THE ASSOCIATION OF CORONAL MASS EJECTION TRANSIENTS WITH OTHER FORMS OF SOLAR ACTIVITY

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Abstract. Coronal mass ejection transients observed with the white light coronagraph on Skylab are found to be associated with several other forms of solar activity. There is a strong correlation between such mass ejection transients and chromospheric Hα activity, with three-quarters of the transients apparently originating in or near active regions. We infer that 40% of transients are associated with flares, 50% are associated with eruptive prominences solely (without flares), and more than 70% are associated with eruptive prominences or filament disappearances (with or without flares). Nine of ten flares which displayed apparent mass ejections of Hα-emitting material from the flare site could be associated with coronal transients. Within each class of activity, the more energetic events are more likely to be associated with an observable mass ejection.

1. Introduction

The relationship among various dynamic forms of chromospheric and coronal activity has been investigated using a number of different observational techniques. Observations of green line transients (DeMastus *et al.*, 1973) show that these coronal disturbances are usually associated with eruptive prominences and large surges; only a few are accompanied by flares – somewhat in contrast to the results of an earlier study by Dunn (1971). Warwick (1965) found a strong correlation between type II radio events and ascending prominences, although Dodge (1975) did not consider prominences or filaments in his flare-type II correlative study. In preliminary reports, Gosling *et al.* (1974) and Munro *et al.* (1974) showed that mass ejection transients observed with an orbiting white light coronagraph are more frequently associated with eruptive prominences than with flares. Large-scale transient X-ray enhancements in the corona are typically associated with the disappearance of Hα filaments both far from active regions (Webb *et al.*, 1976) and within active regions (Kahler, 1977; Pallavicini *et al.*, 1977; Rust and Webb, 1977).

In contrast to the strong correlation between eruptive prominences and the coronal disturbances described above, Hansen *et al.* (1974) found that infrequent abrupt depletions of material from the inner corona inferred from K-coronameter data invariably are associated with Hα ascending material in the form of flare sprays. A similar correlation was obtained by Smerd and Dulk (1971) between moving type IV radio events and flare ejected material.

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Except for the recent studies of white light and X-ray transients observed from Skylab, the inferred correlations were usually based upon relatively small samples of the infrequently observed (at most 5 events per year) and often more energetic events in each class of solar phenomenon. Hence it was not possible to examine the overall picture of dynamic activity. However, due to the thorough observational coverage, the Skylab period data allow a more detailed study of the interrelationships among various forms of solar activity. We wish to ascertain what causes coronal disturbances, and this paper addresses that question by assessing the likelihood that a coronal disturbance is associated with other manifestations of the same abrupt, perturbing event in the lower solar atmosphere.

Combining data obtained from the High Altitude Observatory's white light coronagraph on board Skylab, from ground-based observatories, and from other satellites, we have investigated the association between mass ejection coronal transients and other forms of solar activity such as Hα flares, spatially unresolved soft X-ray events (both flares and gradual-rise-and-fall events), eruptive prominences, sprays, surges, and metric type II and IV radio bursts. These other forms of solar activity will be referred to as 'near-surface' events, in contrast with the coronal transient activity observed above $2R_{\odot}$. After describing the various observations in Section 2, the correlations and implications of the associations are presented in the following sections.

2. Observations

In this section we discuss pertinent solar data – Hα, X-ray, radio – used to associate observed coronal transients with other forms of solar activity. The data were obtained contemporaneously with the High Altitude Observatory's ATM white light coronagraph observations from 28 May 1973 to 3 February 1974 near solar minimum. Between these dates, various time periods are excluded when the intervals between coronagraph images were greater than 12 hr. The largest gaps in the coronagraph data occur on 10–20 June (a camera malfunction), and 16–28 July and 15–19 November (pointing control malfunctions); gaps of about a day also occur when the coronagraph was being reloaded with film.

2.1. Skylab white light transients

The HAO coronagraph on board the Skylab satellite detected some 115 coronal transients during its 227 days of observations. Here we define transients to mean rapid changes in apparent coronal structure occurring on the time scale of a few tens of minutes. Photographs of each coronal transient have been visually examined to determine whether it is a definite mass ejection. Of the 115 observed transients, 77 definite mass ejections have been identified. Mass ejection events are distinguished by increased brightness within the instrument's field of view. Approximately one-third of these ejections have a loop appearance (the most numerous classification); material injected into streamers and amorphous clouds are other such frequently occurring events. Of the remaining 38 events, there are 4 possible mass ejections, 26 re-arrangements, and 8 questionable transients. Re-arrangements manifest themselves as subtle variations in coronal forms and apparently do not cause major restructuring in the corona. Undoubtedly a fraction of these subtle re-arrangements would be classified as major events if they had occurred closer to the solar limb where geometry favors detection of the event with the coronagraph. Events classified as questionable may in fact be due to relatively slow evolutionary changes in streamers or due to peculiar projection effects.

To minimize the difficulties and uncertainties in associating particular events near the solar surface with minor coronal brightness modifications above $2R_\odot$, only the 77 definite mass ejections are considered in the remainder of this paper. This restriction omits only the smallest, and presumably least energetic, transients.

2.2. Other forms of solar activity

Prompt and Comprehensive Reports of *Solar-Geophysical Data*, published by the National Oceanic and Atmospheric Administration (NOAA), are our primary source of information concerning Hα and X-ray flares, and metric radio bursts. Because coronagraphs are most sensitive to coronal changes near the solar limb, only tabulated events occurring within 50° of the limb and concurrent with coronagraph observation are considered.

Activity at the limb – eruptive prominences (EPL), sprays (SPY), surges at the limb (BSL), etc. – as well as additional data on flares and filaments are obtained from reports from individual NOAA observatories, the Air-Weather Service, and the World Data Center. Individual reports provide more detailed information regarding the morphology of events. It must be noted that reports of eruptive prominences are not as complete or as accurate as for flares. Except for large, specular events, the reports are quite subjective; few photographic data are available. Inconsistencies such as whether a prominence erupted or was only active, abound. Often filaments disappear without being noticed, hence it is not possible to distinguish whether material erupted or merely drained back to the solar surface. Most observations are made with Hα patrol telescopes with limited bandwidths. Thus, a large EPL with significant motion along the line of sight may go undetected. Because the contrast between ejected Hα material and the disk decreases rapidly with height from the solar limb, Hα patrol telescopes may fail to detect an eruption that would be obvious when observed with a ground-based coronagraph. The circumstances noted above probably imply that any compilation of eruptive prominence phenomena will not be as complete as a corresponding list of flare activity. Hence, the association between eruptive prominences and other forms of well-observed solar activity will necessarily be underestimated.

3. Associations

To determine which forms of solar activity might be associated with white light coronal transients, we first search for events whose spatial and temporal occurrence nearly coincides with those of observed mass ejections. We then reverse this process, searching for coronal transients which occur in conjunction with EPL's, flares, radio bursts, etc. Because there is generally no observational information available about the nature of an event as it transits between a height close to the solar surface and about $2R_\odot$ for the data described in Section 2, we must establish criteria which, if satisfied, imply that a white light coronal transient observed by the Skylab coronagraph was indeed associated with another form of solar activity.

First, we assume that a transient will not be seen above $2R_\odot$ prior to the onset of its near-surface associated event. If it is measurable, the speed of each white light transient (see Gosling *et al.*, 1976) is used to estimate the transient's departure time from the solar surface (assuming a constant speed). The departure times obtained in this manner are increasingly uncertain for slower moving transients, because transient's accelerations below the coronagraph's occulting disk and their heights of origin are unknown. Thus for slower events, we open the temporal window around the transient's departure times in which the associated phenomena must occur. Usually an ejection's estimated departure time is within 30 min of the reported onset time for the event we take to be associated if the transient's speed was greater than 250 km s^{-1}.

Temporal correlation is not the only criterion; the location of an associated phenomenon must be nearly at the same position angle as its coronal transient (taken here as within 20°). Precise registration is not required for two reasons. First, ejected material need not travel radially outward; eruptive prominences sometimes sever their apparent connection to the surface at only one footpoint. Second, Hα emitting material, monitored by ground-based patrol, comprises but a small fraction of the total white light coronal ejection observed with the Skylab coronagraph (Hildner *et al.*, 1975b; Poland and Munro, 1976; Schmahl and Hildner, 1977); most of the mass in a transient ejection must be coronal in origin and thus may take a slightly different direction of motion.

It is almost trivial to associate extremely energetic phenomena near the solar surface with coronal transients. Because such energetic events normally produce substantial quantities of radiation at all wavelengths and eject more mass at higher velocities, their manifestations are generally well observed far from the solar surface and sometimes can be traced far into the coronagraph's field of view. Near-surface phenomena of lower energy are more frequent, making the association of a particular low-energy event with a coronal mass ejection more difficult. Exacerbating this difficulty is the knowledge that roughly half of the coronal transients should have origins on the backside of the Sun; these ejections may not be associated with any observable phenomena (excepting, perhaps, radio bursts and unresolved X-ray enhancements).

3.1. Near-surface phenomena associated with ejections

Of the 77 obvious mass ejection coronal transients, 25 events are definitely associated with Hα phenomena occuring near the surface of the Sun; another 9 events have probable associations. Near-surface phenomena are not found in association with the remaining 43 mass ejections; perhaps 38 (half of the total 77) transients arise from events occurring behind the limb of the Sun. Specific coronal transients which are definitely associated with near-surface activity are listed in Table I. The first four columns refer to the white light coronal transient; times indicate the first coronagraph observations of the events. The remainder of the table pertains to other forms of associated phenomena. Table II is a similar listing of the ejections with probable associations.

Examination of Table I and II shows that approximately 40% of the ejections that can be associated with near-surface activity were associated with flares, 50% were associated with eruptive prominences or filament disappearances only (no flares were observed), and more than 70% of the events were associated with an eruptive prominence or filament disappearance (with or without flares). Considering just the 25 Table I events with definite associations, only 5 can be classified as flare initiated without an accompanying eruptive prominence or filament. However, in each of these 5 events (2 of which are subflares), Hα material was ejected from the flare site as a surge or spray. Three of the 25 events arise from the eruption of filaments near but not in small active regions which subsequently produced major two-ribbon flares. These have been given the designation Disparition Brusque flare (DB flare) to signify that the eruptive filament apparently was more closely associated with the subsequent transient phenomena than was the flare. Dominating the Hα event associations are eruptive prominences; they are associated with 13 of the white light transients. No flares were observed at the time of these eruptive prominences. Finally, two of the associated Hα events were classified in the observatory reports as both eruptive prominences and sprays, one as a spray, and one as a nearly simultaneous occurrence of an eruptive prominence and flare within the same active region.

Because three-quarters of the Hα events we associate with coronal transients originated in or near active regions, and because transient production is statistically more probable where the sunspot number is large (Hildner *et al.*, 1976), we may strengthen the conclusion of Hildner *et al.* that transients occur when and where the surface magnetic fields are stronger and more complex.

3.2. Coronal ejections associated with near-surface phenomena

To this point, we have considered only those near-surface events associated with coronal transients. Not every flare or eruptive prominence during the Skylab period was followed by a mass ejection transient. This leads us to ask: (1) Do near-surface phenomena exhibit special characteristics when they are associated with coronal transients? and (2) What fraction of near-surface pehonomena is associated with subsequent mass ejections from the Sun? The types of phenomena we consider are flares (both Hα and X-ray), eruptive phenomena at the limb, metric radio bursts, and long duration X-ray events.

TABLE I

White light coronal transients and their associated solar activity

White light transient 1973–1974				Associated Hα event[b]			X-ray (1-8 Å) (Solrad)[b]	Metric radio signal[b]	LDE[c]	GRF[d]	Comments[e] and references
Date	Time	P.A.	Outward radial speed[a]	Description	Time	Location					
10 June	01:50	68		$0.1R_\odot$EPL/SPY	00:52	N13 E90		II			
10 June	09:29	69	450	$0.4R_\odot$EPL	08:15	N13 E90	C2	II	X	X	(1)
25 June	13:37	279		$0.3R_\odot$EPL	07:00	S03 W90					Not associated with active region.
28 June	19:55	93	375	$0.2R_\odot$SPY	18:44	N12 E90	M7		X		
2 July	13:41	250	250	$0.32R_\odot$EPL	11:00	S27 W90	C1		X	X	Not associated with active region.
29 July	16:32	58		DB flare (3B)	13:13	N14 E45	M7	II, IV	X	X	(2) Active region devoid of sunspots.
9 Aug.	15:30	278	155	$0.25R_\odot$EPL	~14:00	N01–35 W90					
10 Aug.	13:31	278	400	$0.2R_\odot$EPL	12:44	N05 W90					(3)
13 Aug.	06:55	306	700	$0.18R_\odot$EPL	<06:50	N42 W90		II			Not associated with active region.
13 Aug.	21:37	268	250	$0.5R_\odot$EPL	17:40	S25 W90			X	X	(4) Not associated with active region.
21 Aug.	14:41	60	525	$0.42R_\odot$EPL	13:19	N19 E90		IV at 1443	X	X	(5)
26 Aug.	23:02	63	150	$0.73R_\odot$EPL	17:57	N20 E90					(6) Not associated with active region.
7 Sept.	13:06	251	>1000	2B flare (DSD)	11:41	S18 W46	X1	II, IV	X	X	(7)
7 Sept.	23:12	280	350	$0.25R_\odot$ EPL	22:18	N18 W90					
10 Sept.	04:08	268	400	$0.1R_\odot$ EPL	02:41	S24 W90					
25 Sept.	02:01	78	> 660	DB flare (1N)	00:34	N29 E73	C2		X	X	Adjacent to active region.

6 Oct.	14:14	274		-N flare (BSD to $0.1R_\odot$)	10:49	S16 W68	C1	II	X		
27 Oct.	16:59	69	620	DB flare (2B)	15:47	N18 E55	M3	II, IV	X		
3 Nov.	01:07	254	>1220	2N flare (LPS)	<00:12	S18 W85	X1	II, IV	X	X	Clouds prevented observations until event was in progress.
14 Dec.	10:02	100	550	$0.12R_\odot$ EPL	09:24	S13 E90					
16 Dec.	11:48	110	365	-B flare (SPY to $0.1R_\odot$)	11:00	S17 E82	C5				
19 Dec.	07:00	70	190	$0.6R_\odot$ EPL	at 06:48	N02 E90					(8) Not associated with active region.
12 Jan.	11:44	124	350	1B flare (BSD, BSL)	10:28	S18 E82					
15 Jan.	11:32	265	425	$0.7R_\odot$ EPL + 1N flare	10:50	N08 W85	M1				EPL and flare occurred simultaneously.
17 Jan.	19:43	277	1000	$0.3R_\odot$ EPL (SPY)	19:25	N07 W90		II		X	Possible flare on the backside of the Sun.

Notes:

[a] Outward radial speeds (km s^{-1}) of leading edges from data prepared for Gosling *et al.* (1976).

[b] Hα descriptions, X-ray, and radio data from NOAA *Solar-Geophysical Data* and NOAA Observatory Reports. Loop prominence system (LPS); disappearing filament (DSF); dark surge on disk (DSD); bright surge on disk (BSD).

[c] Long-duration X-ray events (LDE) from Kahler (1977).

[d] Gradual-rise-and-fall (GRF) from Sheeley *et al.* (1975).

[e] References are:

(1) Hildner *et al.* (1975a).
(2) Michalitsanos and Kupferman (1974).
(3) Gosling *et al.* (1974).
(4) Rust and Hildner (1976).
(5) Poland and Munro (1976).
(6) Hildner *et al.* (1975b).
(7) Gosling *et al.* (1975).
(8) Schmahl and Hildner (1977).

TABLE II

Possible associations of solar activity with white light coronal transients

White light transients				Associated Hα events[b]			X-ray (1–8 Å) (Solrad)[b]	Metric radio signal[b]	LDE[c]	GRF[d]	Comments[e] and references
Date	Time	P.A.	Outward radial speed[a]	Description	Time	Location					
19 June	23:57	270	300	$0.1 R_\odot$ BSL	22:40	N15 W90			X	X	
24 June	19:16	278	135	Prominence disappeared	17:22	S28 W90					Not associated with active region.
26 June	03:48	225	>1140	1B flare (DSF)	01:35	S08 W27	C9	II, IV	X		
8 Sept.	17:58	298	400	EPL/DSD	16:26	N23 W72		II			
15 Sept.	00:32	282	675	Back side flare				IV			(1)
17 Sept.	16:19	268	> 430	Back side flare	15:18			II			Time of type II radio burst.
29 Sept.	14:32	80	100	Prominence disappeared	90:00	N18 E90					Not associated with active region.
21 Oct.	00:54	95		$0.07 R_\odot$ EPL	20 Oct. 17:40	S09 E90			X	X	
10 Jan.	11:38	92		1N flare (SPY, LPS)	09:40	S21 E90					(2)
				?EPL	08:47	S11 E90					

Notes: see notes for Table I.

[e] References are:

(1) Dulk *et al.* (1976).

(2) Munro (1979).

3.2.1. *Correlations with Flares*

A flare's energy appears to be an important factor determining whether or not the flare will be associated with a coronal transient. Because a coronagraph is most sensitive to events emanating from near the solar limbs, we have separately analyzed flares occurring within 10° of the limb, and those between 10 and 50° from the limb. There are several ways to classify the relative energy of a flare – the most common one is the area (Importance increases with area) and brightness (faint, normal, and bright) of the Hα flare emission. Only those flares occurring during frequent coronagraph observations are considered here. Each of the four Importance 2 or larger flares which occurred within 50° of the limb were associated with coronal transients. However, only two of the 18 Importance 1 flares within 10° of the solar limb were associated with transients. No transients were observed with Importance 1 flares which occurred further than 20° from the limb. In all, only three of 62 Importance 1 flares within 50° of the limb were associated with transients. Thus, there may be a flare-energy threshold or an energy dependent process for the parent event of coronal transients. If the energy is sufficiently large, then there is an Importance 2 or larger flare plus a coronal mass ejection.

A different measure of a flare's energy is the maximum soft X-ray flux it produces. If we consider only those X-ray flares observed with Solrad which produce 1-8 Å X-ray flux exceeding 10^{-2} ergs cm^{-2} s^{-1} at 1 AU (Class M1 or greater), we find a slightly higher correlation with transient activity than that which is found for Hα flares alone. While all Hα Importance 2 or larger flares were accompanied by strong X-ray emission, only 8 of the 62 Importance 1 Hα flares were also Class M (or greater) X-ray events; one of these 8 events was associated with a coronal transient.

Two major points arise from this comparison of flares and coronal transients. For flares which occur near the solar limb (e.g., within 10°), where detection of coronal material is most favorable, energetic flares are more likely to cause transients. Secondly, the positional distribution of the transient-associated flares on the solar surface is consistent with the statement that the more energetic events have a greater effect upon the corona (i.e., eject more mass and/or influence a greater volume). This latter statement is deduced from the fact that while no Importance 1 flares further than 20° from the limb could be definitely associated with coronal mass ejections, three of the four Importance 2 or greater flares occurred further than 35° from the limb.

Besides the increased correlation between coronal transients and more energetic flares, there is nearly a one-to-one relationship between those flares with Hα ejected material and flare-associated transients. In fact, every one of the 9 flares (including DB flares) within 50° of the limb that was associated with a coronal transient also had an Hα mass ejection. These Hα mass ejections are variously described by observers as eruptive prominences, flare sprays, and high velocities within disappearing dark filaments. Only one flare with an Hα mass ejection within 50° of the limb (for which suitable observations were made by the coronagraph) did not produce a coronal transient; this particular event, 4 December 1973, is discussed by Wagner and DeMastus (1977).

If we broaden our association criteria, we find additional associations which tend to confirm the close correlation between flares with Hα mass ejections and coronal ejections. That is, 11 or 12 flares with Hα mass ejections had associated transients if the limb flare following the eruptive prominence of 21 August is associated with the secondary set of loops observed in that white light transient (Poland and Munro, 1976) and if the 10 January event (Table II) is truly associated with the listed flare. In selecting Hα mass ejections from the flare site, we exclude material motion confined within the flaring region.

3.2.2. *Correlation with Eruptive Prominences*

More coronal transients were associated with eruptive prominences than with any other phenomenon during the Skylab period. Because eruptive prominences are only classified on the basis of their maximum observed height above the limb (which is dependent upon the bandpass of the Hα filter used, the design of the telescope, seeing conditions, the speed along the line of sight, and the prominence's longitude

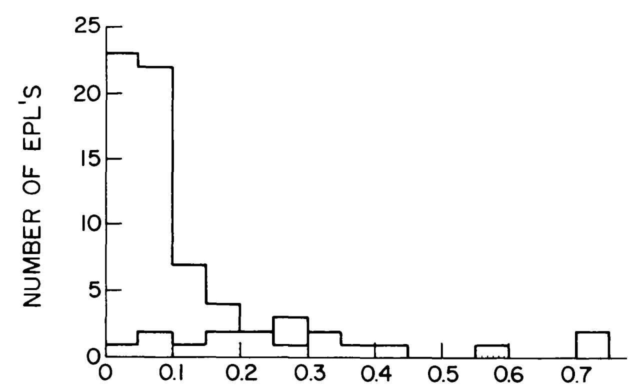

Fig. 1a. Observed maximum heights for all eruptive prominences and those associated with coronal transients during the Skylab mission. The stippled area refers to those EPL's associated with transients.

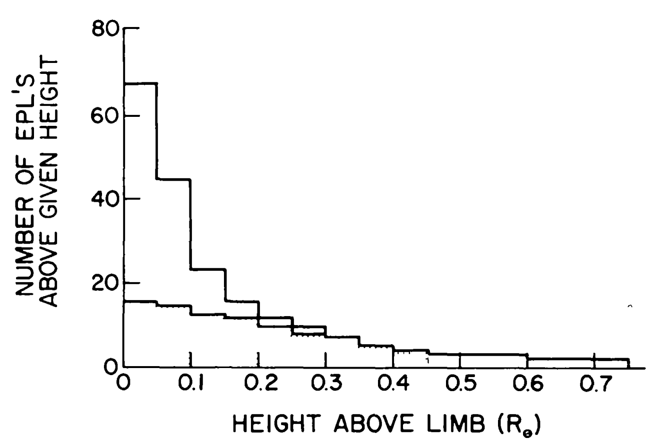

Fig. 1b. The distribution of eruptive prominences rising above a given height and their associations with white light transients.

with respect to the limb), there is no routine method of estimating the energies of these events. Practically speaking, observers sometimes disagree whether to call smaller events eruptive prominences or active prominences.

Even with the difficulties of EPL patrols, we found that during the 227 days when the coronagraph was operational, 101 eruptive prominences near the limb were observed and reported. Another 10 reports refer to the possibility that an eruptive prominence occurred. We exclude the 33 eruptive prominences which were observed when coronagraphic observations were not available for 8 hr following the event or when the corona was too disturbed by a preceding transient to detect another transient. The distribution of the observed maximum heights of the remaining 68 eruptive prominences is given in Figure 1a. The stippled area denotes the subset of those events associated with coronal transients. Two-thirds of the reported eruptive prominences are never observed beyond $0.1 R_\odot$ above the solar limb; fewer than 10% of these low maximum altitude events produced coronal transients. The correlation between mass ejection transients and eruptive prominences increases as the observed height of the eruptive prominences increases. This is most easily seen by studying the distribution of eruptive prominences observed to pass a given height above the limb (Figure 1b). Almost 60% of the eruptive prominences observed above $0.1\ R_\odot$ and every eruptive prominence observed above $0.3\ R_\odot$ is associated with coronal transients. If the observed maximum height of an eruptive prominence can be used as a crude indicator of the energy contained in the event, then we again are led to conclude that coronal transients are more likely to be associated with more energetic events. In fact, we see that essentially all eruptive prominences observed beyond $0.2 R_\odot$ are associated with mass ejections into the solar wind.

3.2.3. *Other Correlations*

As might be expected, metric radio bursts are highly correlated with coronal transients (see Gosling *et al.*, 1974, for a preliminary analysis); both phenomena are manifestations of disturbances in the outer corona. Omitting bursts that seem to be associated with flare phenomena near central meridian passage (based upon the flare's position), 23 reported metric type II and type IV radio events probably occurred within 45° of a limb (based upon temporal, but not spatial, correlations). Of these, 21 were associated with coronal transients; 12 of the 21 also had associated Hα surface events (see Tables I and II). One of the 2 radio events not associated with a coronal ejection was reported as being weak and the other could possibly be associated with an anomalous active region that produced large flares and a major ELP, all without accompanying coronal transients (McMath region 12628, 4 December 1973).

The final classifications listed in Tables I and II are the gradual rise-and-fall (GRF) and long-decay-event (LDE) signature of soft X-rays from Solrad. Sheeley *et al.* (1975) and Kahler (1977) have shown that X-ray events with these signatures – a majority of which involve either an eruption or major activation of a prominence – are often accompanied by transients in the outer corona. Fifteen of the 19 GRF events listed by Sheeley *et al.* probably originated within 50° of a limb when suitable coronagraph observations existed. Mass ejection coronal transients followed 14 of these 15 GRF's. Kahler lists 19 LDE's within 50° of the limb (there is considerable overlap with the GRF list of Sheeley *et al.*); 15 of these 19 events are associated with coronal transients. Again, we see that if a large amount of energy is liberated during an event, as evidenced in this case by enhanced, long-duration, X-ray emission, then an ejection of mass from the Sun is very likely.

In the above compilation, events such as subflares and small bright surges at the limb have been omitted. While it is possible that a few of these events could be associated with mass ejections, no evidence exists to support this hypothesis. Evidently, these events are simply not energetic enough to involve major perturbations in the outer corona.

3.3. Statistical significance of associations

The criteria for claiming associations between coronal transients and other forms of solar activity (see Section 2) was partially based upon a few events where data from other instruments were used to trace ejected material from the surface to well into the coronagraph's field of view. To determine how strong the association criteria are, simple χ^2 tests were applied to the data to check whether the claimed associations could be due to fortuitous occurences of two uncorrelated phenomena. By assuming that solar activity was equally likely to occur in either hemisphere at any time, there are then four segments of approximately 40° in size where activity could occur – the northern and southern portion of each limb. These 40° segments overestimate the $\pm 20°$ position angle criterium for associations presented in Section 2. Thus over the duration of the Skylab period (227 days), the probability of either an EPL or Hα flare occurring in any given segment during a one-hour period is 3.1×10^{-3}; transients have a probability of 3.5×10^{-3}. If all events are uncorrelated, only 0.24 associations between transients and both Hα flares and EPL's would be expected over the entire Skylab period. Note that our definite association count of 25 is over 100 times larger than expected for random distributions; the probability that the 25 associations are fortuitous is vanishingly small ($\sim 10^{-87}$).

Another way to assess the significance of the associations claimed in this paper is to ask how much can the criteria for associations be relaxed and still ensure that the chance of ascribing a correlation to a random set of events is small. Picking 1 chance in 100 as an acceptable criterion for excluding a random distribution, the temporal window for association could be opened to 32 hr for all events, 50 hr for EPL's, and 17 hr for Hα flares and still have a meaningful set of associations. The association criteria used here is even more stringent for the radio bursts, GRF's and LDE's. Disregarding any positional criterion (i.e., using a temporal correlation only), the temporal window can be opened to 47 hr for radio bursts, 43 hr for GRF's and 35 hr for LED's.

As part of the association criteria, it was assumed that transients are only observed after near-surface events. Subsequent analysis showed that in the 3 hr period preceding the temporal criteria used here, only *one* transient occurred before a near surface event; statistically one expects to see 0.71 transients in this time period if the events occur at random. However, because of the uncertainty in estimating the transient's departure time and its initial height above the solar surface (see Section 2), and the uncertainty in the quoted times for some near-surface events (especially EPL's), it is not possible to ascertain whether coronal transients in general precede or follow their associated near-surface event on a time scale less than 30 min from this type of study. Such an analysis must be conducted on a case by case basis when the necessary observations exist to trace the transient material as it propagates outward from the Sun.

From the analysis presented above, the criteria used in this paper for establishing associations between transients and other forms of solar activity ensure that all implied correlations are statistically significant.

4. Discussion

Abrupt mass ejection into the solar wind seems to take place only if the parent perturbation is sufficiently energetic; the energy of the parent perturbation manifests itself additionally in either a large Hα flare, an eruptive prominence to great heights, long duration X-ray emissions (GRF's and LDE's), or radio bursts. However, upon closer inspection, characteristics other than energy may seem to play an important role. We find that the ejection of chromospheric material from a flare site seems to be a necessary condition for the association of a mass ejection transient with the flare, regardless of the flare's energy. In fact, the existence of ejected material from the flare site may be a better clue to the nature of the parent perturbation than is the flare's energy as we consider the association between flares and coronal transients. However, it is not possible to substantiate this statement using the present data because all Importance 2 or greater flares were associated with Hα ejecta.

It also appears that the magnetic field configuration of an active region can influence the production of *coronal* mass ejections. In an instance on 6 September 1973 a large X-ray event (Class X1) occurred as a BSL, rose nearly $0.2R_\odot$ above the limb, but the moving material arched back to the solar surface (hence was not classified as a chromospheric ejection from the flare site). This is an energetic event, but had no coronal or chromospheric mass ejection; the magnetic field presumably contained the event. Another example is an active region on the limb on 4 December 1973 that produced Importance 1 flares with accompanying BSL's to $0.2R_\odot$, an eruptive prominence observed almost to $0.3R_\odot$ above the limb, and a λ5303 inner coronal transient. Yet the outer corona did not respond to the energy liberated near the solar surface. (For more details on this event, see Wagner and DeMastus, 1977.) These events are presumably contained by the magnetic field in the sense of being 'trapped', a term used by DeMastus *et al.* (1973) to describe the appearance of certain green-lined transients.

On the other hand, the mass in coronal ejection events has been shown to be basically coronal in origin (Hildner *et al.*, 1975b; Poland and Munro, 1976; Schmahl and Hildner, 1977). It is possible that changes in the magnetic field can occasionally produce a coronal mass ejection without an accompanying chromospheric signature. X-ray brightenings are frequently found near filament channels where no apparent change in Hα structure can be detected (Webb *et al.*, 1976). This may explain why somewhat more than half of the white light transients could not be associated with surface phenomena (half of the events should originate on the back side of the Sun).

Many conclusions reached in the previous section are remarkably similar to those discussed in the green-line coronal disturbance study of DeMastus *et al.* (1973). For example, of their 23 events for which surface associations are found, 11 or 48% are flare associated (as contrasted with 40% for white light transients) and 8 of these have associated EPL's and BSL's. While all Importance 2 or greater flares within 22° of the limb produced green-line disturbances, only 2 of 14 Importance 1 flares can be associated with a low coronal event – almost identical to the white light transient statistics. Roughly half of the green-line disturbances are associated with EPL's and BSL's alone – again identical to our findings with the exception that white light transients can be associated only with EPL's. Although this previous work refers to disturbances below $1.15R_{\odot}$, is strongly weighted towards active regions, and spans nearly 2 solar cycles, it could be inferred that white light mass ejections and green-line disturbances are different observational manifestations of the same parent phenomenon. However, because the three green-line transients observed during the Skylab period are not associated with white light transients (Wagner and DeMastus, 1977), similar $\lambda 5303$ and white light statistical correlations with Hα activity may still be merely fortuitious. In any event, it appears possible to broaden a statement made by DeMastus *et al.* that the mechanism which releases chromospheric and prominence material well into the corona also produces mass ejections into the solar wind, whether or not chromospheric flare effects appear. This statement concerning flare effects is reinforced by the fact that one-quarter of the white light transients have surface associations far from centers of activity.

The correlation between radio bursts and white light transients found here is essentially identical to that reported in a preliminary study by Gosling *et al.* (1974). Although only 25% of the mass ejections are accompanied by type II and/or IV bursts, nearly all bursts conversely are accompanied by the fastest moving transients (Gosling *et al.*, 1976).

Throughout this paper, we have concentrated upon associations and avoided discussion of the causes of mass ejections. Here we note that most mass ejection transients seem to be accompanied by the eruption of filaments, which we take to indicate a restructuring of the magnetic field configuration in the low corona. Therefore, this study continues to support the speculation already advanced as a result of previous studies that mass (and its accompanying magnetic field) are ejected from the Sun in conjunction with and probably because of this restructuring of the field.

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References

DeMastus, H. L., Wagner, W. J., and Robinson, R. D.: 1973, *Solar Phys.* **31**, 449.
Dodge, J. C.: 1975, *Solar Phys.* **42**, 445.
Dulk, G. A., Smerd, S. F., MacQueen, R. M., Gosling, J. T., Magun, A., Stewart, R. T., Sheridan, K. V., Robinson, R. D., and Jacques, S.: 1976, *Solar Phys.* **49**, 369.
Dunn, R.: 1971, in C. Macris (ed.), *Physics of the Solar Corona*, D. Reidel Publ. Co., Dordrecht, Holland, p. 114.
Gosling, J. T., Hildner, E., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: 1974, *J. Geophys. Res.* **79**, 4581.
Gosling, J. T., Hildner, E., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: 1975, *Solar Phys.* **40**, 439.
Gosling, J. T., Hildner, E., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: 1976, *Solar Phys.* **48**, 389.
Hansen, R. T., Garcia, C. J., Hansen, S. F., and Yasukawa, E.: 1974, *Publ. Astron. Soc. Pacific* **86**, 500.
Hildner, E., Gosling, J. T., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: 1975a, *Solar Phys.* **42**, 163.
Hildner, E., Gosling, J. T., Hansen, R. T., and Bohlin, J. D.: 1975b, *Solar Phys.* **45**, 363.
Hildner, E., Gosling, J. T., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: 1976, *Solar Phys.* **48**, 127.
Kahler, S.: 1977, *Astrophys. J.* **214**, 891.
Michalitsanos, A. G. and Kupferman, P.: 1974, *Solar Phys.* **36**, 403.
Munro, R. H.: 1979, *Solar Phys.*, in preparation.
Munro, R. H., Gosling, J. T., Hildner, E., MacQueen, R. M., Poland, A. I., and Ross, C. L.: 1974, Flare-Related Magnetic Field Dynamics, National Center for Atmospheric Research Publication, p. 139.
Pallavicini, R., Serio, S., and Vaiana, G. S.: 1977, *Astrophys. J.* **216**, 108.
Poland, A. I. and Munro, R. H.: 1976, *Astrophys. J.* **209**, 927.
Rust, D. M. and Hildner, E.: 1976, *Solar Phys.* **48**, 381.
Rust, D. M. and Webb, D. F.: 1977, *Solar Phys.* **54**, 403.
Schmahl, E. J. and Hildner, E.: 1977, *Solar Phys.* **55**, 473.
Sheeley, N. R., Jr., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., Tousey, R., Smith, J. B., Speich, D. M., Tandberg-Hanssen, E., Wilson, R. M., DeLoach, A. C., Hoover, R. B., and McGuire, J. P.: 1975, *Solar Phys.* **45**, 377.
Smerd, S. F. and Dulk, G. A.: 1971, in R. Howard (ed.), 'Solar Magnetic Fields', *IAU Symp.* **43**, 616.
Wagner, W. J. and DeMastus, H. L.: 1977, *Bull. Am. Astron. Soc.* **9**, 369.
Warwick, J. W.: 1965, in J. Aarons (ed.), *Solar System Radio Astronomy*, Plenum, New York, p. 131.
Webb, D. F., Krieger, A. S., and Rust, D. M.: 1976, *Solar Phys.* **48**, 159.