The Global Dynamics of the High-Temperature Corona

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Abstract. This paper surveys coronal motions detected by the *Yohkoh* soft X-ray telescope SXT, emphasizing "global restructuring." Large-scale structures in the solar corona can persist for time scales much longer than those of the supergranulation, and may have larger spatial scales. Flares and coronal mass ejections (CMEs) can disrupt these structures. A grazing-incidence telescope such as SXT provides a view of the corona biased in temperature towards the hotter components, but in a thick "observing slice" (spatial contribution function). This helps in seeing excitation (energy release) but may conceal some of the structural changes. The observations of restructuring largely appear to consist of expanding or outwards magnetic motions, which are endoergic. This suggests a conjecture regarding the existence of *magnetic implosions* on scales not yet detected, as a source of free energy.

Keywords: Corona. X-rays.

1. Introduction

Eclipses and artificial occulters (e.g. coronagraphs) show us the mass distribution of the solar corona, in line-of-sight projection, above the solar limb. Radio and X-ray observations do not have a restriction to limb viewing because of the relative darkness of the disk at these extreme ends of the solar radiation spectrum, and recently we have experienced a wonderful explosion of knowledge from the X-ray and EUV side of the spectrum especially. Following Skylab and many rocket flights, the *Yohkoh* SXT instrument has created a huge database of soft X-ray full-Sun images at an angular resolution normally defined by $4.92''$ pixels (or $2.46''$ for partial fields-of-view).

Time sequences of these images let us follow the hotter parts of coronal eruptions of many kinds, including the Coronal Mass Ejections (CMEs) seen in coronagraphs. They also reveal to us the inner workings of solar flares, and show that the eruptive flares have a close physical relationship with CMEs. This point, controversial several years ago, has now largely been resolved in favor of a close physical connection between flares and CMEs (e.g. Dere et al., 1997). As regards the key question of which causes which, if either causes the other, the answer (if unique) remains ill-understood. However the much-improved quality of the data continue to sharpen our understanding of this question (Hudson and Webb, 1997; Hudson, 1999).

2. The Soft X-ray View

2.1. General

Soft X-ray images of the corona show its hottest parts, but not limited just to the regions of intense variability in the strong magnetic fields of the active regions. The soft X-ray view of the corona thus tells us about transient heating on large scales, as well as about the structure. The structure itself is elusive, partly because of projection effects, and partly because the higher-temperature corona seems less well-defined. A grazing-incidence telescope observes over a broad spectral band, with contributions from a wide range of temperatures, but biased towards the higher temperatures; a normal-incidence EUV telescope (or a spectrograph) observing a coronal emission line views a narrow range of temperature (the "contribution function"), often about an octave wide. Roughly speaking, the solar atmosphere has a temperature range covering a factor of 1000, corresponding to about 10 octaves – in each octave there will be a geometrical view of the corona given by a unique *observing slice*.[1] The soft X-ray observing slice, because of its broadband temperature selection, is relatively rich. A given observing slice is not necessarily sheet-like and may show complicated structure.

The magnetic field in the corona determines its geometry, and we believe generally that the field fills the entire coronal volume in a normally force-free state with plasma $\beta < 1$. The mostly balanced stresses on the field come from line-tying at or below the photosphere, plus the corona's reaction to the acceleration of the solar wind. The line-tying stresses at the lower boundary cause sharp focal points where the intense active-region fields appear and branch out into the corona, while the solar-wind stress is broadly distributed both in angle and in radius. The focusing of active-region fields into small photospheric footprints results in the occurrence of highly inclined magnetic loops at the peripheries of major active regions.

Transient events often disturb this equilibrium and cause restructuring, but we have a great deal of difficulty in describing this restructuring exactly owing to the fine slicing in the temperatures that happen to be observable. When the corona appears to undergo a restructuring, its excitation also changes. In other words, the parts of the magnetic field filled and illuminated by the plasma may change, and this confuses our view of what really may have happened geometrically. In some cases ("simple loop flares") we believe the excitation basically just changes the visibility of the existing structure without any geometrical restructuring on observed scales.

[1] The spatial domain corresponding to the spectral contribution function.

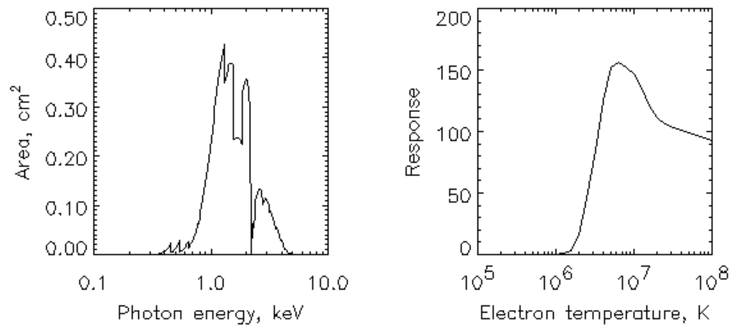

Figure 1. SXT response functions in its AlMg filter. Left panel, total detection efficiency as a function of photon energy; right panel, detected signal as a function of electron temperature with standard theoretical assumptions. Note that the latter shows a broad contribution function, essentially a high-pass filter in temperature.

2.2. SXT

The *Yohkoh* soft X-ray telescope SXT (Tsuneta et al., 1991) follows the tradition of the grazing-incidence telescopes flown on Skylab and on rockets. The spectral response, however, is not so soft because of filter and detector properties. Coupled with the natural distribution of the X-ray emission lines and continua, this means a substantially hotter response than that of familiar normal-incidence EUV telescopes such as EIT or TRACE. The GOES photometers work at still shorter wavelengths. We remind the reader of the SXT spectral response in the wavelength and temperature with the plots in Figure 1. In temperature space SXT essentially looks like a high-pass filter. Normal-incidence EUV telescopes (TRACE and SOHO) have sharply-peaked temperature contribution functions, but outside the temperature domain of the selected spectral features, they may also have broad-band response (Golub et al. 1989; Feldman et al., 1999) or include lines from temperature domains far from the primary design range, i.e. FeXXIV 192Å in the 195Å passband nominally designed for FeXII. In contrast the true spectroscopic imagers (rocket flights including SERTS; the CDS and SUMER instruments on SOHO) have sharply defined temperature contribution functions over a wide range of temperatures, but typically poorer sensitivity and lower time resolution.

2.3. Measuring flows with soft X-ray images

Movies of soft X-ray images sometimes clearly show flowing material. The measurement of the flow field, projected from its original 3D structure because the medium is optically thin, is a matter of correlating the position of a "tracer" from one frame to the next. SXT shows flows along the apparent field direction (Shibata et al., 1992; Strong et al., 1992), as well as perpendicular to the field (e.g. Uchida et al., 1992).

Although the eye can recognize a flow pattern in a movie representation of the images, the quantitative measurement of the velocity field as a function of position is difficult in these high-contrast X-ray images. Frequent sampling and high spatial resolution obviously help. Such a correlation-tracking technique has been applied to the corona with great success by Aschwanden et al. (1999) in characterizing loop oscillations as observed by TRACE. Following tracers has also allowed the use of LASCO images to find sources of slow solar-wind flow (Sheeley et al., 1997). In the EUV observations (TRACE and EIT) one must worry about optical-depth effects, and in general the view of the flow field is restricted to a relatively narrow observing slice (see above) corresponding to the wavelength of observation.

The dimming signatures described in Section 3.2 below represent mainly unresolved flow fields, in which the X-ray images do not have enough resolution or sensitivity to detect tracer features. Still in principle the time profile of dimming as a function of position could be used to infer bulk properties of the flow field. This technique has not yet been applied to the SXT data, and it may be superseded by direct measurements using tracers in the higher-resolution TRACE data.

2.4. What we are interested in

The term "global restructuring," used by Tsuneta et al. (1992) in describing the formation of a giant coronal arcade, aptly encapsulates our present understanding of the process. In using this term we take it to imply the transfer of photospheric flux between domains of different connectivities. The magnetic field has two roles in the corona: it structures the coronal material, because $\beta < 1$, and it also contains energy ($B^2/8\pi$) that must be reduced in order to extract energy during a "restructuring." Thus it seems almost inevitable observationally that whenever some sort of coronal catastrophe occurs (a flare and/or a CME, for example) that it should be detectable as a re-mapping of the coronal field lines. We would expect theoretically that the connectivities of domains mapped onto the photosphere would change, in view of the need for the release of stresses imposed on the coronal field by subphotospheric sources (McClymont and Fisher, 1989). In fact, we would expect in some global sense that an energy release from the coronal field would require a "magnetic implosion," since the magnetic pressure will decrease as energy converts to other forms which will escape from the system (see Section 4). Unfortunately the restructuring inevitably goes hand-in-hand with the excitation (increase of plasma pressure) of some parts of the global structure. This and the need to work with two-dimensional projections makes the measurement of the restructuring geometry difficult.

We would of course like to understand the observations with a theory capable of quantitative prediction. At the present time, this seems to imply the following interesting questions regarding restructuring:

- Where are the magnetic footpoints of the coronal structures in the photosphere, and how do these re-map during an event?
- How does the energy released during a restructuring correlate with the geometrical changes?
- What coronal conditions make a restructuring likely to happen?

Almost all theories of flare and CME development derive energy from local storage in the coronal magnetic field. In the large-scale “opening-closing” models, an eruption opens previously closed magnetic field lines (“opening” in the sense of expansion into the solar-wind flow), which subsequently pinch off via magnetic reconnection to form the flare arcade. This simple picture predicts an inward reconnection flow towards the reconnection point, and exhaust jets at or near the Alfvén speed escaping from it (Forbes and Malherbe, 1986; see Yokoyama and Shibata, 1997, for recent numerical simulations). Both of these flow fields are perpendicular to the field, but they cannot easily be recognized in the observations (e.g. Hudson and Khan, 1996). Likewise the parallel flows involved with loop filling and draining are not easily observed in the images, but have Doppler signatures (“evaporation” or loop-filling; see Czaykowska et al., 1999 for recent image-resolved spectroscopy). Thus the discussion below focuses on investigating the flow fields we do observe in this context.

3. Restructurings

Because of the restricted temperature contribution function of any specific observation, our views of coronal restructurings are fleeting and often obscured by extraneous emissions. At the limb, observing in white light, the effects become more directly visible, but the view at the limb has problems of foreshortening, foreground/background confusion, and limb occultation. The sections below deal in greater detail with arcades, X-ray dimmings, mass motions, and other items. The morphology is complicated, but this may partially be due to the limited nature of our views (the "observing slices"), and the fact that most of the information is so recent. We therefore conclude this section with an attempt at a synthesis.

There has been little direct work on the all-important question of foot-point mapping thus far because of the relatively low resolution of the *Yohkoh* SXT and HXT observations. Sakao (1999) has studied the footpoint motions of the hard X-ray sources in a number of flares, and found them to move systematically with time at 0.5-s resolution, behavior that might generally result if the field lines connected to the hard X-ray sources do probe the location of coronal energy release. Zarro et al. (1999) have examined SXT and EIT images in an effort to identify the re-mapping of photospheric magnetic domains before and after a flare (see also Sterling et al., 2000). Neither of these studies has provided direct footpoint evidence for restructuring, but largely agree with the classical reconnection picture (opening-closing) or with other restructuring theories.

The tracking of coronal restructuring, in the sense intended here, has been a major occupation of theorists and observers associated with the group at Meudon. They have combined observations from ground and space with an evolving capability for modeling the coronal field based upon photospheric measurements (e.g. D 'emoulin et al., 1998). The associations found by this group between flaring regions and key features of the 3D coronal field strongly support the idea of flux transfer (magnetic reconnection) during the energy-release phase.

3.1. Arcades

Arcades of well-defined magnetic loops occur in flare events variously associated with two Hα ribbons, filament eruptions, and the launching of CMEs. Events of this type may occur well outside active regions as "spotless flares," and in extreme cases the two ribbons only appear very faintly in sensitive observations such as HeI 10830Å (Harvey et al., 1986). In an arcade event the loops form a roughly cylindrical tunnel, often with nearly straight ribbons whose length may greatly exceed the network cell size. The ribbons tend to separate with time as the arcade appears to rise into the corona, morphology first noted in "loop prominence systems" in chromospheric lines but now known to reflect the cooling of much hotter loops visible in soft X-rays. Arcade events in active regions may have high temperatures, but the giant arcades of the type described by Tsuneta et al. (1992) have relatively low peak temperatures (Alexander et al., 1994) compared with active-region flares which they resemble. The working hypothesis for describing arcade formation is via the closing-down of field lines opened by the eruption process. If so, the opening of the field prior to its closing-down should manifest itself as *coronal dimming*; see the next section.

3.2. Dimmings

The sudden dimming of regions of the X-ray corona (Hudson et al., 1995) is the analog of the "coronal depletions" noted by Hansen et al. (1974) in white light. In soft X-rays, "transient coronal holes" had been recognized in the Skylab soft X-ray images, and the *Yohkoh* SXT observations add additional types of dimmings (Hudson and Webb, 1997). We can now distinguish five classes of X-ray dimmings, as listed in Table I. These classifications are not necessarily mutually exclusive, but we do not yet have full enough observational material to know for sure.

The X-ray dimmings have several possible physical interpretations: the material could simply cool in place, becoming invisible in X-rays; it could contract inwards towards the flare core as a part of a large-scale reconnection inflow (Tsuneta, 1996); or it could expand outwards as a part of an eruption or a CME formation. The latter two explanations involve magnetic restructuring and are endoergic and exoergic, respectively. Hudson et al. (1996) show that cooling could not have explained the event they studied, because of the short time scale. In most cases the actual motions of coronal plasma, as observed by SXT, go strictly outwards. This coincides with the expectation of an opening of the field leading to a restructuring as an arcade via large-scale magnetic reconnection, but it is not consistent with the closing-down expected from this reconnection. Figure 2 shows cases of large-scale arcade formation with and without dimming signatures; the fact that a one-to-one relationship does not seem to exist means that the working hypothesis needs some elaboration.

Table I. X-ray transient dimmings

Dimming type	Reference to prototype
"Transient coronal holes"	Skylab
Enveloping dimming	Hudson, 1996
Arcade dimming	Hudson et al., 1995
Moving cloud	Hudson et al., 1996
Transequatorial loop	Khan and Hudson, 1999

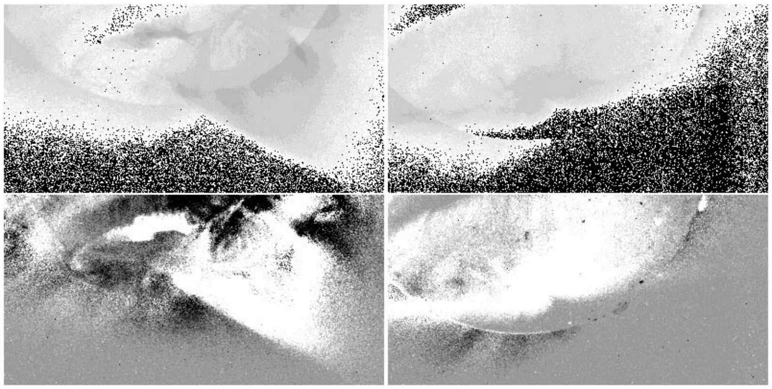

Figure 2. Two large-scale arcade ("global restructuring") events, showing that coronal dimming may or may not occur in otherwise similar events. Left, event of Feb. 24, 1993; right, event of April 14, 1994). In each case the difference image (below) shows a one-day interval before-and-after, with no correction for rotation. The dimming (lower left) is the dark regions surrounding the bright arcade. The Feb. 24 event shows an "enveloping dimming" in the Hudson-Webb (1997) classification, but the April 14 event (cf. Kahler et al., 1998) shows no identifiable dimming signature. The difference image have the same gray-scale range (± 10 units) whereas the direct images above have a logarithmic compression to a total range on the order of 10^3 units.

3.2.1. *Sigmoid Dimmings and Halo CMEs*

Sterling and Hudson (1997) studied one particular form of X-ray coronal dimming, a bipolar "sigmoid" appearing during the launching of a halo CME on April 7, 1997. The mass estimated from dimmed regions amounted to at least 10% of the mass of a typical CME, showing that the "transient coronal hole" formation in this event probably did result in an expansion of large-scale fields from the active region into the solar wind. Hudson et al. (1998) later extended this comparison to a complete sample of eleven halo CMEs, and Zarro et al. (1999) have shown that the EUV dimmings observed by EIT in the April 7, 1997 event matched those observed in soft X-rays, confirming that these dimmings result from evacuation of material, rather than sudden cooling.

In a prototype event (Figure 4), the bright pre-event structure appears as an S shape (typically an anti-S in the northern hemisphere). In some events, such as this one, the sigmoid disappears; in others it appears to remain at least partially extant (Sterling et al., 2000). This calls to mind the partial filament eruptions described by Tang et al. (1986), although the X-ray sigmoid structure certainly is not a filament. Perhaps (a speculation) it represents the active-region counterpart of the hot core observable via soft X-ray emission in a quiescent filament cavity (Hudson et al., 1999).

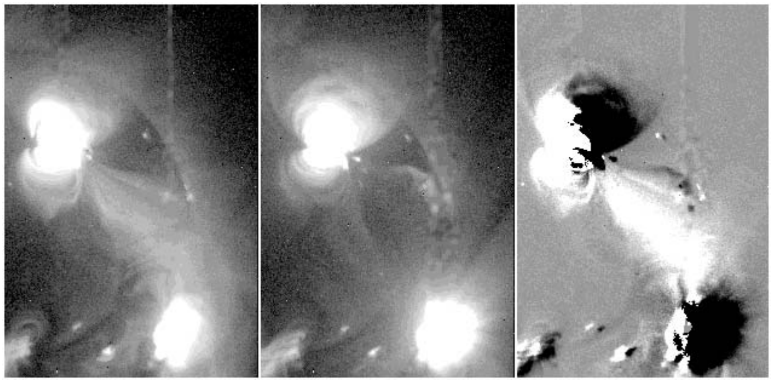

Figure 3. North-South interconnecting loops (left) disappear (middle) as shown in the difference image (right; the sense of the difference is *early* minus *late*, and the image scale has been magnified). Khan and Hudson (1999) show that the global wave launched by an X-class flare at the S end of the structure destabilized it, leading to a CME. A sequence of three homologous events of this type occurred over a three-day span.

The dimmings of this type have a close relationship with coronal "EIT waves" (Thompson et al., 1999); the dimming appears behind the wave as it expands from a compact source.

3.2.2. *Transequatorial Loops and CMEs*

Very recently Khan and Hudson (1999) have pointed out a new category of dimming structure, also related interestingly to both flares and CMEs. The key observation consisted of a series of transequatorial loops connecting the neighborhoods of two powerful active regions. One of them produced a sequence of three flares spaced over a period of about three days; each flare launched an ejection detected initially near the flare core, and on each occasion the NS transequatorial loop structure temporarily disappeared (See Pevtsov, 2000, for a survey of SXT observations of such transequatorial structures). Further, each disappearance then was followed by a CME characterized by a bright front. The timing and general morphology are consistent with the idea that the flare ejection or global wave destabilized the large NS structure, which then became a major component of the CME. A mass estimate from the dimming regions shows that the structure observable in X-rays indeed contained a major fraction of the mass of a typical large CME (3×10^{15} g in the case of the May 6, 1998 event, shown in Figure 3).

3.3. Outwards Mass Motions

In the best of cases, one can detect mass motions directly in movie representations of the X-ray images. From the SXT point of view, this requires elevated pressures in the structures that move, in order to make them more visible. The prototype "moving cloud" observed by Hudson et al. (1996) had the commonly observed pattern of large active-region loops extending apparently sideways away from the core of the region. This pattern often appears with bilateral symmetry, as envisioned in the description of Moore and LaBonte (1980) and interpretable theoretically in terms of a sheared and expanded bipolar structure (e.g. Antiochos et al. 1994) held down in the middle by stronger fields in the core of the region.

We note that many flare ejecta also appear to be of collimated streams or compact blobs (e.g. Ohyama and Shibata, 1998), rather than larger-scale coronal volumes. Such compact ejecta could be related to the mass motions involved in coronal restructuring on larger scales, but also may be closely related to phenomena seen in chromospheric lines – sprays, surges, and filaments.

3.3.1. *Waves*

A wave disturbance may give the appearance of motion, but then leave the ambient corona in place after its passage. Global coronal or chromospheric waves have been known for a long time, as observed at meter waves (Type II bursts) and in Hα (Moreton waves). Recently SOHO/EIT observations have shown their easy detectability at EUV wavelengths as well (Thompson et al., 1998, 1999). SXT has also recently succeeded in detecting a wave disturbance directly in soft X-rays, and Figure 5 shows the structure (piston) whose initial transverse motion appeared to launch the wave.

3.4. Inwards Mass Motions

Heretofore all of the mass motions discussed have been consistent with explosive action *away* from the flare core. *Yohkoh* flare observations from the current maximum activity have at last shown us something about mass motions directed inwards, *towards* the flare core (McKenzie and Hudson, 1999; cf Forbes and Acton, 1996). Note that the field-line shrinkage observed by Wang et al. (1997) was on a longer time scale than that of the flare energy release.

Figure 6 shows an example of the inward flow above a large arcade observed following a major flare on January 20, 1999. The motions consist of a series of dark blobs moving downwards (i.e., from the corona towards the top of the arcade) at projected speeds of 100-200 km s^{-1}. McKenzie and Hudson (1999) interpret these blobs as the cross-sections of relatively warm but low-pressure flux tubes cascading down from the high corona in the aftermath of the CME ejection, perhaps following

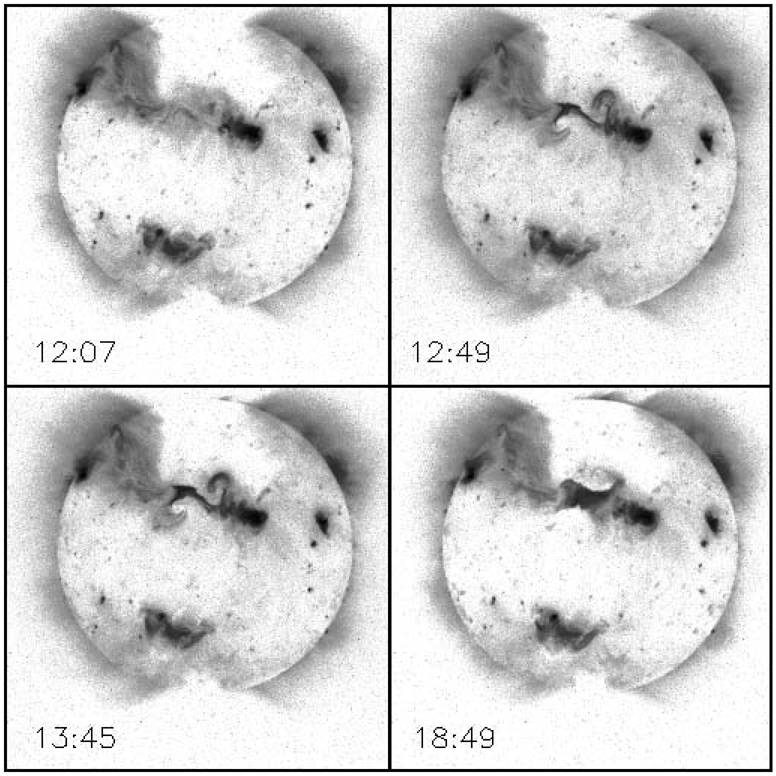

Figure 4. Four views during the evolution of a quiet-Sun sigmoid eruption on October 23, 1997. The sigmoid rapidly brightens, simultaneously with the dimming signature, and then the arcade forms straddling the location of the sigmoid. The labels at the bottom of each image give its time. This sigmoid is an "anti-S", the preferred pattern for the northern hemisphere.

the 3D reconnection scenario presented by Gosling et al. (1995); see also Wang et al. (1999), who describe inflows beginning many solar radii out in the corona, and Klimchuk (1996) for a model of patchy reconnection.. The flow speed seems definitely lower than the likely Alfvén speed, which would be the speed of the outflow jets predicted by fast reconnection models operating at low plasma β. However, as noted by Forbes and Acton (1996), lower speeds would be possible with higher β's. The observations show many blobs moving inwards, apparently perturbing the ray structure of the spiky arcade, and stopping at the arcade itself. The inwards motion appears to have little to do with flare heating; The observations show these blobs only during the decay phase of the flare, not during the impulsive phase where the energy release is most intense.

Flows such as this have thus far been observed only in arcade events that occur at or near the limb, and only in the subset of these events

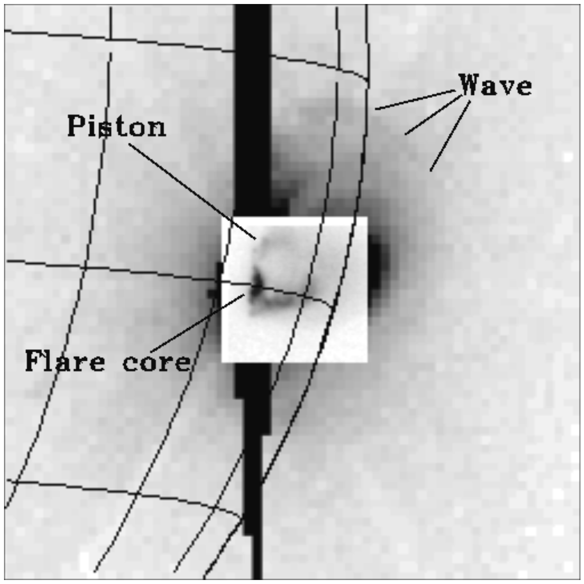

Figure 5. The origin of a global coronal wave associated with a Type II meter-wave radio burst following a flare on May 6, 1998. The feature identified as "piston" existed prior to the flare, and its rapid perpendicular motion appears to have launched the wave. Note the compact scale of this point of origin. Klein et al. (1999) and Klassen et al. (1999) have recently noted similar waves with soft X-ray "piston" counterparts.

that have spiky structures surmounting the arcade. This suggests that the visibility of the dark blobs depends upon the presence of this relatively hot and bright spike structure above the arcade. At the present time there is no theoretical explanation for the presence of this multiple cusp structure (but see Klimchuk, 1996). Although these are the only X-ray observations of flow fields in the cusp region of an arcade flare, we note that selection effects may restrict our view and urge that higher-resolution (e.g. TRACE) data be examined for a more complete picture (see Section 4).

3.5. Synthesis

The data show much evidence for restructuring. Theoretically we require magnetic-field changes to take place, because of the near-universal agreement that the stressed coronal magnetic field stores the energy of an eruption prior to its occurrence. To what extent can we now address the questions raised in Section 2.4?

- Where are the magnetic footpoints of the coronal structures in the photosphere, and how do these re-map during an event? *Virtually no direct progress, even though this can be approached by simple*

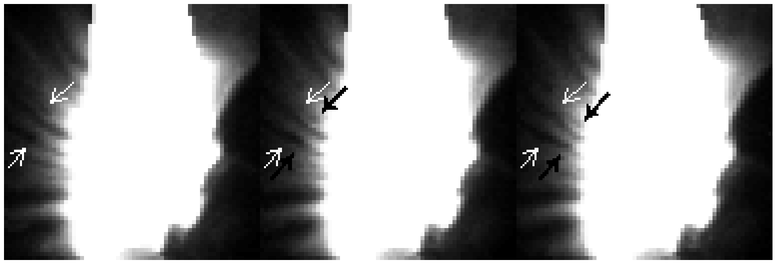

Figure 6. Infalling velocity field observed above a postflare loop system on January 20, 1999 (McKenzie and Hudson, 1999). The arrows point to dark blobs moving downwards between the bright rays of the "spiky arcade" at projected speeds of 100-200 km s^{-1}, in the gradual phase of the flare. In this overexposed view, the ragged structure shows the spikes we identify as multiple cusps strongly correlated in position with the bright loops of the arcade (cf Švestka et al., 1999).

morphological analysis, but see Zarro et al. (1999) and Sterling et al. (2000). The Meudon group (e.g. D 'emoulin et al., 1997) has had success with 3D magnetic model-fitting in a variety of events of different kinds. New observations with TRACE and HESSI are promising, because of the higher angular resolution.

- How does the energy released during a restructuring correlate with the geometrical changes? *There have been few quantitative studies, but see Forbes and Acton (1996) and Tsuneta (1996) for examples of fits to opening-closing models.*

- What coronal conditions make a restructuring likely to happen? *Soft X-ray active-region structures that have sigmoid configurations are more likely to erupt (Canfield et al., 1999). There are also many anecdotal reports of flux emergence as a trigger.*

The overall picture resulting from the soft X-ray observations is that the high-temperature slice of the corona does show the origins of transient openings of the coronal magnetic field. The closing-down of these open field lines is a different matter; certainly we see arcades forming, but normally a CME does not show the expected "pinching-off" of its structure into a disconnection (Webb and Cliver, 1995). Thus we look to streamer cusps at the base of the heliospheric current sheet (e.g. Van Aalst et al., 1999) as a possible site for the reconnection needed to maintain the interplanetary magnetic field intensity.

4. Conjecture

As noted above, the coronal magnetic field both defines the geometry of coronal structures, and at the same time shows the location of its stored magnetostatic energy. This is why restructurings, properly understood, would tell us so much about the physics of coronal variability. For a flare or CME launch to occur, some volume of the coronal magnetic field must restructure itself during the process of energy release. Many numerical experiments (e.g. Sturrock et al., 1994) have shown that the addition of stress to the coronal field causes it to expand; with the exception of the photosphere, there are no walls to restrict this expansion. On the time scale of a flare or CME launch, the photospheric boundary conditions (field, current, mass) must remain fixed (e.g. Melrose, 1997) because of the low Alfvén speed in the temperature-minimum region.

Because the energy density stored magnetostatically equals $B^2/8\pi$, the volume integral of this quantity must diminish during any sudden energy release in any theory deriving flare energy from the coronal magnetic field. This directly implies that the level surfaces (contours) of $B^2/8\pi$ must collapse inwards over least a part of the domain in order to supply the energy. We therefore argue that some of the coronal field lines themselves must withdraw inwards in order to allow the stored energy to decrease in some volume. Observations should allow us to follow such a displacement of a field line or a flux surface during a restructuring event because the distribution of emitting plasma allows us to visualize the field within the limits discussed above in Section 2.1. The identification of individual flux elements between the two states of the restructuring should be possible from their photospheric footprints. This conjecture suggests that solar "magnetic explosions" observable in so many ways (e.g. Moore et al., 1999) really must somehow conceal the existence of powerful magnetic *implosions*, as an expanding supernova shell may conceal the neutron star created at the same time. Since we do not readily observe coronal magnetic implosions, at least on large scales, the field-line collapse might have to take place in compact regions of intense fields, or else in more extended magnetized volumes with relatively low gas pressure.

5. Conclusions

The corona undergoes periodic restructurings in which the large-scale geometry changes abruptly. This process obviously requires magnetic reconnection in some manner, but some of the higher-level questions mentioned in Section 2.4 remain quite open. The recent data are extremely interesting and valuable, but the comments here – based on SXT's partial view of the corona – may quickly become obsolete because of the higher-resolution data available from TRACE. These data, it turns out, include views *at 1″ resolution* of hot and "superhot" flare sources, via the response to the continuum and to an FeXXIV line within the 195Å passband (Golub et al, 1989; Feldman et al. 1999). Adding HESSI observations into the γ-ray range, one can expect a rather complete view of flares and eruptions to emerge from the newer data in the current solar maximum. The *Yohkoh*, SOHO, and TRACE data analyzed to date are so impressive that one might be led to believe that we have a good understanding of the physical processes already. This would not be right, however, because of the inability of current theories of solar flares and CMEs to predict their behavior. The conjecture stated in Section 4 illustrates this theoretical confusion. We continue to be surprised sometimes by the observations, and the theories often feature phenomena that are not observed directly, so in fact our actual understanding remains at a somewhat primitive level.

One key point emerging from the current data, as described in more detail in Hudson (1999), deals with the close relationship between flare effects and CME eruptions. The current data show a much clearer pattern here, partly because of better resolution and sampling, but also because of more comprehensive "observing slices" (see Section 2.1). Radiation from high-temperature sources appears to accompany the occurrence of mass motions, even though the bulk of the flare effects (low-temperature slices) may follow, delayed by some appreciable interval. The simultaneity of the radiation effects suggests that energy dissipation occurs immediately. This would not be consistent with ideal MHD instabilities in which first a restructuring happens, and then reconnection ensues. This simultaneity of radiation (endoergic) and ejection (also endoergic), in the absence of implosion (exoergic) also intensifies the puzzle described in Section 4.

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