SESSION VII

SOLAR BURSTS - RADIO, WHITE LIGHT AND X-RAY OBSERVATIONS

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RADIO AND WHITE-LIGHT OBSERVATIONS OF CORONAL TRANSIENTS

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ABSTRACT

Optical, radio and X-ray evidence of violent mass motions in the corona has existed for some years but only recently have the form, nature, frequency and implication of the transients become obvious. In this paper I review the observed properties of coronal transients, concentrating on the white-light and radio manifestations. The classification according to speeds seems to be meaningful, with the slow transients having thermal emissions at radio wavelengths and the fast ones non-thermal. I then discuss the possible mechanisms involved in the radio bursts and review the estimates of various forms of energy. It appears that the magnetic energy transported from the Sun by the transient exceeds that of any other form, and that magnetic forces dominate in the dynamics of the motions. The conversion of magnetic energy into mechanical energy, by expansion of the fields, provides a possible driving force for the coronal and interplanetary shock waves.

1. INTRODUCTION

As with many other astronomical phenomena, there was an enormous increase in the interest - and number of published papers - about coronal transients when new instrumentation allowed them to be observed clearly and unambiguously. For coronal transients this occurred within the past 5 to 10 years with the introduction of radio telescopes and coronagraphs which give images of the corona on the appropriate time scales of minutes to hours. But, again as with other phenomena, there is a history of half-forgotten preludes. While I cannot do them justice in this short paper, I will mention some of these preludes, particularly the ones which, with hindsight, are known to be manifestations of coronal transients.

Possibly the first were the aurorae, sudden-commencement magnetic storms and polar cap absorption events, arriving a day or so after a flare and bringing particles and shock waves of solar origin. Then

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there were discovered the dramatic eruptive prominences and sprays in Hα, the Type II bursts on radio spectrograms showing the presence of shock waves in the corona, the moving Type IV bursts on radio interferometers showing matter ejected to large distances, and the direct observation of shock waves and particle events in interplanetary space. Finally, about a decade ago, came the very rapid developments in observations of coronal transient events: the Culgoora radioheliograms of moving sources, the OSO-7 coronagrams of moving clouds, the K-coronameter and green-line transient phenomena, and lastly the white-light and X-ray transients seen with so much detail from Skylab.

Within the last five years considerable effort has been devoted to the study of the transient events, both as observed in particular wavelength ranges and by combining observations at several wavelengths. Both in white light and in radio, a sufficient number of transients have been recorded that statistical analyses are meaningful. But only a half-dozen or less were observed simultaneously and in enough detail that the combined data were worth more than the sum of the parts.

In the following I first discuss the observations, the morphology of those events which have been studied in detail, give a tentative classification on the basis of speeds, and estimate the frequency of occurrence. I then discuss the radio emission mechanisms and finally review the estimates of various forms of energy in the transients and the implications about the causative forces.

2. RADIO AND WHITE-LIGHT OBSERVATIONS OF TRANSIENTS

A simple but meaningful division of coronal transients can be made according to their speed: slow, intermediate and fast. The rationale behind the division is as follows: slow transients have characteristic speeds $\lesssim 400$ km s^{-1} and the radio emission comes mostly or entirely from a thermal plasma. Intermediate-speed transients have characteristic speeds between about 400 and 1000 km s^{-1} and the radio emission comes mainly from mildly relativistic electrons ($\sim$100 keV). Fast transients have characteristic speeds $\gtrsim$1000 km s^{-1} and the radio emission comes at least partly from relativistic electrons ($\gtrsim$1 MeV). By characteristic speed I refer to the outward velocity of the outermost well-defined edge, often a shock front or a bright loop of material. The dividing lines at 400 and 1000 km s^{-1} are based on the evidence cited below but are somewhat arbitrary; it is not yet certain whether one category blends into another or if there is a distinct change of character from one to another.

Slow transients, those with characteristic speeds of less than about 400 km s^{-1}, are normally accompanied by eruptive prominences or disappearing filaments, but not by radio bursts (Gosling et al., 1974; Hildner, 1977). However, in at least three cases (Sheridan et al., 1978; Jackson, 1979) slow transients were detected on maps of the quiet Sun made at radio wavelengths. Figure 1 shows one example, the exceptionally slow ($\sim$60 km s^{-1}) and bright white-light transient of 1974 January 21.

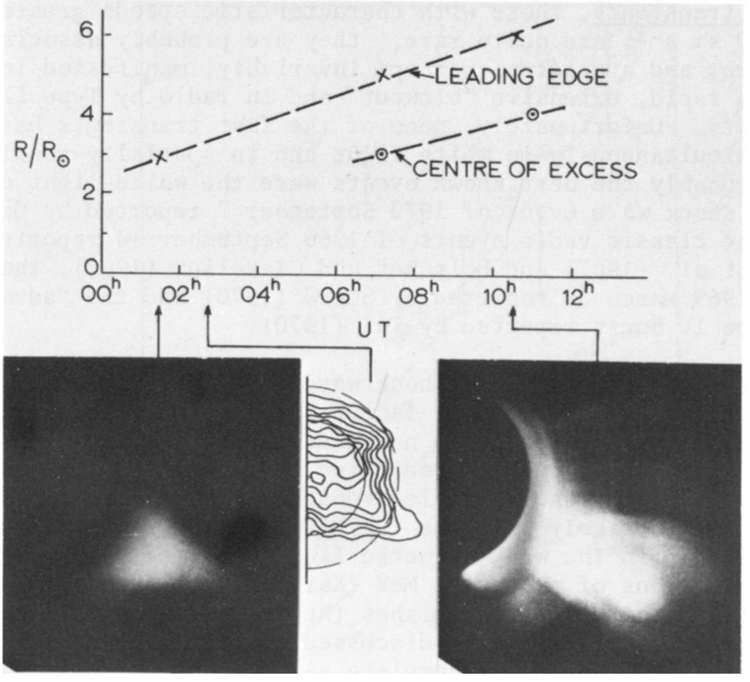

Fig. 1 - A slow mass-ejection transient observed on 1974 January 21 by the High Altitude Observatory coronagraph on Skylab and the 80 MHz heliograph at Culgoora. The dashed semi-circle on the 80 MHz map has the same radius (1.7 $R_\odot$) as the occulting disk of the coronagraph; the solid circle represents the visible disk of the Sun. (From Sheridan 1978.)

The bulges on the 80 MHz quiet Sun map show enhanced radio emission to 2 $R_\odot$ at the position angle of the transient. The excess material seen in white light is presumably at coronal temperatures (Hildner et al., 1975; Poland and Munro, 1976) and is detected at radio wavelengths because of its thermal radiation.

In principle we can compare the white-light brightness (which is proportional to the integral of the electron density along the line of sight) to the radio brightness (which is proportional to the density squared along the line of sight) and derive the degree of inhomogeneity of the corona. In practice this approach has not proved to be successful; quantitative measurements of radio brightness in general imply coronal densities lower than those implied by white-light measurements, a situation reminiscent of that between EUV and radio data. Whether this is simply due to a calibration error in one or the other, or whether there is a fundamental misunderstanding in some aspect of coronal physics, is not known (e.g. Jackson et al., 1979).

Fast transients, those with characteristic speeds greater than about 1000 km s^{-1}, are quite rare; they are probably associated with major flares and are often, perhaps invariably, manifested in white light by a rapid, extensive "blowout" and in radio by Type II and IV radio bursts. Unfortunately, none of the fast transients has been observed simultaneously in white light and in spatially-resolved radio waves. Probably the best known events were the white-light and interplanetary shock wave event of 1973 September 7 reported by Gosling et al. (1975), the classic radio events of 1966 September 14 reported by Boischot et al. (1967) and Boischot and Clavelier (1967), the half-ring event of 1969 March 30 reported by Smerd (1970) and the "advancing front" moving Type IV burst reported by Kai (1970).

For these fast events, a shock wave, probably driven by a large mass of coronal gas, is a major factor. The shock wave, or its associated turbulence, produces non-thermal protons and electrons. The protons, so far as is known, produce no radio emission, but are directly observed near the Earth. The electrons however produce intense radio emission. It is likely that the Type IV radiation is gyro-synchrotron emission which, in the weak magnetic field near the shock fronts, requires electrons of energy $\gtrsim$1 MeV (Kai, 1970). This requirement for relativistic electrons distinguishes the fast transients from the intermediate speed transients to be discussed next. However, largely because of the absence of a suitably complete set of data on these fast events, detailed understanding is lacking.

Transients with intermediate speeds, between about 400 and 1000 km s^{-1}, have been observed simultaneously in white light and in spatially resolved radio waves on just five occasions (Stewart et al., 1974a,b; Kosugi, 1976; Dulk et al., 1976; Gergely et al., 1979). On the basis of these five events, it seems that there are several different varieties and that a categorization is premature. However, the radio properties of the transients can be subdivided as follows: (1) the presence or absence of a Type II burst indicative of a shock wave, and (2) whether the Type IV continuum sources are stationary or moving or both.

Figure 2 (Stewart et al., 1974b) shows the height-time diagram for the second event of 1973 January 11, one which contained both a Type II burst and a moving Type IV burst. From its position and slope as derived from the Type II burst, the shock wave may be either ahead of or in the vicinity of the leading edge of the white-light transient, depending on the assumed density of the ambient corona. The moving Type IV source lags behind, together with the region of maximum white-light brightness, and the Hα material lags still farther behind. Typical speeds in this event were 700-1000 km s^{-1}. An earlier event on the same day (Stewart et al., 1974a) exhibited a very similar behaviour, with the moving Type IV source also following behind the shock front and the front of the white-light cloud.

The event reported by Kosugi (1976) also had similar characteristics: a fast shock wave, moving white-light clouds, moving Type IV

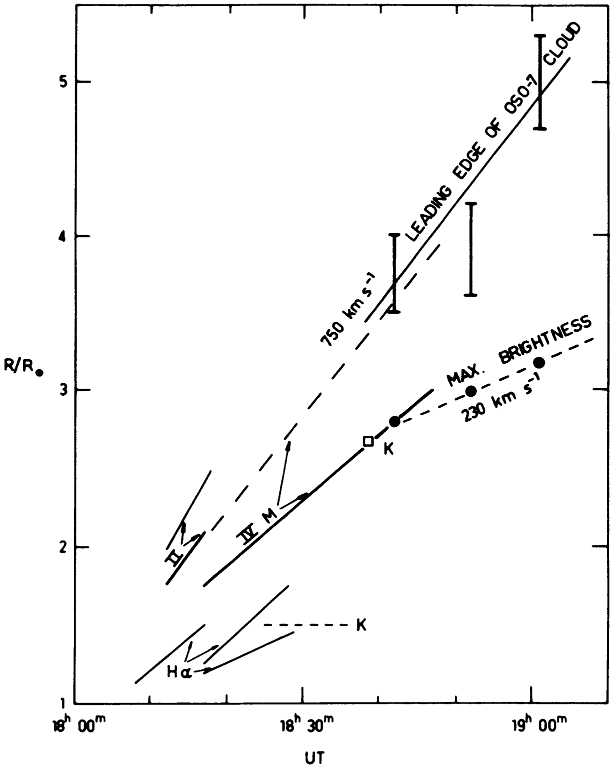

Fig. 2 - Combined projected height-time plots for the coronal transient of 1973 January 11 showing the relationships among the manifestations observed by the Naval Research Laboratory coronagraph on OSO-7 (leading edge and maximum brightness), the Clark Lake sweep-frequency interferometer (Type II and moving Type IV bursts), the Mauna Loa coronagraph (Hα spray) and the Mauna Loa coronal activity monitor (K-corona). (From Stewart et al. 1974b.)

bursts and an Hα spray. Three moving radio sources were observed with the 169 MHz (one-dimensional) interferometer at Nobeyama. The radio sources were possibly associated with several compact white-light clouds observed by the OSO-7 coronagraph; both moved with projected speeds of ~1000 km s^{-1}. A slower, diffuse cloud, also seen in white light, contained the major part of the ejected mass (~4×10^{16} g) and kinetic energy (~1×10^{32} erg). On the basis of speed alone this could have been a "fast transient". I have included it here because of the suggested association of the radio sources with the white-light clouds rather than the shock. However, the precision of the radio data is not high enough to be sure of the association, so that the possibility of its being a fast transient remains.

A different configuration occurred for the event of 1973 September 14-15 (Dulk et al., 1976), where there was no distinct

Type II burst and the continuum sources were stationary. The height-time diagram (Fig. 3) indicates that the major part of the continuum radiation (heavy bars) occurred between the leading edge of the "white-light front" and the outermost loop seen on the coronagraph pictures. The white-light front, or bow wave, is an important aspect of this, and

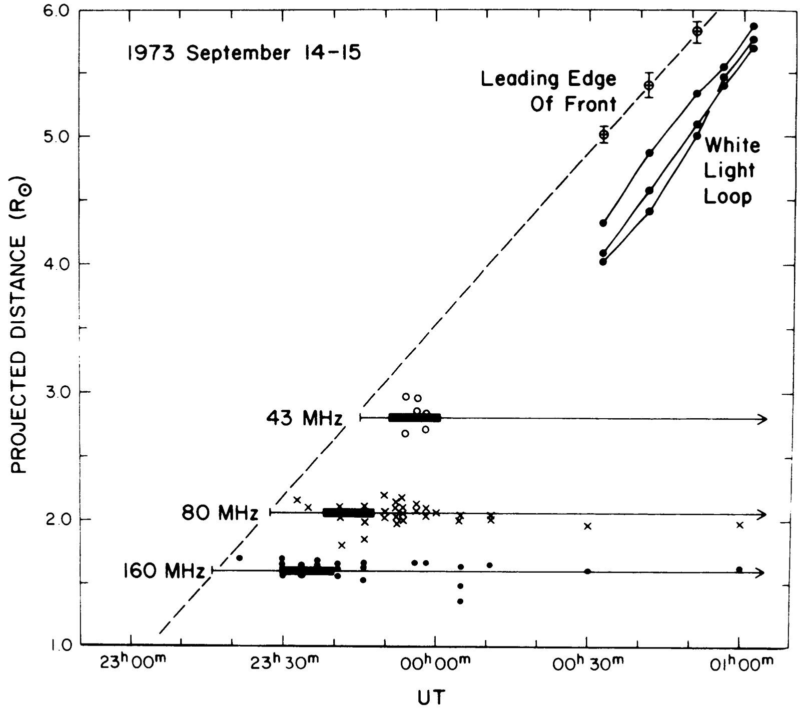

Fig. 3 - Height-time diagram for the coronal transient of 1973 September 14-15 observed by the High Altitude Observatory coronagraph on Skylab and the Culgoora heliograph at 43, 80 and 160 MHz. The height of the white-light loop at three position angles was determined from five coronagraph pictures and the white-light front was found from microdensitometer scans of three photographs. Individual open circles, closed circles and crosses show the radio source heights as measured from spectrograms; heavy bars emphasize the times of high intensity radio emission. (From Dulk et al. 1976.)

perhaps most, transient events. It preceded the bright, distinct loop and main ejecta by about 15 min in time or 0.5 $R_\odot$ in space; in other, slower transients, similar phenomena have been observed much farther ahead of the main transients and have been termed "forerunners" by Jackson and Hildner (1978). For the event of September 14-15 it was surmised that the white-light front was headed by a shock wave, the source of the non-thermal particles required for the radio emission. No Type II burst was visible, probably because the event occurred about

25° beyond the limb, where severe attenuation by the intervening plasma makes plasma emission unobservable.

Unlike the events discussed earlier, the sources of continuum radiation were stationary (despite their association with a moving white-light event) and appeared at greater heights at the lower frequencies. Evidently the non-thermal particles were produced near the bow wave shock, generated radio emission in the region between the shock and the loop, and were left behind to decay or drift away while new ones were produced at successively greater heights.

Two radio emission mechanisms, both requiring mildly relativistic electrons, were found to be possible: plasma radiation at the second harmonic due to particles of $E \approx 10$ to 100 keV infused into the region of compressed plasma between the front and the loop, or gyrosynchrotron emission due to particles of $E \gtrsim 100$ keV trapped in the magnetic field of the same plasma. In the latter case the dispersion with height of the radio sources can be explained by medium (Razin) suppression combined with a decrease in magnetic field strength with height. In either case the density of the compressed plasma inferred from the radio data is about 10 times ambient, a figure compatible with the column densities derived from the white-light data.

The derived magnetic energy density for the September 14-15 event was greater than 10 times the thermal energy density, marginally larger than the kinetic energy density in the densest, fastest-moving portion of the transient, and considerably larger in most other regions. This suggests that the plasma was magnetically controlled, that the magnetized plasma acted as the piston to drive the shock, and that magnetic forces provided the principal mechanism for the ejection of the transient material from the Sun.

Gergely et al. (1979) were able to estimate the magnetic field strength involved in the late phases of the transient of 1973 August 21 (unfortunately their Clark Lake observations did not begin until the leading edge of the transient had passed well beyond the heights probed by the radio data). They found an approximate equality between gas and magnetic pressure at 2 $R_\odot$, but suggested that the magnetic forces were still adequate to propel a magnetic loop from the Sun.

Frequency of Transients

A number of studies which relate to the frequency of coronal transient events have been published. I now summarize the results.

(1) There were at least 77 mass-ejection transients observed in white light during the 227 observing days of Skylab. These are thought to comprise less than half of the total number actually occurring, so the rate of occurrence in 1973-74 was about 0.5 day^{-1} (Munro et al., 1979). Each of the transients caused significant changes in the appearance of the corona.

(2) Of the mass-ejection transients, about half were relatively slow and were associated with eruptive prominences but were not accompanied by flares or radio bursts (Munro et al., 1979).

(3) Radio bursts accompanied all transients whose speed in white light was greater than 500 km s^{-1} (Gosling et al., 1976). Conversely, almost all (21 out of 23) Type II and/or IV radio bursts that occurred within 45° of the limb were accompanied by white-light transients (Munro et al., 1979).

(4) The number of reported Type II bursts during the Skylab period was 36 (Solar-Geophysical Data, 1973-74), which is very nearly the same as the number of flare-associated white-light transients. There was not a one-to-one correspondence of course, because many of the observed Type II bursts originated near disk centre, nearly unobservable by the coronagraph, while many white-light transients originated behind the limb, nearly unobservable in radio waves.

(5) The number of moving Type IV bursts is very small, only 31 being observed with the Culgoora radioheliograph in its first eight years of operation, 1967-1975 (Kai, 1979). Most Type IV bursts (flare continua and slow-drift continua) are not moving, but arise from stationary sources in the corona. But even the stationary continua are small in number; for example, only about 18 were reported during the Skylab period (Solar Geophysical Data, 1973-74). Therefore the number of Type IV bursts is smaller than the number of intermediate or fast white-light transients.

(6) As the number of white-light transients and the number of Type II and/or IV radio bursts is approximately proportional to sunspot number, it is estimated that near the peak of solar activity the frequency of observable transients is about one per day (Hildner, 1977).

(7) There is a close correlation between mass ejection transients, long-decay X-ray events, and the occurrence of prompt solar protons observed near the orbit of Earth (Kahler et al., 1978). One would expect a correlation between the long-decay X-ray events and Type IV radiation, but this relationship has not yet been studied.

We conclude from the above that there is a close correspondence between Type II-IV radio bursts and the intermediate-to-fast mass-ejection transients. It is possible that almost every disturbance that produces a Type II or IV burst also initiates a mass-ejection transient. We should therefore look at the radio bursts as indicators of mass ejections from the Sun and the associated reconfiguration of the corona.

3. RADIO EMISSION MECHANISMS

As discussed above, the radio emission mechanism for the slow transients is mainly or entirely thermal bremsstrahlung. If there is a problem, it lies in explaining the low values of radio brightness observed, values lower than one would expect if the coronal temperature is as high as is generally believed ($\gtrsim 10^6$ K) and the density is as high as the white-light data indicate.

For the transients of intermediate speed, the radio emission mechanism, plasma or gyro-synchrotron, is not certain. While it is generally believed that moving Type IV bursts result from gyro-synchrotron radiation, certain problems remain: (1) The moving Type IV sources usually exhibit a high degree of circular polarization ($\gtrsim 70\%$) and a steep spectral slope ($S \propto f^{-\alpha}$, where $\alpha \approx 7$). These characteristics seem to require the emitting electrons to have relatively low energies (~ 0.1 MeV) and to be embedded in a strong magnetic field ($\gtrsim 3$ G) (Dulk, 1973); yet the high brightness temperature ($>10^9$ K) sometimes observed seems to require most of the electrons to have high energies ($\gtrsim 1$ MeV) and the field to be low ($\lesssim 1$ G) (Stewart et al., 1978). (2) The proportion of sources with high circular polarization is larger than expected if the field orientation, from one event to another, were arbitrary. (3) The reversal of sense of polarization in the late stages of one moving Type IV event at one frequency (160 MHz) and not at another (80 MHz) cannot be explained in a simple way (Nelson, 1977).

The other possible emission mechanism for moving Type IV bursts, plasma emission, has not been explored in detail. For fundamental radiation, seemingly required to produce the high polarization, large enhancements of density in the moving source regions are needed, up to a factor of 40 (Stewart et al., 1978), but these may indeed exist in transients. More difficult perhaps is the need to explain the observed increase in polarization with decreasing brightness, especially in the late stages of the source lifetime (e.g. Robinson, 1978).

For the stationary sources of continuum radiation that sometimes accompany white-light transients the above questions on emission mechanism still apply, but they are compounded by the fact that one source, on 1978 May 7, had an observed brightness temperature of about 5×10^{13} K (this was at 43 MHz; at 80 and 160 MHz the values were $\sim 10^{12}$ K and $\sim 10^{11}$ K respectively) (Duncan et al., 1980). Such high brightness temperatures almost surely imply collective effects in the emission, either plasma radiation or maser action in gyro-synchrotron; otherwise the average energy of the radiating electrons would have to be $\gtrsim 10^9$ eV.

Melrose (1979, 1980) estimates that, under reasonable assumptions about conditions in Type IV sources, both fundamental and second-harmonic plasma radiation saturate at a brightness temperature of $\sim 10^{15}$ K. This makes plasma emission a favourable candidate to explain the bright phases of bursts. Indeed, different bursts may be dominated by different mechanisms, and even within a given burst different mechanisms may dominate at different times. For example, plasma radiation at the second harmonic may dominate during the early phases of certain moving Type IV bursts, when the sources are very bright and of low polarization, and gyro-synchrotron radiation may dominate in the late phases, when the sources are of moderate brightness and high polarization. Unfortunately, under some circumstances it is difficult to distinguish between the two emission mechanisms; both can produce radiation in the x-mode (Melrose et al., 1978) and both can imply the same density (i.e. Razin suppression of gyro-synchrotron emission and harmonic plasma radiation require rather similar densities).

It appears that elucidation of the emission mechanisms of Type IV bursts awaits detailed observations, made concurrently in white light, radio, and perhaps X-rays. Such an opportunity should occur when the SMM spacecraft starts operating and the new heliographs at Nancay and Clark Lake become available to extend the two-dimensional radio coverage now provided only by Culgoora.

4. MECHANICAL AND MAGNETIC ENERGY RELEASE

The shock waves and mass motions of coronal transients represent a release of energy, initiated by solar flares, into and through the corona. The energy is manifested in the mechanical energy of shock waves, as the kinetic energy (KE), potential energy (PE) and enthalpy (EN) of the masses of moving gas, and as transport of magnetic energy.

The most extensive estimate of the magnitudes of the various forms of energy was made for the flare of 1973 September 5 by McLean and Dulk (1978), Webb et al. (1979) and Canfield et al. (1979). Their results can be summarized as follows.

Radiative energy (all λ):	W_{rad}	$\sim 4 \times 10^{30}$ erg
Eruptive prominence:	$W_{PE} + W_{KE}$	$\sim 1 \times 10^{30}$ erg
Emission front:	$W_{PE} + W_{KE}$	$\sim 3 \times 10^{30}$ erg
Shock wave and piston:	$W_{EN} + W_{PE} + W_{KE}$	$\gtrsim 6 \times 10^{30}$ erg
Magnetic energy transported:	W_B	$\gtrsim 1 \times 10^{31}$ erg

The flare of 1973 September 5 was close to the centre of the disk and, probably for this reason, no white-light transient was observed. It was chosen for the study because of the extensive wavelength coverage, not because it was particularly energetic. For other, more energetic events, most of the components listed in the table are 10 to 100 times larger. However, it is probable that the general relationships remain: the radiative energy and mechanical energy are both significant, but the magnetic energy is major. Of course, the flaring process itself need not be the source of most of the energy; rather it may be the trigger for the release of a much larger amount of free energy, stored in the low corona in the form of non-potential magnetic fields.

Lin (1977) has pointed out that the bulk of the flare energy (10^{31} to 10^{32} erg) for some flares resides in the 10-100 keV electrons associated with hard X-ray bursts. He suggests that these electrons may produce the heating and consequent mass motions required for the mass ejections and shock waves, thus invoking what is essentially a non-magnetic, blast-wave model of transients. Lin based his suggestions on studies of the very large flares of 1972 August and invoked a non-thermal model of hard X-ray bursts (which may imply ~10 times the energy of a thermal model). While this blast-wave hypothesis may be able to explain the transients and shocks which accompany very energetic flares, it cannot explain the majority of transients and shocks, those which accompany very modest flares but imply comparable total energies. For the latter at least, the requirement for magnetic energy seems to be unavoidable.

In some cases much of the magnetic energy may be in the plasmoidal configuration of a moving Type IV burst. For such plasmoids the magnetic energy has been estimated to be of the order of 10^{31} to 10^{32} erg (Dulk, 1974). Similar numbers have been derived for other transients, with or without moving sources (Stewart et al., 1974a,b; Dulk et al., 1976; Gergely et al., 1979), and for shock waves in the interplanetary medium (Hundhausen, 1972).

Much of the magnetic energy transported through the low corona in the form of magnetic fields can be made available, through expansion, into mechanical energy of interplanetary shocks and mass motions - i.e. the magnetic energy could well provide the driving forces for the entire transient. In that case the magnetic energy and mechanical energy are not separate entities and both should not be counted as contributing to the total energy of the event - i.e. the latter results mainly from partial conversion of the former.

5. CONCLUSIONS

Coronal transient events are probably the major means by which the corona is restructured. Slow evolution of coronal forms over days and weeks, if it occurs at all, is secondary to the abrupt reconfigurations, many of which eject mass and magnetic fields from the Sun. Only the faster events are accompanied by flares and non-thermal radio bursts, the latter allowing the magnetic field strength to be derived. But in all cases where the magnetic field was derived, its energy was found to be larger than the thermal, potential or kinetic energy of the ejected matter. We are therefore led to the specific conclusion that magnetic forces drive the transient material from the Sun, and to the general conclusion that coronal transients are the manifestations of the evolution of coronal magnetic field in response to changes in the causative currents which mainly reside within the photosphere.

The theoretical work necessary for understanding coronal transients is just beginning. Dulk et al. (1976), Mouschovias and Poland (1978), Anzer (1978), and Pneuman (1978) have suggested models for individual transients, all based on magnetic forces, while Steinolfson et al. (1978)

have suggested models based on a blast wave initiated by an explosive release of energy in the low corona. All studies achieved results bearing some semblance to observed phenomena, but only Pneuman (1978) considered the pre-transient magnetic configuration, and no study investigated the instabilities which initiate the motions or the implications of the forerunner which precede the main body of many transients. In the context of flare loops, Low (1977; 1979) and Heyvaerts et al. (1978) have investigated the conditions for magnetostatic equilibrium and find that in certain circumstances a force imbalance is unavoidable, thus producing violent rising or sinking motions. It may be that further work along this line will provide the needed insight into the coronal transient phenomenon.

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DISCUSSION

Nakagawa: I would like to point out that the fact that the largest energy source is the magnetic energy implies that a part of the magnetic energy stored in sheared magnetic fields is sufficient to drive the phenomena, and no enhanced magnetic field is necessary to drive the transients.

Dulk: You are right that all of the magnetic energy is unavailable to drive a transient. I look at it as only the free energy, or non-potential magnetic energy is available. While this may be only a fraction of the total magnetic energy, it may still be enough to drive the transient.

Vlahos: I want to report on some work we have in preparation at Maryland. We examined the possibility that magnetic loops are moving upwards with $V \geq 400$ km/sec. These loops are acting as magnetic pistons forming shocks at the apex. The electrons accelerated in the shock are trapped and are continuously passing through the shock front after reflection at the foot points. But this model predicts stationary type IV, continuum storms and type IV burst associated with the outward moving loop. Do we see such signatures?

Dulk: On the basis of the structures seen in most of the white light transients, I believe that many involve magnetic loops. However, some transients look like amorphous clouds. Most theoretical ideas are based on magnetic loops.

Regarding reconnections and/or particles at the legs of the loops, the observations show that there are low-lying sources, presumably where the energetic particles are passing through the plasma levels.

Pick: Concerning the association that you have found between slow disturbances and the radio enhancement observed at 80 MHz, are you certain that the radio emission is of thermal origin? The Nançay observations at 169 MHz have shown that in a few cases, a faint noise storm continuum is associated with slow transients (unpublished observations). At 80 MHz, the distinction between noise storm continua and enhancements of thermal origin is more difficult to establish than at higher frequencies. This effect can lead to an overestimate of the thermal continuum.

Dulk: While I agree that one must always be concerned with the possibility of non-thermal enhancements of radiation, in the case of slow transients and dense streamers, the problem is that the electrons inferred from the white-light data are more than sufficient to account for the radio brightness (simply by bremsstrahlung). Adding non-thermal radiation only compounds the difficulty.

Hudson: I would like to point out the existence of another channel for the study of coronal transients, namely the hard x-ray bremsstrahlung of the non-thermal electrons in the different radio sources. The first observation of this kind was the event of 1969 March 30 (Frost and Dennis), and other related events were discovered by OSO-7 on 1971 December 14 and 1972 July 22. In all of these the coronal origin of the hard x-radiation was established by limb occultation. High-resolution images of hard x-radiation should be obtainable in the future.

The original suggestion by Smerd of an association of hard x-ray emission with the FC II meter-wave phenomenon has been confirmed by the 1972 July 22 event.