MAGNETIC RECONNECTION, MAGNETIC HELICITY, & A SOLAR CORONAL ERUPTION

Richard C. Canfield, Alexei A. Pevtsov
Department of Physics, Montana State University
Bozeman, Montana 59717-0350 U.S.A.

Kevin P. Reardon
Osservatorio Astronomico di Capodimonte
Napoli, Italy

ABSTRACT

Moore and Roumeliotis [4] suggested that reconnection plays a central role in the magnetohydrodynamic destabilization of solar prominences, through what they termed "tether cutting". Rust and Kumar [8] have called attention to the possible relevance of conservation of magnetic helicity during the emergence of magnetic flux from subsurface layers of the Sun into the corona and during reconnection events, leading to what they called "helicity charging". We review the work of these authors, and then use their ideas to interpret observations of the filament eruption leading to the famous Yohkoh flare of 22:37 UT 15 November 1991. This event provides observational support for the idea that both reconnection and helicity conservation are crucial to the hydromagnetic destabilization that leads to solar eruptions.

1. WHY DO FILAMENTS ERUPT?

Moore and Roumeliotis [4], following a suggestion by Sturrock, postulated a sequence of pre-eruption events they called "tether cutting", in which magnetic buoyancy, tension, and reconnection all play a role. They made the analogy that a filament is buoyant, and acts like a balloon. It is line-tied to the photosphere by the tension of magnetic field lines, which act like the tethers that hold a hot-air balloon before launch. When field lines in the filament reconnect with those in a contiguous emerging flux system, they are cut. Under certain geometric conditions, this reconnection makes the filament field lines longer and the emerging field lines shorter. The longer field lines plausibly line-tie the filament to the photosphere more weakly. After enough such tether cutting reconnection events occur, the region may become unstable and erupt.

Rust and Kumar [8] hypothesized a fundamentally different sequence of pre-eruption events, which they called "helicity charging". They, too, envisioned a situation in which filament flux reconnecting with emerging flux. However, they added the concept of twisted magnetic fields (a manifestation of non-zero helicity density) to the tether cutting scenario described above. When two field lines reconnect, one must expect their total twist to add algebraically to a high degree of approximation, since the reconnection timescale for two narrow flux tubes is much less than the Alfven timescale of the entire combined flux system. In the case where the filament and emerging flux systems have the same sense (right or left handed) of twist (chirality), longer filament field lines created by reconnection have more twist between their photospheric footpoints than either of the pre-reconnection filament field lines.

2. OBSERVATIONS

The dramatic 15 November 1991 filament eruption in AR 6919 was well observed by both Yohkoh and Mees Solar Observatory (MSO). Canfield *et al.* [1] observed new magnetic flux, indicated by Hα arch filaments, emerging adjacent to the filament throughout a period of six hours prior to its eruption.

Figure 1 shows Hα filtergrams of the active-region filament at two times prior to its eruption. The active-region filament, which erupted in the early stages of the flare, is the oval in the lower right quadrant of each of the two panels. The arrow in the left panel indicates an arch filament. The arrow in the right panel, obtained a few minutes later, indicates that the arch filament has lengthened during what we call a "crossing event". This name is chosen because this lengthened arch filament crosses over the bright area that separates the arch filaments from the active region filament. Nine of these crossing events were identified during the six-hour period of MSO observations prior to the eruption of the active-region filament. During such events nearby bright X-ray structures are observed, as well as significant Hα Doppler shifts within the crossing events themselves.

Although we have no high-resolution vector magnetograms with which to measure magnetic field twist, we nevertheless have Hα imaging spectra that help to understand these crossing events.

Figure 1: Hα filtergrams before (left) and during (right) a crossing event. Terrestrial North is up.

Figure 2: Hα Doppler velocity patterns during a crossing event, from MSO MCCD observations. In the low-resolution Hα spectroheliogram (lower right) the white contour follows the magnetic neutral line, derived from MSO Stokes polarimeter data. The inset (lower left) shows 2 km/s Hα Doppler velocity contours from 16 successive MCCD datasets during a crossing event. The upper panel (showing velocity values in the inset area at these times) explains how grey-scales indicate different times; later contours are lighter. Solar North is up.

The lower part of the oval filament can be seen faintly in the low-resolution Hα spectroheliogram that comprises the lower right panel of Figure 2, although it is rotated relative to Figure 1 because solar North, rather than terrestrial North, is up in the latter figure. In the lower left panel, grey-scale coding of contours in successive spectroheliogram datasets allows us to show that the 2 km/s blueshift Doppler velocity contour moves along the crossing-event structure, away from the region of emerging flux toward the filament flux system, at velocities of 80 – 160 km/s. Not shown in the figure, but shown in the video that accompanied this talk, are the redshift velocity contours. These contours often parallel the blueshift contours early in the crossing events, indicating spin about the crossing-event axis. The adjacent blue-shift and red-shift regions move together along the axis of the crossing-event structure, indicating that the spinning region is propagating along the structure. Typical velocities of this propagation, derived from the leading and following edges of the Doppler shift contours for the first two minutes of crossing events, are of order 100 km/s.

3. INTERPRETATION

It is useful to start the interpretation with the simple cartoon of the Hα crossing-event phenomenon shown in Figure 3. Before reconnection, the cartoon postulates a twisted arch filament and an untwisted filament fibril, both from the side and from the top. It is well known that both filament and emerging flux is twisted ([9] [5], [3]), but the cartoon is simplified to make the point clear that after reconnection, when the crossing-event structure has been formed, the twist that was originally contained only in the emerging flux system is now spread over both reconnected structures.

Figure 3: Cartoon model of the redistribution of twist after reconnection.

The implication of the cartoon for Doppler-shift velocities, as shown in Figure 2, is that after reconnection the crossing-event structure will spin differentially as the twist spreads out from the high twist density structure (the arch filament system) into the low twist density structure (the active-region filament). Reconnection theory predicts velocities of order 0.1 - 1.0 v_A, where v_A is Alfven speed,

$$v_A = B/(4\pi\rho)^{-1/2} = 300(B/100\mathrm{G})/(n_e/10^{12}\mathrm{cm}^{-3})^{-1/2}\mathrm{km\ sec}^{-1},$$

where B is the magnetic field strength, ρ is the mass density, n_e is the electron number density. For $B = 100$ G and $n_e = 10^{11} - 10^{12}$ cm^{-3}, v_A ranges from 300 to 1000 km sec^{-1}. Hence, the observed velocities are what we would expect from the relaxation to a new equilibrium after reconnection.

It has long been thought by solar observers that the amount of twist in prominence magnetic fields was a factor in their stability [7]. Rather clear observational evidence that this is true is contained in the paper by Vrsnak *et al.* [9]. From the theoretical point of view, however, the understanding of the phenomenon is unclear (*cf.* [7] [2]).

Of course, we cannot provide a compelling answer to the question "Why do filaments erupt?" on the basis of this one event. Obviously, when new flux emerges and reconnects with the flux system of a filament, it can either add or subtract from the twist contained in that system. This, of course, could have either a stabilizing or destabilizing effect. The November 15 eruption is one in which the observations of the dynamics imply that twist is being added to the filament flux system. Moreover, it happens that several such events of twist addition preceded the observed filament eruption. Although this single event proves nothing, it suggests that the process called "helicity charging" by Rust and Kumar [8] deserves more careful and systematic study. [1]

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[1] We have made a study of another single event [6] (the eruptive Yohkoh flare of 15:13 UT, 8 May 1992) in which twisted magnetic fields seem to play an important role.