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Temporal profiles of SEP events

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Abstract. This work is a preliminary study of 18 solar energetic particle (SEP) events detected by SOHO/EPHIN between 1996 and 2000. Temporal profiles of Impulsive and Gradual SEP events have been parameterized to determinate differences among SEP events depending on the magnetic connection and Physical conditions of the interplanetary transport.

1 Introduction

Temporal evolution of energetic particle intensities during SEP events observed at 1 AU is determined mainly from the injection at source and the interplanetary transport conditions (magnetic connection between the source and the observer and amount of scattering in the interplanetary medium). According to the "current paradigm" (Reames 1999), the extended intensity-time profiles of gradual events come from continued particle acceleration in spatially extended coronal/interplanetary shocks driven by fast CMEs. Impulsive events are associated with particle acceleration at flare site, locally in the lower corona, showing narrower emission cones (Kallenrode et al, 1992) and shorter time scales. The amount of interplanetary scattering depends on the inherent conditions of interplanetary medium, but also may be affected by the event size, since very large gradual events may generate interplanetary magnetic field turbulence themselves (Mason et al, 1989).

2 Instrumentation and data selection

Temporal profiles presented here were observed with EPHIN instrument onboard SOHO spacecraft, located in an halo orbit around lagrangian point L1. The instrument is a stack of five cylindrical solid state detectors (see Müller-Mellin et al, 1995 for a detailed description), it points permanently in the nominal direction of the interplanetary magnetic field, 45º West from sun-spacecraft line. EPHIN provides counting rates of Hydrogen and helium isotopes in the energy range 4-53 MeV/n, and electrons between 0.25 and 10.3 MeV. Maximum temporal resolution is 1 minute. For this study we have selected counting rates in the lower energy channels: 4.3-7.8 MeV/n for Hydrogen and helium nuclei and 0.25-0.7 MeV for electrons. Pulse height analyzed data have also been examined to obtain ^{3}He/^{4}He ratios for the identification of impulsive events.

We have selected 18 SEPs events between July 1996 and August 2000. Seven events have been classified as impulsive, all of them have event-averaged ^{3}He/^{4}He ratios greater than 0.3 in the energy range 5-9 MeV/n. There is not significant increase in the ion fluxes beyond 30 MeV/n for these events. Nine events have been classified as gradual, all of them have associated CMEs and low ^{3}He/^{4}He ratios (^{3}He is not visible above background for most of them). We have checked solar wind data from MFI and SWE instruments onboard WIND spacecraft, and interplanetary shocks passages have been identified for six of these events in the four days following the CMEs. Five of the gradual events presented here show ion acceleration beyond 50 MeV/n, and they have been detected at ground level (GLEs). Finally, we have selected two events classified in the bibliography as mixed or hybrid events: July 9, 1996 (mixed-impulsive, Laitinen et al, 2000) and December 24, 1996 (mixed-gradual, McKenna-Lawlor et al, 1999).

3 Data analysis

The fifth and sixth columns in Table 1 list the onset times for electrons and protons, determined using 5 minute averaged counting rates. The next four columns contain the

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parameters of the associated flare (location, Hα and X-ray classification, time of maximum in X-ray, and X-ray duration, obtained from Solar Geophysical Data). Columns 11-13 list the parameters of the associated CMEs (LASCO data): First appearance time in C2 coronograph, estimated speed, and direction of propagation. Last column contains the passage times of IP shocks by the position of WIND spacecraft.

Using 30 minute averaged counting rates of electrons, protons and helium nuclei, we measured the time from the onset to the absolute maximum (T_r), the time from absolute maximum until the recovery of initial flux level (T_d), and the ratio R between the maximum differential flux and the differential flux at onset time. When the event is truncated by a subsequent one, T_d is only a lower limit. We also tried a parameterization of the profiles, fitting them to a pulse function:

$$j = j_0 + A(1 - e^{-\frac{t-t_0}{t_1}})^p e^{-\frac{t-t_0}{t_2}} \quad (1)$$

where, j_0 (ambient flux level) and t_0 (onset time) are fixed parameters, and A (amplitude), P (power), τ_1 and τ_2 (characteristic rise and decay times) are fitted parameters. We use this parameterization only to characterize amplitude and rise and decay times, no attempt has been made to modelize interplanetary transport.

Table 2 lists the measured parameters Tr, Td, R and the fitted parameters τ_1, τ_2, A for electrons, protons and helium nuclei. Figure 1 shows the temporal profiles of four gradual and four impulsive events selected among the 18 events presented here.

4 Conclusions

- Event duration and relative increase provide a good distinction between impulsive and gradual events. Total duration of impulsive events for electrons, protons and helium nuclei do not exceed two days. Relative increase factors in particle fluxes are less than 200 for impulsive events, and can reach more than 10^5 for gradual events. Figure 1 shows A vs T_d plot for electrons.
- Fitted parameter τ_1 provides a good characterization of the rise phase steeping, but there is not clear distinction between gradual and impulsive events. Gradual events tend to rise slower than impulsive ones, but there are gradual events with steep rise (May 27, 199) and impulsive events with smooth rise (August 10, 1997).
- All the gradual events show a long diffusive decay phase ($\tau_2 > 0.4$ for H and He). The shape of the decay phase may be affected by interplanetary disturbances like shocks and magnetic clouds. Sometimes (e.g. June 6, 2000) shock passage can be appreciated as a peak in particle fluxes caused by particles trapped near the shock (energetic storm particles, ESP).

Table 1. Selected SEP events and associated flares and CMEs.

				Onset time		Flare				CME			
Event	Class	Date (m d, y)	Date (DOY)	~0.3 MeV electrons (hh:mm)	~6 MeV protons (hh:mm)	Hα Location	Hα/XR Class	Xray tmax (hh:mm)	Xray durat. (min)	C2 App. time (hh:mm)	Primary speed (Km/s)	Direction of propag.	IP Shocks passages DOY:hh:mm
1	MI	Jul. 9, 1996	191	09:04	09:35	S10W30	1B/X2.6	09:12	48	12:28	426	W	-
2	MG	Dec. 24, 1996	359	13:22	15:00	-	-/C2.1	13:11	20	13:28	300	W	-
3	G	Apr. 1, 1997	91	>8:58	14:37	S25E16	1B/M1.9	13:48	36	15:18	296	E	-
4	G	Apr. 7, 1997	97	14:16	16:07	S30E19	3N/C6.8	14:07	29	14:27	830	Halo	100:13:00
5	I	Aug. 10, 1997	222	>17:47	20:28	-	-/B8.6	18:33	27	-	-	-	-
6	G	Sep. 24, 1997	267	03:00	05:45	S31E19	1B/M5.9	02:48	9	02:51[a]	>300	SE	(274:01:00)
7	G	Nov. 4, 1997	308	06:14	08:35	S14W33	2B/X2.1	05:58	10	06:10	830	Halo	310:22:10
8	G	Nov. 6, 1997	310	12:12	15:30	S18W63	2B/X9.4	11:55	12	12:10	1560	W	313:10:00& 313 22:30
9	I	Nov. 28, 1997	332	15:25	16:54	(N19E54)	(SF/C2.2)	(15:15)	(9)	-	-	-	-
10	G	Apr. 20, 1998	110	10:25	11:00	S43W90	EPL/M1.4	10:21	100	10:07	1638	W	113:17:30
11	I	Mar. 21, 1999	80	17:00	18:18	?	?	?	?	-	-	-	-
12	I	Mar. 22, 1999	81	18:06	21:00	?	?	?	?	-	-	-	-
13	I	May. 12, 1999	132	06:55	08:22[b]	?	?	?	?	06:26		N	-
14	G	May. 27, 1999	147	10:55	11:51	-	-/C1.2	09:17	7	11:06	?	Halo	-
15	I	Nov 1, 1999	305	00:00	02:45	N09E12	SF/C1.7	00:30	31	-	-	-	no valid data
16	G	Apr. 4, 2000	95	15:21	16:50	N16W66	2F/C9.7	15:41	53	16:32	984	Halo	97:16:27& 98:09:16
17	G	Jun. 6, 2000[c]	158	16:48	19:15	N20E18	3B/X2.3	15:25	42	15:54	908	Halo	160:09:04
18	I	Aug. 22, 2000[d]	235	00:13	02:23	-	-/C2.5	00:21	32	<00:54	?	NW	-

[a]Moreton wave observed by SOHO/EIT in NOAA AR 8088
[b]Helium onset time (there is not increase in proton flux during this event)
[c]Very long rise time in particle fluxes. Evidence of multiple injection (X2.3 & X1.2 flares at 158:15:25 & 159:15:53 both of them accompanied by halo CMEs)
[d]5 minute averaged fluxes show a second peak probably associated with a SF/C1.1 flare at 235:05:16 in NOAA AR 9131 (N15W34)

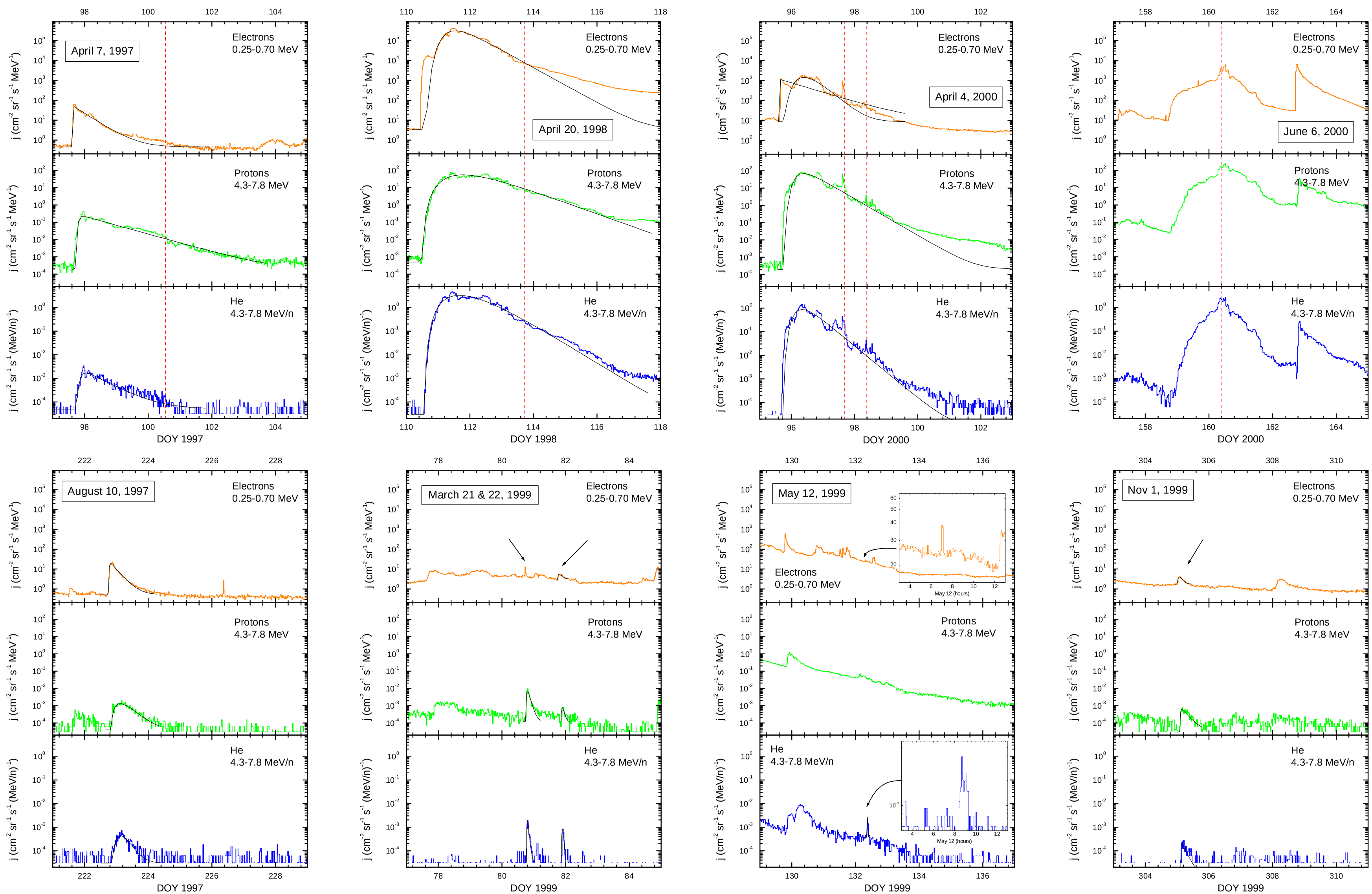

Fig.2. Thirty minute averaged differential fluxes of 4 gradual (top) and 4 impulsive (bottom) events selected among the 18 events studied in this work. Axis scales are the same for all graphs. Dashed lines mark IP shocks passages. Helium fluxes are $^3He+^4He$

Table 1. Measured and fitted parameters of temporal profiles. (Tr, Td, τ_1, and τ_2 in days. A in $cm^{-2}\ sr^{-1}\ s^{-1}\ (MeV/n)^{-1}$, R adimensional)

	Electrons						protons						Helium					
Event	Tr	Td	R	t1	t2	A	Tr	Td	R	t1	t2	A	Tr	Td	R	t1	t2	A
1	0.15	2.71	262	0.004	0.128	998	0.11	2.99	2333	0.013	0.402	0.03	0.11	2.13	237	0.011	0.449	$3.9{\cdot}10^{-3}$
2	0.06	1.68	197	0.002	0.222	155	0.44	3.50	1300	0.123	0.501	0.09	-	-	-	-	-	-
3	0.50	5.40	75.4	0.103	0.668	85.5	0.96	5.96	848	0.350	0.961	0.07	0.73	2.32	28.3	0.905	0.596	$2.1{\cdot}10^{-3}$
4	0.09	3.46	144	0.009	0.429	59.8	0.31	6.22	2529	0.051	0.843	0.34	0.27	2.64	70.1	0.092	0.616	$3.3{\cdot}10^{-3}$
5	0.14	1.64	45.7	0.017	0.234	30.6	0.36	1.65	50.0	0.224	0.269	$8.7{\cdot}10^{-3}$	0.34	0.98	23.7	0.219	0.182	$6.2{\cdot}10^{-3}$
6	0.11	10.7	199	0.009	0.435	55.3	0.21	7.48	162	0.173	0.980	0.02	-	-	-	-	-	-
7	0.07	2.78	1344	0.018	0.282	$1.5{\cdot}10^{4}$	0.23	2.70	450	0.030	1.557	9.32	0.23	2.70	$1.3{\cdot}10^{4}$	0.017	1.262	0.24
8	0.48	7.53	1509	0.105	0.434	$3.3{\cdot}10^{5}$	0.58	7.32	96.0	0.173	0.620	245	0.35	7.34	265	0.134	0.599	6.20
9	0.09	0.96	27.7	0.003	0.085	95.0	0.10	1.02	25.0	0.015	0.193	0.02	0.08	0.79	55.0	$9.0{\cdot}10^{-4}$	0.164	$4.0{\cdot}10^{-3}$
10	1.06	9.57	$1.3{\cdot}10^{5}$	0.366	0.493	$6.2{\cdot}10^{6}$	0.98	9.55	$2.5{\cdot}10^{5}$	0.929	0.659	1405	0.88	9.45	$1.6{\cdot}10^{5}$	1.115	0.523	153
11	0.02	0.08	2.80	-	-	-	0.08	0.50	83.3	0.016	0.070	0.03	0.06	0.27	66.7	0.009	0.033	0.02
12	0.04	0.40	2.01	0.023	0.132	5.3	0.09	0.27	8.1	0.018	0.055	$2.6{\cdot}10^{-3}$	0.07	0.17	104.3	0.053	0.015	1.32
13	$4{\cdot}10^{-3}$	$9{\cdot}10^{-3}$	1.60	-	-	-	-	-	-	-	-	-	0.02	0.10	6.5	0.012	0.0076	0.61
14	0.06	5.35	541	0.002	0.169	1909	0.17	5.37	$2.7{\cdot}10^{4}$	0.007	0.535	2.49	0.06	4.83	286	0.005	1.165	$3.3{\cdot}10^{-3}$
15	0.08	0.37	2.40	0.086	0.068	20.8	0.11	0.71	26.8	0.013	0.204	10^{-3}	0.09	0.38	46.3	0.006	0.151	$2.6{\cdot}10^{-4}$
16	0.71	4.03	221	$4{\cdot}10^{-4}$	0.897	1184	1.08	9.33	$4.2{\cdot}10^{5}$	0.238	0.411	653	0.64	5.31	$1.8{\cdot}10^{5}$	0.270	0.395	8.95
17	1.81	4.00	677	-	-	-	1.75	3.98	$1.1{\cdot}10^{4}$	-	-	-	1.56	3.79	$1.4{\cdot}10^{4}$	-	-	-
18	0.04	1.29	17.6	0.001	0.055	120	0.09	1.44	24.7	1.124	0.463	$7.4{\cdot}10^{-3}$	0.09	2.15	125.0	0.586	0.532	$2{\cdot}10^{-3}$

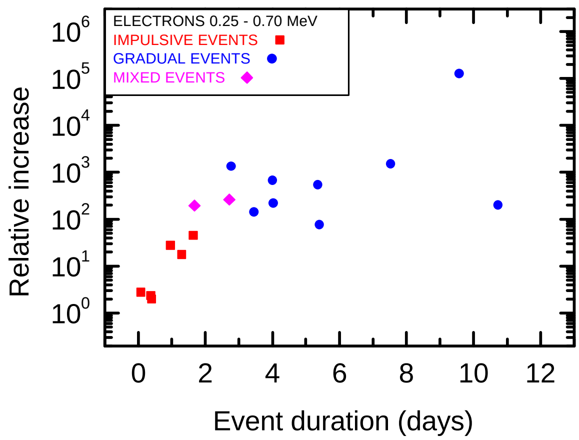

Fig.2. Events durations vs relative increases for 0.25-0.70 MeV electrons.

- Global shape of temporal profiles for gradual events are usually well explained on basis of the magnetic connection between the observer and the 'nose' of the shock where acceleration is strongest (Reames, 1999), which is optimal early in the event for west connected events, and later for east connected events. The extremely long rise times observed in some events (Juny 6, 2000) may be due to additional particle acceleration in shocks driven by a second CME (Kahler, 1993).
- Some gradual events show a prompt peak followed by a secondary maximum or a plateau. This component might be accelerated in the flare but it only could be determined with a more detailed study.
- Candidate flares only could be found for four impulsive events. This sample is too limited to establish correlations between flare properties and SEP profiles. However, temporal profiles for these events probably are mainly determined by interplanetary transport conditions. May 12, 1999 event lasted less than two hours, coinciding with a period of very low solar wind density. In some impulsive events the shape of temporal profiles of electrons, protons and helium are very different between them.

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