CORONAL DISTURBANCES AND THEIR TERRESTRIAL EFFECTS*

(Tutorial Lecture)

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Abstract. Coronal disturbances lead to geomagnetic storms, proton showers, auroras and a wide variety of other phenomena at Earth. Yet, attempts to link interplanetary and terrestrial phenomena to specific varieties of coronal disturbances have achieved only limited success. Here, several recent approaches to prediction of interplanetary consequences of coronal disturbances are reviewed. The relationships of shocks and energetic particles to coronal transients, of proton events to γ-ray bursts, of proton events to microwave bursts, of geomagnetic storms to filament eruptions and of solar wind speed increases to the flare site magnetic field direction are explored. A new phenomenon, transient coronal holes, is discussed. These voids in the corona appear astride the long decay enhancements (LDE's) of 2–50 Å X-ray emission that follow Hα filament eruptions. The transient holes are similar to long-lived coronal holes, which are the sources of high speed solar wind streams. There is some evidence that transient coronal holes are associated with transient solar wind speed increases.

1. Introduction

A great deal has been learned recently about the kinds of coronal disturbances that affect the interplanetary medium and the Earth. Although it is difficult to monitor coronal activity and to trace disturbances from the Sun to the Earth, recent research seems to indicate that when adequate instrumentation is available, some large disturbances can be tracked through the corona and interplanetary space to the Earth. It is more difficult to relate average coronal disturbances to interplanetary (IP) phenomena. And, although some widely accepted coronal signatures of impending IP shocks or protons have proved to be misleading, I hope to show that progress is being made and that more intensive surveillance of the corona may lead to significant improvements in our ability to forecast the geophysical consequences of coronal disturbances.

By coronal disturbances, I mean shocks and coronal mass ejections, and filament eruptions and flares, especially the long-enduring, high-temperature component of flares. Two effects of coronal disturbances will be emphasized here, namely, interplanetary shocks and energetic ($E > 10$ MeV) prompt solar proton events, which I will call proton showers. I will briefly illustrate the effects of coronal disturbances on the earth by discussing the flare of 10 April, 1981 and the terrestrial phenomena associated with it. Then I will review the properties of geoeffective and non-geoeffective flares. Finally, I will discuss evidence that indicates that coronal mass ejections may play a fundamental role in determining the geoeffectiveness of flares.

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2. Terrestrial Effects of a Major Flare

Large flares, such as the one on 10 April, 1981, affect our environment in many ways. The 10 April flare heated the upper atmosphere and increased the drag on the space ship Columbia during its maiden flight, 12–14 April, 1981. On the night of 12 April the flare caused a great red aurora over much of the northern hemisphere, and there was an ionospheric storm that interfered with police communications but not with Columbia's communications. In fact, the flare posed no serious problems for the Columbia. However, if the Columbia's mission had included an EVA (extra vehicular activity) while in a polar orbit, the mission probably would have been postponed to avoid exposing astronauts John Young and Robert Crippen to a proton shower. Solar flare protons with an energy of more than 10 MeV (million electron volts) can easily penetrate the aluminum layers of their spacesuits.

The flare lasted for $3\frac{1}{2}$ hr. At its peak, it covered an area of 2×10^9 km^2 on the solar disk. The flare released over 10^{25} J or about 10^{19} kW-hr of energy, or about 400000 times the total yearly energy consumption of the United States. This amount of energy could easily have been stored in the magnetic fields of the sunspot group even though the sunspots showed no changes as a result of the flare.

In the first ten minutes after flare onset on 10 April,a metric type II burst indicated that a shock wave was passing through the corona. After 58 hours' travel, the shock hit the Earth's magnetosphere and triggered a magnetic storm. The actual change in the magnetic field at the Earth's surface was barely 1%, but the disturbance was sufficient to produce an electrical power outage in Canada. The 12 April magnetic storm, which began only 15 hr after the Columbia's launch, was the largest of the current sunspot cycle.

Precipitating electrons heated the upper atmosphere, which expanded and dragged the shuttle (and other satellites) down to lower orbits 60% faster than expected (Weaver and Abramson, 1981). The early demise of Skylab in 1978 was due to such an unexpected increase in atmospheric drag. Protons with energy up to 500 MeV arrived on 10 April, an hour after flare onset, and they would have posed a potentially lethal threat to astronauts on an EVA in a polar or geosynchronous orbit. In the outer magnetosphere, the peak isotropic proton flux above 50 MeV was about 300 cm^{-2} s – 1 on 10 April. The event was an 'ordinary' proton shower. About ten such showers can be expected each year near the sunspot cycle maximum. The highest fluxes seen in the past quarter century were more than a hundred times higher than in the 10 April event (Stassinopoulos, 1980). They occurred in 'anomalously large' events that happen perhaps one to six times each solar cycle during the rise to or fall from maximum.

3. Proton Showers and the Big Flare Syndrome

Acceleration of protons is thought by many to be accomplished in the shocks that accompany large flares and that are most clearly revealed by the metric type II bursts they excite (Arons *et al.*, 1979). Švestka and Fritzová-Švestková (1974) found a good correlation between type II bursts and proton showers. Recently, however, Kahler (1982a, b) questioned whether type II bursts are any better correlated with proton showers than are other large flare phenomena. Using 1974–80 proton data, Kahler found that type II bursts and many other proton shower 'predictors' are no better correlated with protons than is the peak 1–8 Å X-ray flux, which is a purely thermal phenomenon. In order for a proton shower to be associated with a type II burst, Kahler found that several *auxilliary* conditions were necessary: a long-duration microwave burst, a large area in Hα (importance 2 or larger), and a metric type IV burst. Microwave bursts from non-proton flares with type II bursts were never longer than 10 min. The well-known association of proton showers with metric type IV bursts (Wild and Smerd, 1972) was extended into the decimetric range at 245 and 410 MHz, and Kahler concluded that the key coronal phenomenon associated with proton showers is formation of a post-flare loop system plus some indication of the presence of trapped non-thermal electrons. Apparently, only those shocks associated with a long-lived coronal disturbance accelerate protons.

Another approach to finding the coronal signatures of proton showers was advocated by Lin and Hudson (1976) and by Castelli *et al.* (1967). These authors and others seemed to find correlations between proton production and impulsive phase flare phenomena. The logic behind the association was that larger initial energy releases should produce more energetic shocks and protons. The studies upon which this logic rests were not confirmed (Kahler, 1982b) when the 'big flare syndrome' was accounted for. The big flare syndrome will lead to a positive correlation of any flare phenomenon with any other simply because all aspects of flares strengthen and appear more faithfully in big flares. The strength of the impulsive phase is usually measured by the peak level of microwave radio emission or, when available, by peak X-ray flux at energies above 20 keV. After removing the 0.5 correlation between the peak thermal X-ray (1–8 Å) emission level and peak proton flux, Kahler found no additional association between impulsive phase phenomena and proton flux. However, *long enduring* X-ray events do show a positive correlation with proton showers beyond that accounted for by the big flare syndrome (Nonnast *et al.*, 1982). We will return to this point later.

4. Compact vs Large-Area Flares

Protons with $E > 10$ MeV can excite atomic nuclei in the solar atmosphere. The excited nuclei decay with characteristic gamma ray line emission. Observations of gamma-ray lines, then, provide positive evidence for proton acceleration at the Sun. However, Pesses *et al.* (1981) found no correlation between proton showers and flares with gamma ray emission. In fact, there is a slight anticorrelation. Von Rosenvinge *et al.* (1981) looked for protons from two of the most intense gamma-ray line events detected in 1980, those of 7 June and 1 July. Despite the fact that the 1 July flare was the most intense

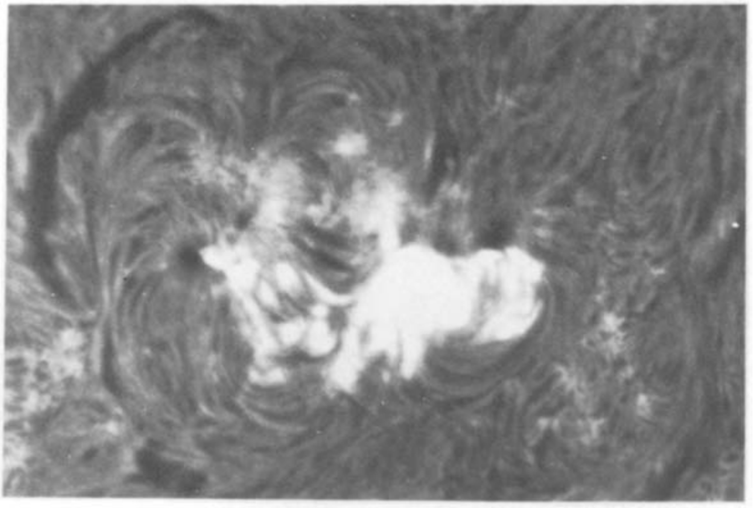
1–8 Å X-ray flare recorded by the Solar Maximum Mission in 1980 and was the seventh most intense flare (out of nearly 2000) in X-rays above 25 keV, it produced neither an interplanetary shock nor a proton shower. Both flares were well-connected to the Earth, since they occurred at heliolongitudes of W 70 and W 38 degrees, respectively. Von Rosenvinge *et al.* calculated that the intensity of protons in interplanetary space was about 100 times less than would be expected from isotropically accelerated protons. The implication is that the protons were beamed downward. Although neither event was observed with the imaging instruments aboard the Solar Maximum Mission, ground-based optical observations (Rust *et al.*, 1981; Rust *et al.*, 1982) indicated that both flares occurred in structures no longer than about 5000 km, and both flares fell rapidly from their peak emission levels in the 1–8 Å X-ray band. Thus, these two flares illustrate in particular the statistical conclusions of Kahler, namely, that brief flares with limited Hα area do not produce proton showers even when the peak X-ray emission level is high.

The distinction in Hα between large, long-lived proton and shock producing flares and equally intense but small, short-lived flares that produce neither protons nor IP shocks is shown by the flares of 1 July, 1980 (Figure 1) and 21 May, 1980 (Figure 2). Their peak soft X-ray levels were X2.5 and X1, respectively, on the NOAA/GOES scale. The maximum Hα area of the 21 May flare was 8.4×10^9 km^2, which is about 20 times the area of the 1 July flare. The 21 May flare was accompanied by an intense metric type II burst with herringbone structure, which indicates electron acceleration at the shock front. The 1 July flare had an intense type II burst, but observations with the radio spectrometer aboard ISEE-3 showed only a group of type III kilometric bursts. Apparently, no effects of the shock on 1 July propagated beyond about $10 R_\odot$. On May 21 there was an SA (shock accelerated) IP radiowave burst following the metric type II burst (Cane *et al.*, 1981).

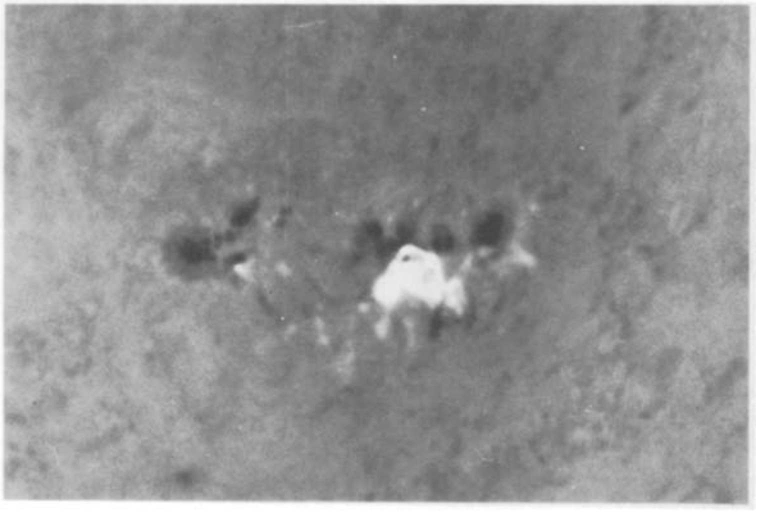
Figure 2 illustrates the eruption of a large filament from the center of the 21 May flare and shows the bright post-flare loops that appeared just after flare maximum. Both of these Hα phenomena are associated with coronal transients (mass ejections) and long-decaying X-ray loops (Rust and Webb, 1977; Sheeley *et al.*, 1975). A sequence of images (Figure 3) from the Solwind experiment confirms that the 21 May flare was associated with a coronal mass ejection. Finally, although the 21 May flare had no gamma rays, it did produce a proton shower at the Earth (Von Rosenvinge and Reames, 1982), although the coronal shock seems to have died before reaching 1 AU.

Characteristics of flares that have no interplanetary consequences (e.g., 1 July, 1980) and those that produce shocks and proton showers (e.g., 21 May, 1980) have been established statistically by Van Hollebeke *et al.* (1975), Kahler *et al.* (1978), and Pesses *et al.* (1981). Comprehensive reviews appear in Manno and Page (1970) and Švestka (1976). Pallavicini *et al.* (1977) classified soft X-ray flares according to their spatial extent and duration. They found that the large-area, long-enduring flares of the 21 May type are usually associated with coronal mass ejections.

1 JULY 1980



Hα FLARE MAX 1630 UT



1 Å FROM Hα 1630 UT

Fig. 1. Optical images of the gamma-ray producing flare of 1 July, 1980. The bright flare knots shown in the lower image are about 3500 km diam. (Holloman Solar Observatory photo.)

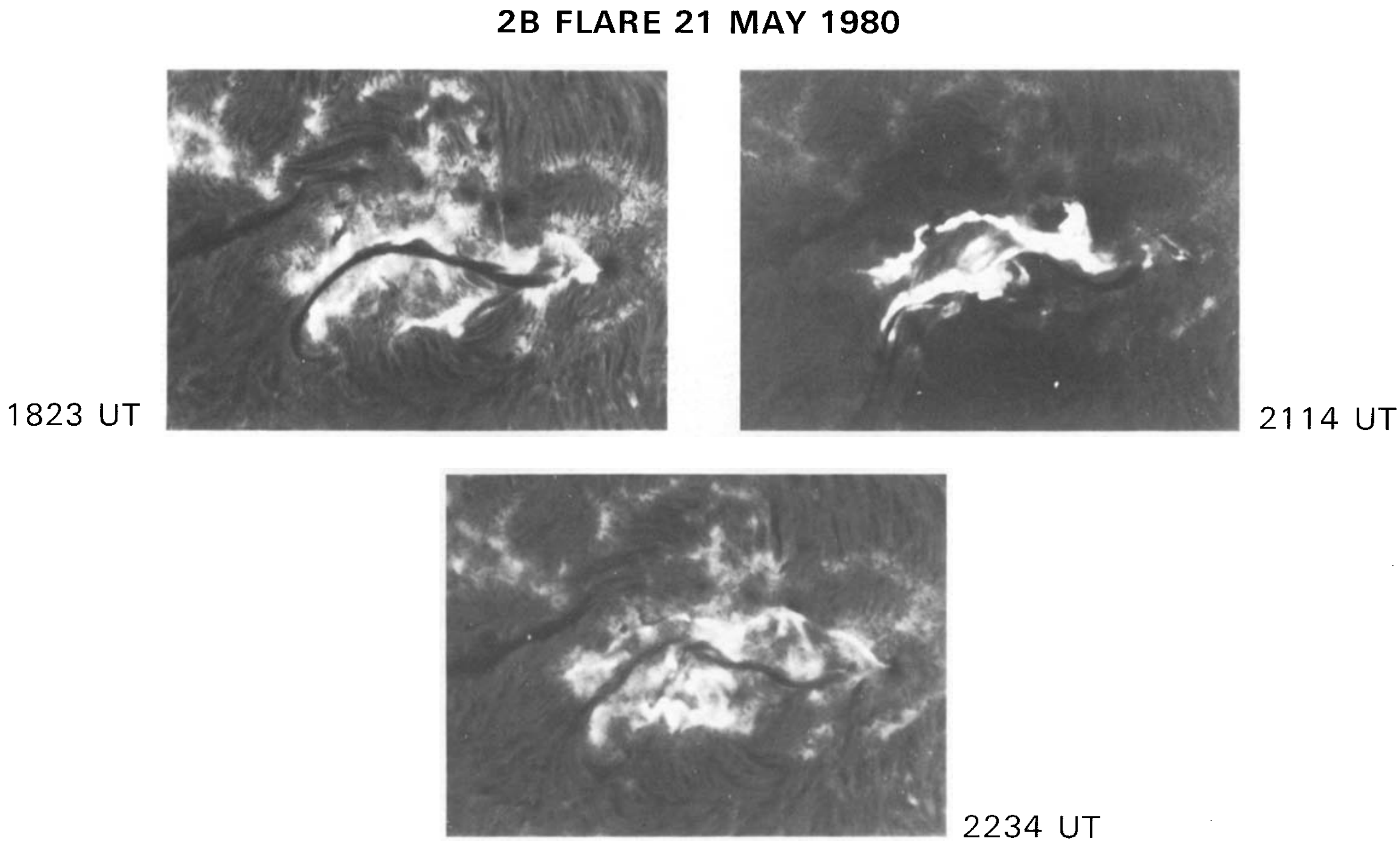


Fig. 2. Hα images from before, during and after the 2B flare of 21 May, 1980. The filament, seen here at 18 : 23 UT, erupted toward the south (downward) at flare onset. Note the bright flare loops connecting the two flare ribbons at 21 : 14 UT. (Holloman Solar Observatory photo.)

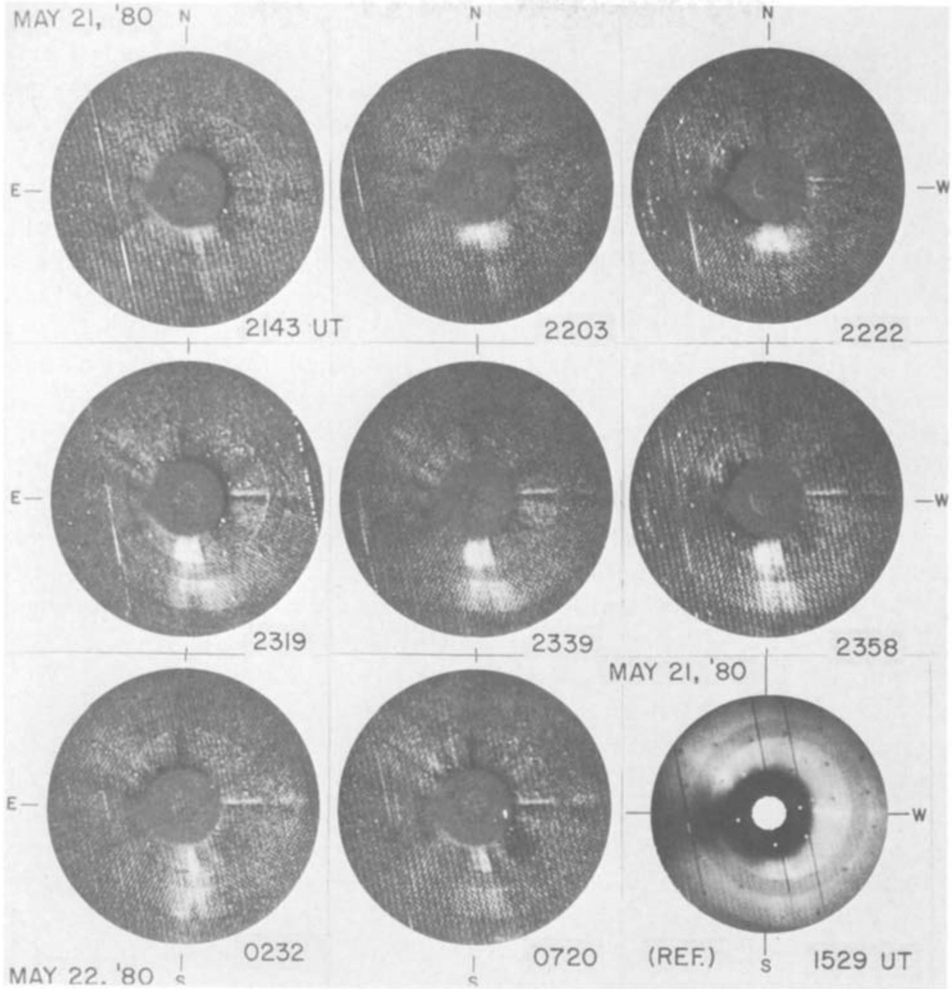


Fig. 3. A sequence of images from the Solwind coronagraph showing a mass ejection transient over the south pole immediately following the 21 May flare, which started at 20:54 UT. (Courtesy of N. Sheeley, Naval Research Laboratory.)

5. Coronal Mass Ejections and Shock Fronts

We must now ask whether coronal mass ejection is a necessary condition for formation of an IP shock or whether mass ejections simply occur more frequently in large flares and are thus just another manifestation of the big flare syndrome. Since those ejections most easily seen with coronagraphs are those moving perpendicularly to the Earth–Sun line, one would not expect them to be correlated with shocks at the Earth. Indirect evidence for IP shock association was provided by Kahler *et al.* (1978), who showed that during the Skylab mission (1973) all proton showers (which we assume are produced by shocks) could be associated either with a mass ejection at the limb or with a long decay X-ray event (LDE). More recently, Sheeley *et al.* (1982) have found that virtually all IP shocks detected at the Helios spacecraft, which was in a plane roughly 90° from the Earth–Sun line in 1979 and 1980, were associated with coronal mass ejections. From this we might conclude that mass ejection is a necessary condition for IP shock formation. However, mass ejection is not a *sufficient* condition for IP shock formation, since there are many more ejections than shocks.

From the work of Gosling *et al.* (1976) it seems that mass ejections fall into two catagories, namely, those moving faster than 400 km s^{-1}, which are associated with metric type II bursts (shocks in the corona), and those moving slower than 400 km s^{-1}, which apparently do not produce shocks either in the corona or in IP space. There remains the possibility that IP shocks have very little to do with mass ejections except for the fact that they both occur in large flares. The central issue is whether the high velocity mass ejections act as 'pistons' which set up a bow shock ahead of them where particles may be accelerated. Such shocks should be distinguished from blast waves arising from the impulsive phase of the flare. These probably produce those type II bursts that are not associated with proton showers and IP shocks. There are several important differences between these shocks as revealed by their type II bursts and bow shocks that may be associated with mass ejections:

(1) The type II bursts sometimes follow curved trajectories whereas coronal mass ejections deviate only slightly from the radial direction.

(2) Type II bursts *always* follow the impulsive phase of a flare (Švestka, 1976), whereas mass ejections sometimes start before the impulsive phase (Wagner, 1982).

(3) Type II bursts decelerate in the corona below about $0.7 R_{\odot}$, (Weiss, 1965), but mass ejections always follow an increasing or constant velocity curve.

Shocks associated with coronal mass ejections would be longer lasting than blast waves and would explain Kahler's two classes of type II bursts. Only those bursts arising from shocks driven by a massive piston, according to this picture, would be associated with particle acceleration.

Observations of type II burst trajectories and type IV locations can be compared with mass ejection images to show whether the piston-driven shock picture is correct. Wagner (1982) summarized recent evidence for divergent type II and mass ejection trajectories in a number of well observed cases. However, there are many cases in which the type II trajectory seems to lead the mass ejection, as it would in a bow shock.

With the ISEE radioheliometer, Cane *et al.* (1982a) studied type II bursts that propagate beyond the corona, i.e., from $5 R_{\odot}$ to 1 AU. Only 16% of metric type II bursts continue into the IP medium. It is yet to be shown that the IP type II events all correspond to mass ejections, but there is one particularly well-studied event now that is nicely explained by the piston/bow shock picture. I refer to the IP shock that followed a large flare on 18 August, 1979 (Figure 4). The curve of velocity vs distance from the Sun is consistent with the shock being piston-driven to about $35 R_{\odot}$. Beyond that point, the velocity of the shock decreased at a rate proportional to $R^{-0.8}$, which is close to the theoretical deceleration rate of $R^{-0.5}$ predicted for non-driven shocks. Apparently, the piston drove the shock for about 3 hr, and although a detailed comparison of the coronal mass observations and the shock trajectory is still underway, it is known that a large

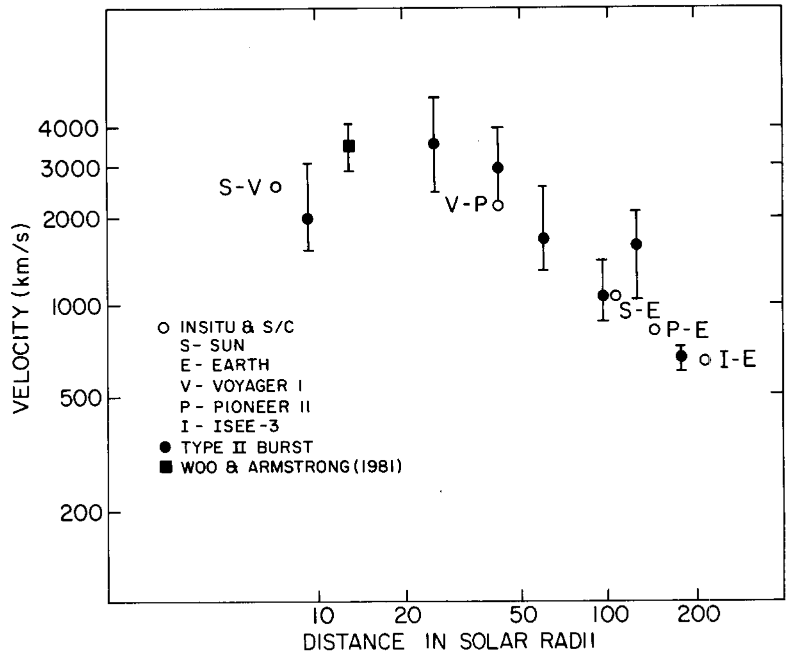


Fig. 4. Velocity of the IP shock on 18 May, 1979, as recorded by the radio-heliometer on ISEE-3 and by solar wind monitors on various spacecraft. Note the increase in velocity to about $35 R_\odot$. (From Cane *et al.*, 1982b.)

coronal mass ejection accompanied the 18 August flare (Sheeley, private communication).

Howard *et al.* (1982) observed a large mass ejection that was directed toward the Earth on 27 November, 1979. The transient apparently originated with a disk-center filament eruption and minor solar flare. There was a type II burst and an IP shock, which reached Earth about 72 hr after the filament eruption. Since no deceleration of the ejecta was observed, Howard *et al.* conclude that the shock wave was at least partially piston driven near the Sun. An intensive search for earthward directed mass ejections is under way, and I think that more positive cases will be found.

6. Transient Coronal Holes

It is of interest to ask what happens to the corona below a mass ejection. Figure 5 illustrates the onset of a mass ejection in the low corona. The ejection slowly accelerated between 1.1 and $5 R_\odot$ until reaching a constant velocity of 250 km s^{-1} (Rust and Hildner, 1976). Only a few such onsets have been observed because spacecraft coronagraphs occult the corona below $2.6 R_\odot$. Using ground-based coronagraph data, Fisher and Poland (1981), found a coronal transient that started before the eruption of an underlying prominence. Their results and a similar study by Gary (1982) indicate that mass ejection preceeds filament eruption *and* flare onset.

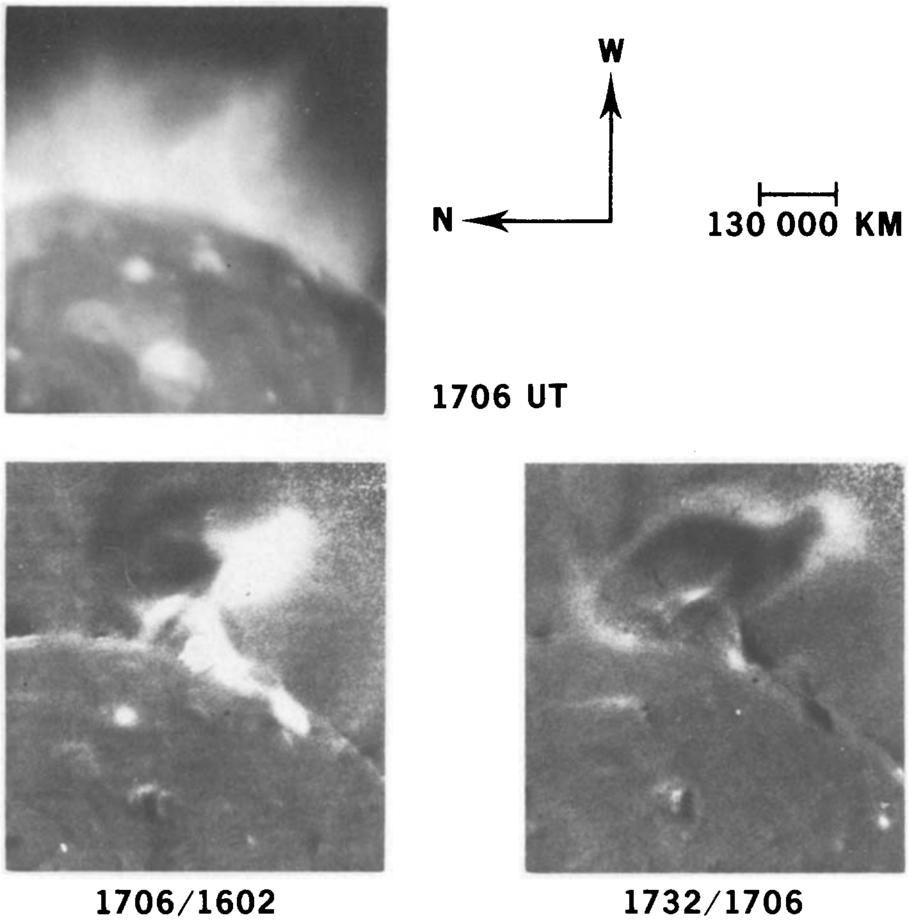


Fig. 5. View of a mass ejection starting in the low corona on 13 August, 1973. The top picture shows the X-ray emitting loop as seen on the original films. The dark coronal depletion is seen in the two lower frames, which are ratios of images taken at the Universal Times shown. The bright hooked feature (left) is the X-ray enhancement marking the location of the Hα filament that erupted beneath the loop. Progress of the loop through the corona during a 26 min period is shown in the lower, right frame. (Rust and Hildner, 1976.)

It is interesting to speculate on what characteristic signature of a mass ejection would be in the low corona. Since IP shocks are followed by a sustained period of high speed solar wind, and *recurrent* high speed solar wind streams originate in long-lived coronal holes (Hundhausen, 1972), then the transient solar wind speed increases might stem from transient coronal holes.

Figure 6 shows the development of a faint, but long decaying X-ray enhancement. The images, like those in Figures 5 and 7, were obtained with the X-ray telescope experiment, S-054, flown on the Skylab/ATM mission 1973–1974. As usual, the X-ray enhancement appeared during the disappearance of an Hα filament (Webb *et al.*, 1976). The

2–54 Å X-ray images reproduced here for the first time reveal that the enhancement is bracketed by two voids. The interval between observations was 90 min, so we may conclude that the voids started to appear after 14 : 50 UT. They were apparent first at 16 : 22 UT, just as the filament was erupting. They were as dark as nearby 'permanent' coronal holes. They were most distinct near 17 : 06 UT; and they disappeared slowly, over a 10 hr period.

Examination of all Skylab exposures obtained through a soft X-ray filter revealed many transient coronal holes of the kind shown in Figures 6 and 7. Because the visibility of the holes depends on the distance from disk center and the proximity of bright active regions, no attempt has been made to catalog or study all of them. However, starting with the twenty-one brightest X-ray enhancements or Long Decay Events (LDE's) observed by Webb *et al.* (1976, their Table I), I examined soft X-ray images for

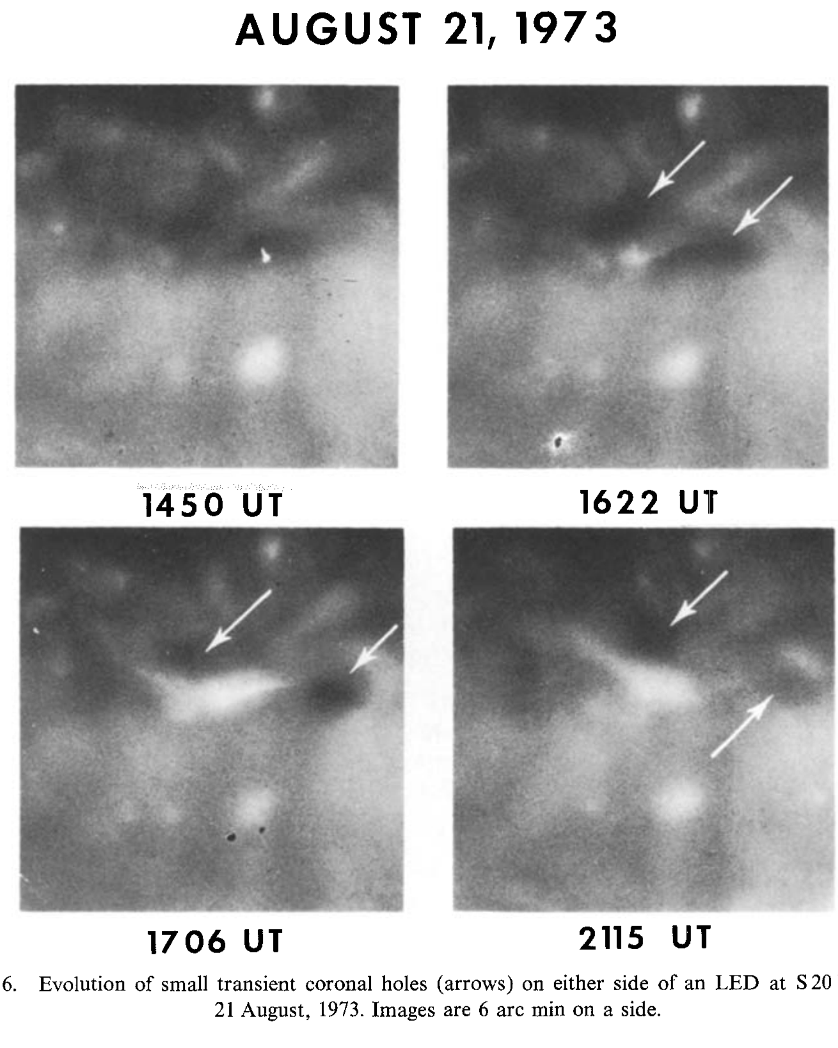


Fig. 6. Evolution of small transient coronal holes (arrows) on either side of an LED at S 20 W 30 on 21 August, 1973. Images are 6 arc min on a side.

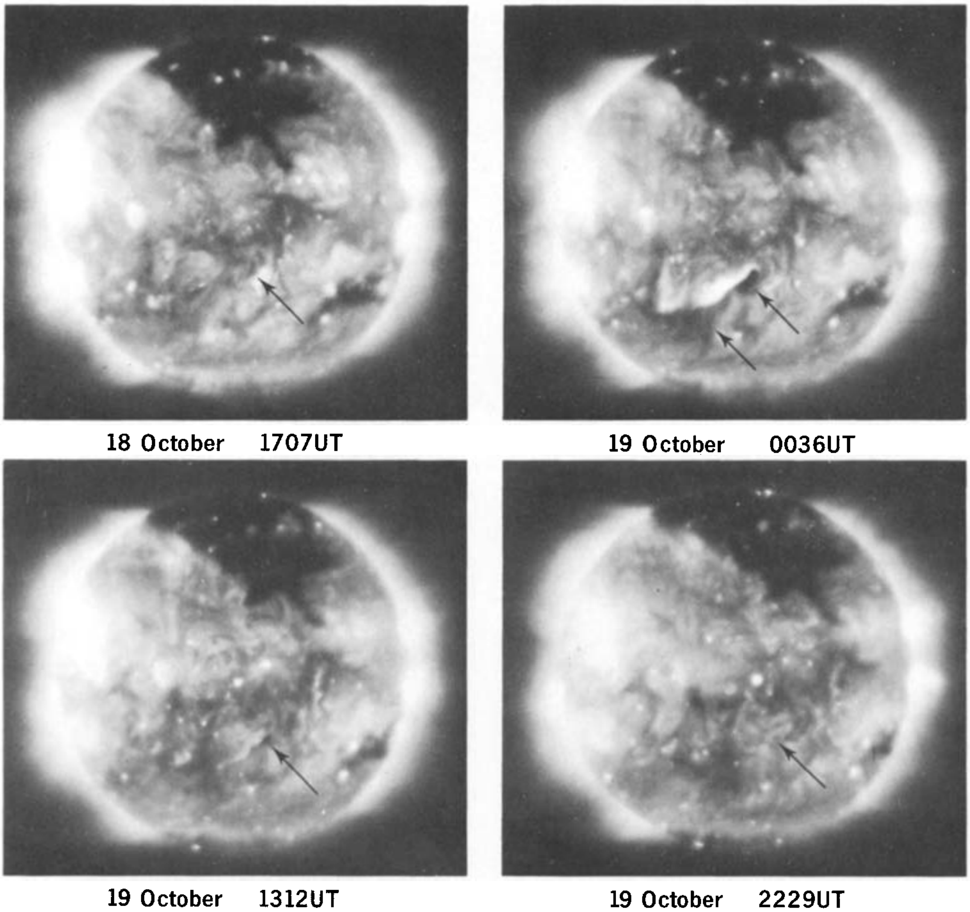


Fig. 7. Evolution of a large transient coronal hole and LDE on 18–19 October, 1973. Note that the hole disappears through gradual contraction of its borders.

transient coronal holes within $0.2R_\odot$ of Hα filament eruption sites. In eleven of the twenty-one events, a clearly-defined void was found. Seven events showed ambiguous evidence of a void. Only three of the twenty-one events showed no darkening at all. In most cases only a single void was seen, but in some cases the associated LDE's themselves could have hidden other voids on the limbward side. In all cases the darkening was transient, lasting less than 48 hr. The largest transient hole had an area of $\sim 5 \times 10^{19}$ cm^2. This hole was adjacent to the major LDE flare of 29 July, 1973.

Transient coronal holes are possibly the same phenomenon as the well-known depletions (Hansen *et al.*, 1974) and rifts (Koutchmy, 1977) seen in the corona at the solar limb because coronal depletions are also associated with eruptive prominences and with ejections (Rust and Hildner, 1976). The mass ejections usually leave a pattern of radial filaments suggestive of open magnetic fields.

If the fields in transient coronal holes are open, solar wind velocity measurements might reveal corresponding transient high-speed streams in IP space. Sullivan and Nolte

(1978) studied LDE's which occurred within 15° of the central meridian. In six out of seven cases, an increased speed at 1 AU was found at the predicted time of arrival of plasma that left the sun at the onset of an LDE. In Sullivan and Nolte's best example, the bulk wind speed increased from 410 km s^{-1} to 480 km s^{-1} hr after LDE onset. They concluded that LDE's possibly signal the introduction of transient high speed streams into the solar wind.

The study of LDE's and IP disturbances is similar to earlier work devoted to disappearing Hα filaments and geomagnetic storms. This work is reviewed by Joselyn and McIntosh (1981), who cite several persuasive incidents when a disappearing filament was the only coronal disturbance that preceeded a geomagnetic storm. However, further statistical studies are required to establish a clear associated between IP phenomena and coronal disturbances other than flares.

The observational evidence for transient field openings presented here may explain why flare-associated solar wind disturbances are followed by high speed streams. Hundhausen *et al.* (1970) found that the solar wind speed following nineteen flare-associated disturbances remained elevated for at least one day, and they concluded that the lifetimes of the sources in the corona may be considerably longer than one day. They also noted that the coronal density at the sources must be unusually low. *These are the properties of transient coronal holes.* We may speculare that LDE-associated but not flare-associated transient coronal holes may presage small transient increases in solar wind speed. The expected IP characteristics – enhanced speed, enhanced magnetic field, and 10–20 hr lifetime are remarkably similar to the interplanetary magnetic clouds reported by Klein and Burlaga (1982).

7. Magnetic Fields in Coronal Disturbances

Filament eruptions and large area flares take place in large-scale ($\sim 10^5$ km) magnetic field structures whose north–south component can be characterized as either oriented parallel or antiparallel to the dipolar component of the solar field. Dodson *et al.* (1982a) studied major flares during the rise phase of the last sunspot cycle, when the global field was predominantly southward (Howard, 1972). From 1967 to 1970, major solar flares were significantly more frequent in large scale field structures in which the magnetic flux was oriented north-to-south, i.e., parallel to the global field. Geomagnetic disturbances, solar wind velocities and solar proton fluxes from regions with southward meridional fields were found to be statistically more intense than disturbances from regions with northward fields. After more detailed study, Dodson *et al.* (1982b) report that the heightened terrestrial effects did not correlate with flare X-ray intensity or with microwave emission. Most of the effect was traced to differences in the 200 MHz radiation between northward and southward flares. The flares in northward directed fields tended to produce less meterwave emission, which implies that they were accompanied by smaller coronal disturbances.

Dodson *et al.* find that the differences between flares in northward directed and southward directed fields are purely solar effects. It will be interesting to see whether the effect reversed during the decay phase of solar cycle 20, when the global field was reversed from its 1967–70 orientation.

Lundstedt *et al.* (1981) report on another possible IP effect of active region magnetic field direction. They studied large flares in the interval 24 August, 1978 through 9 November, 1979 and compared the solar wind velocity near earth on the fourth day after each flare. They concluded that flares in southward directed regions produced a higher average solar wind velocity than did flares in northward regions. This result depends on how a relatively small number of active region fields are interpreted, and it is curious that the sign of the effect is not reversed from what Dodson *et al.* found in the previous solar cycle, as it would be if the effect were truly solar and depended on the direction of the global field in the corona.

If we extend the study of IP disturbances to geomagnetic storms, we find a strong correlation between the direction of the field in the solar wind disturbance that reaches the Earth and the magnitude of the storm. This topic is treated by Akasofu (1983). The direction of the IP field influences the magnitude of geomagnetic storms because the rate of field reconnection depends upon whether the IP field is parallel or antiparallel to the earth's field. Quite aside from this effect, which depends, shall we say, on the orientation of the observer, it may be that solar wind disturbances with southward directed fields were more intense than those with northward fields during the rise phase of the current spot cycle. Joselyn and McIntosh (1981) found that solar filaments that erupted from regions with southward directed fields produced a greater solar wind disturbance than did those from northward field regions. These results are based on relatively few events and further study, especially a study encompassing data from several solar cycles, is needed.

8. Summary and Conclusions

I have reviewed several characteristics of coronal disturbances that produce IP shocks and proton showers. The most geoeffective solar phenomena are large-area flares with long decay ($\gtrsim 4$ hr) profiles in the 1–8 Å X-ray band. Many proton showers are associated with flares that produce a type II burst, and we may therefore speculate that the escaping particles are accelerated somehow by the shock. Pesses (1982) describes mechanisms of particle acceleration in shocks. However, there are many proton showers for which no type II burst can be found. This may be due to anomalous absorption or refraction of the metric radio emission in the corona even when there is a shock in which radio emission is excited. There is a dearth of type II bursts from flares near the solar limbs (Švestka, 1976), and this must certainly be due to the peculiarities of radio wave propagation in the corona.

High correlations have been found between type II bursts and coronal mass ejections, between large flares and IP shocks, between type IV emission and proton showers. As Kahler pointed out, some of the reported correlations are simply due to the big flare syndrome. In all studies of solar disturbances and their terrestrial effects, there have always been a high proportion of embarrassing anomalies. I suggest that the reason for this has been our incomplete knowledge of coronal mass ejections. If there is one primary phenomenon that possibly leads to large-area flares, filament eruptions, particle acceleration and disturbance of the IP medium, it may be the coronal mass ejection. If this view is correct, continuous monitoring of the corona should lead to a far higher success rate for geomagnetic disturbance forecasts than at present. Unfortunately, present capabilities for detection of mass ejections are severely limited. Satellite coronagraphs are very limited in their ability to detect mass ejections aimed at the Earth. Furthermore, the minor depletions, or transient coronal holes, described above, may affect the IP medium without producing a major change in the outer corona.

Two instruments for patrolling the corona come to mind. The 'Christiansen cross' of 128×128 parabolic antennas at Zuy, 45 km from Irkutsk, is nearing completion under G. Y. Smokov of the Siberian Institute of Terrestrial Magnetism, Ionsophere and Radio Wave Propagation. This solar radio telescope operates with $20''$ resolution at a wavelength of 5 cm and will map the lower corona over the entire solar disk every 3 min. Transient coronal holes and a large range of intense and faint coronal events can be monitored.

An instrument more suited to monitoring the corona without daily interruptions is the Wolter type II X-ray telescope, such as that flown on Skylab (Vaiana *et al.*, 1977). In a sun-synchronous orbit, a full disk X-ray imager could follow coronal developments on all scales, from $\sim 3''$ to $\sim 1°$ with temporal resolution of a few seconds.

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