SOLWIND OBSERVATIONS OF CORONAL MASS EJECTIONS DURING 1979-1985
(Invited)

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ABSTRACT

Coronal observations have been processed for parts of each year during the interval 1979-1985. Around sunspot maximum, coronal mass ejections (CMEs) occurred at the rate of approximately 2 per day, and had a wide range of physical and morphological properties. During the recent years of relatively low sunspot number, CMEs occurred at the rate of only 0.2 per day, and were dominated by the class of so-called "streamer blowouts." These special CMEs maintained a nearly constant occurrence rate of roughly 0.1 per day during the entire interval.

I. INTRODUCTION

All but a few months of the Solwind coronal observations have been processed for the interval March 1979 to December 1981 around the maximum phase of sunspot cycle 21. During this interval more than 1000 coronal mass ejections (CMEs) were identified. Their properties have been measured and studied statistically by Howard et al. (1985), and summaries of this work have been published elsewhere (cf., Howard et al., 1984; Michels et al., 1984). In addition, several investigators have studied the associations between these CMEs and a variety of other solar and interplanetary phenomena including soft X-ray events (Sheeley et al., 1983a), metric Type II radio bursts (Sheeley et al., 1984; Kahler et al., 1984b), interplanetary shocks (Schwenn, 1983; Sheeley et al., 1983b, 1985; Woo et al., 1985), energetic proton events (Kahler et al., 1984a), and magnetic clouds (Burlaga et al., 1982).

The Solwind instrument has continued to obtain coronal images routinely since December 1981, and is still doing so at the time of this writing (May 1985). However, our processing of these data was interrupted for about one year while we were converting to a new computer. During the past few months, we have resumed the processing, and are rapidly reducing the observations during 1982-1985. The most striking characteristic of the recent observations is the persistent streamer structure and the substantial reduction in the occurrence rate of coronal mass ejections. The resulting correlation between the occurrence rate of CMEs and the level of sunspot activity (the sunspot number) is similar to that deduced by Hildner et al. (1976) from their study of mass ejections during the Skylab mission in 1973-1974. It is substantially different from the nearly constant CME rate that Hundhausen et al. (1984) derived by combining their SMM observations in 1980 with their reanalysis of the Skylab data. We suppose that the discrepancy results from assumptions about the "dead time" of the Skylab and SMM coronagraphs.

Perhaps even more interesting is the fact that the recent CMEs have consisted primarily of the so-called "streamer blowout" class (cf.,Sheeley et al., 1982; Howard et al., 1985). During 1979-1981 we found that this class of CME constituted only 5% of all mass ejections and only 8% of all "major" mass ejections. During the four months of 1984-1985 for which we have

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processed continuous data, these special CMEs have constituted 36% of all CMEs and 67% of all major CMEs. Furthermore, it appears that the occurrence rate of "streamer blowout" CMEs has been approximately constant during the interval 1979-1985 at a value of nearly 0.1 per day.

In this paper, we shall present a brief summary of these recent results, and refer the reader to the published studies and review papers for more detailed properties of Solwind mass ejections and their associations.

II. THE RESULTS

(a) The CME Occurrence Rate

From their study of 998 CMEs during 1979-1981, Howard et al. (1985) found that CMEs could be conveniently classified by morphological structure and importance. They identified nine more or less distinct classes, examples of which are shown in Figure 1. The importance of a CME is a somewhat subjective quantity, but in effect it is a measure of the CME's projected size and brightness. In practice, the classification was performed by two observers, and the assignment was either major (Y) or minor (N) when both observers agreed on this assignment. The assignment was questionable (Q) when the observers could not agree or when data gaps made the assignment indeterminate. Figure 2 illustrates the importance categories for five different morphological classes of mass ejection.

Howard et al. (1985) found that during the entire interval 1979-1981 the occurrence rate for all CMEs (regardless of structural class or importance category) was 1.8 per day. This determination was based on their choice of 4.5 hrs as the minimum "dead time" required to constitute a data gap. This gave a 66.5% duty cycle. When the minor (N) CMEs were excluded, the occurrence rate was 0.9 per day, which is essentially the same as Hundhausen et al. (1984) obtained from their analysis of CMEs observed by the SMM satellite during 1980.

Figures 3, 4, and 5 illustrate the variation of the occurrence rate on a variety of time scales during 1979-1981. Although there was considerable variation on the shorter scale of 7 days, this variation does not seem to be strongly or consistently related to fluctuations in the sunspot number. However, when we began to process observations during 1984-1985, we found intervals of several weeks at a time when there were no CMEs. We never found such intervals during 1979-1981. After processing completely the observations during June 1984, October and November 1984, and March 1985, we found only 22 CMEs (of all classes and importance categorys), for an average rate of only 0.2 per day. If one corrects this rate using the 4.5-hr dead time correction that was used for the CMEs during sunspot maximum, then the rate increases to 0.4 per day. However, we think this correction is not necessary during sunspot minimum because our difference images show long intervals of 12 hrs or more during which there is no appreciable change at all. Thus, if a CME had occurred in a 12-hr data gap during this phase of the sunspot cycle, we would have seen indications of it.

Figure 6 summarizes our measurements to date. The recent observations have been assigned to the date 1984, and for consistency both the uncorrected value of 0.2 per day and the "overcorrected" value of 0.4 per day have been plotted. For reference, the dashed line indicates the rate that Hildner et al. (1976) deduced from their analysis of the Skylab observations. Although it is probably premature to emphasize the detailed agreement between the Solwind and Skylab results, the comparable trend with sunspot number is both obvious and significant.

If we adopt the value of 0.2 per day for CMEs (of all classes and importances) during 1984-1985, then we find a value of only 0.1 per day when the minor CMEs are excluded. Of these, 67% or 0.07 per day consisted of streamer blowouts. This is comparable to the rate of 0.09 per day for streamer blowouts during 1979-81 when this class constituted only 8% of all major CMEs. Figure 7 shows the occurrence rate for these special CMEs during the interval 1979-1985. Although the statistics are poor, especially for the recent time, the resulting variation is in sharp contrast to that obtained for all classes of CME shown in Figure 6.

(b) The Properties

Figure 8 shows the evolution of a typical "curved front" CME on 18-19 November 1981. Mass ejections like this one constituted at least 15% of the CMEs that occurred in the years around sunspot maximum. Howard et al. (1985) found that such CMEs had average speeds of 584 km/s, spans of 62 degrees in the sky plane, mass of 8.4 x 10^{15} gm, and kinetic energy of 6.4 x 10^{30} ergs. Characteristically, they were associated with long-duration X-ray events (Sheeley et al., 1983a), interplanetary shocks (Sheeley et al., 1985), and energetic protons (Kahler et al., 1984a).

Notice in Figure 8 that a coronal streamer moved southward as the CME transited the field of view. Figure 9 shows the subsequent eruption or "blowout" of this streamer during a 19 hr interval on 19-20 November 1981. Howard et al. (1985) found that the average properties of such streamer blowouts included a relatively low speed of 200 km/s, a span of 44 degrees, a moderately high mass of 5.4 x 10^{15} g, but a relatively low kinetic energy of 0.56 x 10^{30} ergs. One of these streamer eruptions (cf., Figure 10a) was associated with a large shock (cf., Figure 10b) at the Helios 1 spacecraft (Sheeley et al., 1983b, 1985). However, during 1979-1981 most of these streamers and their eruptions occurred at relatively high latitudes and thus did not affect the near ecliptic spacecraft conditions. However, like the streamers with which they originate, the streamer blowout CMEs have tended to occur at relatively lower latitudes during 1984-1985 than they did during 1979-1981. Figure 11 shows a sample of these more recent events, and Figure 12 shows the evolution of a particularly well observed one.

It is interesting to compare some average properties of CMEs observed in the two intervals 1979-1981 and 1984-1985. Whereas the average projected latitude was 45 degrees near sunspot maximum, it was 22 degrees toward minimum. Similarly, the average span in position angle dropped from 44 degrees to 22 degrees. The average CME speed dropped from 472 km/s to roughly 130 km/s, which is consistent with the fact that most of the recent CMEs were the characteristically slow streamer blowouts.

III. DISCUSSION

In view of the preliminary state of our recent results, we can only speculate on their significance. The order-of-magnitude drop in the CME rate between sunspot maximum and the present time is surely significant. It points to a strong connection between the occurrence of CMEs and the level of solar magnetic activity. This seems consistent with the idea that CMEs are tracers of the ejection of flux from the Sun. It is also consistent with the fact that a large fraction of fast CMEs are associated with major X-ray flares, metric Type II bursts, interplanetary shocks, and energetic protons.

On the other hand, the nearly constant occurrence rate of the streamer blowout CMEs points to their possible identification as a normal state of the evolution of coronal streamers.

Such structures are present at all phases of the sunspot cycle. Only their heliographic location evolves with time. Thus, one might speculate that the streamer blowouts are simply phases in the evolution of streamers just as disappearing filaments (eruptive prominences) are phases in the evolution of filaments (prominences). Indeed, it is tempting to suppose that streamer blowouts and eruptive prominences are two aspects of the same process. However, further study is certainly required before we can take this speculation seriously.

Finally, we note the similarity between the helmet-like magnetic structure of coronal streamers and the teardrop structure of planetary magnetotails and comet tails. Thus, it is possible that an understanding of the physics of streamer blowouts will have a broad application to other astrophysical objects.

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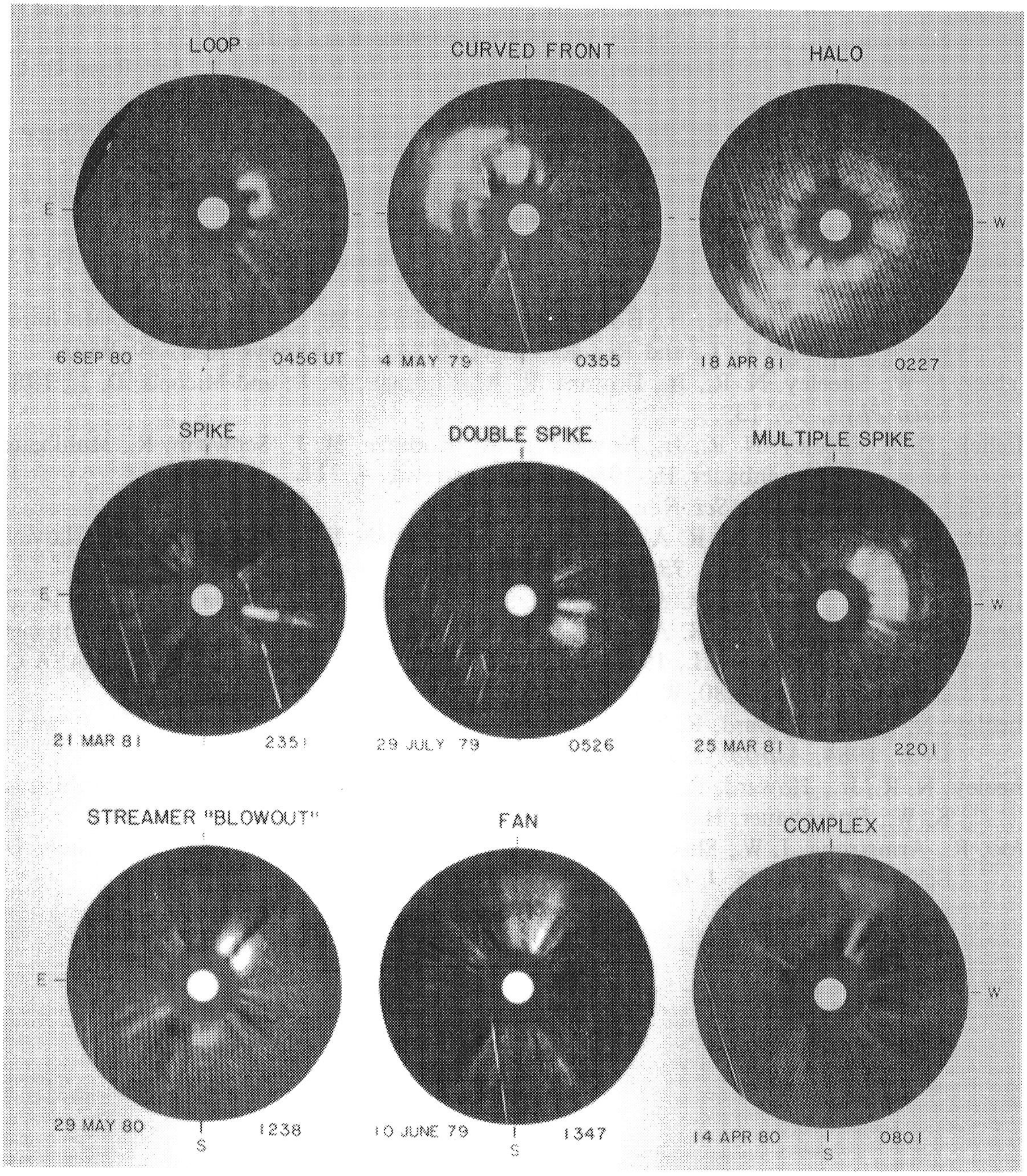

Figure 1. A sample of Solwind coronal mass ejections during 1979-1981 illustrating the variety of morphological classes as defined by Howard et al. (1985). The small white disk indicates the size of the solar disk.

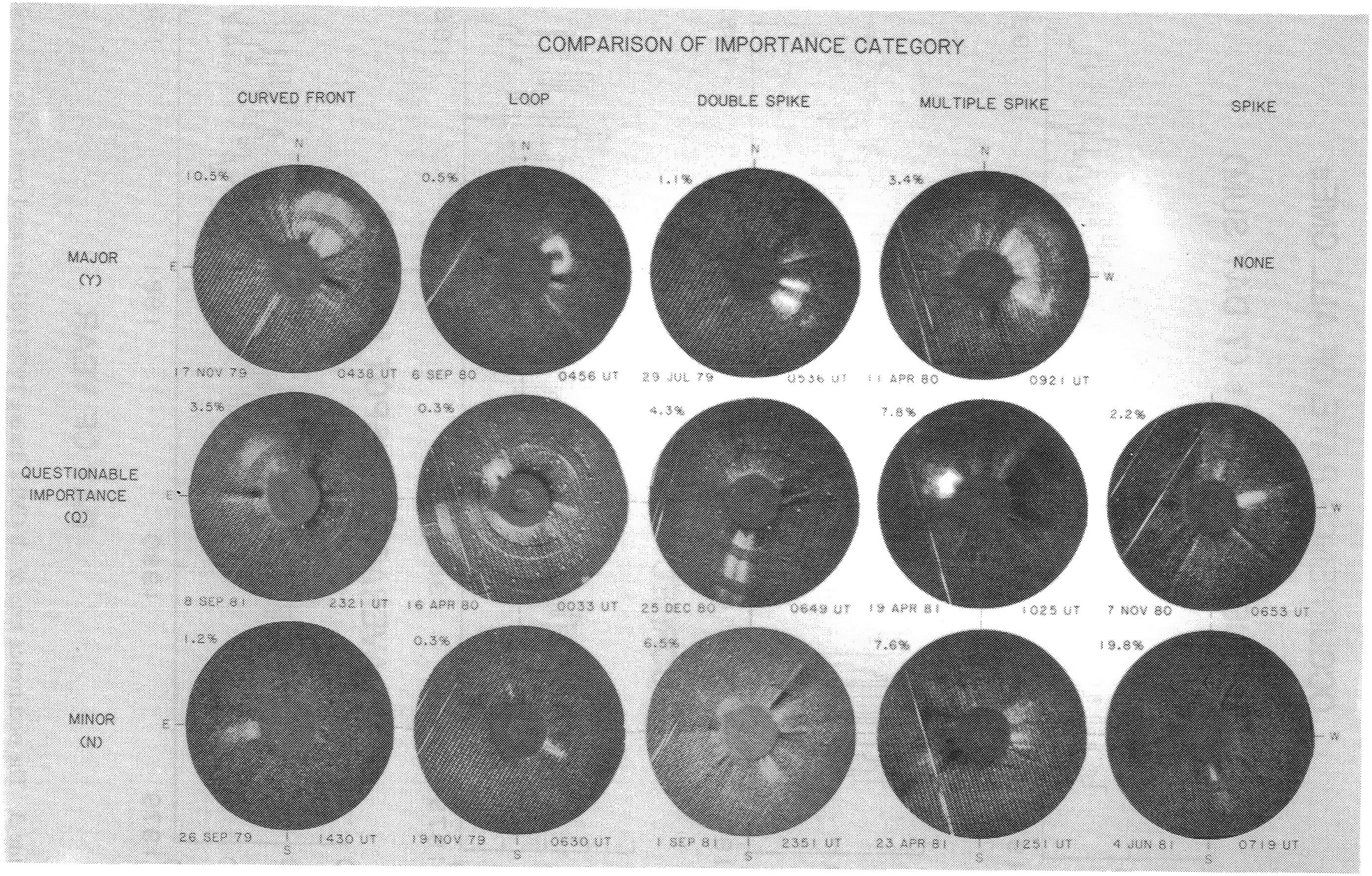

Figure 2. A sample of Solwind CMEs during 1979-1981 illustrating major (Y), questionable (Q), and minor (N) importance categories according to Howard et al. (1985).

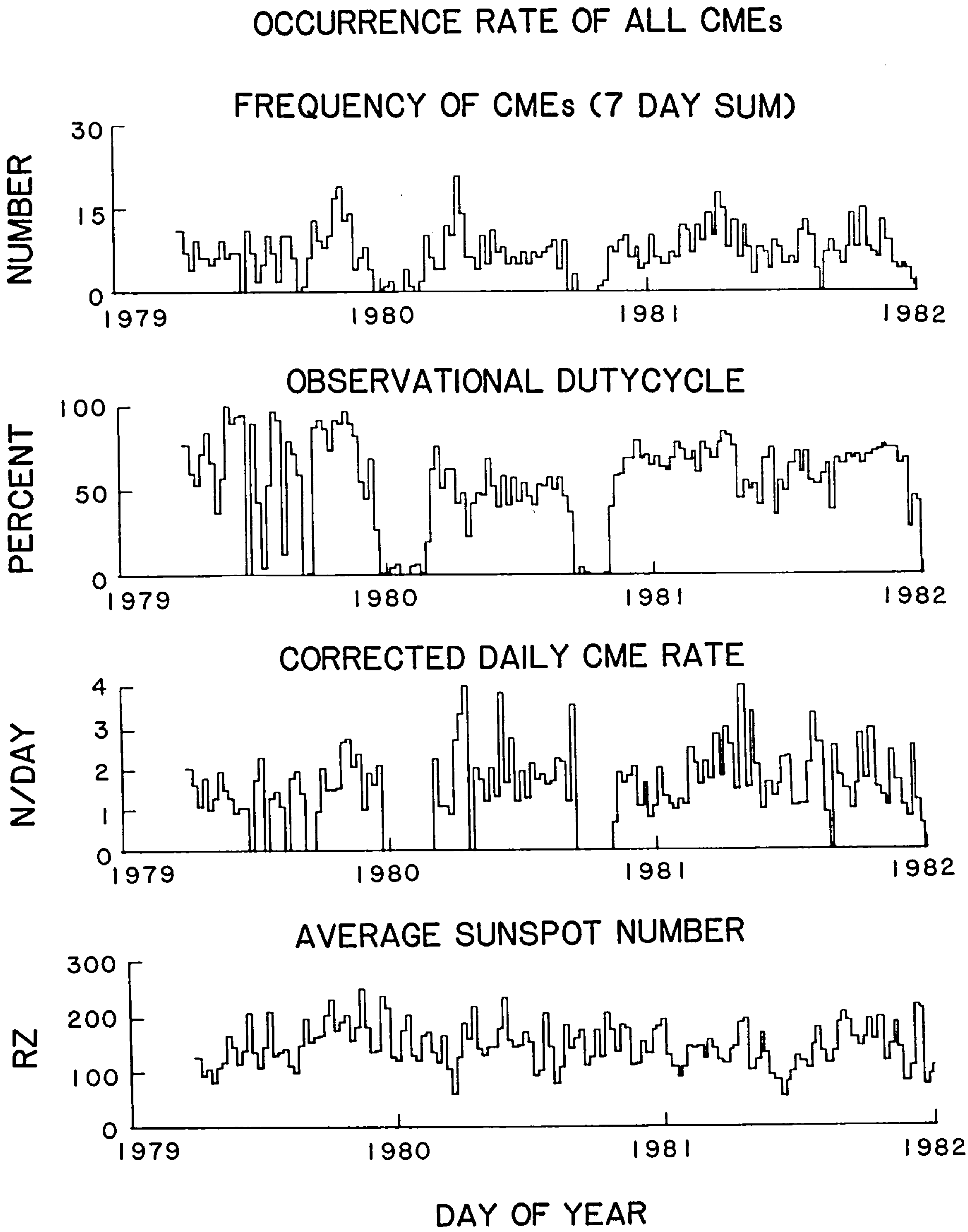

Figure 3. The occurrence rate of all CMEs during 1979-1981 averaged over 7-day intervals.

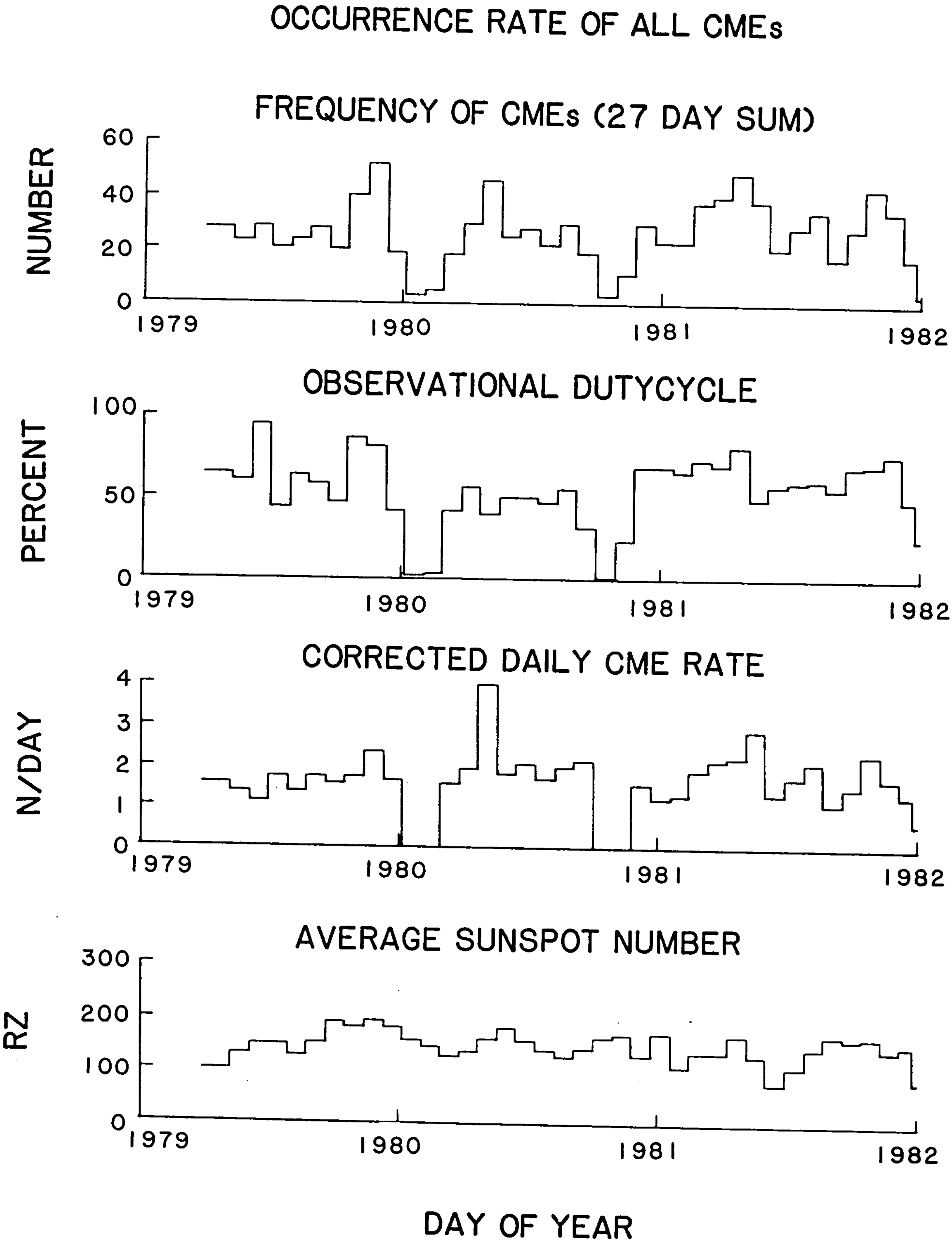

Figure 4. The occurrence rate of all CMEs during 1979-1981 averaged over 27-day intervals.

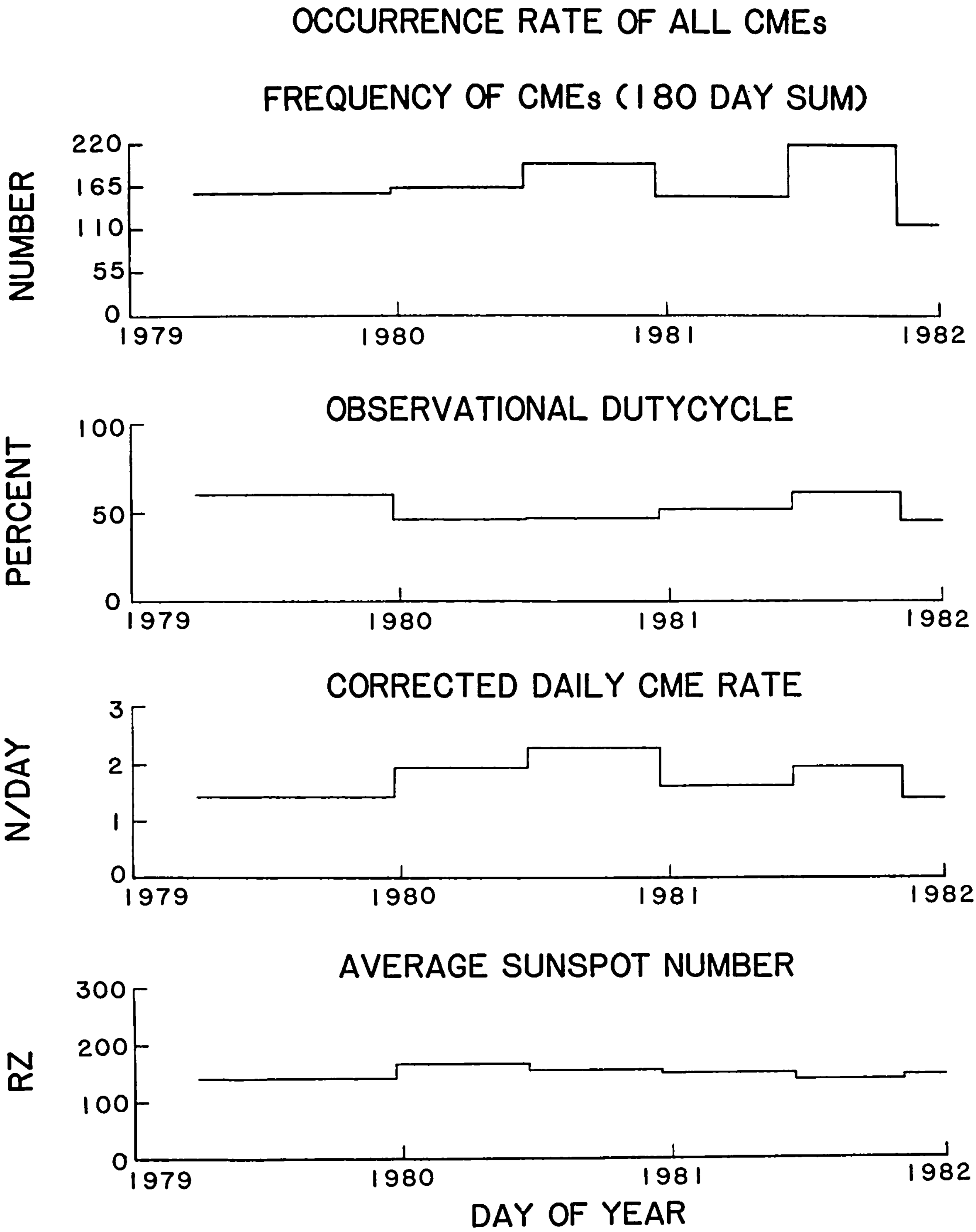

Figure 5. The occurrence rate of all CMEs during 1979-1981 averaged over 180-day intervals.

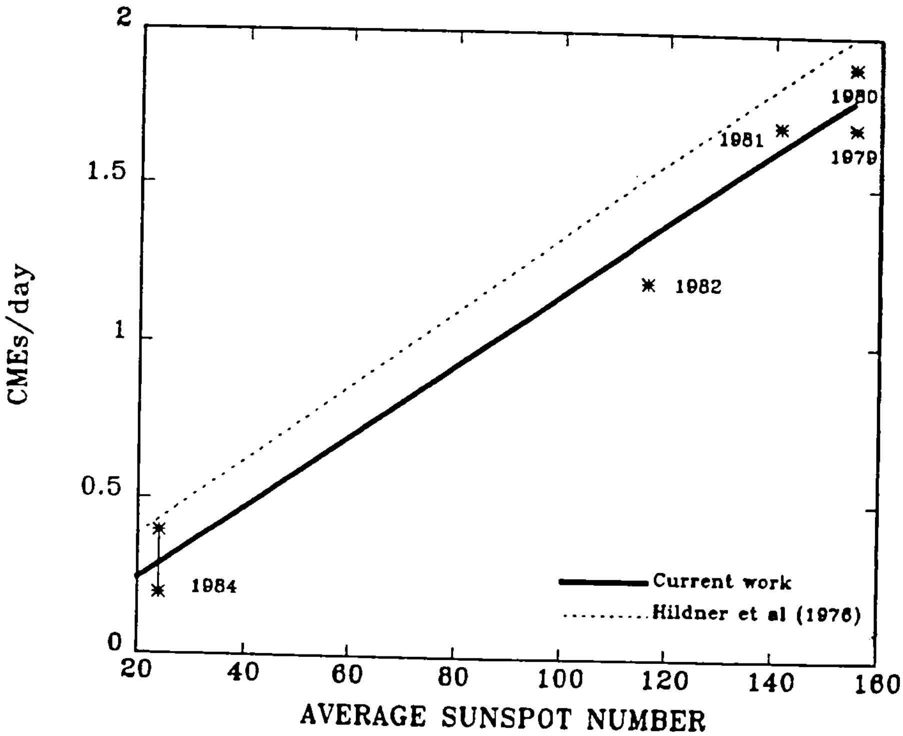

Figure 6. The Solwind CME occurrence rate plotted as a function of the average sunspot number during 1979-1984. The solid line is a least-squares fit to the data with the two points in 1984 treated equally.

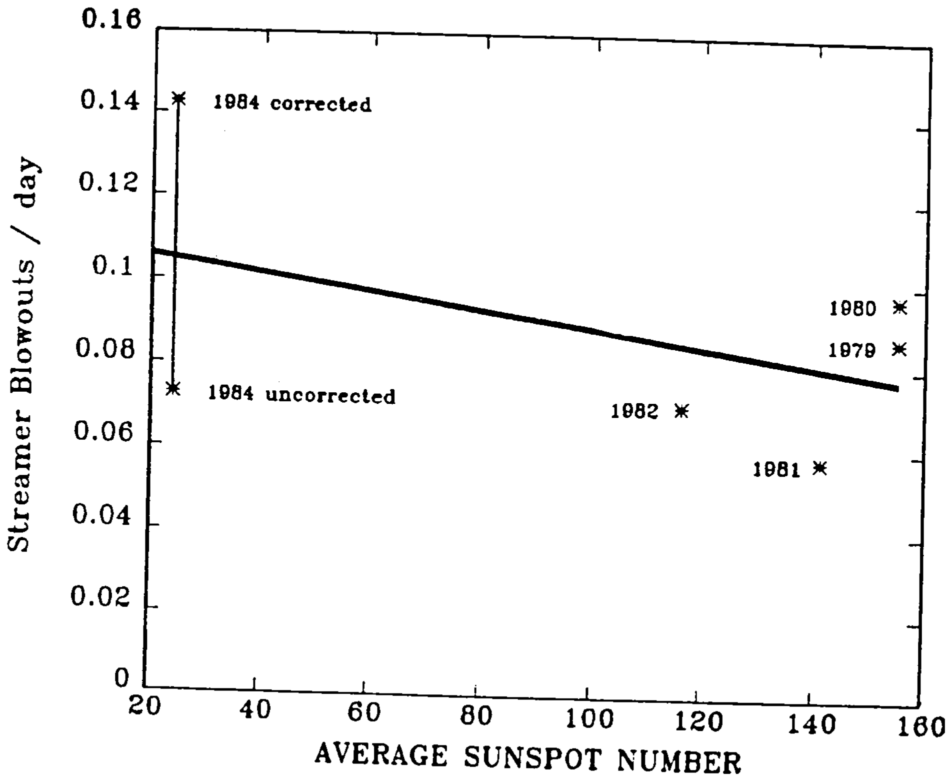

Figure 7. The Solwind occurrence rate for streamer blowout mass ejections illustrating the nearly constant rate during 1979-1984.

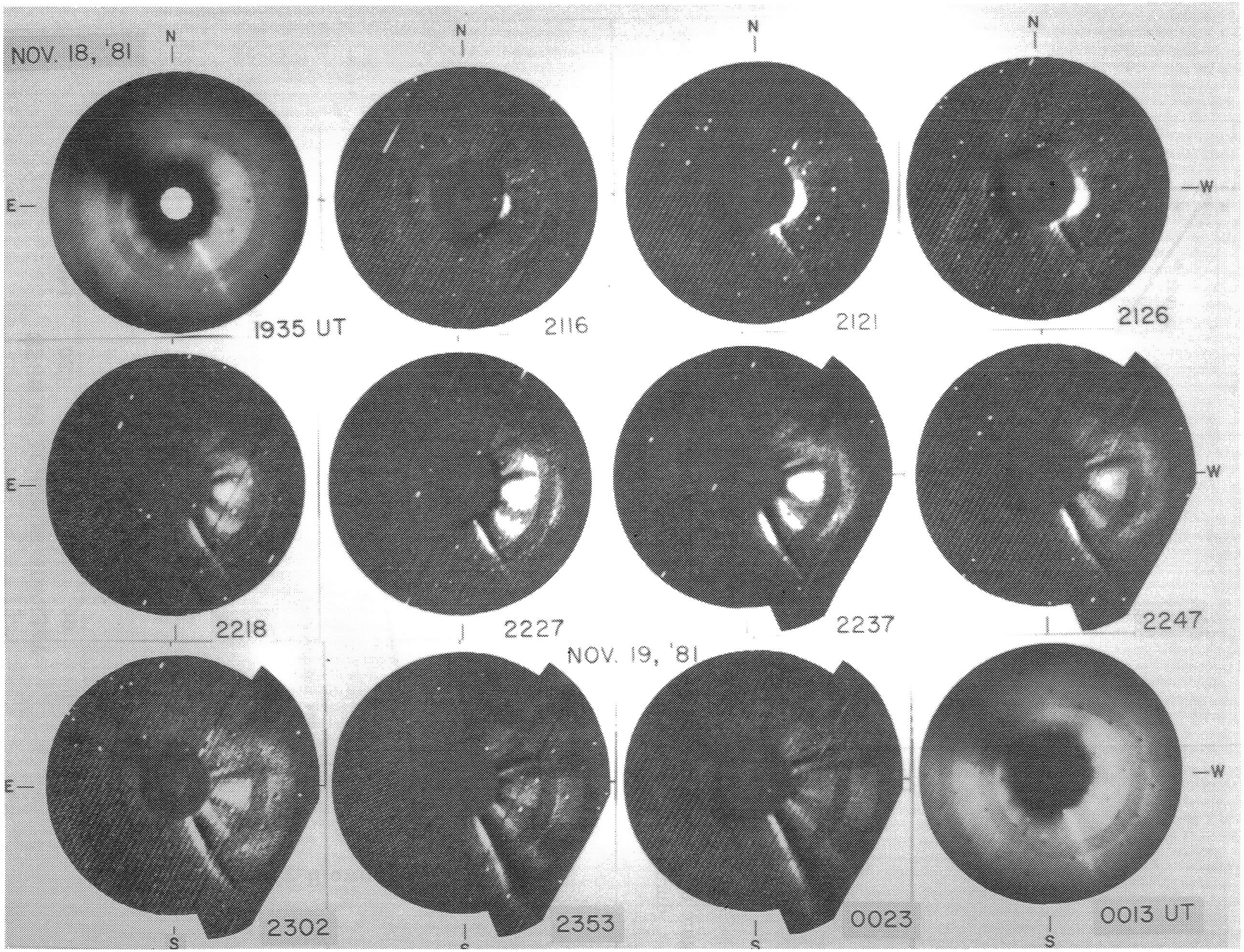

Figure 8. A typical "curved front" mass ejection according to Howard et al. (1985). Such CMEs have become rare in 1984-1985. Note the streamer that was deflected as the CME transited the coronagraph's field of view on 18 November 1981 (cf., Fig. 9).

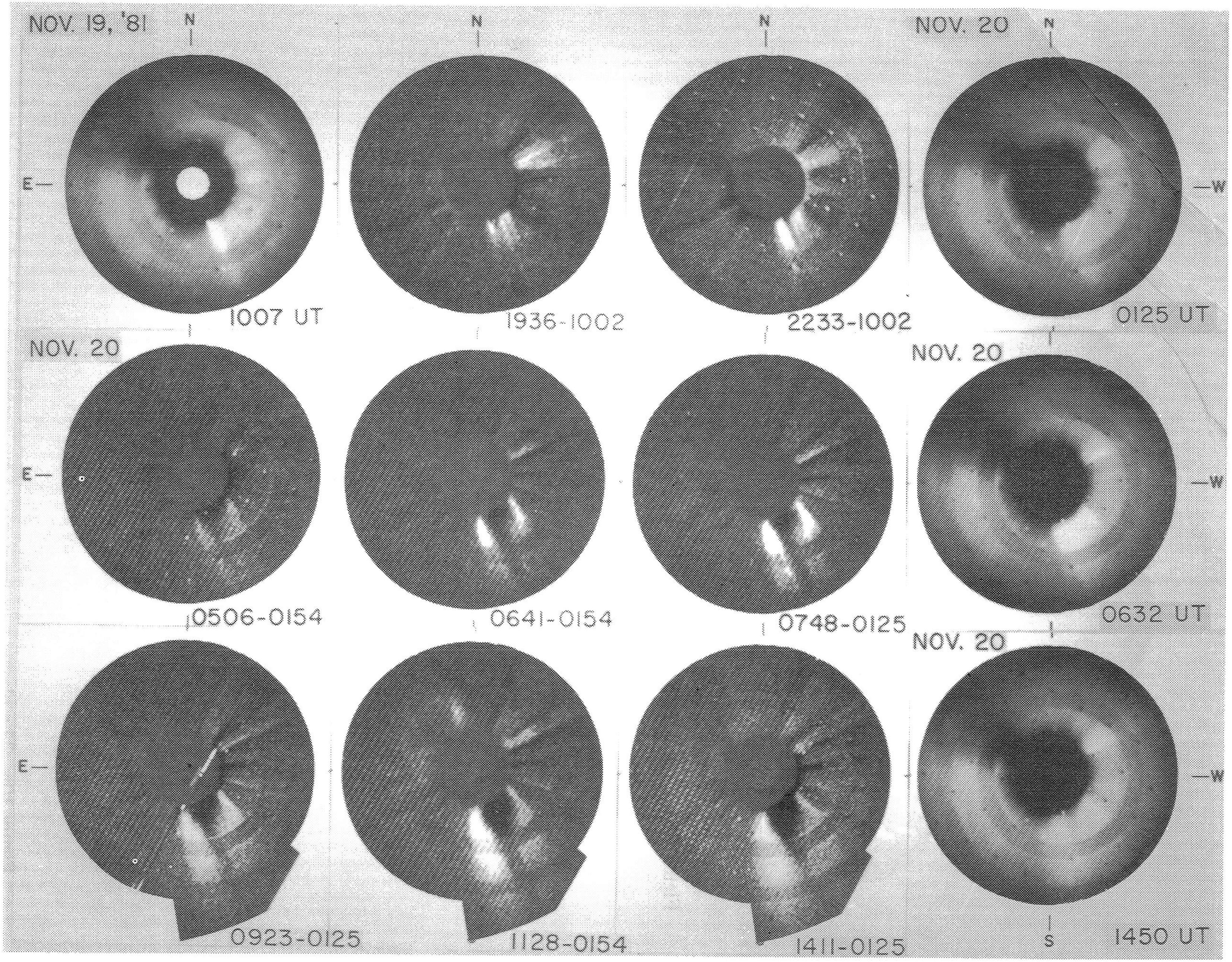

Figure 9. The eruption of the 18 November streamer during a 19-hr interval on 19-20 November 1981 (cf., Fig. 8). This illustrates a typical high-latitude "streamer blowout" CME near sunspot maximum.

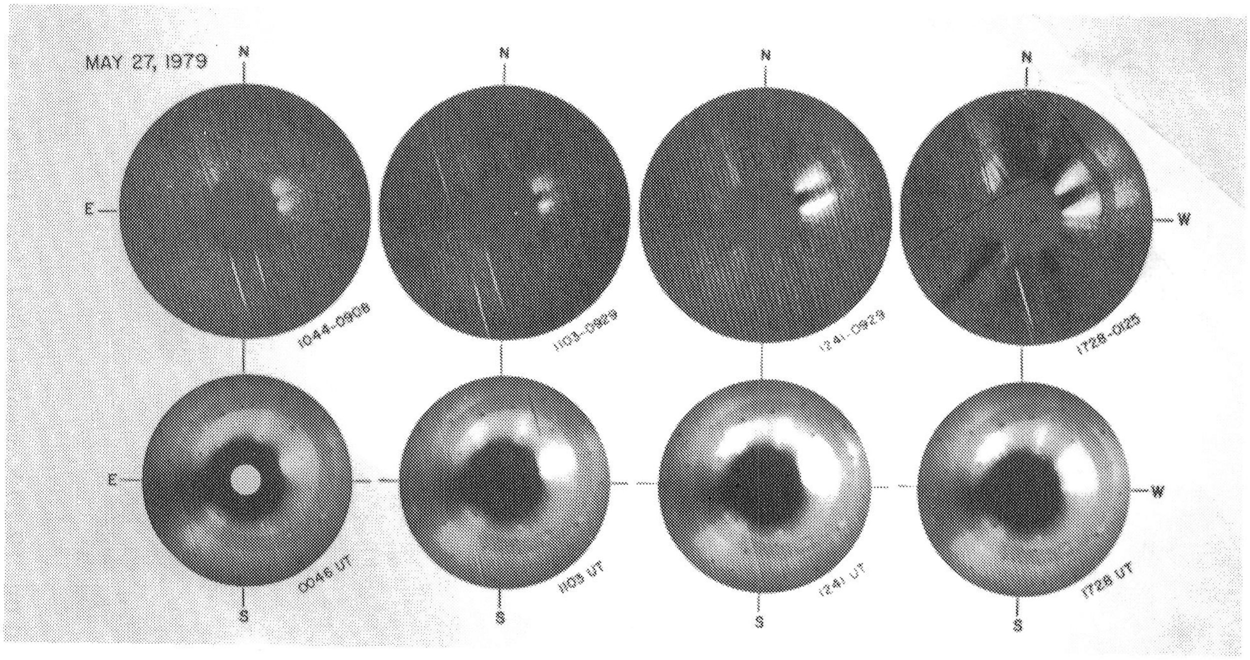

Figure 10a. A streamer blowout on 27 May 1979 , associated with the Helios 1 shock on 28 May (cf., Fig. 10b).

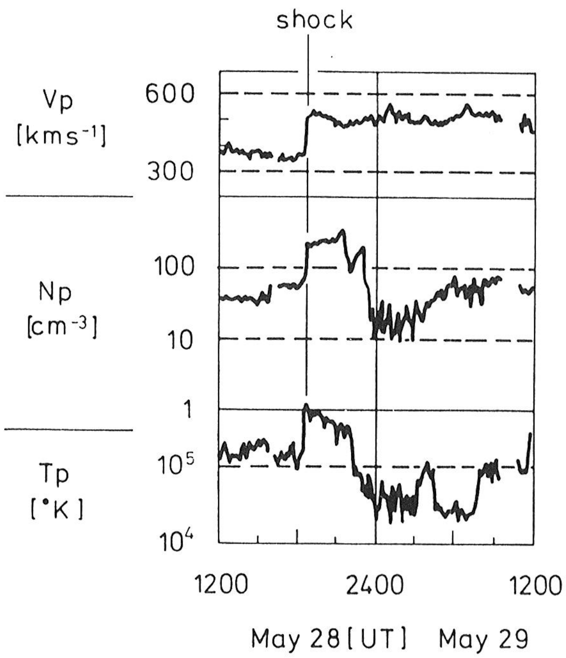

Figure 10b. The plasma measurements of the interplanetary shock at Helios 1 located at 0.43 AU, W90 degrees on 28 May 1979.

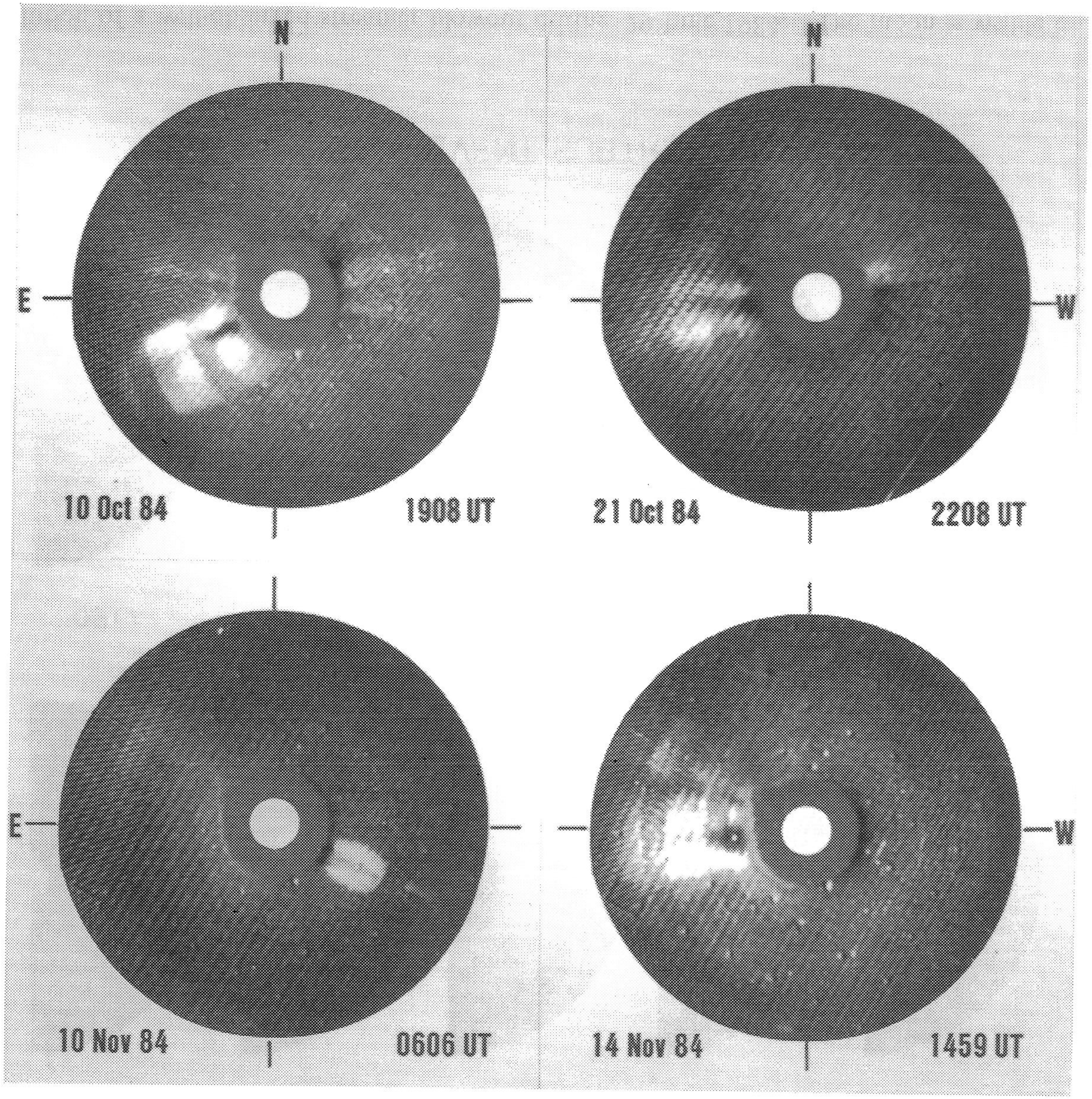

Figure 11. A sample of recently observed streamer blowout CMEs during October-November 1984. Note the relatively low latitudes of the events on 21 October and 14 November.

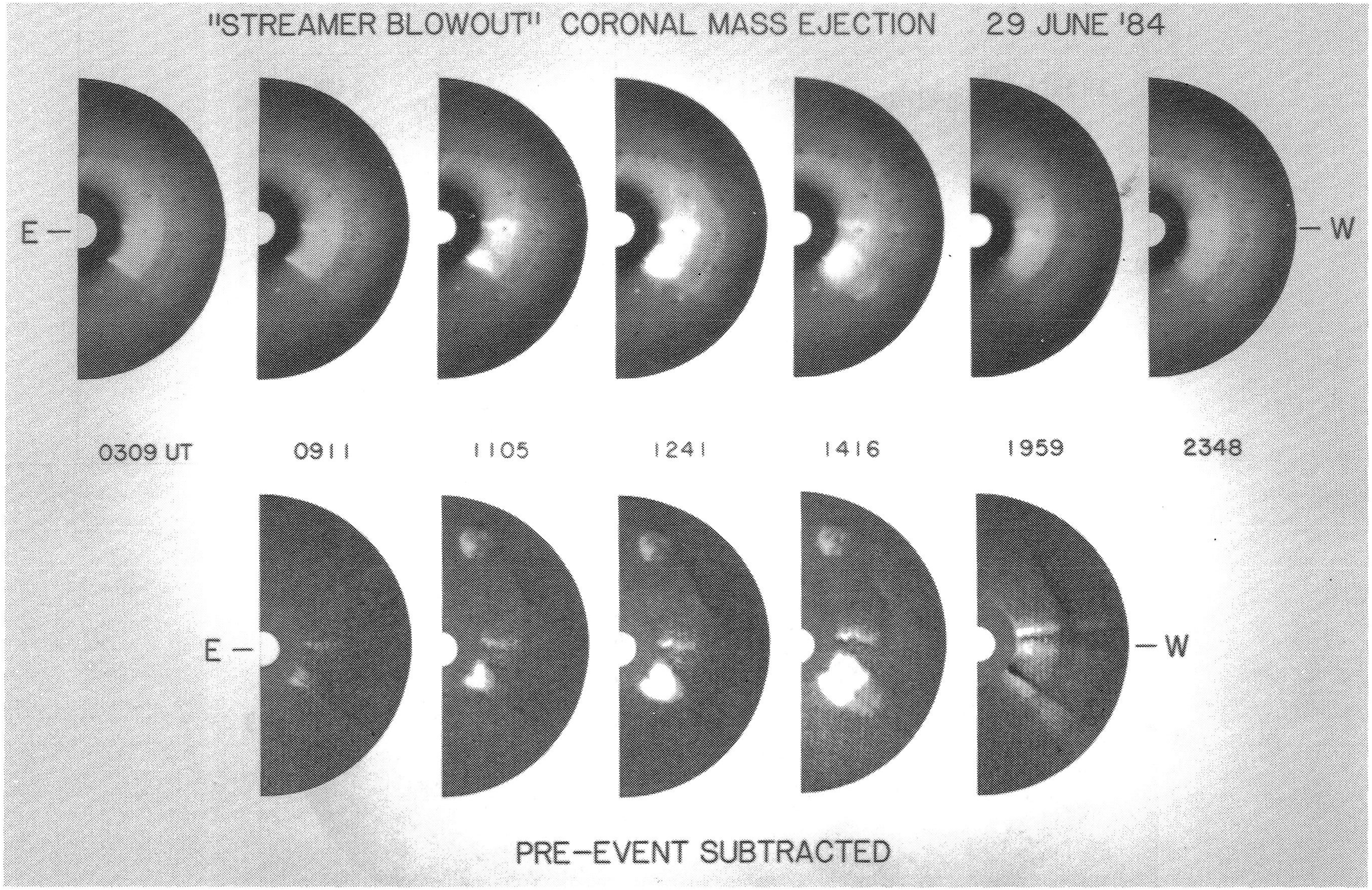

Figure 12. The evolution of a well-observed streamer blowout during 29 June 1984. The moon is visible on the difference images at 1105, 1241, and 1416 UT. The white disks also indicate the size of the solar disk.