*Proceedings of the 30th International Cosmic Ray Conference*
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 1 (SH), pages 67–70

30TH INTERNATIONAL COSMIC RAY CONFERENCE

# Comparing Small and Large SEP Events and the Role of Flares and Shocks

H. V. CANE[1, 2], I. G. RICHARDSON[1,3], T. T. VON ROSENVINGE[1]
[1]*Astroparticle Physics Laboratory, NASA/GSFC, Greenbelt, MD 20771, USA*
[2]*University of Tasmania, Hobart, Tasmania, 7001, Australia*
[3]*CRESST and University of Maryland, College Park, MD 20742, USA*
*Hilary.cane@utas.edu.au*

**Abstract:** We have surveyed the properties and solar associations of the ~300 >20 MeV proton events that were observed near Earth in 1997-2005. About 20% have the properties of so-called "impulsive" events that are considered to arise from acceleration in flares. Another 31% of the events are the large, well studied, "gradual" events, that are considered to comprise only shock accelerated particles. The remaining events are often ignored but comprise ~50% of the events. We find that these events have intermediate properties such that there is a continuum of properties from the smallest to the largest events. It thus seems unlikely that there are two classes of fundamentally different events. Rather, there are two processes, one related to flares and one to coronal mass ejection shocks. As solar events become more energetic, shock acceleration becomes more important because of increasing CME energy. However, the flare characteristics also change so that flare particles in energetic events have different abundances from those in small events. We illustrate this for an impulsive event and another small event.

## Introduction

The reasons for the large variations in solar energetic particle (SEP) event properties are presently under much scrutiny. Small SEP events, that have relative abundances enhanced in comparison with those of the corona and solar wind, are understood to be accelerated in flare heated plasma, presumably in closed loops. Since the particles are detected in space, they clearly gain access to open field lines; type III radio bursts generated by the low energy electron component of these flare particles trace these open field lines. Large SEP events also have associated flares and type III radio bursts [1] but the flares are much longer in duration and usually more intense. Large SEP events are also well associated with interplanetary shocks and the intensity time profiles are organized by the location of the observer relative to the shock [2], indicating that the bulk of the particles in the largest events (particularly below ~25 MeV) are shock accelerated. However, particles with flare-like abundances are also seen at certain energies in some of the largest events and their origin has caused considerable debate. We have proposed that they come directly from the concomitant flare [3] based on high energy Fe and O observations of the 97 largest >10 MeV proton events. We have now studied all >20 MeV proton events in 1997-2005 and, in addition to Fe/O ratios, have looked at electron to proton and helium to proton ratios [4]. We argue that the variations of abundances with energy, from event to event, and with time within a single event, depend on the variable combination of the two essentially independent components. The shock component produces Fe/O of about 0.1 (which may decrease with increasing energy) and He/H of <0.1. Electrons play a minor role in this component. The flare component, which occurs first, results from processes related to reconnection and produces Fe/O ratios near 1. However, depending on the characteristics of a particular flare loop (such as size) a range of e/p and He/H ratios can result. This is illustrated here by comparing two solar events. We also summarize the results from our comprehensive study.

## Data for Two Small Events

Figures 1 and 2 show, for two small western events, some of the types of data considered in our comprehensive study. Figure 1 shows time profiles of Xrays, electrons, protons and helium. The flares were at W67° and W42°, had peak Xray intensities of M2 and M7 and the Hα emissions lasted 51 and 18 minutes. Comparing the top electron profiles and the superimposed grey curves (the scaled ~25 MeV proton curve), and also the bottom electron profiles for the two events, it is apparent that the March 2001 event was richer in electrons than the September 2000 event. The bottom panels show the ~10 MeV/nuc He/H ratios which were about 0.001 for the September event versus 0.1 for the March event. The September 2000 event had few heavy ions above 0.5 MeV/nuc but was Fe-rich at lower energies. In contrast the March event had measurable Fe ions up to about 30 MeV/nuc and was Fe-rich. We suggest that the particles in both events are flare accelerated. The March 2001 event being Fe-rich, electron-rich, He-rich and associated with an impulsive flare is an "impulsive" SEP event. In the September 2000 event the particles are unlikely to be shock accelerated because the CME was too slow (554 km/s) to produce a shock. If the particles are flare accelerated in both cases the different abundances must result from variations in the flaring process. Note the difference between the Xray profiles for the two events. Figure 2 shows radio and coronagraph data. The upper panels show ground based meter wavelength radio data for 30 minute intervals. The vertical lines show the times of Hα flare maxima. For the September 2000 event, the main feature is slow drift type II emission after flare maximum. For the March 2001 event there is also type II emission but it is preceded by strong type III emission that occurs before flare maximum. In the September 2000 event the type III activity is very weak at meter wavelengths and much of it occurs after flare maximum. Although not discernable in this presentation type III is clearly present because it is seen at hecto- and kilo-meter wavelengths. The important difference in the flare process between the two events is likely to be the spatial scale and height in the corona. In the impulsive flare of March 2001 the type III electrons start deep in the corona and occur in two short bursts. In contrast, for the September 2000 event the acceleration is higher in the corona (based on the starting frequencies of the emissions) and comprises many small elements spread over some 20 minutes. The September 2000 and March 2001 CMEs were both relatively minor, as expected with such small flares (see Figure 1). The March 2001 CME had a speed of 1000 km/s, compared with 554 km/s for the September 2000 event.

## Statistical Analysis

We have investigated the following properties and associations for all the >20 MeV proton events:

- e/p and He/H at event onset
- Event averaged and time variations of Fe and O at several energies
- Soft Xray and Hα flare intensities and durations
- CME speeds, sizes and temporal variations
- Meter to kilometer wavelength radio bursts

We find that e/p ratios, comparing ~0.5 MeV electrons with 25 MeV protons, vary over 4 orders of magnitude from about 2000 to $2x10^7$. The He/H ratios (at ~15 MeV/n) vary from $4x10^{-4}$ to 0.6 and are correlated with the e/p ratios with a correlation coefficient of 0.63 for 217 events. Both parameters are correlated with the ~10 MeV/n Fe/O ratio but at a weaker level (cc~0.4 for 120 events). All but 4 of the smallest events were associated with CMEs and all the on- disk events were associated with flares. The 25 MeV peak proton and 0.5 MeV peak electron intensities are loosely correlated with the peak Xray intensities and the CME speeds (cc ~0.5 for ~270 events) and the abundance ratios with flare duration (cc~-0.4 for ~100 events) and CME size (~-0.5 for ~200 events). No parameter plot shows a bimodal distribution. The very largest events are associated with fast CMEs (>~1200 km/s) and IP (interplanetary) type II events, i.e. slow drifting radio emissions at hecto- kilometer wavelengths that originate at CME-driven interplanetary shocks. By contrast, well-defined meter wavelength type II bursts are most common in association with the smaller events, suggesting that they are a flare phenomenon rather than caused by CME-driven shocks. Note that the impulsive event of March 2001 had an extension of the metric type II burst into the hectometer range i.e. a “DH type II” but not the September 2000 event. This casts doubt on the relevance of these emissions for SEP events (see however [5]).

## Discussion and Conclusions

We suggest that in large events there are contributions from flares and shocks. What is observed depends on the particular event and the observer’s location. We also suggest that flare-accelerated particles have different abundance ratios depending on the properties of the flare. Thus it is not appropriate to test for flare particles in large events assuming the relative abundances seen in small flare events. Although we find no bimodality in properties of SEP events it is clear that Fe/O ratios fall into two groups at energies of a few MeV/n [6], although not at higher or lower energies [7]. We suggest that this is because at this energy shock-accelerated particles overwhelm flare accelerated particles in large events and the energy is sufficiently low that there are numerous detectable small flare events as well.

## Acknowledgements

We wish to thank the experimenters of the following instruments for making the data available on the internet: SIS , EPAM and ULEIS on ACE and LASCO, ERNE and EPHIN on SoHO.

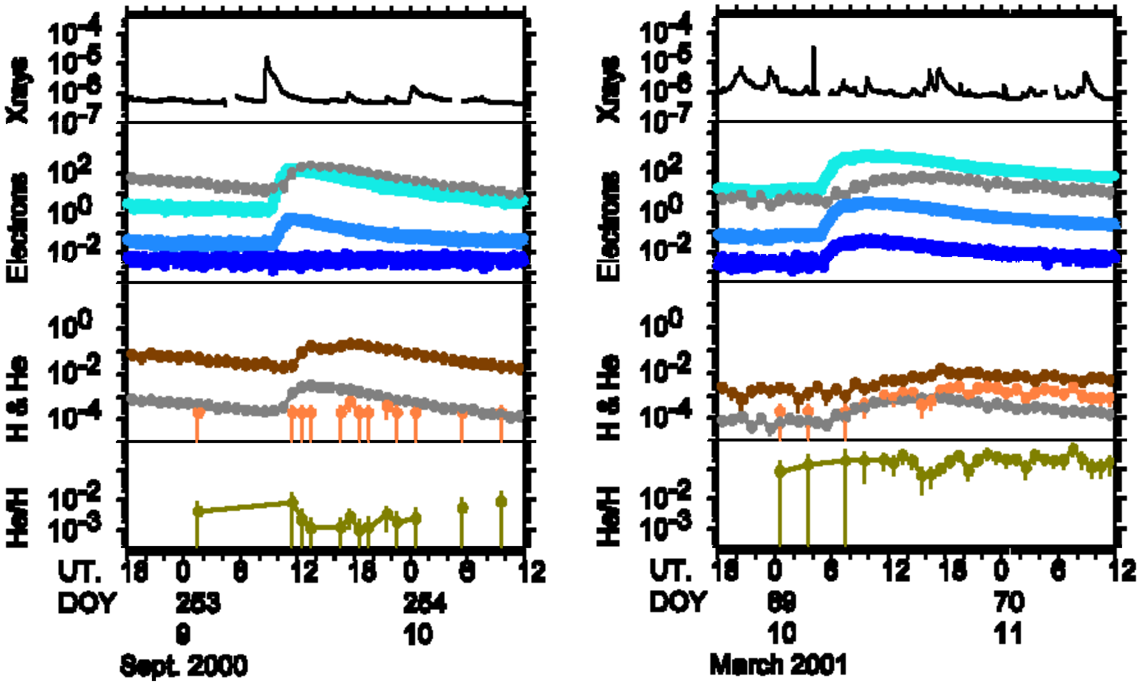


Figure 1: Time profiles for soft Xrays, electrons (0.3-0.7, 0.7-1, and 3-6 MeV), protons (8-10 and 26-32 MeV), He (8-10 MeV/n) and He/H ratio (~10 MeV/nuc). The grey curve is for ~25 MeV protons and is shown, scaled, in the electron panel for direct comparison.

## References

[1] H. V. Cane, W.C. Erickson, and N. P. Prestage, Solar flares, type III radio bursts, coronal mass ejections, and energetic particles, J. G. R., 107, A10, SSH 14-1, 2002.

[2] H.V. Cane, D. V. Reames, and T. T. von Rosenvinge, The role of interplanetary shocks in the longitude distribution of solar energetic particle events, J. G. R., 93, 9555, 1988.

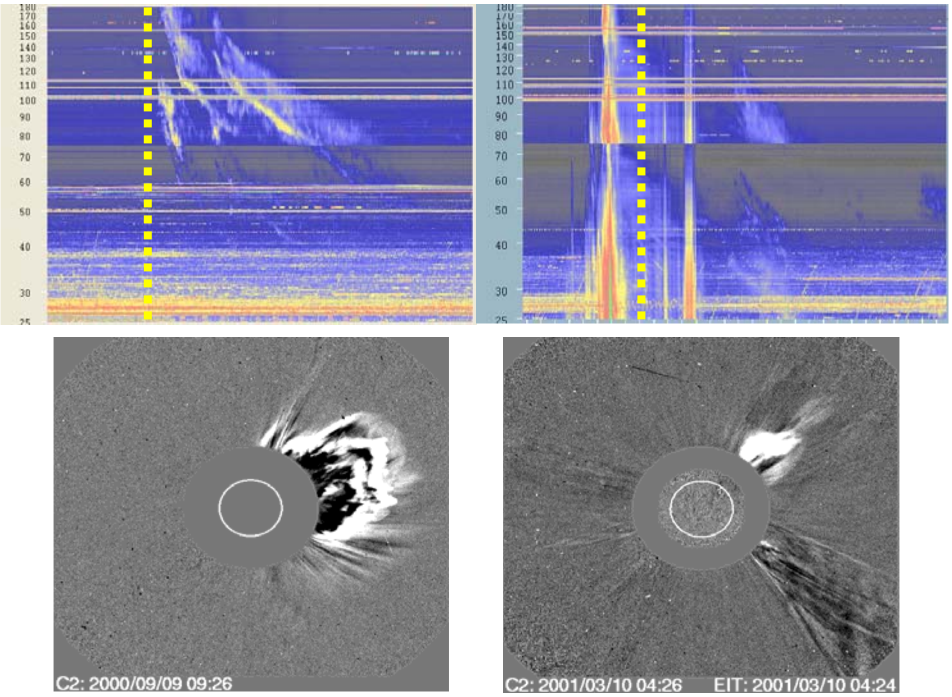
[3] H. V. Cane, R. A Mewaldt, C. M. S. Cohen, and T. T. von Rosenvinge, Role of flares and shocks in determining solar energetic particle abundances, J. G. R., 111, A06S90, 2006.

[4] H. V. Cane, I. G. Richardson, and T. T. von Rosenvinge, Flare and Shock Processes in Solar Energetic Particle Events, in preparation, 2007.

[5] E. W. Cliver, S. W. Kahler, and D. V. Reames, Coronal shocks and solar energetic proton events, Ap. J., 605, 902, 2004.

[6] D. V. Reames and C. K. Ng, Heavy-Element Abundances in Solar Energetic Particle Events, Ap. J., 610, 510, 2007.

[7] J. Giacalone and J. Kóta, Acceleration of solar-energetic particles by shocks, Space. Sci. Rev., 124, 277, 2006.



**September 9 2000** **March 10 2001**

Figure 2: Meter wavelength radio dynamic spectra from the Learmonth observatory showing intensity (more intense emission is brighter yellow/orange) versus frequency and time. The yellow line indicates the time of Hα maximum intensity. The slow drift emissions (type II) originate at coronal shocks and the fast drift emissions (type III) are caused by streaming low energy electrons. LASCO C2 coronagraph images are also shown for the two events.