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SOHO/ERNE Measurements of Energetic He, O and Fe Fluxes during the November 6, 1997 Solar Event

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Abstract

The energetic solar particle event on November 6, 1997 produced the highest particle intensities above MeV/nucleon since the launch of the Solar and Heliospheric Observatory (*SOHO*) spacecraft in December 1995. There was a X-ray flare associated with a coronal mass ejection (CME) which had an exceptionally high leading edge velocity (1560 km/s) as observed by the Large Angle and Spectrometric Coronagraph (LASCO) on board *SOHO*. The Energetic and Relativistic Nucleon and Electron experiment (ERNE), also on board *SOHO*, measured high He, O, and Fe fluxes in energy channels from 4 to 80 MeV/nucleon. The ERNE observations might indicate that there were two energetic particle sources operative in solar atmosphere and/or interplanetary space during several hours after the solar flare eruption.

1 Introduction:

The November 6 particle event was associated with a soft X-ray flare (class X9.4/2B, location S18^{0}W63^0; Solar Geophysical Data 1997) with the maximum intensity at 11:55 UT. At the same time the coronagraph LASCO on board *SOHO* detected an emission of coronal mass ejection. Several ground-based stations observed type III and IV radio bursts and also desimetric bursts (DCIM) starting at 11:52 UT (SGD, 1997). One radio telescope (Izmiran) reports on observation of type II bursts starting at 11:53 UT. The event produced also ground-level enhancements observed by neutron-monitors.

In this work we present time-intensity profiles of solar energetic O and Fe particles at energies above and below 20 MeV/nucleon and compare them with He profiles in the same MeV/nucleon channels. The main purpose of our study is to investigate whether the O and Fe profiles indicate the presence of two injection components as implied by the *SAMPEX* (Mazur et al. 1999) and *ACE*/SEPICA (Möbius et al. 1999) measurements of Fe charge state.

2 Observations:

The ERNE instrument consists of two separate particle sensors, Low Energy Detector (LED) and High Energy Detector (HED) covering the energy range of nuclei from a few MeV/nucleon up to few hundreds of MeV/nucleon. The description of the instrument is given in Torsti et al. (1995).

Figure 1 plots the time-intensity profiles of O and Fe in two energy channels. Time zero of the logarithmic time scale indicates the maximum of the X-ray burst. The vertical line represents the time of the passage of the shock wave of the November 4 event. The profile of the O intensity in 4-13 MeV/nucleon at the maximum is broad, almost constant during 23 UT November 6 - 7 UT on November 7. The profile of the Fe flux is more sharp. The general profiles of both intensities of O and Fe were similar during the whole event. The Fe intensity was in the energy range 4-13 MeV/n on the average 66 % from the O intensity during 6-8 November.

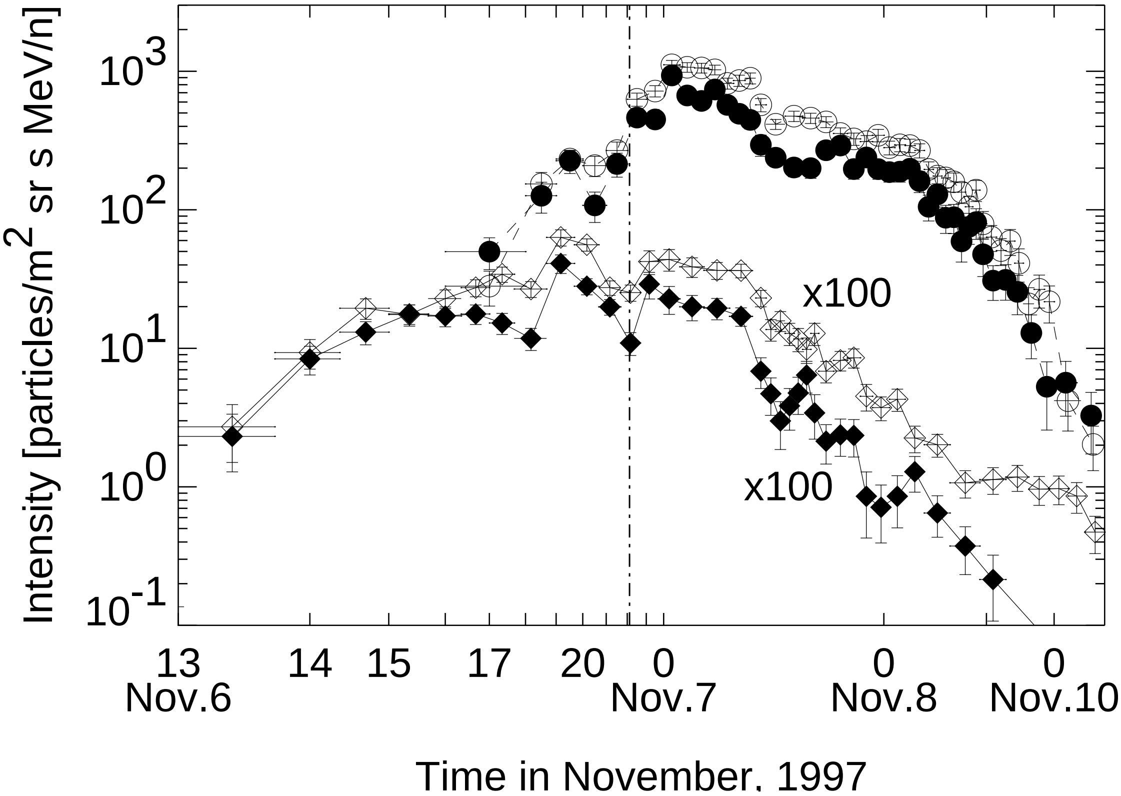

Figure 1: Time-intensity profiles of O and Fe during the November 6, 1997 event. The intensities in the LED energy channel 4-13 MeV/nucleon are shown for O (open circle) and Fe (black circle). The intensities in the high energy channel of HED, 50-80 MeV/nucleon, are respectively for O (open diamond) and Fe (black diamond).

In the high energy channel the intensity of O reached the maximum 0.63±0.08 particles / $m^2 \cdot s \cdot sr \cdot$MeV/nucleon at 18:30 UT. The maximum level was maintained for 1.5 hours. Then the intensity dropped momentarily to 0.25±0.03 particles / $m^2 \cdot s \cdot sr \cdot$MeV/nucleon at 22 UT, and climbed up again. During 6-9 UT on November 7 the intensities dropped rapidly in all four energy channels, e.g. in the case of high-energy O, 2.5-folded, and started quite a smooth exponential decrease which continued for 3 days.

The Fe intensity in the energy range 50-80 MeV/nucleon showed a fast rise during 13:30-14:30 UT. It initiated a new rapid rise at ≈18 UT which brought the intensity to its event maximum level, 0.41±0.08 particles / $m^2 \cdot s \cdot sr \cdot$MeV/nucleon at 19 UT. The width of the maximum was 1.5 hours. A dip in the intensity was seen at 22 UT as was in the case of O. The drop during 6-9 UT, 5.3-fold, was larger than that of the O intensity.

Figure 2 gives the time development of the elemental ratios of O/He and Fe/He during 6-7 November. The high-energy O/He and Fe/He ratios are below the low-energy ratio. There are, however, significant changes in the ratio during the course of time, and also between the high- and low-energy channels.

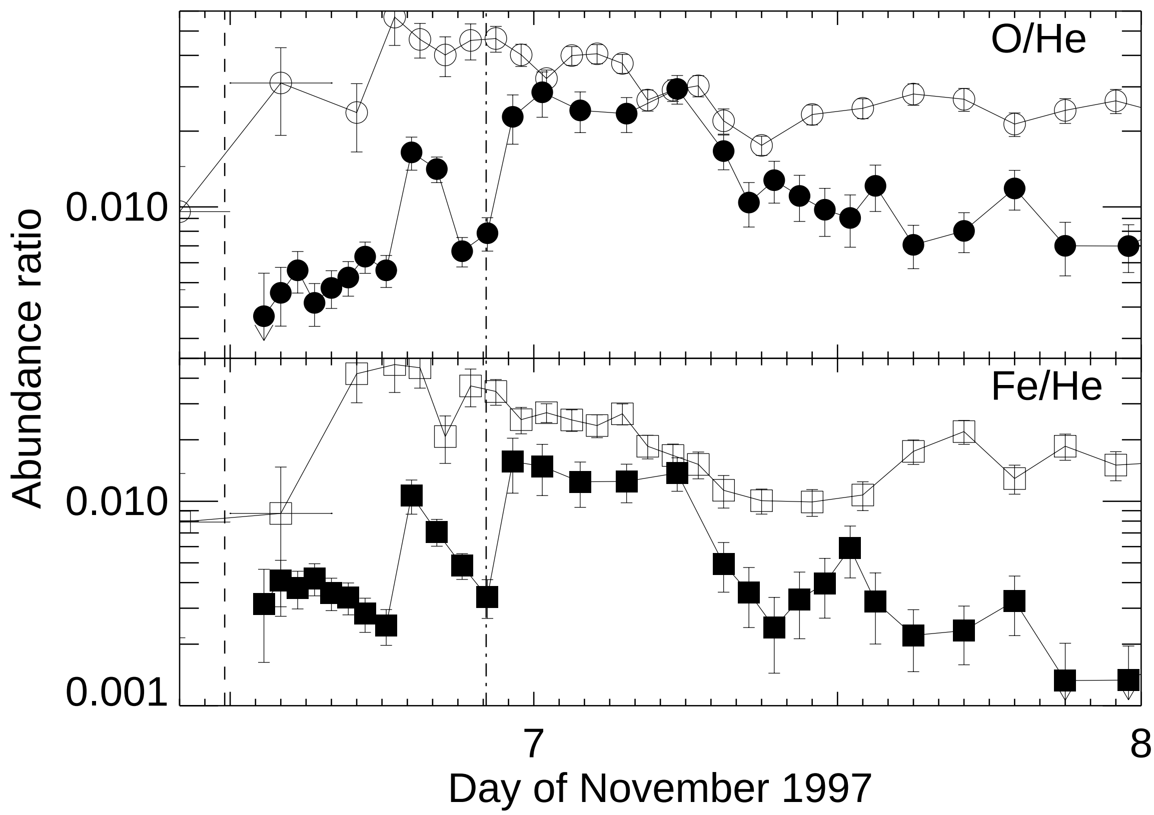

Figure 2: Time sequence of O/He (upper panel), and Fe/He (lower panel) in energy ranges 4-13 (open circle) and 50-80 MeV/nucleon (black circle). Vertical lines represent the time of the maximum of X-ray burst (dash), and the passage of the shock wave of the November 4 event (dot-dash).

As seen in Figure 2, both the O/He and Fe/He ratios either reached the maximum abundance ratios or changed significantly at about 18 UT. In the low-energy channel the O/He and Fe/He ratios reached the event maximum, 0.057±0.02 and 0.047±0.02, respectively. This means that the maximum of the abundance ratios was achieved when the intensities were still increasing, and far from their maximum level.

In the high-energy range, the O/He and Fe/He ratios jumped up to 0.015±0.002 and 0.009±0.002. The ratios returned back to the level prevailing before 18:30 UT November 6 near 5-6 UT November 7. Outside these periods of higher heavy-ion concentration, the O/He and Fe/He ratios developed uniformly and steadily.

Based on the interplanetary magnetic field measurements by *WIND*/MFI there were no major changes in the magnetic field direction during the onset of the event.

3 Discussion:

The slow decrease of the proton and He flux profiles (Figure 1) is representative to continuous particle acceleration by a CME-driven shock propagating into interplanetary space. Based on the observations by LASCO, C. Ct. Cyr (private communication 1998) estimated that a partial CME halo event appeared in LASCO/C2 coronagraph at 12:10 UT on November 6, 1997. The speed of the leading edge was exceptionally high, 1560 km/s. The constant ratios of heavy elements to helium, except for the interval from 18 UT November 6 to 7 UT November 7, (Figure 2) both in low- and high-energy range witnesses that the particle production, storage in sheath region of the strong November 6 shock and shock acceleration/reacceleration, continued up to a distance of few AU.

The overall time-intensity profiles of all species inspected in this study, i.e. He, O, and Fe, indicate a common behaviour during the whole 4-day period November 6-10 which is typical for particles injected from a strong IP shock. In all cases, the passage of the November 4 shock caused a dip in the intensity profiles at E > 20 MeV/nucleon. However, the dip was more pronounced in the case of O and Fe than for H and He. The abundance ratios of heavy elements relative to helium increased during the passage of the sheath region between the November 4 shock and magnetic cloud. This enhancement can be seen in all ratios shown in Figure 2, i.e. O/He and Fe/He.

4 Conclusions:

The observed variations in the abundance ratios of heavy elements to helium give evidence to the existence of two separate injection processes. The first injection was caused by the interplanetary shock driven by the fast CME with leading edge velocity of 1,560 km/s. The onset of a heavy particle intensity enhancement above 20 MeV/nucleon observed by ERNE on board SOHO started at 13:30 UT, about 40-50 minutes after the leading edge of the CME had reached the distance of about 8-9 solar radius above the solar surface. The O/He and Fe/He ratios were at 14 UT 0.0046 ± 0.0017 and 0.0041 ± 0.0019 respectively, and kept that level until 18 UT.

Around 18 UT on November 6, two important changes took place in the particle intensities and abundance ratios above 20 MeV/nucleon. First, at 17:30 UT, He, O and Fe nuclei intensities started a new growth with no apparent change in the overall local magnetic field. About an hour later, the abundance ratios of O/He and Fe/He increased rapidly, in about 60 minutes, 2.6 and 2.9-fold. These ratios stayed at that high level almost unchanged until 6 UT on November 7. The passage of the November 4 shock caused a clear dip of duration of ≈ 2 hours in elemental ratios. From 9 UT on November 7 to the end of the high energy particle event, the fluxes and abundance profiles showed a smooth decrease. These observational results lead us to conclude that most of the time O and Fe nuclei were injected by the interplanetary shock associated with the coronal mass ejection emitted around 12 UT on November 6. However, between 18 UT November 6 and 9 UT November 7, particle fluxes were dominated by particle population with a different elemental composition. Thus, our results support the conclusions by Mazur et al. 1999 that at least two particle injections were active during the November 1997 energetic particle event.

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References

Mazur, J.E., Mason, G.M., Looper, M.D., et al., 1999, Geophys. Res. Lett. 26, 173
Möbius, E., Popecki, M., Klecker, B., et al., 1999, Geophys. Res. Lett. 26, 145
Torsti, J., Valtonen, E., Lumme, M., et al., 1995, Solar Phys. 162, 505