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Comparison between 20.02.94 and 14.04.94 SEP and their possible sources

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Abstract. Two SEP 20.02.94 and 14.04.94 events were analyzed. The 20.02.94 SEP event was connected with the solar flare. The measurement of solar radio showed that a shock wave of velocity ~2000km/s was observed. The 14.04.94 SEP event was not connected with large phenomena in the sun. This SEP connected with CME was considered to be generated in the high solar corona. We analyzed these SEP events using data observed by GEOTAIL, CORONAS-I, GOES, LANL and IMP-8 satellites. We also used geomagnetic data and solar wind data. GEOTAIL, GOES-7 and LANL data showed that particles were accelerated near the sun by shock waves. We compared the characteristics of the shock waves with energetic particles accelerated by the shocks for the both SEP events.

1 Introduction

Accelerated ions in solar energetic particle (SEP) events contain precious information about the acceleration process of solar energetic particles, the particle propagation in the interplanetary magnetic field, and the physical conditions of SEP source. Thus a possible source of energetic particles in SEP is discussed. We selected two SEP events occurred on 20 February and 14 April for analysis of possible sources. SEP-20-February-event was observed after the solar flare M4/3B at X-ray maximum flux at 01:41 UT. Radio emission corresponding to a shock wave of velocity ~ 2240 km/sec was observed after the solar flare (Kondo and Isobe, 1995). The shock wave reached the earth orbit at 09:01 UT, 21 February .

SEP-14-April-event appeared without a solar flare. At 2:00 UT of 14 April, a slow increase of solar X-ray emission in South-East quarter of a solar disk was observed in Yohkoh satellite (McAlister et al., 1996; Crooker and McAlister, 1997). Kahler et al. (1998) showed that a radio emission of the same frequency around one hundred Hz was observed at 6:00, 9:00 and 12:00 UT. A strong geomagnetic storm started at ~20:00 UT on 16 April. The commencement of the magnetic storm was connected with the arrival of the shock wave which appeared in 14-April-solar-event (McAlister et al., 1996; Crooker and McAlister, 1997).

2 Experimental data

We made analysis using GOES-6 and GOES-7 data on energetic protons >5, >10, >30, >50, >60, >100MeV, LANL data on energetic protons, GEOTAIL data on alpha-particles with energy 3-5, 5-10, 10-20MeV/nuc and the solar wind. We also used GOES-6 data on X-ray emission of 0.1-0.8 nm, solar wind data in IMP-8 from OMNI-WEB. Further we used CORONAS-I data for protons 1-4.5, 4.5-60, >10, 12-60MeV, alpha-particles 1.5-3MeV/nuc, and electrons 0.5-1.3MeV for the 14 April flare. Also results of works in Veselovsky et al. (1997) were used.

3 Data Analysis

On panel A in Fig. 1, a time dependence of X-ray (0.1-0.8 nm) flux is shown, where vertical line I shows a maximum time of the flare. For two days after the flare, any additional increase of X-ray flux was not observed. On panel B, time variations of proton fluxes of energies E_p >10, >30, >100 MeV from GOES-7 data are presented. We used flux data observed during first 17 hrs on protons of E_p >30, >50, >60, >100 MeV from GOES-7, which were expressed by an approximation form, $J(T)=A(E)\bullet exp(-B(E)/T)/T^{C(E)}$ where time t was measured from the X-flare maximum t_x; T=t-t_x. This approximation is typical for a diffuse cosmic ray propagation. In this event we have $A = 7.92\bullet10^6\bullet E^{-3.42}$, $B = 47.22\bullet E^{-0.78}$, and $C = 1.5$, substantially energy independent. Here we have $B = R_0^2/D$, where R_0 is the distance between the sun and the earth, and D the diffusion coefficient. Thus we extrapolated energies down to 10MeV. On panel B in Fig.1, the dependence associated with the diffusion was presented by dashed lines. We find a good agreement between extrapolated curves and observed curves up to 17:00 UT, 20 February for >100 MeV, up to 3:00 UT, 21 February for >30 MeV. On the other hand, we

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did not observe a sharp increase of alpha-particle fluxes after the solar flare, as we show the time dependence of alpha-particles in energy regions 3-5 and 10-20MeV in panel C of Fig. 1. In panel D of Fig. 1, a large change of interplanetary magnetic field B is shown as well as its component B_z. Solar wind velocity V and solar wind density N are presented in panel E of Fig. 1.

Before 9:00 UT, 21 February, **B** was ~5nT, B_z was almost ~0 nT, N was ~5cm^{-3}, and V decreased from 550km/sec to 450km/sec. A dynamic pressure of the solar wind was less than 2n Pa, corresponding to quiet time conditions of the solar wind. We did not see any correspondence between the increase of cosmic ray intensity at both ~16:00 UT, 20 February and ~3:00, 21 February and the variation of solar wind parameters near the earth. We observed a sudden commencement (II in Fig. 1) at 09:01 UT, 21 February when a mean velocity of the shock wave was calculated to be ~1330km/sec. The solar wind velocity was 869km/sec at 10:00 UT, 21 February, indicating the shock wave decelerated in its path. The maximum velocity of the shock wave was ~2240km/sec near the sun as known in Kondo and Isobe (1995). The law $V_{sh.w} \sim R^{-0.5}$ was taken as the radial dependence of shock wave in the interplanetary space (Smart and Shea, 1985). Using data of the solar wind near the earth, we assumed there existed a shock wave with such a high velocity for 3 hours at initial stage, and then the shock wave velocity $V_{sh.w}$ began to decelerate. The deceleration law of shock speed was $V_{sh.w} \sim R^{-0.59}$. If we assume a linear $V_{sh.w}$ dependence on distance, then the velocity is expressed as $V_{sh.w} = V_0 - kR$ ($k = 7.32*10^{-6}$). Accordingly the initial velocity was estimated to be 1967 km/sec, which was practically equal to the result in Kondo and Isobe (1995). A particle acceleration seemed to be made by the shock wave, and the plasma density of alpha-particles to be low. An integral spectrum of energetic protons is given by $J(>E) \sim E^{-2.23}$ in an enegy interval 10-100 MeV. When the shock arrived at the earth, we observed a sudden increase of proton storm with the energy spectrum $J(>E) \sim E^{-5.3}$(GOES-7 data). It is found that the energy spectrum of energetic particles during the storm was much softer than that accelerated in solar corona.

Now we shall analyze the SEP event on 14 April 1994. In Fig. 2, results observed by different satellites are shown. In panel A, CORONAS-I data on the solar electron flux in energies $0.5 < E_e < 1.3$ MeV at the polar caps is presented. In panel B the time variation of alpha fluxes received by GEOTAIL is shown. In panel C, time variations of proton fluxes in 1 to 12 MeV range are shown. Lines 1, 3 and 5 correspond to IMP-8 data for proton of E_p >1, >4 and >10 MeV, and lines 2, 4 and 6 correspond to CORONAS-I data for protons 1-4.5, 4.5-65 and >12 MeV (E_e>1.3 MeV), respectively. Analysis showed that we measured only protons in the channel (E_e >1.3 MeV, E_p >12 MeV). Data from GOES-7 were similar to those from IMP-8 and CORONAS-I, but they had a daily variation. We did not analyze data for E_p >30 MeV, because the flux had not significantly exceeded the statistics of background counts.

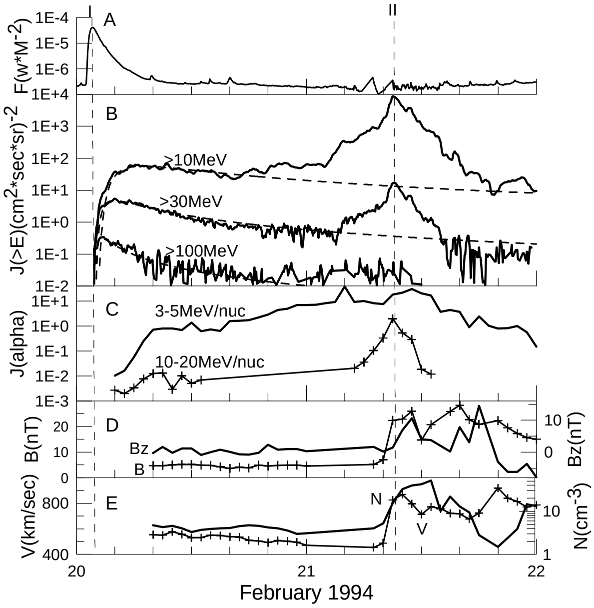

Fig. 1. SEP 20-21 February 1994

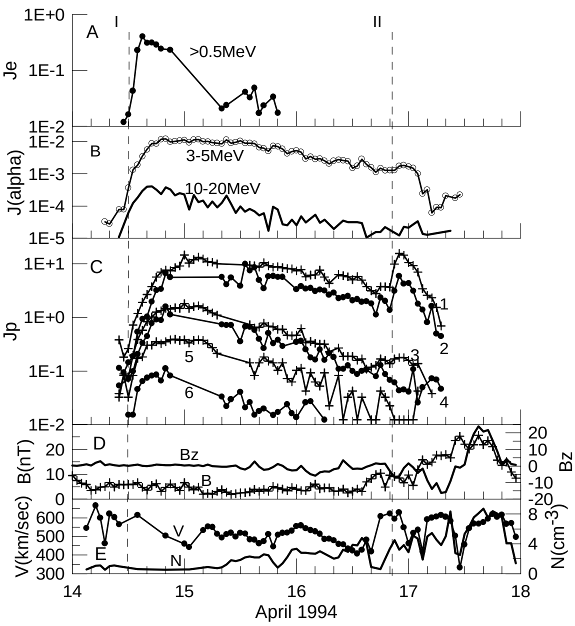

Fig. 2. SEP 14-17 April 1994

Data obtained by various satellites with similar energy channels were more or less same each other within a factor of 2. The increase of all energetic particle fluxes began at 11-12h. UT, 14 April, and then protons of E_p ~ 1 MeV would be accelerated earlier than more energetic particles. As seen from this figure, we know that a large flux of protons from 1 to 10 MeV observed by IMP-8 continued for ~10 hours. A similar trend was observed in GEOTAIL data for alpha-particles of 3-5 MeV/nuc.

In panel D of Fig. 2, time variations of B and B_z from IMP-8, which agreed well with GEOTAIL data, are shown. In panel E of Fig. 2, the time variations of N and V are presented, which agreed with GEOTAIL data. A comparison of data between IMP-8's and GEOTAIL's was made in a period of 6-14 April. It was found that the IMP-8 solar wind velocity exceeded the GEOTAIL solar wind velocity by a factor of 1.1 during the period of 6-11 April, and the IMP-8 solar wind density exceeded the GEOTAIL solar wind density by a factor of 2.5 in the period 6-11 April. That is, the excess of the solar wind velocity reached at maximum 1.25 times as high, and the excess of solar wind density 5 times, up to 14 April, respectively. GEOTAIL was considered to enter the transition region between the shock wave and the magnetopause. GEOTAIL was considered to be in the magnetotail in 17 April. Since 2 April, the Earth was immersed in high velocity solar wind with V~650km/sec. The high velocity solar wind must had finished on 16 April. But we observed the strong magnetic storm (min. Dst=-201nT) which was connected with the arrival of CME at the earth (McAlister et al., 1996). At 20:00 UT, 16 April, GEOTAIL observed a steep increase of solar wind velocity and density. The minimum CME velocity, V was 623km/sec, which agreeed with GEOTAIL data. CME appeared at ~2:00 UT. If V was ~720km/sec, CME would have appeared at ~11:00 UT. CME with such a velocity could not make a shock wave in the high speed solar wind.

4 Discussion

In bottom of Fig. 3, we present dependences of solar wind density N and magnetic field B on the heliocentric distance. The mean velocity of solar wind, V_{sw}, the minimum CME velocity for cosmic ray generation $V_{cr} = V_{sw} + 2V_A$ (V_A = Alfven velocity), and the F_{pl}-plasma frequency are shown in upper panel, together with the CME velocity V(CME) obtained by using results in Kohnlein, (1996). When we compare V_{cr} with V(CME), it is concluded that the SEP event on 20 February 1994 was generated at all distances from the sun, and the velocity of shock wave corresponding to CME arrived at ~2000 km/sec near the sun and ~900 km/sec near the earth. It is interesting that the first maximum of alpha-fluxes appeared later than the maximum of proton fluxes. A slow increase of ion fluxes for protons <30 MeV and alpha-particles <10 MeV/nuc began at ~16:00UT, 20 February before the magnetic storm.

In the14-April-1994 SEP event, CME velocity was equal to ~650 km/sec, and SEP was generated only at distances <0.01 AU and >0.03 AU in ambience of the solar plasma wind of low velocity. Plasma frequencies should be >10 MHz and <1 MHz. Ulysses data in Crooker and McAlister (1997) showed the type-III radio emission of the same radio frequencies as at 6, 9 and 12h UT, 14 April. Prolonged maximums in proton- and alpha- fluxes suggest that particles were accelerated for a long time in >0.03 AU. Onset of increasing fluxes of electrons, protons and alpha-particles around ~11-12h is associated with the phenomena that CME reached the location at distance >0.03 AU, where the slow speed solar wind was immersed in the interplanetary space. An energy spectrum at the maximum of SEP flux on 14 May is given by $J(>E) \sim E^{-1.7}$ in the energy interval 1-10 MeV, whereas the peak spectrum of storm particles on 17 May is by $J(>E) \sim E^{-4.7}$ in the interval 1-4 MeV.

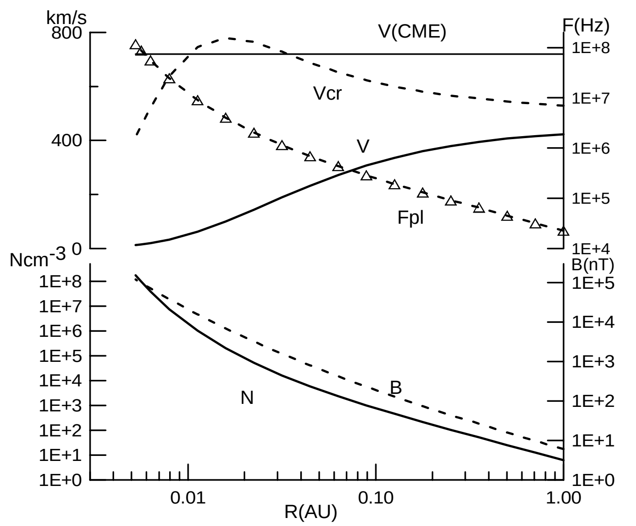

Fig. 3. Distance-dependences of solar wind density N, magnrtic field B (bottom panel) and velocity V (upper panel), alsowe presented Fpl-plasma frequency and Vcr minimum velocity of CME for particle acceleration.
Straight line - realvelocity CME 14-17 April V(CME).

5 Conclusion

Two SEP events occurred on 20 Feb. and 14 April, 1994 were analyzed in this paper. Strong X-rays and the H_{alpha} solar flare were observed in 20-Feb.-1994 event. The type-II radio emission was observed during 250sec, which corresponded to a propagation of the shock wave generated at the solar corona with its velocity 2240km/sec toward the interplanetary space (Kondo and Isobe, 1995). This shock wave could be an important source of SEP event. The density of He ions was probably low. The shock wave moved in the interplanetary space with slowing its speed down. The energy spectrum of storm energetic particles was much softer than that of SEP. The SEP event on 14 April, 1994 was not related to any violent phenomena observed by visible radiation in the solar corona. This SEP event was connected with the activation of giant arc (Kahler et al., 1998). CME velocity directing to the earth was equal to that of a high velocity solar wind. Therefore SEP could appear only in the slow solar wind away >0.03AU from the sun. Ulysses data (Kahler et al., 1998) supports this point of view. The SEP flux was not intense, but the energy spectrum for the SEP event was similar to that for the 20-Feb.-1994-SEP event. Spectra of both CME storm particles were similar, but particle fluxes were very different each other.

References

1. T. Kondo, T. Isobe,"Shock speed estimated from solar type II burst observed on Feb. 20, 1995", STEP SBRSC News, ***Vol.5, No. 1***(Serial No. 13) (1995) 7-8.
2. McAlister, A. H., M. Dryer, P. McIntosh, and H. Singer, "A large polar crown coronal mass ejection and a "problem" geomagnetic storm: April 14-23, 1994", *J. Geophys. Res.*, ***101(***1996)13,497-13,515.
3.. Crooker N. U., A. H. McAlister, "Transients associated with recurrent storms", *J. Geophys. Res.*, ***102***(1997)14,041-14,047.
4. Kahler S. W., H. V. Cane, H. S. Hudson et al., "The solar energetic particle event of April 14, 1994, as a probe of shock formation and particle acceleration", *J. Geophys. Res.*, ***103***(1998)12,069-12,076.
5. Veselovsky I. S., Gotselyuk YU. V., Denisov Yu. I., et al., "Without flare increasing of solar cosmic rays 14-17 April 1994", *Space Res. (Russian)*, ***38, No.2***(1997)127-132
6. Smart D. F., M. A. Shea, "A simplified model for timing the arrival of solar flare-initiated shocks", *J. Geophys. Res.*, ***90***(1985)183-190.
7. Kohnlein W., "Radial dependence of solar wind parameters in the ecliptic (1.1 R_s-61 AU)", *Space Physics*, ***169***(1996)209-213.