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QUANTITATIVE ANALYSIS OF BIDIRECTIONAL ELECTRON FLUXES WITHIN CORONAL MASS EJECTIONS AT 1 AU

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ABSTRACT

The solar wind electron heat flux is carried primarily by suprathermal “halo” electrons beamed antisunward along the interplanetary magnetic field (IMF), indicating effective magnetic connection to the Sun only in one direction. However, electron observations at 1 AU show that counterstreaming halo beams, suggesting closed magnetic structures, prevail within coronal mass ejections (CMEs). These structures might be magnetic “tongues”, tied to the Sun at both ends, magnetically detached plasmoids, or complex flux rope structures. Here we present first results of analysis of ISEE-3 observations within 39 CMEs, including the asymmetry between the counterstreaming beams and its control by the IMF orientation, and the variation of the electron distributions as CMEs convect past the spacecraft. We find that some CMEs contain nearly symmetric electron beams, while others are strongly asymmetric, and that the antisunward beam is generally dominant. The more nearly radial the IMF, the greater is the asymmetry between outward and inward beams. We present an example of a distinctive “strahl-on-strahl” distribution, suggesting continued magnetic connection to the corona, in which a narrow antisunward beam is superimposed on a broader beam. Taken as a whole, our results appear to favor a tongue or flux rope scenario rather than a fully detached plasmoid.

INTRODUCTION

Coronal mass ejections (CMEs) are phenomena in which large volumes of material from the solar atmosphere are released into interplanetary space. Recent *in situ* observations have revealed the interplanetary signatures of CMEs. We believe that the best technique for identifying CMEs is the observation and analysis of solar wind “halo” electrons, that is electrons with energies of ~ 80 eV and greater (at 1 AU) and with distribution shapes which are distinctly different from the thermal distributions. In the typical solar wind, halo electrons are beamed along the interplanetary magnetic

field (IMF) and carry an antisunward heat flux which indicates magnetic connection to a heat source, in this case the corona. The prevailing unidirectional halo beams indicate effective magnetic connection to the corona only in one direction.

Spacecraft observations have shown that the halo distributions within CMEs are characterized by bidirectional halo fluxes streaming in both directions along the IMF /1/. The counterstreaming beams suggest a closed field topology, with the spacecraft connected to a heat source in both directions. Various closed field topologies have been proposed. One model is a simple magnetic "tongue" or "bottle" rooted at both ends in Sun, the second is complete magnetic disconnection as a closed "plasmoid", and the third is a helical "flux rope" structure which suggests a plasmoid in its magnetic signature but which remains connected to the Sun /2/. These topologies, as well as the prevailing "open" IMF, are shown schematically in Figure 1. The purpose of the present study is to evaluate the evidence contained in the halo beams in order to assess the viability of these models.

OBSERVATIONS

The ISEE-3 spacecraft was launched in 1978 and was initially stationed in an orbit about the L1 libration point, 0.01 AU sunward from Earth. The primary measurements used in this study are from the electron analyzer /3/, which accepts electrons in an energy range of 8.5 to 1140 eV and a polar angle range of $\pm 67.5^\circ$ centered on the spacecraft spin plane (roughly the ecliptic plane). A two-dimensional electron spectrum representing one 3-s spacecraft spin is made every 84 s, and includes 16 spectral scans separated in azimuth by 22.5° . Results shown here represent seven discrete energy acceptance bands, from 116-161 eV through 822-1140 eV. Calculations were performed in all seven bands, and results are qualitatively similar for each. Additionally, measurements from a separate ion analyzer were used for solar wind bulk speed and density. Our study also uses one-minute averaged magnetic field measurements from the Jet Propulsion Laboratory magnetometer.

The data base for this work includes 39 CMEs observed by ISEE-3 from August 1978 through January 1980. The events are the same as those listed in /1/, with some of the smaller CMEs combined into single larger events. The CMEs used ranged from 1.5 hours to 36 hours in transit time past the spacecraft, and contain a total of nearly 18,000 electron spectra.

The shapes and intensities of the halo electron beams are highly variable. Figure 2 contains a sampling of various beam configurations. Each panel includes four traces, representing ISEE-3 measurements at 37.3, 71.4, 136.7, and 261.6 eV, ordered from top to bottom. Each trace indicates

log counts (on an arbitrary scale) vs. ecliptic look angle, with 0° denoting the sunward look direction. In all panels, the 37.3 eV (top) trace shows core electrons, with the single broad hump centered at 0° representing antisunward convection. The second (71.4 eV) trace shows various degrees of core-halo superposition, while the two highest energy (i.e., lowest in the figure) traces show purely halo distributions. The top left panel represents a typical “open” field halo shape, with a single beam centered on the IMF. The top right panel shows a CME spectrum; note that the two beams are quite symmetric. The bottom left panel represents another CME measurement; note that for this spectrum the beams are strongly asymmetric in intensity. Finally, the bottom right panel illustrates the variability in beam angular width; this spectrum contains one broad beam and one narrow beam.

ASYMMETRIES

To assess the symmetry of the counterstreaming electron fluxes, the measurement plane (roughly the ecliptic plane) was divided into “outward” and “inward” hemispheres based on the IMF orientation for each spectrum. Each hemisphere is centered on the ecliptic projection of B, with the outward hemisphere being the one directed more nearly antisunward, and contains spectral scans at 8 different azimuths. Interhemisphere comparisons for each energy band were performed for the peak electron count rates observed in a hemisphere and for the counts integrated over the hemispheres. Only hemisphere-integrated results will be shown for some parts of this study; however, peak and integrated results were qualitatively similar in all cases.

Figure 3 displays results of the interhemisphere comparison for the energy range 223-309 eV; results are similar for all halo energies. The plot shows the number of spectra for which the outward hemisphere contained more counts than the inward hemisphere (solid shading), and for which the inward hemisphere dominated (hatching). The data are binned by the ratio of dominant to lesser hemisphere counts. Notable trends are: (1) the outward electron fluxes are dominant roughly 75% of the time; (2) strong outward > inward asymmetries are common, while strong inward > outward asymmetries are rare.

IMF-RELATED TRENDS

In Figure 4 the data are binned by IMF ecliptic orientation. Inward and outward field sectors were folded into a 90-270 degree range; a nominal spiral field of either 135° or 315° would map to 135° in this system. The top left panel shows the frequency distribution for the CME spectra and for all solar wind data. Note that the overall solar wind data are dominated by the peak near the Parker

spiral at 120-140 degrees, while the CME measurements are more uniformly distributed (see also /1/). The CME spectra often have IMF nearly transverse to the solar wind flow (90° or 270°), but also exhibit a skew toward the nominal spiral orientation. The lower left panel shows the frequency distribution of CME measurements for which the outward electron fluxes were dominant in the energy range 223-309 eV, with solid dots based on peak count rates and open dots representing integrated count rates. Trends include: (1) the outward beam dominates more often in terms of integrated counts than for peak counts, and (2) spectra with IMF orientations near radial (180°) are nearly always dominated by the outward beam, while for nearly transverse IMF (90° or 270°) this trend is much less pronounced. The right panel shows the median ratio of dominant-to-lesser beam integrated counts, again binned by IMF azimuth. While the distributions of count ratios for inward-dominated spectra (open dots) show little modulation, for outward-dominated spectra (solid dots) the asymmetries are much larger for nearly radial fields than for transverse fields.

TEMPORAL TRENDS

A superposed epoch analysis was performed to identify prevailing trends in electron counts rates as CMEs pass over the spacecraft. CMEs of less than 8 hours of transit time were disregarded; this reduced the data set to 29 events. Measurements were binned by fractional transit time for a given CME, and were weighted so each event contributed equally to the aggregate data set. Medians of various parameters were then calculated, binning by fractional time. Certain trends, not shown here, were noted which are probably attributable to compressive effects at the leading edges of fast CMEs. For example, count rates in both inward and outward beams tend to increase quickly after CME arrival, reach maxima roughly 20% through the CME transit, then decline slowly. A similar trend is seen in ion bulk speed, while ion density tends to peak near the leading edge.

We noted two transit-time effects which may provide insight into likely topologies. The left panel of Figure 5 shows median 161-223 eV peak count ratios (solid trace) and integrated count ratios (dotted trace) for spectra in which the outward beam was dominant. Note the pronounced trend for high outward/inward count ratios in the last 20% of the aggregate event. This effect typically results from the gradual decay of the inward beam, while the antisunward beam continues roughly unchanged. The right panel shows the median angle from radial of the ecliptic projection of the IMF for all CME data. Note that, on average, this angle declines as CMEs pass over the spacecraft, and that the median angle near the trailing edge roughly matches the nominal spiral angle of 45 degrees.

POSSIBLE DIRECT EVIDENCE FOR MAGNETIC CONNECTION

Halo electrons are subject to a variety of scattering processes. Additionally, the various magnetic topologies suggested for CMEs may result in mirroring and multiple transits of the CME structure. The importance of these factors in modifying the highly variable halo distributions is not completely understood. In the course of this study we discovered distinctive spectra containing compound electron beams, which we will refer to as “strahl-on-strahl” (SOS) spectra. To improve the azimuthal resolution of the measurements, we combined 9 to 12 adjacent spectra during periods in which the IMF was nearly steady in azimuth and had a very small polar angle. Because the measurement timing is asynchronous with spacecraft rotation, this enables construction of distributions with fine angular spacing. Figure 6 shows electron counts at 161-223 eV for a 20-min interval within a CME; the vertical lines indicate the range of observed azimuths for $\pm B$. Note the narrow electron beam superimposed on the broader outward (azimuth -90° to $+90^\circ$) halo beam; this is an SOS spectrum.

We emphasize that such distributions are a recent, preliminary finding. However, a cursory survey indicates that SOS distributions are present in roughly half of the CMEs surveyed, and that they are not present on open field lines. We suggest the following hypothesis. In a magnetic tongue or flux rope the counterstreaming halo electrons may mirror repeatedly, enabling broadening of the beams through various scattering processes. However, halo electrons making their first outward transit are subject to scattering for a much shorter time and thus may be observable as a narrower beam superimposed on the broader, scattered beam.

SUMMARY AND CONCLUSIONS

The observations shown here are an initial attempt at quantitative analysis of the electron observations within CMEs. We summarize the statistical results: (1) the electron beam moving more nearly antisunward is generally larger than its sunward counterpart; (2) The asymmetry is maximal for radial B, and minimal for transverse B; (3) the IMF azimuth within CMEs is distributed more uniformly than for the typical solar wind, but exhibits a similar skew toward the Parker spiral direction (4) beam anisotropies maximize near the trailing edges of CMEs; (5) the magnetic field approaches the spiral direction near the trailing edges of CMEs.

The existence of strong beam asymmetries, and the general dominance of the outward beam, seem inconsistent with a detached plasmoid topology. Furthermore, while either a plasmoid or a magnetic tongue might be expected to have the observed transverse fields near the leading edge, the ultimate

return of the IMF orientation to the prevailing spiral would appear to favor continued magnetic connection to the Sun. The dominance of the outward beam near the trailing edges of CMEs is consistent with regulation of the beams by travel distance from the corona; we would expect the field-aligned path lengths in opposite directions to be most dissimilar near the trailing edge of a magnetic tongue. We find no evidence directly suggesting that CMEs are disconnected plasmoids, and tentatively conclude that the statistical results best support a tongue or connected flux rope model. Future analysis will include assessment of differences between "symmetric" and "asymmetric" CMEs in order to investigate the possible existence of both attached and detached structures.

The strahl-on-strahl distributions discovered in this study offer a new opportunity for use of electrons as tracers of magnetic structure. Our tentative hypothesis is that the SOS spectra represent a superposition of a narrow, pristine halo beam upon a broader, scattered halo beam, requiring continued magnetic connection to the Sun. More extensive analysis of beam widths in CMEs, in the "open" solar wind, and in SOS distributions, will be necessary for assessment of this hypothesis.

We note in closing that if CMEs remain fully magnetically attached to the corona, as in a simple tongue, or partially attached in a flux rope, they open new magnetic flux in interplanetary space. To avoid a monotonic increase in the magnitude of the IMF, some mechanism must return flux to the Sun. One candidate for this mechanism is the coronal magnetic disconnection /4/.

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REFERENCES

1. J.T. Gosling, D.N. Baker, S.J. Bame, W.C. Feldman, R.D. Zwickl, and E.J. Smith Bidirectional solar wind electron heat flux events, *J. Geophys. Res.* 92, 8519 (1987).
2. J.T. Gosling, Coronal mass ejections and magnetic flux ropes in interplanetary space, in: *Physics of Magnetic Flux Ropes*, ed. C.T. Russell, E.R. Priest, and L.C. Lee, American Geophysical Union, Washington, 1990, p. 343.

3. S.J. Bame, J.R. Asbridge, H.E. Felthausen, J.P. Glore, H.L. Hawk, and J. Chavez, ISEE-C solar wind plasma experiment, *IEEE Trans. Geosci. Electron.* GE-16, 160 (1978).
4. D.J. McComas, J.L. Phillips, A.J. Hundhausen, and J.T. Burkepile, Disconnection of open coronal magnetic structures, these proceedings.

FIGURE CAPTIONS

Fig. 1. Schematic diagram of normal open magnetic field and possible CME topologies. The large arrows show the direction of the electron heat flux.

Fig. 2. Four ISEE-3 log count vs. angle electron spectra, each including measurement at the four energies indicated in the legend, illustrating the variability in the halo electron beams.

Fig. 3. Number of outward-dominated (solid) and inward dominated (hatched) CME electron spectra, as a function of hemisphere-integrated count ratio.

Fig. 4. Data binned by magnetic ecliptic azimuth: (top left) distribution of all data and CME spectra; (bottom left) percent of spectra dominated by outward beam; (top right) median ratio of dominant-to-lesser beam integrated counts.

Fig. 5. Medians binned by fractional time of CME transit: (left) peak and integrated count ratios for spectra with dominant outward beams; (right) ecliptic angle of B from radial for all CME data.

Fig. 6. "Strahl-on-Strahl" count vs. angle spectrum. Vertical dashed lines show the range of ecliptic B azimuth during the spectrum interval.

Fig. 1

Fig. 2

Fig. 3

Fig 4

Fig. 5

Fig. 6

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