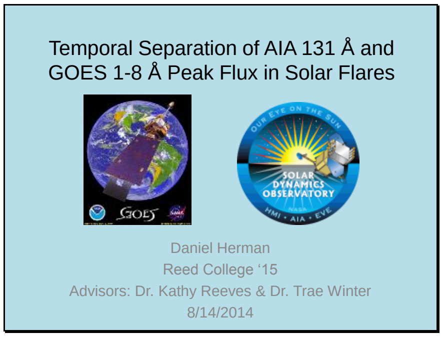
Slide 1



Slide 2

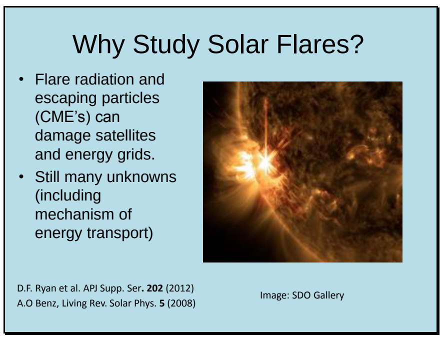
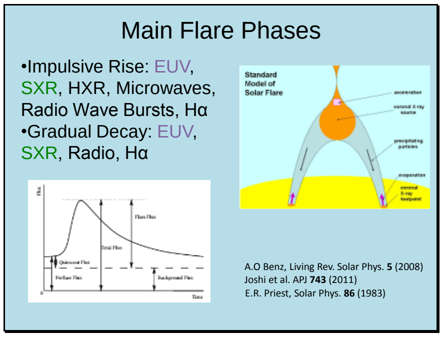


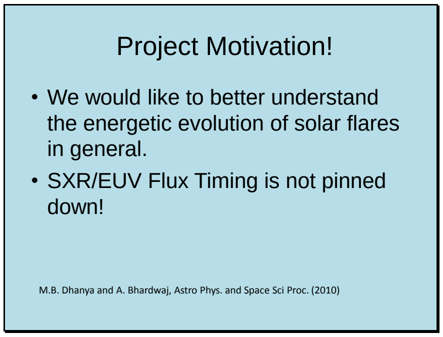
Image: large X class flare in June 2014
Solar flares, giant explosions on the surface of the sun, along with accompanying coronal mass ejections can damage communications satellites and can harm astronauts. The strongest events can even damage energy grids on the surface of the Earth. The underlying energetic mechanisms driving solar flares are still a subject of intense research. Here is a picture of strong X class flare that occurred in June of this year. Events like this can pose a threat to Earth if they occur in the right position on the Solar Disk.
NEXT

Slide 3



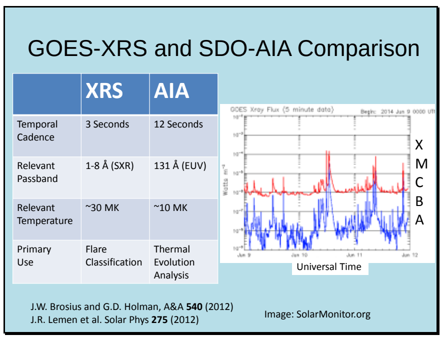
Moving on, I would like to give a brief overview of the main phases of a solar flare. Some quick definitions:
EUV – 10 -124 nm; SXR above 1 Angstrom, HXR below 1 Angstrom. It is important to note that EUV represents cooler emission than X-Rays do. Now for the phases.
After some possible slower pre-flare magnetic reorganization visible in EUV and SXR, flares truly begin when impulsive magnetic reconnection drives large numbers of accelerated charged particles from the corona towards the chromosphere. As the particles interact with the denser chromosphere, they emit HXR bremstrahlung (as well as EUV and SXR and many other wavelengths). As the chromosphere is heated, a pressure gradient drives hot plasma into coronal loops where we see peaking in SXR (and possibly Halpha white light). After the impulsive phase, we see a gradual decay in all wavelengths except radio. An important point is that EUV and SXR are present throughout the entire flare. The image on the bottom left shows an idealized flare SXR lightcurve that clearly delineated the impulsive rise and gradual decay of the flare. NEXT

Slide 4



Our goal in this project is to better characterize how energy is transported throughout the evolution of solar flares. In order to do this, we choose to analyze the timing relationship between peaks in SXR and EUV. This relationship has not been well studied and thus is a logical place to look for answers. NEXT

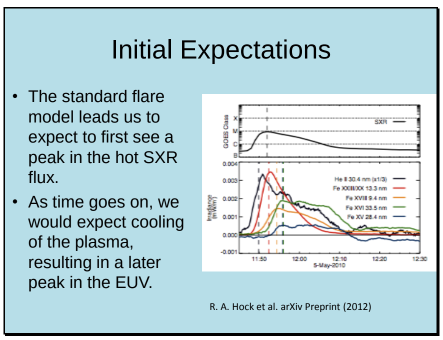
Slide 5



Here I give a summary of relevant characteristics of the two instruments used in my analysis: the x ray sensor aboard the GOES satellites and the atmospheric imaging assembly aboard SDO. Both instruments have quick temporal cadences which is great for our purposes. The GOES 1-8 angstrom passband, visible as red line in the figure on the right, is used to classify solar flares by maximum SXR flux. The classifications are visible on the right Axis. The two peaks in the middle are GOES X-class flares. Note that the SXR flux never reaches down to the A level due to our relative proximity to solar max. AIA has a very different purpose. Because each of the 10 EUV/UV passbands of AIA records ion transitions occurring at different temperatures, AIA can provide a map of the thermal evolution of a solar flare. Also it is important to note that GOES treats the entire sun as one pixel whereas one AIA pixel is .6 arcseconds on the sun. NEXT The

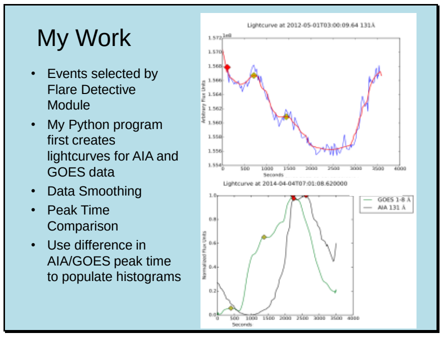
AIA 131 angstrom passband which I analyzed is sensitive to mainly 10 MK (Fe XXI) but also has some sensitivity at lower temperatures (Fe XIII) which I will discuss later. GOES SXR flux generally corresponds to flaring plasma at about 30 MK.

Slide 6



Initially, we thought the impulsive phase of the flare would drive the flare up very quickly to temperatures of about 20 to 30 MK causing the SXR to peak early. As the plasma cools back down to 10 MK and below, we would expect to see EUV emission peak. This pattern is demonstrated in the lightcurve of a medium sized C flare shown on the right. Except for the 304 angstrom line which shows footprint emission not loop emission, we see all of the EUV peaking after the GOES (data is from EVE spectrometer aboard SDO). NEXT

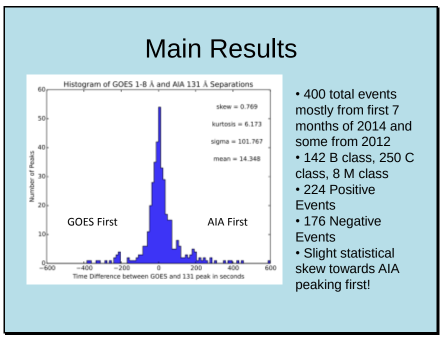
Slide 7



My portion of the project involved the analysis of events selected by Trae’s Flare Detective Module. For these events, I generated lightcurves for AIA and GOES for the duration of the event. Raw 131 Angstrom data is seen as the blue line in the top right image. As you can tell, this data is very noisy and I had to create a smoothing routine that would select off actual flare events from the noise. I worked to create a variable boxcar smoother that works on 7 EUV passbands of AIA as well as the GOES 1-8 Angstrom passband. The red line in the top image represents smoothed data. Once the data is smoothed, it is easier to find peaks that correlate with real flares. The yellow markers in the top image are examples of peaks my program found. The red marker here is a rejected peak. After peak finding, I wrote an algorithm to search for the same peak that Trae’s module found. The algorithm then finds the nearest GOES peak and once it has found a suitable goes peak, the computer turns back to AIA and sees if any AIA event was actually closer. An example of an event where the program found two AIA peaks near a goes peak is visible in the bottom right. The three red markers here represent peaks my program saw as closely related. In the end, my program chooses the absolute closest. After I ran my program on as many events as possible, I populated histograms with the time difference data. NEXT
My program can handle 7 EUV wavelengths from AIA:
94,131,171,193,211,304,335
Top Picture: blue line is raw 131 data, red line is smoothed data
red marker is a throw-away peak (too

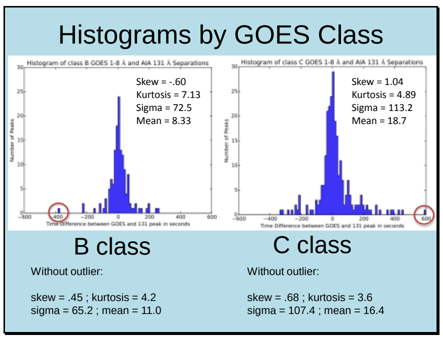
close to the edge for smoothing to be accurate), yellow marker is a relative peak,
Bottom Picture: green is goes and black is aia 131, red marker is the peak chosen by my algorithm

Slide 8



Here is data for all the analyzed events in one histogram. We have 400 events mostly from the first 7 months of year along with some random events from 2012. Of thes 400 events, 142 are B class, 250 are C class and 8 are M class. In the histogram, positive numbers of seconds on the x axis indicate AIA 131 is peaking before GOES and vice versa for negative numbers. In absolute terms, 224 events were positive and 176 were negative. In addition, we see a slight statistical skew toward AIA 131 peaking before the GOES. This surprised us! In order to reveal more about whats happening here, we split the events into histograms by class.
NEXT
400 Total Event (224 Positive Events, 176 Negative Events)
142 B class, 250 C class, 8 M class (no A or X class flares)
Skewed the right statisically as well (not a symmetric distribution) However, to get a better picture I separated the flares by class.
Kurtosis tells us the distribution is “peaked” but not extremely so

Slide 9



On the left we see the B class flares and on the right we see the C class flares. After removing the circled outliers, I recalculated statistical values and saw that the same relative patterns still occurred. The one exception is that the B class skew changed from negative to positive while the C class skew stayed positive. This is an indication that the B flare distribution is much more symmetric than the C class distribution. Surprisingly, we see greater number of positive events than negative events in both B and C flares. Also, note the smaller kurtosis and larger sigma for C class…this indicates a broader distribution for C flares. It is also important to note that I manually checked all outliers with separations above 200 seconds and below -200 seconds for true correlation with GOES peaks and trusted my program for the rest at least for now. NEXT

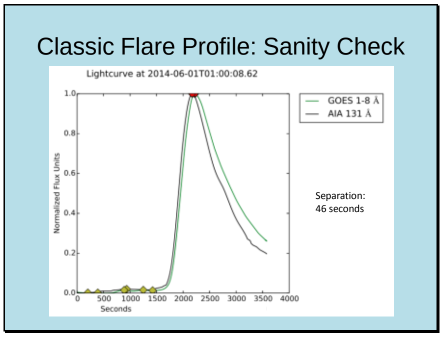
With outliers –

B (pos,neg) = (83,59)….C (pos,neg) = (136,114)…..M (pos,neg) = (5,3)

Without outliers --

Note both means are positive and both skews are positive (indicating preference towards 131 peaking first)

Slide 10



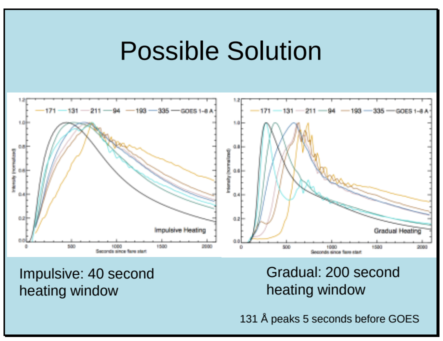
As a sanity check, I show here a typical flare lightcurve of a C 2.4 class event with the standard impulsive rise -> gradual decay pattern that exhibits 131 clearly peaking before the GOES. This picture along with the statistical information about our distributions convinced us to rethink our story. NEXT C 2.4 Event Impulsive-Gradual Shape....AIA definitely preceeds GOES peaks!

- Red markers indicate chosen peaks here

-Note this event shows that initial assumption has to be wrong as this seems to be a standard flare light curve and yet the 131 is peaking first!?

-We needed a new way to explain the temporal evolution of these flares

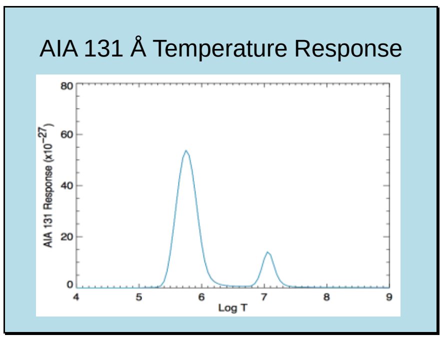
Slide 11



-In the last week or so, we have been analyzing MHD simulations performed by Kathy that show correlation between chromospheric energy input rate and EUV/SXR brightening order in AIA and GOES. If we deposit energy more gradually into chromosphere, we see a spreading out of EUV peaks and we can even get the 131 passband to peak 5 seconds before the GOES. One way to explain this is that the flaring plasma spends more time in relevant temperature zones for 131 passband. However, more crawling around parameter space is necessary (especially parameters governing magnetic structure) in order to see if we can produce events with separations on the scale of minutes. If this hypothesis is right, the emission we are seeing from the 131 passband should be the hot emission…what do I

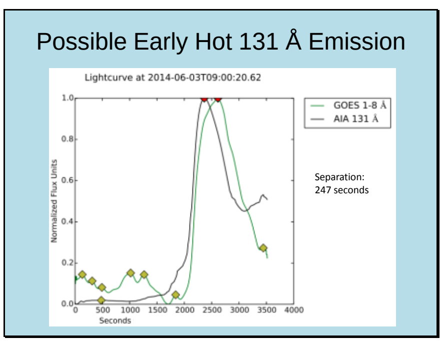
mean by this? NEXT
-40 sec heating window (impulsive)
-200 sec heating window (gradual)
-If this hypothesis is right, the peaks in 131 we see should be dominated by hot 131 emission
- I have picked an example flare with a large positive 131-goes separation to test the hypothesis.

Slide 12



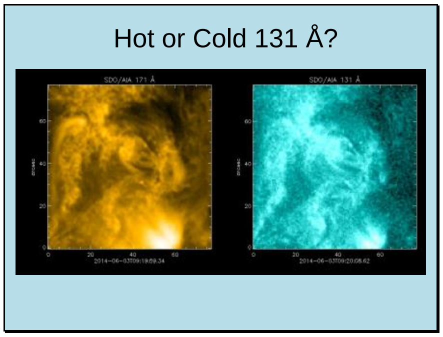
Here is the most recent temperature response function for AIA 131. As you can clearly tell, there are two main regions of sensitivity, one at chromospheric/transition region temperatures and one at flaring plasma levels around 10 MK. NEXT

Slide 13



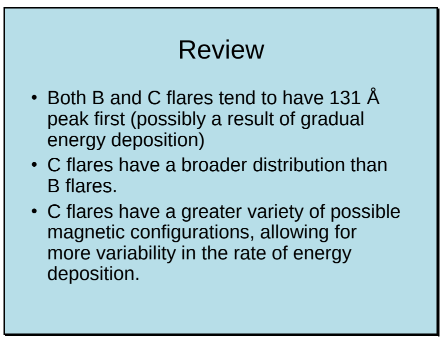
- To test our hypothesis I chose events where the 131 peaked dramatically before the GOES and analyzed them more carefully. Here is the lightcurve for one event where 131 peaks almost 250 seconds before GOES. First, I confirmed that this event was the dominant event on the Sun at the time of goes peak. NEXT
B 4.5 event on 2014/06/03

Slide 14



Next, I created a movie of the event in the 171 and 131 passbands. If the 131 emission is cold, we should see the same flaring in both images. Clearly we do not see the flare in 171 which is good evidence that the emission in 131 is hot emission. NEXT
B 4.5 event on 2014/06/03
Sep:250 seconds
600000 K for 171
10 MK for 131 (hot)

Slide 15



Although we originally thought we would see a skew towards GOES peaking before 131, we actually see the opposite. Our working assumption as of now is that in these cases, the energy is more gradually deposited into the flare loops. The other interesting result is that C flares have a more spread out distribution of 131-goes separation times with an even larger skew in the positive direction. Because larger flares require more complicated magnetic configurations, it is possible that larger flares also have more ways to release this stored magnetic energy, resulting in broader distributions for larger flares. Of course, we would need more M and X flares to test this hypothesis. NEXT

Slide 16

Extensions

- Run my program on more AIA channels for each event.
- More channels could help us narrow down whether we are seeing hot or cold emission in the 131 Å.
- Use GOES catalogue to narrow down spatial uncertainties.
- Use XRT data when available.

The first thing I could do to extend my project is to run my program on more AIA channels for each event. Comparing the 131 emission to emission in the 211 band which has a more localized peak around 2 MK would be able to confirm whether we are seeing hot or cold emission in the 131. Also, it is important that I narrow down spatial uncertainties in my study. To do this, I could only perform my analysis on events in the GOES catalogue of known flares. I could also narrow down spatial uncertainties by using XRT data when it is available for flares. NEXT NEXT NEXT NEXT
Also, could possibly do SXR/EUV timing with both XRT and AIA for flares that XRT has observed (added spatial reference check)
Also, examine X class flares for possible signatures of impulsive energy deposition

Slide 17

Acknowledgements

- Advisors: Kathy Reeves and Trae Winter
- Admins: Jon Sattelberger and Alisdair Davey
- AIA Satellite: Contract SP02H1701R from Lockheed Martin to SAO
- NSF 2014 REU in Solar Physics at SAO, grant number AGS 1263241

THANK YOU EVERYBODY!