The Relation of Variations of Solar and Galactic Cosmic Ray Fluxes with Parameters of Interplanetary Medium Under Quiet Solar Conditions

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Abstract

Relations of long-term and local variations of solar and galactic cosmic rays with parameters of the interplanetary space are investigated by combining IMP 8, SOHO, and Voyager energetic particle data with neutron monitor fluxes. The time profile of quiet-time low-energy (0.5-6.4 MeV) proton intensity is compared with stepwise modulation of galactic cosmic rays in 1998-2001. The relation between variations of spectral parameters of quiet-time galactic cosmic rays (GCR) and those of the interplanetary medium is analyzed.

1. Introduction

During quiet-time intervals of solar activity the proton energy spectrum displays a characteristic minimum in energy range ≈7-50 MeV. Here, quiet-time spectra can be fitted with a function $J_p = AE^{-\gamma} + CE^{\nu}$. The spectral dynamics during different solar cycles (SC) and levels of solar activity had been discussed in [1-3]. The 11-year variation of quiet-time ≈1-10 MeV proton intensity was found to correlate with the number of sunspots without time delay [4]. It has been shown that during the ascending phases of the 21st and 22nd SC quiet-time low-energy particle fluxes exhibited stepwise variations anticorrelating with GCR modulation steps [5,6]. This work discusses the time history of low-energy protons during the rising phase of the 23rd SC.

Studying the dynamics of low-energy proton spectrum in 1974-1991 the value E_{min} (energy at minimum intensity in spectrum) was found to vary over the solar cycle between about 7 and 50 MeV at 1 AU [2]. Here we attempt to determine the size of the spatial region near the point of observation which has the largest influence on the energy spectrum.

2. Time variations of low-energy proton fluxes and GCR modulation

As quiet-time proton intensity we used monthly minimum fluxes of 1.8-3.3 MeV protons J_{min} obtained by the ERNE instrument aboard SOHO. Figure 1

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shows quiet-time low-energy proton variations in 1998-2001 along with neutron monitor Apatity modulation steps indicating clear anticorrelation of the two data sets. During the ascending phase of the 23rd SC quiet time low-energy (1.8-6.4 MeV) proton fluxes varied in nearly opposite phase to the modulation variation of GCR similarly to time behavior in the 21st and 22nd cycles. At 1 AU, these variations last several months to a year, GCR delay by not more than 1-2 months. The same pattern was observed in the outer heliosphere: Fig. 2 displays the time behavior of the 0.57-1.78 MeV and 130-225 MeV proton intensities based on LECP and CRS data, respectively, from Voyager 1 at ≈75-80 AU. Vertical lines mark short time variations (I-IV in Fig. 1 and A,B in Fig. 2) observed in opposite phases. Inclined lines in both figures mark modulation steps of galactic protons and simultaneous increases of low-energy proton intensity. These variations in the 23rd SC were much weaker as compared to those in the 21st and 22nd SC possibly due to the weakness of 23rd SC. The correlation coefficient between quiet-time ≈1 MeV proton intensity and neutron monitor Deep River count rate in 1975-1991 was negative and had two maxima in its absolute value [4]: one with a time lag of no more than one-two months, and a second with 6-7 months. The latter corresponds to a modulation region including perhaps the whole heliosphere. The former indicates the existence of relatively small modulation regions that correspond to time lags of several days.

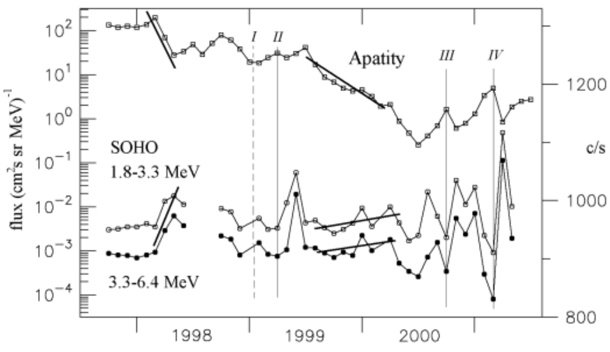

Fig. 1. Comparison of SOHO ERNE proton with neutron monitor fluxes.

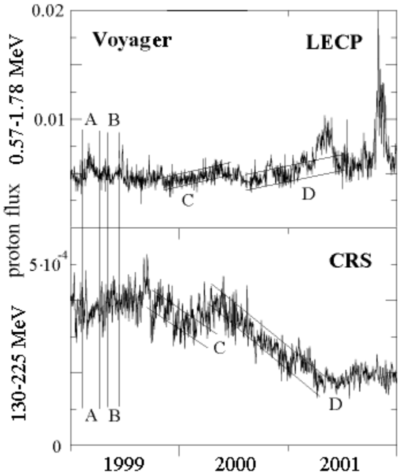

Fig. 2. Time profiles of Voyager proton fluxes.

As shown earlier, in the two previous SC each low-energy particle step ended with a hole, i.e. with minimal intensity in step [6]. The present study gives a similar pattern of steps in the 23rd SC. Also, simultaneously with the low-energy particle holes temporary increases of GCR were observed. Fig. 2 demonstrates that the time lags between short variations marked by vertical lines do not exceed several days. The results seem to confirm the existence of at least two regions of

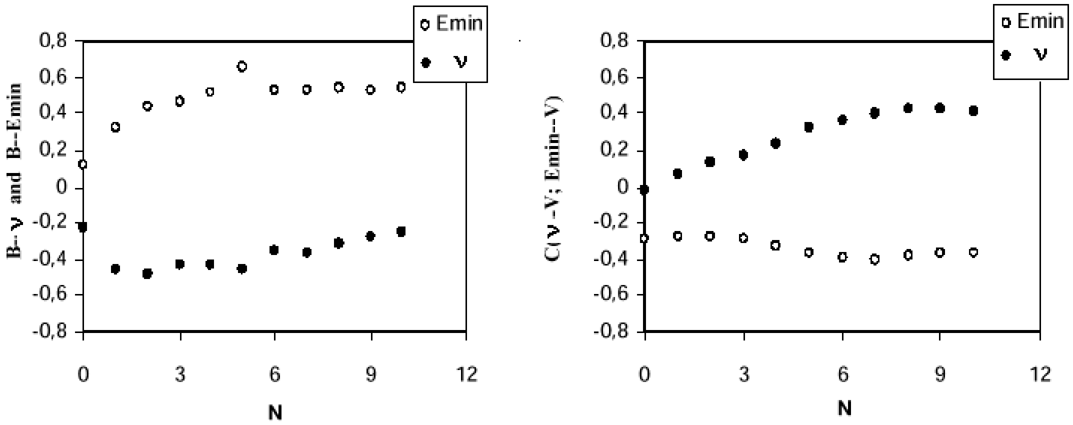

Fig. 3. Correlation coefficients: E_{min} - B and ν - B on the left, E_{min} - V and ν - V on the right for different sizes of spatial regions (parameter N).

modulation as mentioned above. A more reliable estimation of dimensions of the modulation volume was made investigating the connection of quiet-time spectrum characteristics with parameters of the interplanetary medium (IM).

3. Quiet-time proton spectra and relations between GCR and IM parameters

As pointed out in [1], more than a half of 86 quiet periods examined yielded an unexpected result that $\nu > 1$, corresponding to a negative Compton-Getting factor. One can conclude that current theories of GCR modulation do not completely describe processes in the heliosphere. Most probably they underestimate the influence of the nearest space region on the spectra, giving preference to global processes in the whole heliosphere. This is confirmed by the fact that ν changes strongly from one quiet-time interval to another under slight changes of solar activity [3]. It should be noted that ν can be determined only during quiet Sun when the IM is basically clear from solar particles. Such conditions are very rare, especially around SC maximum. Here we attempt to determine the size of the spatial region near the point of observation which has the largest influence on the energy spectrum. The attention is centered around GCRs with energy $> E_{min}$, i.e. the spectral domain determined by E^{ν}.

For this purpose, the values of ν and E_{min} are compared with various parameters of the IM and of the interplanetary magnetic field (IMF) using different time lags. The degree of influence was determined by the correlation coefficients with ν and E_{min} in different conditions. IM and IMF was characterized by daily average solar wind speed (V), its variance and the value of IMF (B) together with its variance. The parameters were averaged for 2N+1 days (N days before zero day, i.e. day of measurement of ν and E_{min}, zero day itself and N days after zero day). As maximum N=5 was chosen for number of days after zero day, as in 5 days solar wind crosses the distance from the Sun to Earth. For N<4 spatial regions towards as well as away from the Sun are involved. For N=4-5 and V=400 km/s the distance involved is 1 AU, so for N>5 the parameters for directions only away from the Sun were used. Due to missing solar wind data only 20 quiet-time intervals could be used to compute the correlation coefficient C.

Figure 3 displays C values for all quiet-time intervals in 1974-1981 showing that C for E_{min} and ν for all volumes (N = 0 - 10) are of different sign, i.e. E_{min} and ν anticorrelates. This indicates that the modulation processes undergo strong dependence on proton energy: as E_{min} increases ν decreases, i.e. the modulation of low-energy protons is weaker for higher energy protons what contradicts to common sense. One can see in Fig. 3 that the C for E_{min} and n and V are small not exceeding 0.4 for all affecting volumes so cannot be considered as valuable. At the same time the influence of the IMF magnitude B is considerably higher with C values reaching 0.6 and -0.5 for E_{min} and ν, respectively. The maximum of C = 0.66 and -0.48 for E_{min} and ν was achieved at N = 5 and N = 2, correspondingly. The N obtained permit to judge the relative dimensions of the most effective volume responsible for GCR proton modulation. The radial dimension of this volume is L $\approx$ 6x10^{-4}V.N [AU] where V is in km/s. Therefore the most effective volume of IMF influence on E_{min} and ν is larger than 0.9 and 0.36 AU assuming V = 400 km/s. One cannot exclude that taking into consideration this local IMF influence on GCR (and partly the influence of solar wind speed) may help to understand the appearance of spectra with n>1 in proton energy region 10-100 MeV and in consequence the appearance of negative Compton-Getting factor.

4. Acknowledgements

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5. References

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