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AUTHOR(S): J.T. Gosling, D.J. McComas J.L. Phillips

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COUNTERSTREAMING SOLAR WIND HALO ELECTRON EVENTS ON OPEN FIELD LINES?

J. T. Gosling, D. J. McComas, and J. L. Phillips

MS D438, Los Alamos National Laboratory, Los Alamos NM 87545, U.S.A.

ABSTRACT

Counterstreaming solar wind halo electron events have been identified as a common 1 AU signature of coronal mass ejection events, and have generally been interpreted as indicative of closed magnetic field topologies, i.e., magnetic loops or flux ropes rooted at both ends in the Sun, or detached plasmoids. In this paper we examine the possibility that these events may instead occur preferentially on open field lines, and that counterstreaming results from reflection or injection behind interplanetary shocks or from mirroring from regions of compressed magnetic field farther out in the heliosphere. We conclude that neither of these suggested sources of counterstreaming electron beams is viable and that the best interpretation of observed counterstreaming electron events in the solar wind remains that of passage of closed field structures.

INTRODUCTION

Solar wind halo electrons (above about 80 eV at 1 AU) are nearly collisionless and are generally beamed outward from the Sun along the interplanetary magnetic field, IMF. This unidirectional flux of halo electrons arises because field lines in the solar wind usually are "open" and are effectively connected to the hot solar corona at only one end. However, discrete interplanetary events in which halo electrons are observed streaming in both directions along the IMF are common at times of high solar activity /1/. These events typically have durations of the order of 12 - 18 hours (although considerably shorter and longer events are also observed), and appear to be reliable signatures of coronal mass ejections, CMEs, in the solar wind at 1 AU. Counterstreaming has generally been interpreted as a signature of passage of closed field structures, i.e., magnetic loops or magnetic flux ropes rooted at both ends in the Sun, or detached plasmoids. In magnetic loops or flux ropes the counterstreaming fluxes of hot halo electrons arise because both ends of field lines threading these structures are rooted in the hot solar corona. Presumably the counterstreaming fluxes are trapped on the field lines and continue to circulate if the field lines disconnect to form plasmoids. All three of these field topologies are consistent with the observation that CMEs generally originate in closed field regions in the solar corona.

Recently Kahler and Reames have noted that at least some counterstreaming electron events are nearly transparent to energetic solar electrons (0.2 - 2.0 MeV) and protons (22 - 27 MeV) and to cosmic rays /2/. On the basis of this observation they have concluded that counterstreaming electron events occur on open, rather than closed, field lines, and that counterstreaming results from reflection or injection behind a shock or from mirroring from a region of compressed field beyond 1 AU. Our purpose here is to demonstrate that counterstreaming electron events in the solar wind at 1 AU do not originate in the manner they suggest, and that it is thus unlikely that the counterstreaming events which we identify as CMEs occur on open field lines.

OBSERVATIONS

Let us first consider the possibility that counterstreaming results from reflection of the solar wind electron heat flux at an interplanetary shock beyond 1AU or from the production of hot electrons at the shock that then travel back to the spacecraft. In either case, if the shock were the source of an additional beam of electrons streaming back toward the Sun along the IMF then one would expect to observe counterstreaming on all field lines connected to the shock. In particular, one would expect to observe counterstreaming immediately following shock passage, for that is the one time when it is certain that a spacecraft is magnetically connected to the shock. However, while counterstreaming electron events often are observed behind interplanetary shocks, the counterstreaming never begins immediately following shock passage. Rather, as illustrated by the event shown in Figure 1, counterstreaming always lags the shock by a number of hours /1/. This aspect of the observations argues strongly against the possibility that beams of halo electrons streaming back toward the Sun along the IMF are commonly produced at interplanetary shocks.

There are several reasons why mirroring from regions of compressed magnetic fields beyond 1 AU is an unlikely source of counterstreaming electron beams. The prime reason is that increases in field magnitude beyond 1 AU are inadequate to mirror large fractions of the highly field-aligned, antisunward-directed, solar wind electron heat flux. Figure 2 shows the field increases required beyond 1 AU to mirror electrons of various pitch angles. As an example, in order to mirror a typical heat flux electron with a pitch angle of 20 degrees at 1 AU, the field strength must increase by a factor of ~8.5 over its 1 AU value. Considerably larger increases are required to mirror particles with smaller pitch angles. Typical field strengths within counterstreaming events at 1 AU are ~10 nT, and considerably stronger fields are not uncommon /1/. Thus field strengths of the order of 85 nT and greater are required beyond 1 AU to reflect electrons with pitch angles less than or equal to 20 degrees at 1 AU.

The left panel of Figure 3 compares 25-day averages of the IMF magnitude observed by Voyager 1 with the variation with distance predicted by Parker's spiral model (the solid curve), while the right panel shows variations in the measured field strength relative to the Parker value at various heliocentric distances. Although the contrast in field magnitude between compression regions and rarefactions is greater at larger distances, the absolute value of the field magnitude within compression regions is generally less than at 1 AU. For example, at 5 AU, where Bp is about 1 nT, the maximum (10-hr average) field strength is about 4.5 nT. Clearly, the field increases required beyond 1 AU to mirror substantial portions of the highly field-aligned electron heat flux are not observed. The reason, of course, is that the overall field magnitude decreases with increasing heliocentric distance, even within compression regions, owing to thel 3-dimensional divergence of the solar wind flow.

In addition, if mirroring were the source of counterstreaming electron beams at 1 AU, then field-aligned loss cone "holes" should be apparent in the mirrored beams since virtually an infinite field increase is required to mirror particles with very small pitch angles. However, measured halo electron angular distributions within counterstreaming events show no evidence for such "holes". The distributions shown in Figure 4 are representative of those observed within these events. Note that the halo beams peak parallel and antiparallel to the field direction, in contrast with what would be observed if one of the beams were a result of imperfect mirroring of the other.

Finally, the number of counterstreaming electron events observed at 1 AU varies roughly in phase with the solar activity cycle /3/. On the other hand, compression regions and shocks are common beyond 1 AU at all phases of the solar cycle, particularly at solar minimum when counterstreaming electron events in the solar wind at 1 AU are rare. This clearly indicates that counterstreaming is not associated with mirroring from compression regions or injection behind shocks beyond 1 AU.

CONCLUSIONS

We conclude that counterstreaming electron events in the solar wind at 1 AU are not produced in the manner suggested by Kahler and Reames. Lacking other viable alternatives for producing counterstreaming beams on open field lines, the best interpretation of the counterstreaming signature is that it is an indication of passage of a closed magnetic field structure. As noted previously, this type of field topology is consistent with the observation that CMEs generally originate in closed field regions in the solar corona not previously participating directly in the solar wind expansion.

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2. S. W. Kahler and D. V. Reames, Probing the magnetic topologies of magnetic clouds by means of solar energetic particles, *J. Geophys. Res.*, *96*, 9419, (1991)

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Figure Captions.

Fig. 1. Solar wind speed and pressure (total kinetic gas plus field) measured by ISEE 3 for a typical transient interplanetary shock (dashed line) and associated counterstreaming solar wind electron event (cross-hatched). The latter is identified as the CME driving the shock.

Fig. 2. Field increase required to mirror a given pitch angle particle. Bo is field strength at the measurement point (1 AU) and B is the field strength required at the mirror point on the same field line.

Fig. 3. Heliocentric variation of 25-day averages of the strength of the IMF measured by Voyager 1 (left panel) and 10-hr averages of the field for selected 170-day intervals at different heliocentric distances (right panel) (from /4/). Bp is the average field value predicted by Parker's spiral field

model.

Fig. 4. Three-dimensional view of a representative two-dimensional solar wind electron distribution obtained during a counterstreaming solar wind halo electron event (from /1/). Note that the field-aligned loss cone "hole", expected if counterstreaming were associated with mirroring in regions of enhanced magnetic field beyond 1 AU, is not present in the distribution above ~80 eV.

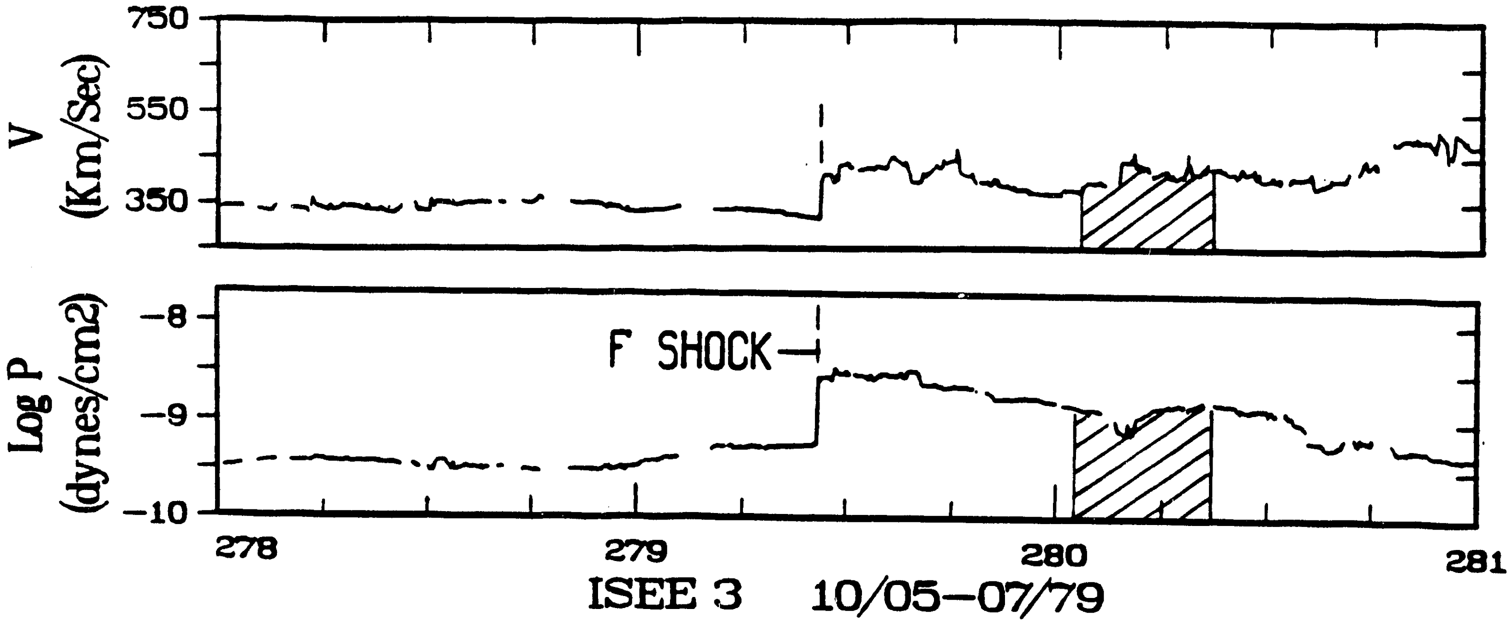
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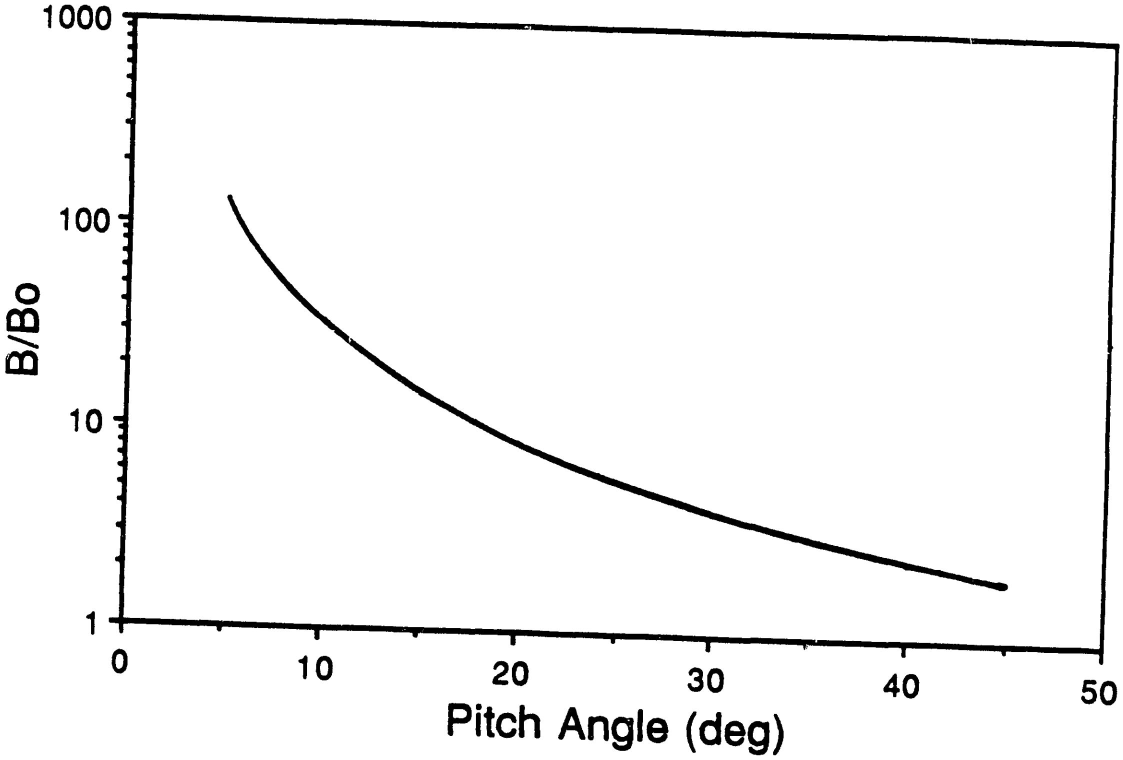
Fig. 1



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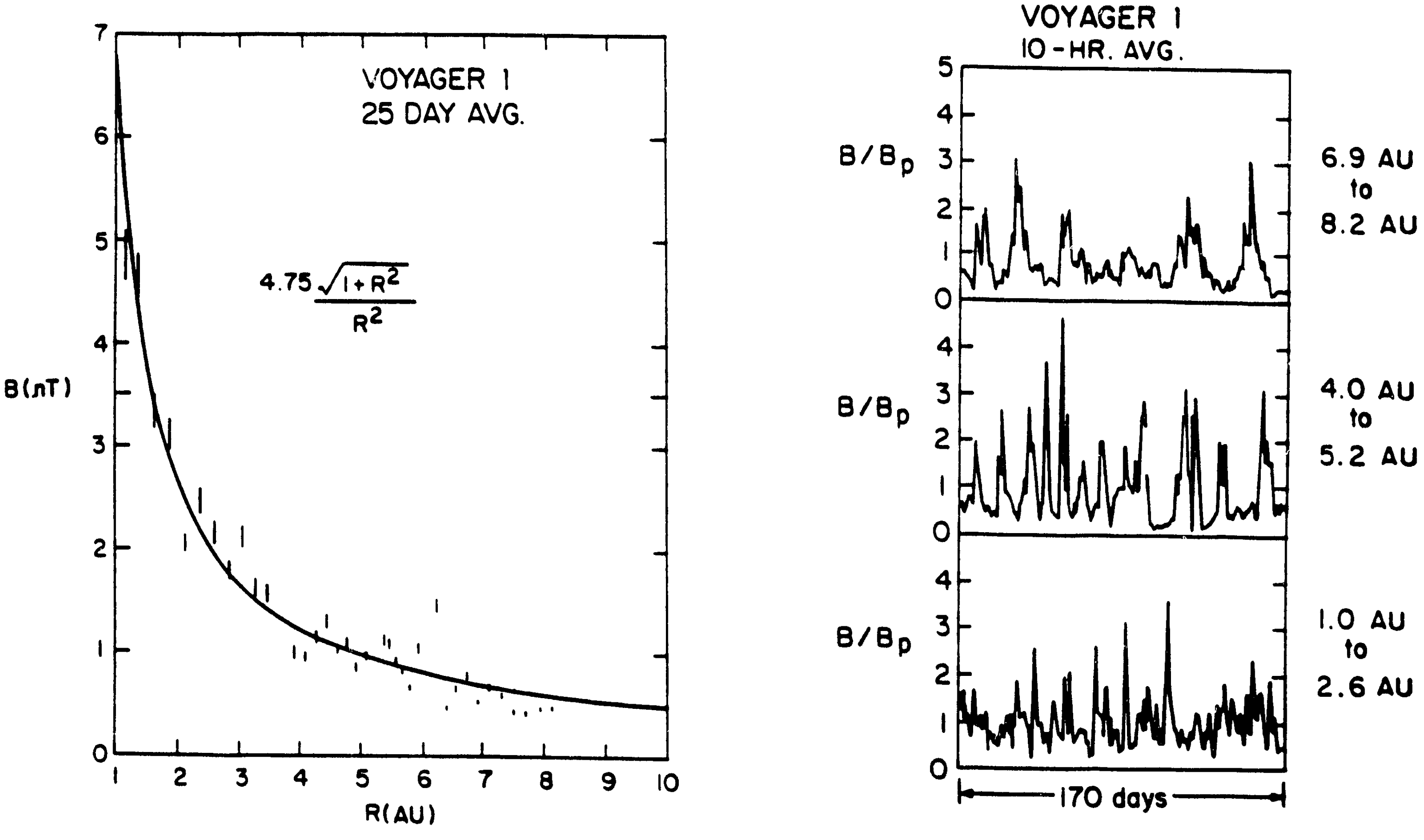
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Fig. 3

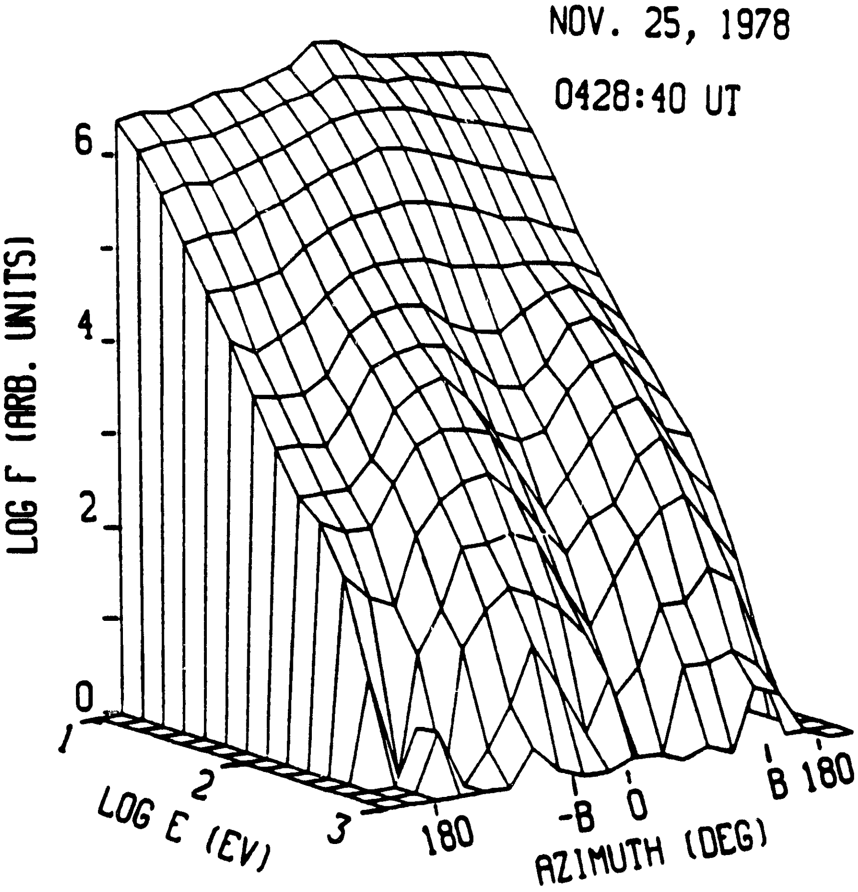
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Fig. 4

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