THE ORIGIN OF SOLAR PARTICLE EVENTS WITH LOW Fe/O

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Abstract

We have studied the origins of particle events which have low Fe/O and find that the majority are associated with interplanetary shocks. Separately we examined Fe/O associated with all strong shocks in the same time period. We substantiate the important role played by shocks by establishing that the average Fe/O ratio for days when a strong shock passes is 0.1, below the average value of 0.2 for large solar proton events and the solar wind. We also show the variations of other elements.

Introduction It is well known that the ratio of Fe to O in solar energetic particles shows a wide variation from about 0.01-10 (Reames, 1988b). An average value for large energetic proton events is about 0.2, which agrees with the value measured in the solar wind (Ogilvie et al., 1989). The highest values of Fe/O are well-associated with the class of impulsive flare events which are enriched in $^3$He (Reames, 1988b; Mason et al., 1980 and refs. therein). Reames (1988a) showed that the abundances of heavy elements in $^3$He-rich flares increase with the temperature of the flare region. This suggests that enhanced abundances occur in flare-heated material and provides an explanation of the enhancements. In contrast, the sources and causes for particularly low values of Fe/O have been investigated only briefly. McGuire et al. (1986) noted that two events in their study which were dominated by shock effects had very low Fe/O ratios. Reames (1988b) also mentioned that low Fe/O values occurred at times of shock passages. In this paper we make a study of events occurring in days when Fe/O < 0.1 at an energy of 1.9 - 2.8 MeV/amu.

Data analysis We used data from the Medium Energy Cosmic Ray Experiment (von Rosenvinge et al., 1978) on the ISEE-3 spacecraft and considered the period from launch (Aug. 1978) to the end of 1985. Excluding days when there were insufficient particles to obtain a significant ratio (we required that the Fe intensity be $>3 \times 10^{-4}$ (cm$^2$ ster sec MeV/amu)$^{-1}$), we found 112 days with Fe/O < 0.1. This corresponded to 53 separate events the majority (77%, 41/53) of which can be associated with solar flares (e.g. Cane et al., 1986a). Two others have been associated with filament disappearances (Cane et al., 1986b) leaving 10 events with non-solar origins. The key to understanding the origins of these events and to the cause of the periods of low Fe/O, is our observation that 72% (38/53) of the days with a low abundance coincided with (26 events), or occurred within a day of (12 events), the passage of an interplanetary shock. For simplicity we determined the presence of a shock by the occurrence of a sudden commencement (SC) geomagnetic storm.

Figure 1 shows the interplanetary magnetic field magnitude and solar wind density and speed for a period in October 1981 which contains 2 days with Fe/O <0.1. Vertical lines indicate the three shocks which occurred in this time period. The lowest panel shows particle data; the traces are intensities of 0 in the ranges 1.9-2.8, 3.9-7.0 and 14.1-24.3 MeV/amu. The * Permanent address: Physics Dept., University of Tasmania, Tasmania 7001

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two X-class flares associated with the high energy particle events are indicated by arrows. The shocks of October 10 and 13 also originated in these flare events as may be seen by the smooth profiles of the particles but the association has previously been made using IP type II emission (Cane, 1985). The October 2 shock does not have a well defined solar origin (no other large flare occurred in this time period) and the absence of high energy particles suggests that the shock originated in some solar event which did not accelerate particles in the low corona; probably a slow mass ejection. October 2 1981 had the lowest Fe/0 ratio (0.009) for the entire period of our study.

The other shocks with associated particle increases with low Fe/0 which could not be associated with a solar event had varying characteristics. At least two had the properties associated with high speed streams i.e. a solar wind velocity increase and density decrease. There were three low Fe/0 events which occurred a solar rotation after another low Fe/0 event.

Figures 2 and 3 show Fe and O intensities for two low Fe/0 events. We show Fe intensities in the ranges 1.9-2.8 MeV/amu and 4-7 MeV/amu (using ‘*’ symbols) and O in the range 1.9-2 MeV/amu (‘*’). Also shown is Fe/0 at 1.9-2.8 MeV/amu (‘*’). In both figures we mark the time and heliolatitude of the associated solar flare. For the July 1980 event (figure 2) there was a strong shock indicated by the vertical line. It can
be seen that both Fe and O peak after the shock and the lowest Fe/O ratio occurs just after this peak. This peaking within 12 hours of shock passage is typical for all strong shocks. Whereas the majority peak just after the shock some events peak at the shock as may be seen in figure 1 for the shock of October 2.

Figure 3 shows one of the 15 low Fe/O periods which was not associated with a shock detected at earth. Like the majority of such days, the Fe and O peaked shortly after a flare which was magnetically connected to the spacecraft. There were 5 'non-shock' events which occurred following large eastern flare particle events for which there must be a shock (see Cane et al., 1988) but it was not observed at earth.

In order to further establish the presence of shocks during periods of low Fe/O we determined the ratio for the 24 hours surrounding all strong shocks in the period Aug. 1978 - Dec. 1983. The list of 55 shocks was obtained by considering all SCs for which the change in mean field amplitude was above 29. For 2 of these there was a data gap, for 7 there were insufficient Fe particles to determine the Fe/O ratio and for a further 4 days it was clear that the ratio was affected by the presence of a flare event. For the remaining 42 days we found a distribution as shown in figure 4 with an average Fe/O of 0.11±0.017. This value is below the average for energetic proton events and the solar wind. Note that 23 of the
strong shocks are associated with an event in our original list of 53
dlow Fe/O events.

Figure 5 shows the variation of other elements on the days when there
were strong shocks. The variations are similar but not the same as in flare
populations (see paper SH 2.2-4). Table 1 compares the mean values
obtained for periods around strong shocks with the "mass-unbiased baseline"
abundances derived by Meyer (1985). In the table the elements are given in
order of increasing M/Q as given by Stone (1989). We find that there is an
approximate organization with respect to M/Q.

<table>
<thead>
<tr>
<th>Element</th>
<th>Shocks</th>
<th>Meyer</th>
<th>Ratio</th>
</tr>
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<tbody>
<tr>
<td>C</td>
<td>100</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>Ne</td>
<td>31 ± 1.5</td>
<td>29</td>
<td>1.1</td>
</tr>
<tr>
<td>N</td>
<td>27 ± 1.3</td>
<td>28</td>
<td>0.96</td>
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<tr>
<td>Mg</td>
<td>41 ± 2.2</td>
<td>42</td>
<td>0.98</td>
</tr>
<tr>
<td>O</td>
<td>190 ± 6.1</td>
<td>224</td>
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</tr>
<tr>
<td>Si</td>
<td>27 ± 2.3</td>
<td>35</td>
<td>0.77</td>
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<tr>
<td>Ca</td>
<td>2.1 ± 0.45</td>
<td>2.6</td>
<td>0.81</td>
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<tr>
<td>Fe</td>
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<td>34</td>
<td>0.68</td>
</tr>
</tbody>
</table>

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References
Cane, H.V. 1985 J. Geophys. Res. 90, 191-197
Cane, H.V. et al. 1986a Ap. J. 301, 448-459
Cane, H.V. et al. 1986b J. Geophys. Res. 91, 13321-13329
Cane, H.V. et al. 1988 J. Geophys. Res. 93, 9555-9567
Meyer, J-P Ap. J. (Supp) 57, 173-204

Figure 5