TRANSIENT DISTURBANCES OF THE OUTER CORONA

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1. INTRODUCTION

I consider it a great honour to give this talk today in place of my friend and colleague, the late Dr. S. F. Smerd, who died last December. All who knew Steve miss his enthusiasm and keen insight into solar physics.

For recent review papers on observations of coronal transient disturbances I refer you to the works of Hildner (1977), Dulk (1979) and MacQueen (1979). Today I will give a brief historical review of this subject, followed by a detailed description of three events observed at radio and whitelight wavelengths, concentrating mainly on the radio evidence. I will not discuss the beautiful soft X-ray, EUV and green-line observations of the lower corona, since they are outside the scope of this review.

2. EARLY OBSERVATIONS

Perhaps the first recognition of a coronal transient was the eclipse drawing by G. Tempel on 18 July 1860 (Eddy, 1974). Next came the detailed observations of eruptive Hα prominences by Secchi and Respighi in the 1870s (Abetti, 1934). From the early 1900s onwards many photographs of eruptive prominences were taken from various observations, including the outstanding coronograph observations of Lyot. Then in the 1940s Bartels and others suggested that geomagnetic sudden commencements which follow large solar flares by about two days could be due to the arrival at the Earth of solar ejecta.

Shock Waves

The first clear indications that geomagnetic disturbances were caused by shock waves came from the metre-wavelength observations of Type II bursts (Wild et al., 1953), which were interpreted as being due to the passage of a shock wave through the corona. An example is shown in Figure 1(a). There is a clear fundamental second-harmonic structure in these bursts. Theoretical work by Ginzburg and others

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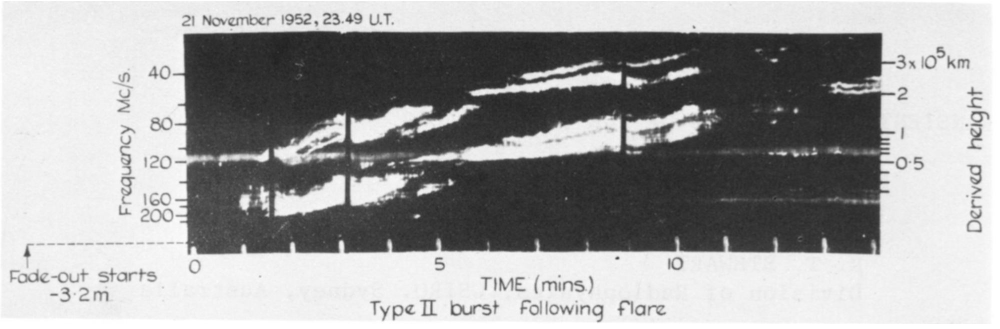

Fig. 1(a) - One of the first dynamic spectral records of a Type II solar radio burst. Note the splitband and fundamental-harmonic structure (Wild et al., 1953).

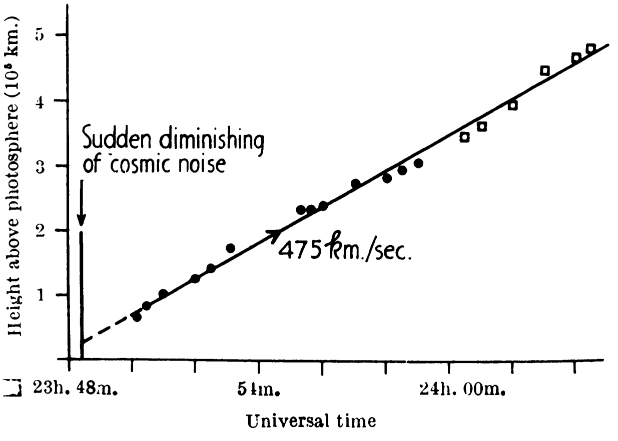

Fig. 1(b) - Derived height-time plot of the Type II burst of Figure 1(a). Fundamental frequencies were converted to heights using a standard plasma density model (Wild et al., 1953).

showed that the emission was plasma radiation from mildly relativistic electrons (10-100 keV), presumably accelerated locally in the corona by the passage of the shock. An early height-time plot of one of these early events (Wild et al., 1953) is given in Figure 1(b), where it can be seen that the slope of the Type II burst extrapolates back nicely to the start of the solar flare.

Later two-dimensional radioheliograph pictures at 80 MHz (Kai, 1970) showed the extent of an advancing front (or bow wave) of a shock-wave disturbance in the corona (Fig. 2a). Note that this advancing front is travelling at a slightly lower projected velocity than that of the Type II shock wave (Fig. 2b). From the 1960s interplanetary shock waves have been observed from spacecraft (Hundhausen, 1972). Kilometre

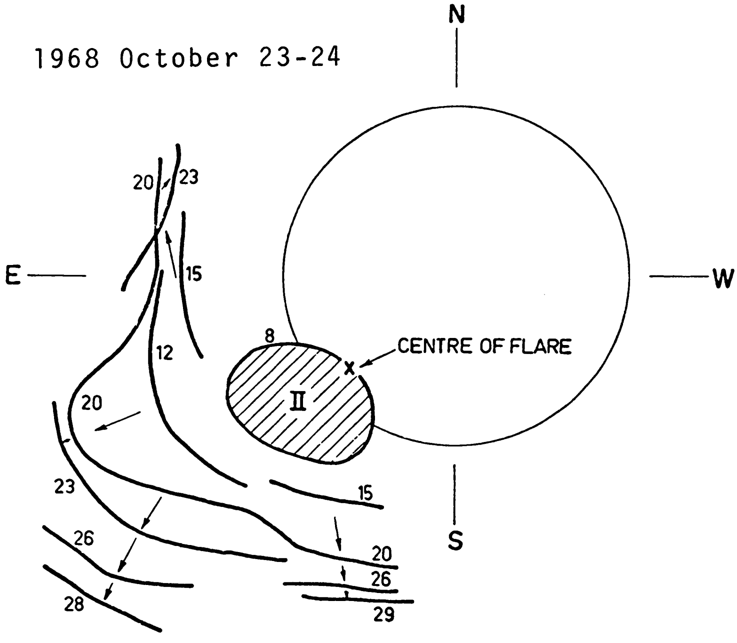

Fig. 2(a) - 80 MHz Culgoora radioheliograph observations on 1968 October 23-24 of an "advancing front" moving Type IV burst (heavy outlines) and a Type II burst (hatched region). Figures on the diagram indicate the elapsed time in minutes since the start of the flare (Kai, 1970).

observations of a Type II burst from IMP-6 (Malitson et al., 1973) showed that the Type II shock wave reached the Earth's orbit (Fig. 3a), thus confirming that the Type II burst is closely associated with the interplanetary shock wave.

We now know that large flares produce not only Type II bursts and interplanetary shock waves but also fluxes of energetic electrons and protons which sometimes escape to the Earth's orbit (Fig. 3b). These cause cosmic ray decreases and auroras.

Expanding Magnetic Arches

As well as the shock-wave-associated disturbances we sometimes see evidence for slower, expanding magnetic arches in the corona. Note the beautiful helical structure in the Hα threads of the eruptive prominence "Grandpa" reproduced in Figure 4(a) (Akasofu and Chapman, 1972). Radio evidence also exists for expanding magnetic arches. For example, the event of 1968 November 22 (Wild, 1969) showed two oppositely polarized (in the circular sense) sources on the legs of an expanding arch and another unpolarized source at the top (Fig. 4b). The leg sources were attributed by Wild to plasma radiation at the 80 MHz plasma level and the top source to gyrosynchrotron emission.

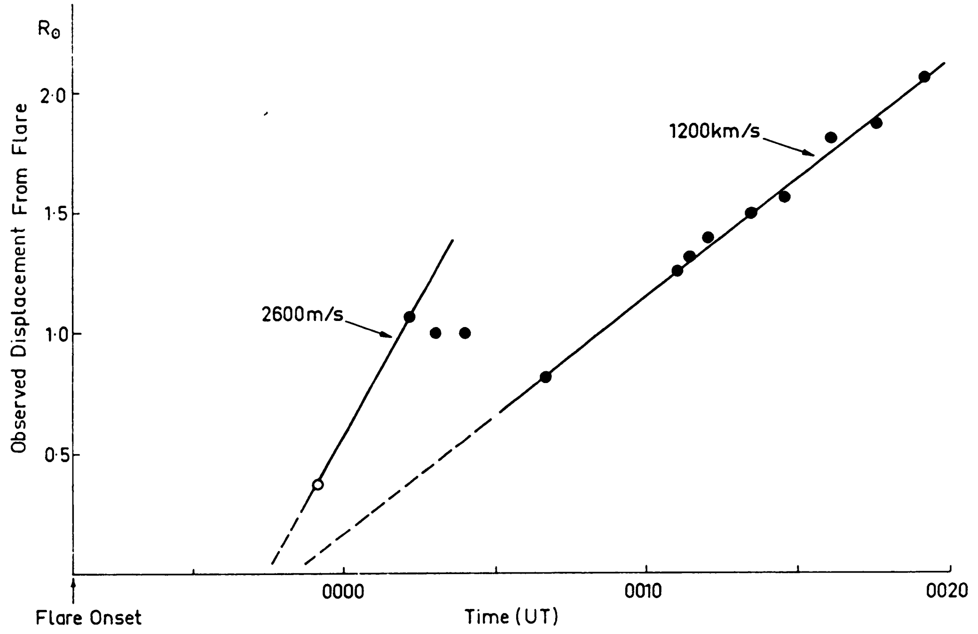

Fig. 2(b) - Plots of the Type II and IVM source displacements with time of the event of Figure 2(a). Note the Type II plot has the steeper slope and precedes the IVM plot (Kai, 1970).

Another majestic expanding arch which might have been magnetically controlled is shown in Figure 5(a). This transient event was observed in white light by the HAO coronagraph aboard Skylab on 1973 June 10 (MacQueen et al., 1974; Hildner et al., 1975). The dark areas indicate the excess coronal mass moving slowly outwards through the corona to heights ~6 $R_\odot$, leaving behind an underlying region of depleted coronal material.

Evidence for fast changes in magnetic field during coronal disturbances can be seen in Figure 5(b). This figure shows changes due to Faraday rotation of signals from Pioneer-6 as they pass tangential to the solar limb at heights ranging from 6 to 11 $R_\odot$ (Levy et al., 1969). Such changes may be associated with the expansion of a magnetic arch during the transient. The active region producing the solar flares associated with these transients was probably the same one which produced the expanding arch event of Figure 4(b).

Ejected Plasmoids

The first moving radio sources were detected by the Nancay interferometer (Boischot, 1958). Since then many examples of isolated moving Type IV sources have been observed by the Culgoora radio-heliograph (Smerd and Dulk, 1971). One of the most spectacular occurred on 1969 March 1-2. Nicknamed "Westward Ho", it moved out to

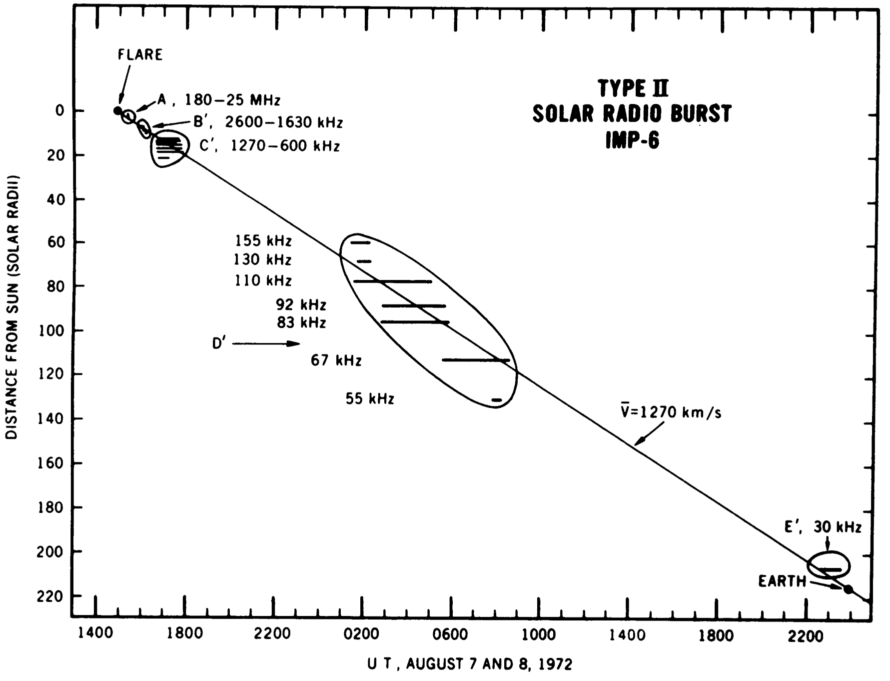

Fig. 3(a) - Derived height-time plot of a Type II burst observed at kilometre wavelengths (Malitson et al., 1973).

a height ~6 $R_\odot$ before it finally faded after separating into two oppositely polarized sources (A and B of Fig. 6b) (Riddle, 1970). The speed of the moving sources was fairly constant at ~270 km s^{-1}; it was considerably slower than that of the Type II burst and Hα spray which preceded it (Fig. 6a). To explain the high degree of circular polarization observed in moving Type IV sources of this kind by gyrosynchrotron emission mechanism one must assume that the (plasmoid) source contains a magnetic field of several gauss (Dulk, 1973).

3. SOME RECENT OBSERVATIONS

Probably the most complete observation of a coronal disturbance to date is the event of 1973 Jan. 11 (Stewart et al., 1974a) in which an Hα flare-spray, a K-coronameter transient, a moving Type IV source and a white-light expanding cloud were observed at successive heights in the corona. The Hα spray, moving Type IV source and the brightest part of the white-light cloud (or the main part of the ejected mass) probably constituted a piston moving outwards behind the Type II shock wave and the leading edge of the white-light cloud (Fig. 7b). Stewart et al. (1974a) estimated that ~10^{16} g of excess mass was ejected in the cloud and that only ~10% of this mass could be accounted for by the K-coronal depletion observed at heights $\leq 1.5\ R_\odot$ (Fig. 7a). Comparable

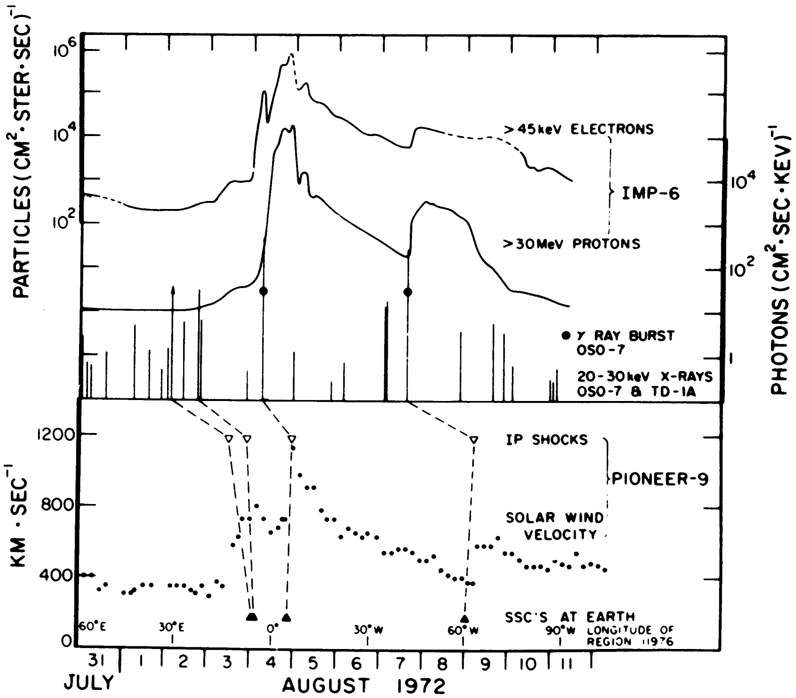

Fig. 3(b) - A summary of solar non-thermal phenomena for the 1972 July 31 to August 11 period, taken from the World Data Center "A" report UAG-28 and Solar Geophysical Data monthly reports. Except for the Pioneer 9 plasma observations at 0.78 AU all the data are from Earth-orbiting spacecraft. Note the correspondence between energetic particle injections, shock waves, γ-ray bursts, and intense hard X-ray bursts (Lin, 1977).

or slightly higher masses are measured behind interplanetary shock waves (Hundhausen, 1972; Hirshberg et al., 1972).

One of the outstanding achievements of the HAO coronagraph on Skylab was the detection of loop transients. A beautiful example of a white-light loop transient is shown in Figure 8 (MacQueen et al., 1974; Gosling et al., 1974). Another such event which occurred on 1973 September 14/15 was associated with a slow-drift continuum radio event (SDC) observed by the Culgoora radioheliograph. The radio continuum sources (A and B of Fig. 9c) were stationary and occurred at progressively greater heights at lower frequencies. A third source C at 160 and 80 MHz was associated with a Type I burst storm in the later stages of the event. From the height-time plot of Figure 10 it can be seen that the radio continuum occurs at a particular height (or frequency) soon after the passage of the leading edge or front of the white-light disturbance and ends with the passage of the white-light loop.

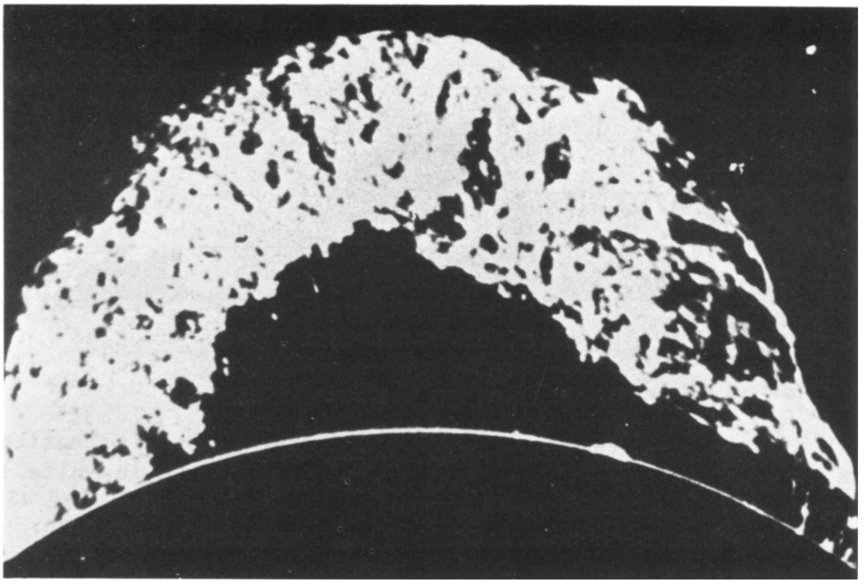

Fig. 4(a) - Eruptive prominence photographed by W. Roberts at Climax in Hα light with a polarizing filter, 1946 June 4^d,69 UT.

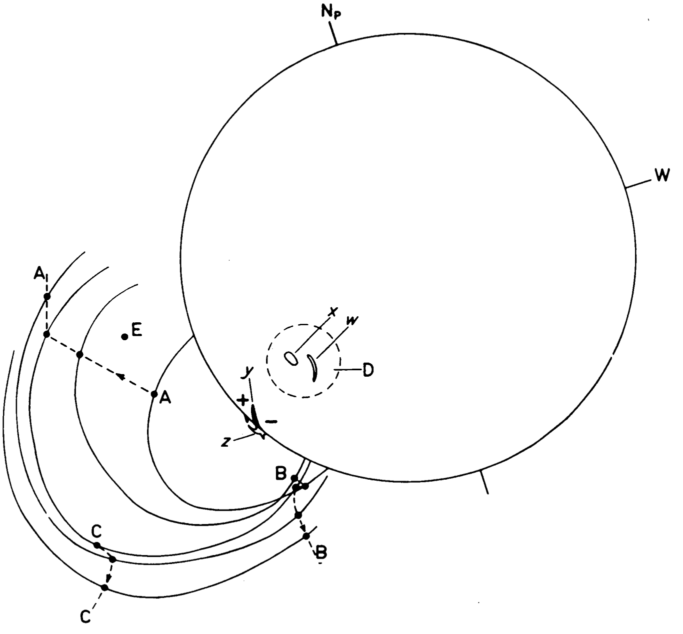

Fig. 4(b) - Observed geometry of the outburst of 1968 November 22. The loops beyond the limb indicate the evolution of the expanding magnetic structure of the moving type IV burst inferred from 80 MHz Culgoora radioheliograms. A,B,C,D and E refer to radio sources, w and x are Hα flares, y is a dark filament which formed during the outburst and z is an active prominence. The + and - signs indicate magnetic polarity (Wild, 1969).

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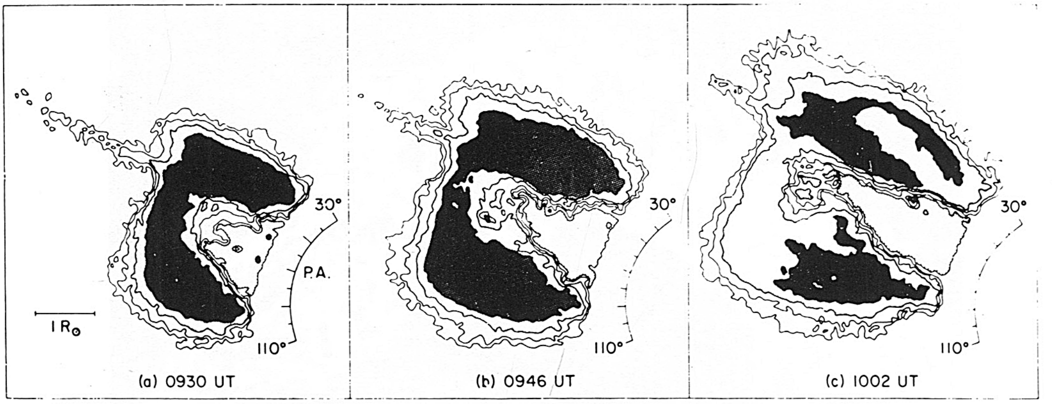


Fig. 5(a) - Contour plots of excess mass (darker colour indicating higher mass) of an eruptive prominence event observed in white light by the HAO coronagraph on Skylab (Hildner et al., 1975). See also white light picture of Fig. 8 which shows several loop structures.

Dulk et al. (1976) have suggested a model for this event in which the energetic electrons emitting the radio continuum event are accelerated locally in the corona by the passage of a shock wave - the particles emitting gyrosynchrotron or second harmonic plasma radiation in the region between the leading edge of the disturbance and the white-light loop (Fig. 10). No clearly defined Type II burst was observed to confirm the existence of a shock wave. However, this is not surprising, because the active region which (presumably) produced this flare event was ~30° behind the western limb of the visible disk.

Dulk et al. (1976) were able to estimate the kinetic and magnetic energy densities at various positions through this coronal transient event. At most places the magnetic energy density was about 10 times greater than the kinetic energy density except at the fastest moving material, where the two were comparable. This suggested that the whole coronal transient event was probably *magnetically controlled* (see later discussion) even after allowing for potential and magnetic energy input.

The third event I want to discuss is an Hα eruptive prominence and a moving Type IV burst observed on 1977 October 4-5. A coloured illustration of this event appears on the back cover of the publication containing the reference Stewart et al. (1978). This coloured photograph shows radioheliograph source centroid positions of both a RH circularly polarized stationary continuum source at 80 and 160 MHz and a LH polarized moving Type IV source at 160, 80 and 43 MHz. The moving source progressed outwards with time along the same direction as the Hα ejecta. Figure 11 shows that for a period ~30 m the fastest moving Hα ejecta were *coincident* with the moving Type IV source.

Stewart et al. (1978) have estimated that the magnetic energy density obtained by assuming a plausible radio emission mechanism for the moving Type IV burst (such as second-harmonic plasma or low-harmonic

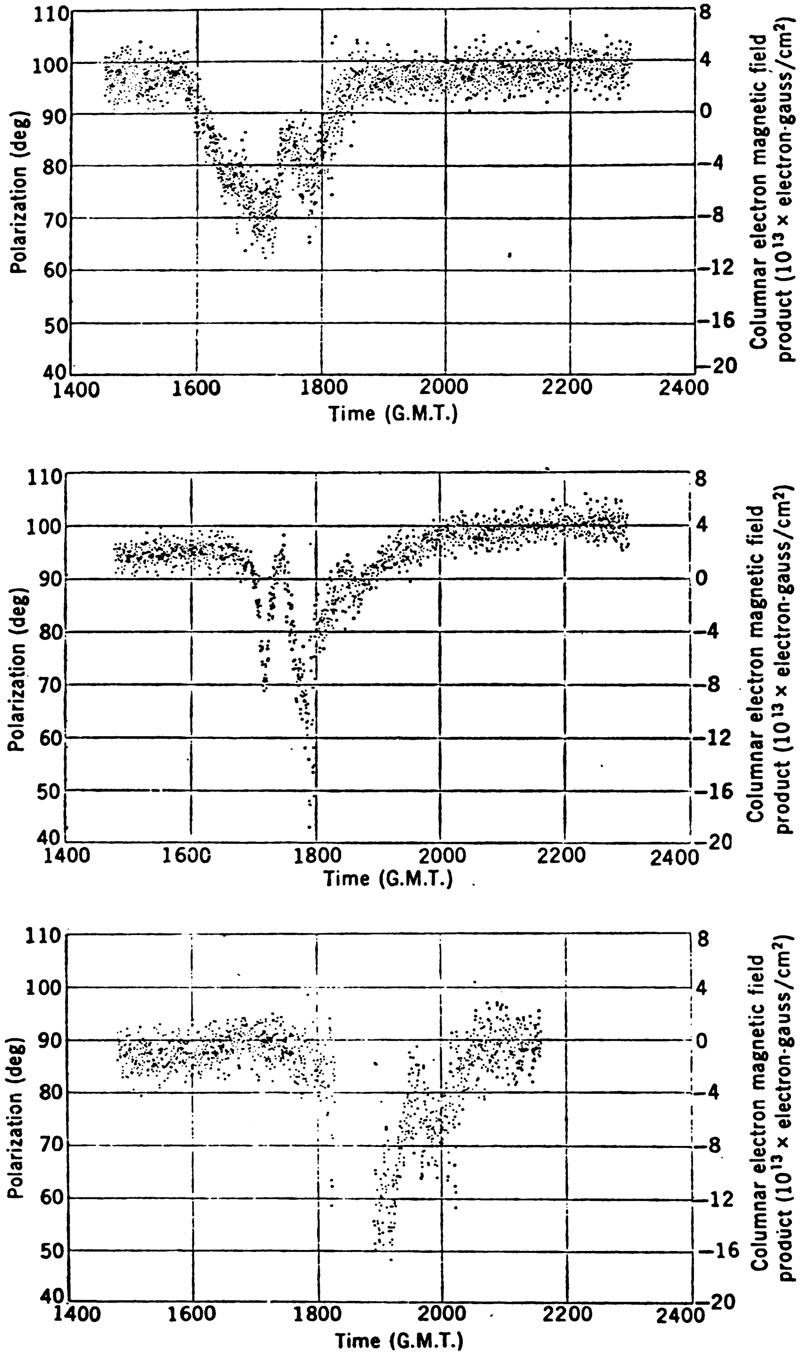
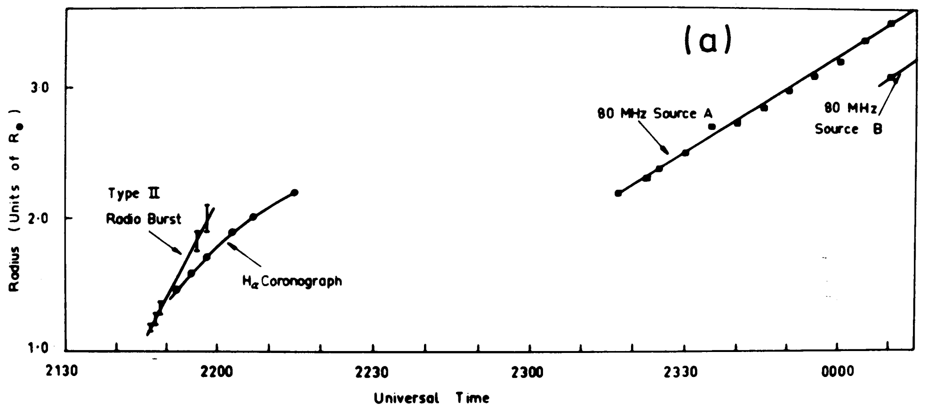


Fig. 5(b) - Plots of the polarization changes (due mainly to Faraday rotation in the corona) of a radio signal from Pioneer-6 passing tangentially to the limb with closest approach of 10.9 $R_{\odot}$ on 1968 November 4 (top figure), 8.6 $R_{\odot}$ on 1968 November 8 (middle figure), and 6.2 $R_{\odot}$ on 1968 November 12 (bottom figure). After Levy et al. (1969).



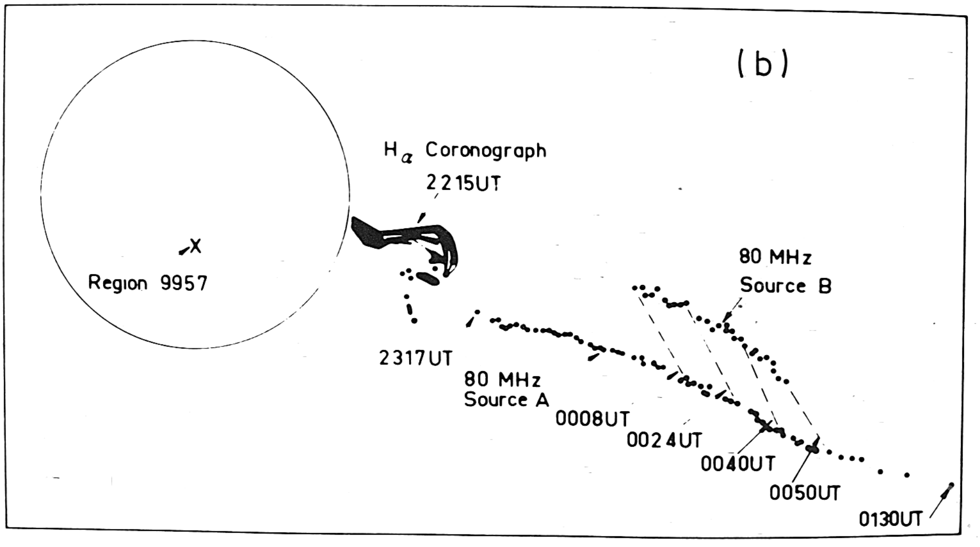


Fig. 6 - (a) The temporal relationship between the Type II radio burst, the rising prominence observed in Hα and the 80 MHz radioheliogram sources on 1969 March 1-2. (b) The spatial relationship between the rising prominence observed in Hα (sketched from a photograph) and the 80 MHz radioheliogram sources (denoted by the positions of the centroids at various times) (Riddle, 1970).

gyrosynchrotron emission) is greater than the kinetic energy density of either the hot plasma in the moving Type IV source region or the cooler and denser material in the Hα ejecta. Hence once again it appears that the coronal transient is *magnetically controlled*. Unfortunately there were no white-light observations during this event, but it seems likely from previous evidence that a white-light transient occurred.

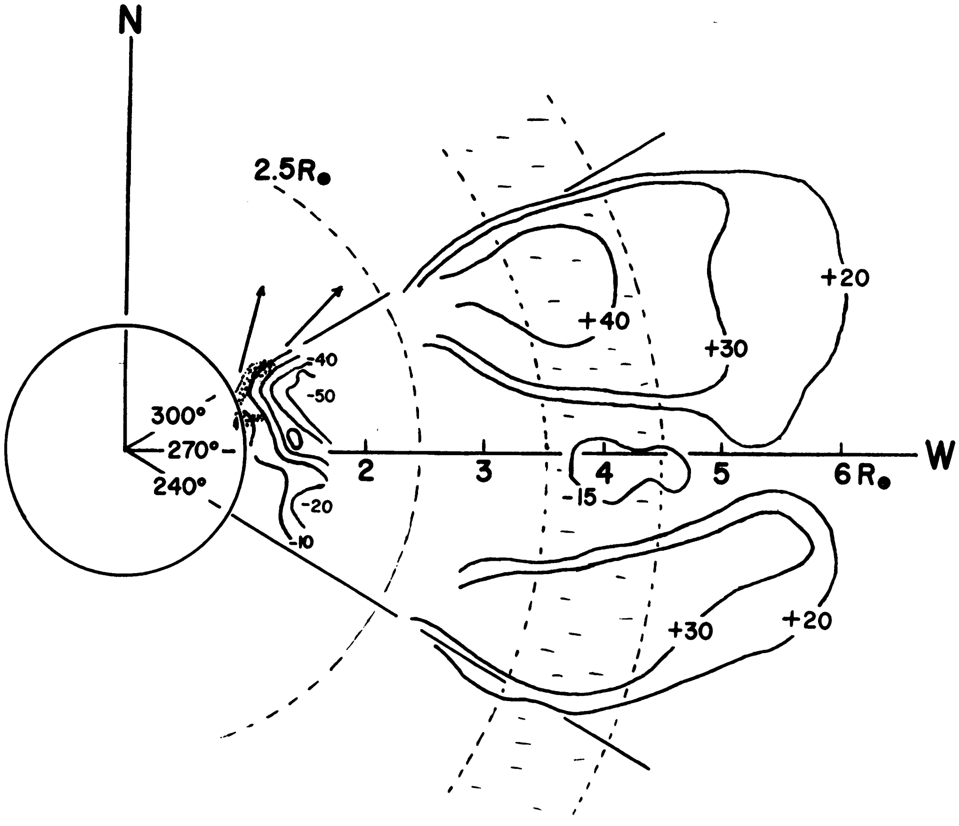


Fig. 7(a) - Composite plots of the percentage change of the brightness of the K-corona (full lines) during the coronal disturbance of 1973 January 11. The contours below 1.6 $R_\odot$ were obtained by subtracting fixed-height scans taken by HAO coronal activity monitor at different times before and after the transient event. The contours between 2.5 and 6.0 $R_\odot$ were obtained by subtracting the OSO-7 coronagraph picture at 00^h14^m from the one at 02^h28^m UT. The stippled region and the arrows indicate the Hα spray and ejection cone. The dashed arc at 2.5 $R_\odot$ indicates the outer edge of the OSO-7 coronagraph occulting disk. The contours show the tangentially polarized component; the polarization of the OSO-7 picture was tangential everywhere except in the hatched region between 3.5 and 4.5 $R_\odot$, where it was radial. The direction of the occulter support of the coronagraph was along the west axis.

4. PROPERTIES OF CORONAL TRANSIENTS

Speed of Transients

The observed speeds of moving Type IV bursts and most white-light excess mass transients vary from ~100 km s^{-1} to ≳1000 km s^{-1} (see e.g. Smerd and Dulk, 1971; Gosling et al., 1976; Hildner, 1977) - i.e. from about the sound speed in the corona (~150 km s^{-1}) to greater than the Alfvén speed (~400 km s^{-1}).

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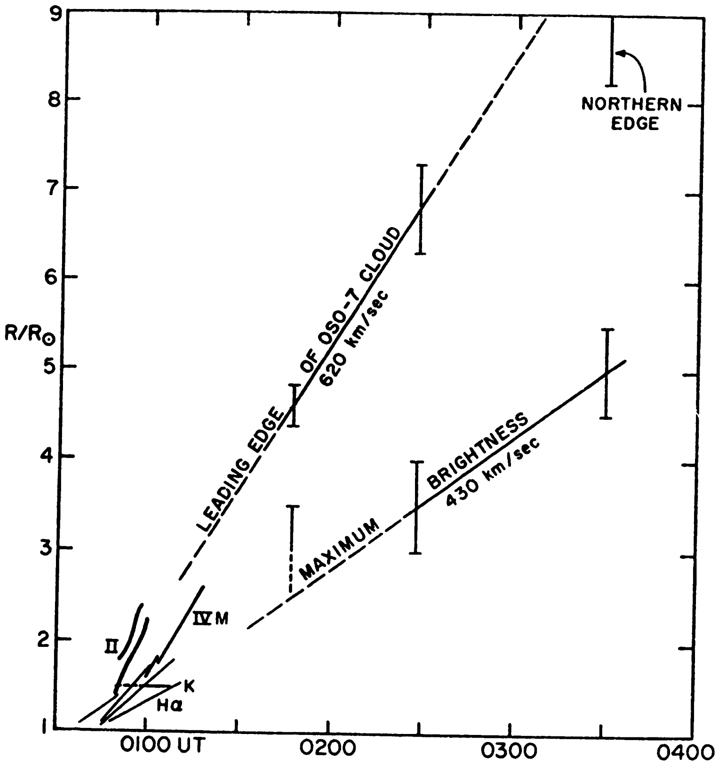

Fig. 7(b) - Combined height-time plots of the observed moving sources in the coronal disturbance of 1973 January 11. The height of the leading edge of the white-light cloud as well as the height of the maximum excess brightness of the cloud is labelled accordingly. The times and errors of measurement for the OSO-7 cloud are indicated. At 03^h30^m only the northern edge of the cloud was in the field of view of the coronagraph. Also shown are the trajectories of the Hα spray material (light lines), the Type II and moving Type IV bursts (labelled II and IVM), and the duration of the K-corona transient at 1.5 $R_\odot$ (labelled K). The projected radial velocities are 430 km s^{-1} (the region of maximum brightness in the OSO-7 white-light cloud), 620 km s^{-1} (the leading edge of the OSO-7 cloud) and 800 to 1200 km s^{-1} (the Type II burst) (Stewart et al. 1974a).

According to Gosling et al. (1976) most flare-associated transients (FLA) have speeds >500 km s^{-1} and these are associated with Type II or IV radio bursts. On the other hand, non-flare events such as eruptive prominences (EPL) have velocities <500 km s^{-1} and are not associated with Type II/IV bursts. Hence it is reasonable to assume that the fastest transients are associated with coronal shock waves. In one event, 1973 September 7, Gosling et al. (1975) were able to show that the ejected mass seen in white light and the inferred mechanical energy input were sufficient to explain an interplanetary shock wave event detected by Pioneer 9.

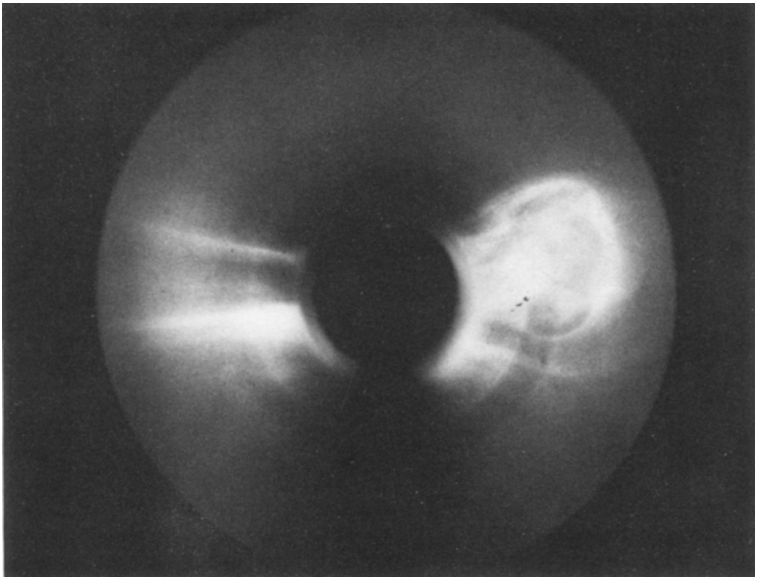

Fig. 8 - HAO white-light coronograph picture of a loop transient event on 1973 June 10 resulting from an eruptive prominence on the east limb of the Sun (MacQueen et al., 1974).

Excess Mass and Mechanical Energy

Table 1 lists the excess mass and mechanical energy input for five FLA events and five EPL events detected by OSO-7 or Skylab. It can be seen that the FLA events are generally more energetic ($E \approx 10^{31-32}$ erg) by an order of magnitude than the EPL events ($E \approx 10^{30-31}$ erg) (with the exception of the EPL event of 1973 August 10), but the two types of events contain about the same excess mass, $M \approx 10^{15-16}$ g. Essentially the difference is due to the faster speed of the FLA events. According to Hildner (1977), about 3% of the mass escaping to 1 AU from the Sun during Skylab period was in the form of coronal transients, and during solar maximum the amount could be as high as 10%. Transients are often preceded by a fore-runner (Jackson and Hildner, 1978) which contains about 10% of the transient mass.

Magnetic Energy Release

Dulk (1973) has estimated that $\sim 10^{31-32}$ erg of magnetic energy are required to explain the properties of a moving Type IV burst source by gyrosynchrotron emission. A similar argument for the 1977 October 4-5 event described above requires $\sim 10^{31}$ erg (Stewart et al., 1978). For two white-light and radio transient events, Dulk et al. (1976) and Gergeley et al. (1979) require 10^{31-32} erg of magnetic energy. McLean and Dulk (1978) calculated that the speed and duration of Type II bursts imply that $>10^{31}$ erg of (mainly) transported magnetic energy is involved in a coronal disturbance.

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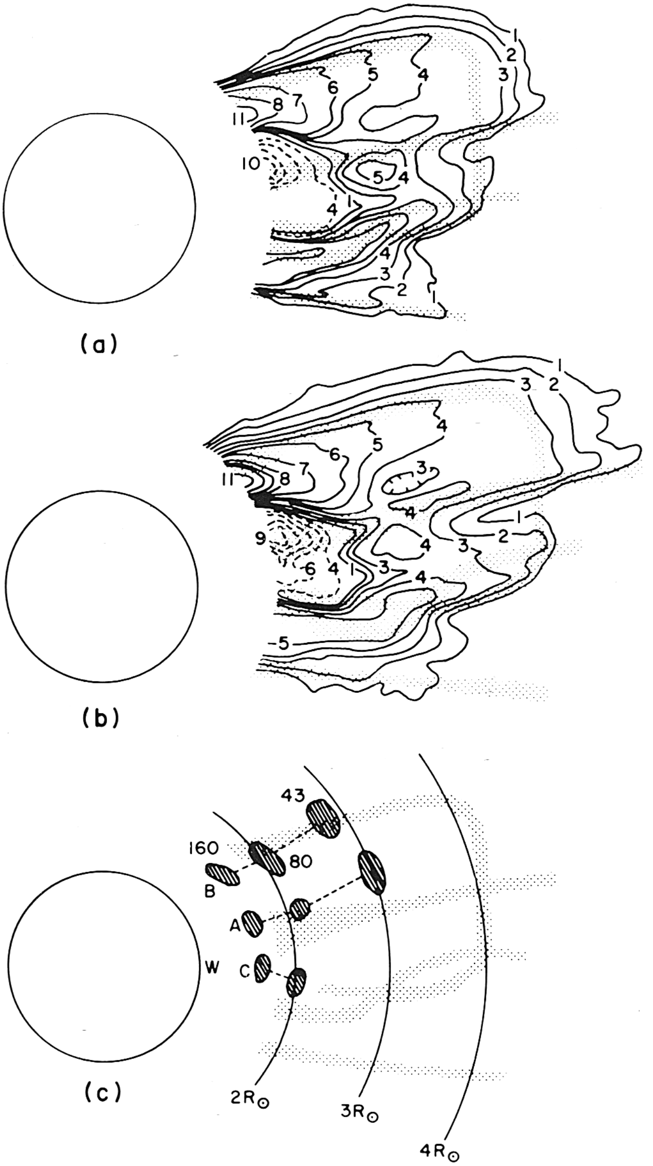

Fig. 9 - Mass (or density) contours of the excess material in the corona on 1973 September 15 at 00^h32^m (a) and 00^h41^m (b). The stippled areas show the location of the principal visible structures at the two times. The hatched areas in (c) represent the positions of the Culgoora radioheliograph sources; all but the source "C" had disappeared before 00^h32^m, the time of the visible structures. Crosses show the positions of the active regions, on and beyond the limb. Dashed contours indicate rarefaction regions where the material was *depleted* relative to the pre-event corona. Sample contour levels in terms of mass, electron density and plasma frequency (the latter two obtained by assuming a disturbance depth of 0.5 $R_\odot$) are given in the Table of Dulk et al. (1976).

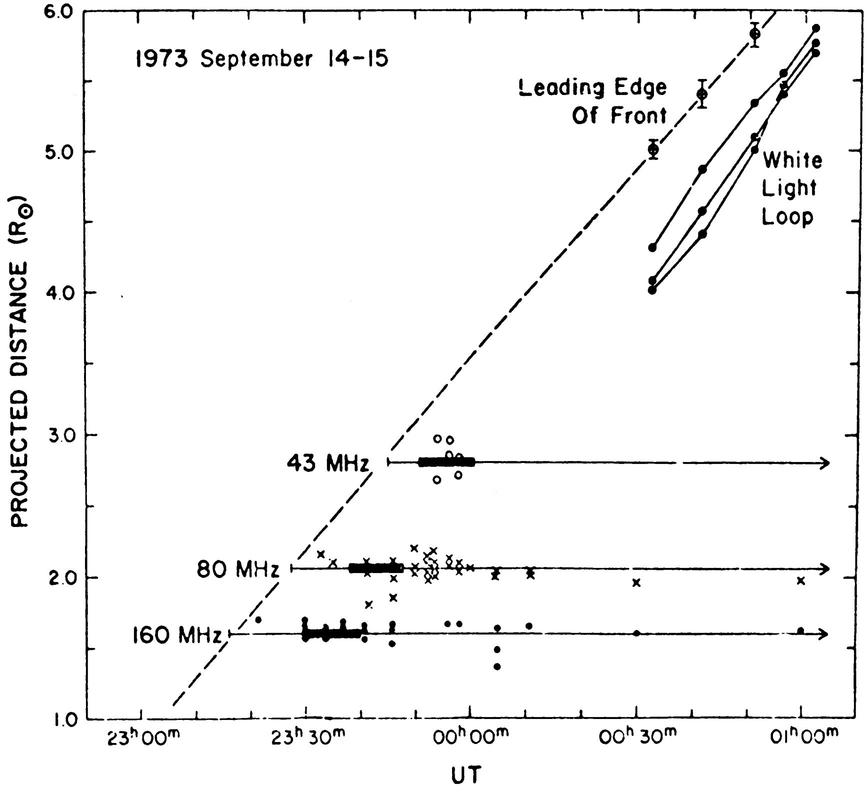

Fig. 10 - Height-time diagram showing the radio and white-light data. Individual points show the radio source heights as measured from radioheliograms. Light lines show the burst durations measured from spectrograms and heavy bars emphasize the high-intensity portions. The height of the white-light loop at three position angles was determined from five coronagraph pictures, and the white-light front was determined from microdensitometer scans of three photographs (Dulk et al., 1976).

We note that these estimated magnetic energies are similar to the total energy required to explain interplanetary shock waves (Hundhausen, 1972). By contrast, the impulsive energy release of mildly relativistic particles in a solar flare is usually $\ll 10^{32}$ erg and just possibly approaches this number in the very largest flares (Lin, 1977). Hence it seems that a major component of the energy in a (flare-associated) coronal transient is in the form of transported magnetic energy behind a shock wave disturbance. There is also sufficient energy in the shock wave to accelerate secondary particles such as MeV electrons and protons (see Fig. 3b) during large solar flares (Lin, 1977).

TABLE 1. PROPERTIES OF CORONAL TRANSIENTS*†

(1) Type	(2) Height range ($R_\odot$)	(3) Outward Velocity (km s^{-1})	(4) Excess mass (g)	(5) Mechanical energy input (erg)	(6) Class	(7) Reference
1971 December 14 $\geq 2.5^h$ UT						
Hα flare spray	1-1.5					
Type II burst	1.5-3	~1700				Kosugi (1976) Fig. 6
Type IVM burst	1.6-3	900-1200				
WL leading edge	5-8	~700				
WL compact clouds	7-9	~1000	3×10^{15}	2×10^{31}	FLA	Brueckner (1973)
WL excess mass	7-9	≤700	4 x 10	10^{32}		
1973 January 11 $\geq 01^h$ UT						
Hα flare spray	1-1.8	300-600		$\leq 10^{30}$	FLA	Stewart et al. (1974c) Fig. 6
Type II burst	1.4-2.4	800-1200				(Dulk, 1973)
Type IVM burst	1.5-2.5	600-700		10^{27}		
WL leading edge	3-9	620				
WL excess mass	3-5	430	3×10^{16}	2×10^{31}		
1973 January 11 $\geq 18^h$ UT						
Hα flare spray	1-2	200-400			FLA	Stewart et al. (1974b)
Type II burst	1.7-2.4	800-1200				Fig. 8
Type IVM burst	1.7-3	500-400				
WL leading edge	3.3-5.3	750				
WL excess mass	2.7-3.2	230	10^{16}	10^{31}		

(1)	(2)	(3)	(4)	(5)	(6)	(7)
1973 September 7 $\geq 11.4^h$ UT						
Hα flare surge	Disk event				FLA	Gosling et al. (1975)
Type II burst		?				
WL leading edge		>960				
WL excess mass			2.4×10^{16}	1.1×10^{32}		
Interplanetary shock wave	~1 AU	722	}	}		
Interplanetary excess mass		600	} 4.2×10^{16}	} 1.2×10^{32}		
1973 September 14 $\geq 23.5^h$ UT						
No Hα flare observed	Behind limb?				FLA	Dulk et al. (1976)
WL leading edge	4-6	720				
WL excess mass	4-6	350	4×10^{15}	$\sim 10^{31}$		
Radio continuum source	1.5-3.0	Nil				
Coronal depletion	$\leq 3\ R_\odot$	~120				
1972 September 18 $\geq 17^h$ UT						
Hα eruptive prominence					EPL	Tousey (1973)
WL excess mass	4-6	250-450	7×10^{15}	1.7×10^{31}		
1973 June 10						
WL leading edge	3.6-5.0	~500			EPL	MacQueen et al. (1974)
WL excess mass			1.8×10^{16}	$\sim 3 \times 10^{31}$		
Coronal depletion	2-4					Hildner et al. (1975)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
1973 August 10						
Hα eruptive prominence					EPL	Gosling et al. (1974)
WL leading edge	2-6	~400				
WL excess mass			4×10^{15}	8.4×10^{31}		
WL loop			$\sim 1 \times 10^{15}$			Anzer and Poland (1978)
1973 August 13						
Hα eruptive prominence					EPL	Rust and Hildner (1976)
Soft X-ray loop	1-2		1.3×10^{15}			
WL excess mass	2-5	Constant acceleration ~12.5 m s^{-1} v<2.6 km s^{-1} max.	1.9×10^{15}	3×10^{30}		
1973 December 19						
Hα EUV eruptive prominence	1-3 $R_\odot$	Slow rise ~14 km s^{-1} then	2×10^{14}	8×10^{29}	EPL	Schmahl and Hildner (1977)
WL cloud	3-6	rapid expansion <100 km s^{-1}	1.8×10^{15}	2.7×10^{30}		

*WL = white light; IVM = moving Type IV burst

†Notes on events are given on the following page.

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1971 December 14: Disrupting WL streamer may have initiated event. 1-D radio positions suggest that three IVM sources may have been associated with the three compact WL clouds. The latter appeared later and at much greater heights than the IVM sources. OSO-7 event.

1973 January 11: K-coronal depletion at heights $\leq 1.5\ R_\odot$ accounts for only 10% of excess mass in WL cloud (3-9 $R_\odot$). OSO-7 event.

1973 January 11: Homologous event to 1973 January 11 $>02^h$ UT; K-coronal brightening observed at 2.7 $R_\odot$. OSO-7 event.

1973 September 7: Only interplanetary shock wave observed so far to be associated with a WL coronal transient. Skylab event.

1973 September 14: Event appears to be magnetically controlled. Radio emission appears to be associated with the region between the leading edge and the loop of the white-light transient. Skylab event.

1972 February 18: Circular WL cloud diameter ~2 $R_\odot$ and density ~$2.5 \times 10^6\ cm^{-3}$ at 5 $R_\odot$ located radially above eruptive prominence. OSO-7 event.

1973 June 10: Skylab event.

1973 August 10: Skylab event.

1973 August 13: There was probably enough mass in soft X-ray loop to explain the WL excess mass at greater heights. Skylab event.

1973 December 19: Only ~10% of Hα prominence mass was expelled from Sun. Skylab event.

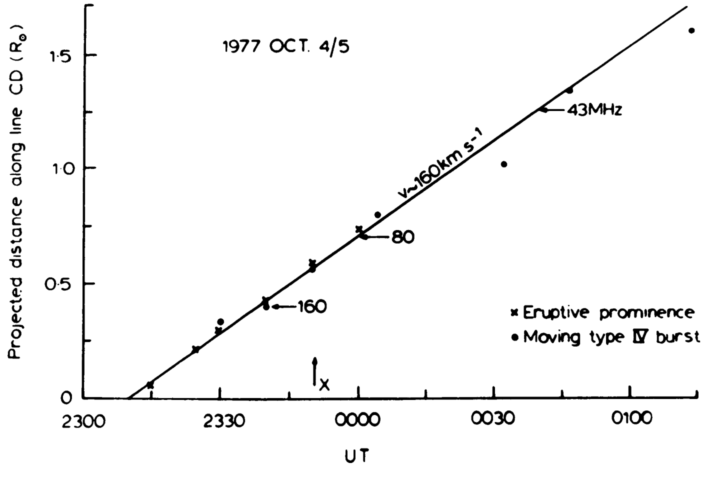

Fig. 11 - Distance versus time plots of the moving fronts of the Hα prominence material and the main type IV sources for the two events. Vertical arrows labelled X indicate times of maximum soft X-ray fluxes. Horizontal arrows indicate the times of maximum radio flux at 160, 80 and 43 MHz (Stewart et al., 1978).

Other Properties of Coronal Transients Suggesting Magnetic Control

Coronal transients appear to be restricted to solar latitudes $\pm 40^{o}$ and to be associated with active regions (Hildner et al., 1976). During Skylab about one transient occurred every two days, but the frequency of occurrence will probably increase during solar maximum because flares, EPLs, Type II and moving Type IV bursts all show a solar cycle dependence (see Fig. 2 of Hildner (1977)). The frequency of white-light transients increases with sunspot number, suggesting that transients occur above strong photospheric magnetic field regions. Hildner et al. (1976) argue that this pattern of occurrence is consistent with their belief that the forces propelling transient material outward are primarily magnetic.

Transients appear to be restricted in latitude, having sides that are slightly inclined away from the radial direction (see Fig. 3 of Hildner (1977)). Even loop transient events do not expand uniformly in all directions but have rather straight sides. The most obvious reason for the transient shape is that the sides of the transient are contained by radially directed magnetic fields (Anzer, 1978).

5. CONCLUSION

All the evidence collected to date can be interpreted as indicating that coronal transients are driven outwards by magnetic forces. The loop and arch-like shapes of white-light events suggest expanding magnetic loops or arches which may have been stable magnetic structures in the lower corona prior to the event.

How the magnetic forces are released is not at all clear from observations, but several mechanisms have been proposed (Dulk et al., 1976; Mouschovias and Poland, 1978; Anzer, 1978. See also papers by Pneuman, Steinolfson and Wu, Maxwell and Dryer, and Nakagawa et al., in this issue). It would be beyond the scope of this paper to discuss these models.

What is clear from the observations is that there is sufficient magnetic energy available in the transient (~10^{32} erg) to explain the energetics of the coronal disturbance.

It is anticipated that the forthcoming solar maximum experiments will greatly enhance our knowledge of this complex and fascinating subject.

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DISCUSSION

Newkirk: We should be very cautious in identifying the forerunners of transients as a shock front. This phenomenon appears to accompany transients regardless of whether the main transient is supersonic or not. If we were dealing with a shock, the density enhancement would depend upon the Mach number. The observations show no evidence for such a relationship.

Stewart: I did not say the forerunner was a shock front.

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Dryer: (Comment) The observations are inconclusive concerning the question of identifying forerunners with shocks. The small density enhancements detected in front of transients are entirely consistent with the notion that a very weak shock (hence, a very small density increase) could be responsible. During the time-dependent mass motion observations by Skylab, OSO-7 or P78-1, we have no evidence concerning the question as to whether the local plasma velocities (within or outside the transients) are supersonic or not. I suggest, therefore, that this question should be considered to be an open one. We must keep in mind, also, the fact that even non-shocked MHD wave motion (with little or even no bulk motion) can produce a moving compression wave, followed by an expansion wave. This could even precede-due to preflare activity- the main type II shock.

Rosenau: (Comment) While the propagation speed of 100 km s^{-1} is indeed too small for a generation of transonic shock (sonic speed is ~ 150 km s^{-1}) a slow shock can be generated. Therefore generation of a shock cannot and should not be precluded.

Moore: In terms of Jerry Pneuman's magnetic configuration sketch for coronal transients, do we usually view transients from the same aspect as in his sketch, or from the side?

Stewart: The same aspect because white-light loops are sometimes observed.

Pneuman: (Comment) The slide that Dr. Stewart showed is, I think, approximately the same view of the transient as in the slide I showed yesterday - since you see a loop-like structure in the white-light photograph.

Sheeley: Why are 10^{33} electrons such a large number? It is a relatively negligible fraction of the number that occurs in a typical coronal transient.

Stewart: There are about 10^{40} thermal ($\sim$1keV) electrons in a mass transient. We require $\geq 10^{33}$ electrons with energies $\geq$ 1 MeV. If these are part of a non-thermal distribution with, say, E^{-3} the number of electrons with energies > 10keV would be > 10^{37} which is an appreciable fraction of the total number of electrons in the transient.

Ivanov: (1) Could you estimate the Alfvenic-Mach number of the shock front? (2) What is characteristical length between shock front and piston front?

Stewart: See Dulk et al. (1976) for specific values but I think the Mach number in this and similar events is quite small ~ 2-4 while the characteristic length is $\leq 0.5\ R_\odot$ at a height of say $5\ R_\odot$.

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