RECURRENT ENHANCEMENTS OF ENERGETIC PARTICLE INTENSITY DURING THE DECREASING PHASE OF 21TH SOLAR ACTIVITY CYCLE

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Abstract

Recurrent enhancements of energetic particle fluxes recorded on board space probes VEGA 1 and 2 during the first half of 1985 formed a long-lasting series of events in the decreasing phase of 21th solar activity cycle. On the basis of intensity data of protons with energies 1-2 MeV measured by IMP 7 and 8 spacecraft it is found that the series spans 26 solar rotations. The characteristic features of these events are: a relatively high stability of the phase of maximum (19 ± 0.5 day of Bartels rotation period) and a dependence of the amplitude of particle intensity increase on solar wind velocity. During recurrent events the flux of 0.04 - 1.0 MeV protons and ions reaches a maximum several hours earlier than >1 MeV particles. After the event the energy spectrum >1 MeV changes only slightly while below 1 MeV it becomes harder ($\delta\gamma \approx 1$). The change of intensity and energy spectrum is compared with ESP events.

Introduction During the decline phase and the minimum of the 11-year cycle of solar activity the recurrent increases (RE) are best represented by the variation of energetic particle fluxes in the interplanetary magnetic field (IMF, Christon, 1981). From January to May 1985 four RE's have been observed on board the VEGA 1 and 2 space probes using the TÜNDE semiconductor telescope that detected protons and ions of energies between 40 keV and 13 MeV (Somogyi et al., 1987). We analyze the connection of RE's with solar wind conditions and interplanetary magnetic field.

Results During solar rotations (SR) 2069 - 2072 (Bartels rotation) the energetic particle data obtained by VEGA 1 and 2 are compared with IMP 7 and 8 measurements (0.97 - 1.85 MeV protons, Solar Geophysical Data, 1985). The results presented in Figure 1 for two SR (2069 and 2072) indicates that the RE profiles, registrated at two different points, are similar. In each of the four RE's particles of roughly the same energy indicate that the difference in the time of maxima, as well as other properties of the profiles at the two different spatial points are determined by corrotation and freezing in of solar wind magnetic field lines. In the case of SR 2072 the time shift of the profiles between VEGA and IMP 8 is about 0.45 day. Taking into account the actual plasma speed ($V \approx 750$ km/s, Solar Geophys. Data, 1985 and Gringauz et al., 1985) together with the radial and azimuthal differences in agreement with Fig.1 we obtain 0.43 day.

Based on IMP 7 and 8 measurements it was found that the RE's mentioned above belong to the same series of events in the declining phase of 21th solar activity cycle. The series lasts for 26 rotations from 2047 to 2072 using the method of superposed epochs. Considered are all those events where the maximum flux of 1 - 2 MeV protons exceeded 0.1 (cm^2 ster s MeV)$^{-1}$ and the days of maximum of the increase are marked. Figure 2 shows the number of events summed up for each day during the solar rotation. This yields a phase distribution of the events in which a statistically significant maximum is found at days 18-19 from the beginning of the rotation.

We tried to find a correlation between the maximum fluxes of 1-2 MeV protons and the solar wind velocity during the series of events. Two distinct parts of the series have been found: during the first part (SR 2047 - 2063) of the events the s.w. speed is lower, $< V > \approx 480$ km/s and the average maximum of proton flux is $< I_m > \approx 0.15$ (cm^2 ster s MeV)$^{-1}$, while for the second part we have a high speed: $< V > \approx 720$ km/s and $< I_m > \approx 2.0$ (cm^2 ster s MeV)$^{-1}$. One can conclude that the RE's associated with high speed streams produce protons fluxes about a factor of 10 times larger.

Thanks to simultaneous measurements aboard VEGA-1 the location of RE's within the structure of the HVSW (high speed solar wind) stream could be determined. Riedler et al. (1985) pointed out that during

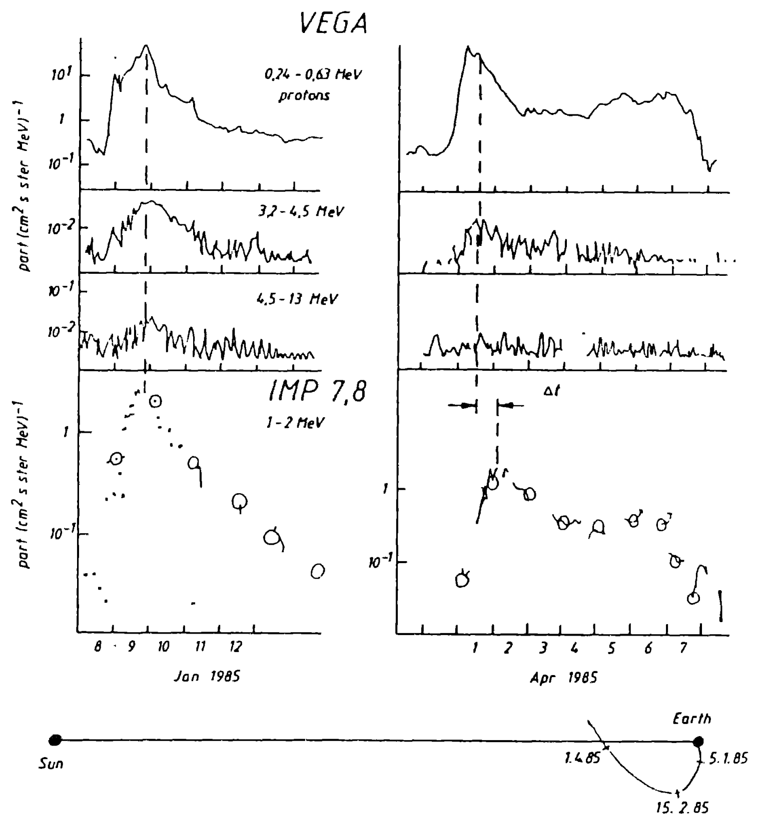

Figure 1

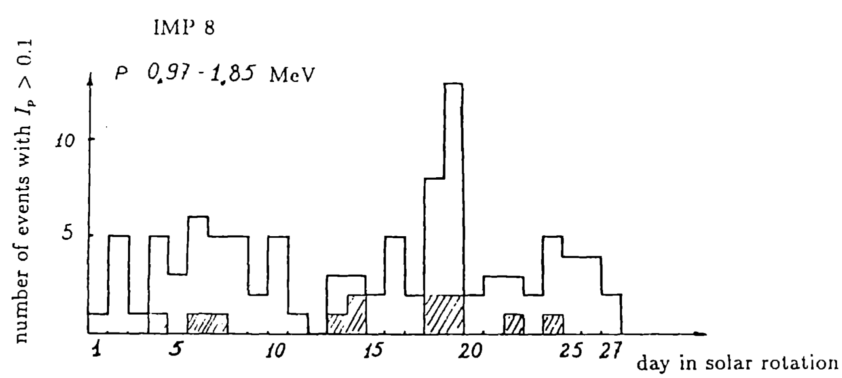

Figure 2

the period considered the interplanetary magnetic field exhibited a two-sector structure. The beginning of positive polarity sectors coincides with the HVSW streams and recurrent disturbances of the IMF during which the field magnitude reached a value of 3 to 4 times larger than its undisturbed one.

In Figure 3 presented are the time profiles of particle fluxes in various energy channels during the recurrent events in SR 2072, the velocity and density of the solar wind plasma together with magnetic field strength. The figure lead us to several conclusions: a) the energetic particle intensity starts to increase in the close vicinity of the maxima of SW density and magnetic field; b) the maximum of energetic particle flux is located at the leading edge of the HVSW stream; c) the larger the particle energy, the later they reach the maximum intensity; and d) with increasing energy the decrease phase of the profile shifts to later times. It is worth to mention that below 10 keV the particles exhibit a maximum intensity near the time of SW temperature maximum. (Gringauz et al., 1985).

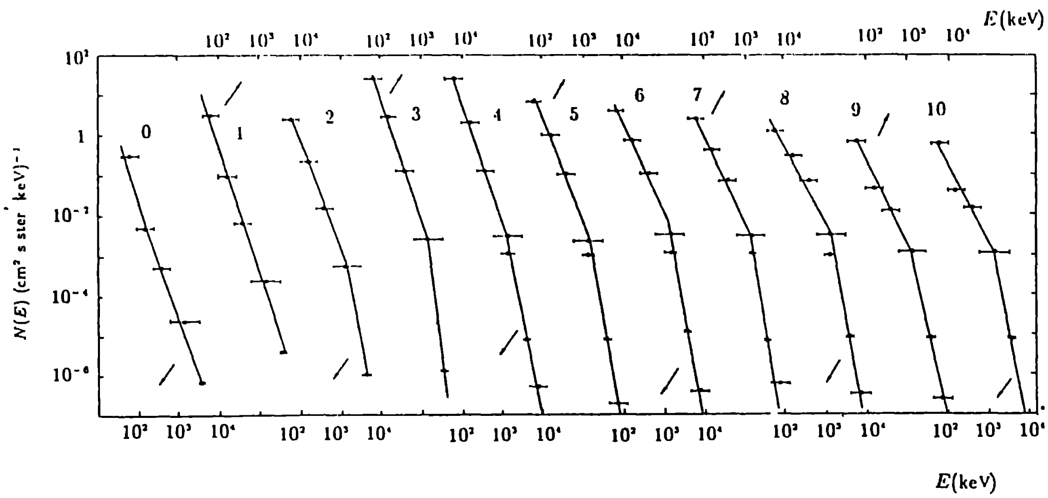

Figure 3

Arrows numbered from 0 to 10 at the top of the figure mark the times when energy spectra were constructed as shown in Figure 4. This figure indicates that a power law function with a single exponent is a good approximation for the spectrum only in the early phase of the event. During the shift in azimuth the spectral slope between 0.6 and 1.0 MeV decreases, while above 1.0 MeV its change is negligible.

In the other recurrent events observed by VEGA-1 the energy spectra behave similarly as Table 1 suggests. During the increasing phase the spectra can be characterized by two exponents where $\Delta\gamma_1$ stands for the decrease of γ_1 during the events.

Table 1

event	0.6 - 1.0 MeV		> 1.0 MeV
	γ_1	$\Delta\gamma_1$	γ_2
7 - 10 Jan 1985	2.7 - 1.4	1.3	4.0 - 4.3
4 - 6 Feb 1985	2.0 - 1.2	0.8	4.0 - 4.3
4 - 5 Mar 1985	1.7 - 0.3	1.4	4.3 - 4.4
31 Jan - 4 Feb 1985	3.0 - 1.8	1.2	4.8 - 5.0

Discussion The time history and energy spectra of energetic particles around 1 MeV reminds to some extent to those observed in pre- and postshock regimes (Richter et al., 1981). In fact, in the preshock regime the particle energy spectra are power-law and the increase of particle energy takes place at consecutive reflections on moving irregularities of the magnetic field (first order Fermi mechanism). The early phase spectra (1 and 2 in Fig. 4) can possibly be explained in terms of this process. The region around the leading edge of the HVSW stream is analogous to the post-shock regime observed in ESP events. Here, the particle diffusion coefficient is $(V_2/V_1)^2$ times smaller than in the preshock regime and, consequently, the particles are effectively precipitated (V_1 and V_2 denote the upstream and downstream plasma speed, respectively). In the model of Scholer and Morfill (1977) which incorporates diffusion, convection and adiabatic deceleration, such a precipitation leads to a particle flux increase roughly proportional to the decrease of the diffusion coefficient. Under these conditions the turbulent acceleration of particles via their interaction with Alfvén and magnetosonic waves becomes effective (second order Fermi mechanism). Fig. 4 and Table 1 demontrates that the energy spectrum becomes harder behind the leading edge of the

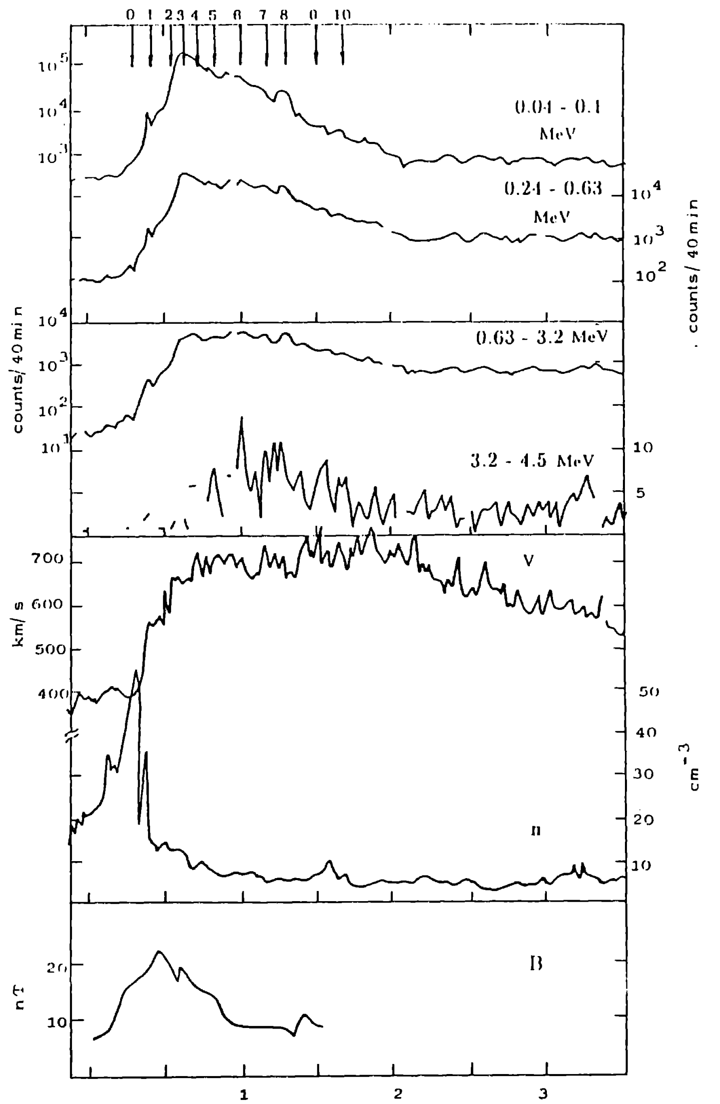

Figure 4

HVSW stream and is possibly transformed into an exponential one, the latter being a general feature of turbulent acceleration (Toptygin, 1980).

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