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COMPARISON OF CMES, MAGNETIC CLOUDS, AND BIDIRECTIONALLY STREAMING PROTON EVENTS IN THE HELIOSPHERE USING HELIOS DATA

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ABSTRACT

Coronal Mass Ejections (CMEs) are large, energetic expulsions of mass and magnetic fields from the Sun; they can significantly affect large volumes of the heliosphere and appear to be a key cause of geomagnetic storms. We have compiled a list of all significant CMEs detected by the HELIOS white light photometers from 1975-1982. We are studying the characteristics of these CMEs, and present preliminary results of their associations with in-situ features, especially magnetic "clouds" and periods of bidirectionally streaming ions, two classes of structures considered indicative of interplanetary loops. Advantages of this data set include reliable association in the interplanetary medium of the white light CME plasma with the in-situ features, and observations of a large number of events over a long time base.

INTRODUCTION

We are using the zodiacal light photometers on the two HELIOS spacecraft to identify and study the characteristics of solar mass ejections in the inner heliosphere. With the photometer data alone, we can determine the brightnesses, durations, masses and outward speeds of these CMEs and can estimate their size scales and topology. In this paper we discuss results of comparison of the subset of these CMEs that enveloped the spacecraft with in-situ HELIOS data, especially those indicative of the passage of loop structures. These data include magnetic clouds identified in the HELIOS interplanetary magnetic field (IMF) and plasma data at MPI-Lindau (provided courtesy of F. Neubauer and H. Rosenbauer, respectively), and periods of bidirectionally streaming protons (BDPs) at energies of ~ 1 MeV observed with the GSFC energetic particle experiment. This data set permits us to make reliable associations in the interplanetary medium over a long time base between many white light CMEs and various in-situ features and CME proxies.

CME IDENTIFICATIONS AND RATES OF OCCURRENCE

Webb and Jackson /1/ used data from the HELIOS-2 photometers, which observed from 1976-1979 and viewed north of the ecliptic plane, to select all significant white light transients which enveloped the spacecraft or passed north of it. Since that study, all of the photometer data have been placed on optical disks. We have used that data base to compile a complete list of transients detected with the 90° photometers on both spacecraft, including HELIOS 1 which operated from 1975-1982 and viewed the south ecliptic pole. Like /1/, we used the lower-latitude photometer data, viewing 16° and 31° out of the ecliptic, to determine the temporal evolution and spatial extent of each event in order to identify and distinguish CMEs from corotating structures /1,2/. In agreement with /1/, we also found that most of the 90° events were the heliospheric manifestation of CMEs.

Following /3,4/, we combined the HELIOS photometer data with Earth-orbiting coronagraph data to derive the annual occurrence rate of CMEs over 1.5 solar cycles, from 1973-1989 (Figure 1). The HELIOS observations of CMEs fill in the period from before the minimum through the maximum of cycle 21. The CME rates derived from the HELIOS and SOLWIND data are in good agreement during the period of overlap, 1979-1982. The main result is that the CME rate tracks the sunspot cycle in both amplitude and phase.

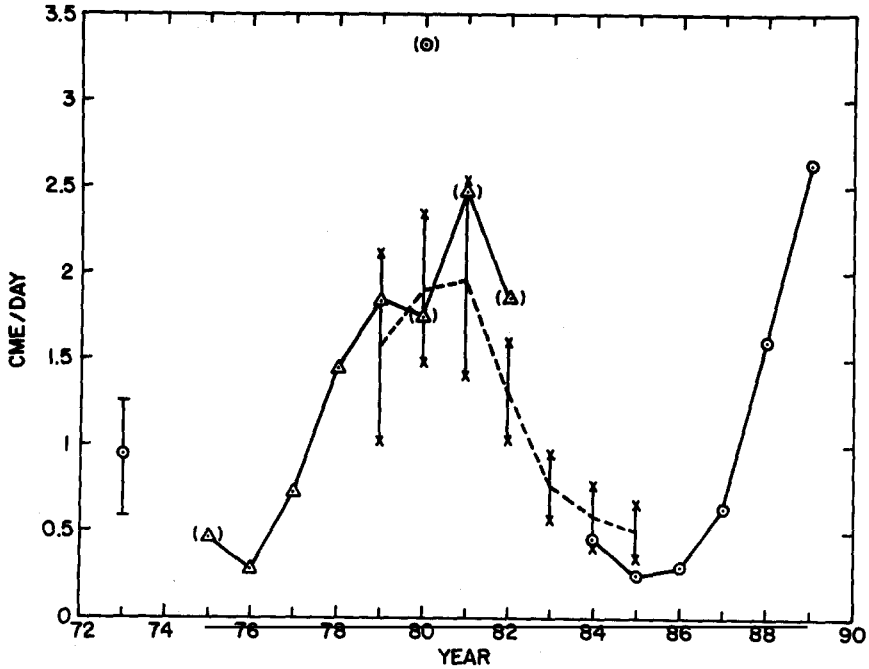

Fig. 1. Annual occurrence rates, in CMEs/day, of CMEs over the solar cycle. Data are from Earth-orbiting coronagraphs on t Skylab, SMM ('o') and P-78 ('x') satellites. Two P-78 rates are given for each year: one for all observed CMEs and a lower o for only "major" CMEs. HELIOS rates are shown as triangles. All rates have been corrected for duty cycles and instrument visibility functions as discussed by /3/.

THE CHARACTERISTICS OF CMES IN THE SOLAR WIND

The purpose of this phase of our study was to compare the time intervals of those remotely-viewed CMEs which likely enveloped the HELIOS spacecraft with other transient solar wind structures, such as magnetic clouds, low energy bidirectional flows, shocks, and so-called "driver gas", to better understand the structure and evolution of CMEs in the heliosphere. In this paper we emphasize preliminary results on the correspondences of CMEs with magnetic clouds and BDP flows, because these provide evidence of strong fields and the field topology in the interplanetary medium.

Our method was to compare the time intervals of the spacecraft-grazing CMEs with periods signifying the passage o magnetic clouds and BDP flows as determined from the in-situ HELIOS data. A transient was considered to have enveloped the spacecraft if at least one significant in-situ density enhancement (i.e., >10 cm^{-3} above background) occurred during the time interval of the white light transient. The set of magnetic clouds was identified by Bothmer and Schwenn by analyzing periods of strong field exhibiting coherent rotations with low plasma β and low proton temperature, T_p. The BDP events were selected by Reames using the criteria discussed by /5/, primarily periods of ≥ 2 hr. duration of strong bidirectional flows of <2 MeV protons near the azimuthal direction of the IMF. These data sets were selected independently and then intercompared. The data permit us for the first time to make reliable associations between white light CMEs detected in the solar wind and their in-situ signatures, thereby minimizing th ambiguities which have plagued other studies.

Figure 2 shows an example of one of the periods, from HELIOS 1 at 0.9 AU in January 1975, exhibiting all of the in-situ features mentioned above. The top left panel shows a characteristic proton event originating in an eruptive solar flare on Jan. 5. Two shocks passed the spacecraft on Jan. 6, 2043 UT and Jan. 8, 0021 UT. Bidirectional flow of the ~ 1 MeV ions occurred over a 4 hr. period during a T_p spike in the trailing portion of driver gas following th first shock. Longer post-shock BDP flows were also observed at lower energies by another MPI experiment on HELIOS 1 /6/. The other panels display in-situ plots of plasma and IMF data during this interval. Density enhancements followed each of the shocks and lay within the interval of the white light transient, denoted "CME" o the T_p panel. The IMF data reveal a small magnetic cloud that was imbedded in the plasma after the first shock; not the smooth IMF rotations, especially in θ.

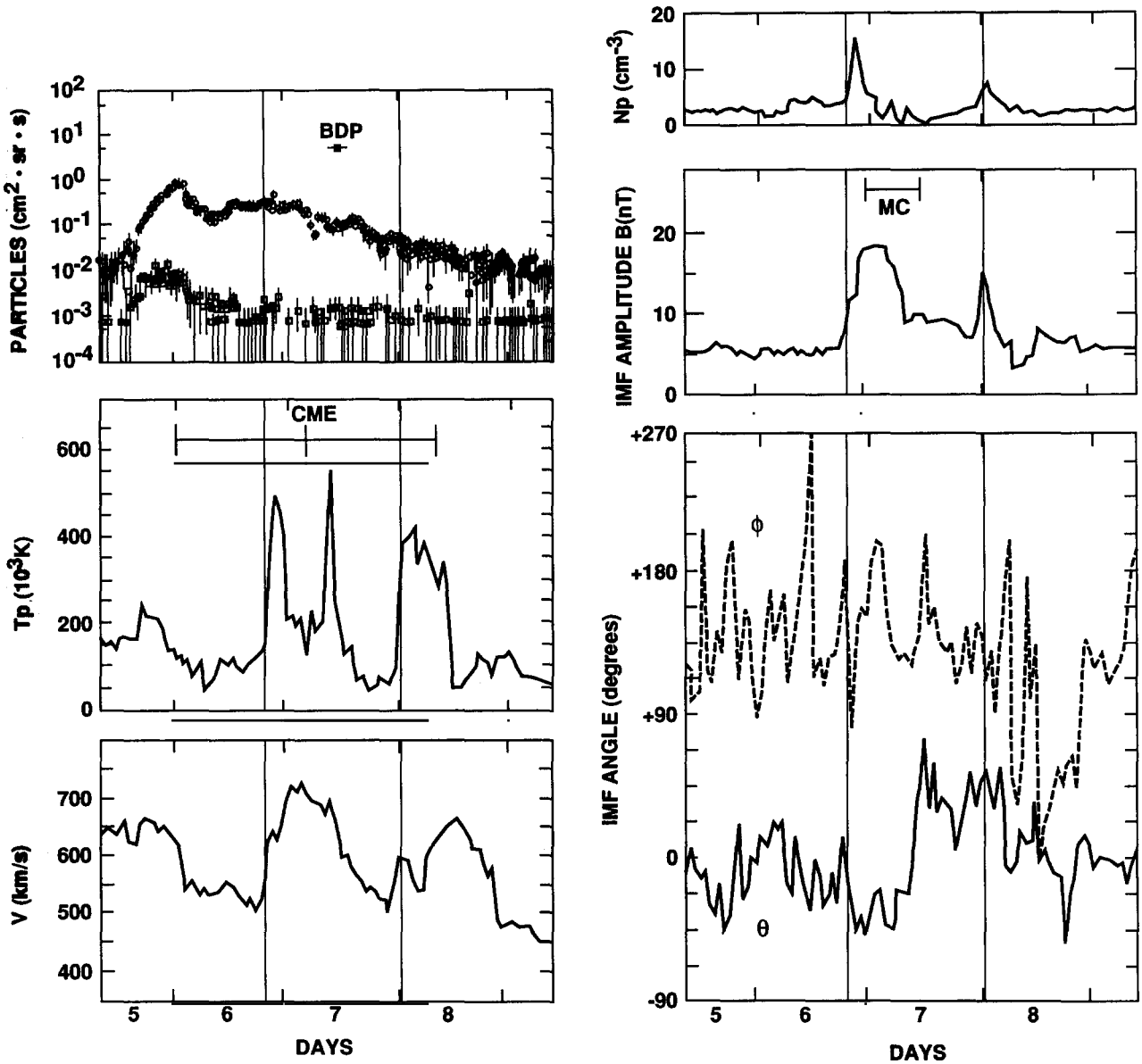

Fig. 2. HELIOS 1 in-situ plots of proton flux from the GSFC energetic particle experiment (top left) and of plasma proton temperature, T_p, flow speed, V, density, N_p, and IMF amplitude, B, and directions, ϕ and θ, for this interval. Passage times of two shocks are denoted by thin, vertical lines. Time intervals of the BDP flow, CME and magnetic cloud are indicated by horizontal bars on the particle flux, T_p and B plots, respectively.

We chose two methods for studying the in-situ characteristics of the CMEs. The first was a detailed statistical examination of the associations of HELIOS 2 in-situ features occurring during the CME intervals using one-hr. averaged data from the NSSDC tape. We found that 87% of the 62 definite HELIOS 2 CMEs had appropriate densi enhancements during the intervals, suggesting envelopment of the spacecraft by the CME. About half of these enhancements were coincident with the white light peak, within the time resolution of the photometer data. Most of the spacecraft-grazing CMEs were associated with long-lived coherent rotations of the IMF, and about half with shocks and magnetic clouds. These results agree with those found by /1/ using the preliminary HELIOS 2 data set.

For the second study, we compared all of the CME intervals at both spacecraft with the magnetic cloud and BDP lists. Thirty definite magnetic clouds occurred during periods with photometer data. 67% (20 of 30) of these clouds occurred during a CME interval. Of the remaining ten, only two clearly involved no nearby CMEs. Conversely however, only 17% (20 of 115) of the CME intervals with adequate IMF coverage were associated with listed cloud There were about as many BDP events (142) as CMEs (130) with overlapping coverage; the CME and BDP events were associated at about ~40% in either direction. The BDP flows were relatively brief, in agreement with the e-folding time of 3.5 hr. found by /5/, and could occur anywhere within the associated magnetic cloud or driver gas. Most occurred within 35 hr. following the onset of the CME. The duty cycle-corrected occurrence rate of the HELIOS CMEs was ~5 times greater than that of the clouds. The CME rate was about the same as the BDP rate. The HELIOS cloud and BDP rates generally agree with previous results using ISEE and IMP data at 1 AU.

SUMMARY

Most of the white light transient events detected by the HELIOS 90° photometers from 1975-1982 were identified as CMEs. Combining the annualized occurrence rates of these heliospheric CMEs with those observed by coronagraph we find that the CME rate tends to track the sunspot cycle in both amplitude and phase. Most of the HELIOS CME were associated with in-situ density enhancements and IMF rotations; about half coincided with shocks. Although 2/ of the listed definite magnetic clouds occurred during CME intervals, only 17% of all HELIOS CMEs could be associated with the clouds. BDP events and the CMEs were associated at about 40% in either direction. The associated BDP flows were brief and occurred within 35 hr. following CME onset.

In the future, we will study in detail the in-situ characteristics of individual CMEs, especially those exhibiting attributes of loop structures. In addition to the magnetic cloud and BDP data, we will compare the CME data with HELIOS intervals exhibiting bidirectional flows of low energy (≤ 1.5 KeV) halo electrons, and post-shock periods containing other signatures of driver gas, such as flows of enhanced helium abundance.

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