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Comparison among solar energetic particle events detected by COSTEP/SOHO* experiment

R. Gómez-Herrero[1], L. Del Peral[1], J. J. Blanco[1], M. Prieto[1], T. Nieves-Chinchilla[1], M. M. Espinosa[1], C. Martín[1], M. D. Rodríguez-Frías[1], J. Sequeiros[1], H. Kunow[2], R. Müller-Mellin[2] and H. Sierks[2]

[1] *Departamento de Física, Universidad de Alcalá, 28871 Alcalá de Henares, Madrid, SPAIN*
[2] *Institut für Reine und Angewandte Kernphysik. Otto-Hahn-Platz 1, D-24118 Kiel, GERMANY*

Abstract

A comparative study of three impulsive solar events produced in July 1996 and two gradual-CME associated events produced in November 1997 has been performed using data from EPHIN instrument aboard SOHO spacecraft. Temporal evolution of the differential energy spectra of electrons in the energy range 0.25-10.4 MeV and H & He nuclei in the energy range 4.3-53.0 MeV/n has been determined for these events. Isotopic abundances of H and He have been obtained separately for each event.

1 Introduction:

The SOHO observatory, launched in December 1995, reached its final destination, an halo orbit centered in the L1 Lagrange point, in February 1996 from where it is continuously observing the Sun from its privileged position outside the Earth magnetosphere. The Electron Proton Helium Instrument (EPHIN) and the Low Energy Ion and Electron Instrument (LION) performs the COSTEP (Müller-Mellin et al., 1995) experiment that studies the suprathermal and energetic particle populations of solar, interplanetary, and galactic origin. SOHO is a 3-axis stabilized spacecraft where the EPHIN and LION sensors point to the nominal interplanetary magnetic field direction at 0.9 AU and 45º West of the spacecraft-Sun line.

2 Observations and data analysis.

In July 1996, at the beginning of the 23th solar cycle, three solar proton events (SPE) produced at the same NOAA 7978 active region were detected by the COSTEP collaboration sensors the 9th (observed on the solar disk at S10W30), 12th (at S11W72) and 14th (not observed, beyond the limb). The aim of this work is the comparison of these SPEs with the two events detected at ground level (GLEs) during November 1997, originated at the NOAA 8100 active region, observed on the solar disk at S14W13 (Nov. 4 event) and S18W63 (Nov. 6 event) respectively. High solar activity was observed during this month, and a total of 93 X-ray flares were detected by the satellites of the NASA International Solar-Terrestrial Physics (ISTP) program (Solar Geophysical Data, 1997). Table 1 lists the X-ray flares associated to the five particle events studied here.

Table 1. *X-ray flares associated to the particle events studied in this paper. 2nd column shows the time intervals selected for the analysis of EPHIN data.*

Event Date	Time Interval Selected (doy)	Start (UT)	Max (UT)	End (UT)	Disk Location	NOAA Region	X-ray Classif.	H_α Classif.
1996 Jul. 9	191.35-194.38	9:01	9:12	9:49	S10W30	7978	X2.6	1B
1996 Jul. 12	194.38-196.64	15:13	15:30	16:31	S11W72	7978	C4.9	1F
1996 Jul. 14	196.64-198.00	13:30	15:00	15:00	-	-	C1.6	-
1997 Nov. 4	308.26-310.51	5:52	5:58	6:02	S14W33	8100	X2.1	2B
1997 Nov. 6	310.51-317.84	11:49	11:55	12:01	S18W63	8100	X9.4	2B

2.1 Isotopic abundances. Pulse height data have been discriminated following the procedure by Bronchalo et al., 1999 in order to obtain isotopic abundances of hydrogen and helium. Based on these results background subtraction has been performed. The isotopic abundances obtained are listed in Table 2 and differences in the isotopic composition between July 1996 and November 1997 events have been observed. The November events present an isotopic composition far from those of the quiet time periods values due to their high intensities. By contrast the isotopic composition of the July 96 events present low intensities and their abundancies are close to those of the quiet time periods. Figure 1 shows the dependence of ^{4}He/p ratio with time in the energy ranges: 4-8 MeV/n, 8-25 MeV/n, 25-41 MeV/n and 41-50 MeV/n. Figure 2 shows the energy dependence of ^{4}He/p ratio for November 1997 events and July 9th 1996 event.

Table 2. *Hydrogen and Helium isotopic abundancies in the energy range from 4 to 50 MeV/nucleon. -Quiet times are obtained for the 152 first days of the 1996 EPHIN data, during quiet time periods at the end of the 22nd solar cycle. SEP abundances are the average of 15 large SEP events in the period 1974-1981.*

	Energy range	**^{4}He/p**	**^{3}He/^{4}He**	**^{2}H/p**
1996 July 9 event	4-50 MeV/n	$(1.8\pm0.2)\cdot10^{-1}$	$(1.8\pm0.9)\cdot10^{-2}$	$(4\pm3)\cdot10^{-3}$
1996 July 12 event	4-50 MeV/n	$(2.0\pm0.2)\cdot10^{-1}$	$(5\pm7)\cdot10^{-2}$	$(6\pm7)\cdot10^{-3}$
1996 July 14 event	4-50 MeV/n	$(5\pm2)\cdot10^{-1}$	$(8\pm10)\cdot10^{-2}$	$(6\pm8)\cdot10^{-2}$
1997 November 4 event	4-50 MeV/n	$(2.10\pm0.02)\cdot10^{-2}$	$<1.4\cdot10^{-2}$	$<4.3\cdot10^{-3}$
1997 November 6 event	4-50 MeV/n	$(2.09\pm0.01)\cdot10^{-2}$	$<1.4\cdot10^{-2}$	$<5.3\cdot10^{-3}$
1996 quiet time periods	4-50 MeV/n	0.70 ± 0.02	$(3.2\pm0.4)\cdot10^{-2}$	$(1.7\pm0.2)\cdot10^{-2}$
SEP$^{(*)}$	7-15 MeV/n	10^{-2}	<0.03	$<10^{-3}$
Photospheric$^{(*)}$		0.11	$1.7\cdot10^{-4}$	$1.6\cdot10^{-5}$

* *Mc. Guire et al., 1986*

The same isotopic ratios has been obtained for flares temporally close that took place in the same active region. In the July 1996 events, an increase of one order of magnitude in the helium abundances were observed (Figure 1). Nevertheless the helium overabundance found are not intrinsic features of the events analyzed but of the anomalous component of the cosmic radiation during the solar minimum, that has to be taken into account for these low intensity events. This result has been confirmed with the July 12th and 14th events where the ratio ^{4}He/p increases substantially while these events present very low intensities.

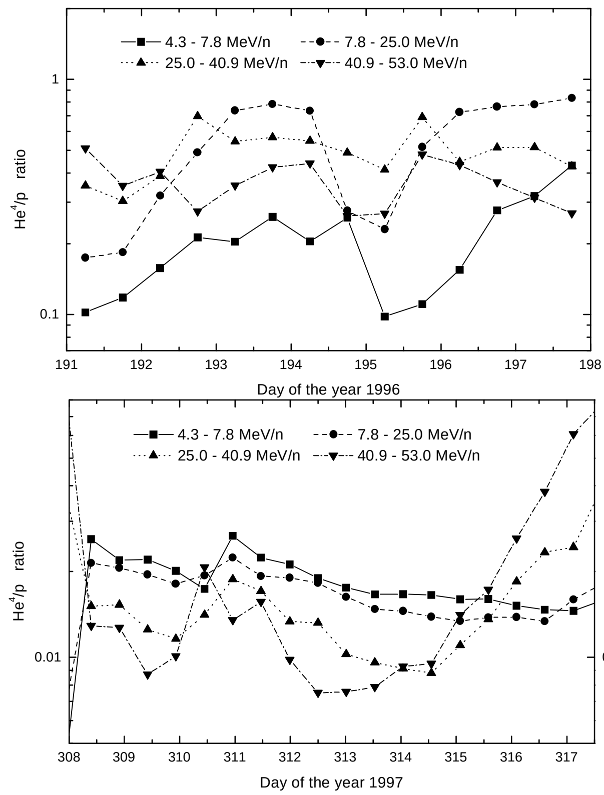

***Figure 1**. ^{4}He/p ratio vs time during July 1996 events (top) and November 1997 ones (bottom).*

2.2 Differential energy spectra. Energy spectra for electrons, protons and helium nuclei of the selected events have been obtained using Pulse-height-analyzed particles detected by the EPHIN instrument. Pulse-height spectra have been normalized to the fluxes data.

In order to examine the temporal behaviour of the differential energy spectra in the periods 8th-15th of July 1996 and 4th-13th of November

1997, we have taken temporal subintervals and fitted the spectra to a power-law $dJ/dE = j_s E^{-\gamma}$, where j_s is a scale factor and γ is the spectral index. Figure 3 shows the behaviour of the spectral index for electrons, protons, and Helium of the July 96 (Figure 3B) and November 97 (Figure 3B') events. It can be observed how at the beginning of the event the proton energy spectrum is hard (i.e. 0.65 for the November 4th event), becoming softer as the time from the flare increases. By contrast, the electron differential energy spectrum becomes harder at late stages of the event. Electrons are affected by the passage of an halo CME observed by LASCO on November 4th that produces high-energy electrons accumulation in the front part of the CME passage (Figure 3B').

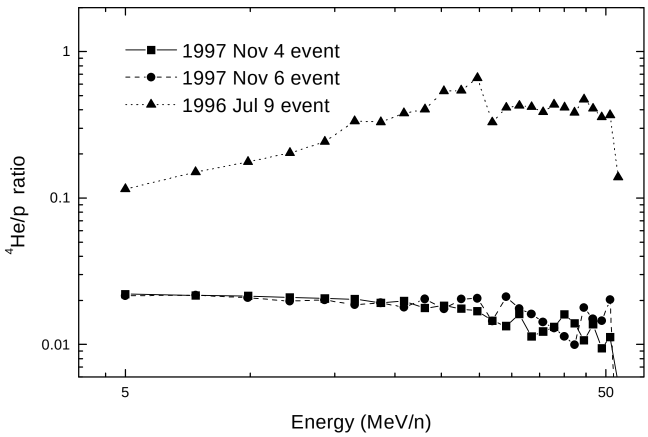

Figure 2. *Energy dependence of ^{4}He/p ratio.*

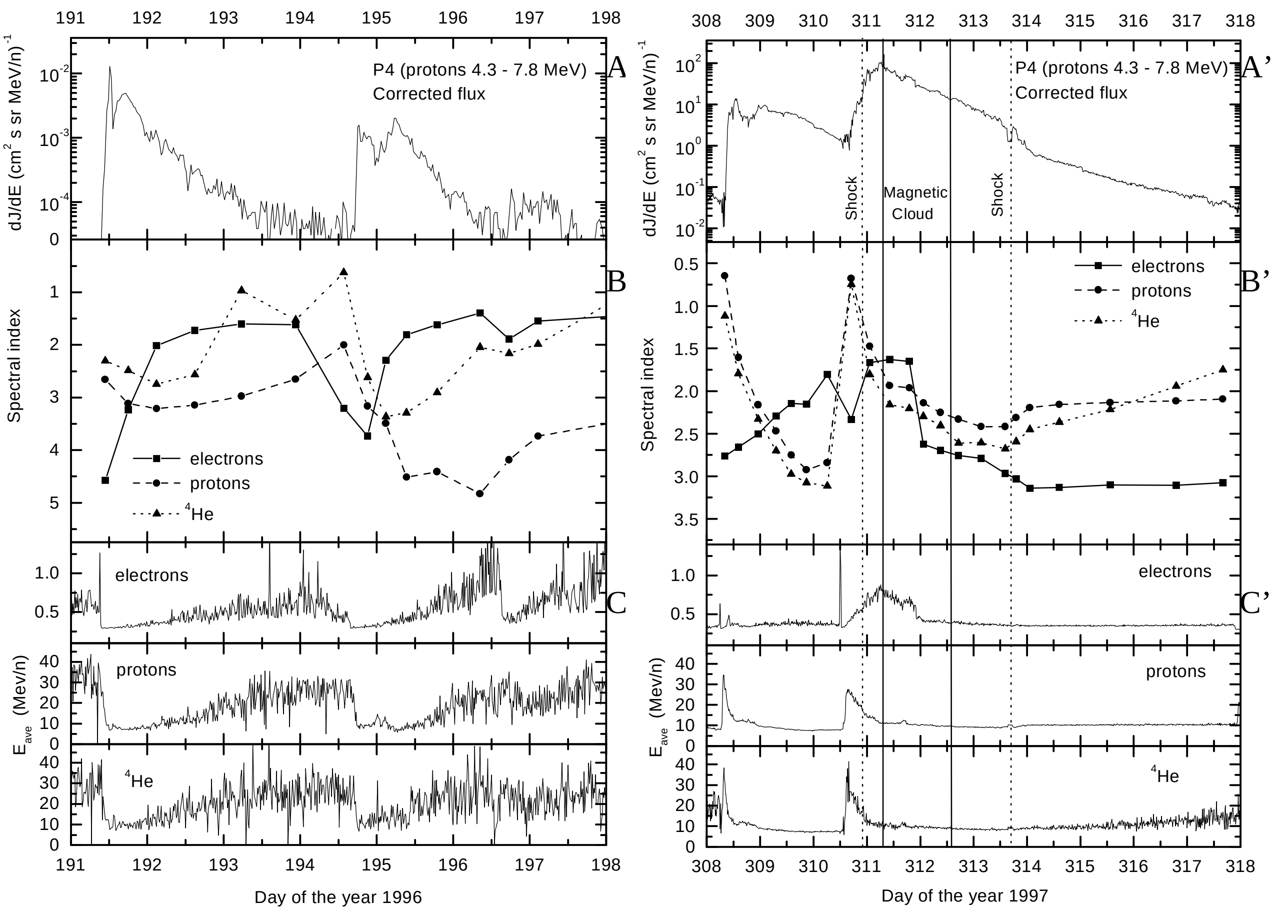

Figure 3. *(A,A'): Proton flux in the P4 channel of the EPHIN instrument during July 1996 (left) and November 1997 (right). (B,B'): Temporal evolution of the spectral index for electrons, protons, and helium-nuclei differential energy spectra of the July and November events. (C,C'): Average energy of electrons, protons and helium nuclei. Dashed lines on the right panel mark the passage of shocks associated to Nov 4 and Nov 6 CMEs.*

Figures 3C and 3C' show the average energy per particle calculated in the energy range covered by EPHIN (0.25-10.4 MeV for electrons, and 4.3-7.8 MeV/n for H and He nuclei). This parameter confirms the tendency observed on the spectral indexes: For November 1997, the proton and ^{4}He energies reach their highest values at the beginning of the events and then decay to a constant value. The increase in helium energy (decrease in γ) at the end of the November 6th event is caused by the galactic contribution. For July 1996, the average energy is high when galactic component is dominant, and it is low when particles originated in a solar event arrive to the instrument.

3 Conclusions.

July 1996 and November 1997 events have been compared and their isotopic abundancies have been obtained. The events that took place in the same active region present a similar pattern, while important discrepancies have been found between both kind of events. From the temporal behaviour of the ^{4}He/p ratios, it has been found for July 1996 events low helium abundancies during the SPEs, while at the end of the events the helium abundances reach the typical values of the quiet time periods. November 1997 events present an opposite behaviour on the ^{4}He/p ratios, and the major increase of ^{4}He/p ratio was observed during November 6th event.

The differential energy spectra of the events have been obtained and a power-law has been fitted to the spectra. The spectral indexes of electrons, protons and helium have been found. The main conclusion of this analysis is that energetic ions are detected since the beginning of the event, while high energy electrons detection takes place at the end of the SPE. Also it has been checked how a CME passage can affect the electron spectrum that becomes harder from the detection of the shock driven by the CME until half of the CME has passed, when the spectrum turns softer quickly.

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References

Müller-Mellin, R. et al, 1995, Solar Physics 162, 483.
Bronchalo, E. et al, 1999, Nuclear Instruments & Methods in Physics Research-A 425, 361.
Mc. Guire, R.E. et al, 1986, ApJ 301,938.