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Energetic Particle Associations to Interplanetary Shocks During Seven Years of SOHO/ERNE

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Transient interplanetary (IP) shock passages are usually identified by abrupt changes in the plasma parameters, but sometimes they are also associated with energetic storm particles (ESPs). The maximum observed energies of the ESPs usually reach few MeVs per nucleon, and occasionally even few hundred MeVs per nucleon. We have initiated a statistical study of ESP events observed by SOHO/ERNE. In the first stage, we gathered a comprehensive database of IP shock candidates (529 entries from which 243 are reliable fast forward shocks) using several ready-made shock lists. Then we classified the possible ESP signals of the fast forward shocks, and inspected the proton spectra of selected cases. Our study period is from May 1996 to April 2003. We present the preliminary results.

1. Introduction

Coronal mass ejections and their interplanetary counterparts (ICMEs) are the primary drivers of transient interplanetary shocks [1]. Investigation of transient interplanetary shocks is important because of their role in particle acceleration [2] and as a cause of geomagnetic storms [3]. Shock passages are usually identified by abrupt changes in the solar wind plasma parameters, but sometimes they are also associated with energetic storm particles (ESPs) [4]. Acceleration of ESPs in transient interplanetary shocks has been studied by Tsurutani and Lin [5], Kallenrode [6], Lario et al. [7], and Ho et al. [8], and the time development of proton energy spectra by van Nes et al. [9] and Meyer et al. [10]. Energetic storm particles may provide information not only on the shock acceleration processes, but also on the structure and evolution of the shock [11]. Furthermore, since the intensities of ESPs often start to rise several hours before the shock passage, ESP observations can possibly be used as precursors of approaching shocks/ICMEs potentially causing geomagnetic storms.

We have initiated a statistical study of energetic storm particle events observed by SOHO/ERNE during the seven-year period between May 1996 and April 2003. We have gathered a comprehensive database of IP shock candidates using several ready-made shock lists and searched for associated ESP events and/or preceding solar particle events from the ERNE observations. Here we present the overall statistics of the survey and the preliminary results of the evolution of the energy spectra of ESPs during the first seven years of the present solar cycle.

2. Database

We started to compile our own database with the use of four different shock lists available on the internet. The used lists are *the Celias Shockspotter list* (http://umtof.umd.edu/pm/Figs.html), *the list by Berdichevsky et al.* (http://pwg.gsfc.nasa.gov/wind/current_listIPS.htm), *the ACE shock list* (http://www.bartol.udel.edu/~chuck/ace/ACElists/obs_list.html), and *the list by Davin Larson* (http://sprg.ssl.berkeley.edu/~davin/IPShocks.html). For the completeness, we added every single entry in the above lists to our database, even though all the lists contain candidates that are not shocks (may be other MHD discontinuities). The total number of entries in the database reached 529. None of the lists given above covered the whole study period. The covered periods and the number of referenced entries are given in Table 1.

Table 1. Database Study Period: 1.5.1996 - 30.4.2003

	Cover	Referenced entries[a]		Total database entries[b]		Percentage covered[c]		Unique entries[d]	
Reference	period	ALL	FF3	ALL	FF3	ALL	FF3	ALL	FF3
Celias list	26.9.96 →	193	161	519	240	37 %	67 %	20	3
Berdichevsky	→ 17.2.03	379	220	518	240	73 %	92 %	132	12
ACE list	2.9.97 →	296	195	478	223	62 %	87 %	81	12
Davin Larson	→ 25.6.98	84	44	115	54	73 %	81 %	36	3

(a) the number entries to the database from the reference list, (b) the total entry number from all the lists during cover period,
(c) referenced entries divided by total entries, (d) the number of referenced entries that were not listed in other lists

Next, we determined the MHD modes of the candidates from the solar wind data (WIND, ACE and SOHO), and classified the plasma jumps. The candidates with unambiguous plasma jumps gained quality 3 (294 cases). If the jumps were less reliable (e.g., smoother), quality 2 was given (92). If the plasma jumps were somehow weird, quality 1 was assigned (61), and if the candidate did not even look like a shock, quality 0 was selected (82). The statistics for the candidates with quality 2 or 3 are presented in Figure 1.

After the first classification, we looked for ESP signals in the SOHO/ERNE energetic proton and helium data (1.5-130 MeV/n), concentrating only on the quality 3 fast forward shocks (FF3). We also classified the ERNE data availability: A: data available also for the possible primary SEP event (time window of five days was used), B: data available only for the possible ESP event, C: data available but corrupted, and D: no data. The data availability for the FF3 shocks is shown in the inset of the right panel of Figure 1. We categorized also the ESP signals into four classes. We considered clear intensity enhancements at several energy channels with no velocity dispersion as ESP event candidates. Possible ESP signals can occur over the galactic background or be superposed over a SEP event. When the enhancement was temporally close to the shock passage and/or was noticeably peaked, level 3 was assigned, and when the temporal relationship was less reliable, level 2 was given. Level 1 was selected, if only a small intensity enhancement was seen at some limited energy range, and level 0 when there was no signals. This classification is subjective to some extent. The typical characteristics of the different ESP signals are shown schematically as a free-hand curve on the right panel of Figure 1. The statistical results are presented as columns in the right panel of Figure 1.

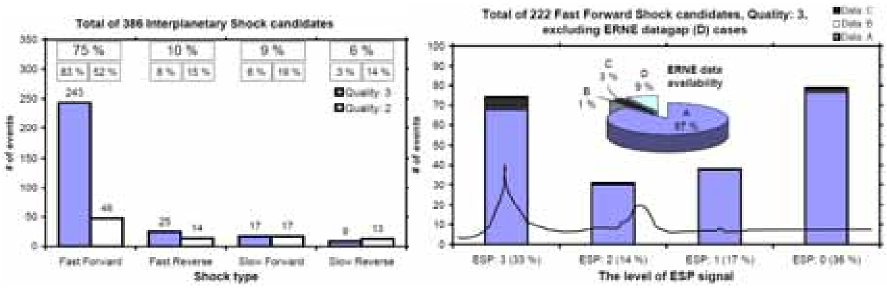

Figure 1. The overall statistics of the database. The observed shock types are presented in the left panel, which displays only the high-quality candidates (see text for details). The percentages over the columns give the ratios of different shock types when only the corresponding quality is considered, and the uppermost percentages are for all the high-quality (2 and 3) candidates. The columns on the right panel present the levels of ESP signals associated to the highest quality fast forward (FF3) shock candidates. The shocks with no ERNE data (D) are excluded. The ERNE data availability for the FF3 shocks is shown in the inset (see text for details). The free-hand curve on the columns shows schematically the characteristics of the different ESP signals (see text for details).

3. Results

For the present preliminary analysis of proton energy spectra we chose all the FF3 shocks that are reported in the SOHO/Celias Shockspotter list, and exclude the cases where ERNE data availability is C (corrupted data) or D (no data). We determine the ERNE proton spectra for the resulting 151 cases in the energy range 1.5-12 MeV. For simplicity, we calculate the spectra by integrating proton intensities over 15 minutes centering in the shock passage times reported by Celias. This approach will cause some errors in the calculated spectra, because the possible ESP intensities do not necessarily peak at the shock passage time [9], and on the other hand the maximum intensities can be detected at different times at different energy channels. Therefore these spectra can be called "blind spectra". The motivation for this approach is that such a calculation could easily be done in real-time, and used for forecasting purposes. For the blind spectra we fit a power law in the standard form: $I(E) = aE^b$, where *I(E)* is the observed intensity at energy *E*, and *a* and *b* are the fit parameters, *b* being the spectral index.

Figure 2 presents the evolutions of the fit parameters during the solar cycle 23. There seems to be no trend in the evolution of the spectral indices. On the other hand, the *a*-parameters seem to get larger values during the solar activity maximum compared to the minimum. The standard deviations of both parameters seem to reach the minimum during the activity maximum. The last panels show the overall goodness of these blind power law fits. It is apparent that the majority of the spectra can be described by the power law, although there are also cases for which such fits failed.

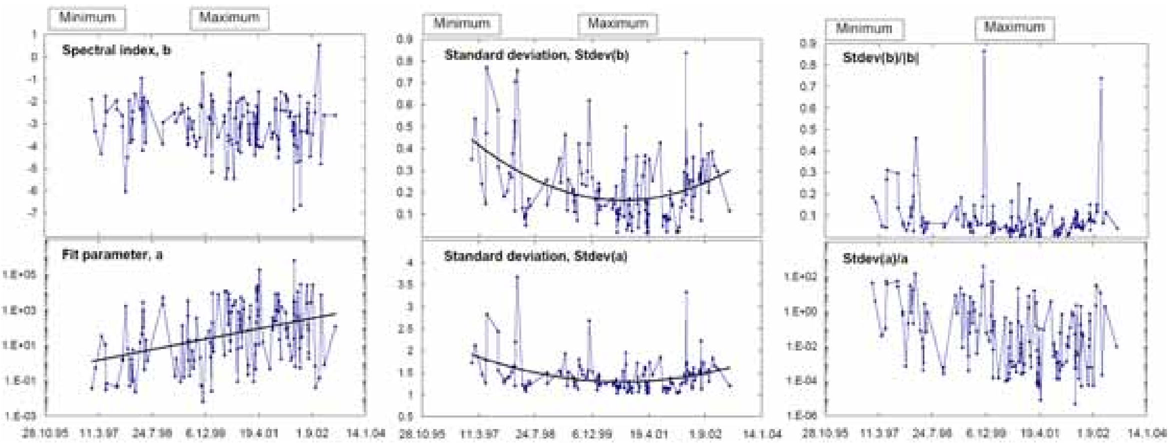

Figure 2. The evolutions of the power law fit parameters during the solar cycle 23. The approximate solar activity minimum and maximum are marked at the top of the panels.

The statistical results of the fit parameters are presented in Figure 3. On the left panel is the distribution of the spectral indices, which for the whole sample (shaded area) could be described with a Gaussian distribution. Nevertheless, the distribution breaks into two partly overlapping distributions when divided according to the ESP signal classification: the average spectrum for the "ESP: 3" group (clear peak) is significantly steeper than for the "ESP: 0" group (no ESP signal). On the right panel is presented the distribution of the *a*-parameters. As expected from Figure 2, the distribution for the whole sample looks non-Gaussian because of the solar cycle variation. Again, the sub-distributions of the "ESP: 3" and "ESP: 0" groups populate the different sides of the total distribution.

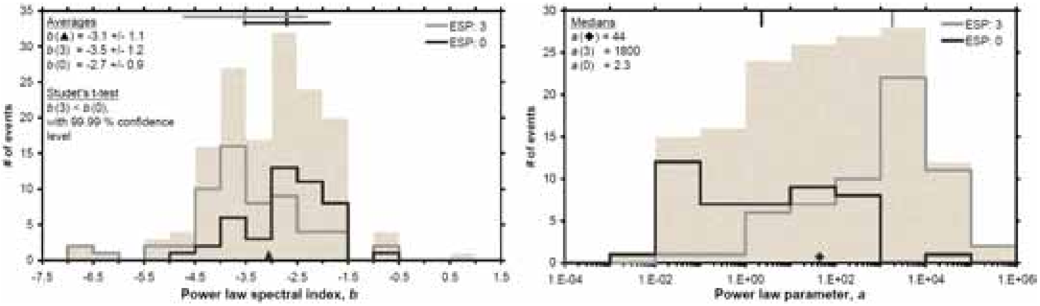

Figure 3. The distributions of the proton power law fit parameters. The proton spectra were derived for the 151 highest quality fast forward shock passages with integration time of 15 minutes centered on the SOHO/Celias shock passages. The fits of the proton spectra were made in the energy range of 1.5-12 MeV. The spectral indices, *b*, are presented on the left panel, and the other fit parameters, *a*, on the right panel. The shaded areas correspond to the distributions of all the 151 events. The distributions of the events with ESP signal levels 0 and 3 are marked with black and grey thick lines, respectively. Note, that the shaded areas include also the events with ESP signal levels 1 and 2. The spectral index averages and standard deviations of the "ESP: 0" and "ESP: 3" groups are marked on the left panel, whereas the medians of the *a*-parameters are given on the right panel. Triangle and diamond correspond to the average of the spectral indices and the median of the *a*-parameters for the whole sample, respectively.

4. Discussion

We have compiled a database containing several hundreds of IP shocks (and other structures) from May 1, 1996 to April 30, 2003. The initial input to the database came from the four ready-made lists, from which the list by Berdichevsky et al. seemed to have the highest rate of FF3 shocks (92 %). For all the highest quality shocks, the derived MHD modes are: FF = 83 %, FR = 8 %, SF = 6 % and SR = 3 %. Considering only FF3 shocks with ESP signal levels 3 or 0, we can conclude that 48 % (74/153) of the fast forward IP shocks produced ESPs (protons) at energies greater than 1.5 MeV, which is a somewhat higher ratio than the 27 % of Tsurutani and Lin [5] and 33 % of Lario et al. [7], but comparable to the 53 % of Kallenrode [6].

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References

[1] G.M. Lindsay et al., J. Geophys. Res. 99, 11 (1994).
[2] D.V. Reames, Space Sci. Rev. 90, 413 (1999).
[3] I.G. Richardson, E.W. Cliver, and H.V. Cane, Geophys. Res. Lett. 28, 2569 (1999).
[4] U.R. Rao, K.G. McCracken, and R.P. Bukata, J. Geophys. Res. 72, 4325 (1967).
[5] B.T. Tsurutani and R.P. Lin, J. Geophys. Res. 90, 1 (1985).
[6] M.-B. Kallenrode, J. Geophys. Res. 101, 24393 (1996).
[7] D. Lario et al., Proc. of the 10th Int. Solar Wind Conf., 640 (2003).
[8] G.C. Ho et al., Proc. of the 28th Int. Conf. Cosmic Rays, 3689 (2003).
[9] P. van Nes et al., J. Geophys. Res. 89, 2122 (1984).
[10] J. Meyer, G. Wibberenz, and M.-B. Kallenrode, Adv. Space Res. 13, 363 (1993).
[11] H.V. Cane, Nucl. Phys. B (Proc. Suppl.) 39A, 35 (1995).