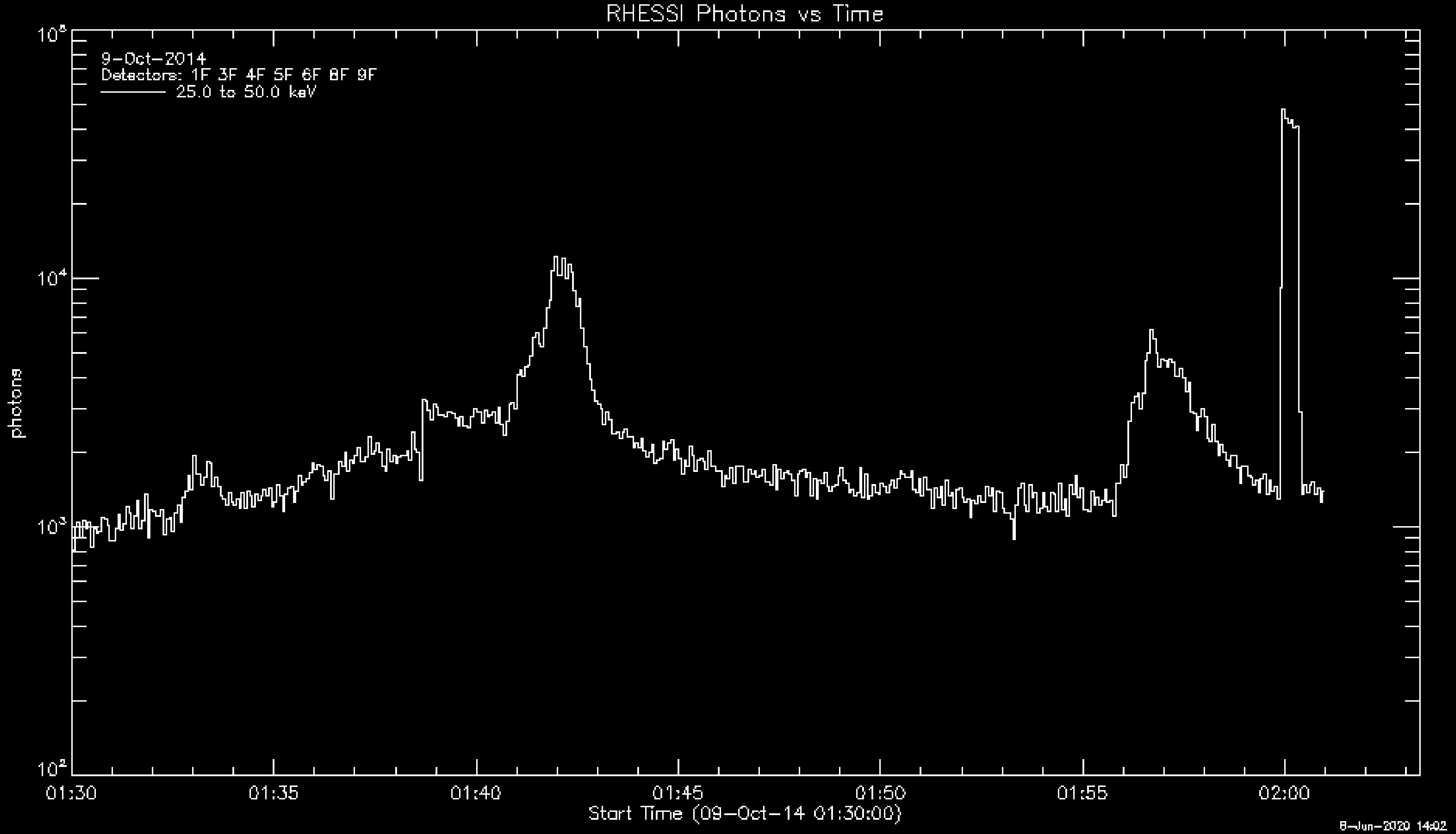
- Hard X-ray and ultraviolet emissions in solar flares have been shown to be temporally correlated for complete flare regions (Alexander and Coyner, 2005). For larger, more complex flares, the temporal correlation of the full flaring region persists, however individual sources may be uncorrelated or only correlated to a portion of the event. Emission evolves in a series of localized sources.
- One side effect of the sun's plasma behaving like a fluid, is magnetic field lines warp and bend. When these field lines warp, it creates a kink point, or an X point which serves as a magnetic reconnection site. When the magnetic field lines reconnect, it creates X-ray emissions through the release of high energy electrons. When these particles are jettisoned, they slam back down into the sun with an incredible force. This impact with more dense plasma creates ultraviolet emissions in response. If these are correlated and coming from the same source, it is indicative of UV and hard X-ray emission having the same physical origin, the flare reconnection event. We show evidence of an event where the reconnection sites evolve throughout the flare.
- To prove our hypothesis, we created a versatile code framework that is capable of data acquisition for the 1600Å and 1700Å wavelengths specifically. Our code is also able to handle data from any wavelengths of the Solar Dynamics Observatory's Atmospheric Imaging Assembly instrument (Lemen, et. al, 2012, Pesnell, Thompson, & Chamberlin, 2011). This allows for more complete pictures of the emission response in localized regions.

X-Ray components



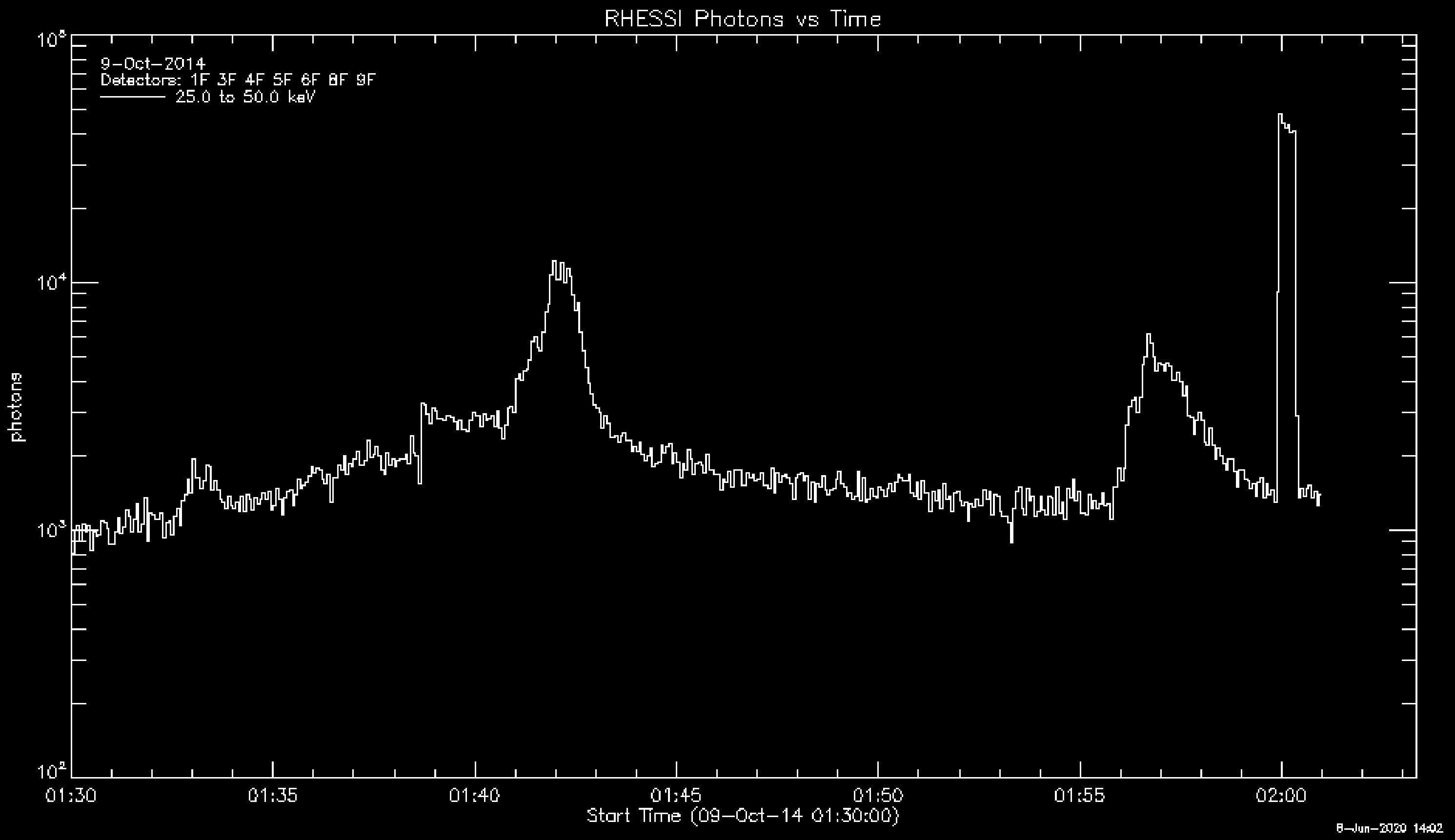
- Obtained from Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)
- Selected 2 energy bands for analysis
  - 6-12 keV (Soft X-Ray)
  - 25-50 keV (Hard X-Ray)
- Hard X-Rays show primary event particle emission
- Soft X-Rays show thermal response to the primary and secondary event particle emission

RHESSI Initial Data



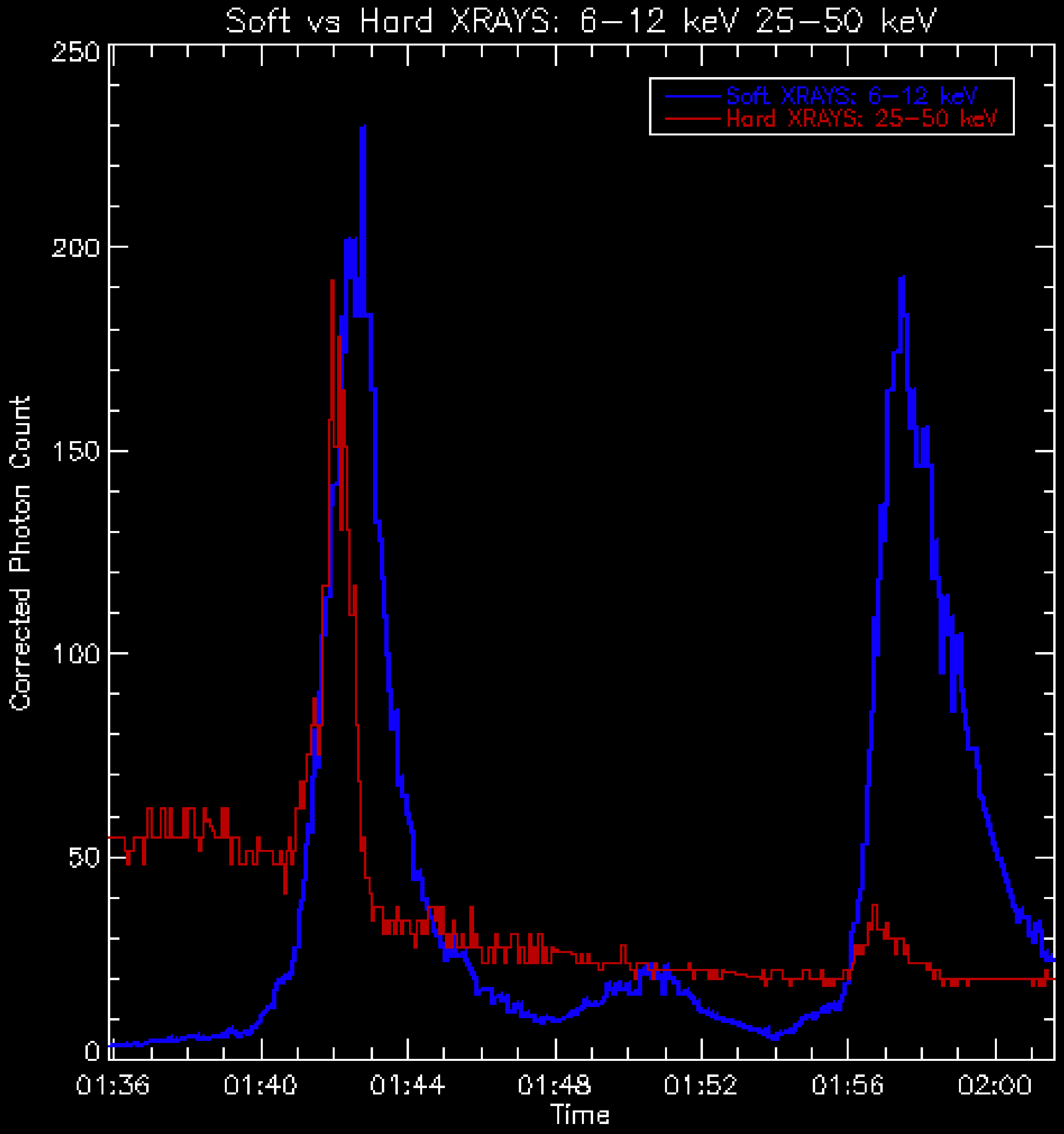
RHESSI data

- Photon count value for 25-50 keV
- Two peaks can be seen around 01:42 and 1:58
- Large spike at 02:00 is an attenuation switch, not connected to the flare.
- By comparing all UV data to this X-Ray data we can see how the flaring region is behaving, and how the particle emission is connected to reconnection.

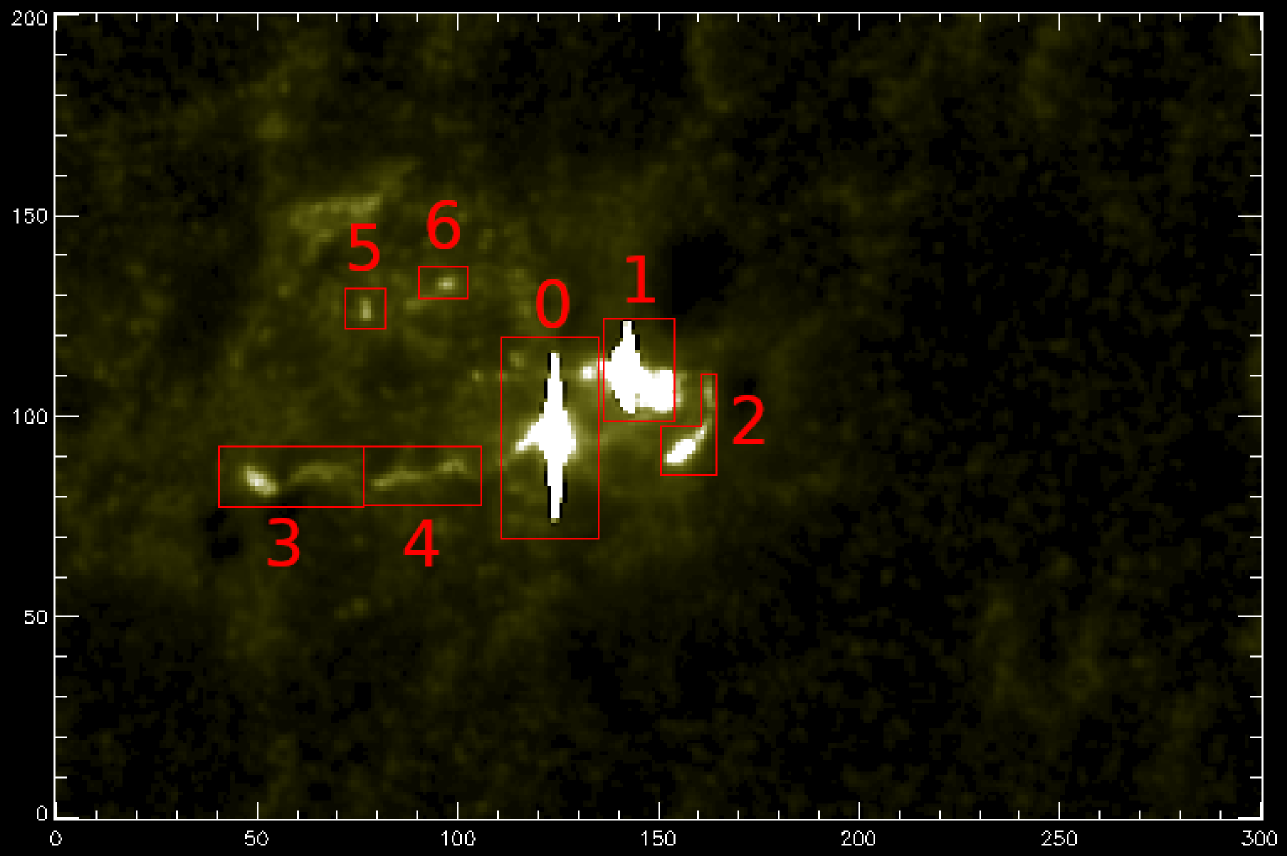


Hard X-Ray vs Soft X-Ray

- Hard X-Ray emissions primarily present in the primary solar event with a partial presence in the later event.
- Soft X-Rays 6-12 keV are present for primary event and secondary event. In addition, the middle event that peaks around T=1:51 is indicative of thermal fluctuation in the solar plasma.

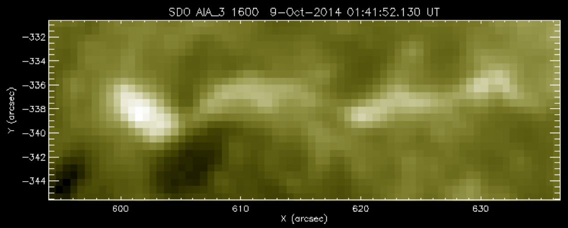


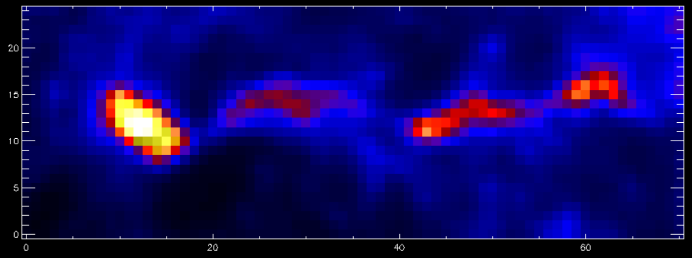
Regions of interest



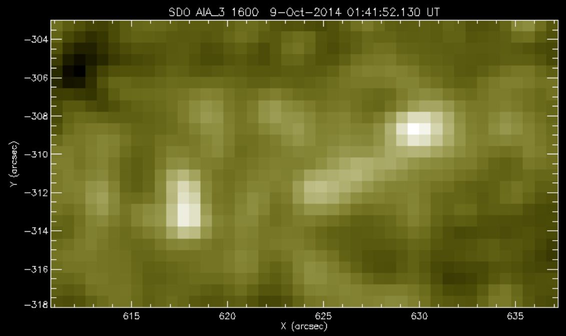
- Regions 0, 1 and 2 are most of note producing the most particles
- Regions 3-6 were not a significant source of particle emission.
- Region 4 has some coincidence due to its special relation to the primary event region, though not enough to indicate magnetic reconnection.

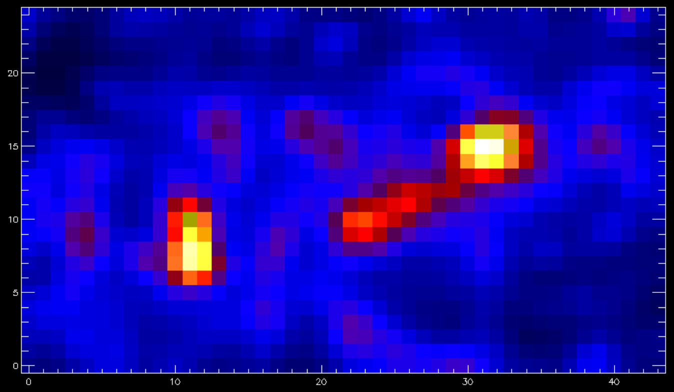
Regions 3-6





3-4

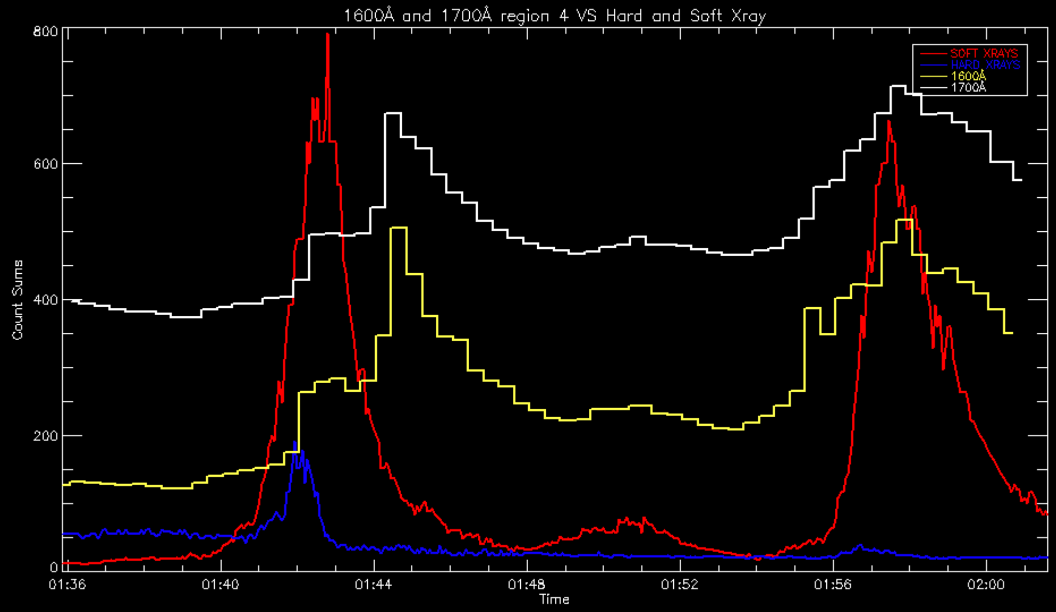




5-6

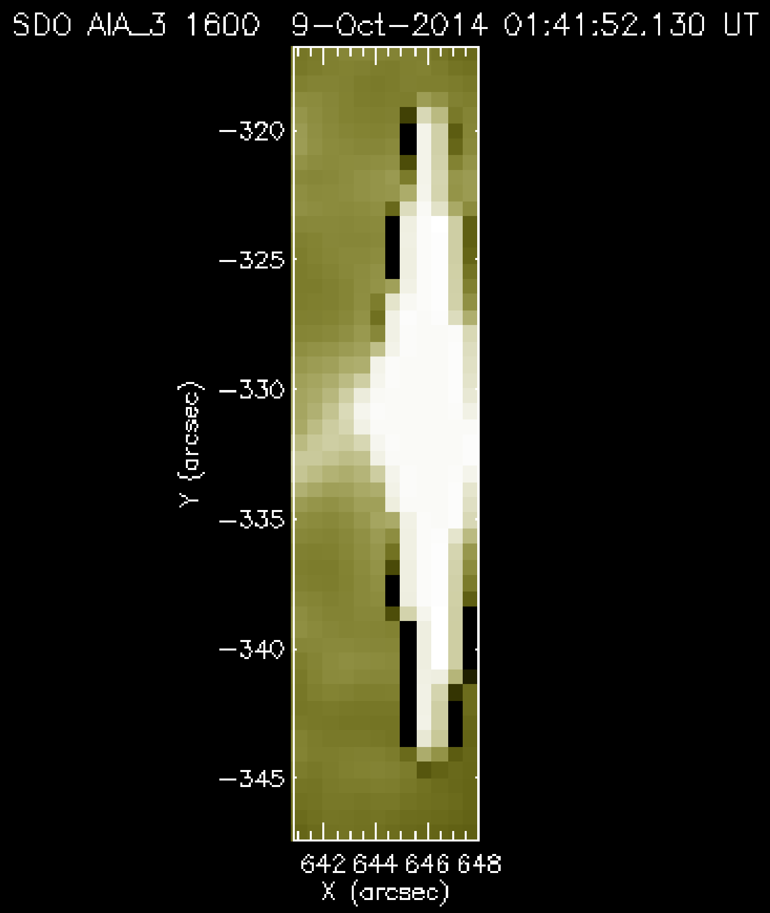
- Golden image was created with the AIA 1600 colortable
- Right image was created with The STD GAMMA-II color table (loadct, 5)
- The data presented in regions 3-6 produced graphs that indicated that they were not primarally correlated with the solar event.
- It is likely that these regions, while in the local event region, are not a primary source of UV Radiation.

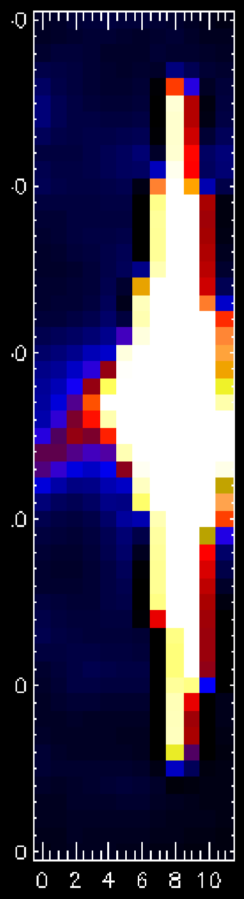
Regions 4 Data



- Region 4 (1600Å in yellow and 1700Å in white) is minorly connected with the event due to its relatively close proximity.

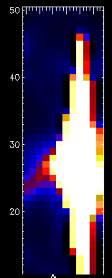
Region 0

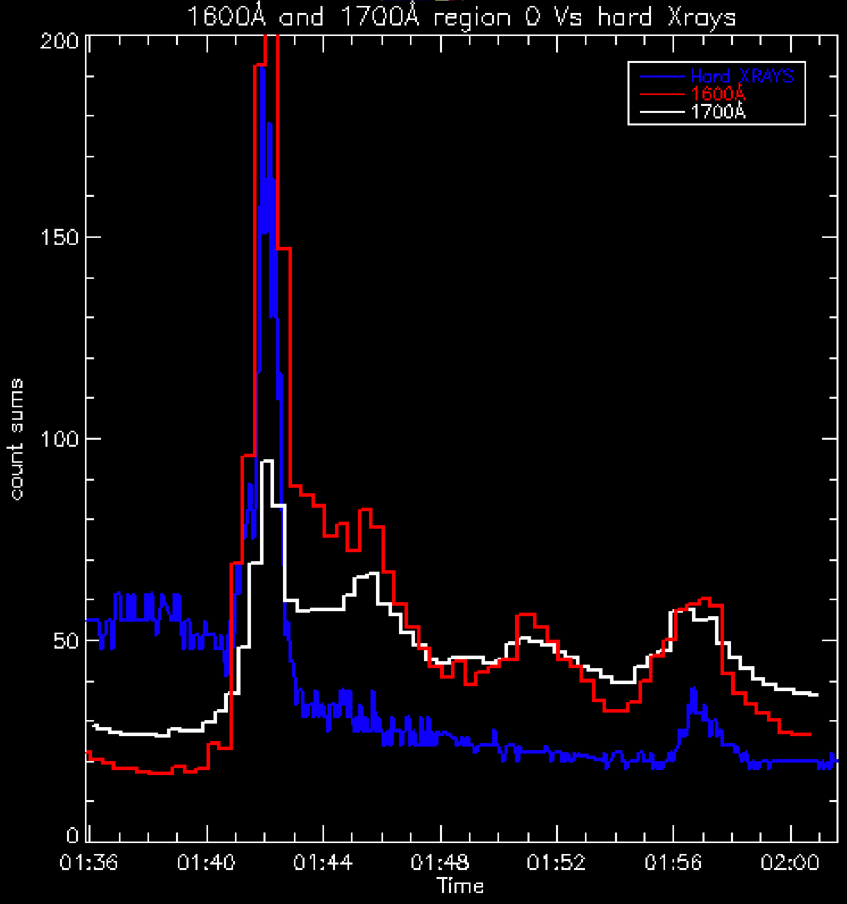




- This is the region of interest that has the single largest data point value right around the center of the diamond.
- For 1600Å
  - 6336.25 Counts per Pixel
- For 1700Å
  - 17509.14 Counts per Pixel
- The max value in the code is very important.
  - Used for growing all regions quickly.
- Max value can be viewed as counts per second on that particular pixel

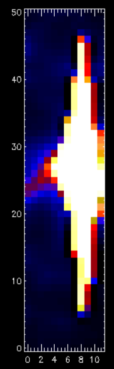
Region 0

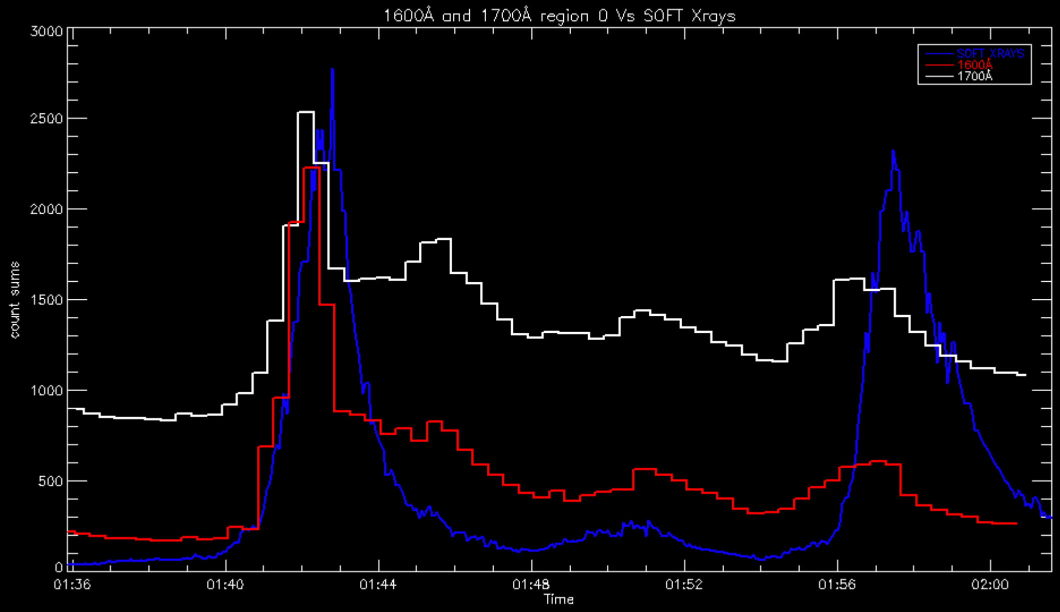




- 1600Å and 1700Å Curves correlate primarily to the peak event.
- Clear X-Ray coincidence with both early onset and subsequent flare.
- Thermal fluctuation events in the middle peaks at T= 1:45 and 1:51

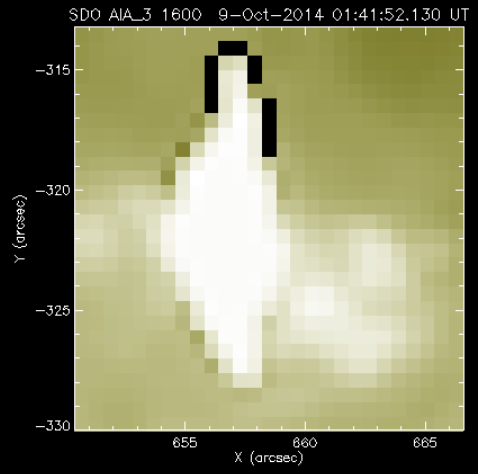
Region 0

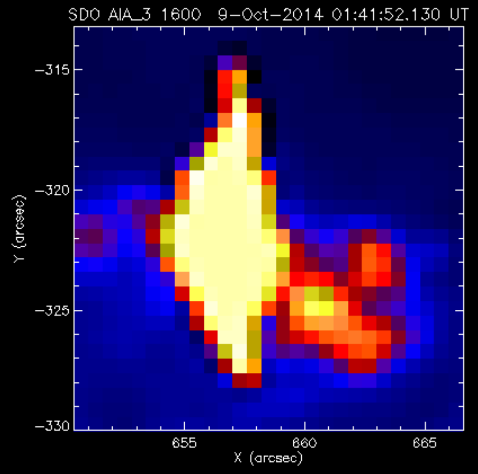


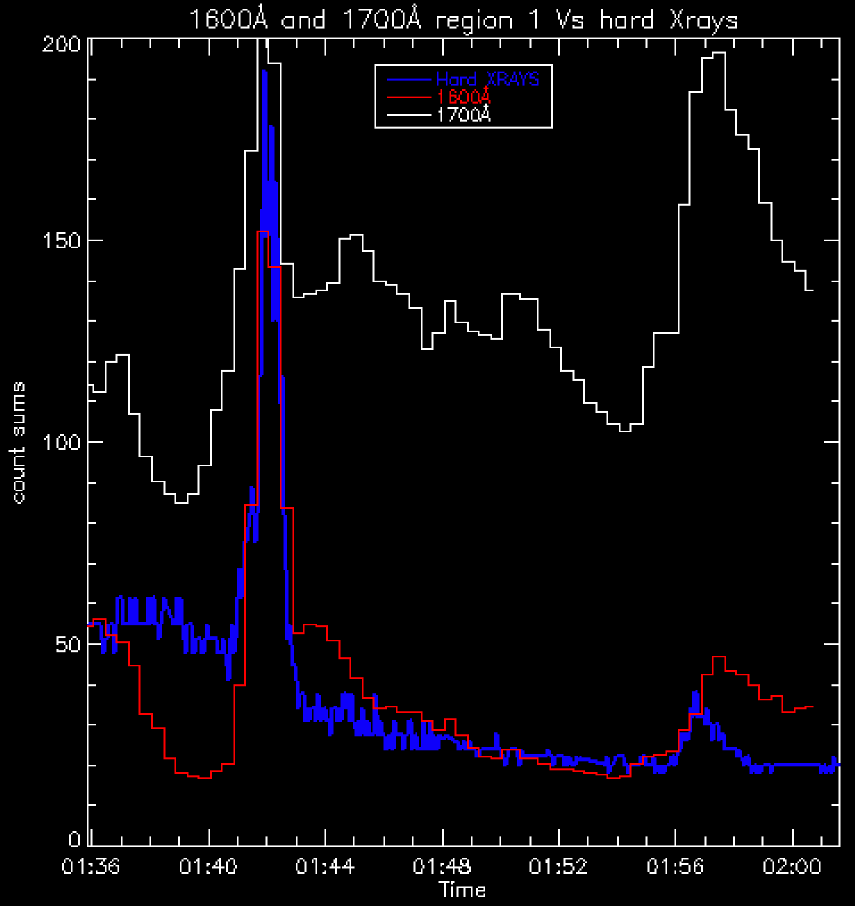


- Both UV curves correlate primarily to the first event
- Soft X-Ray (blue) Curves indicate there is some thermal fluctuation coinciding with event release around 1:51
- Apparent correlation with primary event, less so with secondary.

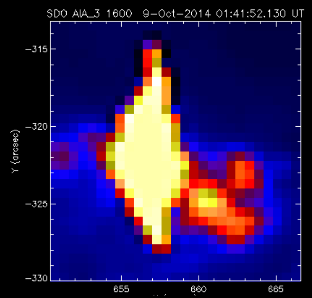
Region 1

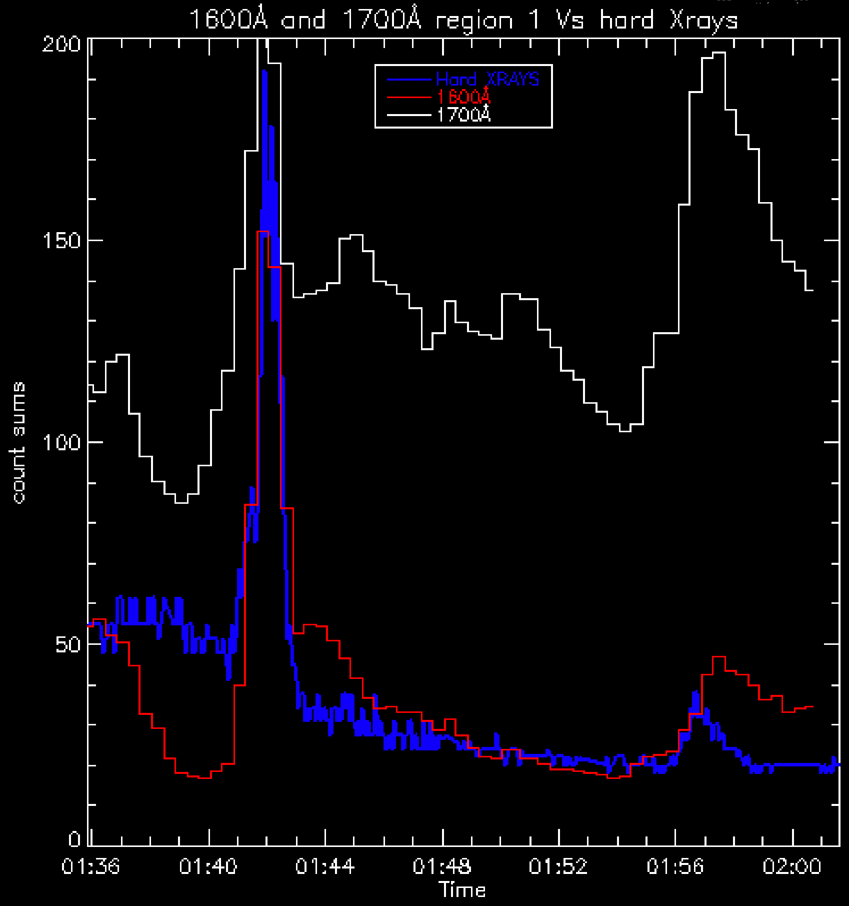

SDO AIA_3 1600 9-Oct-2014 01:41:52.130 UT
Y (arcsec)
X (arcsec)


SDO AIA_3 1600 9-Oct-2014 01:41:52.130 UT
Y (arcsec)
X (arcsec)


1600Å and 1700Å region 1 Vs hard Xrays
Hard XRAYS
1600Å
1700Å
count sums
Time

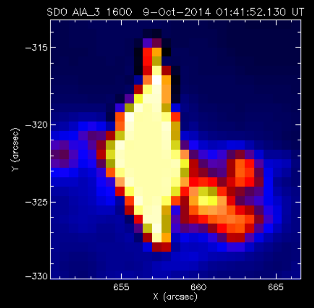
Region 1 Data

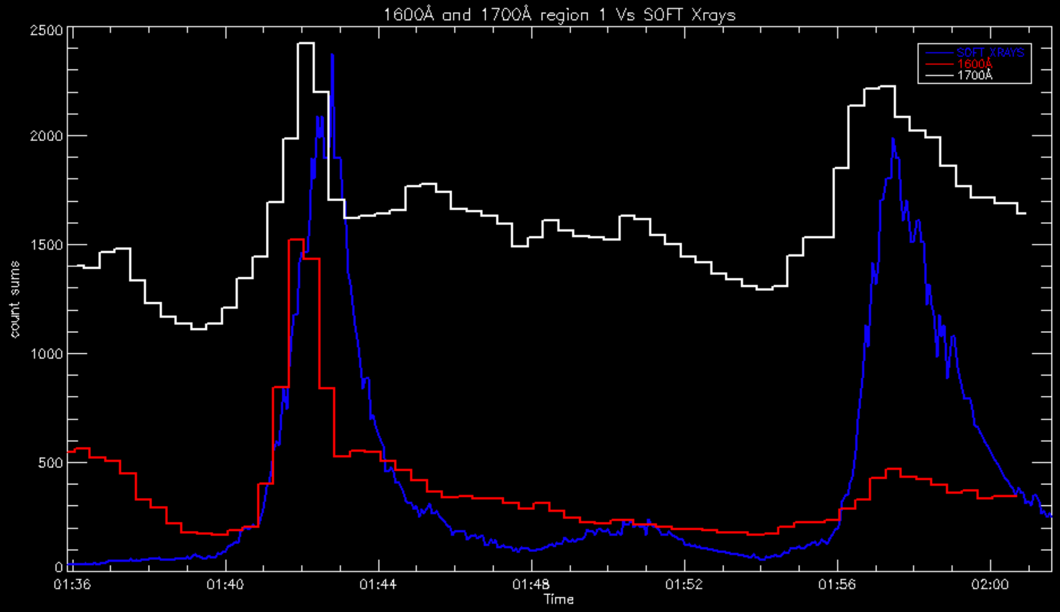




- Region 1 has a stronger correlation with the hard X-Rays than region 0
- Initial hard X-Ray burst (blue) at the main peak with some thermal response on the shoulder. The second peak increases when the X-Rays increase again.
- Thermal response indicated from the smaller middle peaks of the 1700Å graph

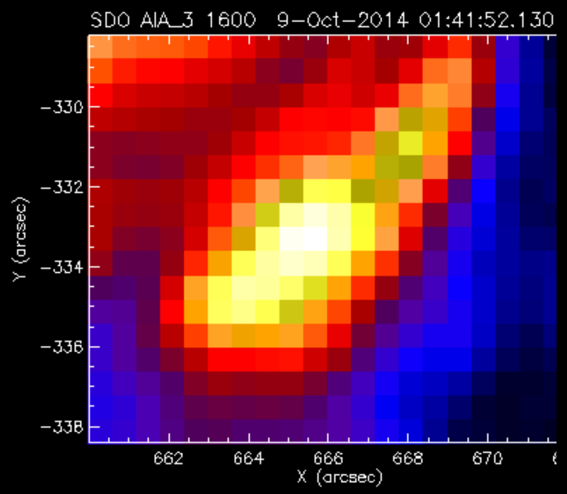
Region 1 Data

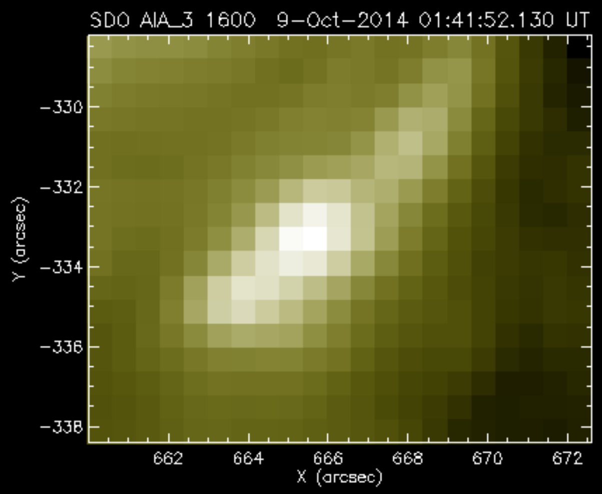


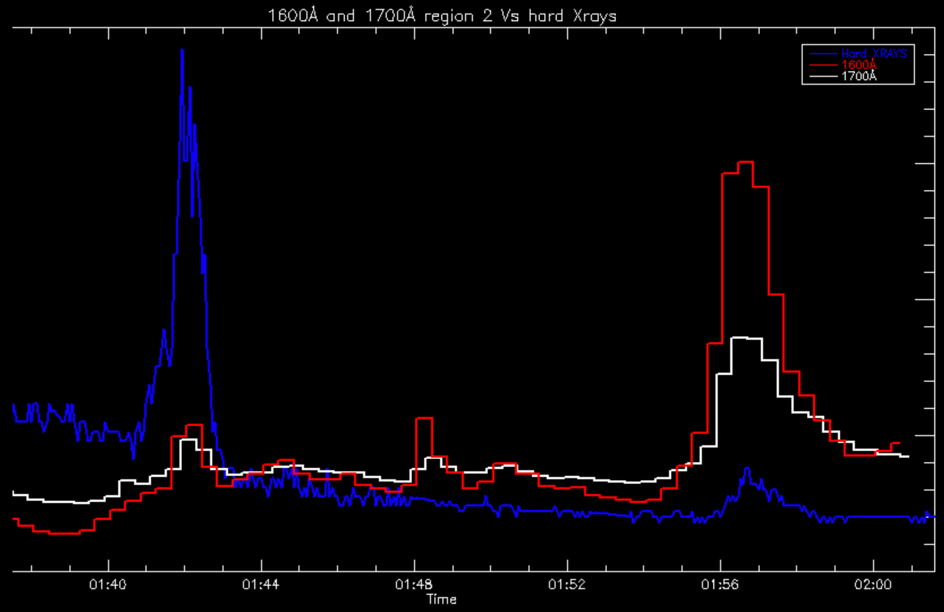


- More correlation in 1700Å for secondary event than for 1600Å

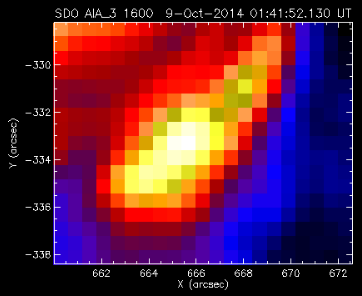
Region 2 Image

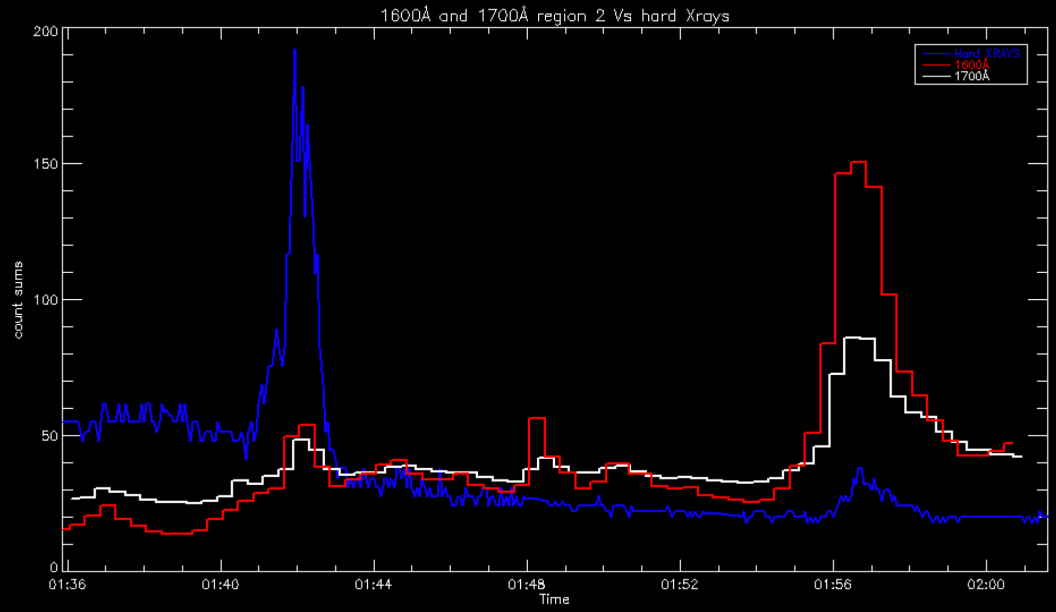






Region 2 data





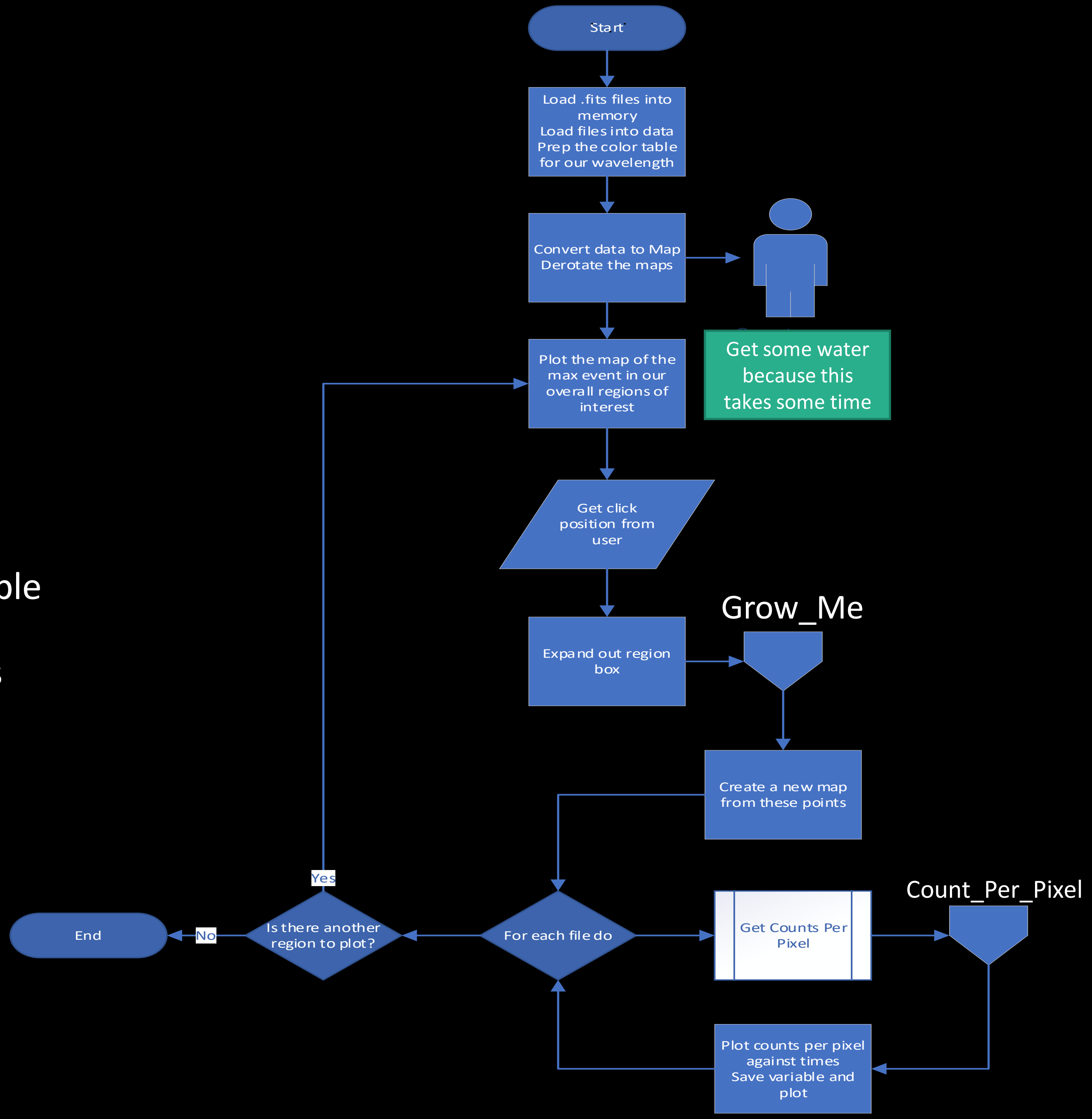
- Region 2 has more correlation with the secondary event than region 0 or region 1.
- Likely indicates a magnetic field reconnecting to a different part of the plasma.

Program Goals

- Extract Data provided from SDO in the form of .fits files
- Select regions of interest from the flare
- Extract total counts per pixel value from each unique region of interest.
- Save the extracted data for further analysis.

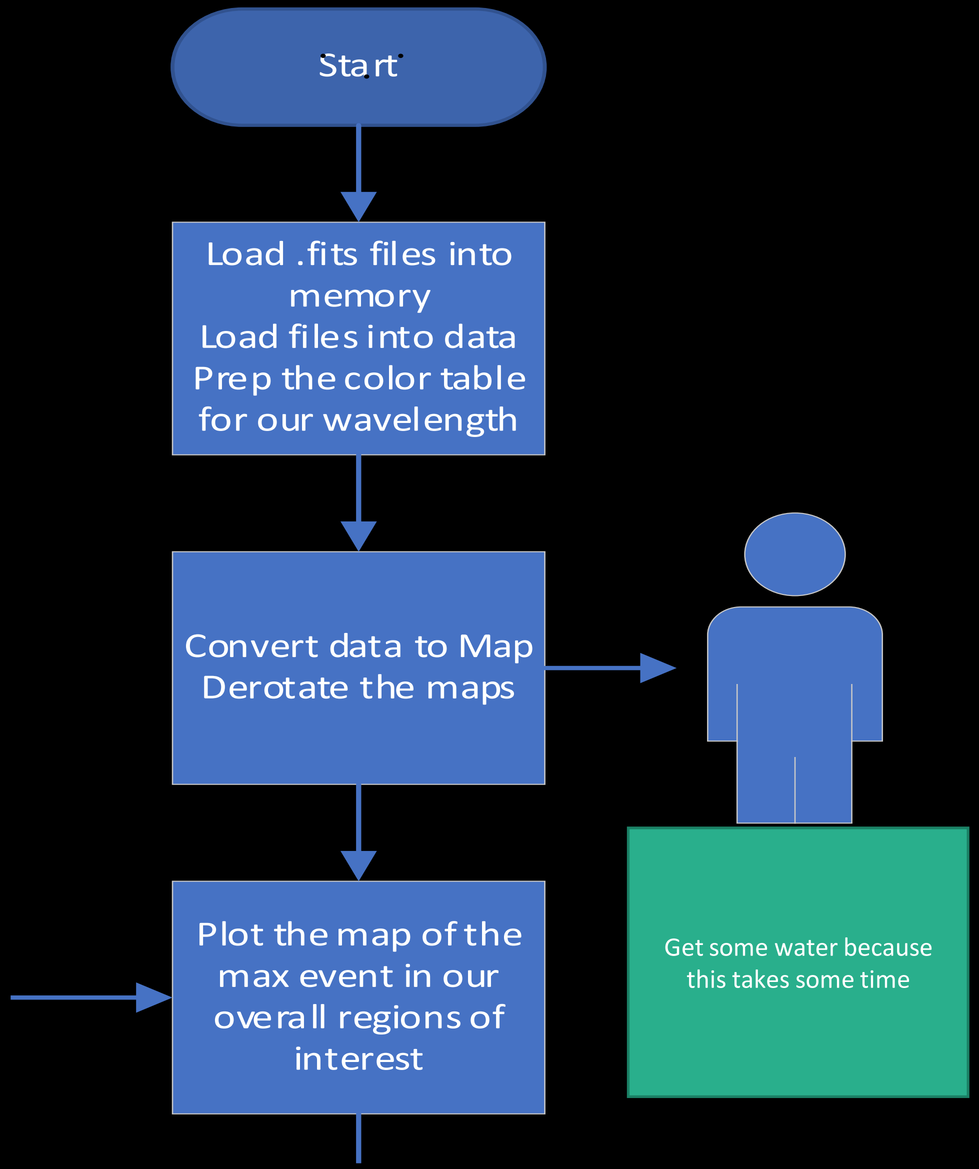
Main

- Main body of the program.
- Includes 2 sub functions
  - Grow_me
  - Count_per_pixel
- This part of the program is responsible for passing and handling of data, primarily in the form of Maps in this case.
- For each file we want to extract the total counts per pixel value for the regions of our solar flare.



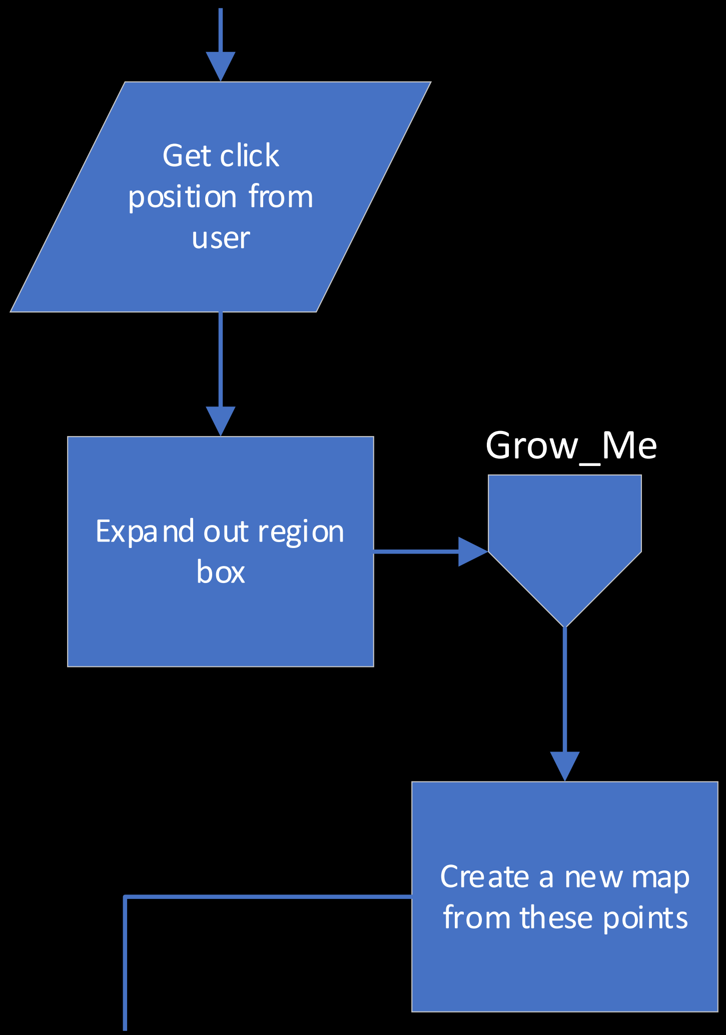
Main

- Load the .fits files into memory
- Load the data from the .fits files
- Preps the color table
- Convert the data to maps
- Derotate the maps
  - Very important for spatial correlation of values.
- Display a macro view of the overall region of interest at the point in time when largest emission was found
  - This image is used for region selection.

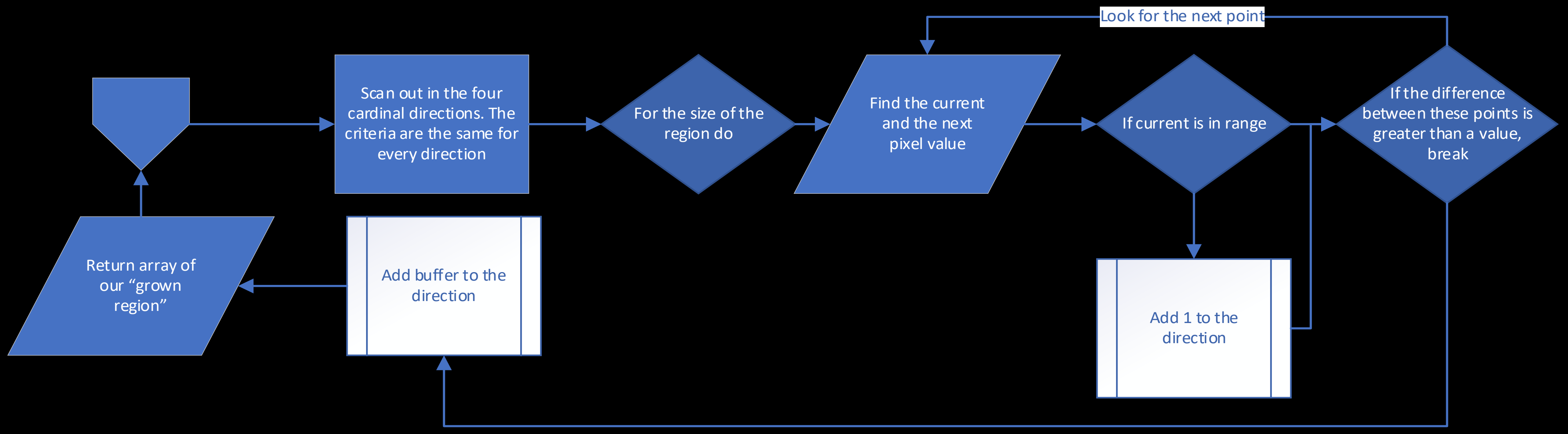


Main

- The user clicks on a particular region they want to examine
  - To save time regions 3-6 were hard coded. This has since been fixed, but the hard coded data was used for analysis, due to time constraint.
- The program expands the region out by using the function Grow_me.

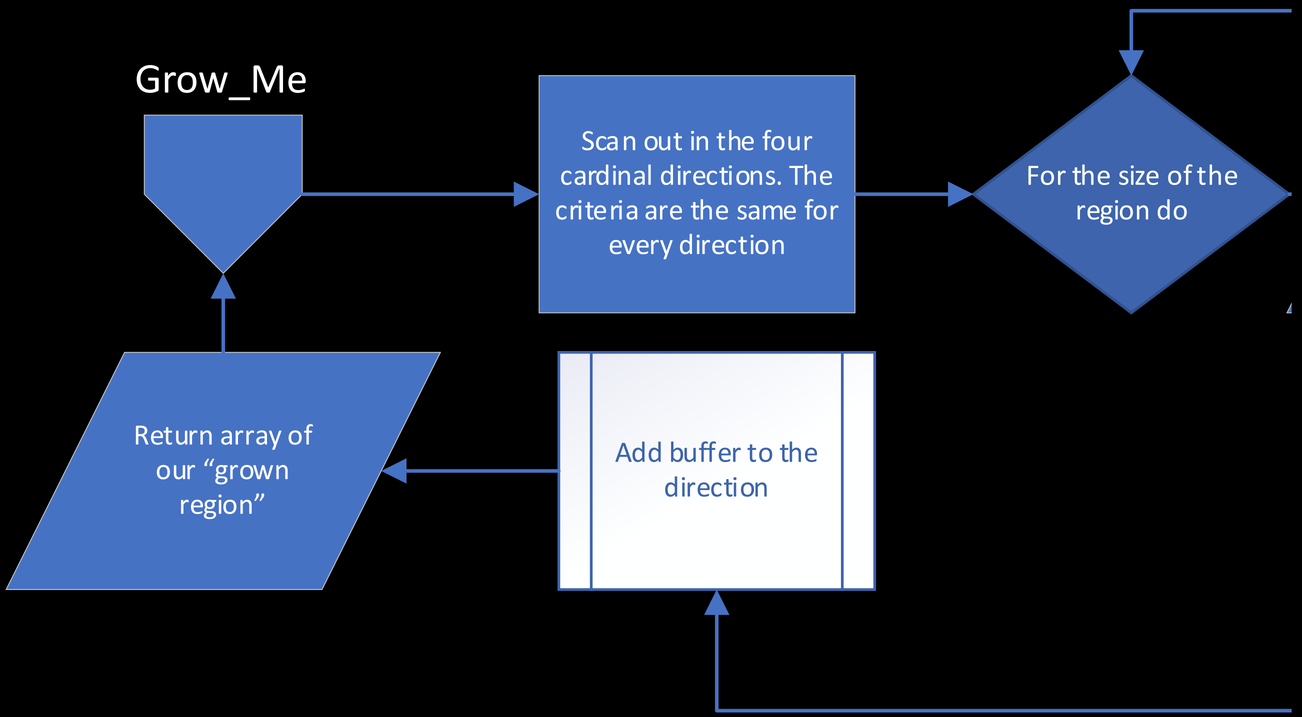


Grow_Me Function Overview



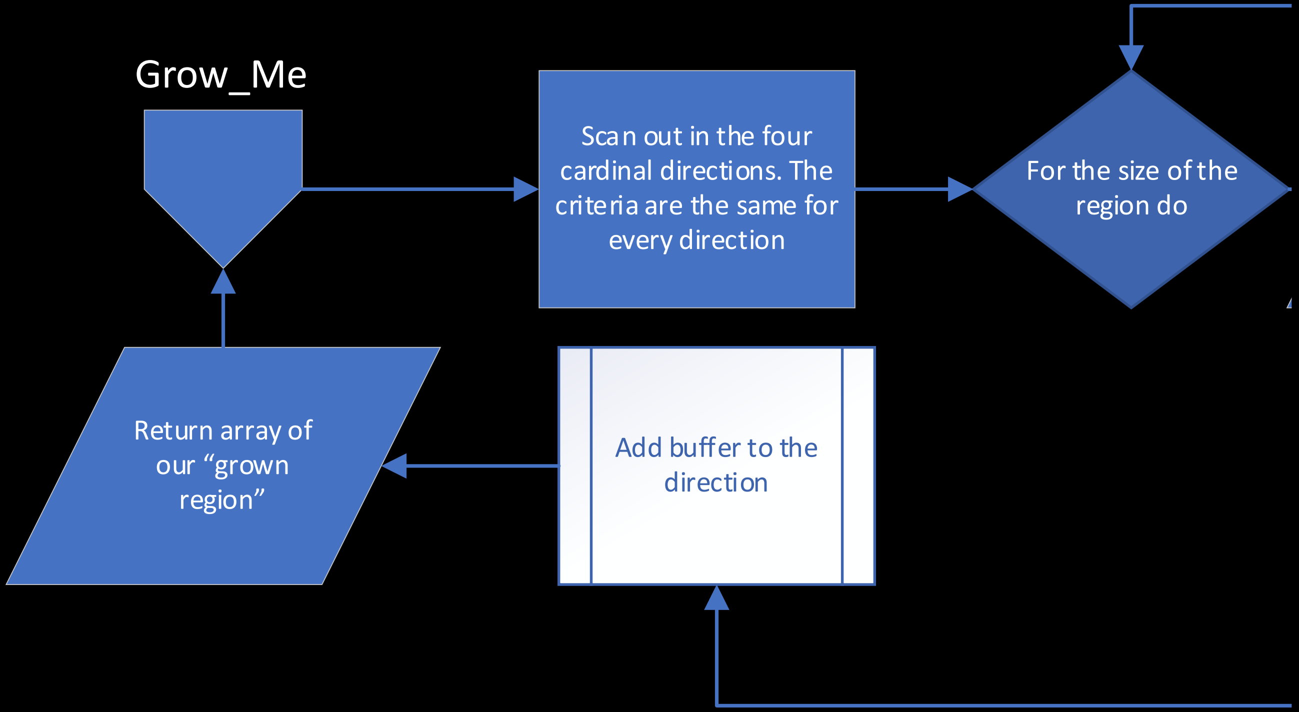
Grow_Me

- This process is the same for each cardinal direction, only the direction we scan is different.
  - for +x, add I to the x part of the array
  - For –y subtract 1 from the y part of the array
  - Etc.
- Treats the data like a 2 dimensional array in the form of (x,y) with x values corresponding to their position in the X direction, likewise for the y direction.
- Count values are stored in (x,y) format.



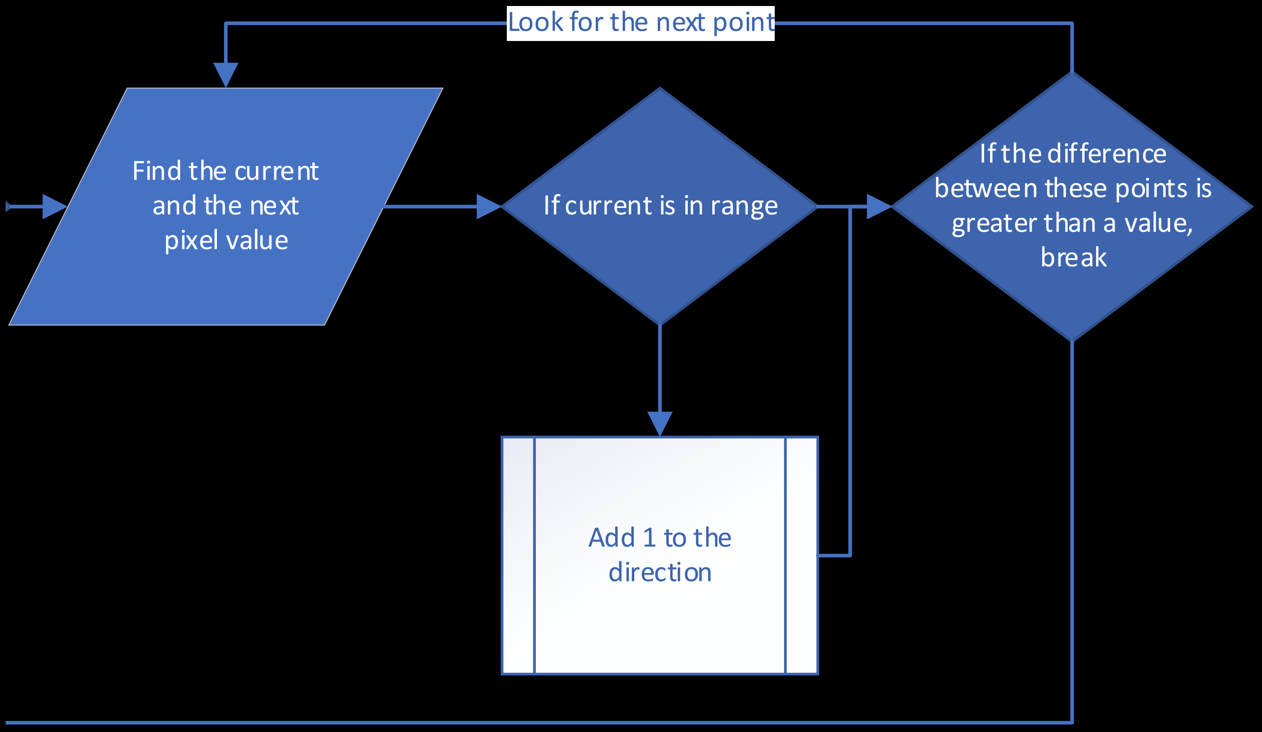
Grow_Me

- Effectively this function is 4 single for loops with logic that tells it when to quit.
- For this event, the size of the regions never exceeded a value of 20 for our scanning direction (exit condition 1).
  - This value is changeable for other flares with larger or smaller regions.
- Increment the for loops by adding the pixel spacing (dx or dy) to the iterator for the particular map.
  - Different sub_maps this function receives can have different dx/dy values, this ensures a consistent function.



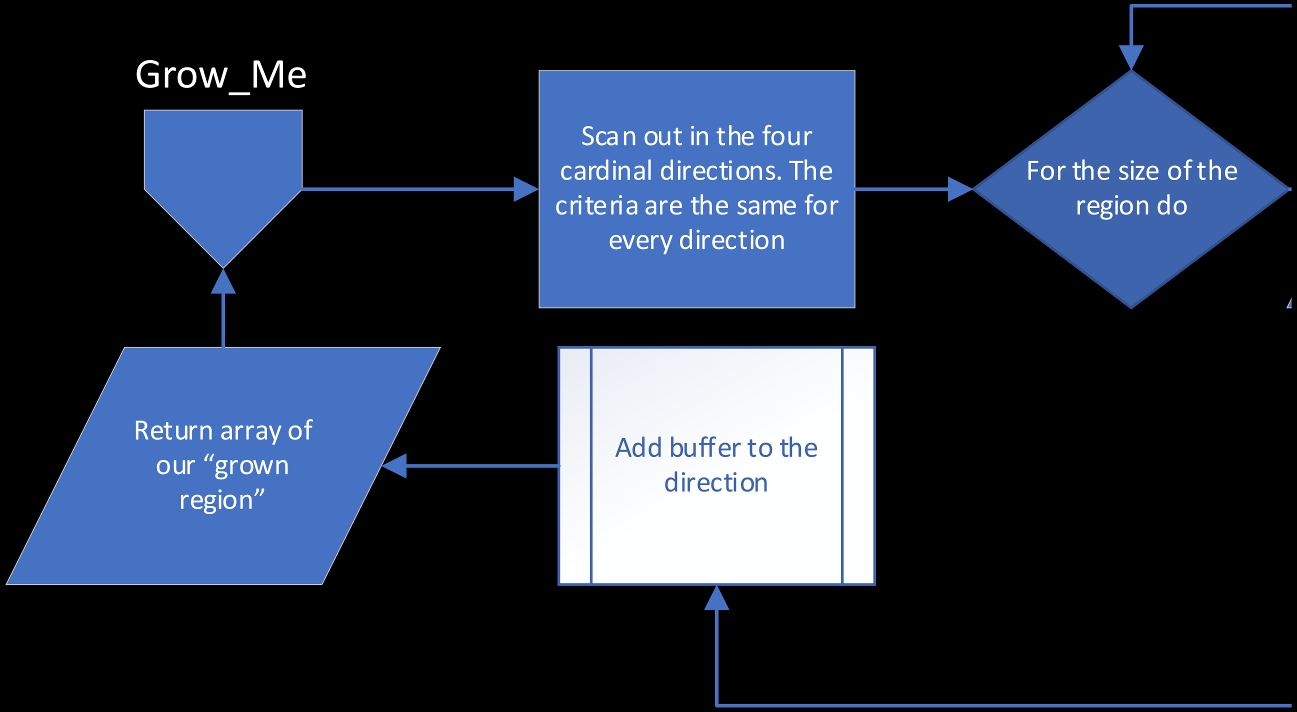
Grow_Me

- The program finds the data values at the current point and at the next point.
  - Represented by data(x,y)
- If the current value is in range, it will add 1 to our spacing counter if not, this function ends (exit condition 2)
- It also checks the difference between the current and the next value, as for this event in 1600 Å is always under 1000 for our most notable regions of interest: 0, 1 and 2 (exit condition 3).
  - This value is flexible, and the user can change it for their solar event.

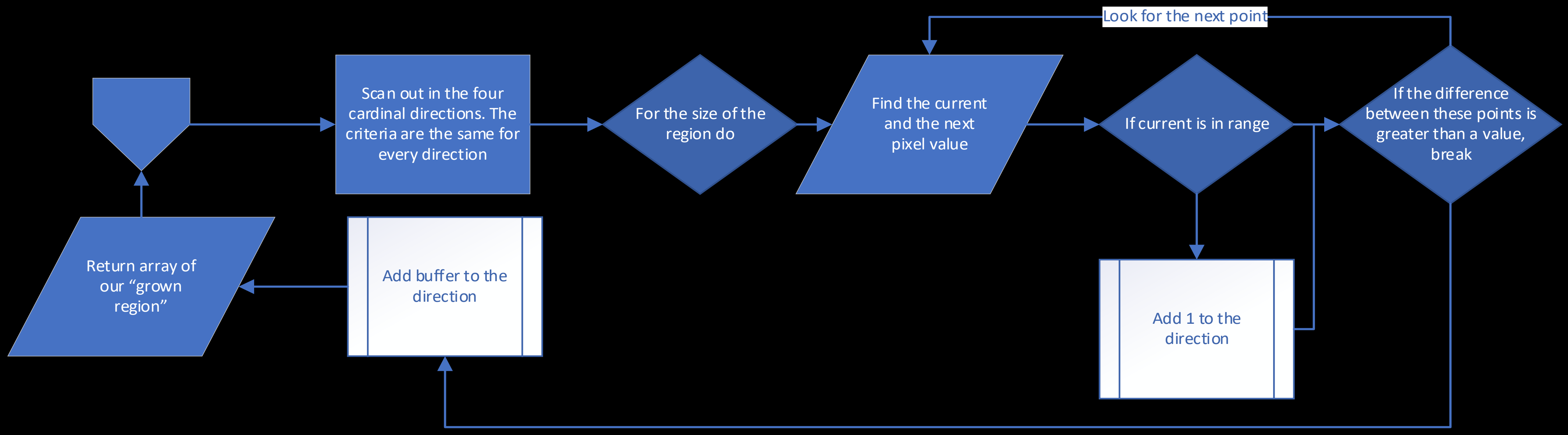


Grow_Me

- The program then adds a small buffer to all directions and returns the array of our newfound “grown region”
- The x/y buffer is also a variable that the user can change if necessary.
    - Also serves to combat irregularities in very small regions or irregularly shaped regions.



Grow_Me Function Overview

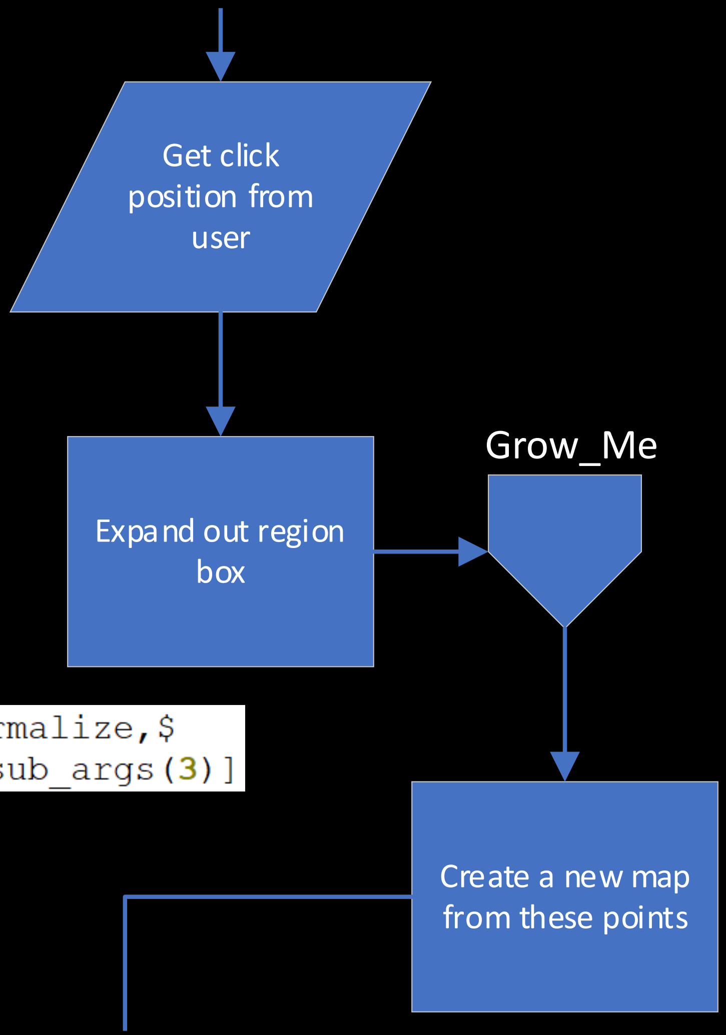


Main

- Grow_me returns an array that matches the form of the sub input for the index2map built in IDL function, this is intentional.
- If we think about this in the cardinal direction point of view
  - [-x, +x, -y, +y]
  - These values are the range that will be used to create a sub_map of the region.

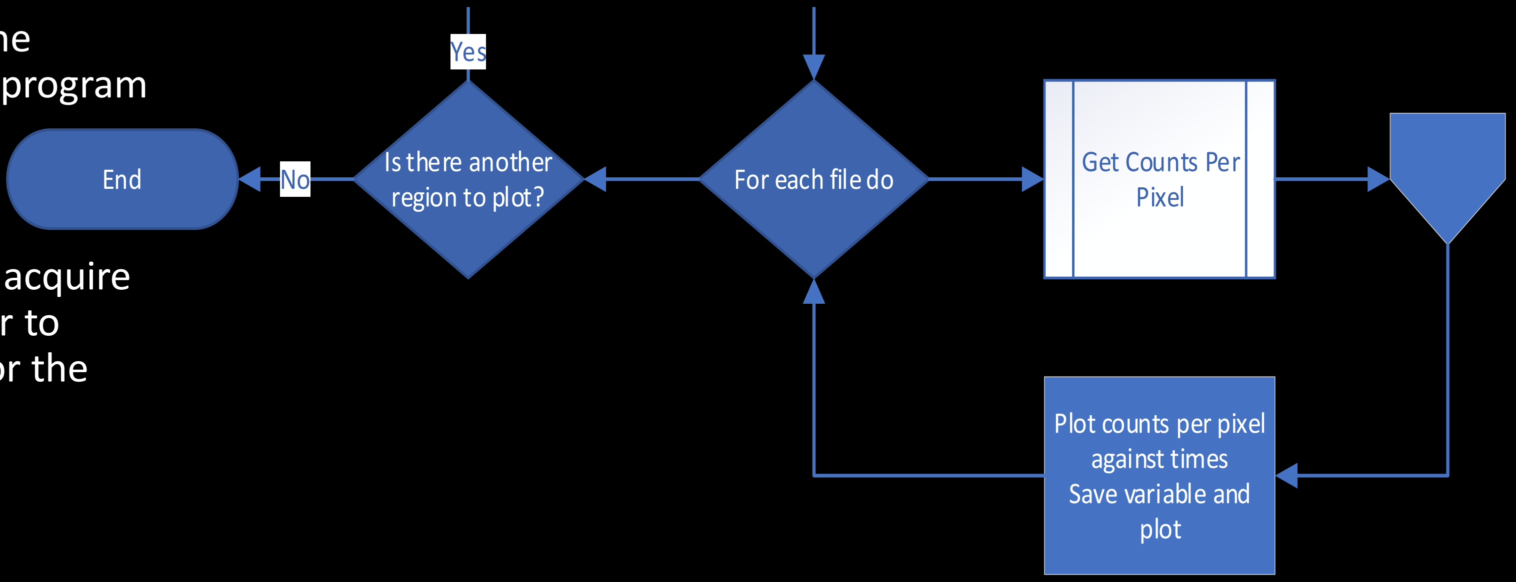
```
index2map,index,data2,regionmap1, /double, /normalize,$
   sub = [sub_args(0),sub_args(1),sub_args(2),sub_args(3)]
```

- Now that we have a sub map of our region, we can start examining it much closer.

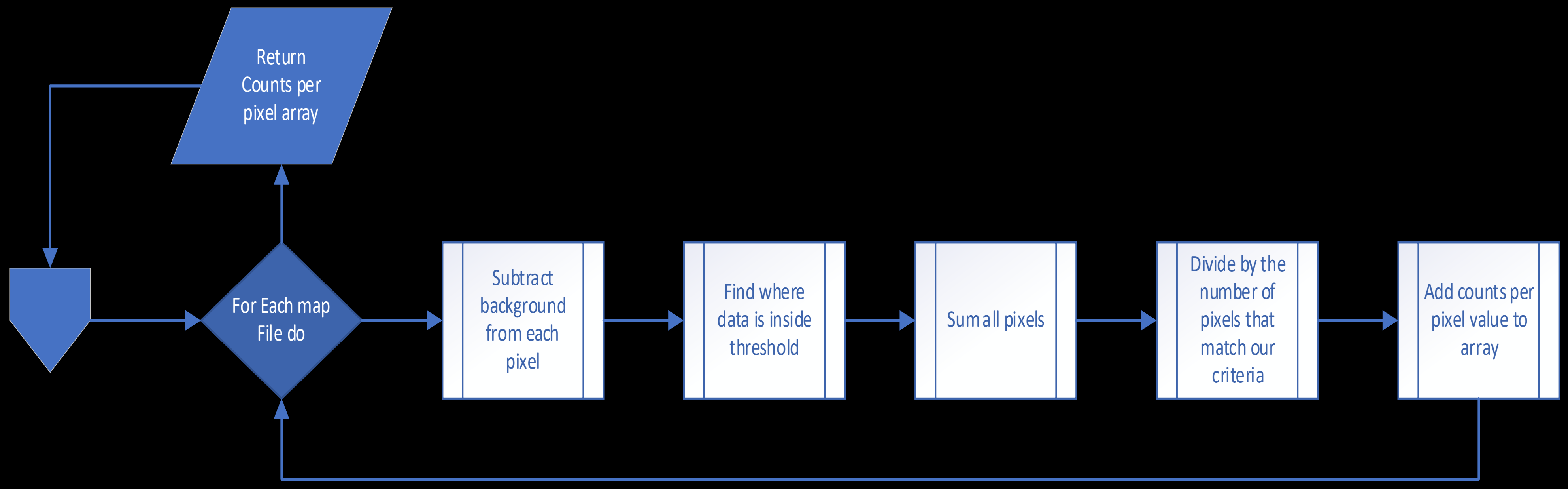


Main

- By using the amount of files as the iterator, we are able to keep the program scalable.
- For each image the program will acquire the total counts per pixel in order to graph it against the X-Ray data for the same solar event.
    - Data by RHESSI satellite

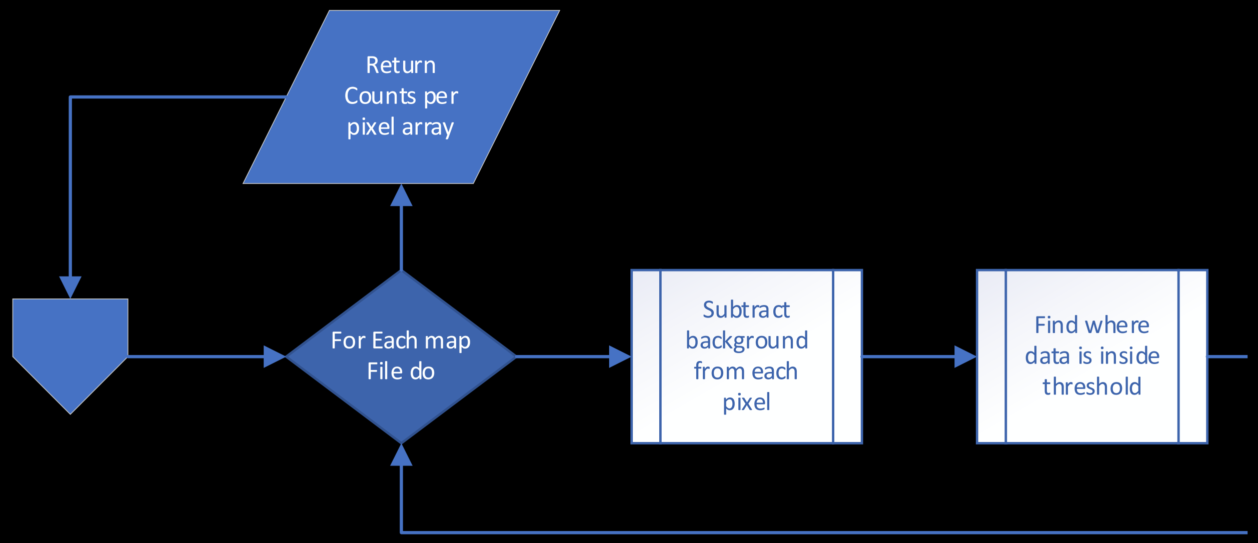


Count_per_pixel



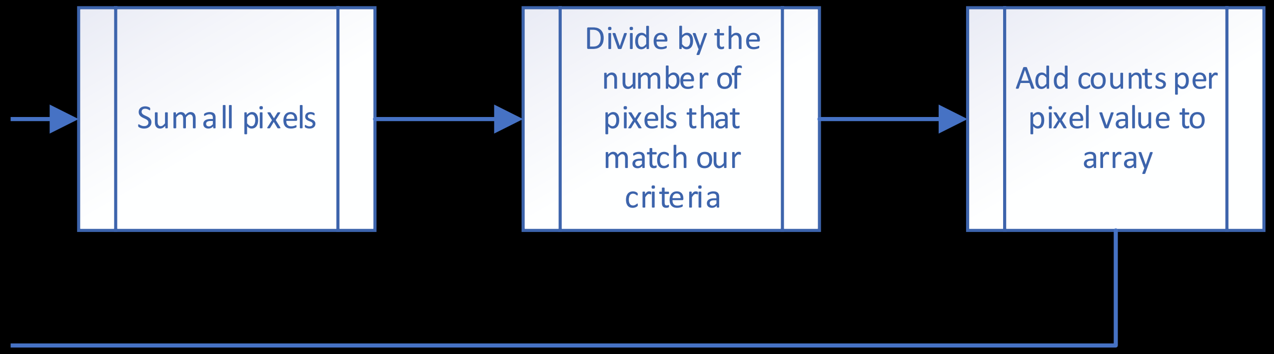
Count_per_pixel

- For each file in the given map region:
- subtract the background from each pixel value.
- For this flare, the following values were used.
  - 1600Å: 42 Counts Per Pixel
  - 1700Å: 393.395 Counts Per Pixel
- find where the data is above the threshold.
  - 2* the background value is the minimum threshold default value; changeable.

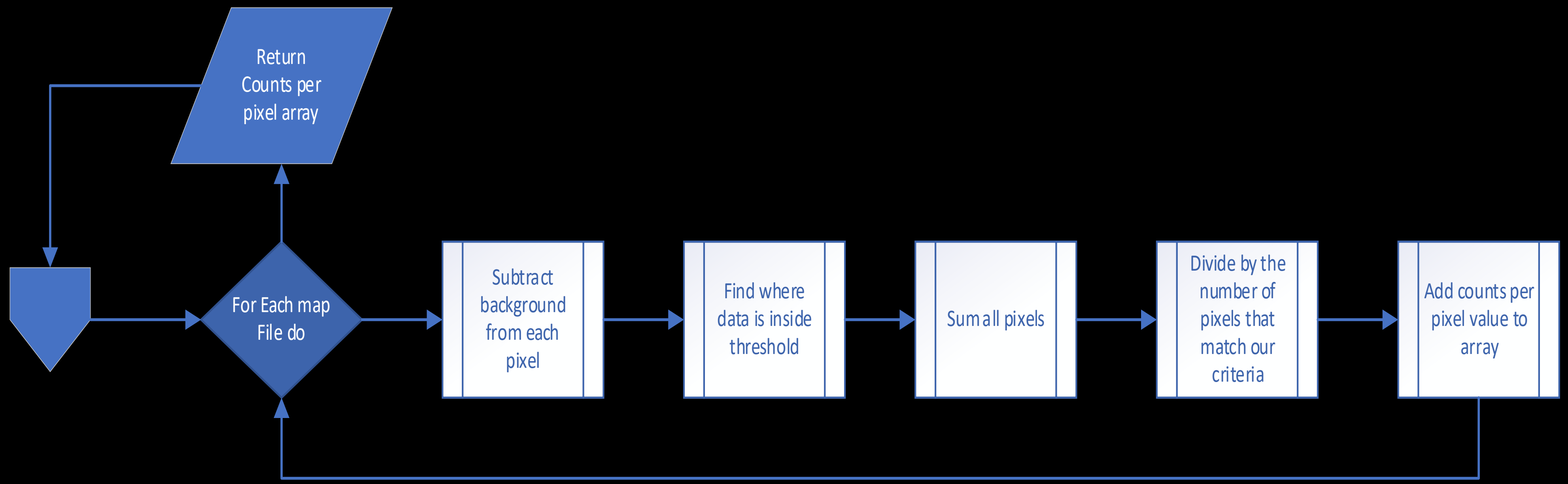


Count_per_pixel

- Sum all values found for the region
- Divide the summed value by the number of pixels
  - Note this is the number of pixels within our threshold, NOT the total number of pixels in the region itself.
- Add this value to an array with index corresponding to the file
- Return the array containing the total counts / pixel.

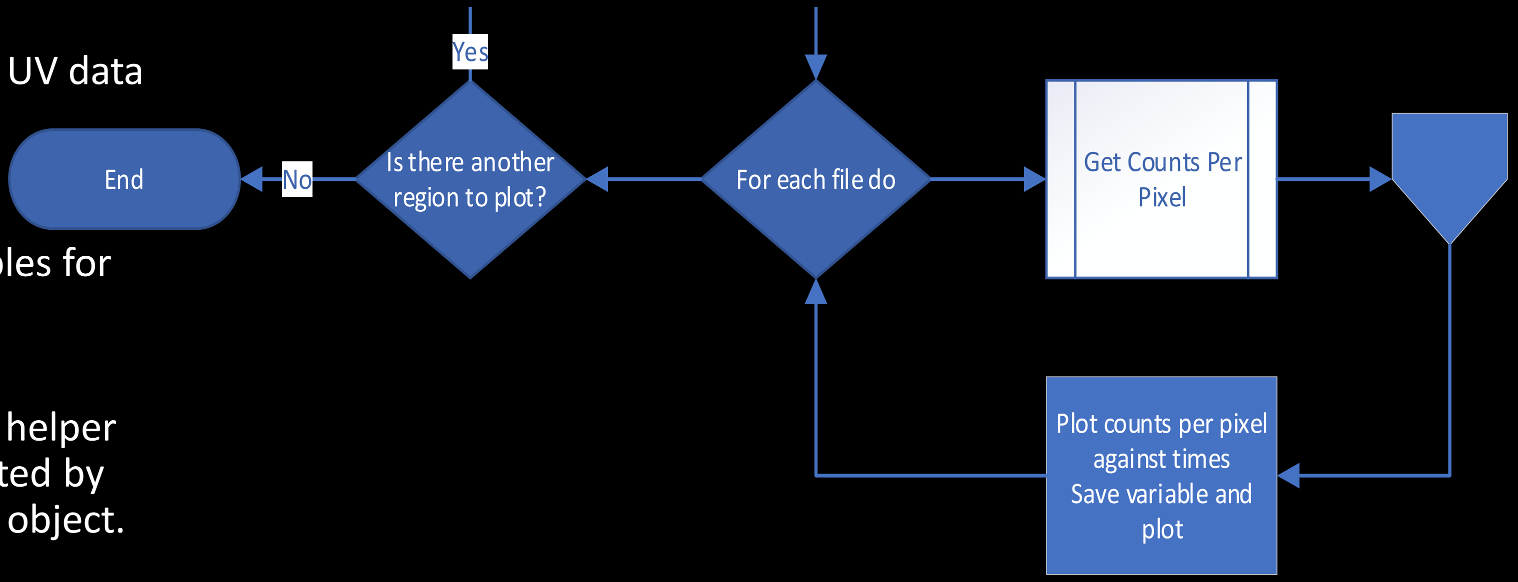


counts per pixel



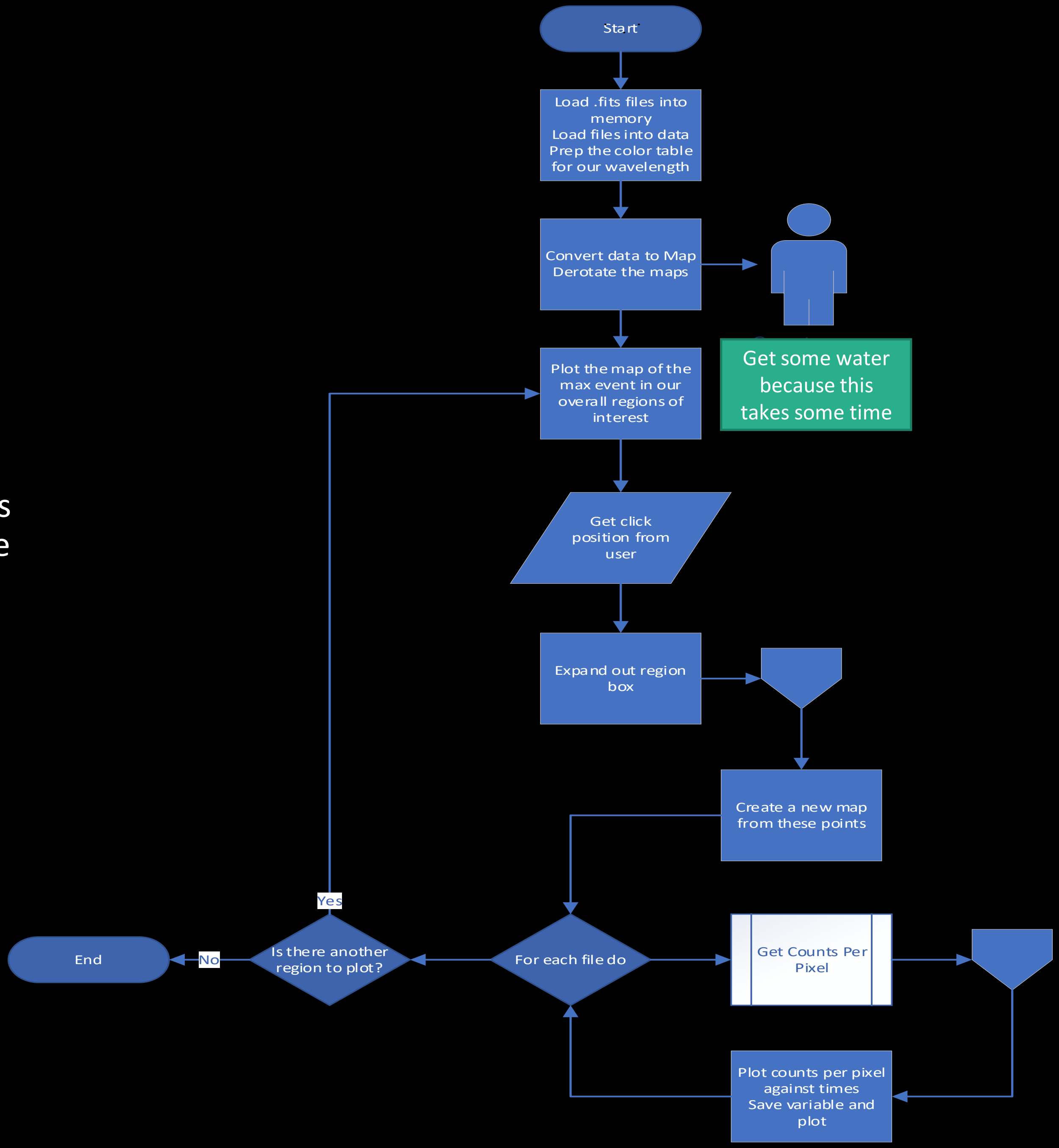
Main

- The base program only plots the UV data for each region alone.
- It does, however, save the variables for manual plotting.
- Such a change could be easily implemented by adding another helper function that plots the data created by this program as well as the hessi object.
  - See appendix plot code chart
- Plotting of the graphs in the presentation were created manually by using utplot and outplot.



Main

- This code does not check for duplicate values due to time constraint.
- For the solar event selected, the code does not generate a region that overlaps with another because of their respective locations.
- Future implementations would need to check for a duplicate value before obtaining Counts_per_pixel.



Sample manual plot chart

```
;region 0 16 and 1700 Å vs hard xrays
utplot, anytim(time, /ext), data.countrate[3,*], color = 50, thick = 1.5, xstyle = 1, title = '
outplot, mytimes1700[*], region0_1700_sum[*]*.02, psym=10, color = 255, thick =2
outplot, mytimes1600[*], region0_1600_sum[*]*.1, psym=10, color = 110, thick=2
imd_legend, ["Hard XRAYS", "1600Å","1700Å"], color = [50,110,255], position = 12

;region 1 16 and 1700 Å vs hard xrays
utplot, anytim(time, /ext), data.countrate[HARD,*], color = 50, thick = 1.5, xstyle = 1, title
outplot, mytimes1700[*], region1_1700_sum[*]*.02, psym=10, color = 255, thick =2
outplot, mytimes1600[*], region1_1600_sum[*]*.1, psym=10, color = 110, thick=2
imd_legend, ["Hard XRAYS", "1600Å","1700Å"], color = [50,110,255], position = 12

;region 2 16 and 1700 Å vs hard xrays
utplot, anytim(time, /ext), data.countrate[HARD,*], color = 50, thick = 1.5, xstyle = 1, title
outplot, mytimes1700[*], region2_1700_sum[*]*.02, psym=10, color = 255, thick =2
outplot, mytimes1600[*], region2_1600_sum[*]*.1, psym=10, color = 110, thick=2
imd_legend, ["Hard XRAYS", "1600Å","1700Å"], color = [50,110,255], position = 12
```

Conclusions

- The code extracts data that can be further analyzed to find evidence of magnetic reconnection.
- The M1.3 Primary flare and the M1.4 secondary flare on October 09, 2014 from 01:35:52 to 02:00:54 has data that indicates strong correlation for magnetic reconnection points moving from one part of the solar plasma to another.
  - Regions 0 or 1 to region 2.

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