OBSERVATIONAL EVIDENCE FOR CORONAL MAGNETIC RECONNECTION DURING THE TWO-RIBBON FLARE OF 21 MAY 1980

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The 21 May event was a large two-ribbon flare which occurred in active region 2456 at S13W15. The flare was extensively documented by coordinated Hα, X-ray, and magnetograph observations. In particular, spatially resolved images in hard X-rays were obtained by the Hard X-ray Imaging Spectrometer (HXIS) aboard SMM. Hence this flare comprises an ideal example for studying the spatial relationship between the X-ray and Hα-ribbon morphologies. Although evidence has been reported for magnetic flux emergence at the beginning of this flare (Harvey, 1983), it appears that a potential field (rising source-surface) model may adequately represent the major large-scale features of the magnetic configuration believed to result from fieldline reconnection in the corona during the decay phase (Kopp and Pneuman, 1976).

The enhanced ohmic heating associated with magnetic merging suggests trying to observe the signature of the reconnection process directly in the form of localized thermal X-ray emission from the region around the neutral point. As reconnection proceeds and the neutral point rises into the corona, we would expect the X-ray source region to move to sequentially greater heights above the flare site and the emission to shift toward lower energies. For a flare located at some distance from the center of the solar disk, then, the centroid of X-ray emission should appear to drift toward the limb as the event progresses. Moreover, the X-ray source drift rate should roughly mimic that of the Hα ribbons - i.e., it should be rapid at first, whereas later in the event, as the ribbons become nearly stationary in position, this motion should be greatly reduced. These trends should be readily observable for the flare of 21 May, 1980.

To this end we measured the flare ribbon separation over the time interval from 21:00 to 23:00 U.T. from full-disk Hα filtergrams provided by NOAA's World Data Center. The resulting profile of ribbon separation versus time displays a steep initial rise, starting from a separation of ~25,000 km at 21:05 U.T. and growing to ~38,000 km at 21:30 U.T. Subsequently the ribbon motion slows down considerably, and a maximum separation of ~45,000 km is reached by 23:00 U.T.

In the same time interval an analysis of HXIS images of the flare region reveals that the location of maximum X-ray emission shifts gradually southwards with time, while showing up in progressively lower energy channels. We assume that, in the highest energy channel of HXIS for which measurable emission is present at any instant, the position of the brightest pixel corresponds to the tops of newly reconnected field lines. Then one can take into account projection effects and easily derive the true height of these loops, provided that they lie vertically above the chromospheric magnetic neutral line. The position of strongest HXIS emission is shown as a function of time in Figure 1, in

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terms of either projected distance from the $H_{\parallel} = 0$ line (left scale) or height above the solar surface (right scale). A more detailed description of the HXIS observations of this flare has been given by Švestka and Poletto (1984).

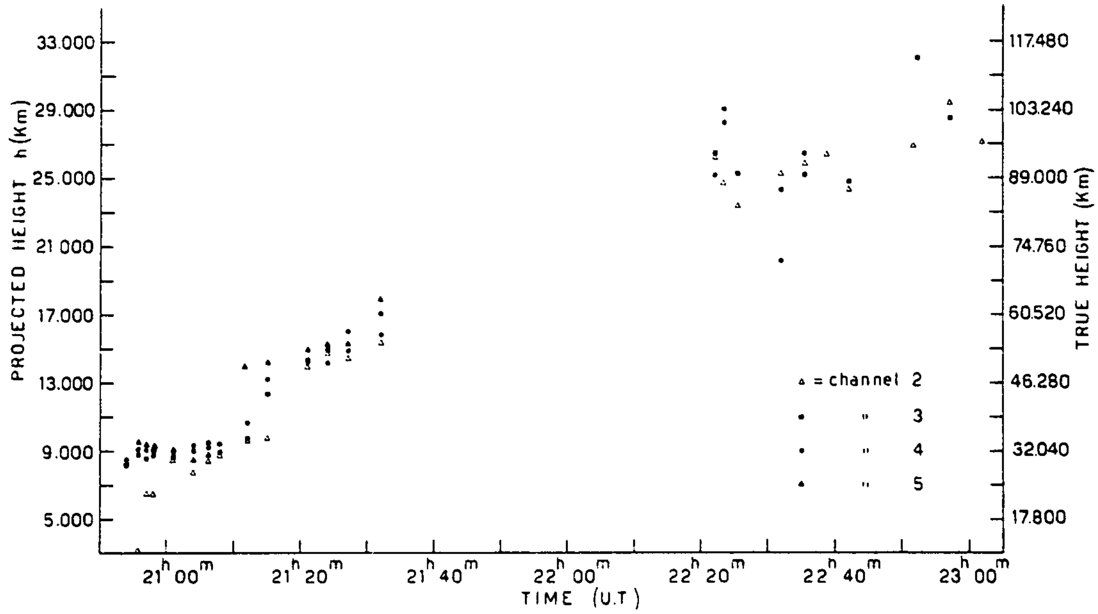

Figure 1. Position of the brightest X-ray emitting region as a function of time. Left scale: the projected distance of the region from the magnetic neutral line ($H_{\parallel} = 0$) in the chromosphere. Right scale: true height derived under the hypothesis of vertical loops.

In view of the qualitative agreement between the observed and expected behaviors of the hard X-ray emitting region, we have attempted to test these ideas more rigorously by using a specific magnetic field model for the reconnection geometry to predict the height of the neutral point as a function of Hα ribbon separation. Using the observed ribbon-separation time history mentioned above, this prediction can then immediately be compared with the true heights of the X-ray source region shown in Figure 1.

The magnetic model used for this purpose has been described at length elsewhere (Kopp and Poletto, 1984). It consists of an axisymmetric potential field model between the solar surface ($r = r_o$) and an equipotential spherical source surface ($r = r_1 \geq r_o$), joined smoothly to a nonpotential radial field beyond r_1. For simplicity the normal component of the surface magnetic field in the active region is approximated by one "lobe" of a single high-degree Legendre polynomial, chosen to represent approximately the location and latitudinal width of the region. The neutral point lies on the source surface directly above the chromospheric $H_{\parallel} = 0$ line, and the reconnection process is modeled by allowing r_1 to increase with time in a prescribed manner. Within the framework of this simple model, the leading edges of the expanding flare ribbons are defined by the intersection with the solar surface of the two magnetic separatrices passing through the neutral point.

For the 21 May, 1980 flare, the physical size and disk position of the active region are well represented by the 21-st lobe of a P_{48}-field.

The solid curve in Figure 2 shows the resulting theoretical prediction of ribbon separation as a function of height of the neutral point. The open circles, by comparison, give the observed separation of the leading edges of the Hα ribbons versus the true height of X-ray emission. This comparison clearly reveals that, although the empirical relation exhibits the same overall trend as the predicted one, the X-ray emission for a given ribbon separation appears to originate from a greater height than that where the reconnection is occurring. There are at least two possible explanations as to why this behavior differs from the results of previous studies (e.g., Kopp and Poletto, 1984).

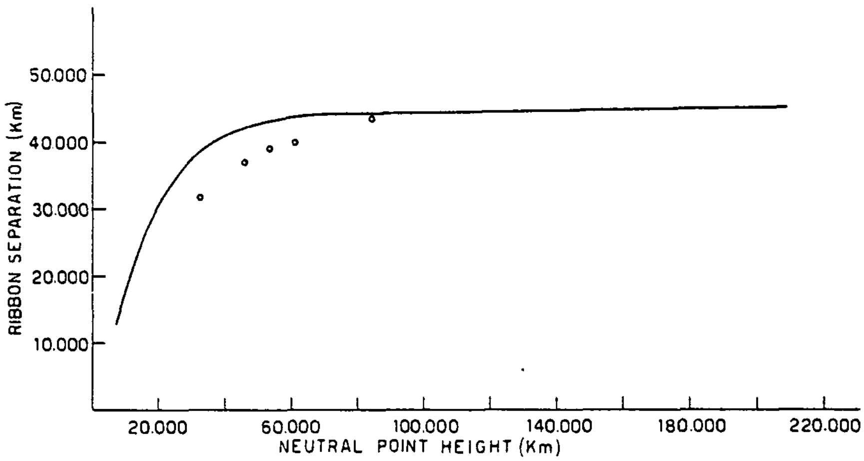

Figure 2. Solid curve: predicted relationship between ribbon separation and neutral point height. Open circles: HXIS loop heights versus ribbon separation.

First, note that spatially resolved X-ray observations of two-ribbon flares prior to the SMM generally tended to emphasize the softer spectral regions, with relatively low sensitivity in hard X-rays. But, as we indicated at the outset, the position of the reconnection region at any time should correspond to the zone from which the very hardest thermal X-rays are being emitted, with softer X-rays coming from lower heights. Therefore, unless the hard X-ray emission from a particular flare is unusually intense, such data could have easily caused one to underestimate the height where reconnection is occurring. In this case the apparent conformity found earlier between observations and model predictions would be fortuitous. To improve the agreement in the present example, one could perhaps modify the model slightly by considering that the actual fieldline geometry near the neutral point may have a more slender cusp shape than that which characterizes the source-surface model. This would raise the reconnection region to coincide spatially with the hard X-ray source region, while leaving unchanged the remaining properties of the model.

Alternatively, we consider the possibility that the reconnected loops do not lie in a vertical plane; such has already been suggested by Švestka et al. (1982). If the loops were inclined away from disk center, then the true heights from which the HXIS emission originates would be lower than we have estimated here, and the observed hot loop heights might still coincide with the predicted neutral point heights. However, this situation could only be described adequately by a three-dimensional model.

On the basis of correlative observations of a single flare, one cannot decide between these two possibilities. It could also be the case that each of these explanations applies at different times during a given flare, depending upon the magnetic field configuration at the sun's surface; additional examples of two-ribbon flares with complete X-ray and magnetograph coverage are needed to draw a definite conclusion.

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