RECONNECTION DRIVEN CORONAL TRANSIENTS

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The association of coronal transients with two-ribbon solar flares is well established. During the Skylab period, every two-ribbon flare when observed close enough to the limb was accompanied by a coronal transient. Flares do not occur with all transients, however many of these transients are associated with soft X-ray enhancements in the corona similar to but less energetic than the intense X-ray loops that occur with two-ribbon flares [cf. MacCombie and Rust (1979) for a review]. The eruption of a filament seems to be the ingredient common to all these events - more so than flares. For these reasons, we consider this class of phenomena, regardless of whether a flare occurs or not, to be exhibiting a common physical process. To produce chromospheric emission requires a substantial amount of energy. Hence, one should expect chromospheric flares to be associated with only the most energetic phenomena. Nevertheless, the most comprehensive observations covering a wide range of wavelengths (Hα, EUV, X-ray, radio, white light) are available for the large two-ribbon flares, and the study of these events sheds the most light on the mechanism which produces coronal transients.

The most striking feature of two-ribbon solar flares are the large flare loop systems which rise slowly upward to great heights in the corona beginning at the very onset of the flare and persisting for some 10-20 hours following the flash phase. The loops are seen in Hα, EUV, and soft X-rays with the cooler Hα loops nested beneath the hot X-ray loops. The footpoints of the loops are rooted in the chromospheric flare ribbons which expand slowly outward from the magnetic neutral line during the course of the flare. The Hα loops are rooted to the insides of the ribbons and the X-ray loops to the middle and outside. A careful examination of the observations shows that the system is <u>not</u> comprised of rising fluxtubes but, rather, of discrete stationary <u>new</u> loops being formed at progressively higher levels in the corona. All of these observations are consistent with the concept that the loops are formed via <u>magnetic</u>

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reconnection of field lines distended outwards by the eruption of the pre-flare filament [cf. Pneuman (1979)]for a review .

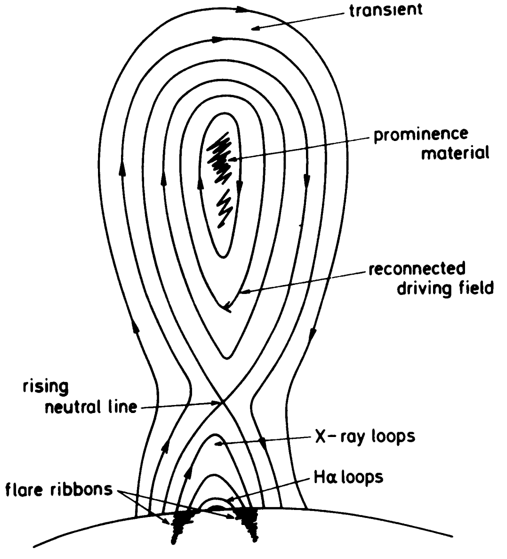

Fig. 1 Schematic of Transient and Flare Loop Configuration

If this concept of the two-ribbon flare (and similar enhancements without flares) is correct, then the propulsion mechanism for the coronal transient can be understood as a natural consequence of the reconnection process. When two oppositely directed field lines reconnect, a lower loop is formed rooted to the solar surface (the flare loop). In addition, an upper loop disconnected from the surface is produced. We suggest that this upper disconnected new flux provides the driving force for the transient and prominence material. A schematic of the geometrical configuration of the transient and flare loop system is shown in Figure 1.

The feasibility of this mechanism can be demonstrated by a crude mathematical example. Using the same formulation of the MHD equations as well as the same geometrical model for the transient geometry (an arcade with a semi-circular top and radial legs) as employed by Pneuman (1979a), the equation of motion for the transient can be written in the form

$$V \frac{dV}{dS} = \left(\frac{\alpha F^2}{8\pi \rho_o D_o S_o^{\ 4}} - \frac{B_o^{\ 2}}{4\pi\beta\rho_o S_o} - \frac{GM_\odot}{S_o^{\ 2}} \right) \left(\frac{S_o}{S} \right)^2 \qquad (1)$$

where V is the velocity, S the displacement from the solar center, F the reconnected flux, ρ_o the reference density*, D_o and S_o the initial

*Here, the density should be interpreted as an average over the transient and prominence material.

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width and displacement of the arcade, B_o the initial field strengh in the transient at its top, $\beta = \tan\theta/(1+\tan\theta)$, θ being the half angle between the transient's legs, and α is a constant relating the field strength behind the transient to the reconnected flux. In deriving Equation (1), we have made the assumption $D \propto S$ (D being the width). This is borne out by the observations and by previous solutions of equations of this type (Pneuman, 1980) . In order to relate F to the displacement, we note two properties of the reconnection process. Firstly, the strength of the fields that reconnect early in the event is expected to be much larger than of those that reconnect later - since these are lower down in the corona. Secondly, as the process proceeds upward into the corona, the velocity of the neutral point decreases. Hence, the rate of reconnection is faster during the early stages. For these two reasons, we expect the reconnected flux to increase sharply in the beginning but quickly approach a constant value when the increments to the total flux become negligible. This dependence of the flux on time should also be reflected in its dependence upon S since S is a monotonically increasing function of time. These considerations lead us to parameterize F as $F = K[1-(S_o/S)^k]$ where K is the limiting value of the flux and k determines how quickly the flux achieves this limiting value.

Now, the solution of Equation (1) is straightforward. Assuming $V = 0$ at $S = S_o$, the terminal velocity (at $S = \infty$) is given by

$$V^2_{\text{terminal}} = \frac{2k^2}{(k+1)(2k+1)}\left(\frac{\alpha K^2}{4\pi\rho_o D_o S_o^{\,3}}\right) - \frac{B_o^{\,2}}{2\pi\beta\rho_o} - \frac{2GM_\odot}{S_o} \quad .$$

Thus, the terminal speed of the transient is increased, not only by larger magnitudes of reconnected flux (large K), but also by adding a given amount of flux at a faster rate (large k). A more complete and precise model of this process is currently under preparation (Anzer and Pneuman, 1979).

Finally, we touch on two additional flare associated phenomena which we believe can be understood within the context of the present model - moving Type IV radio bursts and proton events. It is generally believed that the Type IV burst consists of synchrotron radiation produced by relativistic electrons. We suggest that these electrons are energized by the reconnection process and injected into the upper closed fields where they remain trapped. Similarly, protons are injected into this same region behind the transient's leading edge. The unusually late arrival time of energetic protons at 1 AU after major flares could be explained as due to the inability of the protons to escape across the field lines of this closed geometry of the transient. Hence, the protons cannot reach the earth until the transient does.

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DISCUSSION

Kahler: Which comes first: do you first have reconnection which then drives the filament upwards or does the filament first erupt, setting up the reconnection process?

Pneuman: For this mechanism to work, it does not really matter. One could visualize the prominence lifting allowing field lines underneath to collapse inward and reconnect. Alternatively, the reconnection could start first, providing additional magnetic flux beneath the filament which pushes it outward. It may be difficult to distinguish between these two possibilities observationally, but I tend to favor the latter explanation.

Kuperus: I am interested to know whether the prominence eruption is because of reconnection or just the opposite.

Pneuman: This is essentially the same question that Dr. Kahler asked. It is the fundamental question. I favor the reconnection starting first only for the reason that only one mechanism need be evoked for the whole process rather than having to explain the destabilization of the filament as well. The other possibility is that both occur together and are really a manifestation of the same process.

Newkirk: Your model appears to leave the corona in a state after the transient which is just the opposite from that observed. One of the outstanding characteristics of loop-like coronal transients is that the corona in the range 1.5 to 6 $R_\odot$ appears to be open after the passage of the transient with the "legs" of the loop visible for many hours. The final configuration of your model is one with closed fields or a coronal stream.

Pneuman: That's right. A coronal streamer is formed during this process and the field lines above the helmet (in the coronagraph's field of view) are indeed open, being held open by the solar wind. As the X-ray observations suggest , the reconnection rate and rise rate of the neutral point slows down, and the neutral point comes to rest at some height in the corona determined by the equilibrium conditions. Hence, the closed loops rooted to the surface never reach the field of view of the coronagraph and one only sees open field lines there as you said.

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Sheeley: In their study of the Skylab/ATM observations of coronal transients, the HAO team emphasized that they found no evidence for the expulsion of magnetic flux from the Sun. In particular, although the curved front of each loop-like structure passed through the coronograph field of view, the ends of the "loop" always seemed to remain tied to the photosphere. Assuming that your reconnection-driven model is correct, why do you suppose the HAO team never saw the back end of a closed loop move outward across the field of view?

Pneuman: In the schematic I showed you can see that, in this model, the outer legs of the transient do remain rooted in the photosphere. It is only the very inner part that is disconnected. I don't think the white light photographs rule that picture out. The inner part of the transient appears rather confusing in the pictures.

I believe that you do see these isolated inner loops in the moving Type IV emission. This emission is of a globular shape and, since it is produced by relativistic electrons, they must be confined in a closed field geometry. Otherwise, the emission volume would expand dramatically.

Michels: During the observations of a white light transient, the frontal loops are visible throughout a long period, while the volume expands greatly - where does the mass come from that is necessary to maintain this luminosity?

Pneuman: This model, of course, does not consider the origin of material for either the flare loops or transient. I'm not sure that additional material is actually needed for the transient, but I can't give you a more definite answer than that.

Anzer: (Comment) There is enough mass already contained in the pre-event helmet.

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