Sequences of electron and proton events with similar characteristic decay times

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Energetic charged particles: serve as probes monitoring the interplanetary medium, its quasi-stationary magnetic field having different temporal and spatial variations, characterized by the spectrum of the magnetic field inhomogeneities

One of the main characteristics of particle fluxes reflecting IM state is the SEP event decay rate which is determined by conditions in the IM.

Functional form of the decay allows to judge about propagation mechanism.

There are two regular forms: power-low and exponential

Power-low – either trapping between CME shock front and strong magnetic field near the Sun, or
diffusive propagation in the infinite space.

Diffusive model with absorbing boundary at the distance r_o or with the volume limited by a boundary outside of which particles fly away freely

exponential decay $\tau = r_o^2 / \pi^2 \kappa$

Prevalence of convection and adiabatic deceleration over diffusion, gradients, scattering and drift results in exponential form

$$\tau = 3r/2V(2 + \alpha\gamma),$$

r - distance from the sun, V solar wind speed, γ –spectral particle index, E - kinetic energy

$$\alpha = (E+2mc^2)/(E+mc^2)$$

qualitatively right dependence on all parameters

However, diffusion takes place in any case.
no scattering →neither convection nor adiabatic deceleration!

Scattering at the magnetic field inhomogenieties. Spectra of inhomogenieties.

Since τ depends on the magnetic field characteristics and solar wind speed, the invariance of τ for some time indicates combined invariance of space parameters in the same time period.

Sectors of homogeneity in the inner heliosphere

Experimental data

IMP-8/CPME (1974-2001)
electrons 0.5-0.8 MeV, protons 4.6-15 MeV

SOHO/COSTEP (1995-2010)
electrons 0.25-0.7 MeV, protons 4.3-7.8 MeV

Selection criteria:
exponential decays only (about 90% of regular profiles)
electron flux >10 times background, decays longer 24 hours

Due to high values of background the number of exponential electron ~0.5 MeV decays is considerably less than that of MeV protons

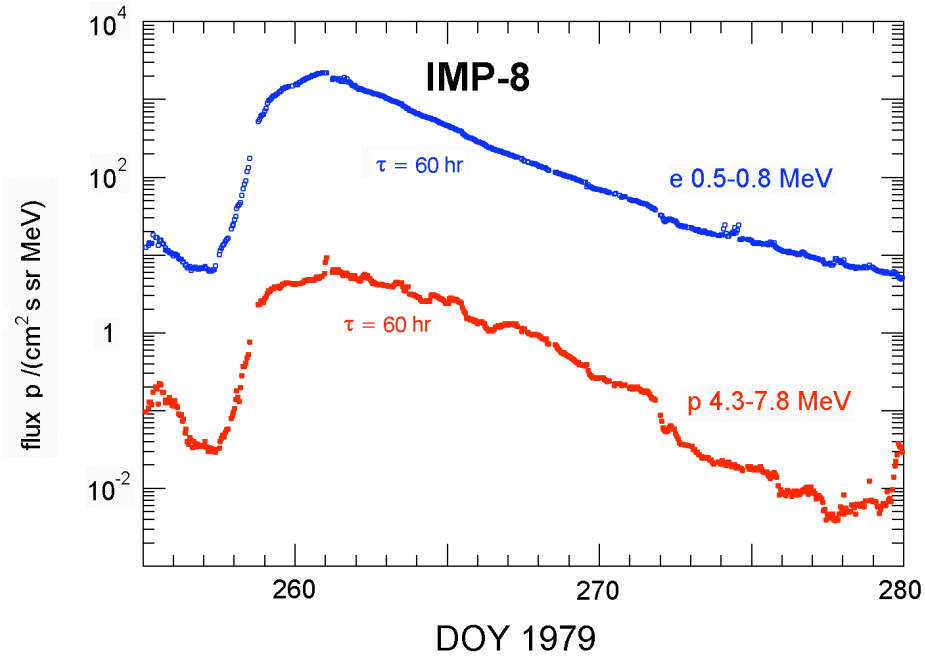
The temporal length of decay is related to the spatial extent of the homogeneous sector

Ftp of magnetic field line connecting the observer with the Sun slides over its surface with the speed of 13.3°/day due to solar rotation. So the decay with invariant τ for ΔT days shows the characteristics of IM defining the propagation of definite-kind particles to be stable and quasi-homogeneous within angular sector $\Delta\varphi = 13.3 \cdot \Delta T°$.

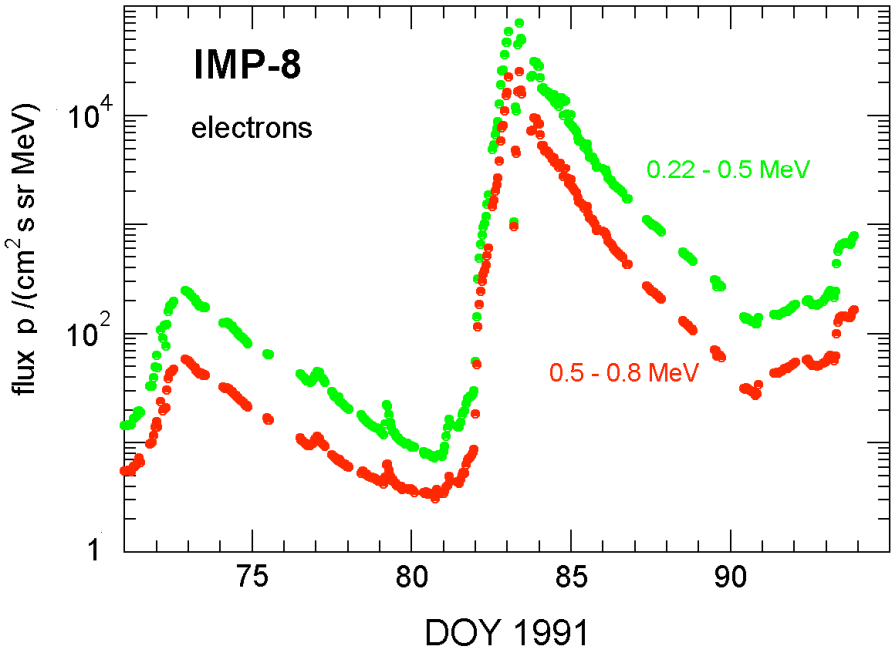
Decays of single events, as a rule, continue not longer than 7-10 days (sector $\Delta\varphi$ = 90-120°) and this is a limit of observation of homogeneity intervals for single events.

Additional possibility of observation of broadening of homogeneity intervals is sequences of succesive events.

32 sequences of events with invariant decay times of electrons and (or) protons in 1974-2010. Earlier we considered 40 proton sequences during 1974-2001 years



A single SEP event in 1979 with very long, almost identical decay profiles in electron and proton fluxes ($\tau_e = \tau_p \approx 60$ hr).

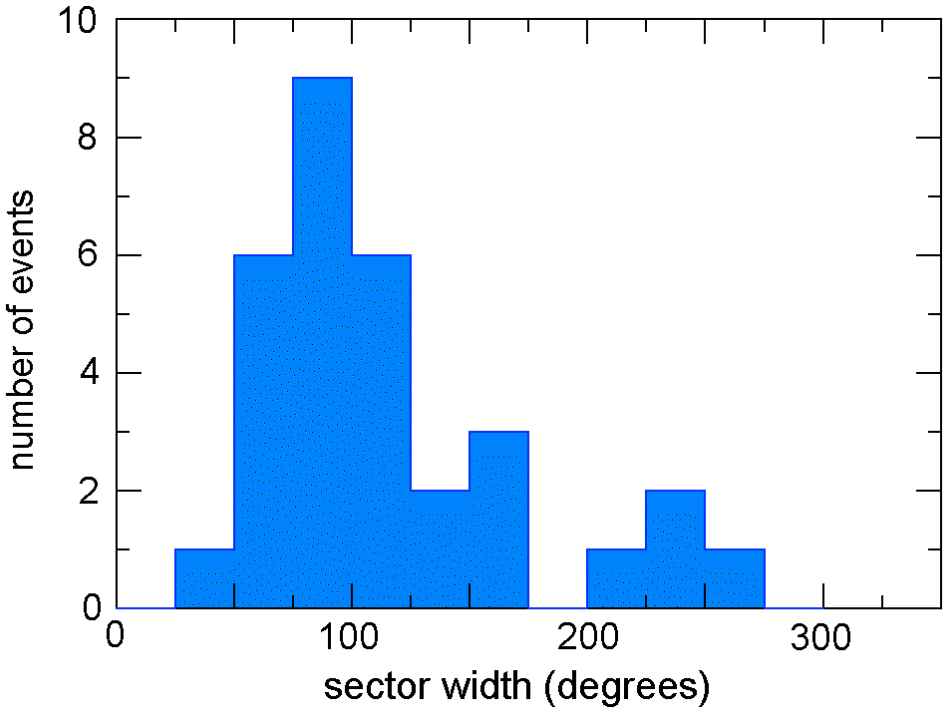


Successive electron events:

τ_e = 52 hr (14-21 March)

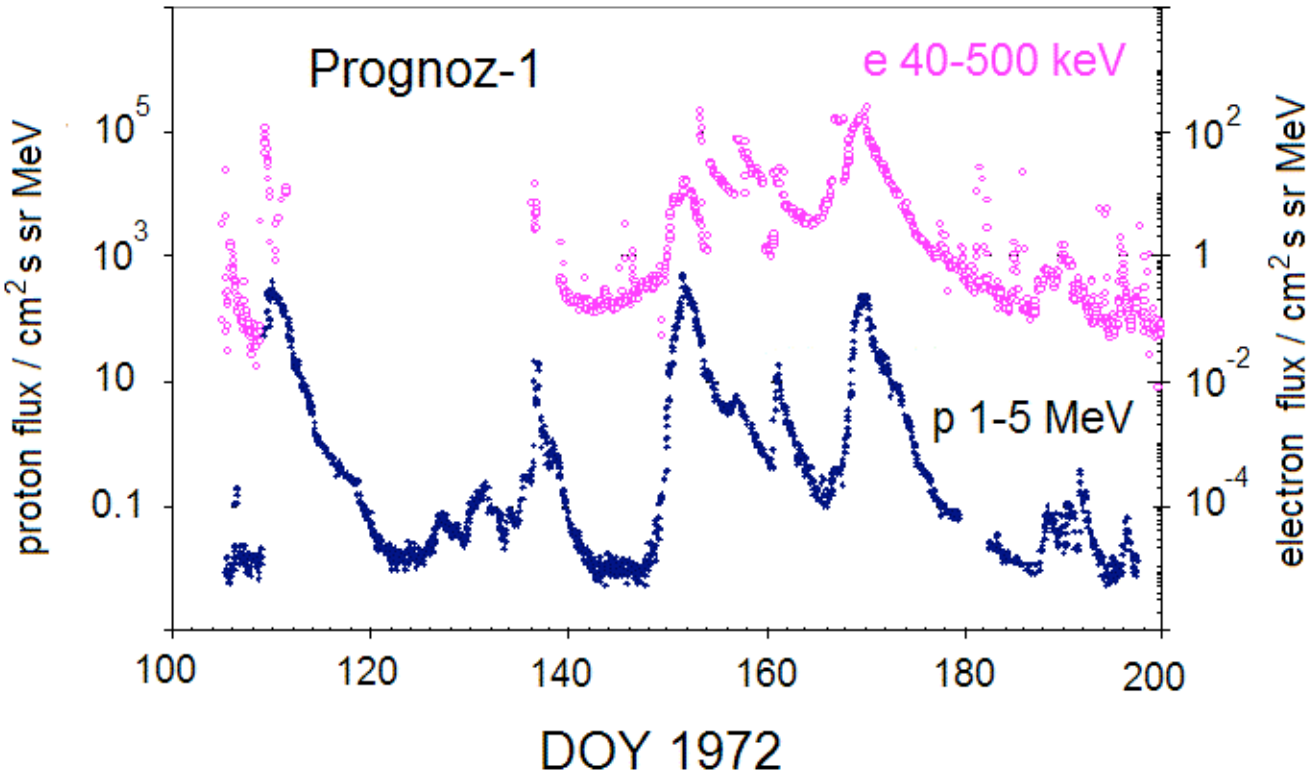
τ_e = 25 hr (24-30 March)

Distribution of the angular extent of homogeneity sectors (electrons)



32 sequences of SEP decays (1974-2010)

Uniformity and quasi-stationarity of the interplanetary medium within sectors up to 100° is frequently observed, even longer homogeneous sectors of up to 180°. An exceptionally long period exceeding two solar rotations was seen by Prognoz-1 in April-June 1972



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Single events: all possible relations between τ_e and τ_p are observed

$$\tau_e = \tau_p, \quad \tau_e > \tau_p, \quad \tau_e < \tau_p .$$

In event sequenceses practically always $\tau_e \geq \tau_p$

$\tau_e = \tau_p$:

The slope of the power spectrum of magnetic field irregularities is unchanged between the resonant wavelengths of protons and electrons
$\Rightarrow$ suggests the similarity of their acceleration and propagation characteristics during successive events

$\tau_e > \tau_p$:

Slower decay of electron fluxes may indicate additional acceleration or more effective confinement within the propagation region

Difference between τ_e and τ_p is partly due to different value of α:
$\alpha = 2$ for protons, $\alpha = 1.5$ for electrons (at ~0.5 MeV).

Argument for convection and adiabatic deceleration.

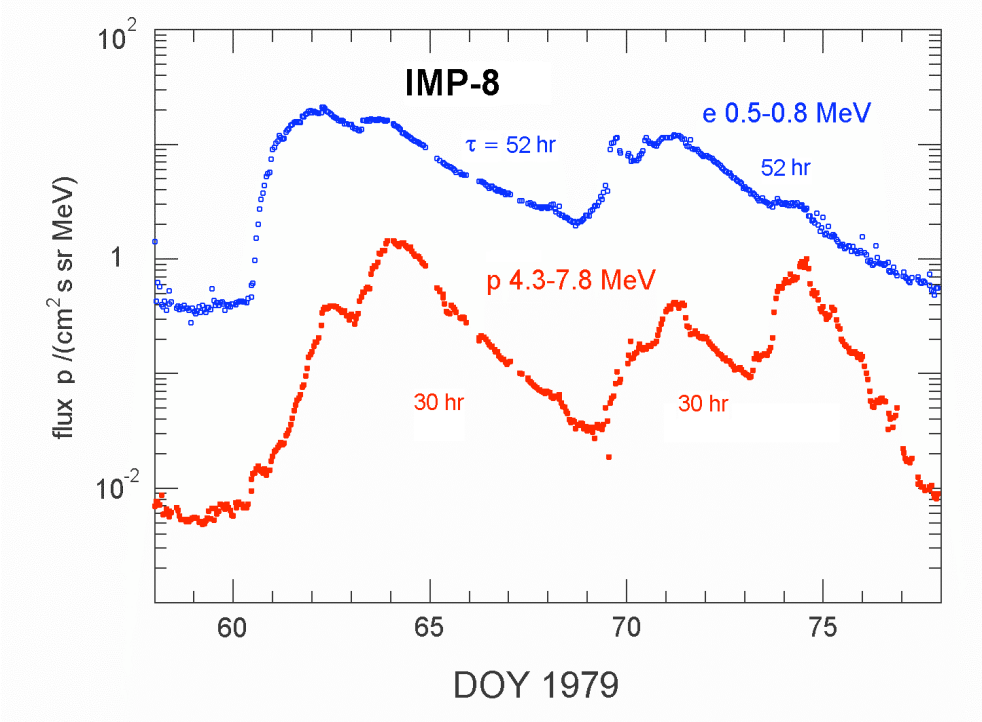
The value of τ is determined by two factors:

- adiabatic deceleration of particles in the solar wind and
- scattering on irregularities of the IMF.

The solar wind speed is the same for different species and different energies, we assume that differences between τ_e and τ_p as well as the energy dependence of τ is due to changes in energy spectrum (γ) and scattering properties between successive events.

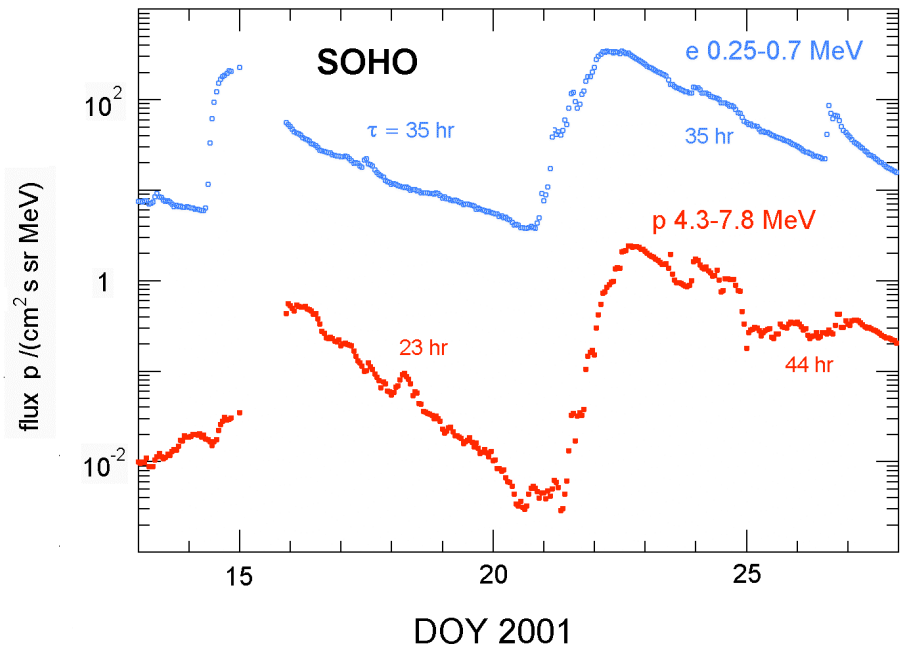
The power spectrum of the magnetic field can vary differently at high and low frequencies. If the power remains constant near the resonance frequency of electrons but changes at low frequencies, then a sequence is seen for electrons only and vice versa.

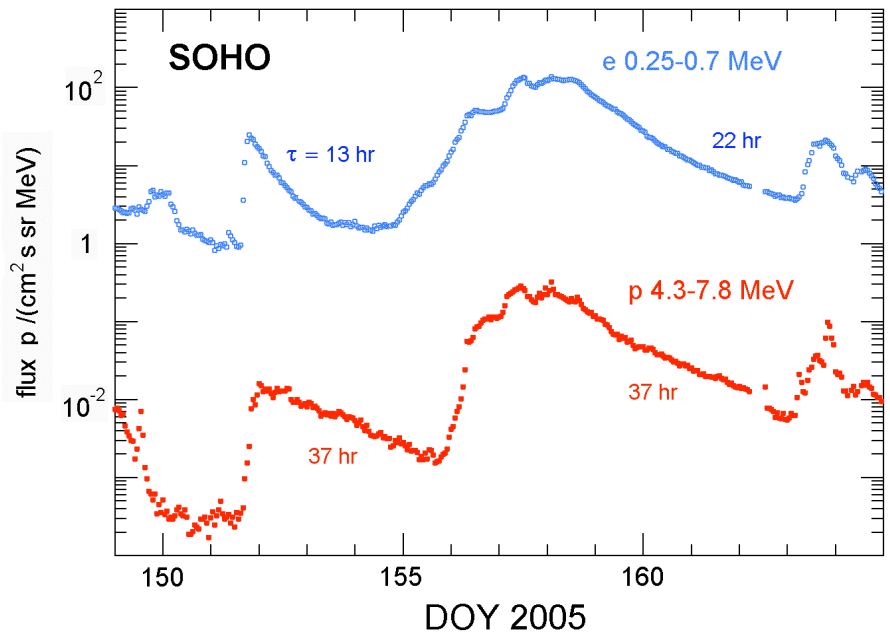
Two different mechanisms give rise to the decay profile: further analysis is needed to determine their relative importance.



A sequence of 3 successive SEP events in March 1979

τ_e= 52, τ_p =30 hrs



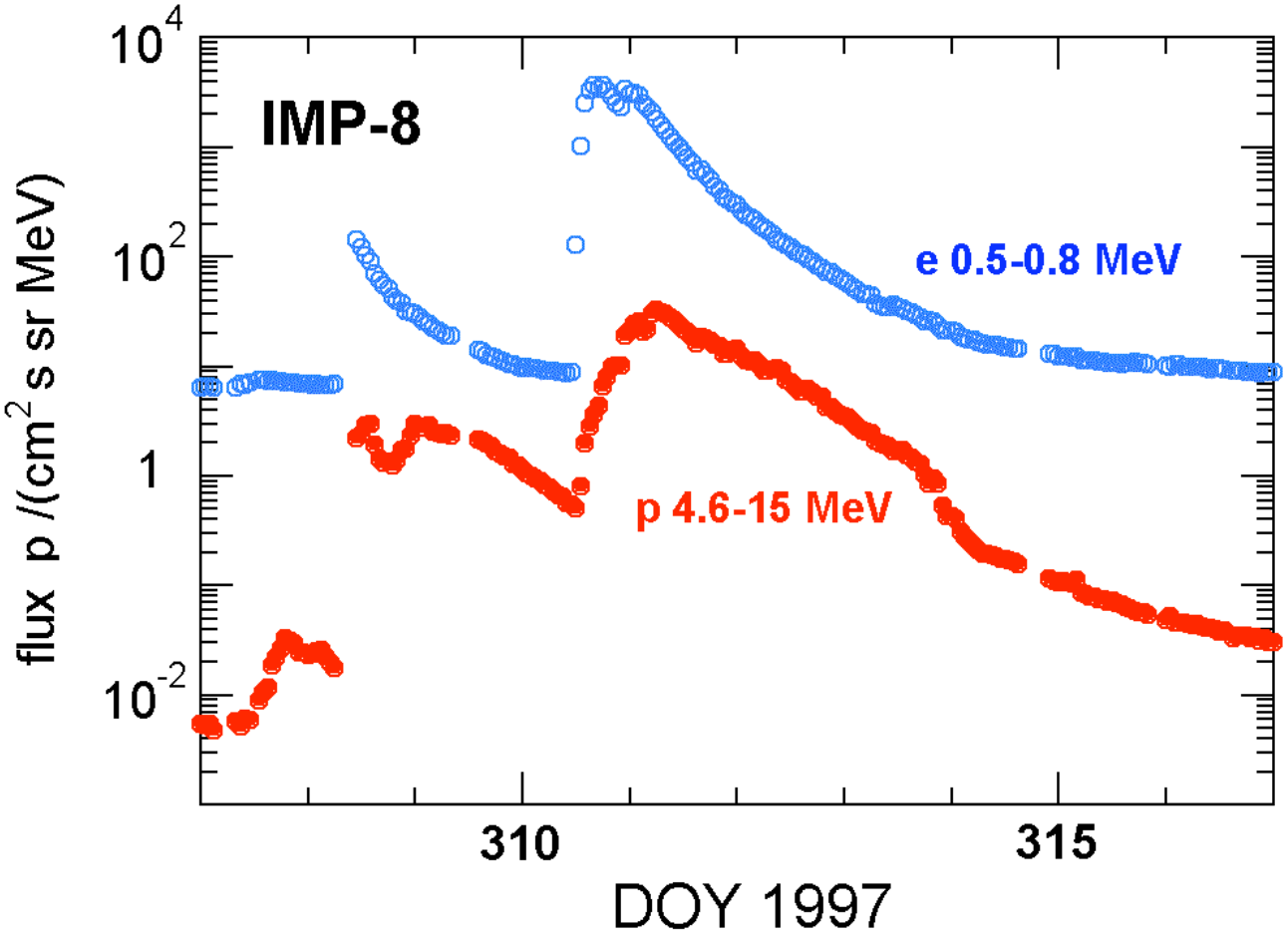


An electron sequence not accompanied by a proton sequence.

A proton sequence with similar decay rates but not accompanied by an electron sequence.

Sometimes in sequences, just as in single events, there are exponential decays for one species and power-low for another. That is simultaneously in a wide angular spread different mechanisms of propagation and losses of electrons and protons are valuable.

Invariability of different mechanisms for electrons and protons over a wide spatial range



Different behavior of e and p
electrons: power-law decay
protons: exponential

Conclusions

Sectors of homogeneity in the inner heliosphere: τ, the characteristic time of exponential decay of SEP events remains constant within 5%.

The invariability of decay time during single and successive events suggests that angular spread of sectors of homogeneity >15°, rather frequently is 45-90° (15° for single events), several cases with sectors >180°, exceptional: extend to 360°.

This suggests that more than a half of near-Sun space can have quasi-stationary characteristics of magnetic field and its fluctuations, and/or satisfies the conditions of stability of convection and adiabatic deceleration, following active processes quasi-stationary conditions are restored

Proton and electron decays with invariant τ

Electrons only: power in high frequency range stationary
Protons only: power in low frequency range stationary
Simultaneous: stationarity over a wide frequency range

Event sequences: usually $\tau e \geq \tau p$ (similarly to single events) – similar propagation
mechanisms and loss processes, adiabatic deceleration dominate
$\tau e < \tau p$ can be due to change of scattering properties.

Different functional forms of e and p decays show evidence for simultaneous invariability of different mechanisms for these species over a wide spatial range

Thank you for your attention