AGU Monograph galley style, v1.0, 21 Mar 97

SOFT X-RAY SIGNATURES OF CORONAL EJECTIONS

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We have a new view of the time behavior of the inner solar corona via the extensive soft X-ray observations of *Yohkoh*. These show many forms of expansion of coronal material, ranging from highly collimated structures (jets) to large-scale evacuations ("dimmings") of the diffuse corona. We review these effects, emphasizing those probably related to CMEs, and present a preliminary classification scheme of the large-scale ejections seen in soft X-rays. The new observations bring clarity and focus to the well-established scenario of filament channel → CME → X-ray arcade. The associated X-ray brightening typically occurs in a close temporal relationship with the ejection as inferred from the dimming, but the location of the ejected mass may be displaced from the region of strongest brightening. The soft X-ray observations thus far have shown no clear example of the familiar three-part structure of CMEs as seen in white-light coronal images.

1. INTRODUCTION

The solar wind and disturbances within it originate in the solar corona. This paper reviews the recent increases in our knowledge of this region of space, emphasizing the new views of coronal transient phenomena made possible by the Soft X-ray Telescope (SXT) on *Yohkoh*. The coronal mass ejections (CMEs) constitute the largest and most energetic of these transient events. In our usage "coronal mass ejection" refers to the phenomena seen with a white-light coronal imaging instrument [*e.g., Hundhausen*, 1996].

The soft X-ray view of the solar corona differs substantially from the familiar view provided by white-light imagers. We therefore begin this review by discussing the differences. We then list various kinds of soft X-ray disturbances interpreted as ejecta, and conclude by describing the X-ray phenomena we believe to be most directly associated with the CME phenomenon. The original soft X-ray imaging observations from *Skylab* (see *Sturrock* [1980]) showed some of the same phenomena seen by *Yohkoh*, but not in such detail; see for example *Kahler* [1992] or *Webb* [1992] for reviews of the earlier data on CMEs.

The work of identifying X-ray coronal features with coronal mass ejections remains in its early stages. An initial survey of the *Yohkoh* data [*Klimchuk et al.*, 1994] showed that many X-ray eruptive events [*cf. Rust and Hildner*, 1978] occurred at the limb. *Hiei et al.* [1993] described an X-ray "streamer re-formation" event that almost certainly involved a CME, and *Sime et al.* [1994] gave preliminary comparisons of two events observed by the HAO Mauna Loa K-coronameter with *Yohkoh* observations. Beyond this, the current literature presents few examples of approximately simultaneous white-light and X-ray observations. There are several reports of associations between coronal X-ray events and either interplanetary observations or non-simultaneous coronagraph observations [*Lemen et al.*, 1996; *McAllister et al.*, 1996a; *Weiss et al.* 1996]. Data from the K-coronameter at Mauna Loa Solar Observatory and from the coronal instruments on board SOHO are already changing this situation. Because of the rapid pace of observational work, we have tried to include some literature published after 1996 (the Chapman Conference on CMEs), and to incorporate ideas from these observations in the discussion.

Finally, we note that CMEs play an important role in stimulating geomagnetic activity [*Gosling*, 1991; *Webb*, 1995]. *Hudson* [1997] has recently reviewed some of the same material presented here but with an emphasis on the application of the solar observations to geomagnetic storms. That paper presents some additional data, including a list of dimming events (see below) observed prior to 1996.

2. THE X-RAY VIEW OF THE CORONA

We normally image the solar corona in white light or in the coronal emission lines in the visible range. This can be done during eclipses or via coronagraphs, but the brightness of the solar disk restricts the observations to the region above the solar limb. To see the corona against the disk requires going to long (radio) or short (X-ray) wavelengths to reduce the photospheric competition. The lower temperature of the visible photosphere makes it appear dark in X-rays; at radio wavelengths the height of optical depth unity rises far up into the corona, so again the photosphere becomes invisible. Because most of the corona is hot, it has the highest contrast in EUV and soft X-radiation. For general information please refer to standard monographs, *e.g.*, *Kundu* [1964] or *Zirin* [1988]. In this section we briefly summarize coronal morphology as seen in soft X-rays, then make some comments about the specific limitations of the X-ray observations, with emphasis upon the *Yohkoh* soft X-ray telescope.

The X-ray spectrum of hot plasma consists of the emission lines and continua of highly ionized atoms and, at typical coronal temperatures (*i.e.,*, 1-3 $\times$ 10^6 K, below the temperatures achieved by flares), the emission lines dominate energetically. The complicated structure we see in the lower solar atmosphere in an X-ray image is defined by small-scale magnetic fields. These simplify with height and eventually map into the solar-wind flow, which has a predominantly bidirectional magnetic structure (with inward-pointing and outward-pointing sectors) dominated by the flow itself. Most of the magnetic field lines extending into the heliosphere originate in coronal holes, which thus provide the sources of the high-speed solar wind. Other areas of "open" magnetic fields (defined as field lines that extend beyond the Alfvénic critical point of the outward flow) exist elsewhere, for example in the hearts of active regions as evidenced by the occurrence of Type III radio bursts with high starting frequencies. The larger open-field regions are dark as viewed with a soft X-ray telescope. The slow component of the solar wind is less well understood, but probably originates in or near large closed-field regions of the solar atmosphere at lower latitudes [*e.g.*, *Withbroe et al.*, 1991].

In addition to the quasi-steady structure of the X-ray corona, there are transient events of many kinds. These usually take the form of injections of mass into apparently stable magnetic loop structures (microflares, flares, arcade events). Ejective events, well-observed in the sense that successive images actually show the motion of the structure, frequently occur, most often in association with flare-like brightenings. The ejected mass, along with its frozen-in magnetic fields, may become a part of the outward flow into the solar wind [*Uchida et al.*, 1992]. The soft X-ray emission rapidly drops with height, however, so that identifying soft X-ray ejecta with solar-wind features requires some interpolation.

Because in soft X-rays we see the general corona and transient features such as ejections, we have the possibility of observing CMEs directly in emission as they actually start. The *Yohkoh* observations represent the first soft X-ray imaging data suitable for these purposes since the *Skylab* observations. *Yohkoh* began observations in September, 1991. A comparison of these improved X-ray data with those in white light (or other wavelengths), at the times of CME launches, should have high priority.

There are several substantial differences between soft X-ray observations of the *Yohkoh* type, and white-light observations. Most of our knowledge of CMEs comes from the white-light data, so it is important to understand the differences in the data reported here. The X-ray images show the entire Earth-facing hemisphere, offer a better view near the surface of the Sun, and provide some information on temperatures and densities. The fields of view are typically different, with a coronagraph viewing structures higher up in the corona

($\geq$1.2R$_S$ projected height) compared to those viewed near the surface ($\leq$1.5R$_S$) in X-rays. Another difference between the white light and X-ray observations is that of their line-of-sight dependences. The white light emission arises from Thomson scattering of photospheric radiation, but the X-ray emission arises directly from the emission of the hot coronal gas; X-radiation is isotropic and not concentrated in the plane of the sky. X-rays thus let us see the source of the emission against the disk and so determine the heliographic coordinates of any discrete source.

The white-light brightness (K-corona) varies in proportion to the electron density, and does not depend on the temperature. In contrast, the X-ray emission is a complicated function of density (approximately the square) and the temperature. For the thinnest *Skylab* X-ray filter, for example, *Kahler* [1976] found the signal to depend on the square of the electron pressure. The SXT signal S is a stronger function of temperature, T (d(lnS)/d(lnT) $\sim$ 2-6), than that of *Skylab* and is biased towards shorter wavelengths. These different instrumental dependences mean that similar coronal features may look quite different when viewed in X-ray or white-light emissions.

Tsuneta et al. [1991] give a full description of the *Yohkoh* SXT instrument, which uses a grazing-incidence mirror, a set of broad-band filters sensitive in the range 0.3 - 3 keV (4 - 40 Å), and a CCD sensor with 1024×1024 pixels 2.45$''$ square (see *Acton et al.* [1992] for an survey of the data). The telemetry capacity of *Yohkoh* allows the transmission of about 20 whole-Sun images, with 2×2-pixel summations ($\sim$5$''$ The *Yohkoh* SXT provides a global view of the corona within its total field of view, which is a square 0.70° across. pixels), per 97-minute orbital period of the spacecraft. A flare mode is normally triggered at about the GOES C2 level, some 2×10^{-3} ergs(cm^{2}sec)$^{-1}$ in the 2–8 Å (1.5-4 keV) band. This results in the loss of full-Sun imaging for an extended interval, in exchange for more telemetry devoted to high-resolution observations of the flare itself, with a maximum field of view 10$'$ square. The optical axis of the telescope is almost always pointed so that the entire disk is visible, except during special operations.

3. SXT OBSERVATIONS OF SOLAR MASS LOSS

The *Skylab*, Solwind *P78-1*, and *Solar Maximum Mission* observations generally showed a complicated relationship between the white-light CMEs they observed and the soft X-ray corona as inferred from the GOES photometry [*e.g., Kahler et al.*, 1992]. This situation could be attributable to poor temporal data coverage in the coronagraphs, to poor GOES X-ray sensitivity to the main bulk of the ejected coronal material, or of course to a weak physical relationship. With the improved data cadence and sensitivity of the *Yohkoh* X-ray images we hoped to find consistent signatures of CMEs in the low corona [*e.g., Klimchuk et al.*, 1994]. This turned out not to be so simple: some of the CME motions may be observed directly in X-rays, but the morphology can also be different. *Yohkoh* detects some kinds of coronal mass ejection not resembling CMEs at all. We summarize the ejection events in different categories below. While the categories may overlap, there are clearly different physical effects at work, as distinguished by the direction (parallel or perpendicular to the field) and speed of the motion. Parallel flows much slower than the Alfvén speed are common, suggesting hydrodynamic driving, while perpendicular flows provide good evidence for magnetic driving. Following this list we discuss "dimming", which we think of as one of the best soft X-ray signatures of the onset of a CME, in a separate section.

3.1 *Expanding active-region loops*

One of the first discoveries in the new X-ray data was the tendency for some active-region loops to expand at intermediate speeds (10-50 km s^{-1}), rather than remain static [*Uchida et al.*, 1992]. This observation suggests that magnetically-driven outward flows from active regions may contribute to the global coronal structure or even to the slow, dense component of the solar wind [e.g., *Hick et al.*, 1995]. Such a mechanism may also be of general interest for stellar mass loss.

3.2 *Soft X-ray jets*

Highly collimated jets, of various types, occur frequently in the *Yohkoh* soft X-ray observations [*Shibata et al.*, 1992; *Strong et al.*, 1992]. These appear to be essentially hydrodynamically driven flows along the large-scale magnetic field, and are strongly linked to flare-like effects near their feet. *Yokoyama and Shibata* [1995] suggest magnetic reconnection in an emerging-flux scenario as the key physical mechanism.

We believe that at least some of the magnetic fields involved are unipolar and open to the heliosphere because of the identification of the jets with meter-wave Type III bursts [*Aurass et al.*, 1994; *Kundu et al.*, 1995; *Raulin et al.*, 1996]. Closed-field structures also support similar behavior, including meter-wave U-bursts [*Pick et al.*, 1994], "two-sided loop jets" [*Shimojo et al.*, 1996], and jets that re-enter the chromosphere at large (0.5 solar radii) distances from their point of origin [*Strong et al.*, 1992].

3.3 *Flare ejecta*

Direct *Yohkoh* soft X-ray imaging of flares may show motion, mostly outwards. These motions are distinguishable (as image displacements) from the presumably field-aligned flows associated with "evaporation" detected mainly in soft X-ray emission-line blue shifts [*e.g., Acton et al.*, 1982]. Compact flare ejecta range from the relatively slow (<500 km s^{-1}) outward motion of compact blobs, to faster outward motions during some flares (>500 km s^{-1}). The flare-related flows [*Shibata et al.*, 1995] in the soft X-ray observations may take various forms, as do those at lower temperatures (surges and sprays). We distinguish these from jets (above) but do not really know yet whether this distinction is physically justified. Certainly, many flare ejecta are not jet-like from the point of view of collimation and velocity.

3.4 *CME-like ejecta at the limb*

Klimchuk et al. [1994], in an early study of the *Yohkoh* data based upon the standard movie images, found expanding features at the limb which had similar parameters (widths, speeds and occurrence rates) as those of CMEs observed in coronagraphs (see also *Sime et al.* [1994]; *Hundhausen* [1996]). Recently *Gopalswamy et al.* [1996] have described *Yohkoh* observations of a slow ejection at the limb on 10-11 July 1993 that appeared to incorporate the three elements of a "classic" CME – front, cavity and embedded filament. In this case the filament was well-observed with the Nobeyama 17 GHz radioheliograph, and the front clearly was a slowly-rising magnetic structure. The mass of this event was estimated as 1.2 $\times 10^{14}$ g, at the low end of the range of masses of white-light CMEs [*Hundhausen et al.*, 1994], but not very different from the mass found by *Hudson et al.* [1996b] for a different *Yohkoh* SXT mass-ejection event. It has not yet been possible to do a thorough calibration of the *Yohkoh* data set against coronagraph data, but there are many common event periods with the Mauna Loa K-coronameter observations (*A. Hundhausen*, personal communication 1995; also see below).

3.5 *Filament eruptions*

The behavior of Hα filaments has always provided one of the best guides to the occurrence of a solar eruptive event (the *disparition brusque*). *Skylab* data showed the X-ray coronal structure of the channel in which the filament forms and the bright, long-duration loop arcade which appears late in the event. The new X-ray data show many beautiful examples of arcades of this type [*Alexander et al.*, 1994; *Hanaoka et al.*, 1994; *Khan et al.*, 1994; *Lemen et al.*, 1996; *McAllister et al.*, 1992; 1996a; *Tsuneta et al.*, 1992; *Watanabe et al.*, 1992; 1994]; these observations are bringing the puzzling relationship between the filament and the CME into sharper focus. The sense of chirality of the filament, in such cases, appears to be related to that of the magnetic cloud resulting from the eruption [*Bothmer and Schwenn*, 1994; *Rust*, 1994; *Bothmer and Rust*, this volume]. An important new link in this chain is presented by *Martin and McAllister* [this volume]: the chirality of an erupting filament bears a fixed relationship to the skew of the resulting X-ray arcade. These insights offer encouragement that the pre-event coronal configuration can eventually be linked to the geoeffectiveness of the event, since this depends upon the field orientation and flow properties.

4. THE "DIMMING SIGNATURE"

At times and locations expected for CME launches, *i.e.* near an LDE flare or large arcade event, a large volume of the soft X-ray corona may rapidly become significantly dimmer. Coronal depletions were first described using HAO K-coronameter data by *Hansen et al.*, [1974], and corresponding X-ray effects (in the *Skylab* data) by *Rust and Hildner* [1978]. *Rust* [1983] describes the dimming effect as viewed against the disk as a "transient coronal hole". The *Skylab* observations, however, were limited in sampling and photometry and not well optimized for detecting such effects. The *Yohkoh* SXT data also have sampling limitations; with more frequent images and better image dynamic range the velocity field could have been measured more easily. The new results are nevertheless extensive, and will be described in more detail below.

In some of the cases studied thus far, the dimming appears to be amorphous and unstructured. It results in a decrease of the coronal surface brightness directly above the accompanying brightening. In other cases a structured mass flows outward from the region that dims. The dimming or outward mass flow can occur either above or near the brightening, or can be widespread in the vicinity of the brightening. *Hudson et al.* [1996b] point out that the radiative cooling time for such spatial and temporal scales greatly exceeds the characteristic time scale of the dimming, consistent with the interpretation in terms of material ejection. The strong temperature dependence of the soft X-ray signal noted above suggests that adiabatic cooling upon expansion will result in a rapid brightness decrease with height, as is observed during the outward motion.

Large-scale clouds adjacent to the sites of solar flares have been directly observed to move outwards and disappear during the flare brightening. Large-scale X-ray clouds were also observed during Skylab, but not to disappear rapidly [*Rust and Webb*, 1978]. In the best-studied SXT event, on 13 November 1994, the coronal cloud moved outward in a direction consistent with radial and a projected (constant) velocity consistent with the range expected from a CME [*Hudson et al.*, 1996b].

Other excellent examples of disappearing clouds are the events on 27 February 1994 and 6 February 1995. Some large-scale flare ejecta [*e.g.*, *Manoharan et al.*, 1996; R. L. Moore *et al.* (poster paper, Chapman Conference on CMEs, 1996)] show two-lobed structures in the pattern described by *Moore and LaBonte* [1979], strongly suggesting non-vertical motions. In many of these cases the outward motion takes the form of a succession of large-scale loops, each physically moving outwards as established by the image continuity from frame to frame.

The first *Yohkoh* SXT event directly associated with white light observations, on 23-24 January 1992, consisted of a streamer disruption followed by a re-formation observed by the Mauna Loa K-coronameter [*Hiei et al.*, 1993]. This event also provides an excellent example of coronal dimming [*Hudson*, 1996], allowing a determination of the probable time of the CME launch (the bulk of the dimming occurred between 08:00 and 11:00 UT, consistent with the non-observation of a CME at Mauna Loa because of local night). The event occurred just at the limb, and the coronal dimming occurred both above the location of the arcade formation and to either side. The dimming region thus appeared to envelop the region that brightened. In other large arcade events, the standard *Yohkoh* movie clearly shows the dimming to occur on a large scale. In some other large events dimming does not appear to be present, as in the event of 14 April 1994. The event of 24 February 1993, for example, appears to unmask a large region of the south polar coronal hole and also to be in the "enveloping" category (see below) [*Harvey et al.* 1996].

We can measure the mass of such a dimming region, especially if it has the form of a discrete cloud. For the ejected cloud of 13 November 1994, we derive a lower limit of 4×10^{14}g. Only a lower limit is possible because of confusion with the brighter parts of the flare, the lack of complete knowledge of the differential emission-measure distribution, and the theoretical problem of estimating any replenishing mass coming from the deeper atmosphere. This latter difficulty results from the continuous nature of the outward flow during the interval of flare brightening, and from the contrast problem (the difficulty of detecting faint features near bright ones). For the 24 January 1992 large-scale event, a rough mass estimate is about 10^{15}g. These estimates are consistent with the range of white light CME masses, which are 10^{14} to 10^{16} g [*Hundhausen et al.*, 1994].

For events in which we can see the ejected cloud of material actually departing from the low corona (*e.g.*, on 21 February 1992, 28 August 1992, 27 February 1994 and 13 November 1994) we can in principle determine the flow field of the ejected material. Difference images show that the flow tends to be everywhere outwards, with no obvious trace of the inward flow that might be expected if large-scale magnetic reconnection were the source of the flare energy [*Hudson et al.*, 1996c]. T. Watanabe *et al.* (poster paper, Chapman Conference on CMEs, 1996) presented an Hα image of the 28 August 1992 event locating an erupting filament within the X-ray cloud whose outward motion constitutes the dimming. This suggests an identification of the X-ray dimming volume with the void component of the classical 3-part visible CME.

5. CLASSIFICATION OF X-RAY DIMMING SIGNATURES

The X-ray dimming phenomena most probably associated with CME launching have a variety of morphological properties. We discuss here a preliminary classification scheme for such events, with main emphasis on the description of the dimming signature. The formation of a long-enduring arcade of hot loops occurs in each case; statistically such long-duration X-ray events are well associated with white-light CME occurrence [*e.g., Sheeley et al.*, 1983]. The dimming signature is of fundamental importance because it probably represents at least some of the expelled mass of the CME itself. Not all arcade events with filament eruptions or other good CME proxy signatures show clear dimming signatures. We do not know at present if this is due to the detection biases intrinsic to the X-ray observations, but we suspect so and suggest that appropriate coronal observations will always show a depletion or dimming of the corona at the time of a CME. Figures 1-4 shows representative examples of each of the four types of dimming event.

Dimming above an LDE flare (Figure 1). There are several examples of events in which the dimming signature appears over a well-defined volume *above* the arcade that is forming: 21 February 1992 [*Tsuneta*, 1996] and 28 August 1992 are the prototype events *Hudson et al.* [1996c]. Such events must be observed at the limb.

Cloud ejections (Figure 2). In other flare-associated events, a well-defined X-ray coronal cloud adjacent to the flare moves away from the flare region and disappears. Events in this category include 27 February 1994 [*Hudson et al.*, 1996a] and 13 November 1994 [*Hudson et al.*, 1996b]. The observations suggest a large-scale twist (approximately one turn) in each cloud. The double-lobed ejecta of the 25 October 1994 event [*Manohoran et al.*, 1996] may also fit in this category.

Enveloping dimmings (Figure 3). We identify these as "streamer blowout" CME events seen in white light [*Howard et al.* 1985; *Hundhausen*, 1993]. The classic example of this in the *Yohkoh* data is the event of 24 January 1992 [*Hiei et al.*, 1993; *Hudson*, 1996].

Transient coronal holes (Figure 4). The diffuse corona near an arcade development on the disk occasionally dims at or near the time of the X-ray brightening, strongly suggesting the formation of a new area of open field lines. These areas are not permanent, gradually filling in after several hours or a day or so. The term "coronal hole" is used because in X-rays the brightness of these areas can decrease to approximately the level of the larger and more permanent coronal holes.

6. ASSOCIATION OF X-RAY AND WHITE-LIGHT SIGNATURES

The comparison of the new X-ray signatures of coronal ejections must be understood in the context of white-light coronagraph data. Since the demise of SMM in late 1989 there have been no spaceborne coronagraph instruments, until the current era of SOHO. Thus, during most of the lifetime (to date) of *Yohkoh*, white light CME observations were only available from the ground-based Mauna Loa K-coronameter with the usual problems of day/night cycles (a typical observing day of ~5 hr.) and weather (including the airborne dust effects of Mt. Pinatubo).

D. Webb and H. Hudson (poster paper, Chapman Conference on CMEs, 1996) reported on a preliminary examination of the SXT data for transient X-ray features (involving brightenings and outward motion) near the appropriate limb location occurring before and during periods when white light CMEs were observed at Mauna Loa. We found that nearly 2/3 of the CMEs were associated with a transient X-ray structure, usually a loop, and a majority of these loops had at least one foot in a flaring active region. Consistent with previous results, the X-ray feature typically did not lie symmetrically underneath the CME.

The other major new source of white-light data is the LASCO suite of instruments on SOHO. These data appear to be qualitatively superior to previous white-light coronal observations [see *Howard et al.*, this volume]. Although LASCO observes transients resembling the classical events observed by the *Skylab*, SOLWIND and SMM coronagraphs, it has better sensitivity and a larger field of view than these instruments, enabling it to observe other kinds of outward flows that may also be identifiable in the soft X-ray observations. At this time, no study comparing flows or ejections observed by SOHO at visual wavelengths and by *Yohkoh* in soft X-rays has been carried out. However we have made preliminary surveys which show that there have been many events observed in common, both with LASCO

(*C. St. Cyr*, private communication 1996) and also with other SOHO instruments.

7. TIMING AND CAUSALITY

The physical processes involved in launching a CME remain poorly understood, so the X-ray view of the behavior of the lower corona during well-defined CMEs is of great interest. In cases where a large-scale flow can actually be observed in soft X-rays, we can learn about the geometry of the ejection process and the origin of the ejected mass. Even in the more common cases where only a dimming of diffuse coronal material can be detected, the relative timing of the X-ray dimming signature and the X-ray brightening might point towards the direction of causality. Standard models of large-scale magnetic reconnection suggest that post-flare loop arcades might occur after some delay relative to the CME onset. This indeed appeared to be the case from earlier soft X-ray observations with less sensitivity than the *Yohkoh* observations, *e.g.*, *Hundhausen* [1996], but the *Yohkoh* observations indicate that the flare-related arcade brightening may occur with little or no delay [*Hudson* 1997]).

The filament eruption is well-known to begin, by activation including turbulent motion and a slow rise, well before the main part of the X-ray arcade development. Recent data confirm this pattern well (*Hanaoka et al.* 1994; *Khan et al.* 1994; *McAllister et al.* 1996b]) and suggest that the main arcade development takes place when the filament has risen to about 10 times the width of the arcade.

The *Yohkoh* observations show a wide variety of soft X-ray loop arcades, extending this type of observation beyond that found with *Skylab* and *Solar Maximum Mission.* They confirm the *SMM* observation of "giant arches", which may be morphologically distinct from the post-flare loops [*Švestka et al.*, 1996]. Either kind of loop system – or perhaps both or neither – may be identifiable with the large-scale reconnection scenario (see *Tsuneta* [1996], for a positive view of such a picture, or *Hudson and Khan* [1997], for a skeptical view). *Klimchuk* [1996] comments on the absence of reconnection signatures in CME development, but *Kahler and Hundhausen* [1992] point out that the "legs" of CMEs may in fact consist of multiple cusp (bipolar) structures.

8. CONCLUSIONS

Soft X-ray imaging of the solar corona reveals several forms of mass ejecta, some of which are new with the *Yohkoh* SXT observations. Compared with the traditional coronagraph or K-coronameter observations, the

Yohkoh data have better sensitivity and sampling, and view the entire visible hemisphere. Events probably associated with CMEs often show clearly measurable dimmings of the X-ray corona near the site of a flare or arcade brightening. We interpret the X-ray dimmings as the expansion and opening of magnetic field lines during the early phase of a CME (A. McAllister *et al.*, poster paper, Chapman Conference on CMEs, 1996). Transient coronal holes, dimmings seen against the disk, usually appear at the same time or later than the first arcade brightening and are skewed relative to its center, suggesting that they mark the evacuated feet of the flux ropes of the rising CME. In general the main arcade brightening follows the mass ejection and the impulsive phase of any associated flare ("impulsive" here means non-thermal energy release as detected in hard X-ray bremsstrahlung; *Hudson et al.* [1994] show that this occurs even in slowly-rising arcade events).

In some of the cases that have been studied, the *Yohkoh* SXT observations show details of the origin of the ejected material. For example, the 13 November 1994 cloud event has the appearance of a large structure with approximately one full twist ($\sim 2\pi$); the structure appears to be anchored at one end in a flaring active region [*Hudson et al.*, 1996b]. The 21 February 1992 event and others, on the contrary, appear to dim only above the developing arcade, even when viewed from apparently different perspectives relative to the arcade axis. Finally some of the large-scale arcade events appear to show large-scale dimming both at and remote from the arcade location. These different dimming signatures suggest that there may be a variety of physical processes involved.

The relationship between CMEs and flares or flare-like brightenings also does not seem now so simple as previously thought; it now appears in many cases that there is no appreciable delay between the launching of mass and the associated flare brightening [*e.g.*, *Hudson* 1997]. This is consistent with recent discussions of this relationship by *Feynman and Hundhausen* [1994] and *Harrison* [1995]. Our comparison of SXT and Mauna Loa data better elucidates the physical interpretation of CME onsets. Under the CME one can usually find a brightening and expanding X-ray structure, which is typically looplike with one end embedded in a flaring active region. On the other hand, such expanding loops are not usually associated with the Mauna Loa CMEs, despite having speeds, widths and occurrence rates similar to those of CMEs [*Klimchuk et al.*, 1994]. Thus, we conclude that the dimming effect seems a more consistent X-ray signature of CME *onset*, if not occurrence.

Do flares and CMEs divide naturally into two classes of events? We note that no single parameter of a solar flare or arcade disturbance has been reported to exhibit actual bimodality, *i.e.,* a distribution function with two resolved maxima. All parameters seem to have broad or unimodal distributions, suggesting that flares and CMEs form a continuum with the same underlying physics. On the other hand several properties of the interplanetary counterparts of CMEs clearly have bimodality (see *Reames* [1994] and references therein).

Phenomena observable in the low corona, on the solar disk, in principle give us our earliest possible hint that a CME has been launched and might strike the Earth. We can hope that further understanding of these phenomena may even help us to predict the terrestrial consequences ("space weather"). Unfortunately we currently have no firm theoretical basis for such predictions, but we can hope that further empirical understanding will also help us to understand the basic physics.

Acknowledgments. This work was supported under NASA contract NAS 8–37334 (HSH) and under NASA contract NAGW-4578 and Air Force contract AF19628-96-K-0030 (DFW). *Yohkoh* is a mission of the Institute of Space and Astronautical Sciences (Japan), with participation from the U. S. and U. K. We would like to thank A. Hundhausen and E. Hiei for pointing out the 16 January 1993 event, and C. St. Cyr for maintaining a list of CME events observed on SOHO. E. Hildner pointed out the possible role of adiabatic cooling in the soft X-ray observations of CME counterpart events during discussion at the Chapman Conference on CMEs, 1996.

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Figure 1. An "LDE flare dimming" in a limb event of 28 August 1992. This and the subsequent figures have reversed colors and have north at the top, west to the right. The top frames show the filamentary structure that had formed above the flare loops prior to the flare. This filamentary structure rises as the diffuse corona in the same region dims, almost simultaneously with the flare brightening. *Hudson and Khan* [1996] show difference images, demonstrating the outward motion of the filamentary structure. As mentioned in the text, these hot filaments appeared to wrap around a cool filament seen in Hα (*Ta. Watanabe*, personal communication).

Figure 2. A "cloud dimming" associated with the long-duration flare of 13 November 1994 [*Hudson et al.*, 1996b]. The flare proper is outside the field of view of the two images to the SW (lower right). Prior to the left image, the structure seen had been rising steadily as the flare brightened, and in the interval shown (about an hour) it disappeared almost completely except for the dimly-seen legs.

Figure 3. An "enveloping" dimming event, that of 24 January 1992 [*Hiei et al.*, 1993; *Hudson*, 1996]. The plot at the bottom shows light curves from two regions of the corona, one (*) to the S of the developing arcade, and one (+) at its brightest point at about 12:00 UT. The image at the top shows the difference of two images (14:33 minus 06:01), with the zero contour overlaid; the boxes show the locations integrated to generate the light curves. Note that the light curve from the cusp region shows an initial dimming, followed by an increase as the tip of the bright cusp enters the integration box. The voids left by the blowout are the regions S and N of the arcade, plus the areas at the top of the image on the disk.

Figure 4. Example of transient coronal holes. The image at left (16 January 1993, 12:46:23 UT) shows two regions (enclosed within dashed lines) that dimmed suddenly. These regions fit within the S-shaped bright structure that evolves with time to become the bright arcade seen at right (14:58:23 UT). The dimmed region does not quite reach the darkness level of the south polar hole.

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