Solar Flares in Metastable Magnetic Arches

Frank W. Hutchison[1], Sanjiv K. Tiwari[2,3], Ron L. Moore[4,5], Navdeep K. Panesar[2,3], Alphonse C. Sterling[5]

[1]Georiga Institute of Technology, Atlanta, GA; [2]Lockheed Martin Solar and Astrophysics Laboratory, Palo Alto, CA; [3]Bay Area Environmental Research Institute, Moffett Field, CA;
[4]Center for Space Plasma and Aeronomic Research (CSPAR), UAH, Huntsville, AL; [5]NASA Marshall Space Flight Center, Huntsville AL

Abstract

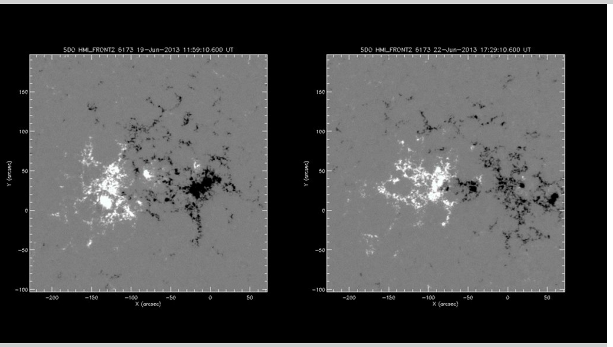
We present two GOES-class C1.5 confined (non-ejective-eruption) solar flares that occurred in a simple bipolar active region (AR) on separate days: 2013 June 19, 22. The observations are from the Solar Dynamics Observatory (SDO): transition-region and coronal UV and EUV images from SDO's Atmospheric Imaging Assembly (AIA), and line-of-sight magnetograms from SDO's Helioseismic and Magnetic Imager. It appears that this AR's magnetic field had the overall form of an arch having no sharp polarity inversion line or sheared-field filament and/or filament channel snaking through its core. No AR-spanning sigmoid field erupts to make either flare. In the UV and EUV images, the flare ribbons turn on suddenly, do not spread apart substantially, and do not grow much wider. The AR's magnetic flux content shows no conspicuous rise or decline on the day of either flare. These results suggest that these confined flares might work quite differently than flares that fit the filament-eruption-based standard model for confined flares like Moore et al. (2001). We present a cartoon depicting a magnetic loop having left-handed magnetic twist surrounded by right-handed-twist field in a magnetic arch, supposedly metastable against reconnection. We conjecture this equilibrium configuration of opposite-twist arched field could be bumped/triggered to suddenly reconnect, thereby consuming the embedded opposite magnetic twist and heating a flare loop like those in our two flares.

Introduction

Solar flares are phenomena that predominantly occur in active regions of the sun. There are different classes of flares based on the amount of energy released. A large proportion of the flares studied have been observed to work similar to one another, leading to models such as Moore et al. (2001) that describe ejective and confined standard flares. In models such as these, flares have clearly defined neutral lines between oppositely polarized regions. Close to the neutral line is the core field, and in certain instances it can be sheared along the neutral line. The sheared core field has a filament above the neutral line. Eventually the magnetic field lines going from one polarized side to another touch, leading to magnetic reconnection (tether cutting). The bases of the new field lines are flare ribbons that start to spread away from the neutral line. Above the core field resides the envelope field. The newly reconnected field lines either move down into the core field or up into the envelope field. Further reconnection in the core field starts with the lower field lines but eventually includes the upper field lines. This leads to an explosion. If the explosion opens the envelope field, the result is an ejective eruption with more magnetic reconnection and coronal mass ejection (CME). If the explosion does not breach the envelope field, the result is a confined eruption with magnetic reconnection ceasing and no CME.

Goal

The purpose of the project is to analyze two flares that occurred on June 19, 2013, and June 22, 2013, and compare those observations with flares that better fit the standard model. If we can better understand the mechanisms that start these particular flares, we might be able to apply the same understanding to the mystery of coronal loop heating.



Figs. 1-2

HMI line-of-sight magnetograms of the first flare at 12:00 UTC on June 18, 2013 (Fig. 1) and of the second flare at 17:30 UTC on June 22, 2013 (Fig. 2).

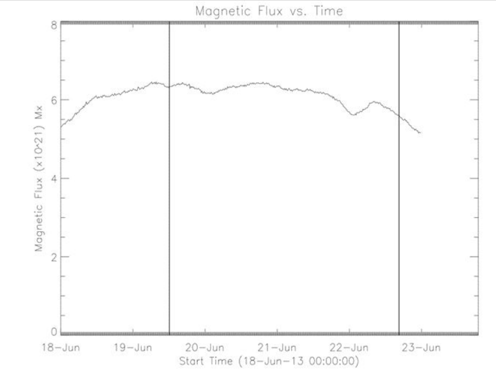
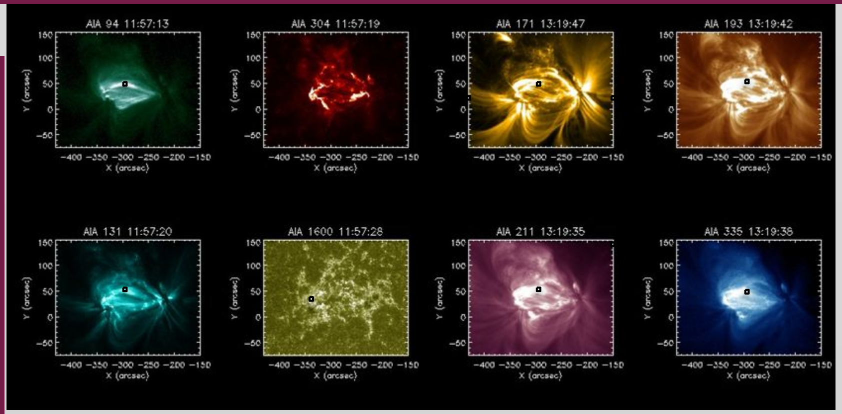


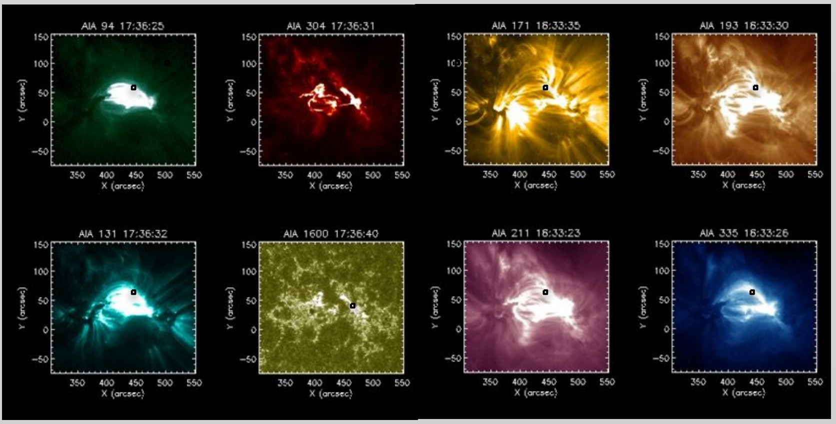
Fig. 3

A magnetic flux plot starting on June 18, 2013 and ending on June 23, 2013. The flux does not fluctuate significantly during the times when the flares occur. The vertical lines represent when each flare occurred.



Figs. 4-7

All figures are AIA images. Figs. 4 and 6 show 94, 304, 131, and 1600 Å. Figs. 5 and 7 show 171, 193, 211, and 335 Å. Figs. 4 and 5 correspond to the first flare, and Figs. 6 and 7 correspond to the second flare. Each figure is when the flare is most easily visible for those wavelengths. The boxes indicate what area was used for the light curves.



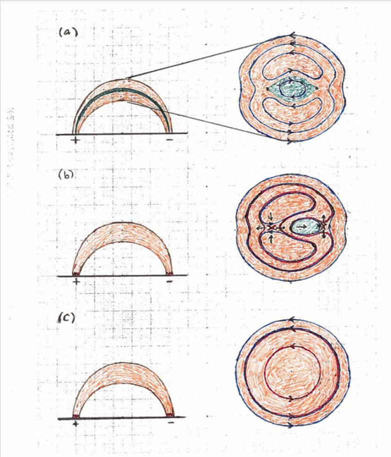


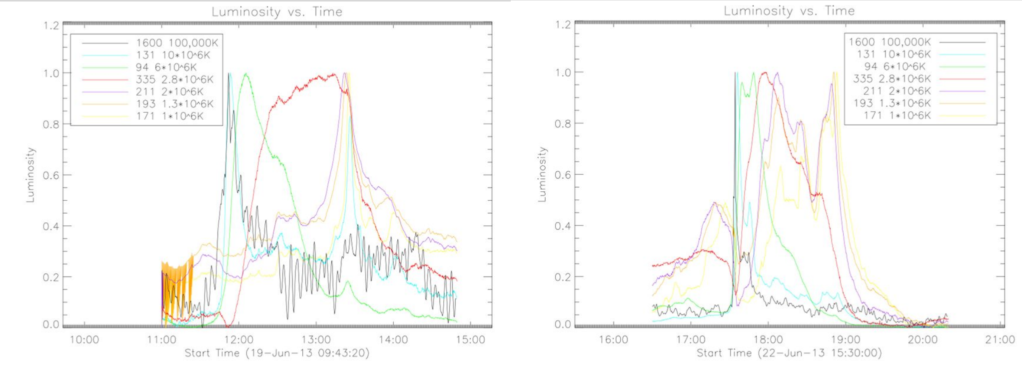
Fig. 10

A cartoon that is a possible alternative explanation to the standard model of how these flares work.

Acknowledgements

I would like to thank the UAH CSPAR/NASA Heliophysics REU Program for giving me an opportunity to participate in this research. I would also like to thank my mentors: Dr. Tiwari, Dr. Moore, Dr. Panesar, and Dr. Sterling for all their guidance. Finally, special thanks to Christine, Al, Dr. Yalim, and Stephen, because without them I would never have understood the "wonder" that is IDL.

Results and Methods



Figs. 8-9

Fig. 8 is the light curve of the first flare, while Fig. 9 is the light curve of the second flare. For both, the peak of the 1600 Å ribbons is before the hottest wavelengths of 131 and 94 Å. The temperature decreases and enters the ranges of the other EUV wavelengths, leading to peaks in the 335, 211, 193, and 171 Å. Temperatures for each wavelength are provided from Lemen et al. (2012).

We used the Joint Operations Science Center (JSOC) website to download fits files of the Solar Dynamics Observatory's (SDO) AIA wavelengths in 94, 131, 171, 193, 211, 304, 335, and 1600 Å as well as line of sight magnetograms. We then used IDL to convert and analyze the data. For the period June 18, 2013 to June 23, 2013, magnetograms and AIA were taken at a 15-minute cadence. When we analyzed each flare individually, we downloaded AIA and magnetogram images for a 230-minute duration starting an hour before each flare. For the 230-minute duration, AIA images were taken at a 12s cadence while the magnetograms were taken at a 3-minute cadence. Sub-maps were used for the loops of EUV wavelengths and ribbons of 1600 to generate light curves. Fixed difference and 304/1600 contours on magnetograms images were created and then turned into movies. After analyzing the data, movies, and images, we found that there was no clearly defined neutral line or filament. There was also no shearing in the core field. Instead, the flare ribbons turned on suddenly, moved inconsequentially, and remained relatively constant. The ribbons did not have a long duration and turn off quickly.

Conclusion

The results seem to suggest that these two flares do not act in the same way as flares that fit the standard model like the one described in the introduction. The trigger mechanisms appear to be different. So, we present an alternative possibility to the standard model (shown in Fig. 10). For the cartoon, (a) is before reconnection, (b) is during reconnection, and (c) is after reconnection. The three drawings in the first column are lengthwise vertical cross-sections of the middle of a metastable flux-tube loop of an active region magnetic arch. The three drawings in the second column denote the magnetic field twist component in the orthogonal cross-section through the top of the loop. In each of these drawings, orange is where the magnetic flux has a right twist, while green is where the magnetic flux has left twist. For the second column of drawings, blue represents non-reconnected magnetic fields, and red represents reconnected magnetic field lines. For (a), the null points are denoted with dots that are at the end of the green (left twist) region. In (b), a red X denotes reconnection in each null region. Arrows show reconnection inflow and outflow to and from the reconnection on the left side of the green domain. Two arrows show outflow from the reconnection on the right side of the green domain, and another arrow shows that the green domain (which by now has moved to the right enough that it no longer intersects the lengthwise vertical cross-section) is being expelled to the right. In (c), the left-handed magnetic twist has been entirely consumed by its reconnection with right-handed twisted magnetic field, so that the arch loop no longer has any left-handed magnetic twist in it. In (b) and (c), the jagged red at the loop feet represents flare-ribbon brightness in the feet of the flaring loop.

References

1. Onset of the Magnetic Explosion in Solar Flares and Coronal Mass Ejections
Ron L. Moore et al. 2001, ApJ

2. New Evidence that Magnetoconvection Drives Solar–Stellar Coronal Heating
Sanjiv K. Tiwari et al. 2017, ApJL

3. The Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO)
James R. Lemen et al. 2012, Sol Phys 275, 17-4