REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 03-09-2003

2. REPORT TYPE Final Report

3. DATES COVERED *(From – To)* 05-Jun-01 - 03-Oct-03

4. TITLE AND SUBTITLE
Space Weather Effects: Decay Phases in Gradual and Impulsive Solar Energetic Particle Events

5a. CONTRACT NUMBER ISTC Registration No: 2063p

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5d. TASK NUMBER

5e. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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Moscow 119899
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8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
EOARD
PSC 802 BOX 14
FPO 09499-0014

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
ISTC 00-7047

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report results from a contract tasking Skobeltsyn Nuclear Physics Institute of Moscow State University as follows: This is an investigation of the decay phases of gradual and impulsive solar energetic particle (SEP) events associated and non-associated to coronal mass ejections (CMEs) and CME-driven shocks. The contractor will use the multispacecraft (m/s) data obtained in the 1970s and 1980s to develop understanding of processes of particle transport and losses and the role of travelling shocks for formation of particle intensity-time profiles at late phase of event at different radial distances and heliologitudes of the observer. This will be done based on a database of energetic protons, alphas and electrons, as well as solar wind and interplanetary magnetic field, from the Prognoz, the Venera, the Vega, the Phobos 2, the Helios and IMP 7,8 spacecraft. The correlated observations will be used to test modern models of SEP event formation. Practical application of the results to be obtained is related to the problems of space weather, as well as radiation hazards during manned space missions and radiation affects on materials and instruments.

15. SUBJECT TERMS
EOARD, Astronomy & Astrophysics, Astronomy

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18, NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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ISTC 2063p

Final
Project Technical Report
ISTC 2063p

"Space Weather Effects: Decay Phases in Gradual and Impulsive Solar Energetic Particle Events"

(From 1 June 2001 to 31May 2003 for 24 months)

Elena Isaevna Daibog
(Project Manager)
D.V.Skobeltsyn Istitute of Nuclear Physics
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June 2003

This work was supported financially by European Office of Aerospace Research and Development (EOARD) of USAF and performed under the contract to the International Science and Technology Center (ISTC), Moscow.

ISTC 2063p

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(From 1 June 2001 to 31 May 2003 for 24 months)

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The purpose of the project is the investigation of solar energetic particle (SEP) events associated and non-associated to coronal mass ejections (CMEs) and CME-driven shocks with the practical application to the problems of space weather and monitoring of radiation conditions in interplanetary space. Scientific goals of the project are related to the basic problem of solar cosmic ray physics which includes the determination of flare vs. CME-driven shock contributions to particle fluxes in SEP events.

Up to now most investigations have been directed to the rising parts of events and especially to the peak fluxes. As a rule, the declining phases of SEP events were considered to less extent although they are informative too. Under supposition of the solar origin of SEPs the features and conditions in a source at the Sun becomes unessential during decay phase and effects and peculiarities of particle acceleration and losses in interplanetary space becomes more pronounced. So decay times of SEP intensity profiles can tell us much about the processes in SEP enhancements.

Keywords: Sun, Interplanetary Medium, Magnetic Field, Particles, Shocks, CMEs, Decay Times, Spectral Index, Spacecraft .

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Contents

Introduction

1. **Title of the Project**
   Space Weather Effects: Decay Phases in Gradual and Impulsive Solar Energetic Particle Events.

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5. **Commencement Date, Duration**
   June 1, 2001, duration – 24 months

The purpose of the project is the investigation of solar energetic particle (SEP) events with the practical application to the problems of space weather and monitoring of radiation conditions in interplanetary space. Scientific goals of the project are related to the basic problem of solar cosmic ray physics which includes determination of flare vs. CME- driven shock contributions to particle fluxes in SEP events in interplanetary space (accelerated in flares and by CME-driven shocks), forecasting of radiation-dangerous events and determination of properties of interplanetary medium (populated by the particles observed) by the parameters of particle fluxes.

Expected results

At the project elaboration:

- the statistically provided data base of SEP events

- definition of empirical dependencies of SEP event decay phase characteristics (such as particle flux decay rate, energetic particle spectrum, anisotropy of particle fluxes etc.) upon a distance from the Sun and heliolongitude under various conditions in solar corona and in interplanetary space;
- influence of flare and shock accelerated particles on the observed fluxes at decay phases of events;
- determination of conditions of spatial and temporal invariance of particle spectra during SEP event decay phase;
- detailed examination of SEP event characteristic decay time intensity variations over the solar activity cycle

From the practical point of view obtained results can be applied to space weather models if someone considers space weather as a set of heliospheric phenomena including interplanetary shocks, recurrent high velocity streams in solar wind, plasma clouds etc. In particular, SEPs data are suitable for estimations of characteristic spatial scale of interplanetary shocks and their parameter (velocity etc.) variations with radial and azimuthal distance.

Technical approach

The Project was elaborated using the whole totality of the data sets on solar wind, interplanetary magnetic field and solar energetic particles that was obtained during long period of observations in space, as well as the data on coronal mass ejections, flares and other phenomena of solar activity. The Project foundation is the data of m/s measurements in which the same SEP events together with solar wind conditions were observed at different space regions simultaneously. The database includes the results of measurements onboard the Helios-1,2, IMP-5,7,8, GRANAT and ISEE-3, as well as data of recent observations onboard SOHO and WIND s/c. Also the results were included obtained by the project authors earlier onboard Prognoz, Venera, Vega and Phobos s/c.

According to the Project 2063 Work Plan the work has been performed in the directions formulated in tasks 1-6.

Task 1. Selection of SEP events according to the accepted criteria and elaboration of the data base for proposed investigations.

Task 2. Detailed examination of characteristic decay times, spectra and anisotropy of the 1 to 100 MeV proton intensities in SEP events observed at different radial distances over azimuthal range available for observations.

Task 3. Looking for a correlation of the decay time of particle intensity and spectral index with the speed of the shock associated to a given SEP-event.

Task 4. Investigation of the functional form (power or exponential function) of particle intensity during the event decline.

Task 5. Studying relationships between SEP event particle fluences and both interplanetary space conditions and CME parameters

Task 6. Analysis of variations of decay times over solar activity cycle.

All principal objectives of the technical schedule, listed in the Work Plan, were completed. Sometimes scope of activity was extended according to the logic of investigations.

According to the Project 2063 Work Plan and in addition to it the work has been performed at:

- selection of SEP events and elaboration of the initial multispacecraft data base for 1977-1983 events;
- enlargement of the data base due to IMP 8 1974-2001 data

Statistical analysis of the next features of decay phase in SEP events has been performed:

- Statistical analysis of SEP decays: distributions of characteristic decay times, spectral indices and total durations of exponential declines;
- Energy spectra of SEPs;
- Periods of time profiles with and without shocks;
- Functional form of decays of SEP events;
- Invariance of charged particle time profiles during the late phase of SEP events according to multi spacecraft observations.
- Correlation between decay rate, spectral index and shock speed
- Periods of quasistationary conditions in interplanetary space according to the data on successive SEP events
- Influence of the neutral current sheet on the particle fluxes during decay phase of SEP events
- The dependence of characteristic decay time and spectral index on the flare site .
- Investigation of proton fluences and adjacent questions;
- Energy dependence of characteristic decay time in exponential decay of proton SEP events
- Analisis of variations of decay time and spectral index over solar activity sycle

The results of investigatin of these SEP event phenomena are described below

Selection of SEP events and creation of the database

One of the main stages of the work under the Project was creation of the solar energetic particle (SEP) events for most prolonged period of time. It was possible in the present investigation on the basis of multi spacecraft measurements to embrace a period from 1974 to 2001, that is more than two solar activity cycles (21-st cycle started in the middle of 1976, 22-nd - in the middle of 1986 and 23-th - in the middle of 1996)
For systematic analysis of the decay phase of SEP events at first selection of events according to the shape of their time ptofiles has been made: only the events with exponential declines were took into consideration.

Our selection criterion for SEP events has only a limited meaning. It is clear that the intensity-time profile of the SEP event depends not only on the number of accelerated particles, but is also influenced by four factors. These are (1) the angular separation between the source and the observers magnetic footpoint, (2) the radial distance, (3) the coronal and interplanetary propagation conditions and (4) the background. Independent of radial distance there is a background level variation of a factor of about 3 during the solar cycle, beside any variation of background due to a preceding event (Kallenrode et al., 1992). Using the adopted criteria the database of gradual and impulsive SEP-events related to flare/CME associations and flares only, correspondingly, was done.
Primary data base consisted of 122 gradual and 100 impulsive events (see Tables 1A and 2A of the 1-st Year Report). In the Tables there are the lists of flares, CMEs, interplanetary shocks and spacecraft data. These are the date of the flare, the flare onset and location in Hα and the X_t-burst amlitude from Solar Geophysical Data. CMEs are presented by observed locations (position angle and angular width) and speeds. These parameters are visible projections of the real values onto the sky plane. Under supposition that CME originates on the Sun nearby a flare site (Reames et al., 1996) and moves radially from the Sun we recalculated observed speed to near real one according to procedure discribed in (Daibog et al., 1996). This value is also shown in the Table 1A. Shock data include the observation points, their radial distances and longitudes relative to the flare (azimuth) and average (transit) speeds.
Unfortunately observations of CMEs began only from March 1979 and for earlier events we could use only data on interplanetary shocks, which are well correlated with CMEs.
The spacecraft data in the database include locations of the observation points, characteristics of SW and IMF at them and the coronal footpoint of the observer`s magnetic field line.
In the database particle data are the values of fluxes of a given particle specie in a given energy range at any time during an event observation at a given s/c. The database contains the results obtained onboard the Helios 1 and 2, IMP8, ISEE3, Prognoz, Venera, SOHO and GRANAT.
Patterns of time profiles of protons with the energies >4, >10, >30 and >60 MeV are shown in Figs 1a,b,c. These are the results of measurements obtained by CPME instrument onboard IMP-8 satellite in 1974-2001.
The Project is devoted to the systematic study of decay phases of solar energetic particle (SEP) events in the inner heliosphere for better understanding of SEP dynamics.
For systematic study of decay phases of solar energetic particle (SEP) events all flux rises were took into account, independently of their etymology: whether these were flares, corotating or ESP events, because it is clear that in space weather tasks, particularly in the forecast of radiation hazard we must not limit ourselves to «classical»

SEP events, associated with well connected flares. That is why the primary data base was enlarged and all events with the peak flux of >4 MeV protons**,** exceeding 2-3 $(cm^2\ s\ sr)^{-1}$ were considered independently of the shape of time profile, decrease rate and anisotropy of particles throughout the event.

Only those exponential parts of time profiles were took into consideration when either exponential dependence continued longer than 12 hours, or intensity decreased more than half an order of magnitude. 476 parts of all time profiles with exponential declines were selected.

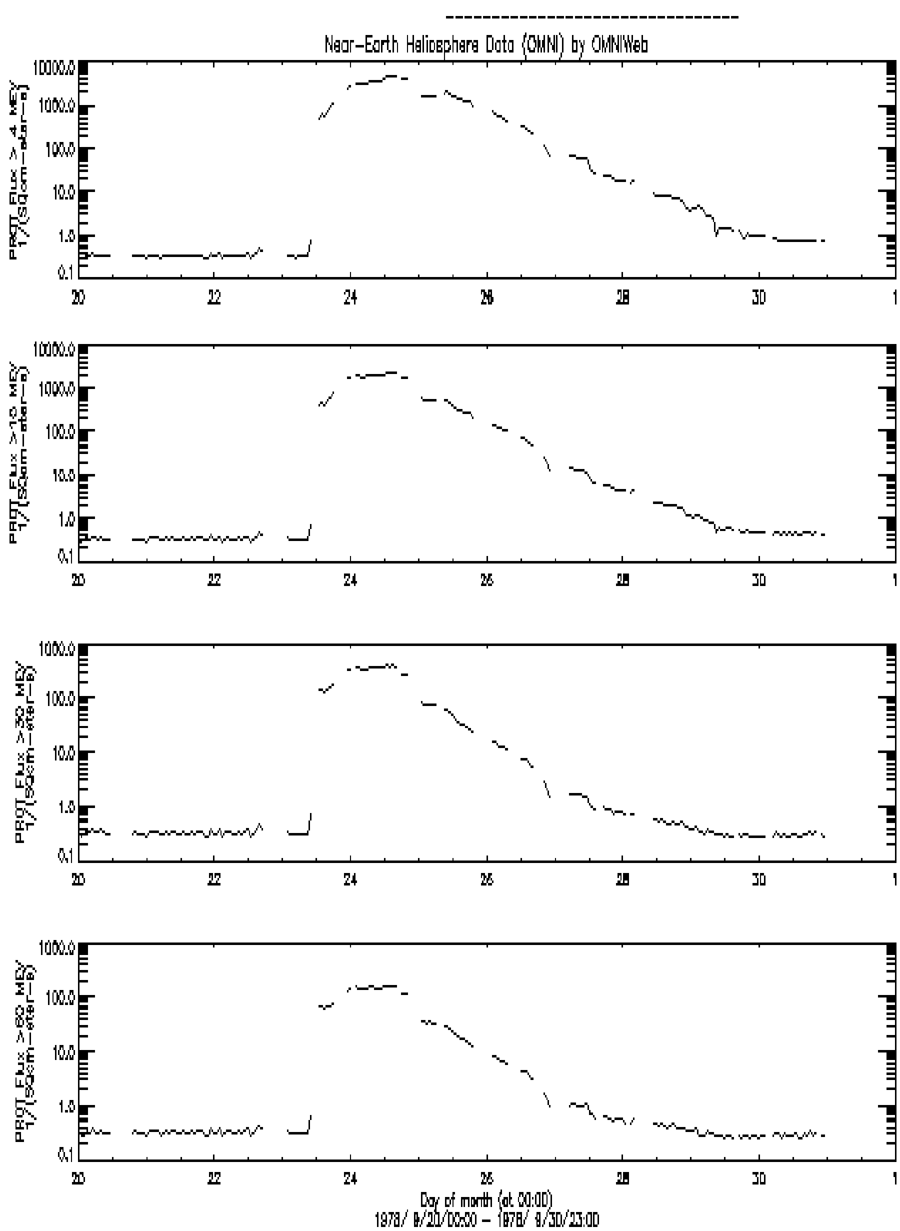


Fig. 1a. Pattern of proton flux time profiles for energies >4, >10, >30 and >60 MeV beginning from Sept. 20, 1978. Dashed line in the figure top shows selected interval of the exponential decay presented in the Table 1A (Attachment).

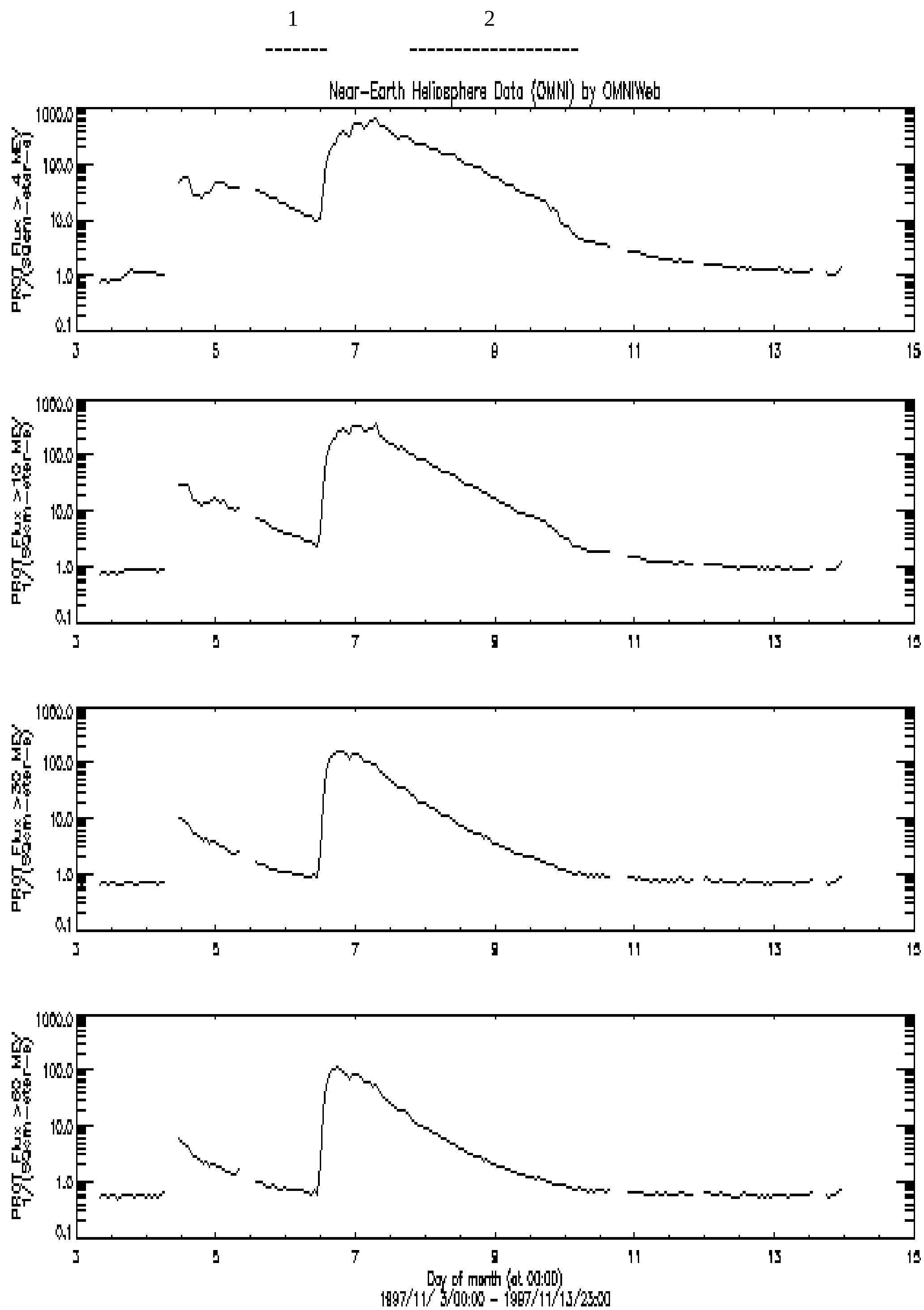


Fig. 1b. Pattern of proton flux time profiles for energies >4, >10, >30 and >60 MeV for sequence of events beginning from Nov.3, 1997. Dashed lines in the figure top shows selected intervals of the exponential decay presented in the Table 1A (Attachment).

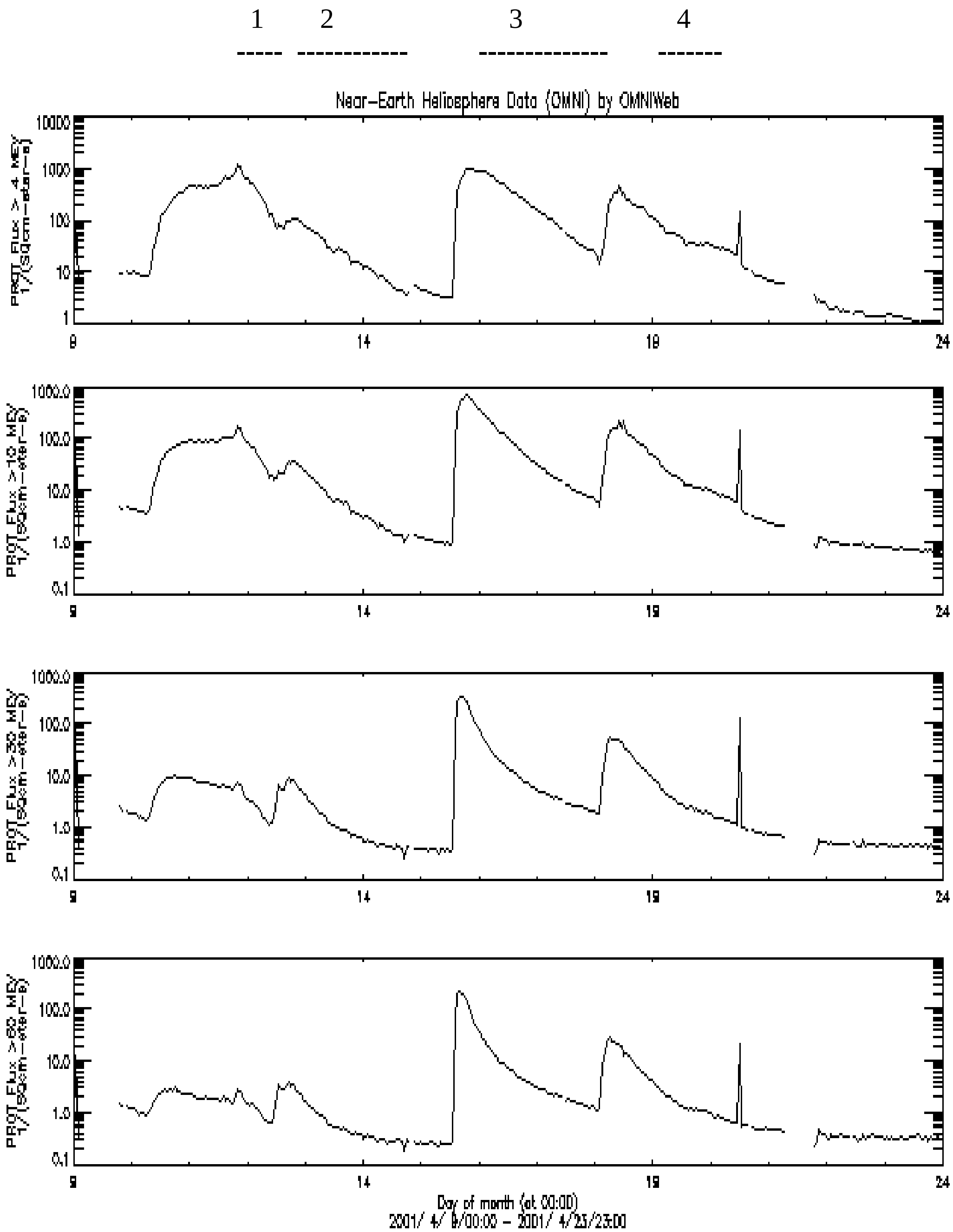


Fig. 1c. Pattern of proton flux time profiles for energies >4, >10, >30 and >60 MeV for sequence of events beginning from Apr. 9, 2001. Dashed lines in the figure top shows selected intervals of the exponential decay presented in the Table 1A (Attachment).

Statistical investigation of the decay phase of SEP events

Over the whole list of selected events the values of characteristic decay times, τ, of proton Ep >4 and >10 MeV fluxes were defined at the exponential-shape parts of time profiles. These values are presented in the Table 1 of Attachment. This table includes as well the values of peak fluxes of protons with energies > 10 MeV, total durations, ΔT; spectral exponent, γ, for the beginning of exponential decline in the energy range 4-60 MeV and exponent of peak flux spectra from Catalogues of solar proton events (Catalog of Solar Proton Events, ed. by Yu.I. Logachev).On the basis of this table statistical investigation of the values of characteristic decay times of all exponential parts of declines was carried out, as well as their durations and spectral indices. Figs 2 a,b,c show distributions of these parameters.

Accomplished investigations show that distributions of proton flux decay rates are not strongly dependent on their energies, at least in the energy interval 4-10 MeV. This was analyzed in detail when we considered the effect of temporal and spatial invariance in the spectra of protons and electrons in the major SEP events (see below). By virtue of this we hope in the future to consider characteristics of the decay phase only for one energy and chose the energy 4 MeV as the most representative for the whole set of events. However, estimating the radiation doze through the whole event, it's necessary to take into account different energies depending on the thickness of protection behind which the object of interest is placed.

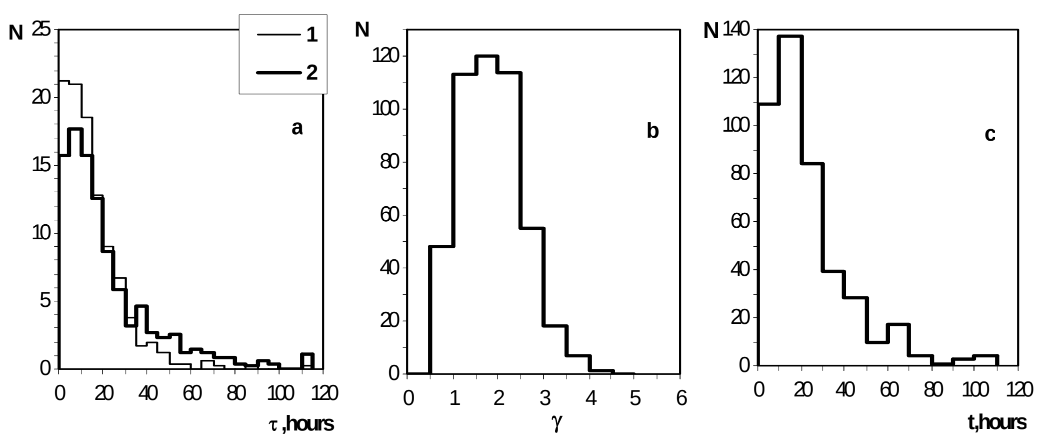


Fig.2a. Comparison of decay time distributions, τ, of >4 MeV and >10 MeV protons. Both are normalized to 100 events:
1) - >4 MeV protons, 2) - >10 MeV protons.

Fig.2b Distribution of proton integral spectrum exponents, γ, in the energy range 4-60 MeV for 476 parts of exponential declines of proton fluxes.

Fig.2c. Distribution of SEP events on the duration of the exponential decay of the > 4 MeV proton flux

The energy spectrum of solar cosmic rays is the most important characteristic of the acceleration process in a solar flare and the physical conditions in the acceleration region. Various acceleration mechanisms combined with different conditions in the acceleration region give different energy spectra of accelerated particles. In particular, the form of the spectrum and the total amount of accelerated particles in a source are closely related to the energetics and the mechanism of the flare itself.

It's necessary to distinguish between current instantaneous spectra during an event and peak flux spectrum that to some extent is the injection spectrum. We examined both of them.

The maximal values of proton fluxes of different energies at a distance of 1 AU from the Sun were used. These values may correspond to different moments of time for particles of different energies. If the emission of accelerated protons is considered to be pulse-like and their propagation - diffusive, then the energy spectrum based on the maximal observed values of proton fluxes of different energies will be the spectrum of protons leaving the Sun for interplanetary space, i.e., be emission spectrum of solar protons.

Energetic spectra exponents of considering events are limited in narrow interval with the average value of integral spectra exponent 1,7 ±0,8. It must be noted that energetic spectrum of protons is one of the main characterstics defining radiation doze behind different protection screens. Most dangerous are hard spectra with small values of γ. As all events that have occured during 25 years of observation (more than 2 total solar activity cycles) are included in this distribution, one can definitely say that no serious deviations of energetic spectra from their average values can happen. In the present distribution only 10% of spectra have values of γ less than 1, and practically all of them concern the low-power events.

Durations of the exponential parts of declines, as can be seen from the Table 1, are mostly about or less than 20 hrs. Simultaneously in 20% of events durations of the exponential parts are about two days and more. As a rule this concerns the most powerful events, which are of major interest both from the point of view of particle propagation in interplanetary medium investigation and of radiation hazards forecasting during such events.

Periods of time profiles with and without shocks

One of the Project tasks was systematic analysis of the decay phase of SEP events associated and non-associated with the shocks. To develope understanding of processes of propagation and losses of particles and a role of interplanetary shocks in forming intensity time profiles during the decay phase at different dictances from the Sun and at different heliolongitudes of the observer multispasecraft data of 70-80-th were used, as well as the data on energetic protons, solar wind and interplanetary magnetic field from s/c IMP-8.

Interplanetary shock waves and CME-driven shocks strongly influence upon flux decay rates and on SEP spectra. For analysis of this influence distributions of τ and γ values were built for SEP events with and without shocks. These distributions are presented in the Table 2 and Figs. 3 and 4 (a,b,c).

Figs. 3 and 4 (a,b,c) and the table permit to compare distributions of the values of τ (Ep>4 MeV) and γ separately for time intervals accompanied and non-accompanied by shocks. One can see that shocks steepen declines of time profiles (τ decreases) Average

values of τ during shock associated and non-associated periods are 10,9and 13.8 hrs, respectively.
Distributions of γ-s are more compact than those of τ, there is no considerable deviations from their average value <γ> = 1,7. Spectra of proton fluxes during shock associated periods soften (γ increases) compared with non-shock periods (<γ> = 1,9 and 1,7, correspondingly). Such a situation show that acceleration mechanisms and trapping of particles due to the shock is more effective for low energy particles.

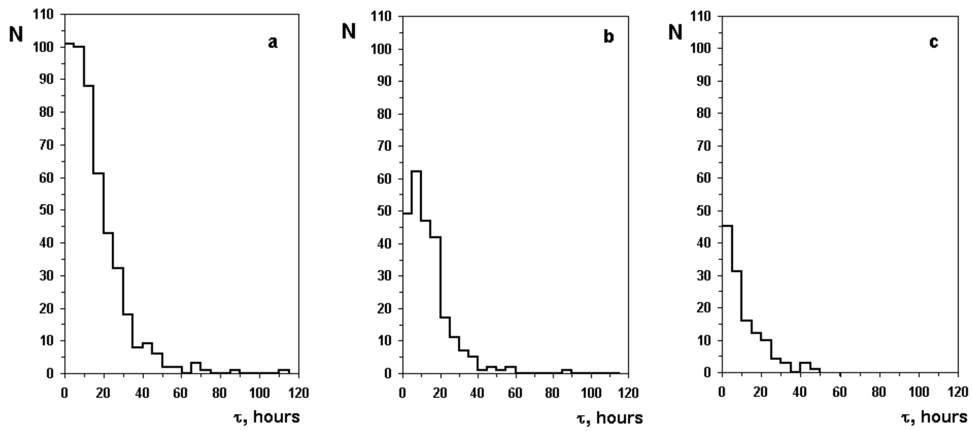


Fig. 3. Distribution of characteristic decay time, τ, of proton >4 MeV fluxes
a) all periods with exponential declines
b) periods without shocks
c) periods with shocks

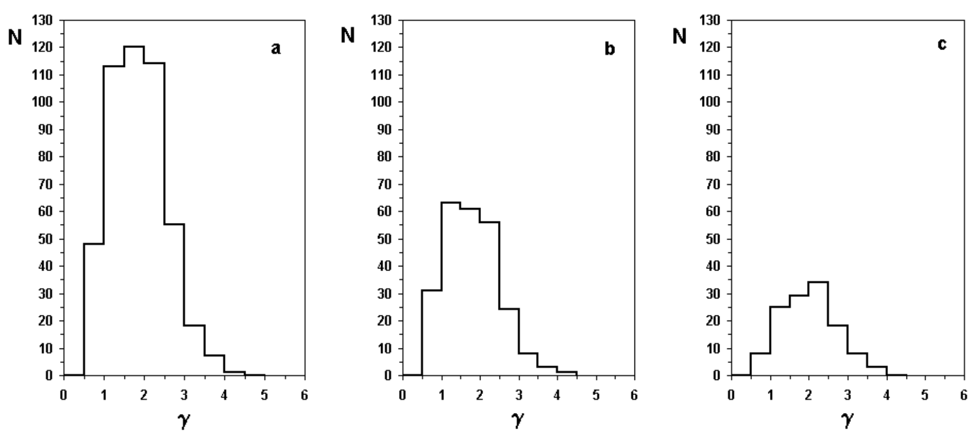


Fig.4. Distribution of proton integral energy spectrum exponents, γ, in the energy range 4-60 MeV. The value of exponent, γ, relates to the beginnings of exponential decline periods
a) all periods with exponential declines
b) periods without shocks
c) periods with shocks

Special analysis of total durations of SEP events dependent on their shock association was carried out. and distributions of the total durations, ΔT, of exponential declines with and without shocks has been built. Results of this consideration are presented in Fig5. One can see that these distributions differ insignificantly for $\Delta T > 10$ hrs, while for $\Delta T < 10$ hrs the relative number of shock associated events is 30- 40 % higher than without shocks. This can be due to the fact that at our selection criteria short duration events often represent regions of shock-trapped particles, which rapidly pass by the observer. Average value of decays without shocks $\Delta T = 0{,}8 \pm 02$ days. In extreme cases duration was longer than 5-7 days. These events have a large value of characteristic decay time and are most radiation dangerous.

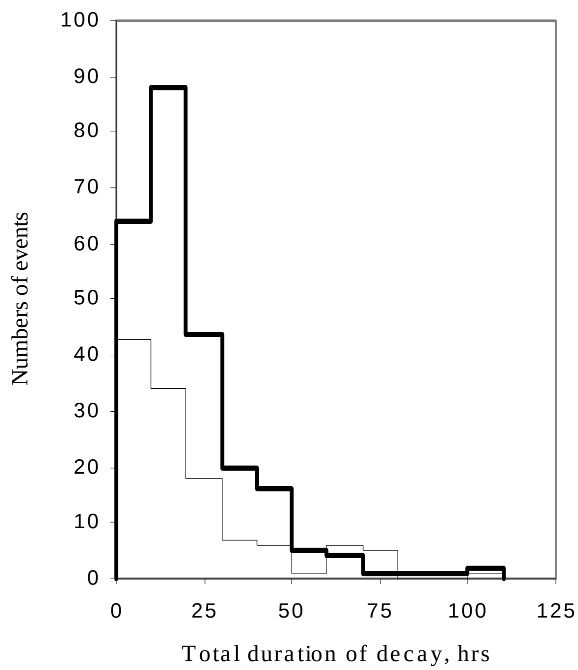


Fig.5. Distributions of total durations of decays
- accompanied by shock (thin line)
- non-accompanied by shock (solid)

Functional description of decays of SEP events

It was proposed in the Project to investigate the functional form (power or exponential) of the SEP event declines. This is of a great importance from the point of view of adequacy of the theoretical models considered.

By purely diffusive process of particle propagation flux declines must be power-law ($J(t)=At^{-n}$, where n = 3/2 for classical diffusion in the three dimentional space), by prevailing of process of convection in the solar wind they must be exponential-law ($J=J_o exp\text{-}t/\tau$), where τ is characteristic decay time (Forman,1970, Jokipii,1972).

As was shown in (Daibog et al., 2003a) exponential-law character of low energy (< 30 MeV) proton flux declines are observed very often and according to our hypothesis could be a criton of interplanetary medium state. Really a rate of SEP flux decays is defined only by particle spectrum and parameters of interplanetary medium.

As was told above decay shape is of exponential form if convective processes prevail over diffusion. Then τ could be described as $\tau = 3r/2U\Gamma$, where r is a distance of the observer from the Sun, U - solar wind speed, Γ –particle spectral index in impulse representaion $J(p) \sim p^{-\Gamma}$ (Forman,1970; Jokipii, 1972).

In the energy representation $J(E) \sim E^{-\gamma}$, that gives $\Gamma=2\gamma-1$. Forman (1975) and Jokipii (1972) have obtained for Γ the next expression: $\Gamma=2+\alpha\gamma$, where $\alpha=(2M_oc^2+E)/(M_oc^2+E)$, E – particle kinetic energy, M_oc^2 – particle rest energy. When the energy value is small $\alpha\approx 2$ and $\Gamma = 2(1+\gamma)$. Somewhat different dependences of Γ on γ, obtained in these papers do not influence sufficiently on the character of τ dependence on U and on the spectral index γ. In both cases τ is reversely proportional both to U and γ, and thus for different events with the same products $U\Gamma$ the values of τ will be the same as well.

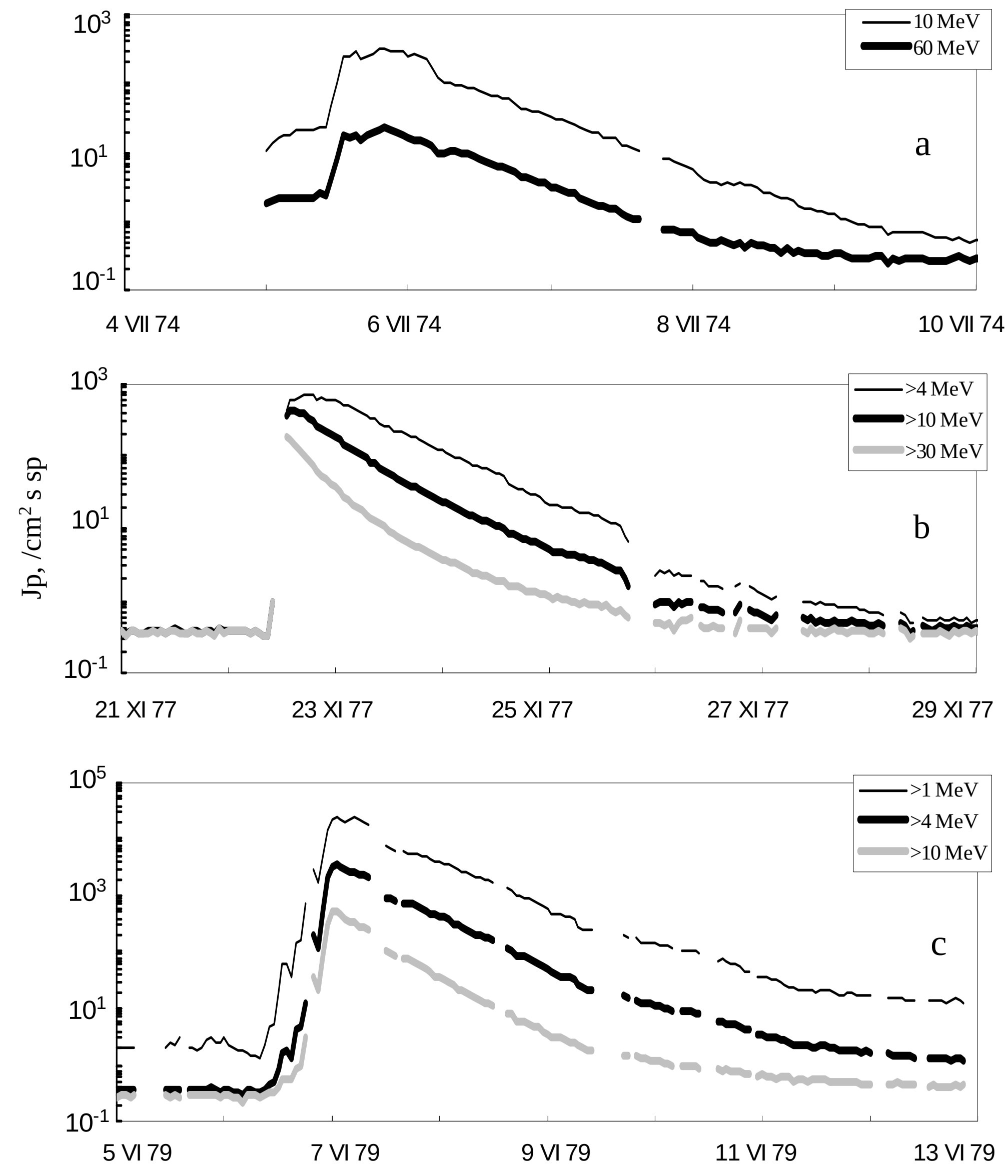


Fig.6. Patterns of different shapes of solar proton fluxes registered at the IMP 8 s/c after their peak values:

a) the event with the exponential decays of >10 and >60 MeV protons during about two days

b) the event with the exponential decay of low energy (>4 MeV) protons and a power-law for the high energy (>30 MeV) protons.

c) the event with a long (up to 4 days) exponential decay of 1 to >10 MeV protons.

In fig.6 presented are the patterns of events with different functional dependences of proton fluxes on time during their declines. Fig 6a demonstrates the event in which exponential decay of protons of high energy (>10 and >60 MeV) was observed for nearly two days, in fig.6b exponential-law decline is valid only for low energy protons (> 4 MeV) while for high energies exponentiality violates and for > 30 MeV protons the functional dependence is power-low. Fig.6c demonstrates the event with very long exponential decline of 1 to10 MeV protons for the event of June 7, 1979.

Such a situation (exponentiality at low proton energies and power-law at high energies) is in agreement with theoretical ideas: exponential decline is typical under predominance of convection over diffusive processes Forman (1975) and Jokipii (1972), which is more realistic for low energy particles, though, as fig.6a demonstrates, sometimes exponential-law decline take place even at rather high energies (60 MeV). In a case of event presented in fig.6a solar wind speed was 600-700 km/s, however even at this value of solar wind speed diffusive processes turned to be supressed.

It was shown that in most cases, when the time profile following the maximum is smooth and free of disturbances, the exponential function gives the best approximation in nearly 90% of the cases for proton energies above about 1 MeV. Also important to note is that this exponential decay starts very soon after the maximum, not only in the late phase, and keeps going sometimes for one to two weeks.

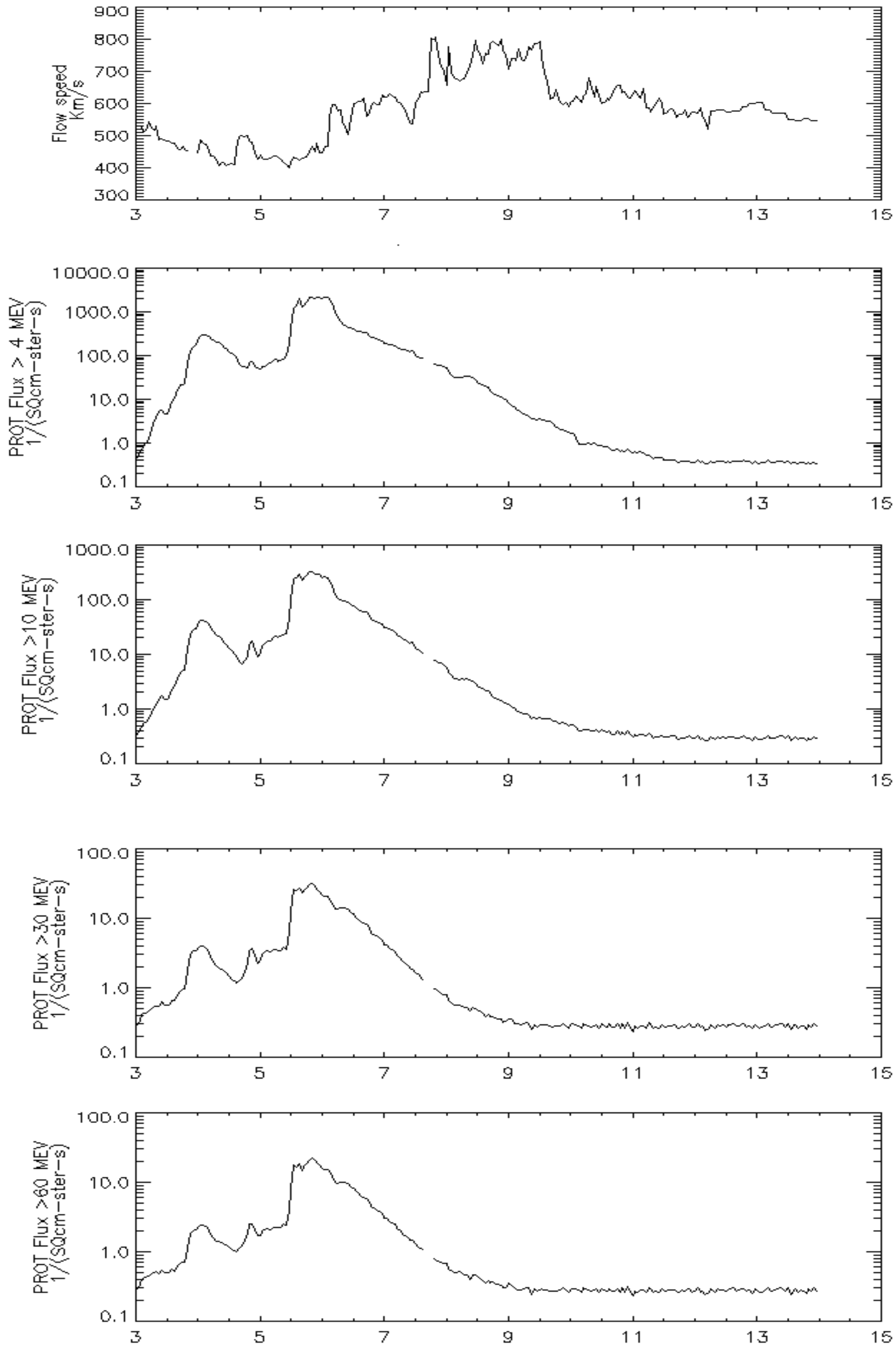
The comparison of experimental values of characteristic decay times, τ, with those obtained previously in different theoretical models (Forman 1970,1971, Owens, 1979) shows that theoretical τ values are reasonably close to the fitted slopes in nearly 50% of all cases if one uses the average solar wind speed values,U, measured later when the corresponding plasma in which particles were convected arrives to the observer. This might be a surprisingly high number bearing in mind that in rare case remains U constant for a sufficiently long time.

For mathematical description of the decay phase of SEP events and their correlation with IM properties it was supposed that the declines of particle fluxes after their short-time injection are defined by a number of physical processes, the main of which are diffusion (d) and convection (c) in the interplanetary medium and adiabatic deceleration (ad) in expanding solar wind. Taking into account these three factors permits to define characteristic decay time as

$$1/\tau = 1/\tau_{d} + 1/\tau_{c} + 1/\tau_{ad}$$

Such discrimination of processes in the IM permits to analyze the reasons of power or exponential declines of SEPs after their maxima. It was pointed out that in the data base created for this Project only about 10 % of declines are described by the power law. As a rule those are during periods of weak solar wind when convection may be neglected ($1/\tau_c$ is small and the main process is diffusion). Such a picture is often observed for high energy particles when two processes - convection and adiabatic deceleration may be neglected, especially if particle energy spectrum is hard.

It was shown that the power-law decline must be observed also in a case of adiabatic deceleration of particles trapped in the region between the front of the shock going away from the Sun and strong magnetic fields near the Sun (above it was supposed that particles were trapped in an expanding volume element in the solar wind).



July 1974

Fig.7a A pattern of the exponential decline in all integral energy channels (>4, >10, >30, >60 MeV) in the event of 6.07.1974.
Upper panel shows variations of solar wind speed.

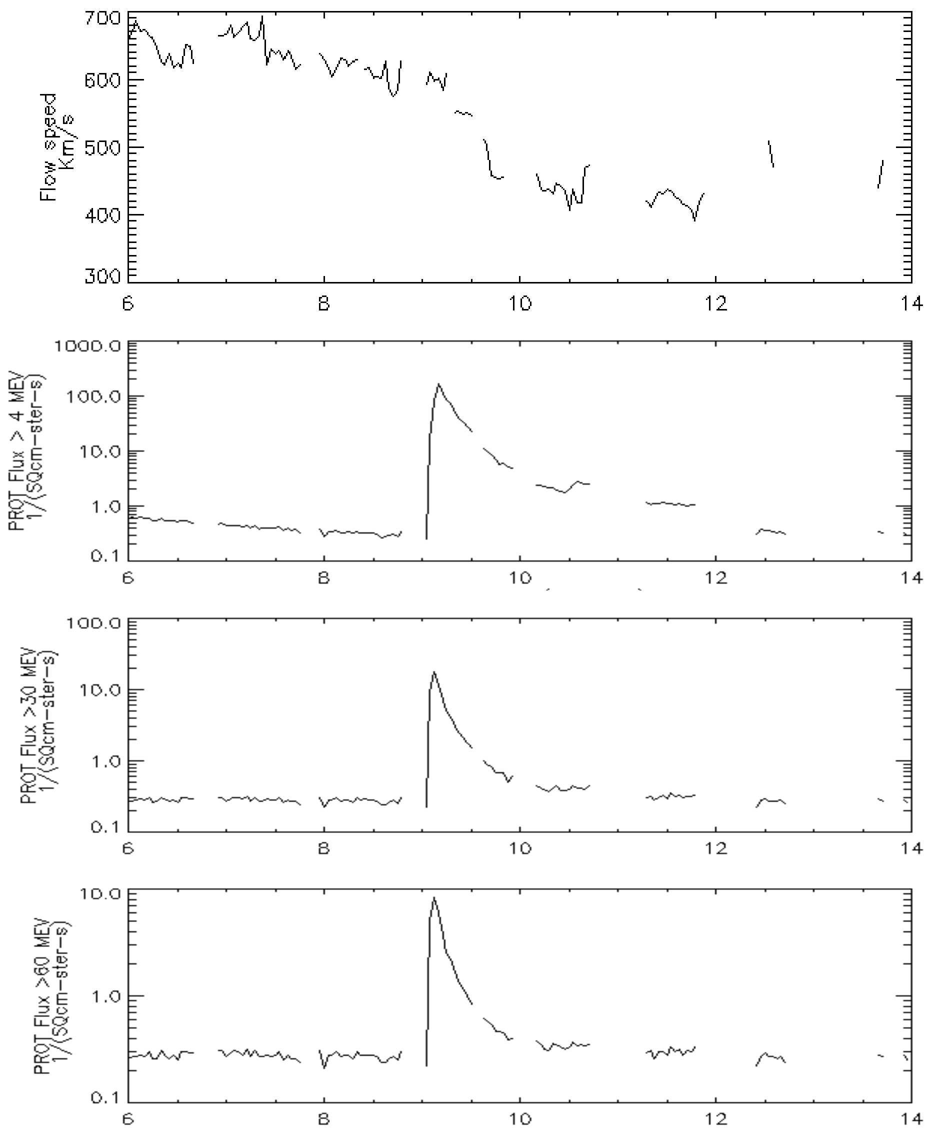


Fig.7b. A pattern of the power-law flux decline in July 9,1985 event in all energy integral channels (>4, >30, >60 MeV).
Upper panel shows variations of solar wind speed.

Sometimes those events are observed in which low energy proton (< 5-10 MeV) declines may be described by the exponential law ($J = J_o \exp{-t/\tau}$) while high energy (> 10-30 MэB) by the power dependence ($J = J_o\, t^{-\delta}$). The patterns of all three kinds of declines for high and low energy particle are presented in Figs.7a (exponential declines for all energies), 7b (power-law declines for all energies), 7c (exponential decline for low energy, power-law decline for high energy). Upper panels represent time variations of solar wind speed.

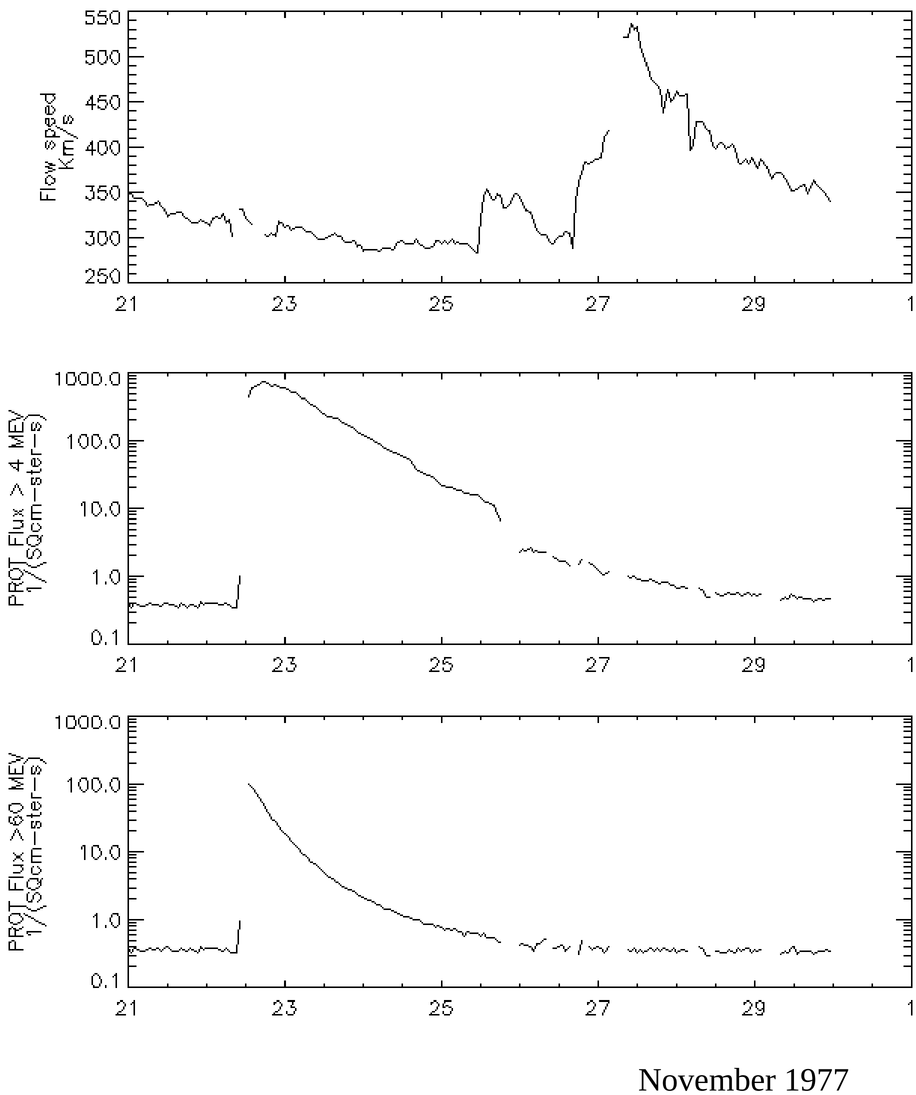


Fig.7c. A pattern of the 22.11.77 event with the exponential decay of low energy (>4 MeV) protons and a power-law for the high energy (>30 MeV) protons. Upper panel shows variations of solar wind speed.

It must be noted that more rapid exponential decay is more favorable from the point of view of radiation hazards during space missions, especially for technical elements behind thin protection screens: solar batteries, optical instruments, detectors of scientific devices.

Invariance of charged particle time profiles during the late phase of SEP events according to multispacecraft observations

The question was considered about existence of spectral invariance in electron events, similar to that observed previously in proton SEP events. It was important from the point of view of searching of arguments in favor of electron acceleration by CME driven shocks.

20 enhancements of 4-13 and 13-27 MeV protons and 0.3-0.8 and 0.8-2.0 MeV electrons were selected that were simultaneously observed at Helios1 and Helios2 s/c at the distance 0.3-1.0 AU from January 1976 to March 1980 (detailed description of the events is presented in (Daibog et al., 2000)).

The analyses showed that 17 events from 20 candidates had signs of invariant spectra of both protons and electrons. 13 of them were completely invariant. Some characteristics of these events are placed in Table 1.

Table 1

Parameters of SEP events with invariant spectra

Date	T_{on}	λ	R, AU		$\Delta\lambda$		U_{sh}, km/c	
			Helios1	Helios2	Helios1	Helios2	Helios1	Helios2
19.09.77	09.57	W 57	0.62	0.71	E84	E108	760	НД
24.09.77	05.50	W120	0.57	0.64	E25	E48	1160	860
22.11.77	09.45	W 40	0.66	0.61	W78	W47	470	660
01.01.78	21.45	E 06	0.95	0.93	W34	E01	1130	950
13.02.78	01.16	W 20	0.95	0.95	W65	W69	НД	870
08.04.78	01.10	W 11	0.50	0.51	W49	W20	690	720
23.09.78	09.44	W 50	0.74	0.72	E71	E110	800	780
11.12.78	18.33	E 14	0.70	0.75	W41	E05	740	
16.02.79	01.23	E 59	0.98	0.97	E04	E36	НД	950
01.03.79	09.55	E 58	0.94	0.93	W10	E30	980	810
09.03.79	09.35	E 80	0.91	0.84	E11	E52	920	590
27.04.79	06.43	E 17	0.46	0,36	W30	E32	880	НД
19.12.79	21.56	E 36	0.62	0.75	W34	E18	650	900

In the table: the date of the flare associated with the SEP event; T_{on} - the time of the flare onset in Hα (UT); λ - is flare heliolongitude;R - is the observer's heliocentric distance; Δλ - is the observer's longitude relative to the flare (W - westward, E - eastward from the observer's point); U_{sh} -is the transit shock speed at the observer's point (DG - is a data gap, the blank - is absence of effect).

Two examples of the invariant spectra events are shown in Figs. 8a and 8b.

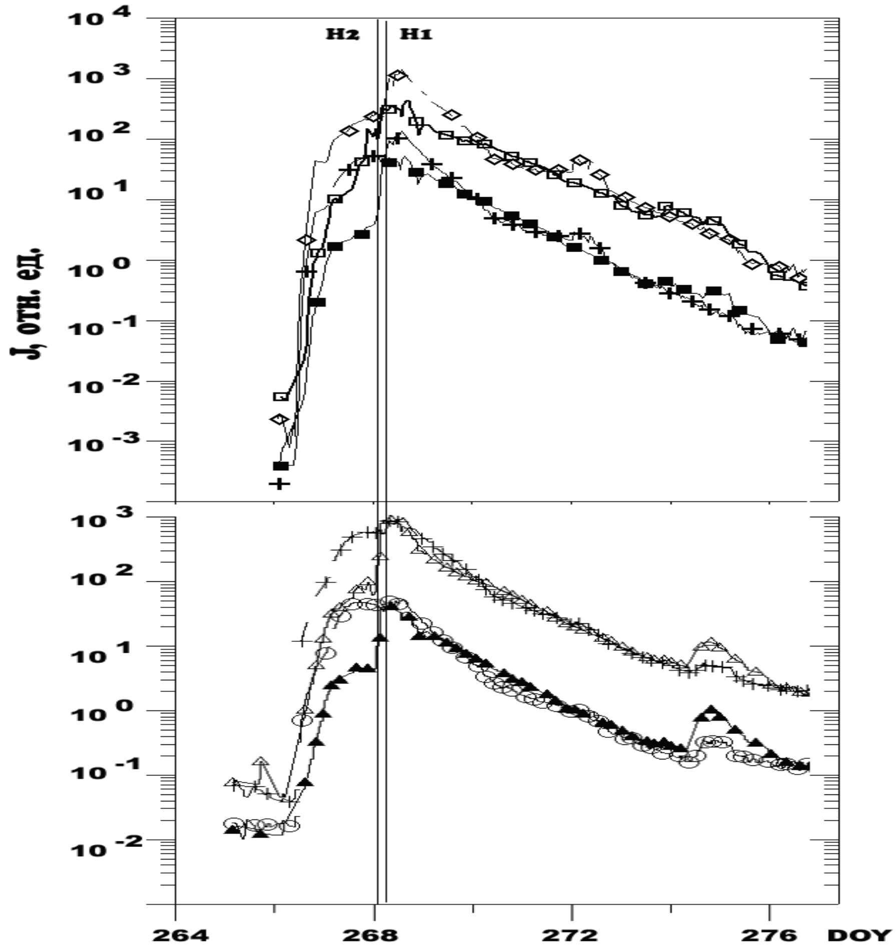


Fig 8a. Time profiles of proton (a) and electron (b) intensities in the event of Sept. 23 (DOY 266), 1978. J -is hourly averaged counting rate.

(a) diamonds - 4-13 MeV protons, crosses - 13-27 MeV protons according to Helios 1 data; light and filled squares according to Helios 2 data, correspondingly.

(b) crosses - 0.3-0.8 MeV electrons, circles - 0.8-2.0 MeV electrons according to Helios 1 data; light and filled triangles according to Helios 2 data, correspondingly

It can be seen that late after the time of the intensity maximum and the passage of an interplanetary shock at the s/c intensities of protons and electrons with the same energy are close in magnitude and decrease with nearly the same τ on both s/c.and one can say about "complete" invariance of particle spectra. For the event of 23.09.78 invariance of proton spectra was observed over a longitude interval of about 160° (Reames et al., 1996, Reames et al.,1997). Here we can see that electron intensity profiles have the same characteristics as the proton ones and this continued at least until October 8, demonstrating high stability of conditions in a very large spatial region.

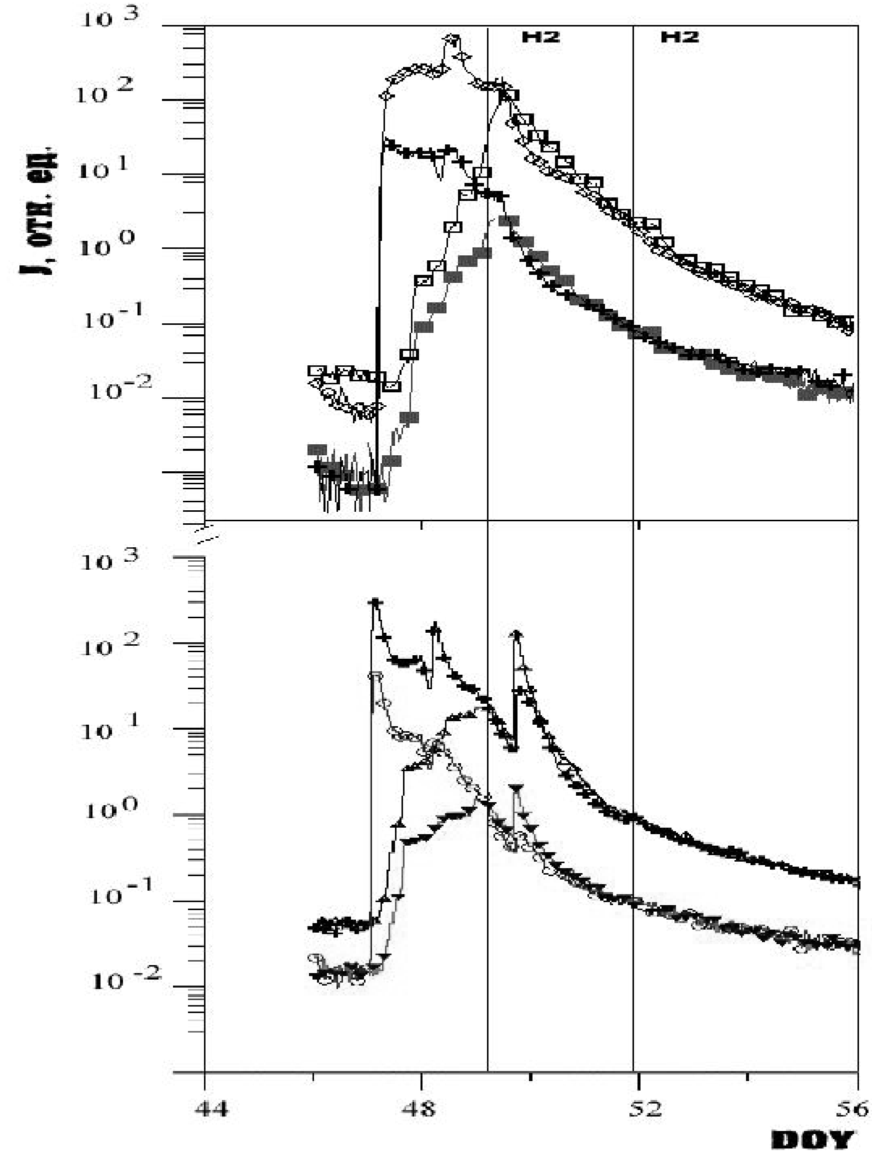


Fig. 8b. The same as fig.8a for Feb.16 (DOY 47), 1979 event

The event of 16.02.79 was accompanied by two shocks. The first one is associated with 16.02.79 flare located at E59 at 1:44 UT, the second - with the flare on 18.02.79 at 36 UT located at W13. The latter was impulsive flare and caused electron enhancements on both s/c . The decay times of these enhancements are considerably less than late in the event (5÷10 hrs comparing to 50 hrs in the late phase). Thus contribution of electrons from this additional ejection during the decline of the whole event is reduced after midday of 19.02.79.

The analyses of the totality of events shows that spectrum invariance late after maxima of SEP events are observed for both protons and electrons. Sometimes τ for electrons are 20-30% larger than for protons, this can be explained by better storage conditions for electrons compared to protons in the region between the shock front and converging magnetic field near the Sun. Invariant spectra seem to occur in all gradual SEP events.

One may expect that the more to the west from the line Sun center - flare (i. e. from the nose of the shock) the s/c is located, the more is the delay of invariance onset due to waiting of the arrival of field lines connected to the eastern flank of the shock.
In a case of events connected to the eastern flank the observer just from the onset of event locates in the invariance region and the onset of this regime outstrips the shock arrival.
It was found in Reames et.al.(1996) that delay (or advance) of the invariance onset times of proton intensities increase with increasing longitude separation of spacecraft from the flare location. For eastern flares this is explained by existing of time intervals between crossings at s/c field lines connecting to the quasi-parallel region on the eastern flank of the shock and to the longitude at the shock, that primary arrival at the observer, while in a case of western flares s/c is connected to this region from the very beginning.

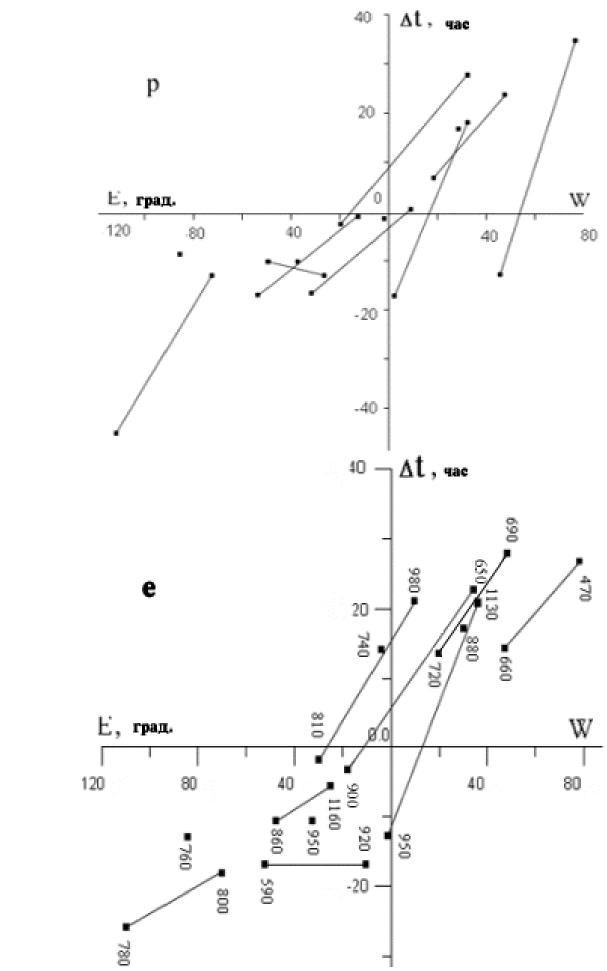


Fig. 9. Delay (negative) and advance (positive) time intervals, Δt, of invariance onset relative to the shock arrival versus corresponding heliolongitude distance, Δλ, between the s/c and a flare. Straight lines join the points corresponding to simultaneous measurement at Helios 1 and Helios 2 s/c. Figures near the points - transit shock speeds at the observation points

The question arises whether electrons also “feel” this difference in flare-spacecraft locations, as well as about magnitudes of these delays and advances. We analyzed the proton and electron profiles and were convinced that in 13 of 17 events with invariance properties it was possible to determine the time of onset of invariance regime both for protons and electrons. These events are presented in the Table 1.

In Fig.9 plot of delay and advance time intervals Δt versus corresponding longitude distance, $\Delta\lambda$, are presented for all events considered (Daibog et.al. 2003b). Here left side of the plot concerns the events from the eastern relative to the spacecraft flares, right - from the western ones.

Positive Δts correspond to advances, negative - to delays. In a case of protons all events associated with eastern relative to s/c flares turned to be in the quadrant corresponding to delays, with central flares - become invariant together with the arrival of the shock, most of western events - in the quadrant with advances.

In a case of electrons all eastern events, but one, occupies the quadrant with delays, all western events but one – the quadrant with advances. One can see the tendency of increasing of discussed time intervals ,Δt, with increasing $\Delta\lambda$.

Additionally for illustration of this conclusion the points corresponding to observations of the same event at different points are joined by straight lines. The values of shock transit speeds are presented near each point.

Unfortunately the statistics is not numerous, measurements were made at different distances from the Sun, and this caused large scattering of the points. This is also due to considerable variations of solar wind speed and possible changing of angular sizes of shocks at different distances from the Sun.

In the absence of diffusive scattering particle intensities in the region of invariant spectra have to be identical all the way from the Sun. The events observed by Helios 1 and 2 at distances 0.3-0.6 AU and possibly near the Sun-Earth line where considered. It was found that, in spite of the low number of events there were those in which Helios intensities became nearly equal to those observed at IMP 8 after the shock crossing the respective s/c. (Daibog et al. 2001).Thus the effect of spatial invariance in flare-shock associated events is valid not only in wide angular regions but at different distances from the Sun from 0.3 to 1 AU as well. A pattern of such event is shown in Fig. 10**.** That was the April 30, 1976 small event after a flare at S08W46, 20:47 UT: relative positions of flare and the s/c were similar to those in Sep 23, 1978 event. Helios 1, 2 were at 0.65 AU and 0.42 AU, respectively, and at longitudes about W160. >4 MeV proton intensities at all three s/c become very close at the time after shock arrival to IMP-8. Marked are shocks at Helios 1 and 2 (IMP-8 shock transit speed 910 km/s). The angular distance between the magnetic foot points of the Helios 1 and 2 s/c were only 10 deg but it took about 3 days before intensities became equal. This may indicate the change of particle propagation conditions at about 0.5 AU

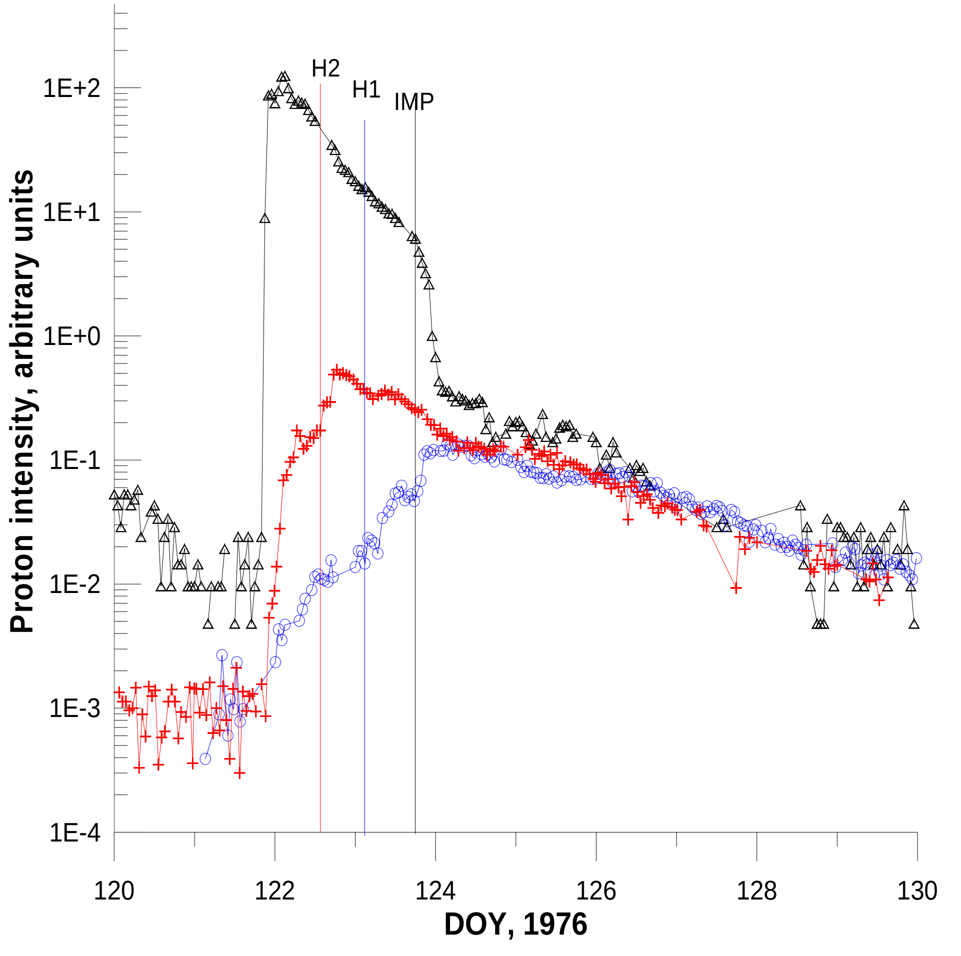


Figure 10. The fluxes of proton in SEP event 30 April 1976

Correlation between decay rate, spectral index and shock speed

Investigation of correlation between rates of decay of proton >4 MeV intensities, which can be described in exponential form J = J_0 exp(-t/τ), spectral index in integral representation calculated for the start time of exponential decline and associated shock speeds was fulfilled on the data base of IMP-8 in 1974 - 2001

A plot of characteristic decay times, τ, as a function of the shock speeds, U, has been built for two criterions of event selection: 1 - first after maximum exponential parts of declines (as a matter of fact, this includes in many cases shock peaks); 2 - parts of declines after shock peaks, if any. The first criterion concerns the time just after shock crossing the observation point, the second one could be attributed to particle trapping, described above. The table of events, presented in the Annual report was used, also new table 2A (see attachment) was created, containing parameters of declines for second criterion selection, which are "mixtures" of the full table data. The results are presented in Figs 11a (including shock peaks) and 11c (without shock peaks).

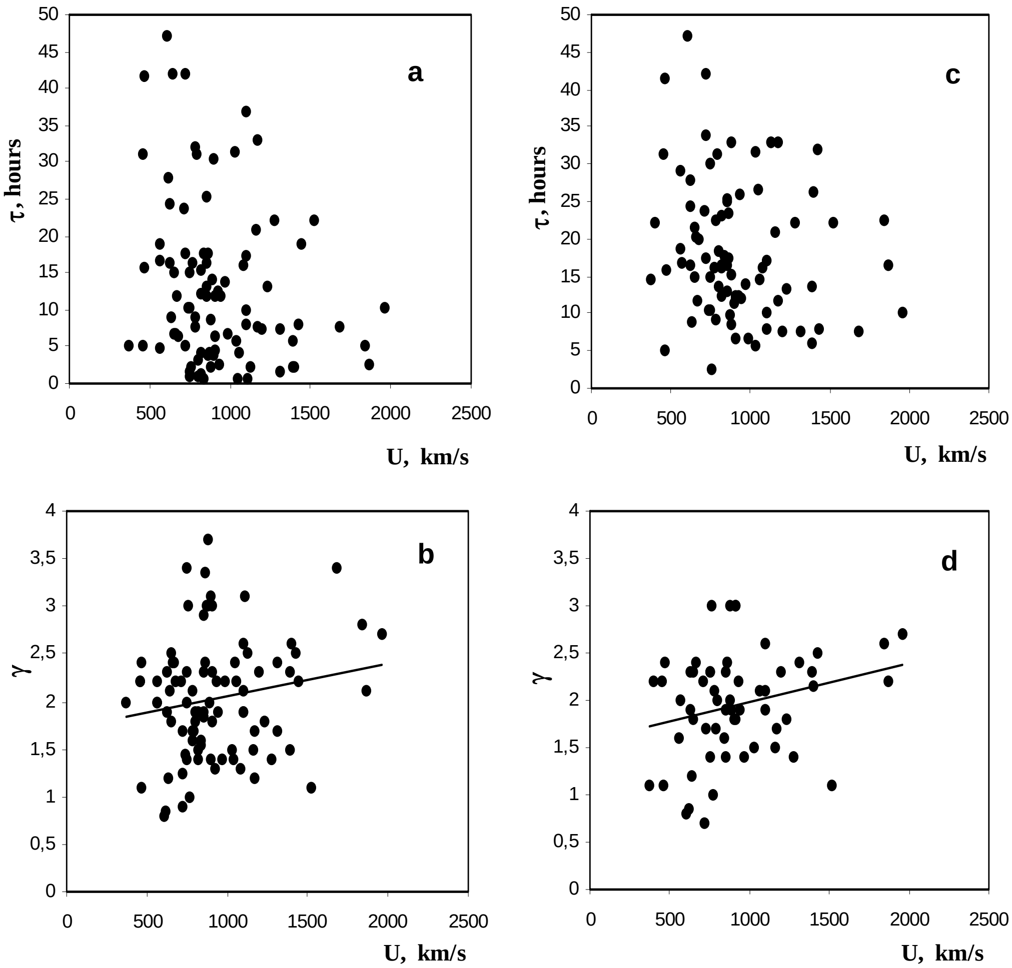


Fig.11. Depence of characteristic decay time, τ, and spectral index, γ , on the shock speed, U

There is no clear functional dependence between τ and U. (Fig. 1). However, in spite of very large scattering of points, some limiting dependence can be noted which means that very large τ takes place only for small values of U and that high shock speed is associated with small τ. Figs 11b (including shock peaks) and 11d (without shock peaks) show correlation between spectral index, γ, and a shock speed. Again, point scattering is very large, but some tendency of slight increasing γ with the shock speed, U, exists.

The task was to try to look for a correlation of the decay time of particle intensity with the speed of the shock associated to a given SEP-event. It`s essential that SEP-events were observed at various angular distances relative to the shock nose and that longitudinal dependence (as well as radial) of shock speed must be taken into consideration. In the model developed by Reames et al. (1996) particles are supposed to

be quasi-trapped in an expanding flux tube between the high magnetic field near the Sun and the moving high magnetic field region downstream of the travelling shock.
Though the authors suggest declines to be caused only by the expanding volume and adiabatic deceleration, as a matter of fact, they don't take into account reflection from the outwardly propagating shock front. If this would be considered, we may hope to obtain a correlation between shock speed and decay time and thus to confirm the above model.

They proceed from the model (Reames et al. 1996) that describes the evolution of the particle distribution as being governed by transport equation in mixed coordinates (Ruffolo 1995) and write down a full Fokker-Plank equation taking into account streaming, convection, μ-diffusion, adiabatic focusing and adiabatic deceleraton.
A rigorous derivation of the decay time of the differential intensity would require a full solution of transport equation, subject to appropriate source function, initial and boundary conditions. A number of successive simplifying suggestions (ignoring fresh particle injection from the receding shock; scatter-free motion in the whole volume except of the shell mentioned above; negligible cross field diffusion; isotropic particle distribution with negligible gradient along the flux tube; power law energy spectrum with constant power index) as a matter of fact reduce the task to the simple isotropic diffusive model with adiabatic deceleration in the expanding solar wind. So by many suppositions, simplifications and angular averaging there was obtained the solution for t-dependence of τ, that is intrinsic for any diffusive model. So in the framework of their suppositions it would be natural to expect the same dependence both for shock associated and non-associated events, because adiabatic deceleration in the expanding solar wind takes place in both cases. All the suppositions, mentioned above, permit to approximate the decay of the differential particle intensity by

$$\tau = t/(2\gamma + 2),$$

where t is the time, γ - spectral index.

It can be demonstrated that the similar result may be obtained just formulating the accepted one by one additional suppositions, simplifications and angular averaging as the main conditions of the task One can formulate the simplest task of particle motion in an expanding one-dimensional volume and assume all particles moving parallel and reflecting from the ends going away. As in Reames we suppose that particles at any moment are uniformly distributed in the volume and their momentum spectrum is expressible in the form $p^{-2\gamma}$. Then from the continuity equation

$$\partial F/\partial t + \partial(F*\partial l/\partial t)/\partial l + \partial(F*\partial p/\partial t)/\partial p = 0,$$

taking into account that $\partial p/p = -\partial l/l$, where $l = l_0 + Ut$ is the volume length, U is the shock speed, we obtain for $\tau = -F*\partial F/\partial t$, at $t >> l_0/U$

$$\tau = t/(2\gamma - 2).$$

As this consideration is absolutely transparent and as it is very difficult to check Reames et al. chain of simplifications, one can suppose as a right this solution. As a matter of fact, both of them very approximately concern the real picture, because we are not at liberty to choose the radial dependence of distribution function, which has to come from the solution of a complete Fokker-Plank equation. But the essential fact is that in both solutions τ decreases with increasing γ. Simultaneously, as mentioned in (Ruffolo, 1995) deceleration alone leads to an intensity-decay time in the expanding solar wind

$$\tau = C /(\gamma -1),$$

where τ_d can be obtained from

$$1/\tau_d = 2V_{sw}/3r,$$

V_{sw} is the solar wind speed.

One can see that γ-dependence of this formula is similar to the above ones, but τ does not depend on t and inversely proportional to V_{sw}.
Thus a question of correlation between τ and γ is closely connected with the task of τ - shock speed relation.
Analyses of IMP 8 data permitted to obtain a plot of decay times as a function of spectral indices (Daibog et al., 2003a). The parts of time profiles with and without shocks were considered separately and the results are presented in Figs 12a (including shock peaks), 12b (without shock peaks) and 12c (without shocks).

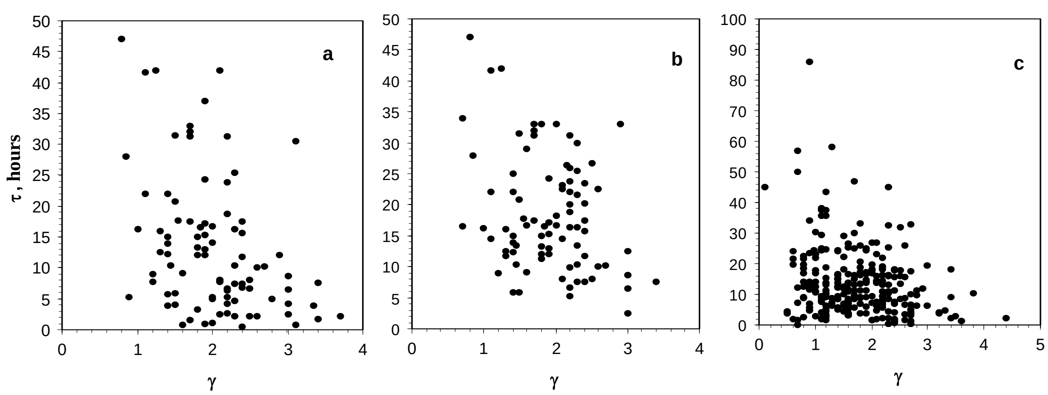


Fig.12. Correlation between proton >4 MeV decay time, τ, and spectral index, γ
a – for first criterion
b – for second criterion
c – without shock

The tendency of decreasing τ with increasing γ definitely exists in shock associated events (especially in Fig. 12a). But some limiting dependence for the parts of time profiles without shocks must be noted as well. Qualitatively Figs 12b and 12c differ for small values of γ and τ. However, we must underline that this situation contradicts neither to pure diffusive model nor to the model with particle trapping between the shock front and the Sun. Most probable adequate model must take into account continuous particle acceleration by shocks.

Periods of quasi-stationary conditions in interplanetary space according to sequences of SEP events

In the case of no additional particle injection during the decay phase of event decay rate for particles of definite kind and energy is determined by the state of the interplanetary magnetic field, more exactly, by its inhomogeneity spectrum in the region of particle propagation. Declines of low-energy (1-10 MeV) proton fluxes can often be described by exponential law: $J = J_o \exp(-t/\tau)$, where τ is the characteristic decay time. This may be explained by convective effects and adiabatic deceleration of particles during their propagation in interplanetary medium.

Statistical investigation of proton declines indicated (Daibog et al., 2003c) that the characteristic decay times in SEP events change in a wide spread from 1 to 100 hours with the average value of $\tau \approx 14$ hours. Simultaneously it was discovered that sometimes very long exponential declines are observed with constant τ, they last up to 5 days and longer. Over 3 solar cycles (1971-2001) about one hundred declines with constant τ for more than 7 days were collected. Even longer declines are observed very seldom, because at the end of events it is difficult to extract solar particles from the background and impossible to judge about the state of the interplanetary medium (IM) in the absence of an indicator of this state. However, sometimes it turns out that after some SEP event, the second, third etc. events follow one by one and thus it is possible to check the state of IM through a longer period of time.

It was pointed out that looking at successive events one can notice the existence of rather long time intervals (two weeks to one month, and even longer in a few cases) during which the characteristic decay phases of events in these periods are very similar. Periods with short decay times can be followed by long ones. Large and small events are observed with similar declines (Daibog et al., 2003c).

For investigation of sequences of SEP events data from Prognoz 1, 2, IMP 5, 8, Helios 1, 2, VEGA, GRANAT and SOHO s/c within a long time interval from 1971 to 2001 were used. Prognoz, IMP, and GRANAT are Earth orbiting satellites permanently located at 1 AU, SOHO also located near the Earth at the L1 libration point at 0,01 AU upstream of the Earth, while Helios and VEGA were located at 0.3÷1.0 AU and 0.7÷1.0 AU correspondingly, that is why we indicate in the Table 2 the radius and heliolongitude of s/c for Helios and Vega observations. There were analyzed exponential decays of proton integral >4 MeV fluxes, as well as differential 1-5, 4,6-15, 1-20 MeV fluxes and selected both long lasting exponential decays and sequences of events with similar (with an accuracy 20%) values of τ.

Fig. 13 a,b shows two patterns of such a decline. Fig.13a shows the decay of fluxes of proton Ep 2-4,6 MeV and Ep 4,6-15 MeV with $\tau = 32 \pm 2$ hours through two weeks period. Two decays of >10 MeV protons in November 1997 (Fig.13b) were characterised by $\tau = 15 \pm 1$ hrs. for a week. One of the outstanding events of September 23, 1978, studied earlier by Reames et al. (1996, 1997) and Daibog et al. (2000), when, according to Helios 1 and 2 data, an exponential decay with $\tau = 33$ hrs was observed for about two weeks.

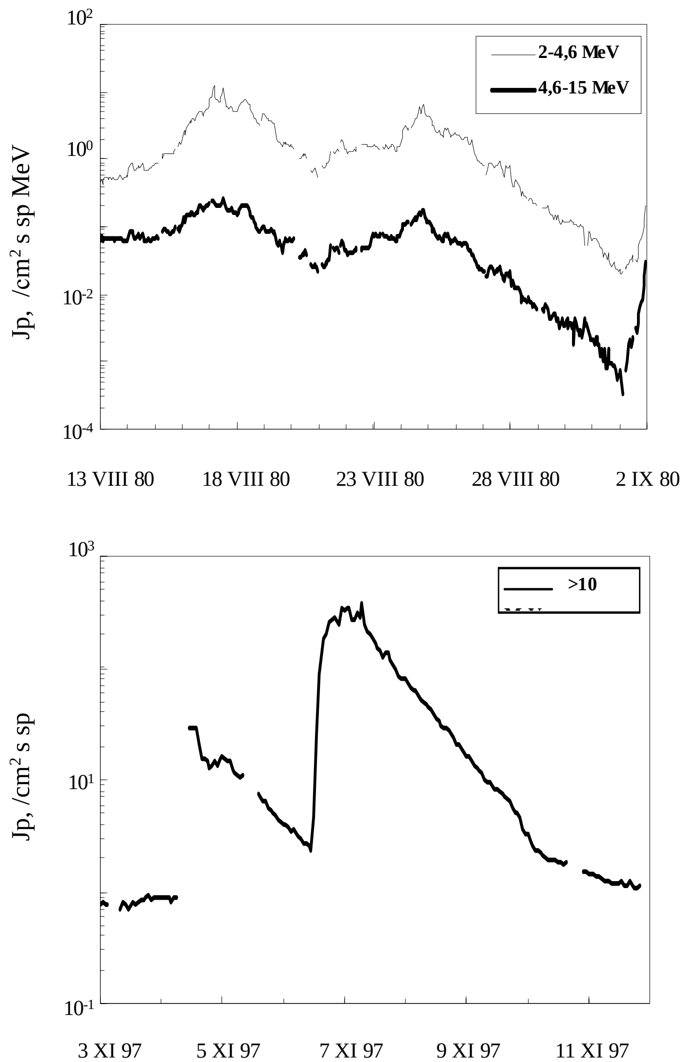


Fig.13. Two patterns of double SEP events (upper panel: the events of August, 15 and 25, 1980; lower panel: the events of November, 4 and 6, 1997) with identical decrease rates of different energy proton fluxes as observed at IMP 8. For the former case τ equals 32±2 hrs, for the latter – τ =15-17 hrs.

Figure 14 shows a pattern of the sequence of 3 events of the total duration about 9 days. This says that during this time everywhere in the inner heliosphere, at least nearby the solar equator plane, the conditions of interplanetary magnetic field (IMF) were stable that resulted in a practically constant proton decay times in the sequence. It turned out that such sequences were observed even longer, sometimes up to one month and more.

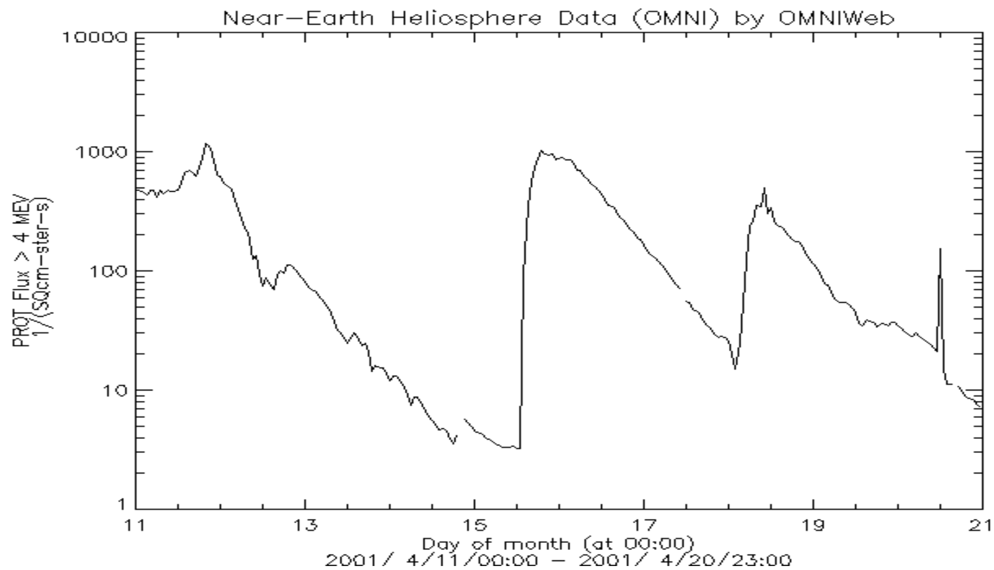


Fig. 14. Pattern of proton flux time profiles for energies >4 MeV for sequence of events beginning from Apr. 9, 2001.

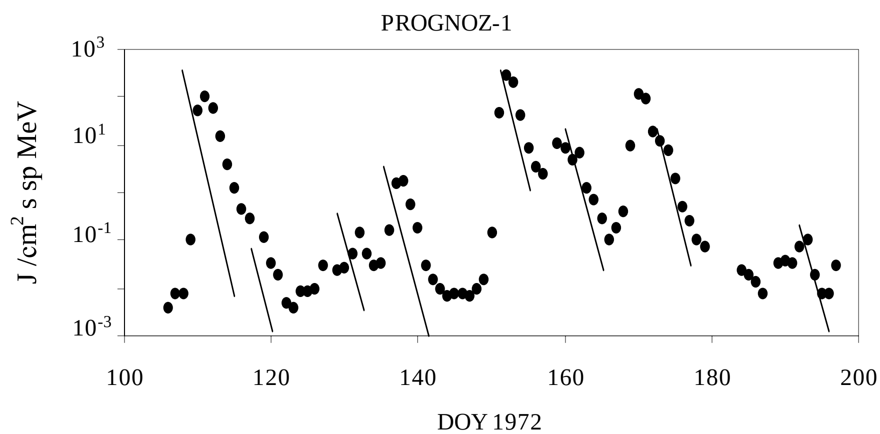


Fig. 15. Solar proton fluxes registered onboard the PROGNOZ satellite in April-July 1972. Similar declines are marked by dotted line.

According to Prognoz 1 and 2 data from April to August 1972, that is, during 3.5 months, 8 subsequent events were observed with practically the same declines of proton 1-5 MeV fluxes (Fig. 15) $\langle\tau\rangle = 16\pm1$ hours (Vernov et al.,1972). A similar situation was registered aboard IMP 5 for 0.9-1.5 MeV protons (Van Hollebeke et al., 1974). This means that prior to two extremely powerful flares of August 4 and 7, 1972, the Sun did not create any sufficient disturbances and interplanetary medium for more than three months was quasistationary returning to this state after all flares of different power that happened during that period.

The interpretation of this fact is rather obvious. In the “old diffusive language” we might point out that the mean free path was constant throughout the whole period. In the recent language of exclusive shock acceleration one would formulate this as a similarity of particle holding between strong magnetic field near the Sun and the shock front and particle acceleration in interplanetary space.
It must be noted that due to solar rotation during such considerable periods of time a spacecraft is connected by magnetic field lines to different regions on the Sun: both with flare sites and with quiet surface. However, the interplanetary medium remains magnetically homogeneous in a wide angular range that manifests itself in the constancy of τ. This result indicates the existence of long intervals comparable with the period of the solar rotation of quasi constancy of conditions that determine the particle lifetime in the inner heliosphere. If long duration exponential decay is observed, it means that the IM state is stationary in a wide angular interval (one day observation due to the Sun rotation equals to a 13.3° longitude interval). One-week duration of decline with constant τ corresponds to a stability of conditions in about a quarter of inner heliosphere.

In Table 2 exhibited are the characteristics of reliably identified sequences of two and more events, which were observed as a rule during more than a week through 1971-2001, that is, nearly for three solar activity cycles. One can see from the Table 2 that the values of τ range from 5 to 50 hrs, one order of magnitude, and this may be the scale of variation of IM parameters responsible for particle propagation (for example mean free path in the case of diffusive propagation). Average value of τ along all sequences declines equals 16 hours, and it concerns approximately to 30% of the whole) time during which diagnostics of interplanetary medium with the help of sequences of events is possible. It's necessary to note that this value of τ coincides with $\langle\tau\rangle = 14.7\pm3.0$ hours obtained in analysis the whole statistics of exponential declines during 1974-2001 (Daibog et al., 2003d).

The existence of stationary conditions in IM was discussed previously, we could mention the idea of “uniform particle reservoir” by Roelof et al., (1992) and McKibben et al., (2001). Also it was discussed in connection with so called “superevents”, which are long lasting enhancements of the interplanetary particle population observed initially in the inner heliosphere and then propagate to the outer heliosphere (up to 35 AU) with speeds of about 800 km/s. As one hypothesis for the origin and storage mechanism for these events it is suggested that a system of large interplanetary shock waves exists. The collision and superposition of a variety of flare initiated shocks outside of Earth orbit leads to the efficient particle acceleration.

Table 2

Onset date of series: year/mo/day	S/c, Ep (MeV)	N	ΔT, days	τ, hours	Heliocoordinates of s/c Helios and Vega: Distance from Sun (AU), heliolongitude	Notes
1971.04.02	IMP-5; 0,9–1,5	9	108	11,2 ÷ 24,0		
1972.04.20	P-1,-2; 1,0- 5,0	9	101	14,6 ÷ 24,2		
1974.12.22	H-1; 4 – 13	3	16	11,0 ÷ 14,0	R=0,95; $\varphi=-7^o$	
1976.03.16	IMP-8; 4-12,5	3	15	40,0 ÷ 42,0		S
1978.04.01	H-1; 4 – 13	5	23	7,0 ÷ 10,0	R=0,6; $\varphi=-60^o$	S
1978.06.11	IMP-8; 4-12,5	2	10	22,0 ÷ 230		
1978.07.14	IMP-8; 4-12,5	2	14	23,0 ÷ 24,0		
1979.02.27	H-1; 4 – 13	2	6	13,7 ÷ 14,5	R=1,0; $\varphi=-60^o$	S
1979.02.18	H-2; 4 – 13	4	25	12,5 ÷ 19,0	R=1,0; $\varphi=-15^o$	S
1979.06.04	IMP-8; 4-12,5	6	61	15,0 ÷ 18,0		
1979.07.07	IMP-8; >4	3	46	17,5 ÷ 22,0		
1979.08.05	H-1,-2; 4 – 13	2	18	16,5 ÷ 19,0	R=0,9; $\varphi=120^o$ H1 R=0,9 $\varphi=170^o$ H2	S
1979.11.06	IMP-8; 4-12,5	5	19	12,0 ÷ 17,0		
1980.05.27	H-1; 4 – 13	7	14	4,0 ÷ 8,5	R=0,4; $\varphi=-30^o$	S
1980.07.03	IMP-8; 4-12,5	3	26	21,5 ÷ 22,5		S
1980.08.02	IMP-8; 4-12,5	5	45	33,5 ÷ 38,0		S
1980.12.01	IMP-8; 2-4,6	5	26	17,0 ÷ 18,0		S
1981.05.12	H-1; 4 – 13	3	8	11,5 ÷ 13,0	R=0,7; $\varphi=-100^o$	S
1981.07.02	IMP-8; 4,5-15,0	3	33	31,0 ÷ 37,5		
1981.08.28	IMP-8; 4,5-15,0	3	32	48,0 ÷ 53,0		S
1981.11.16	IMP-8; 4,5-15,0	2	11	7,3 ÷ 7,6		S
1981.11.24	H-1; 4 – 13	3	24	13,5 ÷ 16,0	R=0,7; $\varphi=80^o$	S
1981.12.09	IMP-8; 4,5-15,0	2	4	9,0 ÷ 12,0		S
1982.01.03	IMP-8; 4,5-15,0	2	14	18,0 ÷ 19,3		S
1982.06.03	H-1; 4 – 13	3	9	7,0 ÷ 10,8 ±1	R=0,6; $\varphi=-120^o$	S
1982.07.10	H-1; 4 – 13	3	20	15,0 ÷ 19,0	R=0,5; $\varphi=-105^o$	S
1983.05.12	IMP-8, > 4	4	5	9,0 ÷ 13,0		S
1984.02.16	IMP-8, > 4	2	8	17,7 ÷ 17,7		S
1986.01.19	Vega-1; 4,5-13	3	25	13,2 ÷ 15,6	R=0,95; $\varphi = -2^o$	
1990.03.31	GRANAT; 1-20*	5	60	20,0 ÷ 24,5		
1990.08.06	GRANAT; 1-20*	2	15	20,0 ÷ 23,0		
1991.03.25	GRANAT; 1-20*	2	15	36,5 ÷ 38,0		
1991.05.13	GRANAT; 1-20*	6	37	10,0 ÷ 12,0		
1992.11.24	GRANAT; 1-20*	3	15	11,8 ÷ 12,5		
1997.10.07	SOHO; 0.7-6	4	27	10.5 ÷ 15		
1997.11.05	IMP-8; 4,6-15,0	2	4	15,0 ÷ 18,0		
1998.01.19	SOHO; 0.7-6	3	18	12.5 ÷ 14.5		
1998.10.21	SOHO; 0.7-6	4	32	11 ÷ 15.5		
1999.05.27	SOHO; 0.7-6	2	12	18 ÷ 20		
2001.04.12	IMP-8; 4,6-15,0	3	7	11,7 ÷ 14,5		

N -- a number of solar events in the sequence;

ΔT - a duration of the sequence from the start of the first to the end of the last day;

mark "S" means that the sequence took place during a superevent

In spite of conditional conception of superevents (see for example (Müller-Mellin et al., 1986 and Dröge et al., 1992)), the most important moment is the high stability of conditions in interplanetary medium in the inner and outer heliosphere for long periods of time. It was natural to suppose that individual SEPs happened during a superevent have some common featuteres and this might be decay time. Dröge et al., (1992) identified 16 superevents between 1974 and 1986. Those cover a spectrum of sizes, ranging from large, well-defined events (Müller-Mellin et al., 1986) to less obvious cases. Really, most part of sequences described above happened during periods of 11 superevents. These are N 2, 4, 6, 7, 8, 9, 10, 11, 13, 15, 16 from Dröge et al., (1992). They are marked by the sign "s" in Table 2. The September 23, 1978 event with two weeks decay also took place during a superevent. However, other sequences in 1974-1986 do not belong to periods of superevents, as well as in other 4 superevents decay times of subsequent SEPs differed from event to event.

Thus, one can see that the sequences of events with similar τ occur both during and between superevent periods. This means that situation of stable propagation or trapping conditions is not inherent exclusively to the periods of superevents. However, this investigation is important for space weather forecast. If a SEP event has occurred during a period of stable high particle background (an order of magnitude higher than quite value) for a few days, then for the following particle enhancement one may expect the decay time similar to that in a previous event and thus, according to the peak intensity time, the total event duration. This also permits to predict the total radiation dose throughout the event.

Thus, it turns out periodically that either the interplanetary medium parameters determining conditions of energetic particle propagation (diffusion, convection and adiabatic deceleration) or the conditions of trapping of particles, accelerated in flares and at coronal and interplanetary shocks, between strong magnetic fields near the Sun and shock front, stay quite stable for long periods of time. The investigation of such sequences of events can also be useful for forecasting characteristics of following SEP events.

Influence of the neutral current sheet on the particle fluxes during decay phase of SEP events

Crossing of the neutral current sheet during observations near the ecliptic plane is associated with a recurrent shock. Speed of such a shock is about 400 km/s and its influence on the structure of charged particle fluxes may be significant.

In many investigations current sheet was considered as an obstacle for charged particle propagation as this is a region where co-rotating standing bow shock is generated which might change temporal characteristics of particle fluxes at both sides of the shock.

Detailed analysis of the influence of current sheet on the features of SEPs during the rise phase was performed by Kahler et al.(1996).

Recent observational results suggested that the current sheet may be an important factor in organizing the propagation of shocks and SEPs. Kallenrode (1993) found that times to SEP onset and to SEP flux maximum were more delayed for E ~ 0.5 MeV electrons and E ~ 20 MeV protons when the observer and solar source region were on opposite sides of the current sheet than when they were on the same side. Shea et al., (1995) reported that for 22 of 27 ground level events (GLEs)) the solar source regions were in the same magnetic polarity as the Earth. This was taken as evidence for preferential particle propagation in the polarity structure of the solar source region. Studies of interplanetary disturbances also support the idea of an important role for current sheets. Henning et al. (1985) found solar wind speeds to be slower following large flares in the same source surface polarity as the Earth. Since their speed distributions were qualitatively consistent with the results of Cane's (1988) shock studies, their work also suggests that shocks weaken when they cross a neutral sheet.

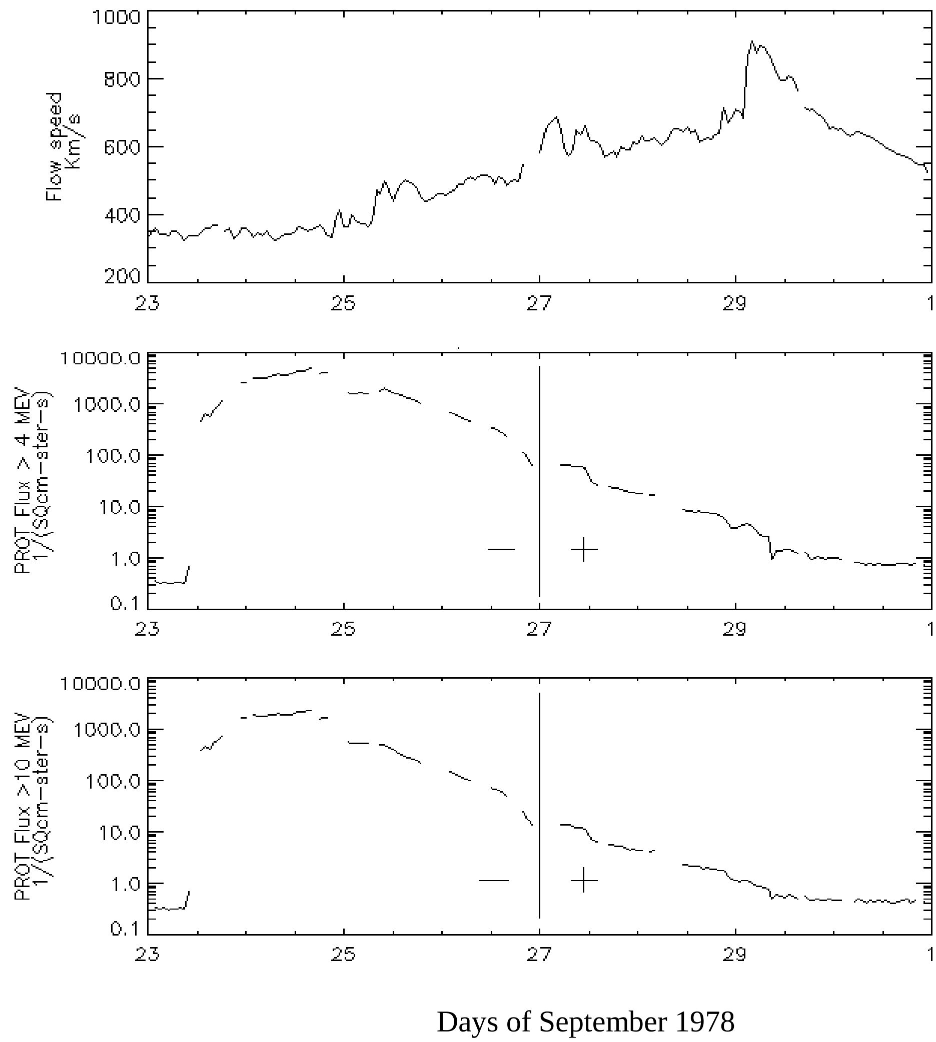


Fig.16a. The pattern of crossing the current sheet during Sept.23, 1978 event. Time-dependences of proton fluxes (> 4 and >10 MeV – two lower panels), as well as solar wind speed (upper panel).

Kahler et al. (1996) have examined 134 large SEP events to look for the effect of the heliospheric current sheet on the propagation of SEPs They found no significant differences in the onset times, risetimes, or peak fluxes between SEP events with same-polarity source regions and SEP events with opposite-polarity source regions.

An examination of the rise phases of several individual SEP event flux profiles also fails to show the modulation expected when a sector boundary is crossed. It appears that if the speed or strength of the CME-driven shock depends on the position of the source surface current sheet, that modulation does not significantly affect SEP production, at least during the first few hours of shock propagation from the Sun.

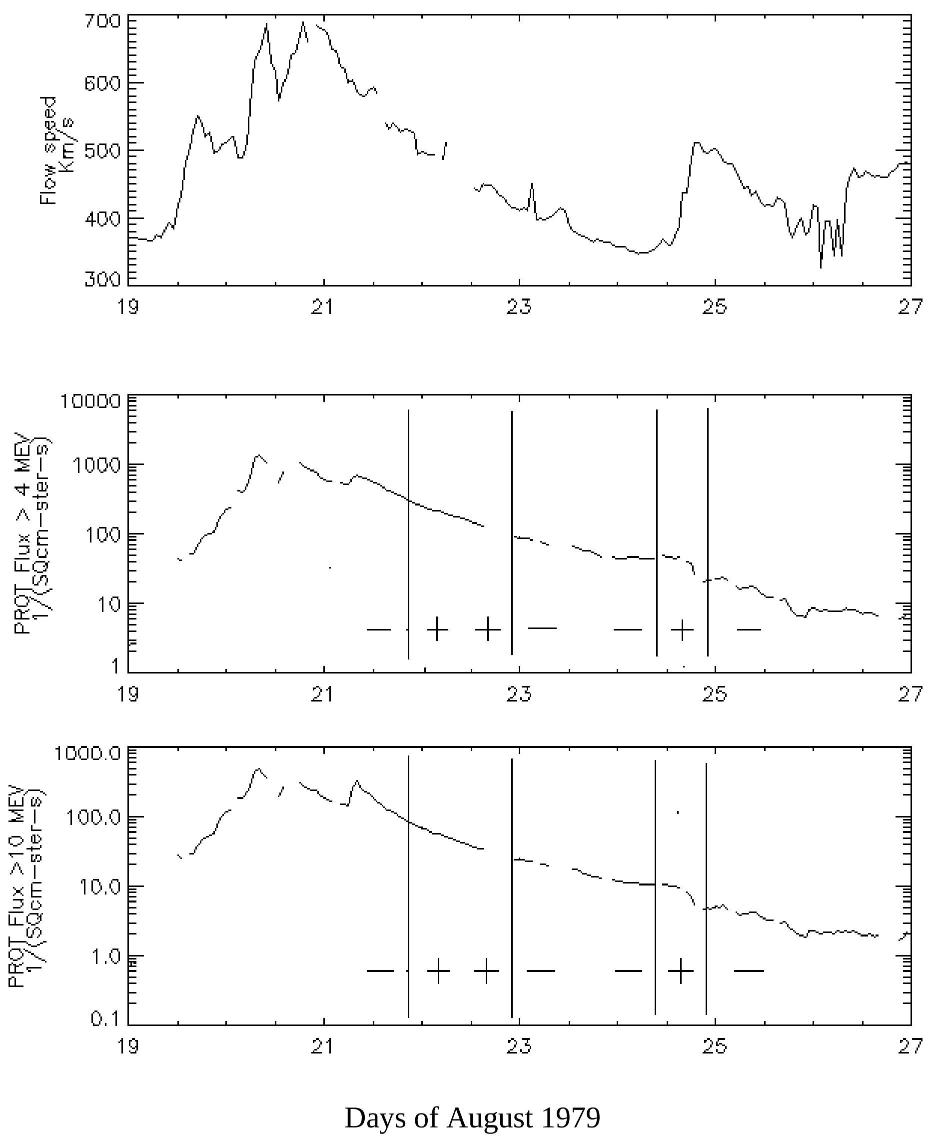


Fig. 16b. The same as Fig. 12 for Aug. 19, 1979 event under multiple change of magnetic field polarity.

Influence of the current sheet on the decay rate of particle fluxes may be examined during both isolated events and sequences of events with the similar declines.
The existence of sequences with coincident decay time suggest that during the time interval of the sequence IM was in a steady state near the point of obervation. However, as this point (the location of the s/c) travels 13.3º a day relative to the IMF due to solar rotation, the observed sequence extends to a considerable angle: about 90º for a week-

long series and 180º for 2-weeks. Then, within this region the propagating conditions for energetic particles will be similar (for exponential decays, the values of τ vary very slightly), and consequently, the IMF assumes invariant characteristics, that is, uniform over heliolongitude and constant with time.

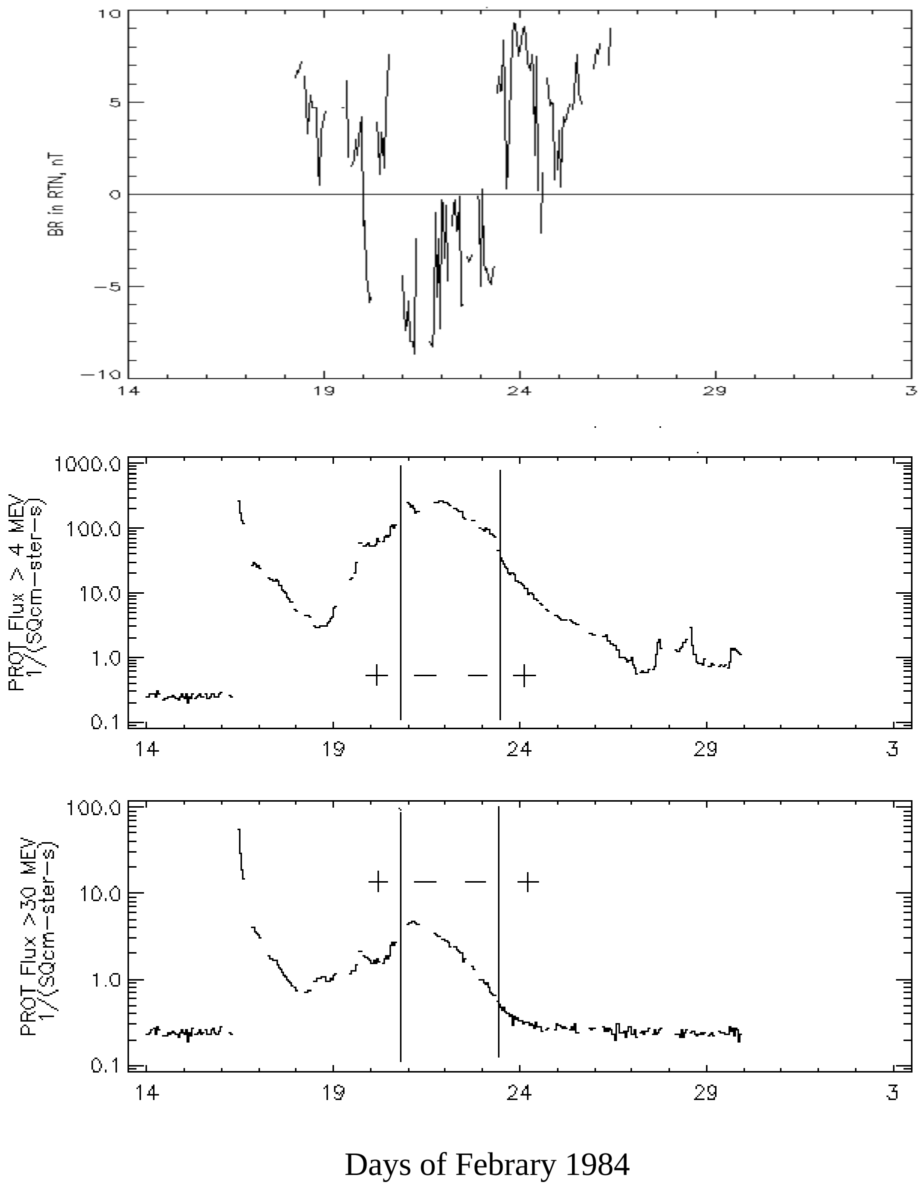


Fig.16c. The pattern of crossing the sector boundaries during two subsequent events in Feb. 1984, which shows no considerable influence on the fluxes of both low (>4 MeV) and high (>30 MeV) energy protons (middle and lower panels). Upper panel represents the direction of the radial component of the interplanetary magnetic field.

Does this stability propagate in heliographic latitude, to the different sides of the neutral current sheet? To answer this question the position of the spacecraft (i.e the Earth) with respect to the neutral sheet was studied during the sequence observed. It turned out that many, especially long sequences begin at the same sign of the IMF (with Earth located above – or below – the neutral sheet), and end with an opposite magnetic field polarity (the Earth crossed the neutral sheet in between). During this time τ did not change. An example of such event, where the crossing of the neutral sheet takes place in the middle of the decay phase, is the event of 1978.09.23, and the value of τ did not react to the sheet crossing, only the particle fluxes exhibited some fluctuations (Fig.16a). This observation suggests that both hemispheres (above and below the current sheet) were identical during the event series from the viewpoint of particle propagation. In Fig.16b another pattern of event, Aug.20, 1979 where the crossing of the neutral sheet takes place in the middle of the decay phase. In Figs.16a and 16b also time variations of plasma density and solar wind speed is presented (upper panel).

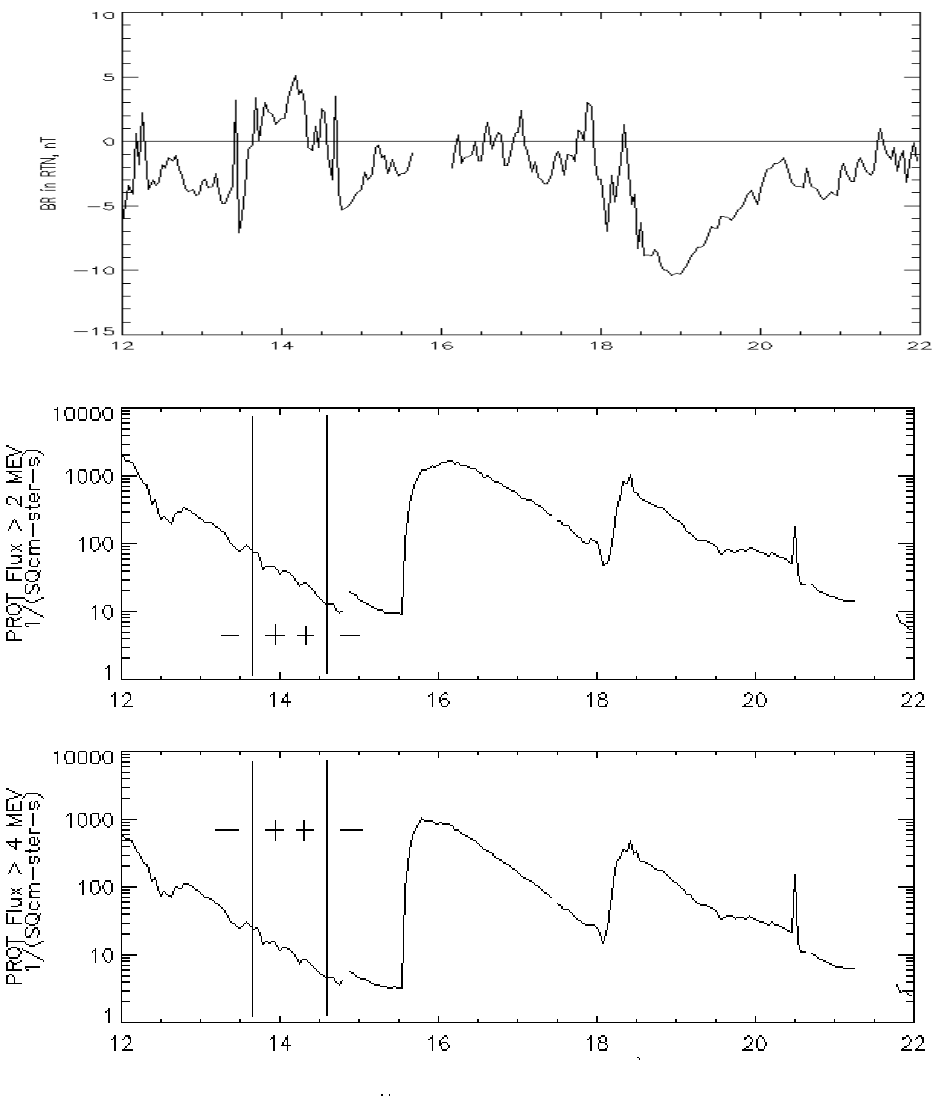


Fig. 16d. The same as Fig.14 for Ep> 2 MeV and Ep> 4 MeV proton fluxes for the sequence of events during April 2001.

Figs. 16c and 16d present the patterns of crossing the current sheet during the sequences of events in Feb. 1984 and April 2001. Upper panels are time variations of radial component of interplanetary magnetic field. One can see that sector boundary does not considerably influence either on the proton flux or decay rate of the events in the sequence.
It mus be noted once more that earlier papers arrived to contradicting conclusions. The existence of the neutral sheet (in the solar corona) between the flare and foot point of the magnetic line connected to the s/c is interpreted as an obstacle for particle propagation between the flare site and the s/c.

Investigation of proton fluences and adjacent questions

Particle fluence during the event, equally with the energy spectrum, is the main radiation characteristics of the event because for taking into account total radiation influence on the studied object it's necessary to know the total number of particles with definite energy fallen into it.
Particle fluence is defined as the total number of particles of definite energy fallen down 1 cm^2 through the event. It's very important to predict the value of fluence before the end of the event, which can be as long as a week or more after power flares. Such a prediction in extraordinary situations gives a chance to undertake preventive actions against radiative defeat of living organisms and elements of space devices.

Study of fluences was fulfilled on the basis of 126 major events during a period 1974 - 2001 that is for more than two solar activity cycles. This includes the whole 21-st and 22-nd cycles, as well as the major events of the 23-rd cycle. Only those events were took into account in which proton >4 MeV flux exceeded 50 particles/cm^2ssr which corresponds to the average fluence of about 10^7 particles/cm^2sr and is equivalent to the absorbed radiation dose of about 10 rad. Such a dose is not sufficiently dangerous but for most power fllares fluence can mount to 10^{10} part/cm^2 that is 1000 times higher and this threaten with serious radiation defeat, especially taking into account that all the energy releases in a thin layer equal to the scatter free path of protons with definite energy (4 MeV in our case), which corresponds to the thickness of sensitive layer of solar batteries. Protons of higher energy penetrate dipper and there energy releases in larger volume. For inner parts of spacecraft the most danger are protons with energies > 30-50 MeV.

The analyses showed that approximate prediction of proton fluence is possible according to the peak flux of particles that can be described by the simple dependence lgF=algJmax. This is well seen in the upper panels of fig. 17a,b,c,d where fluence is represented as a function of proton peak flux, Jmax, for the set of energies: 4, >10, >30 and >60 MeV. However dependence of the fluence on Jmax somewhat differ from event to event and one can see considerable dispersion of points in the figures. This dispersion is explained by different durations of events, more exactly by different decay rates of particle fluxes after maximums of events, which is characterized in a case of exponential declines by characteristic time τ defined from the dependence $J(t) = J_{max} \exp(-t/\tau)$. The more τ, the slower the decay and the more the fluence value.
For taking into consideration decay rates of the events products Jmax*τ were additionally considered. The results are presented in fig. 17(light circles) and one can

see that scattering of points is considerably reduced comparing with the filled circles. Thus this parameter permits to predict the value of fluence over the whole event by the first 1-2 days from the beginning of declines. This is most important for large gradual events that are really radiationally dangerous.

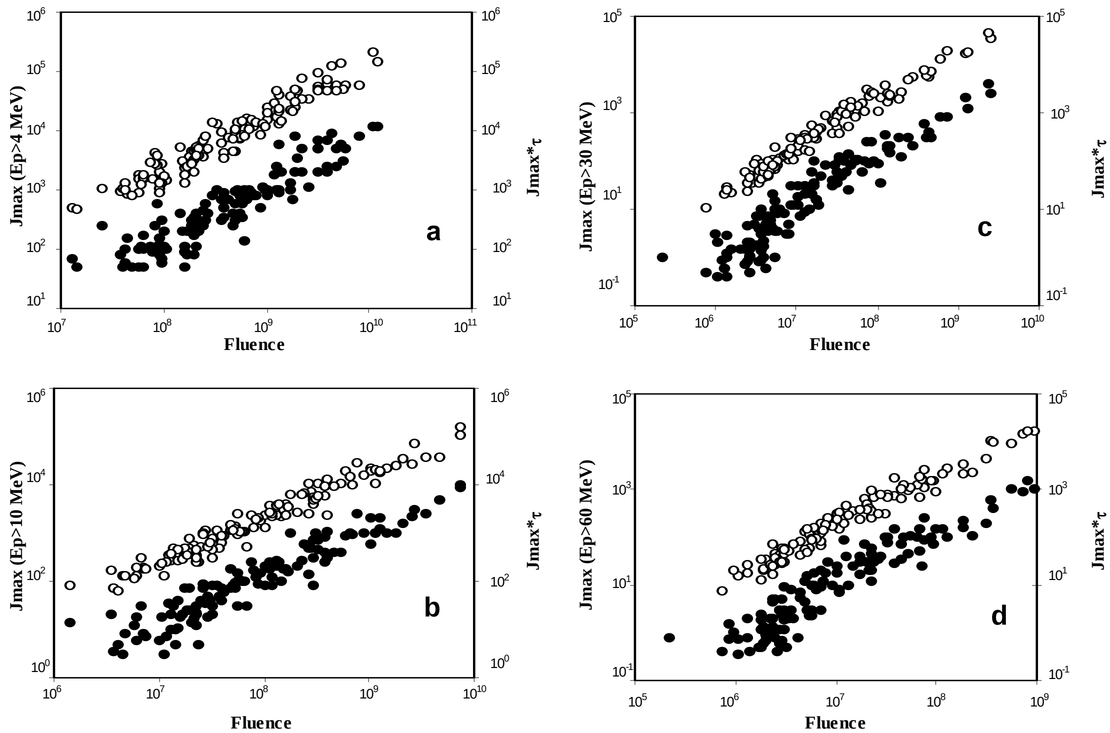


Fig.17. Dependence of proton a) for Ep>4 MeV, b) Ep>10 MeV, c) Ep>30 MeV and d) >60 MeV fluence though the event on the peak intensity Jmax(•) and Jmax*τ (o) and on the product of peak intensity and characteristic decay time

There was analysed the influence of some parameters of interplanetary medium (average through the event solar wind speed, average absolute value of interplanetary magnetic field and average magnetic field decline to the ecliptic plane) on the main characteristics of SEP events: fluence, characteristic decay time and proton peak flux. It turned that niegther of these parameters practically influence on the peak flux of event, while characteristic decay time, τ, is considerably influenced both by the solar wind speed and the value of interplanetary magnetic field. τ is reversely-proportinal to both of these parameters (decrease rate of proton intensity increases with increasing both solar wind speed and absolute value of interplanetary medium). Patterns of these dependenses for protons with the energy >4 MeV are shown in Figs. 18 a,b**.** Such a dependence is somewhat weaker for fluences, however, the similar conclusion may be made for thier envelope.

It must be noted absolute absence of any dependence of all event parameters on the magnetic field direction.

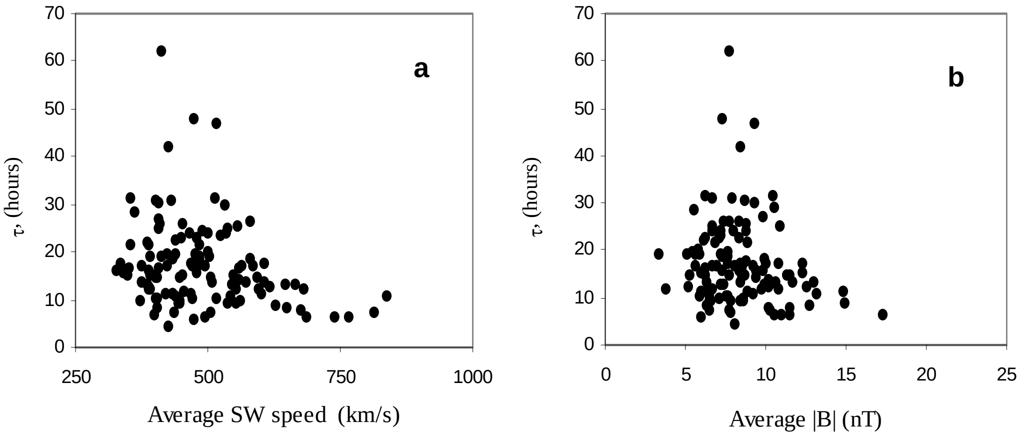


Fig.18. Dependence of the characteristic decay time on average through the event solar wind speed (a), average absolute value of magnetic field, $|B|$ (b).

Energy dependence of characteristic decay time in exponential decays of proton SEP events

Decay rates of particle fluxes in different events are practically independent from the power of event. Simultaneously particles of different energies behave differently not only during the flux rise until its maximum but also during decays of events. As a rule a value of τ decreases with increasing of energy, though a small number of events show opposite dependence.

To study the energy dependence from a large number of exponential declines in the data base (more than 200) the events with exponential decays were selected for which τ could be determined within an accuracy of 10% for high-energy differential channels (4.6-15, 15-25 and 25-48 MeV), i.e. sufficiently powerful events, because in weak events protons with the energies of about 25 MeV either are absent or their fluxes are so small that it's impossible to determine characteristic decay time, τ, due to comparable event and background intensities. Also selection criteria in this investigation was that the time profiles following the maxima were smooth and free of considerable disturbances. Here the fluxes of 4.6-15 MeV proton usually reach 1part /(cm^2 s sr MeV) or slightly less.

109 such events were found during the period 1973-2001 (Daibog et. al., 2003e), and the exponent assuming power-law energy dependence $\tau = CE^{-\alpha}$ was determined (E is the proton kinetic energy). Due to the wide energy intervals, the errors in determining τ was about 10% due to not strict exponentiality and small flux variations. The accuracy of determination of α is about 30%. Presented in Fig.19, the distribution of α values can be considered to consist of three separate groups: (1) τ independent of proton energy ($-0.1 < \alpha < 0.1$, 40 events); (2) τ decreasing with energy ($\alpha > 0.1$, 57 events); and (3) a small group with τ increasing with energy ($\alpha < -0.1$, 12 events). Thus predominantly, τ is either independent of or decreases with proton energy. A constant τ results in spatial and temporal invariance in the spectra of energetic particles in gradual solar events discussed in **(**Reames et al., 1996; Daibog et. al., 2000)**)** when nearly identical spectra are seen over large heliolongitude region some time before or after shock arrival depending on the relative positions of the flare and observation point. We assume that it

is possible to interpret the second group (decreasing τ) as having a “memory” of diffusion propagation at the early stage near the Sun. Indeed, diffusional decay time profile (power-law shaped) is proportional to $D^{-3/2}$, where $D=\lambda\upsilon/3$ (λ is scattering mean free path, υ is the particle speed) is diffusion coefficient increasing with the particle energy under reasonable assumptions about λ dependence on particle energy. Thus even exponential decays, which are most probably related to convection and adiabatic deceleration rather than to diffusion,

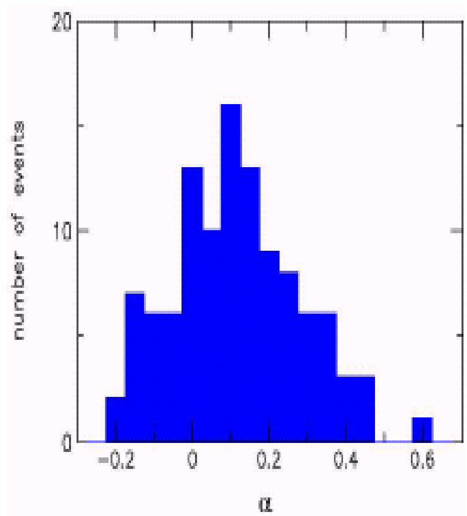


Fig.19 The distribution of the values of α for 109 SEP events

are in some cases evidently are influenced by diffusion (Forman, (1970); Owens, (1979). The most surprising result is the presence of the group with negative α. This group includes events with practically all possible values of τ from 5 to 30 hours. Since the background was subtracted, this means that a negative α is not simply an instrumental effect and might indicate that some additional exotic effects of propagation and/or acceleration can play a role.

The dependence of characteristic decay time and spectral index on the flare site

Under observation of solar cosmic ray fluxes near the Earth the observer is connected to the Sun at heliolongitude about W60 (it can vary according to the value of solar wind speed). If the flare occurred at this heliolongitude, then particles generated during the flare would come to the observer by the shortest way. If the flare took place at other solar meridian it would be possible to expect another rise time and slower decay after peak intensity.

McCracken et al. (1971) studied properties of decay phase of few solar flare events according to Pioneer 6-9 observations. Following them we write the cosmic ray density as $U(r,\psi, T, t)$. In this function, ψ is the heliolongitude of the intersection of the nominal

Archimedes spiral through the point of observation with the solar surface. ψ is reckoned westward from a fixed point on the rotating Sun, where r, T, and t are the distance from the Sun, the particle kinetic energy, and time respectively. Since the cosmic radiation remains associated with the same magnetic tube of force as it is convected out of the solar system, a cosmic ray population "co-rotates" with the Sun. That is the population remains associated with the same values of ψ throughout its lifetime in the solar system.
The rate of change of U with time, as observed by a spacecraft is given by:

$$dU/dt = \partial U/\partial\psi \, d\psi/dt + \partial U/\partial t$$

$\partial U/\partial t$ includes the effect of adiabatic deceleration. Clearly, the two terms in this formula will add, or partially cancel depending on whether the observer is on the Eastern, or Western side of a cosmic ray population. Any discussion of the decay phase of observed SEP event, therefore requires knowledge of the dependence of U upon heliolongitude.
As was discussed above exponential declines testifies that convective processes dominate over diffusive and Forman (1970) has shown that the particle density will vary in time as:

$$U = U_0 \exp(- 2V(2 + \alpha\gamma)t /3r)$$

where the dependence of U on ψ has been ignored.
Then taking into account this dependence we can write the observed variation as

$$dU/dt = \partial U/\partial\psi \, d\psi/dt - U/\tau, \quad \tau = 3r/2V(2 + \alpha\gamma)$$

Approximating the total change in U to an exponential in which $dU/dt = -U/T$, where T is the observed time constant, then

$$-1/T = U^{-1}\partial U/\partial\psi \, d\psi/dt - 1/\tau$$

and if over a limited range of ψ, $U^{-1}\partial U/\partial\psi = 1/\psi_0$, then

$$1/T = 1/\psi_0 \, d\psi/dt + 1/\tau$$

For the events considered by McCracken et.al., (1971) $d\psi/dt = 0.54°\mathrm{hr}^{-1}$, ψ_0 is about $\pm 30°$.
Indirect indication for such a dependence was also obtained in (Dalla, 2003) where ΔT was considered as a function of ψ. The Helios 1,2 data show a possible trend for the total duration of a particle event, ΔT, to decrease as the location of the associated flare changes from eastern to western longitudes with respect to the magnetic footpoint of the detecting spacecraft, within the range of values of .$\Delta\psi$ in [-180,+90].

It was interesting if such a dependence exists for the whole statistics of events considered in this investigation.
On the basis of more than 200 events the dependence of the characteristic decay time, τ, on the flare heliolongitude during 1974-1996 (two complete cycles of solar activity) was analyzed. The result is that τ is statistically independent from the flare heliolongitude, while the particle arrival and peak time in some cases are significantly delayed with the

increase of the distance of the flare site from the optimal heliolongitude where magnetic field line is connected to the observation point. The dependence of τ on the heliolongitude is presented in Fig.20 (upper panel)

McCracken et al. (1971) have also obtained indications for the events considered that at late times (> 2 days) the spectral exponent, γ, near 10 MeV is dependent on the heliolongitude of the observer relative to the centroid of the particle population injected by the flare. This effect results in a variation in spectral exponent over the range $2.0< \gamma < 4.5$. Again, our statistical consideration does not confirm this fact. The dependence of γ on heliolongitude is shown in the Fig.20 (lower panel)
This says that after SEP event maximum particle propagation in the interplanetary medium is controlled mainly by IM conditions in the neighborhood of observation point, and the structure of coronal magnetic fields does not influence on the shape of time profile during this phase.

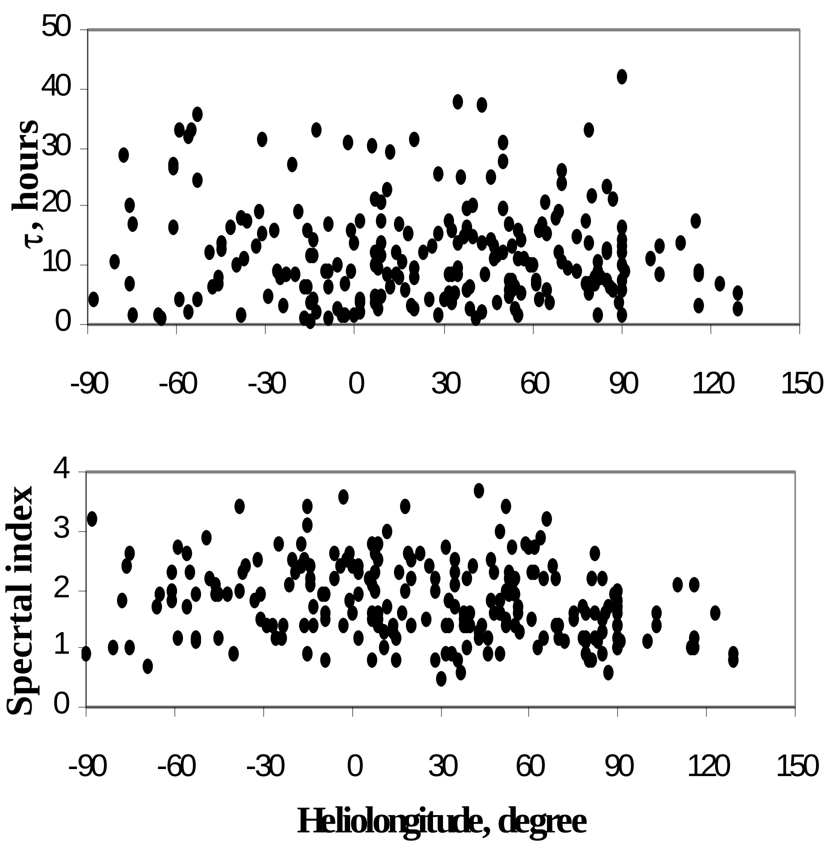


Fig.20. Scatter plots of decay times, τ (upper) and spectral index, γ (lower) versus flare heliolongitude

This conclusion is also important from the prognostic point of view because this facilitates forecasting of the total radiation dose.

Analysis of variations of decay times and spectral indices over solar activity cycle

Up to now nobody has undertaken systematic consideration of such the question and it has only been noted as a tendency of more rapid intensity decline for some events at quiet Sun periods.

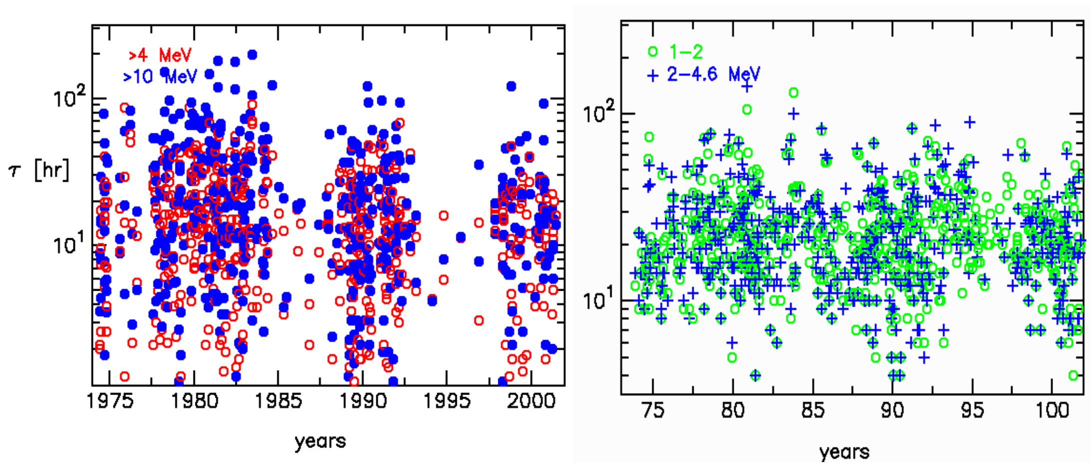


Fig.21a. Temporal variation of τ for integral channels of protons (left panel) and differential (right panel)

Figure 21 a and b display all values of τ and γ in exponential declines according to selection criterion all along the time from 1974 to 2001**.** Here τ is characteristic decay

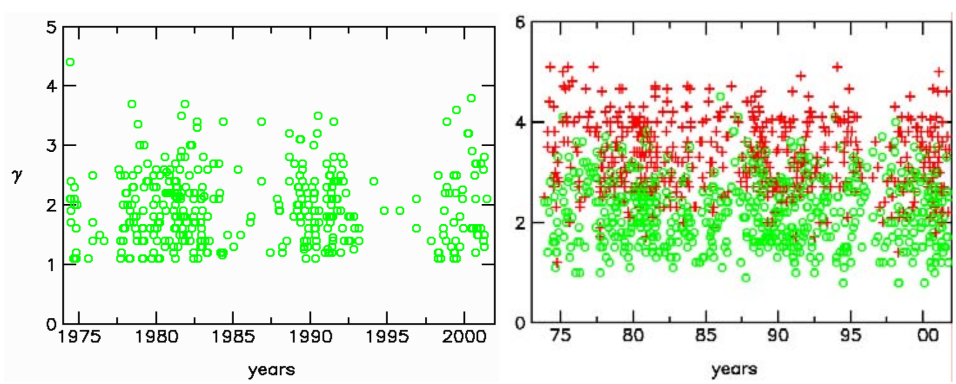


Fig.21b. Temporal variation of γ for integral(left panel) and differential (circles: 1-4.6 MeV, crosses: 4.6-25 MeV) channels (right panel)

time of proton flux at energies >4 MeV (integral channels) and 0.5-48 MeV (differential channels) during the time of exponential decline, ΔT; the value of γ corresponds to the initial moment of the exponential decline period. The variation of the over two solar cycles suggests little variation with energy, although in individual cases they can differ considerably which means that γ can change during the time ΔT.

There was no discrimination according to the character of event, whether it was diffusive, associated with shock waves or other phenomena. In Fig. 21a,b all possible kinds of particle enhancements are represented independently from their nature, and thus, the observed spread of values of τ and γ apparently reflects the totality of phenomena in the interplanetary medium because over more than tree solar activity cycles, most probably, everything happened that could happen at all. Neither τ nor γ does experience obvious variation with the level of solar activity, apart from the minima, where the width of the distributions seems to drop, possibly reflecting the stationary character of the interplanetary medium, to which it returns after various disturbances. In solar activity minimum there are less disturbances and the interplanetary medium can return to its undisturbed state. At maximum, the medium is disturbed practically all the time. The number of declines is changing from cycle to cycle; it was by 20% higher during the 21st cycle (1977-1987) than in the 22nd, which corresponds to the relative power of these cycles.

Conclusion

Many natural features of behavior of solar energetic particle fluxes in the decay phase of SEP events were ascertained under the Project investigation. One of the most important practical conclusions is that it is possible in principle to forecast the total number of particles through the event (fluence) on the base of the beginning of exponential flux decline. This may be useful for averting breaking-down elements of space devices and the danger of radiation defeat of space crews (forestalling switching off the equipment, delays of entrance to the open space, change for radiation-safe modules of spacecraft, etc.)

Executed investigations are perspective from the point of view of their further development. A number of revealed dependences can not be explained in the framework of current theoretical models and need an adequate theoretical interpretation.

Simultaneously it became clear during the work under the Project that some features must be considered in more detail. Thus up to now there is no exhaustive clearness on the complex of causes influencing on the characteristic decay time, τ, which changes from event to event by one order of magnitude and especially interrelations of these causes. It's possible that available experimental data are not enough for solution and new experiments are necessary, which would be founded on the new theoretical consideration of particle acceleration on the Sun and by shock waves, as well as their propagation in the interplanetary medium.

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List of published papers and reports with abstract

1. Energetic Electron Spectra in Solar Energetic Particle Events Associated and Non-Associated to Coronal Mass Ejections
V. Stolpovskii, E. Daibog, G. Erdos, S. Kahler , K. Kecskemety and H. Kunow
Proceedings of 27-th International Cosmic Ray Conference, Hamburg, Germany 2001, v. 8, p. 3454.

We considered energetic electron spectra in solar energetic particle (SEP) events after flare/coronal mass ejection (CME) associations and after flares only using measurements onboard various spacecraft (s/c) at radial distances of 0.3-1 AU during the 21st solar activity cycle. Statistics included about a hundred events of both types. More than 50 events of each type were observed simultaneously at various points of the inner heliosphere. Energy spectra in the range 0.3 to 3 MeV were generated from maximum flux at each energy. The relationship between the exponent of integral electron spectrum, γ and CME speed, V and angular width was considered and it was obtained that electron spectra become harder with increase of V. The best correlation between γ and V arrives when the observer`s magnetic footpoints are in the limits of the CME angular width. In this case the best fit approximation of $\gamma(V)$ looks as $\gamma \propto V^{-0.5}$ with γ and V in the range of 4.5-1.5 and 500-2000 km/s, correspondingly.

2. Decay Phases in Gradual and Impusive Solar Energetic Particle Events
E. Daibog, V. Stolpovskii, G. Erdos, S. Kahler, K.Kecskemety and H. Kunow
Proceedings of 27-th International Cosmic Ray Conference, Hamburg, Germany 2001, v. 9, p. 3631.

We have studied the decay phases of energetic particle (SEP) events associated and non-associated to coronal mass ejections (CMEs) and interplanetary (IP) shocks using multispacecraft observations in the end of 1970s and 1980s. Here several examples of successive SEP events observed simultaneously at widely spaced s/c are presented. It is pointed out that often during long time intervals (up to one month) the decays of >4 MeV proton and >0.3 MeV electron intensities are very similar over a wide range of angles between the observer and proposed source (up to 60 o and more). The spatial and temporal invariance of the particle intensities during the late phase of large proton events associated to the fastest CMEs and CME-driven shocks is valid not only in a wide angular regions but at different distances from the Sun from 0.3 to 1 AU.

3. Invariance of charged particles profiles during the late phase of SEP events according to multispacecraft observations
E.I.Daibog, V.G.Stolpovskii, S.W.Kahler
“Kosmicheskie issledovaniya”, 2003, v. 41, №2, p. 140-147

Using simultaneous observations from Helios-1 and Helios-2 s/c we examined properties of spatial and temporal invariance of E>4 MeV proton and E>0.3 MeV electron spectra during a decay phase of SEP events after flare - CME - CME-driven shock associations. Spectra and decay times of charged particles are nearly invariant over large angular distance from the flare point. According to the west or east position of s/c relative to the shock nose we observe delay or advance of invariance onset times following the shock arrival times increasing with angular distance growth.

4. **Statictical characterictics of SEP event flux declines through a long period of time (1974-2001)**

E.I. Daibog, S. Kahler, K. Kecskeméty, Yu.I. Logachev

Izvestiya RAN, seriya fizicheskaya, v. 67, № 4, p. 482, 2003.

On the basis of statistically homogeneous data from IMP 8 statistical analysis of characteristic decay times, τ, of proton > 4 MeV fluxes was performed during time intervals with the exponential flux declines. For these intervals the exponents of integral energy spectra, γ, in the energy range 4-60 MeV were determined as well. Correlation of τ and γ with interplanetary space conditions under presence or absence of shock waves were analyzed.

5. Periods of Quasi-Stationary Conditions in Interplanetary Space According to Sequences of SEP Events

E.I. Daibog, Yu.I. Logachev, S. Kahler, K. Kecskeméty

COSPAR02-A-00646 abstract , Houston, USA, 2002

Characteristic decay times of particle fluxes in SEP events as a rule vary considerably from event to event. We discovered, however, that sometimes the successions of events with very close decay times were observed during long time intervals (up to month, and longer in few cases). The values of characteristic decay times differed in different successions.

Such successions of events took place during practically all superevents in the 21-st cycle of solar activity. However, we can see few time intervals characterized by similar flux declines between periods of superevents as well. Thus, we can state that it turns out periodically that either the interplanetary medium parameters determining conditions of energetic particle propagation (diffusion, convection and adiabatic deceleration) or the conditions of trapping of particles, accelerated in flares and at interplanetary shocks, between strong magnetic field near the Sun and shock front, are rather stable during long periods of time.

Investigation of such successions of events may be useful from prognostic point of view.

6. Statistical Study of Spectral Characteristics of SEP Event Flux Declines during 1974-2001.

E.I. Daibog, Yu.I. Logachev, S. Kahler, K. Kecskeméty, S. McKenna-Lawlor

COSPAR02-A-00546 abstract , Houston, USA, 2002

Interplanetary medium is not an empty space for propagating of previously accelerated particles, but it itself influence on particles changing their energy (accelerating, as well as decelerating them) due to interaction with magnetic field inhomogeneouties. These processes manifestate in energy spectra of SEP events. Here integral energy spectra of

protons in the energy range 4-30 MeV are investigated on the basis of a homogeneous data set obtained by the CPME instrument aboard the IMP 8 satellite between 1974 and 2001 for all SEP events with >4 MeV proton flux, exceeding 2-3 part/cm^2 s sr.
Another important characteristic of SEP events is the rate of decrease of particle flux, which, as well as peak flux time, is an integral character of the interplanetary medium within a considerable volume, surrounding an observation point.
It is shown that the average values of spectral index, γ, and characteristic decay time, τ, are changing along with the solar activity phase.
The distributions of γ and τ are obtained in SEPs with and without shocks and during different phases of events: just after peak flux and late after maximum.

7. **Sequences of SEP Events as an Instrument of Indicating Quasi-stationary States of Interplanetary Medium**

Daibog E.I., Logachev Yu.I., Kahler S.W., Kecskemety K.

“Kosmicheskie issledovaniya”, 2003, in press

Time profiles of energetic solar particles observed in the interplanetary medium (IM) after solar flares is formed to a great extent by the structure of interplanetary magnetic field (IMF) and its inhomogeneouties moving from the Sun with solar wind speed. Decay of particle flux after its maximum as a rule is independent from the flare power and formed mainly by the propagation conditions in the IM. Under purely diffusive propagation of solar particles flux decline is described by the power law. However very often it turns out exponential-law that indicated considerable influence of convection and adiabatic deceleration during particle propagation in the expanding solar wind.
In the present paper SEP events with long duration exponential declines are considered as well as sequences of events with similar exponential declines lasting one-two weeks and longer. The existence of sequences with coincident decay time suggests that during the time interval of the sequence the IM was in a steady state near the point of observation and due to solar rotation permits to judge about the heliolongitudinal extension of the homogeneous region in the IM. As a rule this extension over heliolongitude is from a quarter to a half of the near ecliptic space and even occupies the whole near the Sun space in few cases of sequences of similar proton declines lasted for about a month and longer.

8. Some Statistical Properties of the Decay Phase of SEP-events

K. Kecskeméty, E.I. Daibog, S. Kahler, Yu.I. Logachev

Proceedings of 28-th International Cosmic Ray Conference, Tsukuba, Japan, Jul-Aug, 2003, in press

Generalized parameters characterizing the state of the interplanetary medium (IM) include the functional form and the rate of decline of charged particle flux in solar energetic particle (SEP) events. The shape of the particle flux decline is of particular importance: power-law time dependence indicates the dominance of diffusive propagation, whereas exponential-law decline emphasizes convection transport. Depending on the solar wind speed both exponential (at <10 MeV) and power-law (>30 MeV) declines can be present in the same event. A statistical investigation of SEP events extended for a long period suggests that about 90% of SEP decays are characterised by exponential declines. Distributions of the total durations, T, of exponential declines with and without shocks differ insignificantly for T>10 hrs. Values of the decay time obtained theoretically are reasonably close to the fitted slopes in nearly half of all cases if one uses the average V solar wind speed values measured when the corresponding plasma in which particles were convected arrives to the observer. Dependences as the variation of the decay time with energy and angular distance of the observer from the flare heliolongitude are considered as well.

9. Statistical characteristics of SEP event flux declines through a long period of time (1974-2001)

Daibog E.I., Logachev Yu.I., Kahler S.W., Kecskemety K.

Abstracts of 18-th ECRS, Moscow, SH04P, 2002.

The rate of decrease of particle flux, as well as peak flux time, is an integral character of the interplanetary medium within a considerable volume, surrounding an observation point. We performed a statistical analysis of the rates of decrease in all SEP events with >4 MeV proton flux, exceeding 2-3 part/cm^2 s sr, on the basis of a homogeneous data set obtained by the CPME instrument aboard the IMP 8 satellite between 1974 and 2001. We consider the intervals of intensity time profiles, during which declines were characterized by exponential law typical for <50 MeV protons of most SEP events. The distribution of characteristic decay times, τ, of >4 MeV and >10 MeV protons for 355 events has been built.

The comparison of a complete set of events from 21 and 22 solar activity cycles indicates that both the total number of events and the average values of τ differed in these cycles. Integral energy spectra of proton fluxes in the energy range 4-30 MeV were also obtained for the above time periods. In addition, we analyze the correlation of τ, the durations of exponential declines and spectral exponents with interplanetary medium conditions, in particular with CMEs and interplanetary shocks.

10. Invariance of proton time profiles during the late phase of SEP events: multispasecraft observations.

Daibog E.I., Stolpovskii V.G., Kecskemety K.

Pisa Solar Wind 10 conference, Pisa, Italy, 2002, abstract SIV 43.

Using simultaneous observations from Helios-1,-2 and IMP-8 s/c we examined the properties of spatial and temporal invariance of Ep>4 MeV proton and Ee>0.3 MeV electron spectra during the decay phase of SEP events after flare-CME – CME-drived shock associations. The spectra and decay times of charged particles are nearly invariant over large angular distances from the flare point. According to the west or east position of s/c relative to shock nose we observe delay or advance of invariance onset times following the shock arrival times increasing with angular distance growth.

11. Diagnostic of the state of the interplanetary medium according to the decay phase of SEP events.

Daibog E.I., Kecskemety K. , Kahler S., Logachev Yu.I. EGS-AGU-EUG Joint Assembly Nice, France, 2003 Gephysical Research Abstracts, Vol. 5, 02204, 2003

Generalized parameters characterizing the interplanetary medium (IM) state are the shape and the rate of decline of charged particle flux in solar energetic particle (SEP) events (just as the temperature of persons' body to some extent is a generalized characteristics of his state of health).

The shape of the particle flux decline is of particular importance: power-law time dependence says about prevalence of diffusive propagation of particles, exponential-law decline about convective processes. Depending on the solar wind speed both kinds of declines may be realized in the same event: exponential for low energy (< 10 MeV) particles and power-law for high energy (>30 MeV) ones.

Statistical investigation of SEP events during a long period of time (from 1968 to 2001) shows that 90 % of SEP decays are characterised by exponential declines. Distributions of the values of characteristic decay time, τ, shows that most part of the time during which diagnostics is possible the interplanetary medium is in a "basically disturbed" state characterised by $\tau=16 \pm 6$ hrs. This permits to say about predominant quasi stable state of the interplanetary medium, which takes about one half of the total time.

As SEP events usually last few days, the rest time such a diagnostics is inaccessible. However, often SEPs follow one by one and all events in the sequences have similar decay times, τ, which indicates stability of conditions in the IM during the hole sequence. This permits to analize the IM state not only for 2-4 days of individual event but during 2-3 weeks and longer. The most prolonged sequence and IM stable state was observed in 1972 by IMP-5 and Prognoz-1. Duration of this period took above 2 months, i.e. more than 2 full Solar rotations.

12. Successions of Solar Particle Events as an Instrument for Diagnostics of Interplanetary Medium Conditions.

E.I.Daibog, Yu.I.Logachev

Abstract of the report at the conference of CIS and Baltia countries "Actual problems of physics of solar and stellar activity" Nyzhnii Novgorod, June 2003, p. 86

The values of characteristic decay times of particle fluxes in SEP events as a rule vary considerably from event to event. We discovered, however, that sometimes the successions of events with very close decay times were observed during long time intervals (up to month, and longer in few cases). The values of characteristic decay times differed considerably from succession to succession.

Such successions of events took place during practically all superevents in the 21-st cycle of solar activity. However, we can see few time intervals characterized by similar flux declines between periods of superevents as well. Thus, we can state that it turns out periodically that either the interplanetary medium parameters determining conditions of energetic particle propagation (diffusion, convection and adiabatic deceleration) or the conditions of trapping of particles, accelerated in flares and at interplanetary shocks, between strong magnetic field near the Sun and shock front, are rather stable during long periods of time.

Decay Phase of Solar Proton Fluxes on the Base of Statistical Investigation of About 300 SEP Events

E.I.Daibog, Yu.I.Logachev

Abstract of the report at the conference of CIS and Baltia countries "Actual problems of physics of solar and stellar activity" Nyzhnii Novgorod, June 2003, p. 90

The interplanetary space is not a passive medium for propagating previously accelerated particles, but in itself influences the particles by changing their energies due to interactions with magnetic field inhomogeneities. In this report the integral energy fluxes of protons in the energy range 4-30 MeV are investigated on the basis of two data sets. The first is a homogeneous set of data obtained by the CPME instrument aboard the IMP 8 satellite between 1974 and 2001. Selection criterium is >10 MeV proton fluxes exceed 10 particle/cm^2 s sr. The second consists of lower energy proton fluxes in the range of 0.75-6 MeV measured by the LION instrument aboard SOHO between 1995 and 2001.

Important characteristics of SEP events include the rates of decrease of particle flux, which, as well as peak flux time, is an integral characteristic of the interplanetary medium within a considerable volume, surrounding an observation point. It is shown that the average values of energy spectral index, γ, and characteristic decay time, τ, are all changing with the solar activity phase. The distributions of γ and τ are obtained in SEPs with and without shocks.

14. Statistical Properties of the Decay Phase of SEP-events

Kecskemety K., Daibog E.I., Kahler S.W., Logachev Yu.I.

Abstracts of International Solar Cycle Studies Symposium 2003: "Solar variability as an input to the Earth's environment, June23-28, Tatranska Lomnica, Slovak Republic, Abstract VIII 7p, p.108

Generalized parameters characterizing the state of the interplanetary medium (IM) include the functional form and the rate of decline of charged particle flux in solar energetic particle (SEP) events. The shape of the particle flux decline is of particular importance: power-law time dependence indicates the dominance of diffusive propagation, whereas exponential-law decline emphasizes convection transport. Depending on the solar wind speed both exponential (at <10 MeV) and power-law (>30 MeV) declines can be present in the same event. A statistical investigation of SEP events extended for a long period suggests that about 90% of SEP decays are characterised by exponential declines. Distributions of the total durations, T, of exponential declines with and without shocks differ insignificantly for T>10 hrs. Values of the decay time obtained theoretically are reasonably close to the fitted slopes in nearly half of all cases if one uses the average V solar wind speed values measured when the corresponding plasma in which particles were convected arrives to the observer. Dependences as the variation of the decay time with energy and angular distance of the observer from the flare heliolongitude are considered as well.

15. Peroids of Quasi-Stationary Conditions in Interplanetary Space According to Sequences of SEP Events

E.I. Daibog, Yu.I. Logachev, S. Kahler, K. Kecskeméty
Advanses in Space Research, 2003, in press

The values of the characteristic decay time of particle fluxes in SEP events vary, as a rule, considerably from event to event. We discovered, however, that at times sequences of events having similar decay times were observed over long time intervals (up to one month, and even longer in a few cases). The values of the decay times, however, differed in different sequences. Such sets of events took place during nearly all superevents in the 21st cycle of solar activity. However, we can see a few time intervals characterized by similar flux declines in periods between the superevents as well. Thus, it turns out periodically that either the interplanetary medium parameters determining conditions of energetic particle propagation (diffusion, convection and adiabatic deceleration) or the conditions of trapping of particles, accelerated in flares and at interplanetary shocks, between strong magnetic fields near the Sun and shock front, stay quite stable for long periods of time. The investigation of such sequences of events can also be useful for forecasting characteristics of SEP events.

16. Statistical Study of Spectral Characteristics of SEP Event Flux Declines during 1974-2001.

E.I. Daibog, Yu.I. Logachev, S. Kahler, K. Kecskeméty, S. McKenna-Lawlor
Advanses in Space Research, 2003, in press

The interplanetary space is not a passive medium for propagating previously accelerated particles, but in itself influences the particles by changing their energies due to interactions with magnetic field inhomogeneities. These processes are manifested in the energy spectra of SEP events. Here the integral energy fluxes of protons in the energy range 4-30 MeV are investigated on the basis of two data sets. The first is a homogeneous set of data obtained by the CPME instrument aboard the IMP 8 satellite between 1974 and 2001 for all SEP events where >10 MeV proton fluxes exceed 10 particle/cm^2 s sr**.** The second consists of lower energy proton fluxes in the range of 0.75-6 MeV measured by the LION instrument aboard SOHO between 1995 and 2001**.** Other important characteristics of SEP events include the rates of decrease of particle flux, which, as well as peak flux time, is an integral feature of the interplanetary medium within a considerable region, surrounding the observation point. It is shown that the average values of energy spectral index, γ, and characteristic decay time, τ, are all changing with the solar activity phase. Distributions of γ and τ are obtained in SEPs with and without shocks (and during different phases of events: just after peak flux and late after maximum).

List of presentations at conferences and meetings with abstracts

1. **27-th International Cosmic Ray Conference, Hamburg, August 2001. Two reports**

Energetic Electron Spectra in Solar Energetic Particle Events Associated and Non-Associated to Coronal Mass Ejections

V. Stolpovskii, E. Daibog, G. Erdos, S. Kahler , K. Kecskemety and H. Kunow

We considered energetic electron spectra in solar energetic particle (SEP) events after flare/coronal mass ejection (CME) associations and after flares only using measurements onboard various spacecraft (s/c) at radial distances of 0.3-1 AU during the 21st solar activity cycle. Statistics included about a hundred events of both types. More than 50 events of each type were observed simultaneously at various points of the inner heliosphere. Energy spectra in the range 0.3 to 3 MeV were generated from maximum flux at each energy. The relationship between the exponent of integral electron spectrum, γ and CME speed, V and angular width was considered and it was obtained that electron spectra become harder with increase of V. The best correlation between γ and V arrives when the observer`s magnetic footpoints are in the limits of the CME angular width. In this case the best fit approximation of $\gamma(V)$ looks as $\gamma \propto V^{-0.5}$ with γ and V in the range of 4.5-1.5 and 500-2000 km/s, correspondingly.

Decay Phases in Gradual and Impusive Solar Energetic Particle Events

E. Daibog, V. Stolpovskii, G. Erdos, S. Kahler, K.Kecskemety and H. Kunow

We have studied the decay phases of energetic particle (SEP) events associated and non-associated to coronal mass ejections (CMEs) and interplanetary (IP) shocks using multispacecraft observations in the end of 1970s and 1980s. Here several examples of successive SEP events observed simultaneously at widely spaced s/c are presented. It is pointed out that often during long time intervals (up to one month) the decays of >4 MeV proton and >0.3 MeV electron intensities are very similar over a wide range of angles between the observer and proposed source (up to 60 o and more). The spatial and temporal invariance of the particle intensities during the late phase of large proton events associated to the fastest CMEs and CME-driven shocks is valid not only in a wide angular regions but at different distances from the Sun from 0.3 to 1 AU.

2. 18-th Eurorean Cosmic Ray Symposium, Moscow, July 2002

Statistical characteristics of SEP event flux declines through a long period of time (1974-2001)

Daibog E.I., Logachev Yu.I., Kahler S.W., Kecskemety K.

The rate of decrease of particle flux, as well as peak flux time, is an integral character of the interplanetary medium within a considerable volume, surrounding an observation point. We performed a statistical analysis of the rates of decrease in all SEP events with >4 MeV proton flux, exceeding 2-3 part/cm^2 s sr, on the basis of a homogeneous data set obtained by the CPME instrument aboard the IMP 8 satellite between 1974 and 2001. We consider the intervals of intensity time profiles, during which declines were characterized by exponential law typical for <50 MeV protons of most SEP events. The distribution of characteristic decay times, τ, of >4 MeV and >10 MeV protons for 355 events has been built.

The comparison of a complete set of events from 21 and 22 solar activity cycles indicates that both the total number of events and the average values of τ differed in these cycles. Integral energy spectra of proton fluxes in the energy range 4-30 MeV were also obtained for the above time periods. In addition, we analyze the correlation of τ, the durations of exponential declines and spectral exponents with interplanetary medium conditions, in particular with CMEs and interplanetary shocks.

3. COSPAR, Houston, USA, August 2002
Two reports

Peroids of Quasi-Stationary Conditions in Interplanetary Space According to Sequences of SEP Events

E.I. Daibog, Yu.I. Logachev, S. Kahler, K. Kecskeméty

The values of the characteristic decay time of particle fluxes in SEP events vary, as a rule, considerably from event to event. We discovered, however, that at times sequences of events having similar decay times were observed over long time intervals (up to one month, and even longer in a few cases). The values of the decay times, however, differed in different sequences. Such sets of events took place during nearly all superevents in the 21st cycle of solar activity. However, we can see a few time intervals characterized by similar flux declines in periods between the superevents as well. Thus, it turns out periodically that either the interplanetary medium parameters determining conditions of energetic particle propagation (diffusion, convection and adiabatic deceleration) or the conditions of trapping of particles, accelerated in flares and at interplanetary shocks, between strong magnetic fields near the Sun and shock front, stay quite stable for long periods of time. The investigation of such sequences of events can also be useful for forecasting characteristics of SEP events.

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4. Pisa Solar Wind 10 conference, Pisa, Italy, October 2002

Invariance of proton time profiles during the late phase of SEP events: multispasecraft observations.

Daibog E.I., Stolpovskii V.G., Kecskemety K.

Using simultaneous observations from Helios-1,-2 and IMP-8 s/c we examined the properties of spatial and temporal invariance of Ep>4 MeV proton and Ee>0.3 MeV electron spectra during the decay phase of SEP events after flare-CME – CME-drived shock associations. The spectra and decay times of charged particles are nearly invariant over large angular distances from the flare point. According to the west or east position of s/c relative to shock nose we observe delay or advance of invariance onset times following the shock arrival times increasing with angular distance growth.

5. **EGS-AGU-EUG Joint Assembly Geophysical Research), Nice, France, April 2003**

Diagnostic of the state of the interplanetary medium according to the decay phase of SEP events.

Daibog E.I., Kecskemety K. , Kahler S., Logachev Yu.I. EGS-AGU-EUG Joint

Generalized parameters characterizing the interplanetary medium (IM) state are the shape and the rate of decline of charged particle flux in solar energetic particle (SEP) events (just as the temperature of persons' body to some extent is a generalized characteristics of his state of health).

The shape of the particle flux decline is of particular importance: power-law time dependence says about prevalence of diffusive propagation of particles, exponential-law decline about convective processes. Depending on the solar wind speed both kinds of declines may be realized in the same event: exponential for low energy (< 10 MeV) particles and power-law for high energy (>30 MeV) ones.

Statistical investigation of SEP events during a long period of time (from 1968 to 2001) shows that 90 % of SEP decays are characterised by exponential declines.Distributions of the values of characteristic decay time, τ, shows that most part of the time during which diagnostics is possible the interplanetary medium is in a "basically disturbed" state characterised by τ=16 ± 6 hrs. This permits to say about predominant quasi stable state of the interplanetary medium, which takes about one half of the total time.

As SEP events usually last few days, the rest time such a diagnostics is inaccessible. However, often SEPs follow one by one and all events in the sequences have similar decay times, τ, which indicates stability of conditions in the IM during the hole sequence. This permits to analize the IM state not only for 2-4 days of individual event but during 2-3 weeks and longer. The most prolonged sequence and IM stable state was observed in 1972 by IMP-5 and Prognoz-1. Duration of this period took above 2 months, i.e. more than 2 full Solar rotations.

6. **International Solar Cycle Studies Symposium 2003: "Solar variability as an input to the Earth's environment, June23-28, Tatranska Lomnica, Slovak Republic**

Statistical Properties of the Decay Phase of SEP-events

Kecskemety K., Daibog E.I., Kahler S.W., Logachev Yu.I.

Generalized parameters characterizing the state of the interplanetary medium (IM) include the functional form and the rate of decline of charged particle flux in solar energetic particle (SEP) events. The shape of the particle flux decline is of particular importance: power-law time dependence indicates the dominance of diffusive propagation, whereas exponential-law decline emphasizes convection transport. Depending on the solar wind speed both exponential (at <10 MeV) and power-law (>30 MeV) declines can be present in the same event. A statistical investigation of SEP events extended for a long period suggests that about 90\% of SEP decays are characterised by exponential declines. Distributions of the total durations, T, of exponential declines with and without shocks differ insignificantly for T>10 hrs. Values of the decay time obtained theoretically are reasonably close to the fitted slopes in nearly half of all cases if one uses the average V solar wind speed values measured when the corresponding plasma in which particles were convected arrives to the observer. Dependences as the variation of the decay time with energy and angular distance of the observer from the flare heliolongitude are considered as well.

Director of SINP MSU
professor M.I.Panasyuk

Project Manager E.I.Daibog

Attachments

Table 1A

Table of solar cosmic ray events according to the data of CPME instrument from the IMP-8 spacecraft during 1974-2001

The columns are:

1. The date of the beginning of the time interval (typically 10-15 days), covering a group of events.
2. Beginning of the exponential period during the event
3. J_{max} - proton Ep > 10 MeV $(cm^2 ssr)^{-1}$ peak flux during the event.
4. Characteristic decay time for J(Ep>4 MeV) for the exponential period. Index "b" – flux at the end of period ΔT is close to the background.
5. The same as 4. for J(Ep>10 MeV).
6. Exponent of energetic spectra for exponential period.
7. The duration of the exponential period .
8. The marks are
   P – the first exponential period after maximum of the event
   W - exponential period without shocks
   Sh –exponential period with the shock
   I – exponential period with the shock not influenced on the rate of intensity decline.

The values of τ , γ_{decay} and ΔT were obtained from the time profiles of proton fluxes

Table 1A includes information on 208 SEP events during the period from 1974 to 2001, with the peak fluxes exceeded 2-3 protons/cm^2.s.ster

1	2	3	4	5	6	7	8
Years, date	Month, day	J_{max} (>10 MeV)	τ > 4 MeV	τ > 10 MeV	γ_{decay}	ΔT, hours	Note
1974 06	06. 09	3	2,1	3,6	4,4	1	P, W
	06. 10	----	2,0	8,9	2,1	2	Sh
1974 06	06. 29	0,2	9,6	29,2	1,7	18	P, W
	07. 04	30	7,5	8,1	2,4	12	P, Sh, I
	07. 06	300	2,6	4,4	2,1	2	P, Sh
	07. 06a	----	17,2	14,3	1,9	36	W
	07. 08	----	12,0	15,1	2,1	40	----
1974 08	08. 21	0,4	25,0	78,0	1,1	20	W
1974 09	09. 14	100	27,0	18,2	2,0	30	P, W
	09. 16	2	5,2	7,8	2,0	12	Sh
	09. 18	1	14,5	24,8	1,1	24	----
	09. 21	100	15,9	12,5	2,3	27	P, W
	09. 21a	----	7,3	5,7	2,1	24	Sh
	09. 25	10	19,7	23,4	0,6	18	W
	09. 25a	10	1,8	1,8	1,1	1	P, W
	09. 27	----	40,0	49,7	0,6	36	Sh

1974 11	11. 05	40	2,6	3,5	1,2	3	W
	11. 06	----	7,1	4,9	1,1	14	P, ----
	11. 07	----	25,4	39,1	1,6	18	W
	11. 08	0,8	3,9	5,9	1,6	8	P, W
	11. 14	0,5	19,8	36,6 **b**	2,0	24	P, W
1975 08	08. 21	5	----	8,8	0,7	8	P, W
	08. 22	8	9,1	11,0	0,8	12	P, W
	08. 23	----	18,0 **b**	28,7 **b**	1,1	20	P, ----
1975 11	11. 21	1	8.7	18,8	1,4	3	P, ----
	11. 22	0,8	1,3	4,7	2,5	1	P, ----
	11. 22a	----	14,3	60,0 **b**	1,7	12	----
	11. 23	----	29,2 **b**	60,0 **b**	----	15	----
1976 03	03. 27	1,2	50,0 **b**	66,0 **b**	0,7	44	P, W
	03. 29	0,8	57,0 **b**	83,0 **b**	0,7	60	P, W
1976 04	05. 01	200	14,1	12,1	0,9	40	P, W
	05. 03	----	2,2	2,9	1,5	6	Sh
	The	begining	of	21-nd	cycle	SA	
1976 08	08. 23	15	5,6	5,0	1,4	10	P, W
	08. 23a	----	11,7	17,0 **b**	1,4	18	----
1977 07	07. 28	1,5	26,0	54,0	2,6	24	P, W
	07. 29	1	2,1	3,4	2,6	2	P, Sh
	07. 30	----	25,0 **b**	33,0 **b**	----	30	----
1977 09	09. 14	4	32,0	35,0 **b**	2,5	31	P, W
	09. 17	30	16,5	9,3	1,4	>12	P, W
1977 09	09. 22	>1	29,2 **b**	54,0 **b**	1,1	>48	P, Sh
	09. 25	100	23,0	20,0	1,0	45	P, W
1977 10	10. 12	5	3,0	4,2	1,2	6	P, W
	10. 13	----	18,2	27,4	1,2	30	P, ----
1977 11	11. 23	400	15,0	10,4	1,4	60	P, W
	11. 24	----	15,0	15,0	1,6	----	----
	11. 25	----	4,9	5,5	2,0	10	Sh
1977 12	12. 28	1,5	13,9	23,4	1,6	30	P, W
1978 01	01. 04	5	2,3	4,5	2,5	5	P, ----
	01. 08	2	7,5	12,0	2,2	12	P, W
1978 02	02. 14	1000	2,7	2,8	2,2	10	P, Sh
	02. 15	----	26,0	22,0	2,2	99	----
	02. 18	-----	26,0	52,0 **b**	----	----	----
1978 03	03. 09	0,8	14,4	37,8	2,0	36	P, Sh, I
1978 04	04. 09	1,5	37,5	81,0 **b**	1,1	36	P, W
	04. 13	>20	16,2	21,6	1,7	24	W, I
	04. 13a	----	16,2	21,6	1,7	----	Sh, I
	04. 15	----	44,0 **b**	150 **b**	----	42	----
	04. 18	6	8,3	11,1	1,0	12	P, Sh
1978 04	04. 20	15	6,2 **b**	7,3 **b**	0,9	14	P, W
	05. 01	2000	29,0	29,0	1,7	20	P, Sh
	05. 03	----	3,9	4,7	1,9	12	Sh

1978 05	05. 07	>300	9,4	8,9	1,1	10	P, W
	05. 08	----	9,1	9,7	1,1	12	P, W
	05. 09	----	24,0 **b**	57,0 **b**	----	30	----
1978 05	06. 02	20	2,2	3,8	3,7	12	P, Sh
	06. 10	----	12,3 **b**	34,5 **b**	2,0	>12 (<24)	P, ----
1978 06	06. 25	40	6,6	5,4	2,5	20	P, Sh
	06. 27	----	21,4	42,0 **b**	2,3	>20	----
1978 07	07. 13	10	16,3	38,3	2,3	40	W
	07. 17	----	26,9	55,0 **b**	1,8	30	----
1978 07	07. 25	0,8	30,0	96,0 **b**	1,7	30	P, W
1978 09	09. 08	4	5,9	11,2	1,6	9	P, W
	09. 09	----	22,0 **b**	42,5 **b**	2,1	24	Sh
1978 09	09. 25	3000	12,0	12,0	1,8	60	P, Sh
1978 10	10. 05	1	40,0 **b**	73,0 **b**	1,5	50	P, ----
	10. 09	5	8,5	13,9	1,4	12	P, Sh
	10. 10	15	7,0	8,2	1,5	14	P, W
1978 11	11. 11	15	15,7	19,0	2,6	12	P, W
	11. 12	8	3,9	5,6	3,35	6	----
1978 12	12. 13	3	19,5	46,0	3,0	50	P, W
	12. 14	1,5	2,4	5,7	3,0	4	Sh
1979 02	02. 17	30	4,0	2,7	1,1	3	P, W
	02. 18	10	0,9	1,2	1,4	1	P, Sh
	02. 19	4	16,7	22,0	1,6	54	P, W
1979 03	03. 03	3	35,5	32,4	1,1	14	P, W
	03. 05	4	24,3	34,4	1,9	18	P, W
	03. 07	----	42,7	78,0	1,6	60	Sh
1979 04	04. 04	25	12,5	23,3	1,4	18	P, W
	04. 05	30	4,6	3,5	2,3	2	P, Sh
	04. 05a	----	1,3	1,8	3,0	2	P,
	04. 07	----	12,5 **b**	---	----	12	----
1979 05	05. 30	1	8,1 **b**	19,2 **b**	2,4	12	P, Sh
1979 06	06. 07	600	11,7	10,0	2,4	48	P, Sh
	06. 10	----	16,7	47,0 **b**	2,7	24	----
1979 07	07. 07	20	17,5	13,2	2,4	72	P, Sh
1979 08	08. 22	350	20,0	18,7	1,6	36	P, ----
1979 09	09. 19	90	86,0	66,0	0,9	96	P, W
	09. 24	0,3	43,0	50,0	1,1	60	P, ----
1979 11	11. 06	04,	22,1	---	1,5	12	P, W
	11. 09	1	17,7	29,3	2,0	12	P, W
	11. 10	0,9	10,4	27,3	1,8	12	P, ----
	11. 11	----	42,0 **b**	----	1,2	72	Sh
1979 11	11. 16	80	4,2	4,9	2,3	12	P, Sh
	11. 17	----	13,7	18,6	2,5	22	----
	11. 18	----	31,2	94,0 **b**	----	24	----
	11. 22	2,5	13,5	19,6	1,6	18	P, W
	11. 23	----	31,2 **b**	78,0 **b**	----	36	----
1980 01	01. 11	2,5	7,0	15,6	2,6	14	----
	01. 12	----	45,0	75,0	2,3	20	W

	01. 13	----	7,7	21,4 **b**	2,1	14	Sh
1980 01	01. 26	1,5	27,6	20,9	1,6	12	P, ----
	01. 28	0,7	12,2	34,5	0,8	12	Sh
	01. 30	1	22,4	72,0	0,8	14	P, W
	01. 31	0,9	7,1	13,3	1,6	10	P, W
	02. 01	----	29,5 **b**	66,0 **b**	0,8	20	----
1980 02	02. 07	>3	13,9	15,6	1,4	24	P, W
	02. 09	----	33,0	42,0	1,1	48	P, ----
	02. 14	----	48,0	----	----	30	----
	02. 16	0,8	8,7	----	1,7	16	P, W
	02. 18	----	43,0 **b**	----	----	30	----
1980 03	03. 31	1	0,7	1,0	2,5	2	P, Sh
	04. 05	>8	38,0	18,2	1,1	18	P, W
	04. 06	----	12,0	18,2	1,7	24	Sh
	04. 09	----	17,4 **b**	----	1,8	18	----
1980 06	06. 24	0,8	16,7	39,0	2,0	16	P, Sh
	06. 25	----	21,9 **b**	70,0 **b**	1,0	18	W
	06. 26	----	21,9 **b**	---- **b**	0,75	20	Sh
	06. 28	0,6	30,3 **b**	62,5 **b**	1,0	22	P, W
	06. 30	0,3	13,1 **b**	31,3 **b**	----	10	----
1980 07	07. 19	100	10,0	9,5	2,6	20	P, ----
	07. 26	3	5,6	7,1	2,8	12	P, Sh
1980 08	08. 07	2,5	12,5	15,3	1,4	20	P, ----
	08. 09	----	34,0 **b**	----	1,3	24	----
	08. 16	0,6	45,5	----	1,9	72	P, Sh
	08. 23	0,5	16,2	----	2,2	20	P, W
	08. 25	----	16,2	----	----	14	----
	08. 26	----	34,0	----	----	24	----
1980 09	09. 04	0,8	2,1	4,4	2,55	3	----
	09. 05	----	33,0 **b**	86,0 **b**	2,55	48	----
1980 10	10. 19	7	13,0	20,0	2,2	168 (60)	P, W
1980 10	11. 02	0,5	18,0	69,0 **b**	2,2	24	P, W
1980 11	11. 12	1,5	18,2	37,7 **b**	2,4	50	P, W
	11. 15	3	2,7	3,8	1,0	4	P, W
	11. 16	----	---	76,0 **b**	1,4	96	----
1980 11	11. 24	8	8,0	11,5	2,5	14	P, Sh
	11. 27	----	23,8 **b**	51,0 **b**	2,2	20	Sh
	12. 02	1,8	6,6	6,0	2,6	4	P, W
	12. 04	----	68,0 **b**	146 **b**	2,2	120	----
1980 12	12. 30	0,5	14,3	43,5 **b**	2,2	22	P, W
1981 02	02. 22	0,3	7,3	23,3	1,3	8	P, W
	02. 25	0,35	25,0	41,0 **b**	1,9	>10 (<20)	P, W
1981 03	03. 07	1,5	5,1	4,7	1,2	6	P, W
	03. 08	----	28,8 **b**	36,5 **b**	1,6	28	----
1981 03	03. 26	1	21,5	17,4	0,6	24	P, W
	03. 28	0,8	7,0	23,0	2,4	12	P, W
	03. 31	20	4,2	10,1	2,7	16	P, W
	04. 02	10	16,9	19,2	2,0	20	P, W

	04. 05	10	8,1	9,4	1,1	20	P, W
	04. 06	----	43,5 **b**	62,5 **b**	1,8	48	----
1981 04	04. 12	10	8,5	10,0	2,15	20	----
	04. 19	----	15,7	23,7 **b**	2,4	24	Sh
1981 04	04. 26	100	20,8	23,4	1,8	>12 (<20)	----
	04. 28	90	13,1	15,0	2,3	12 (+20)	P, W
	04. 29	100	8,3	7,3	1,6	16	P, W
	05. 01	100	4,7	4,7	0,9	20	P, W
	05. 01a	----	47,0 **b**	49,0 **b**	0,7	66	Sh
1981 05	05. 12	150	11,0	11,0	2,3	18	P, W
	05. 14	----	33,0	25,0	2,3	18	----
1981 05	05. 18	90	4,2	4,2	2,2	14	P, Sh
	05. 19	12	14,5	17,3	2,1	22	P, W
1981 06	06. 06	0,3	35,0 **b**	118 **b**	1,7	25	P, ----
	06. 11	0,35	58,0 **b**	180 **b**	1,3	60	P, W
	06. 19	0,6	12,5 **b**	----	0,8	8	P, W
	06. 20	----	55,0 **b**	----	----	32	----
1981 07	07. 21	100	18,0	11,0	1,5	36	P, W
	07. 25	10	2,1	2,6	2,6	6	P, Sh
	07. 26	----	26,4	59,0 **b**	2,15	48	----
1981 08	08. 10	30	7,8	8,7	2,8	18	P, Sh
	08. 12	----	26,7	62,5 **b**	2.1	60	----
	08. 16	----	20,5 **b**	66,5 **b**	1,8	24	P, W
1981 08	08. 23	1,5	2,3	3,4	3,5	2	P, Sh
	08. 24	----	10,8	24,0 **b**	2,2	24	W
	10. 28	----	36,0 **b**	----	----	15	----
1981 09	09. 08	8	12,0	13,0	2,9	30	P, W
	09. 10	0,7	25,0	31,5	1,4	26	----
1981 09	09. 22	0,25	7,5	11,5	1,6	10	P, ----
	09. 26	0,8	28,5 **b**	39,0 **b**	1,6	----	P, ----
1981 09	10. 02	1,5	1,4	4,4 **b**	1,9	3	P, Sh
1981 10	10. 11	80	15,0	23,0	1,8	22	P, ----
	10. 15	>300	31,5	31,5	1,5	30	P, ----
1981 11	11. 12	>1	6,3	13,5	2,8	12	P, W
	11. 16	2	11,3	18,3	1,8	12	P, W
	11. 16a	----	2,8	12,5 **b**	1,4	4	P, Sh
1981 11	12. 25	1,5	1,9	3,4	3,7	2	Sh
1981 12	12. 10	100	10,4	10,4	2,3	45	P, W
1982 01	02. 01	1000	33,0	18,8	1,7	24	P ----
	02. 02	300	20,8	18,6	1,5	78	P, Sh
	02. 09	4	11,4	13,0	1,5	24	P, ----
1982 03	03. 07	20	7,3	7,0	2,2	14	P, W
	03. 08	----	13,3	21,8	2,5	32	----
	03. 10	----	43,0 **b**	---	----	36	----
1982 03	03. 31	2	6,3	11,7	3,0	18	P, W
	04. 02	----	15,0	---	1,4	20	W
1982 04	04. 24	0,9	3,3	6,7	3,0	6	P, Sh
	04. 25	----	11,3 **b**	32,2 **b**	1,6	15	P, ----

1982 06	06. 06	4	8,0	27,0	2,1	16	P, Sh
	06. 09	20	41,6	50,0	1,1	40	P, Sh
	06. 12	10	25,0	50,0	1,7	14	P, W
	06. 15	5	28,0	33,2	1,2	24	P, ----
	06. 16	----	115	115	1,2	50	----
	06. 20	----	22,6	39,8 **b**	1,8	24	----
	06. 22	----	55,2 **b**	178 **b**	----	60	----
1982 06	06. 30	>1	25,0 **b**	34,0 **b**	0,8	24	P, ----
1982 07	07. 13	3000	1,5	1,3	1,7	4	P, Sh
	07. 14	----	22,0	24,0	2,2	36	----
1982 07	07. 23	>300	3,9	4,9	1,9	8	P, W
	07. 23a	----	15,0	18,7	1,7	24	W
	07. 26	----	8,3	11,2	1,7	30	W
1982 09	09. 06	25	1,7	2,2	3,4	2	P, Sh
	09. 08	0,9	4,7	12,2	3,3	10	P, W
1982 09	09. 21	0,6	0,8	2,1	2,6	4	P, Sh
	09. 22	----	24,3 **b**	60,0 **b**	1,1	24	P, W
1982 11	11. 24	90	2,5	2,0	2,1	5	P, Sh
	11. 24a	15	2,1	2,0	2,2	3	P, W
	11. 25	8	16,3	17,3	2,2	20	P, W
	11. 27	200	5,6	4,2	1,7	12	P, W
	11. 27a	----	14,0	26,6	1,3	24	----
	11. 30	10	11,8	10,9	1,4	16	P, Sh, I
1982 12	12. 08	900	6,4	6,3	1,5	8	P, W
	12. 09	----	29,0	17,3	1,5	24	W
	12. 12	----	36,0 **b**	35,0 **b**	2,1	48	----
1982 12	12. 18	80	9,4	10,4	1,4	12	P, W
	12. 19	5	22,0	10,4	1,4	20	Sh
	12. 20	----	7,8	8,0	1,6	24	P, W
	12. 22	----	23,0	32,5 **b**	1,6	24	----
1982 12	12. 28	150	13,8	9,8	1,9	32	P, W
	12. 30	----	33,0	73,0 **b**	2,3	62	----
1983 01	01. 02	----	43,0	----	----	30	----
	01. 06	1,5	24,1	15,1	0,6	18	P, W
	01. 09	0,6	8,1	18,3 **b**	1,3	12	P, Sh
1983 02	02. 04	100	5,0	8,3	2,8	----	P, Sh
	02. 07	----	22,6	40,0 **b**	2,15	----	----
1983 03	03. 14	0,4	12,5	31,3 **b**	1,4	----	P, W
1983 04	04. 16	2	12,2	12,2	0,7	12	P, W
	04. 25	0,7	43,5	55,0 **b**	1,2	32	P, W
1983 05	05. 12	1	11,7	19,0 **b**	0,9	10	P, W
	05. 13	----	10,0	22,4 **b**	1,2	6	P, W
	05. 14	----	47,0 **b**	78,0 **b**	1,8	----	----
	05. 16	1,8	8,9	18,8 **b**	2,6	14	P, W
	05. 17	----	13,0	40,0 **b**	1,8	----	----
1983 06	06. 15	8	70,0	37,5	0,8	40	P, ----
	06. 17	----	3,8	3,1	1,0	6	----
	06. 24	----	67,5	104 **b**	1,4	----	----

	06. 28	----	90,0 **b**	197 **b**	----	96	----
1983 10	10. 03	0,8	4,9	13,0 **b**	2,7	6	P, W
	10. 04	----	3,8	11,0 **b**	2,1	6	Sh
1984 01	02. 01	>2,5	6,5	7,8	2,7	12	P, W
	02. 02	----	23,0	44,0	2,1	14	W
	02. 08	0,5	23,0 **b**	52,0 **b**	1,0	28	P, W
1984 02	02. 16	200	2,6	2,6	0,8	2	P, W
	02. 17	----	10,7	14,6	1,0	18	W
	02. 23	30	6,5	7,4	2,2	14	P, W
	02. 24	----	19,5	24,0	2,2	28	----
1984 03	03. 14	40	6,3	6,3	1,2	4	P, W
	03. 14a	10	13,6	13,6	1,2	6	W
	03. 16	----	37,5	33,0	1,2	36	W
	03. 22	----	45,0 **b**	63,5 **b**	----	22	W
1984 04	04. 26	1200	13,0	12,5	1,2	28	P, W
	04. 30	----	27,0	38,0	1,15	----	----
1984 05	05. 21	1	4,4	8,9	1,2	5	P, W
	05. 22	----	26,7 **b**	53,0 **b**	1,2	----	----
	05. 24	5,5	9,0	11,5	3,4	>24 (<48)	P, W
1984 08	08. 27	6,5	12,0	---	1,5	----	P, ----
	08. 28	----	41,0	122	----	----	----
1985 01	01. 23	2,7	16,4	24,8	1,3	----	P, Sh
1985 04	04. 26	100	3,4	3,8	2,6	10	P, W
	04. 27	----	12,5	21,0	2,6	----	----
1985 07	07. 09	80	4,4	4,5	1,5	12	P, W
1986 02	02. 15	100	17,5	18,7	1,7	120	P, Sh, I
1986 03	03. 07	18	9,1	17,9	1,8	>12 (<24)	P, W
1986 05	05. 05	2,1	14,1	19,3	1,0	30	P, W
	The	begining	of	22-nd	cycle	SA	
1986 11	11. 03	0,9	4,0	----	2,4	2	P, W
	11. 04	1,6	2,1	6,0	3,4	6	P, W
1987 05	05. 30	1,4	9,0	13,8	1,2	18	P, W
1987 11	11. 09	----	13,8	21,6 **b**	2,1	50	W
1987 12	12. 31	0,7	14,1	12,9	1,9	>18 (<60)	P, W
	01. 04	80	15,3	16,3	2,0	36	P, Sh, I
	01. 07	----	24,4	57,0 **b**	1,9	60	Sh
1988 03	03. 26	1,7	1,7	2,4	1,2	4	P, W
	03. 26a	----	6,3	7,6	1,3	8	W
1988 06	06. 30	80	8,3	10,4	1,4	16	P, W
1988 08	08. 26	7	4,2	6,8	3,2	6	P, W
	08. 28	2,5	31,0	27,0	2,8	15	P, ----
	08. 31	1	7,4	13,0	2,4	12	W
1988 10	10. 12	>3	16,9	18,8	1,0	17	P, W
	10. 15	----	34,0	61,0	0,9	36	P, W
1988 11	11. 09	7	21,4	18,9	0,8	24	P, Sh
	11. 10	----	28,0	36,5	0,8	36	Sh, I

1988 12	12. 18	15	13,3	19,5	1,8	40	P, W
1989 01	01. 05	1,8	10,2	21,0	2,7	----	P, ----
1989 03	03. 08	20	1,0	1,3	1,9	2	P, Sh
	03. 10	80	18,2	12,2	2,0	18	P, W
	03. 13	1000	2,1	1,8	2,3	>6 (<12)	P, Sh
	03. 14	----	13,5	18,0	2,3	----	----
1989 03	03. 19	>50	7,5	6,8	2,3	30	P, Sh
	03. 20	----	12,1	13,0	2,3	14	----
	03. 24	80	1,5	2,3	2,0	2	P, W
	03. 25	----	32,5 **b**	36,5 **b**	2,3	40	W
1989 04	04. 12	150	9,4	9,4	2,0	14	P, W
	04. 15	12	25,4	18,0	2,3	100	W
1989 05	05. 05	7	3,6	3,1	1,8	4	P, W
	05. 06	25	5,6	4,5	2,2	5	P, W
	05. 07	----	30,5	27,0	3,1	----	Sh
	05. 09	----	26,0 **b**	44,0 **b**	2,5	36	----
1989 05	05. 23	12	0,7	0,9	3,1	2	P, Sh
	05. 24	6	47,0	51,0	1,7	45	W
1989 06	06. 18	12	4,5	4,9	0,5	12	P, W
	06. 19	----	18,4	20,8	0,8	10	P, W
	06. 23	----	7,5	25,0 **b**	2,1	>12 (<24)	P, W
	06. 23a	----	21,8 **b**	---	----	24	----
1989 06	06. 29	2,7	1,8	2,5	2,4	----	P, W
	06. 30	2,1	1,2	2,5	2,4	----	P, W
	07. 01	3	1,2	1,6	2,7	1	P, W
	07. 01a	>4	6,0	7,3	2,6	12	P, Sh
1989 07	07. 25	20	13,0	11,0	0,9	>12 (<24)	P, W
1989 08	08. 14	5000	5,8	7,1	1,4	12	P, Sh
	08. 17	900	16,0	18,0	1,3	12	P, Sh
	08. 20	----	27,0	49,0	1,25	36	----
1989 09	09. 05	5	2,1	3,1	2,3	> 4 (<20)	P, W
	09. 06	----	24,0	48,0	1,9	>36 (<48)	----
1989 09	09. 13	25	9,1	9,8	1,9	12	P, W
	09. 14	----	14,6	19,8	1,9	30	P, W
	09. 18	2	2,3	6,4	1,1	----	P, Sh
1989 09	10. 03	2,5	7,1	7,1	0,7	6	P, W
1989 10	10. 20	>1000	19,6	15,0	0,8	>16 (<30)	P, W
	10. 24	3000	5,5	7,4	1,4	> 4 (<16)	P, W
	10. 26	2000	12,5	11,5	1,3	24	P, Sh
	10. 29	----	14,2 **b**	23,2 **b**	0,8	>15 (<36)	W
1989 11	11. 09	15	1,7	2,8	2,2	8	P, Sh
1989 11	11. 15	70	8,7	10,4	0,8	10	P, W
	11. 17	2,5	16,5 **b**	29,8 **b**	0,7	>12 (<24)	Sh
	11. 20	2,8	8,7	7,0	1,8	> 8 (<15)	P, W
	11. 22	1,5	17,2	25,8 **b**	1,8	18	P, W
1989 11	11. 28	>30	1,7	2,1	2,0	> 3 (<6)	P, W
	11. 29	----	37,0	42,0	2,0	36	----
	12. 01	2000	5,9	5,9	1,5	12	P, Sh

	12. 04	10	11,4	19,7	1,6	18	P, Sh, I
1990 02	02. 03	3	6,8	7,3	0,9	2	P, W
	02. 03a	----	15,6 **b**	23,5 **b**	0,9	10	----
1990 02	02. 14	1	0,3	3,1 **b**	2,3	2	P, W
1990 03	03. 20	700	6,6	6,9	2,2	>14 (<24)	P, W
1990 03	03. 29	12	1,9	1,0	2,1	3	P, W
	03. 30	1,5	4,2	9,4 **b**	3,0	8	P, Sh
1990 04	04. 09	12	18,8	21,4	2,2	>12 (<30)	P, W, I
	04. 12	5	0,5	0,6	2,4	1	P, Sh
	04. 12a	----	32,5 **b**	120 **b**	----	36	----
1990 04	04. 17	9	7,0	7,0	1,9	----	P, Sh
	04. 19	7	13,0	15,3	1,7	12	P, W
	04. 22	----	13,0	15,3	----	----	----
1990 04	04. 29	100	3,1	7,4	1,6	14	P, W
	05. 02	----	12,0 **b**	47,0 **b**	1,5	15	P, W
1990 05	05. 08	5	7,5	8,1	1,1	----	P, W
	05. 12	1,5	48,0 **b**	94,0 **b**	1,6	90	P, ----
1990 05	05.22	270	1,8	2,1	0,6	3	P, W
	05. 23	----	24,3	14,0	0,97	12	W
	05. 24	----	10,0	7,0	0,95	10	----
	05. 27	90	5,0	6,0	0,5	> 6 (<24)	P, Sh
	05. 30	>20	3,8	3,1	1,3	> 6	P, Sh
	05. 31	----	24,3	27,4	1,4	27	P, W
1990 06	06. 14	4	3,5	4,9	3,2	14	P, Sh
1990 07	07. 14	2,5	2,7	6,3	3,5	8	P, W
1990 07	07. 27	18	32,0	29,0	1,7	72	P, Sh
	08. 02	----	16,5	17,5	1,9	40	W
	08. 04	----	46,0	61,0	1,7	50	----
1990 12	12. 23	>2	10,4	10,4	1,2	6	P, W
	12. 25	>1	21,6	24,0	0,8	12	P, W
1991 01	01. 29	7	32,8	48,5	2,7	48	P, W
	01. 31	180	8,3	7,7	2,3	24	P, W
	02. 03	----	42,0 **b**	---	2,1	54	----
1991 02	02. 09	6	7,0	10,0	1,8	----	P, W
	02. 26	3	10,8	18,8	1,6	----	P, W
	02. 27	----	54,0	97,0	1,25	20	----
1991 03	03. 24	3000	1,9	1,9	1,2	> 3 (<8)	P, Sh
	03. 25	900	3,1	3,1	1,2	8	P, W
	03. 25a	----	47,0	57,0	1,2	60	----
1991 04	04. 04	30	2,1	8,3	2,5	3	Sh
	04. 06	20	33,0	31,0	1,8	60	P, W
1991 04	04. 17	1	16,0	31,2	2,5	14	P, W
	04. 23	3,7	19,0	36,0	1,8	24	P, Sh
	04. 25	----	14,6	36,0	1,7	36	Sh
1991 05	05. 13	110	12,5	9,6	1,8	14	P, Sh
1991 05	05. 22	----	5,2	12,5	2,2	6	P, Sh
	05. 24	4	7,3	39,0	2,0	8	P, W
1991 05	06. 02	10	4,7	7,0	2,1	5	P, W

	06. 03	15	4,3	7,0	2,3	4	P, W
	06. 03a	----	33,0	37,0	2,6	14	----
	06. 04	40	1,6	---	2,6	3	P, W
1991 06	06. 12	250	7,8	8,1	1,2	6	P, Sh
	06. 13	>300	11,7	18,2	1,3	----	P, ----
1991 06	06. 16	1000	24,0	17,0	1,4	20	P, W
	06. 18	----	13,5	20,0	1,45	26	Sh
1991 06	07. 03	70	26,0	27,4	1,8	36	P, W
1991 07	07. 09	>150	1,5	1,9	2,4	2	P, W
	07. 10	30	9,7	9,7	2,8	16	P, W
	07. 12	7	7,6	7,6	3,4	12	P, Sh
1991 08	08. 28	150	6,8	5,2	2,4	8	P, Sh
	08. 28a	----	20,2	22,9	2,4	40	----
1991 09	09. 07	2,7	11,3	12,0	2,4	10	P, W
	09. 08	----	6,4	12,0 **b**	2,1	8	P, W
1991 09	10. 02	7	15,4	17,5	1,9	20	P, Sh
	10. 02a	----	23,2	40,0	2,1	28	----
1991 10	10. 28	30	0,9	1,2	2,4	2	P, W
	10. 29	----	10,7	28,2	2,4	22	P, ----
	10. 30	90	---	28,3	0,6	----	P, ----
	10. 31	40	0,6	1,7	2,4	2	P, W
1991 12	12. 22	2	11,2	28,8	2,8	----	P, W
	12. 23	----	33,3	65,0	1,9	48	Sh
	12. 26	2	3,5	8,9	2,8	6	P, Sh
	12. 29	2,2	13,4	28,8	2,5	24	P, W
	12. 31	1,2	7,7	16,7 **b**	2,5	> 8	P, Sh
	01. 04	1,9	5,5	10,4 **b**	0,9	2	P, W
	01. 05	1,2	35,5	53,0 **b**	1,2	----	P, W
1992 02	02. 08	12	9,1	13,2	1,6	----	P, Sh
1992 02	02. 26	2	3,0	6,3	2,7	3	P, W
	02. 26a	1,5	0,3	1,0	2,7	3	P, W
	02. 27	5	15,7	12,0	2,4	12	P, W
	02. 28	1,2	17,7	41,0 **b**	2,4	20	P, W
1992 03	03. 08	5	3,8	5,7	0,5	----	P, W
	03. 11	----	68,0	94,0	0,8	60	----
	03. 16	8	16,2	38,0	1,4	24	P, W
1992 05	05. 10	1000	6,3	4,2	2,2	24	P, Sh
	05. 11	----	20,0	13,5	2,2	36	----
1992 06	06. 27	80	12,3	11,8	1,4	30	P, W
	07. 01	5	13,5	28,6	1,8	----	P, W
1992 08	08. 05	2	5,5	12,0	1,4	----	P, W
	08. 07	2	18,7	19,2	1,8	50	W
1992 10	11. 01	>200	9,2	9,9	1,8	> 8	P, ----
	11. 05	----	42,0	38,6	1,25	50	----
1992 11	11. 30	4	13,9	13,2	1,6	18	P, W
1993 03	03. 05	20	15,0	16,0	1,4	44	P, W
	03. 07	8	4,9	5,6	1,4	6	P, W
	03. 13	40	11,5	16,0	1,6	----	P, W

1994 02	02. 21	1000	4,3	4,2	2,4	12	P, Sh
1994 10	10. 20	>10	5,9	8,0	1,9	----	P, W
	10. 21	----	16,0	---	1,9	----	----
1995 10	10. 20	>40	11,3	11,4	1,9	40	P, W
	The	begining	of	23-nd	cycle	SA	
1996 11	11. 30	1,7	3,1	7,8 **b**	1,6	4	P, W
	11. 30a	----	14,3 **b**	35,4 **b**	2,1	5	----
1997 11	03. 05	----	16,2	15,1 **b**	1,4	22	W
	03. 07	300	17,9	12,1	1,0	48	P, W
1997 11	11. 14	2	12,6 **b**	19,3 **b**	1,0	----	P, W
1998 04	04. 23	----	20,0	24,5	0,8	60	Sh
1998 04	04. 30	3	8,3	22,3	2,5	12	P, W
	05. 02	2	7,1	14,9	1,2	6	P, Sh
	05. 03	50	16,9	15,1	0,8	24	P, W
	05. 04	10	0,6	1,2	1,1	2	P, Sh
	05. 04a	----	11,5	7,3	0,95	6	----
	05. 04**b**	----	22,0 **b**	28,7 **b**	0,85	20	----
1998 05	05. 06	30	15,4	11,8	1,2	18	P, W
	05. 08	----	14,7	20,1	1,2	16	----
	05. 10	----	18,9 **b**	23,0 **b**	1,2	16	W
1998 06	06. 18	1,5	2,1 **b**	6,8 **b**	1,1	2	P, W
	06. 19	----	22,0 **b**	46,0 **b**	0,8	10	----
1998 08	08. 26	400	6,3	6,3	1,6	12	P, W
	08. 29	----	21,0	25,0	1,5	30	----
1998 09	09. 25	25	1,3	2,6	1,9	8	P, Sh
1998 09	10. 02	400	8,9	10,0	2,2	14	P, Sh
	10. 03	----	25,0	47,0 **b**	2,2	62	----
1998 10	10. 19	6	4,7	6,3	1,4	2	P, Sh
	10. 20	----	11,0 **b**	21,9 **b**	1,0	18	W
	10. 21	----	47,0 **b**	120 **b**	----	---	----
1998 11	11. 06	6	18,0	26,5	3,4	20	P, W
	11. 08	4	3,9	3,6	2,3	10	P, Sh
1998 11	11. 14	200	1,7	2,1	0,7	4	P, W
	11. 15	80	23,5	18,3	0,9	32	P, W
1999 01	01. 23	10	9,5	13,2	2,2	8	P, W
	01. 24	----	22,0	38,2 **b**	2,2	24	W
1999 02	02. 17	1	8,7 **b**	----	1,3	6	P, W
	02. 18	----	3,1 **b**	----	1,3	2	Sh
1999 04	04. 25	20	11,3	12,2	1,7	8	W
1999 05	05. 06	4	18,0	31,7 **b**	2,5	68	P, Sh
	05. 08	----	23,0	51,0 **b**	1,2	----	----
	05. 10	2	9,2 **b**	9,4 **b**	1,1	12	P, W
1999 05	05. 27	0,5	11,1	12,5	1,2	12	P, W
	06. 03	3	24,0	21,4	1,4	----	P, ----
	06. 05	40	19,2	22,3	2,2	80	P, W
1999 06	06. 23	1	29,5 **b**	----	1,1	18	P, W

	06. 26	2,5	1,4	2,6	3,6	2	W
	06. 26a	2	1,7	5,2	2,5	3	P, Sh
1999 09	09. 15	1,2	16,2	55,0 **b**	1,8	30	P, W
	09. 15a	1	1,8	7,3 **b**	1,3	2	P, Sh
1999 11	11. 19	1,5	27,0	39,5 **b**	2,1	26	P, W
	11. 20	----	12,0	----	2,25	----	----
	11. 21	----	40,0 **b**	----	----	----	----
1999 12	12. 10	0,9	5,2	22,5 **b**	1,6	8	P, W
2000 04	04. 05	>20	3,9	4,5	3,2	----	P, W
	04. 06	5	11,5	12,5	3,2	6	----
2000 06	06. 09	40	10,4	12,2	3,8	14	P, W
	06. 11	30	12,5	11,2	1,6	8	P, Sh
	06. 12	----	8,1	15,6 **b**	1,6	8	P, ----
2000 07	07. 13	3	20,8	29,1	2,9	12	P, Sh
	07. 16	200	12,5	14,1	1,6	20	P, Sh
	07. 17	----	27,8	26,0	1,6	26	----
	07. 23	10	5,2	8,4 **b**	1,6	12	P, W
2000 09	09. 14	150	17,8	18,2	2,5	24	P, W
	09. 17	10	3,9	6,0	2,7	----	P, W
	09. 18	----	28,0	92,0	2,1	24	Sh, I
	09. 20	1	24,8 **b**	52,0 **b**	1,2	18	P, W
2000 10	10. 17	10	26,7	23,0	1,6	70	P, W
	10. 27	8	17,5	27,2	2,7	26	P, W
2000 11	11. 09	10000	7,8	7,3	1,6	27	P, W
	11. 10	500	11,3	14,0	1,5	----	Sh
	11. 11	----	1,7	2,1	1,5	8	----
2000 11	11. 25	80	9,9	7,3	1,5	8	P, W
	11. 27	800	20,9	16,2	1,5	36	P, Sh, I
2001 01	01. 30	30	9,9	8,3	2,7	48	P, W
	01. 31	2	9,9	8,9 **b**	1,6	----	Sh
2001 03	03. 31	20	3,4	2,0	2,6	----	P, Sh
	04. 05	100	22,2	17,5	1,4	50	P, Sh
2001 04	04. 12	100	5,0	6,0	2,8	10	P, Sh
	04. 13	40	13,8	9,4	1,3	44	P, Sh
	04. 16	800	12,4	10,0	1,5	48	P, W
	04. 18	200	11,1	10,0	1,0	24	P, Sh
2001 05	05. 21	>8	20	15	----	----	----
2001 06	06. 16	20	16,0	13,9	2,1	16	P, W

On the basis of this table distributions of different parameters of SEP events were built, allowing to obtain statistically well grounded conclusions. Several (from 1 to 7) time intervals were distinguished for each event during which proton flux decayed according to the exponential low. Each of them was considered independently. It may be noted that sometimes for long lasting events, when the decay phase consisted of several exponential periods, it was possible to choose one longer time interval (sometimes it was the whole decay) which could be described by a single characterstic decay time, interrupted either by some short (forbush-like) decrease or by some additional flux, temporary disturbing general exponential behavior. These events are of special interest and will be analyzed in detail after completion the statistical study.

Table 2A

Flares and shocks associated with SEP events

		FLARES					SHOCKS					DECAYS	
Year		Month, day	Hours, minutes	Imp.	Longi-tude		Month, day	Hours, minutes	$\Delta T = T_{sh} - T_{fl}$ Hours, minutes	Speed, км/s		τ > 4 MeV	γ decay
1		2	3	4	5		6	7	8	9		10	11
1974		07.03	08:01	2B	E08		07.04	15:34	31:33	1315		7,5	2,4
		07.04	13:38	2B	W08		07.06	03:22	37:44	1100		17,2	1,9
		09.10	21:21	2B	**E 61**		09.15	13:43	112:22	370		14,5 (5,2)	1,1 (2,0)
1977		11.22	09:45	2B	W40		11.25	12:26	74:41	560		29,0 (4,9)	1,6 (2,0)
1978		02.13	01:15	2N	W20		02.14	21:47	44:32	930		26,0 (2,7)	2,2 (2,2)
		04.11	13:34	2B	W56		04.13	19:29	54:15	770		16,2	1,0
		05.31	10:06	3B	W43		06.02	09:13	47:07	880		33,0 (2,2)	2,0 (3,7)
		06.22	16:23	2B	E16		06.25	08:25	64:02	650		21,6 (6,6)	2,3 (2,5)
		07.10	05:55	3B	E61		07.13	00:15	66:20	625		16,3	2,3
		09.07	23:30	1N	W17		09.09	02:54	27:24	1520		22,0	1,1
		09.23	09:44	3B	W50		09.25	07:18	45:34	910		12,0	1,8
		11.10	00:48	2N	E01		11.12	01:00	48:12	860		23,5 (3,9)	2,4 (3,35)
		12.11	18:33	2B	W50		12.14	01:27	54:54	760		19,5 (2,4)	3,0 (3,0)
1979		02.16	01:44	3B	E59		02.18	03:05	49:21	840		16,7 (0,8)	1,6 (1,6)

		FLARES					SHOCKS					DECAYS	
Year		Month, day	Hours, minutes	Imp.	Longi-tude		Month, day	Hours, minutes	$\Delta T = T_{sh} - T_{fl}$ Hours, minutes	Speed, kм/s		τ > 4 MeV	γ decay
1979		03.01	09:55	3N	E53		03.04	04:46	66:51	625		24,3	1,9
		04.03	04:17	1B	W05		04.05	01:56	45:39	910		12,5 (4,6)	3,0 (2,3)
		06.05	04:55	2B	E14		07.06	19:30	62:35	665		11,7	2,4
		07.04	19:03	1B	E36		07.06	19:30	48:27	860		17,5	2,4
		11.15	21:22	2B	W35		11.18	02:10	58:48	790		31,2	1,7
1980		01.25	19:03	2B	W50		01.28	15:43	68:40	605		47,0	0,8
		02.05	17:27	1B	W09		02.07	12:18	42:51	970		13,9	1,4
		04.04	14:54	1N	W35		04.06	10:59	44:05	940		12,0	1,9
		06.21	01:21	1B	W90		04.24	02:48	73:27	565		16,7	2,0
		07.17	05:36	2N	E06		07.18	19:27	37:51	1100		10,0	2,6
		10.14	05:41	3B	W06		10.18	01:14	91:31	455		31,2	2,2
		11.23	17:51	1B	W20		11.24	22:58	29:07	1430		8,0	2,5
		11.23	17:51	1B	W20		11.26	04:21	58,30	710		23,8	2,2
1981		04.14	23:30	1N	E73		04.18	15:03	87:33	470		15,7	2,4
		04.28	<22:05	SB	W90		05.01	07:45	>57:40	<720		34,0 (5,2)	0,7 (0,9)
		05.13	03:33	3B	E55		05.15	02:52	47:19	880		8,7	3,0
		05.14	08:05	3N	E35		05.16	05:32	45:27	910		6,5	3,0

		FLARES					SHOCKS					DECAYS	
Year		Month, day	Hours, minutes	Imp.	Longi-tude		Month, day	Hours, minutes	$\Delta T = T_{sh} - T_{fl}$ Hours, minutes	Speed, км/s		$\tau > 4$ MeV	γ decay
1981		05.16	07:53	3B	E14		05.17	23:02	39:09	1060		14,5 (4,20)	2,1 (2,2)
		07.24	07:47	1N	E56		07.25	13:22	29:35	1400		26,4 (2,1)	2,15 (2,6)
		08.07	19:01	1B	E25		08.10	04:34	53:33	780		22,5 (7,8)	2,1 (2,1)
		09.06	21:02	1N	E49		09.08	21:46	48:44	850		25,0 (12,0)	1,4 (2,9)
		10.07	22:59	1N	E83		10.10	14:34	63:35	650		15,0	1,8
		10.12	06:15	2B	E31		10.13	22:40	40:25	1030		31,5	1,5
		11.14	<22:09	2B	W47		11.16	20:29	>46:20	<900		11,3 (3,8)	1,8 (1,4)
		12.09	18:17	2B	W16		12.12	01:44	55:27	750		10,4	2,3
1982		01.30	23:25	2B	E13		02.01	11:00	35:35	1170		33,0	1,7
		02.01	13:50	3B	W09		02.03	01:29	35:39	1160		20,8	1,5
		03.30	05:23	1B	W00		04.01	13:15	55:42	750		15,0	1,4
		06.04	13:13	1B	E54		06.06	02:44	37:31	1100		8,0	2,1
		06.05	07:26	2B	E46		06.09	00:40	89:14	465		41,6	1,1
		07.12	12:35	3B	E35		07.13	16:17	31:17	1310		22,0 (1,5)	2,2 (1,7)
		09.04	00:25	2B	E38		09.06	07:53	55:28	750		33,0 (1,7)	2,9 (3,4)
		11.23	11:09	1N	W54		11.24	09:22	22:13	1870		16,3 (2,5)	2,2 (2,1)
		12.07	23:41	1B	W86		12.10	07:21	55:40	750		30,0 (1,1)	2,3 (2,0)

		FLARES					SHOCKS					DECAYS	
Year		Month, day	Hours, minutes	Imp.	Longi- tude		Month, day	Hours, minutes	$\Delta T = T_{sh} - T_{fl}$ Hours, minutes	Speed, км/s		τ > 4 MeV	γ decay
1982		12.17	18:20	3B	W20		12.19	02:54	32:34	1280		22,0	1,4
		12.25	06:10	2B	E45		12.27	07:15	49:05	850		13,0	1,9
1983		02.03	05:41	2B	W07		02.04	04:15	22:34	1840		22,6 (5,0)	2,6 (2,8)
1984		05.22	15:01	2B	E26		05.24	08:45	65:44	635		9,0	3,4
1986		02.14	09:09	1N	W78		02.16	18:38	57:29	725		17,5	1,7
1988		01.02	21:11	3N	W18		01.04	20:12	47:01	885		15,3 (14,1)	1,9 (2,0)
		11.08	12:29	2N	W07		11.11	07:53	67:24	620		28,0	0,85
		12.16	08:26	2B	E33		12.17	18:24	33:58	1230		13,3	1,8
1989		01.04	16:03	1N	W60		01.05	13:24	21:21	1960		10,2	2,7
		03.06	13:54	3B	E71		03.08	17:55	52:01 +	800		18,2 (1,0)	2,0 (1,9)
		03.11	19:33	2B	E10		03.13	01:27	29:54	1390		13,5 (2,1)	2,3 (2,3)
		03.17	17:29	2B	W61		03.19	04:23	34:54	1200		7,5	2,3
		04.11	21:34	----	W08		04.13	22:24	48:50	850		25,4	2,3
		05.05	07:20	2B	E04		05.07	05:22	46:02	900		30,5	3,1
		05.22	00:00	2B	E15		05.23	13:46	37:46	1110		47,0 (0,7)	1,7 (3,1)
		08.12	13:57	2B	W38		08.14	06:13	40:16	1035		5,8	1,4
		08.16	00:58	2N	W85		08.17	15:41	38:43	1080		16,0	1,3

		FLARES					SHOCKS					DECAYS	
Year		Month, day	Hours, minutes	Imp.	Longi-tude		Month, day	Hours, minutes	$\Delta T = T_{sh} - T_{fl}$ Hours, minutes	Speed, км/s		τ > 4 MeV	γ decay
1989		10.24	17:38	2N	W57		10.26	14:27	44:49	925		12,5	1,3
		11.15	06:38	2B	W28		11.17	09:25	50:47	820		16,5 (4,1)	0,7 (1,5)
		11.26	17:49	2B	W03		11.28	07:42	37:53	1100		37,0	1,9
		11.30	11:45	2N	W52		12.01	17:49	30:04	1390		5,9	1,5
1990		03.19	04:38	1N	W39		03.20	22:43	42:05	990		6,6	2,2
		03.28	07:27	2N	W35		03.30	07:29	47:53	870		9,8 (4,2)	2,2 (3,0)
		04.06	06:18	1N	E50		04.09	08:43	74:25	560		18,8	2,2
		04.10	11:44	1N	W04		04.12	03:26	39:42	1050		26,7 (0,5)	2,5 (2,4)
		07.25	22:21	2N	E56		07.28	03:31	53:10	780		32,0	1,7
		07.30	06:32	2N	E42		08.01	07:41	49:09	850		16,5	1,85
1991		01.31	01:57	2B	W35		02.02	18:42	64:45	640		42,0	2,1
		04.02	22:51	2N	E02		04.04	11:42	36:51	1130		33,0 (2,1)	1,8 (2,5)
		05.18	05:30	2N	W87		05.22	00:18	90:48	460		25,0 (5,2)	1,8 (2,2)
		06.11	01:05	2B	W15		06.12	10:12	33,07	1170		11,7 (7,8)	1,3 (1,2)
		06.15	06:33	3B	W70		06.17	10:19	51:46	800		13,5 (3,2)	1,45 (1,8)
		07.11	08:35	3B	W52		07.12	09:24	24:49	1680		7,6	3,4
		08.25	00:26	2B	E76		08.27	15:15	62:49	660		20,2 (6,8)	2,4 (2,4)

		FLARES					SHOCKS					DECAYS	
Year		Month, day	Hours, minutes	Imp.	Longi-tude		Month, day	Hours, minutes	$\Delta T = T_{sh} - T_{fl}$ Hours, minutes	Speed, kм/s		τ > 4 MeV	γ decay
		09.29	15:13	3B	E31		10.01	18:14	51:01	815		23,2 (15,4)	2,1 (1,9)
1992		02.06	09:28	2B	W09		02.08	14:28	53:00	785		9,1	1,6
		03.15	01:20	2B	E27		03.17	09:51	56:31	740		10,4	1,45
1992		05.07	06:35	2N	E48		05.09	19:57	61:22	680		20,0 (6,3)	2,2 (2,2)
		06.25	17:49	1B	W69		05.27	20:35	50:46	820		12.3	1,4
		11.02	03:10	2B	W90		11.04	13:12	58:02	720		42,0	1,25
1993		03.06	19:44	2B	E29		03.08	21:37	49:53	840		17,7	1,55
1994		10.20	05:53	1N	W53		10.22	08:49	50:56	820		16,0 (1,3)	----

Notes:
Column 1 - years of the event
Column 2,3,4 and 5 - month, day, hours and minutes of the flare, its importance and longitude
Column 6,7,8 and 9 - month, day, hours and minutes of the shock arrival, delay of the shock relative to the flare and transit shock speed, defined from ΔT;
Column 10 and 11 - decay time τ and spectral index γ for decline. In brackets – the value of τ and γ for the events, when the regular decline was preceded by the shock-peak