Deriving Magnetic Reconnection Rate in the M6.5 Flare on 2015 June 22 With Highest Spatial Resolution

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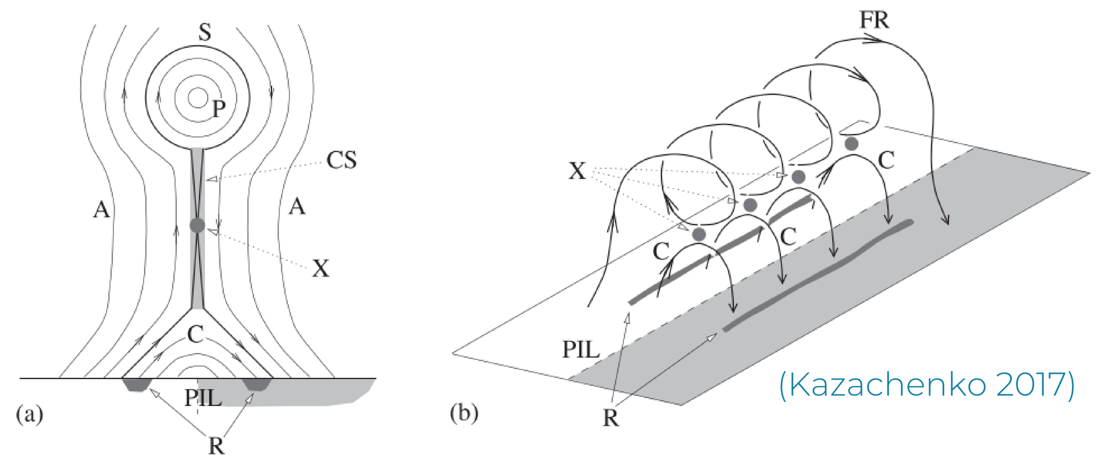
Introduction



The goal of this study is to quantitatively derive magnetic reconnection rate in a solar flare. Although direct measurements of reconnection rate at the reconnection site (X) in the coronal reconnecting current sheet (RCS) are still not possible at this time, two physical quantities, electric field E and reconnection flux change rate $\dot{\Phi}$, can be obtained from flare morphology observations and regarded as a proxy for the coronal reconnection rate (Forbes & Priest 1984) . The Reconnection flux change rate $\dot{\Phi}$ can be calculated by

$$\dot{\Phi} = \frac{d}{dt}\int B_z\, da$$

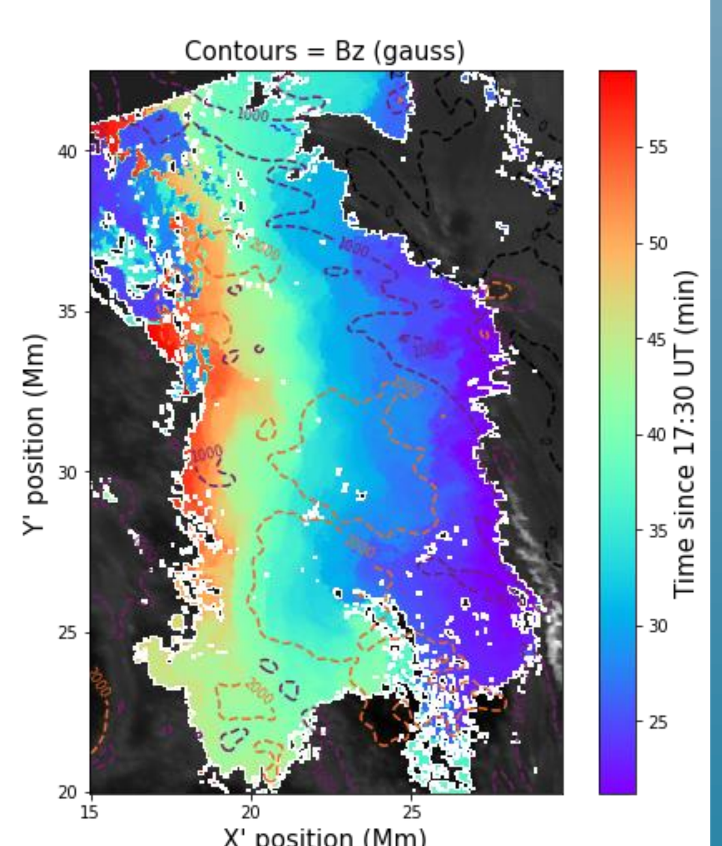
where B_z is the outward magnetic field at the ribbons (R) and da is the newly brightened area. If the standard 2D model applies, this reconnection rate is proportional to the reconnection rate E along the coronal separator,

$$E = v_{rib} B_z$$

where v_{rib} is the ribbon velocity. Both B_z and v_{rib} are contributing factors in deriving E. To the extent that the reconnection rate E is constant and uniform along the third dimension, we would expect there to be a negative correlation between v_{rib} and B_z.

Data

The advantage of my study is the high-resolution (0.09"/pixel) Hα data from the Goode Solar Telescope (GST) at the Big Bear Solar Observatory. A light bridge region between two sunspots is clearly resolved, and I can track the flare ribbon motion across this region of weaker B_z. The cadence was about 28.3 s. B_z was obtained from GST's Near-infrared imaging spectrometer (NIRIS) and is assumed to not change significantly over the course of the flare.

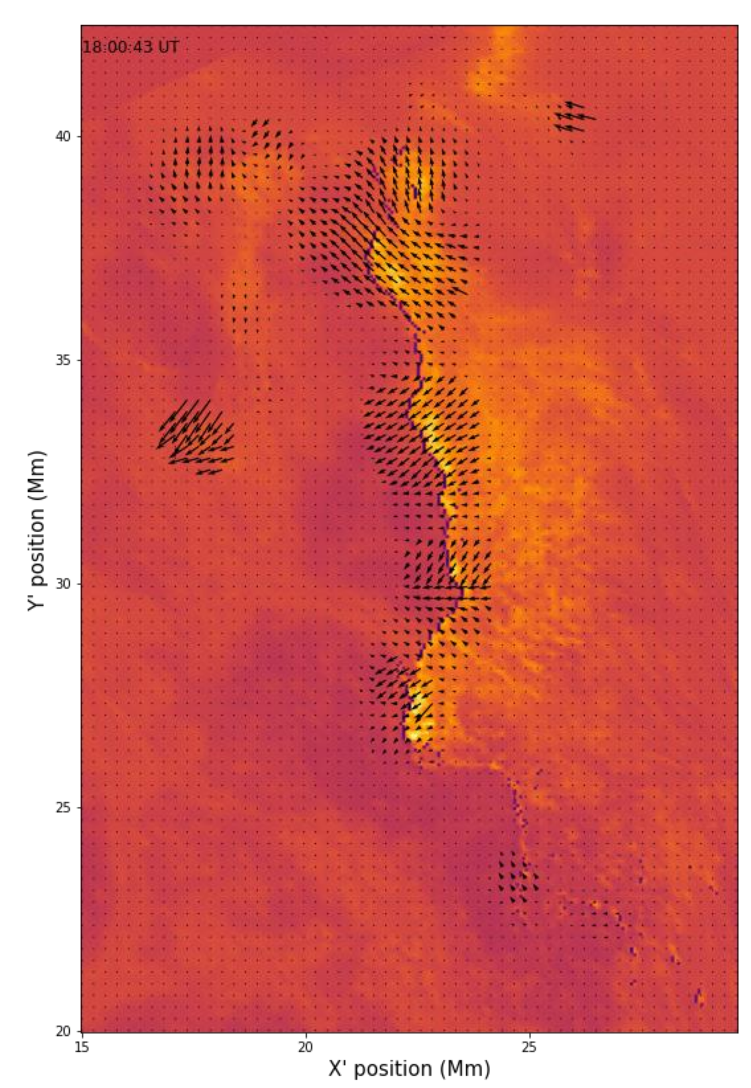


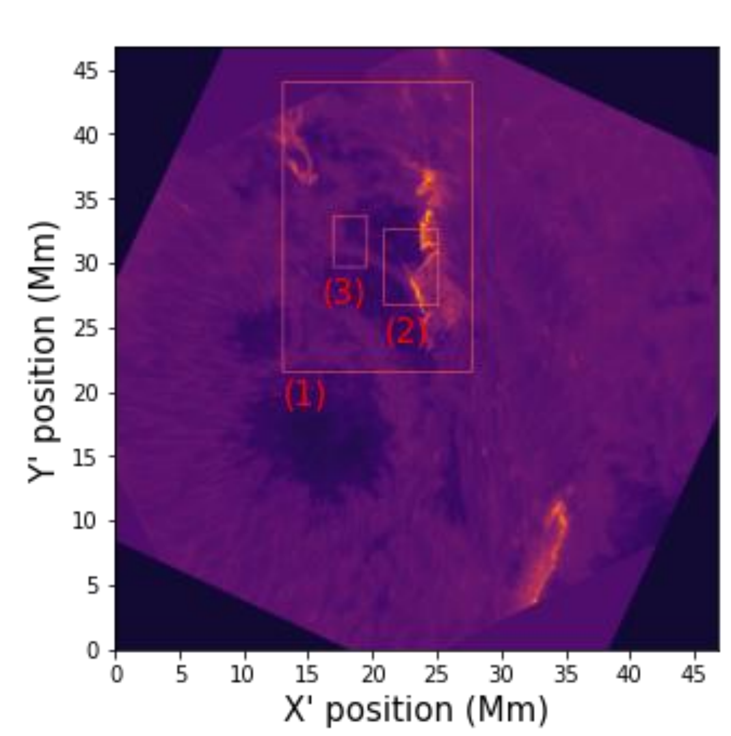
Methods

This section describes the methodology for finding the ribbon velocity for the interested reader. First, the data is cropped and rotated so that the ribbon moves horizontally. The horizontal component will act as a proxy for perpendicular ribbon velocity. A preflare image is subtracted away to remove the background sunspots. A local correlation tracking (LCT) method is employed to find the ribbon velocity everywhere. A window size of 1 Mm is employed to compromise between program run time and ability to see large changes in position.

Once velocity is found it remains to detect the leading edge. The edge detection algorithm employed is called the canny method. It requires hysteresis threshold values which are found empirically. Only pixels with intensities above a certain threshold are included. Edge pixels leading the main ribbon such as those from small brightenings are manually removed, and the array is traversed to only keep the easternmost pixel of each row. Overall, the edge detection does not work perfectly, as at times the ribbon is not bright enough or distinct enough.

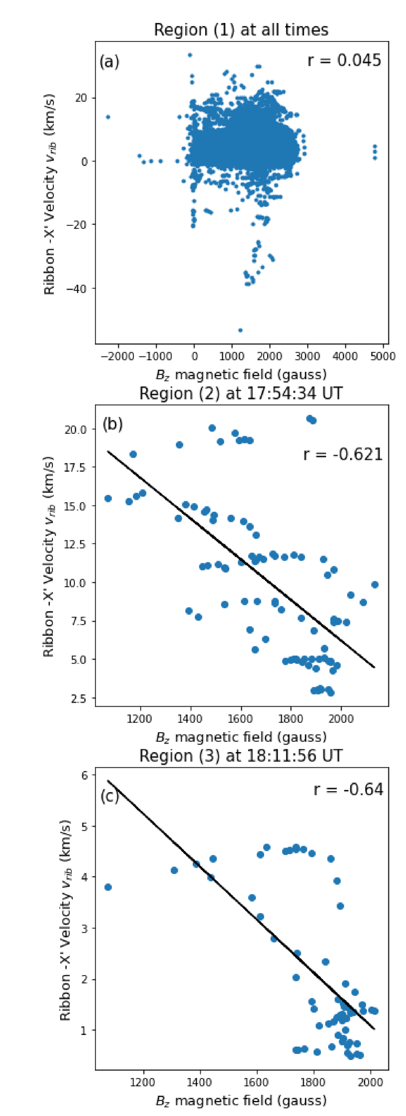
To take advantage of the high resolution Hα data, we can focus on some smaller regions of the flare. The ribbon enters the light bridge region of weaker magnetic field at region (2) and leaves the light bridge region at region (3). The entire flare ribbon passes over region (1).

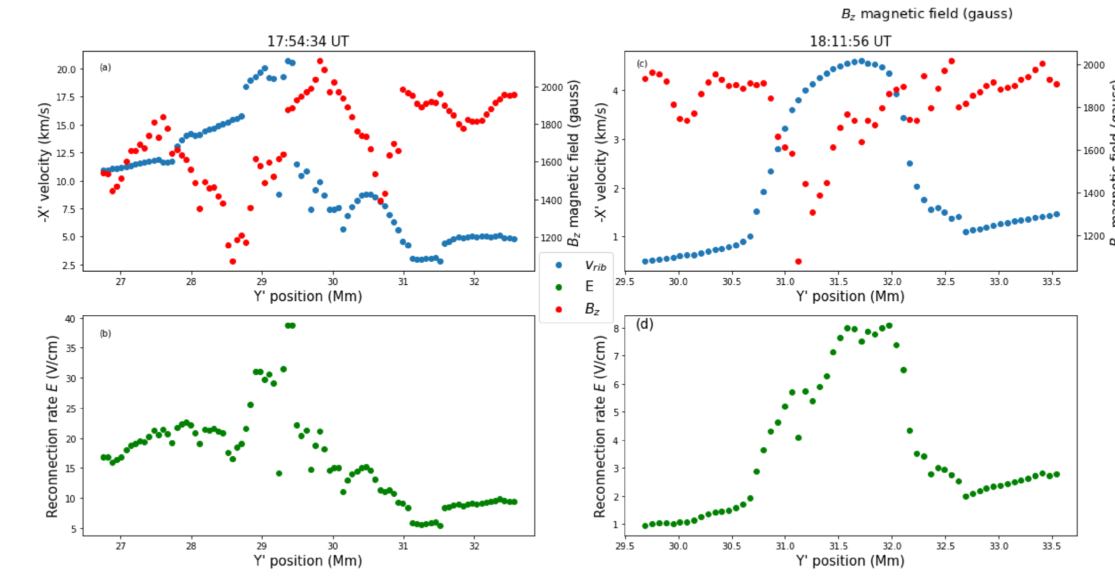




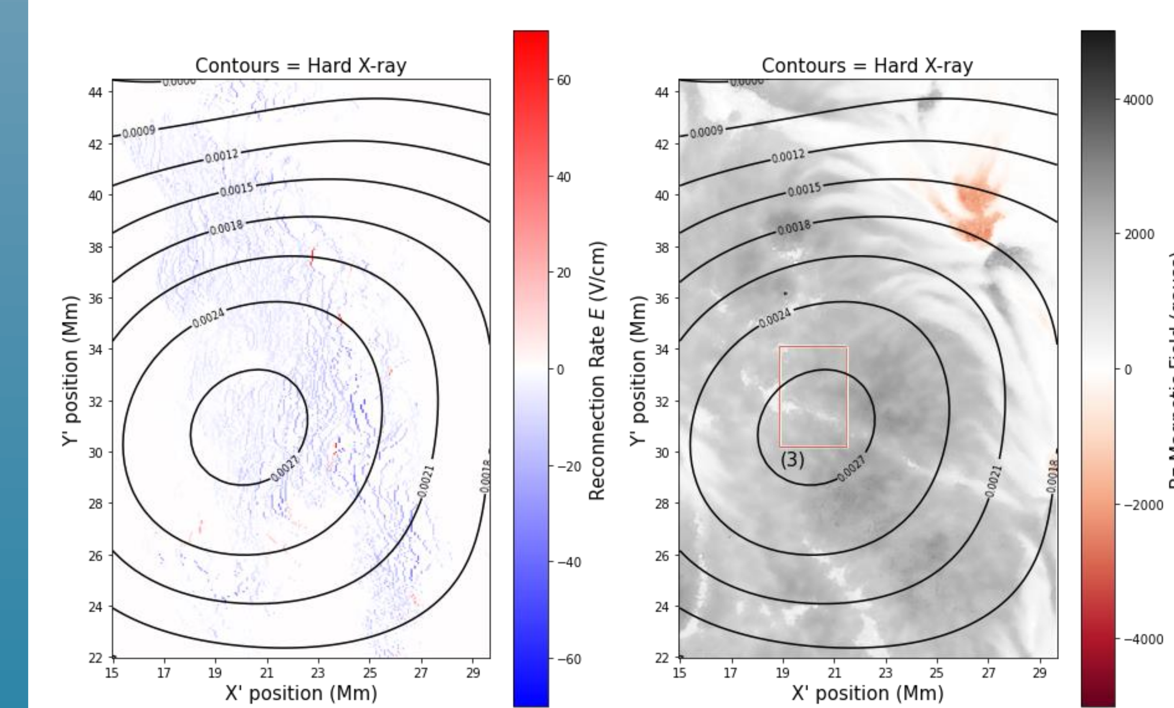
Results

To the extent that the reconnection rate E is constant and uniform along the third dimension, we would expect there to be a negative correlation between v_{rib} and B_z. An inverse relationship between v_{rib} and B_z only exists for short times at small areas of the flare. As seen to the right, considering all detected pixels, there is no correlation, suggesting E is not constant or uniform. Only at specific locations and times is v_{rib} negatively correlated with B. For instance, in region (2) when the ribbon enters the light bridge and region (3) where the ribbon exits the light bridge. As seen below, for these two specific times, enhancements in v_{rib} are cospatial with drops in B_z and vice versa. E is more uniform than the velocity distribution, although still not approximately uniform.



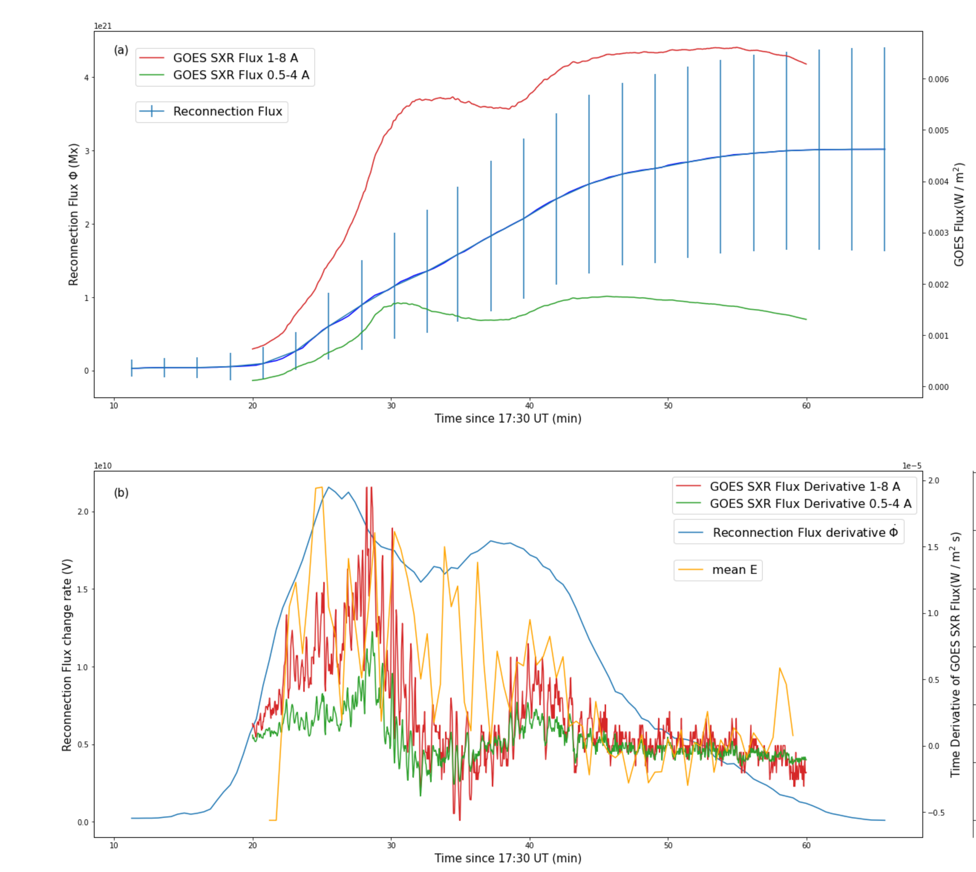


Next, I compare the spatial distribution of E with Nonthermal 50-100 keV hard X-ray (HXR) emission from RHESSI. The peak HXR emission is located on the light bridge near region (3), where there is a relatively weak E. E appears to be strongest in the west near the polarity inversion line.



Results (cont.)

Besides spatial distribution of E, we are also interested in the temporal evolution of $\dot{\Phi}$, calculated using a well-known method (Kazachenko 2017). It is well known that the soft X-ray (SXR) flux derivative correlates with the HXR flux (Neupert 1968). The smoothed $\dot{\Phi}$ exhibits two peaks at approximately the same time as peaks in SXR derivative. Average E is enhanced during the peaks and between the peaks. Others have also seen correlations between HXR and $\dot{\Phi}$ (Qiu 2004).



Conclusion

The reconnection rate E is found to not be uniform in space or constant in time. Only at certain times and places, such as when entering or exiting the light bridge, is there a negative correlation between v_{rib} and B_z. The spatial distribution of E is calculated using high spatial resolution and is found to not be cospatial with the peak nonthermal HXR. Reconnection flux change rate $\dot{\Phi}$ is confirmed to correlate with nonthermal SXR derivative curves, and E exhibits some correlation.

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