THE THREE DIMENSIONAL NON STATIONARY MODEL OF THE FORBUSH DECREASE OF GALACTIC COSMIC RAY INTENSITY WITH THE CHANGEABLE SOLAR WIND VELOCITY

Anna Wawrzyńczak-Szaban
Michael V. Alania

University of Podlasie, Poland

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Outline

- Show rigidity dependence of the GCR intensity variation during the Forbush decrease (Fd) – September 2005
- Show the increase of the IMF turbulence in the lower frequency range during the Fd (increase of the exponent ν of the PSD of the IMF components during Fd in comparison with before and after the Fd)
- Compose model of the Fd including changes of the
  - turbulence of the IMF
  - solar wind velocity
  - turbulence of the IMF and solar wind velocity

Motivation

In our study the we have shown that (e.g. Wawrzynczak and Alania 2005, 2008, 2010) the changes of the rigidity R spectrum

$$\frac{\delta D(R)}{D(R)} \propto R^{-\gamma}$$

of the Forbush decreases (Fds) determined by NM and ground MT data, are related with the changes of the Power Spectral Density (PSD) of the IMF's turbulence (PSD $\propto$ f $^{-\nu}$, f is a frequency) in the lower part of frequencies;

namely the exponent γ depends on the exponent ν in the range of frequency of the IMF turbulence f ~ 10^{-6} - 10^{-5} Hz

Motivation

We suppose that a relationship between the exponent γ and the exponent ν exists owing to the dependence of the diffusion coefficient K of GCR particles on the rigidity R

$$K \propto R^{\alpha}$$

[Jokipii, 1966; Hasselman and Wibberentz , 1968 Jokipii, 1971, Toptygin, 1985]

The parameter α depends on the exponent $\boldsymbol{\nu}$ of the PSD of the IMF turbulence according to the quasi linear theory (QLT) as

$$\boldsymbol{\alpha = 2 - \nu}$$

(ν- exponent of the PSD of the IMF turbulence PSD $\propto \mathbf{f}^{-\nu}$)

Motivation

Based on the relationship between the rigidity spectrum of GCR intensity

$$\delta D(R)/D(R) \propto R^{-\gamma}$$

and the GCR intensity variation

$$\delta I/I \propto K^{-1}$$

$$\delta D(R)/D(R) \propto \delta I/I$$

$$R^{-\gamma} \propto K^{-1} \Rightarrow R^{-\gamma} \propto R^{-\alpha}$$

$$\gamma \propto \alpha \quad \Rightarrow \quad \gamma \propto 2 - \nu$$

there should exist a relation, between the exponent γ of the rigidity spectrum of the GCR intensity and the exponent ν of the PSD of the IMF

$$\gamma \propto 2 - \nu$$

Rigidity Spectrum

Rigidity Spectrum was calculated with use of the coupling coefficients by the method presented by

Dorman 1963, Ahluwalia and Ericksen1971; Yasue et al, 1982

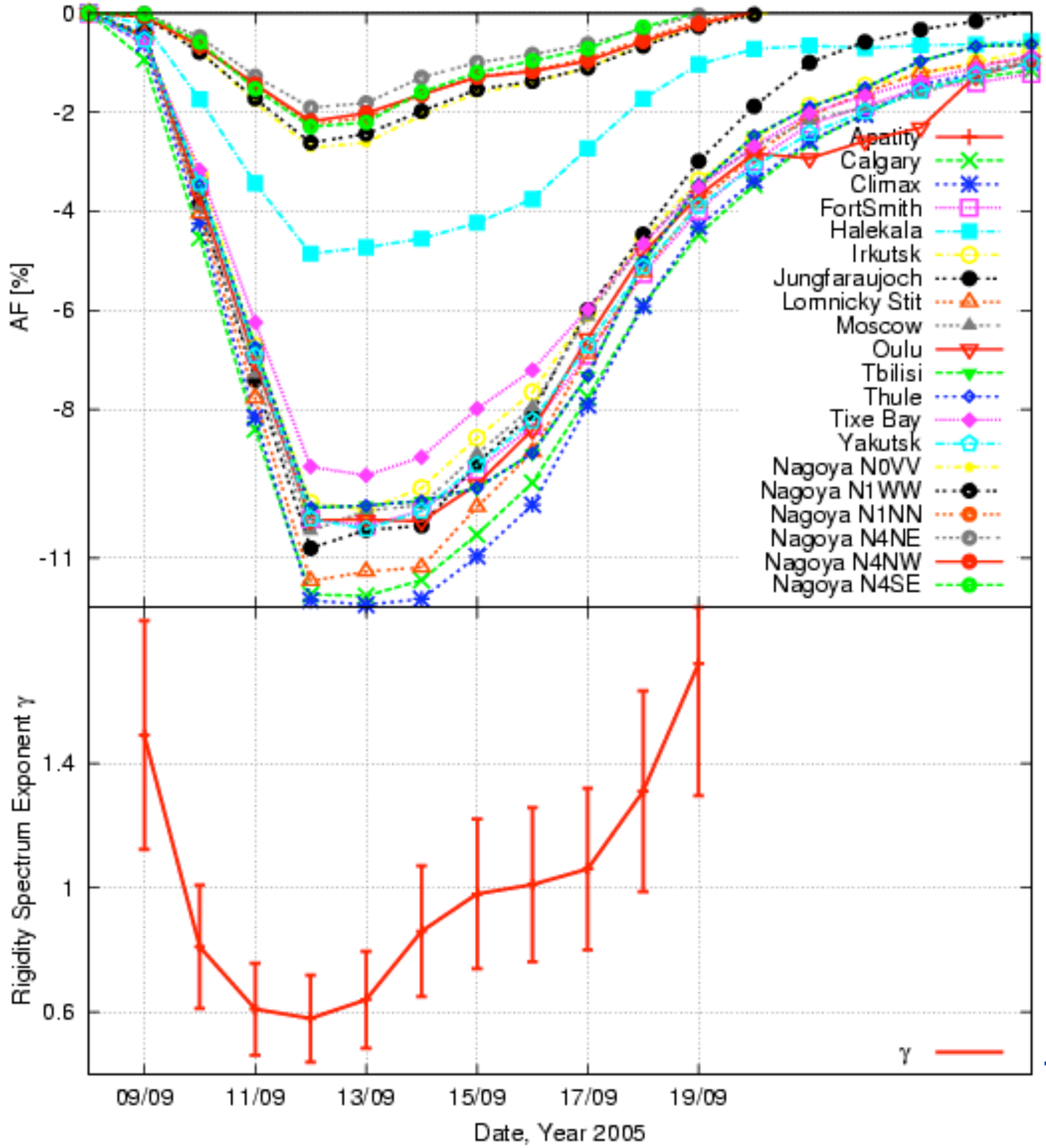
$$\frac{\delta D(R)}{D(R)} = \begin{cases} A\left(\frac{R}{R_0}\right)^{-\gamma} & for \quad R \le R_{max} \\ 0 & for \quad R > R_{max} \end{cases}$$

Amplitude of the Fd

Upper limiting rigidity beyond which the Forbush decrease of GCR intensity vanishes

R_0= 1 GV

September 2005



14 NM
6 MT

$$\frac{\delta D(R)}{D(R)} \propto R^{-\gamma}$$

September 2005

$$f \approx 10^{-6}\,Hz \div 10^{-5}\ Hz$$

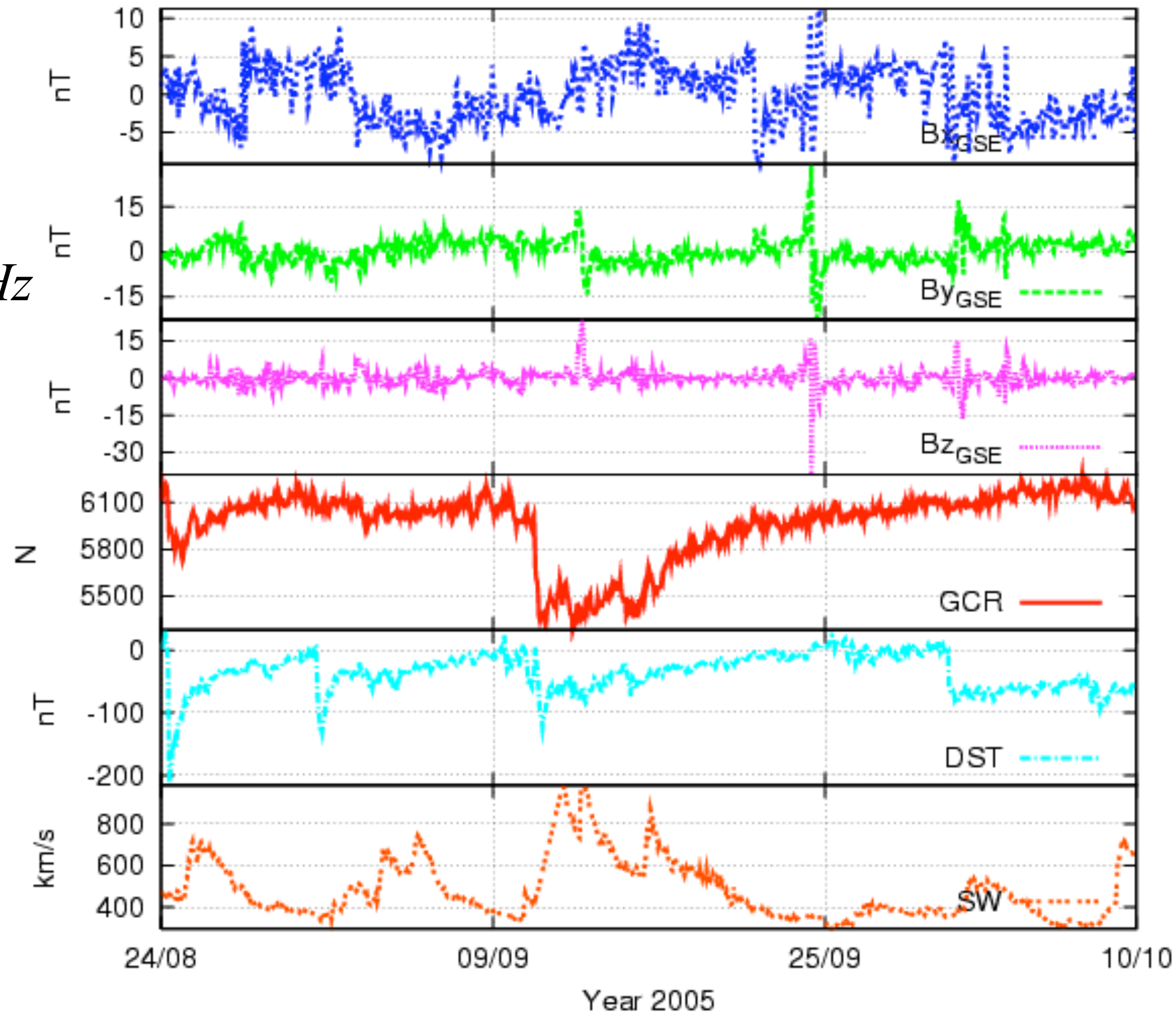
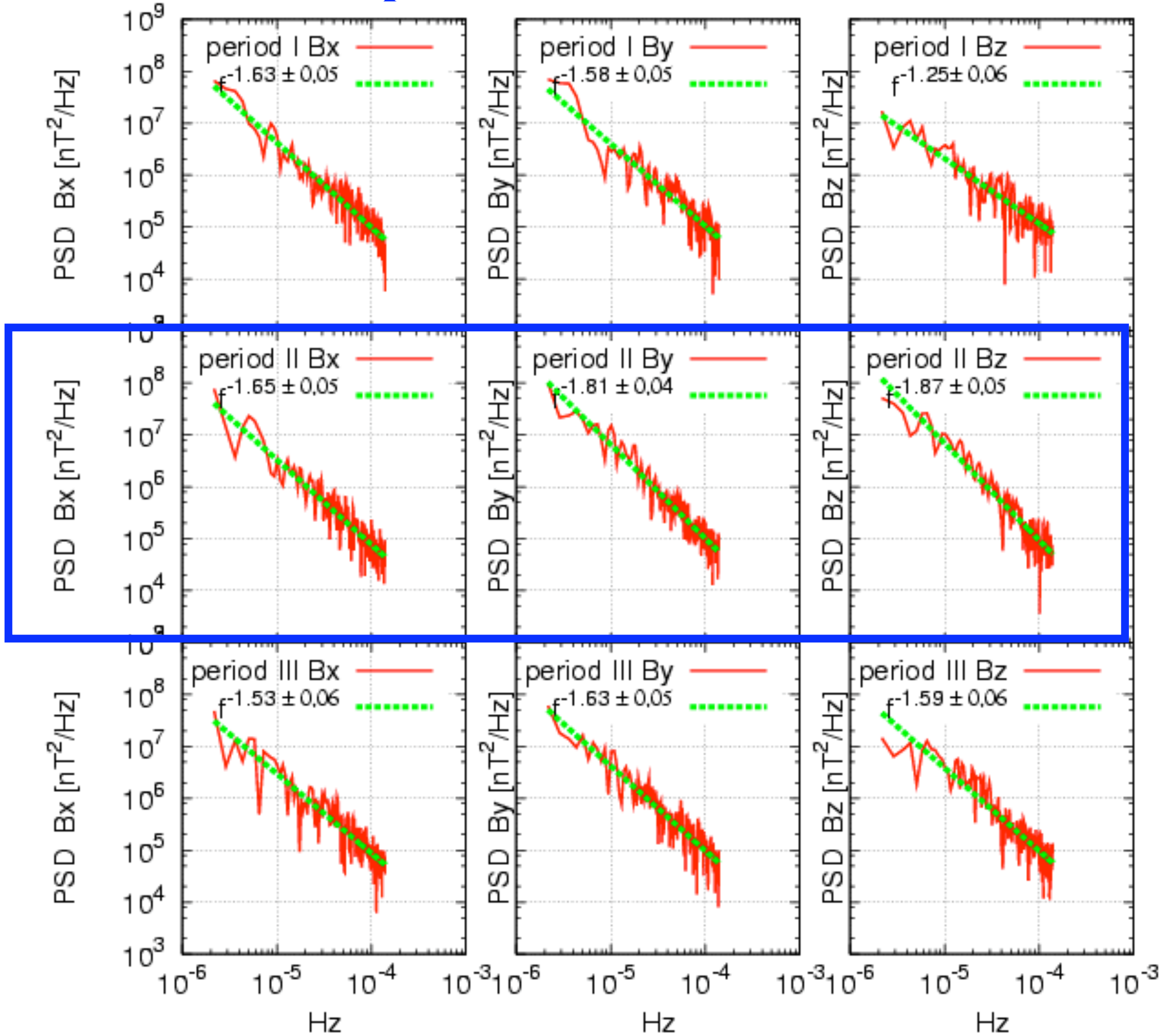


Fig. Changes of the Bx, By and Bz components of the IMF (from ACE), GCR intensity by Moscow neutron monitor, DST index and solar wind speed (SW) in the period of 24 August–10 October 2005.

PSD IMF September 2005



I: before Fd,

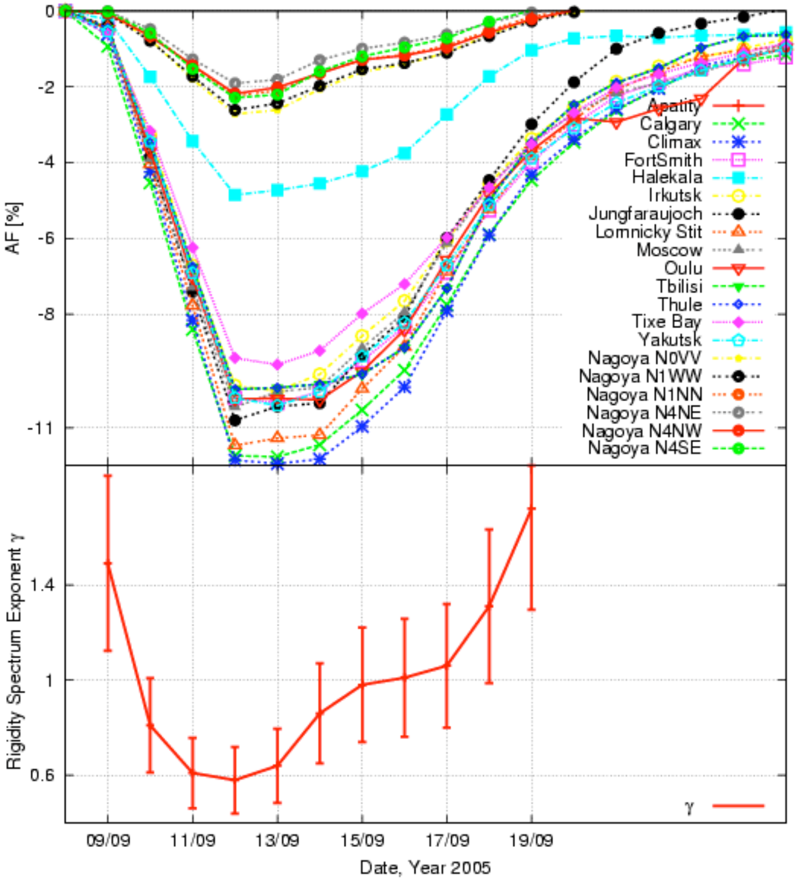
II: during Fd,

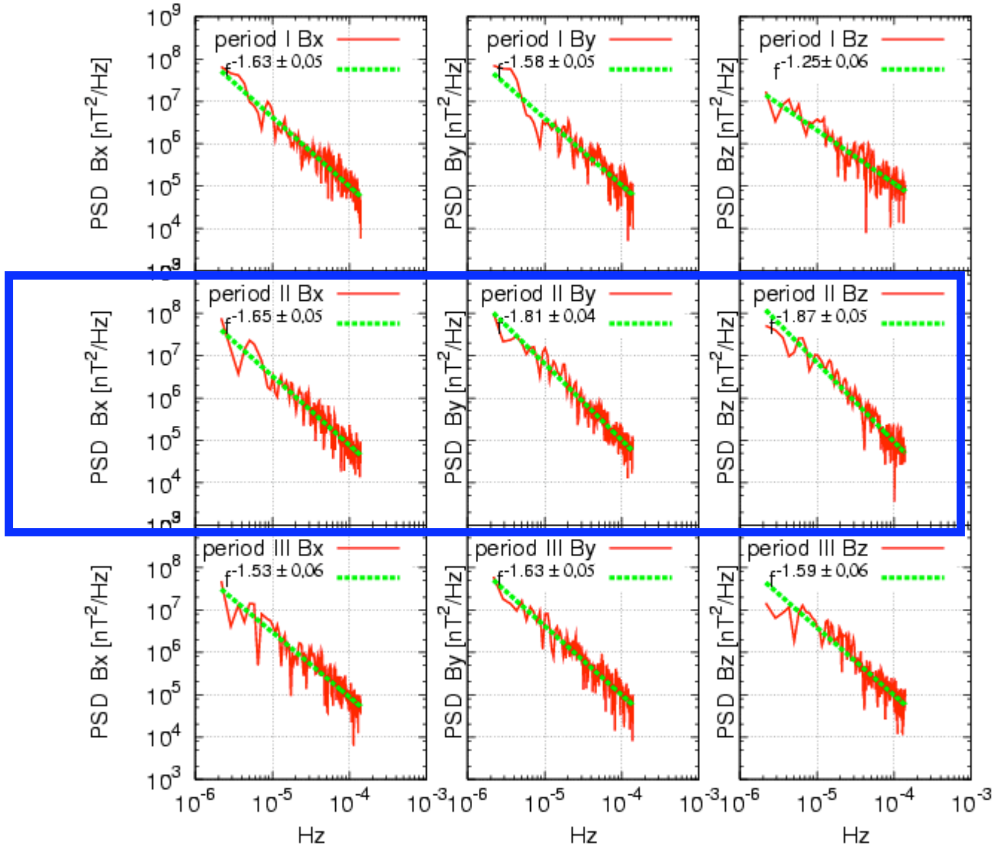
III: after Fd.

We observe the increase of ν during the Fd as is expected.

Fd September 2005

- Data shows that $\gamma \propto 2 - \nu$





What about model?

Model of the Fd

The Forbush decrease of the GCR intensity is non-stationary process and for its description the non-stationary transport equation should be used (Parker, 1965):

Model of the Fd

For the dimensionless variables f ,r and t in the spherical coordinate system the equation can been written as:

[illegible]

The equation was transformed to the algebraic system of equations using the implicit finite difference method and then solved by the Gauss-Seidel iteration

Equation Coefficients

Diffusion Tensor

[illegible]

[Alania 1978, Alania 2002]

Boundary and Initial Conditions

Initial condition with respect the rigidity:

[illegible]

Initial condition with respect the time:

$$f(r,\theta,\varphi,R_k,t)\Big|_{t=0} = f(r,\theta,\varphi,R_k)$$

Boundary conditions with respect the spatial coordinates:

[illegible] [illegible]

[illegible]

[illegible] [illegible]

Fd Model 1 (change of exponent ν)

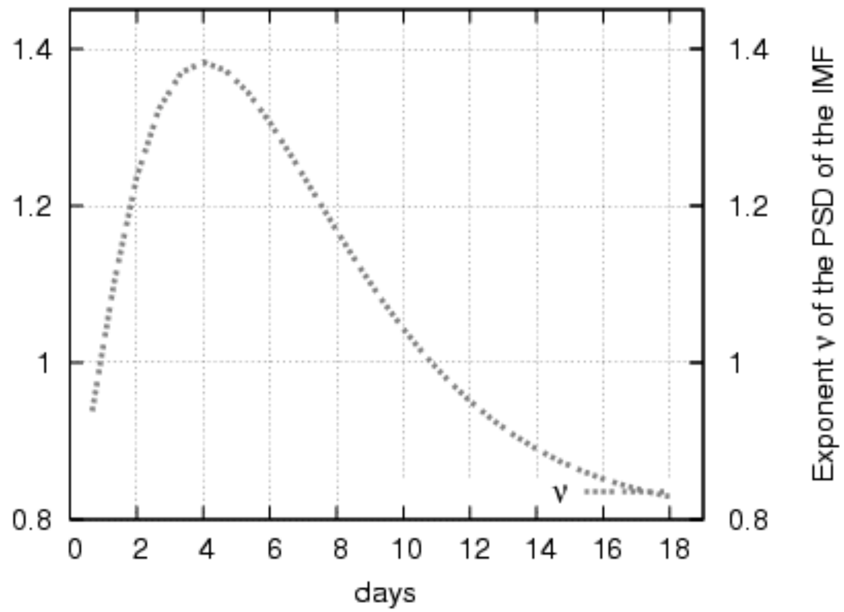
- Diffusion coefficient

$$K_{II} = K_0 \, K(r) \, K(R,t)$$

$$K_0 = 4.2 \times 10^{21} \; cm^2/s$$

$$K(r) = 1 + 0.5r$$

$$K(R,t) = R^{\alpha(t)} = R^{2-\nu(t)}$$



$$\nu(t) = 0.8 + 35 * (t - 0.1)^{1.5} * Exp(-8 * (t - 0.1))$$

- Change ν(t) restricted in time and space

$t \in (0.1;0.9)$ $\quad r < 15\,AU$ $\quad \theta \in (60°;120°)$ $\quad \varphi \in (140°;220°)$

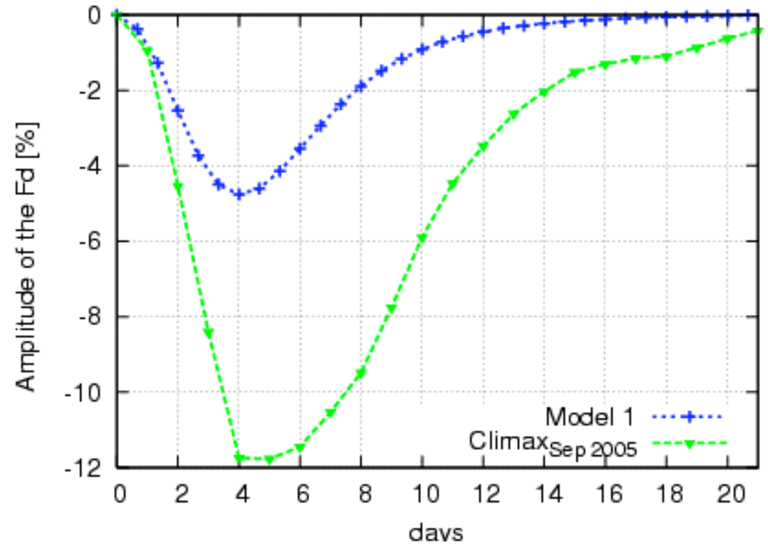
Fd Model 1 (change of exponent ν)

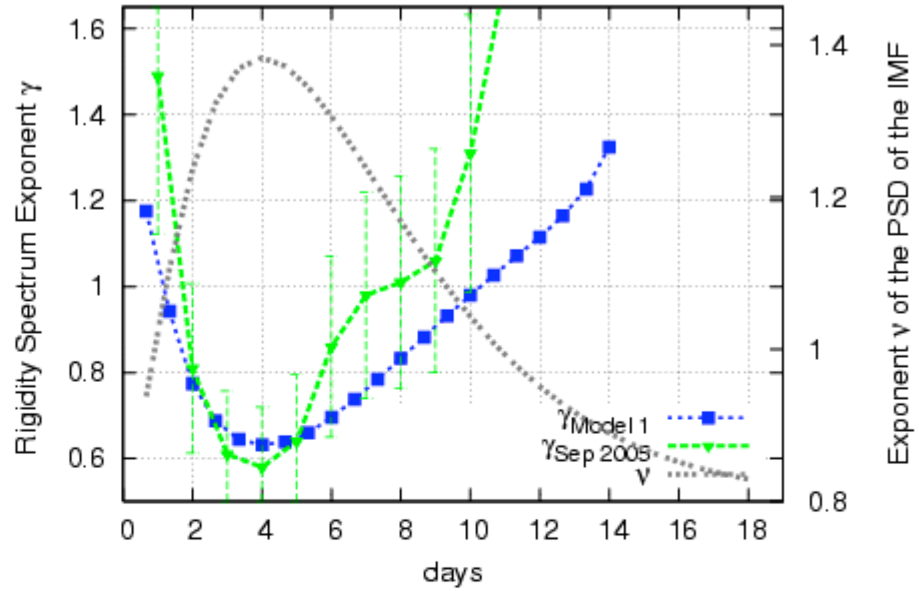
Based on numerical solution of the TPE we calculated:

- the expected amplitude of the Fd

- rigidity spectrum exponent γ as follows:

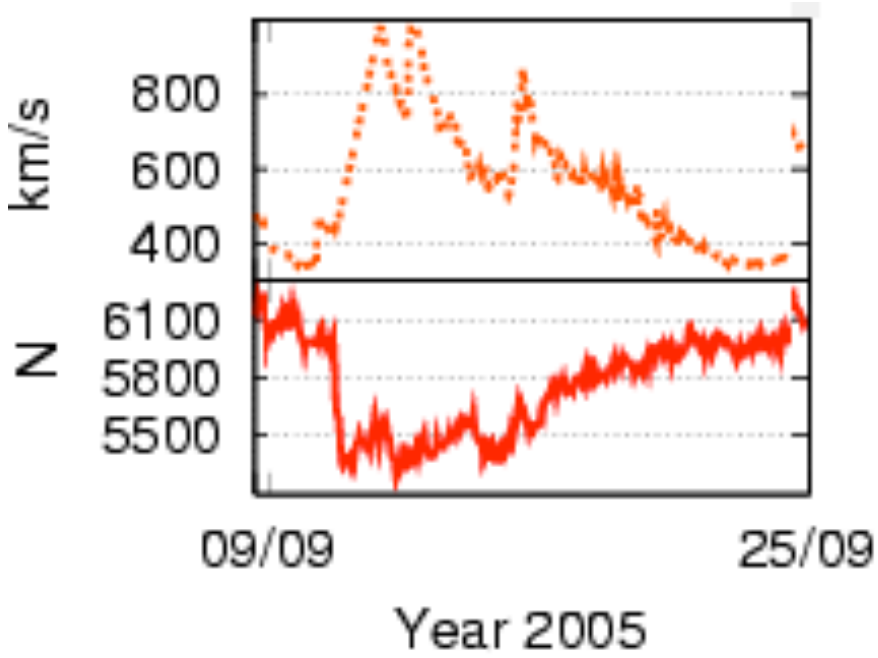
[redacted]





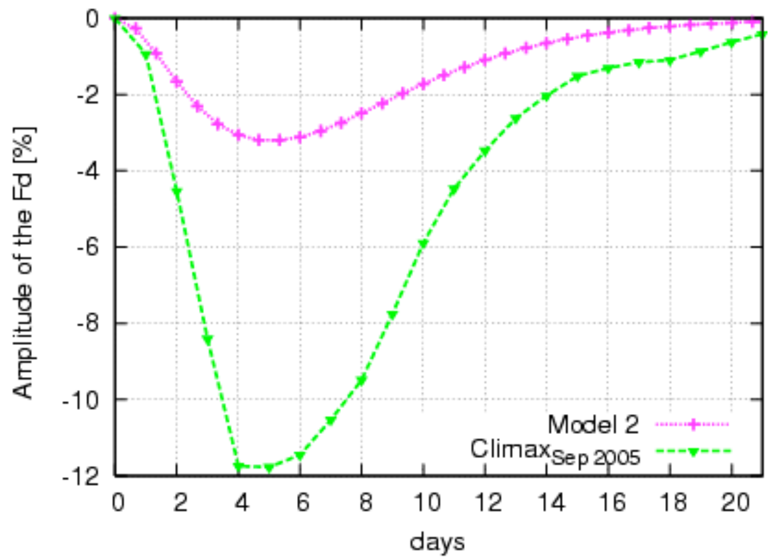
Model - Fd September 2005

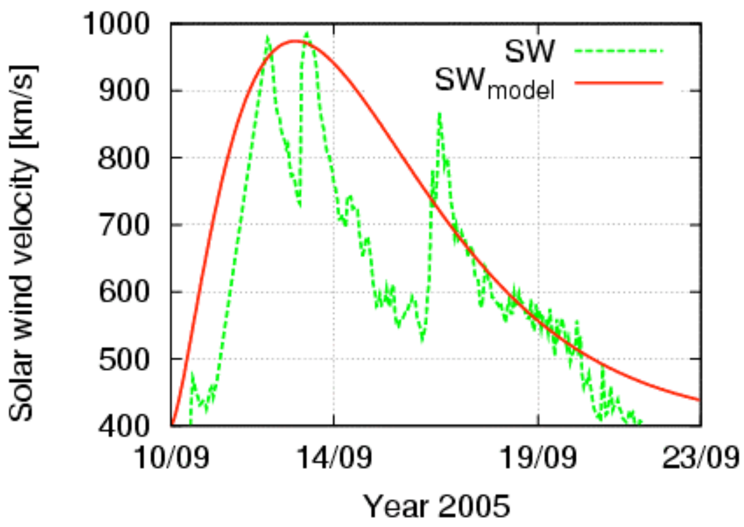
- In the presented model of the Fd as a main reason of the Fd we assumed the increase of the IMF turbulence in the restricted vicinity of space and time
- Previously in our models we considered the constant solar wind velocity V=const
- To construct a realistic model of the Fd we have to take into account, the change of the solar wind velocity

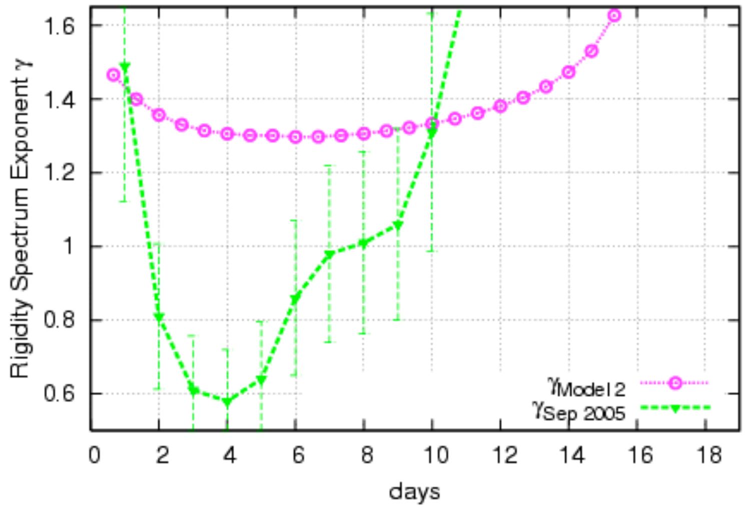


Fd Model 2 (change of SW velocity)

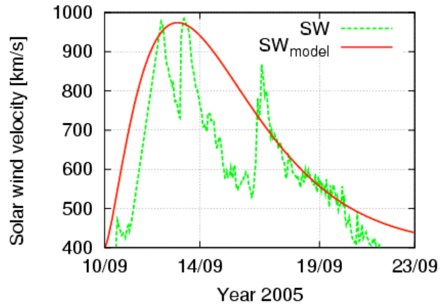
Let's see what we obtain if, as a reason of the Fd we assume only the change of solar wind velocity?



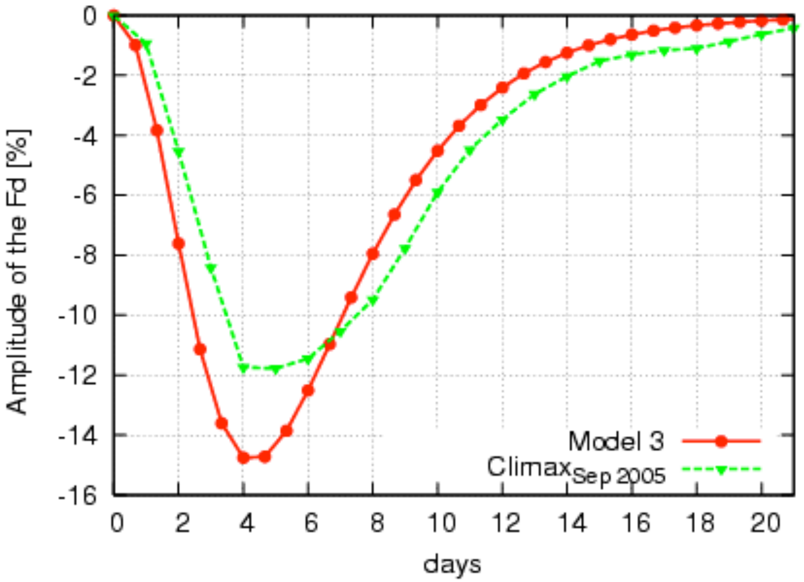


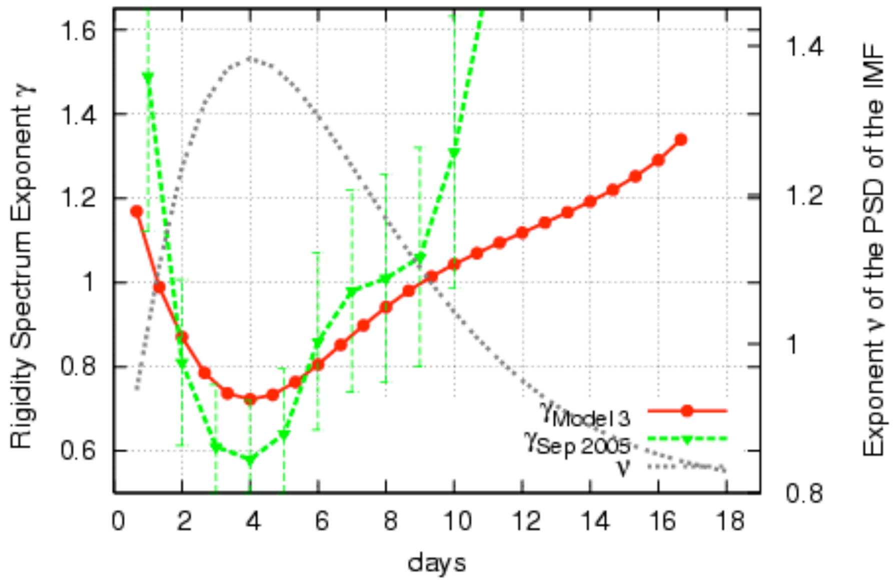


Fd Model 3 (change of SW velocity and change of exponent ν)

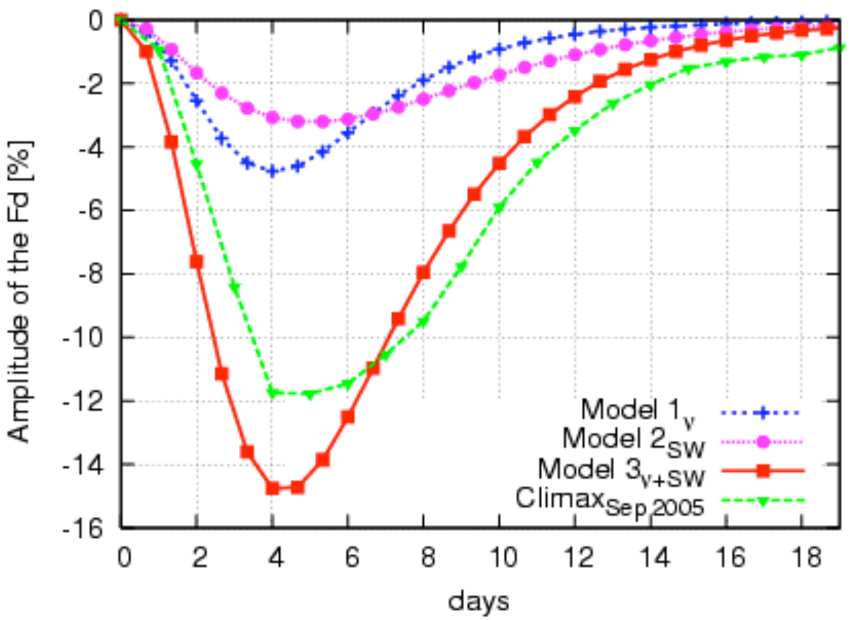


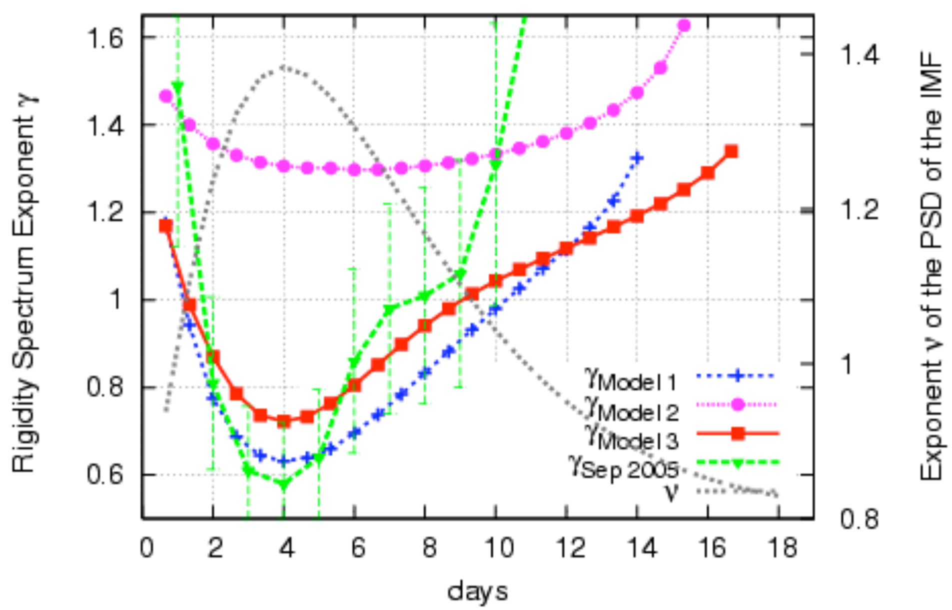
Model 3 = Model 1 + Model 2





Fd models - comparison

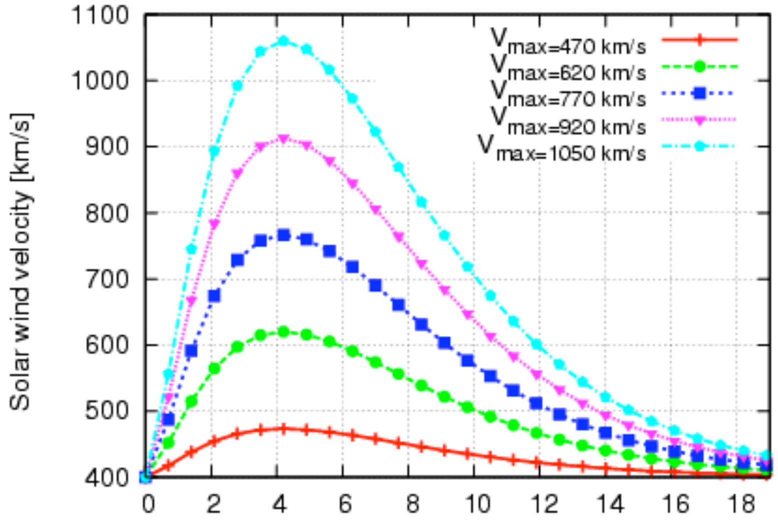


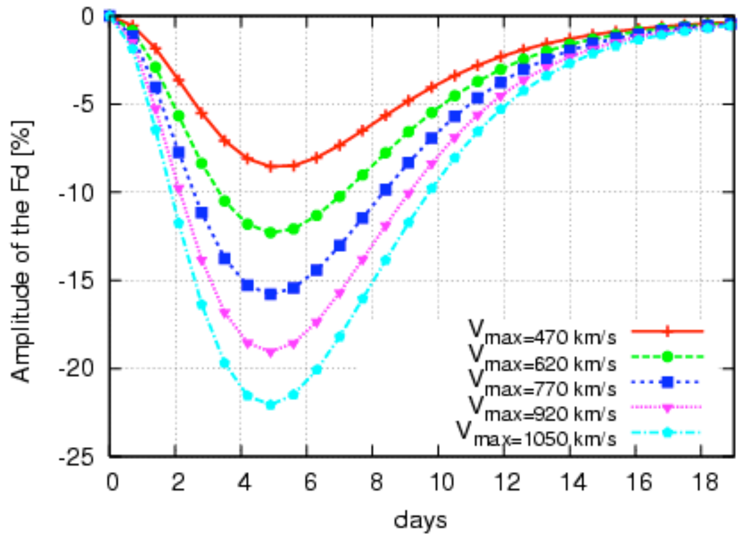


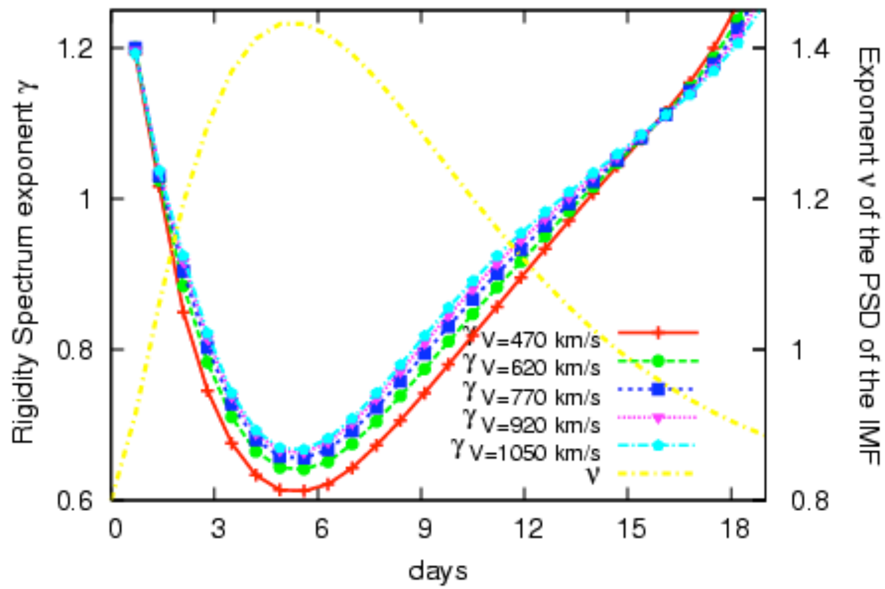
So, realistic model of the Fd requires both :

- the exponent ν change
- the solar wind velocity change

Rigidity spectrum and SW velocity







- Exponent γ weakly respond to the changes of the solar wind velocity

Conclusions

- The relationship between the exponent γ of the rigidity spectrum of the Fd of the GCR intensity and the exponent ν of the PSD of the IMF turbulence (frequency range $f \sim 10^{-6}$Hz $\div$ 10^{-5} Hz) is observed during the Fd occurred in 9-25 September 2005
- The proposed models reasonably describe the behavior of the exponent γ during the Fd. Modeling calculations are compatible with the results obtained based on the neutron monitors and ground muon telescopes experimental data and confirms a dependence of the expected rigidity spectrum exponent γ of the Fd on the exponent ν of the PSD of the IMF turbulence;
- Exponent γ does not respond to the changes of the solar wind velocity (changes of convection),
  though amplitudes of the Fd of the GCR intensity depend on different levels of convection in the rigidity range of 10$\div$50 GV of GCR.

Acknowledgements

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Thank You

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PSD of IMF

$$PSD(f) = a\, f^{-\nu}$$

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{V} f \quad \Rightarrow k \propto f$$

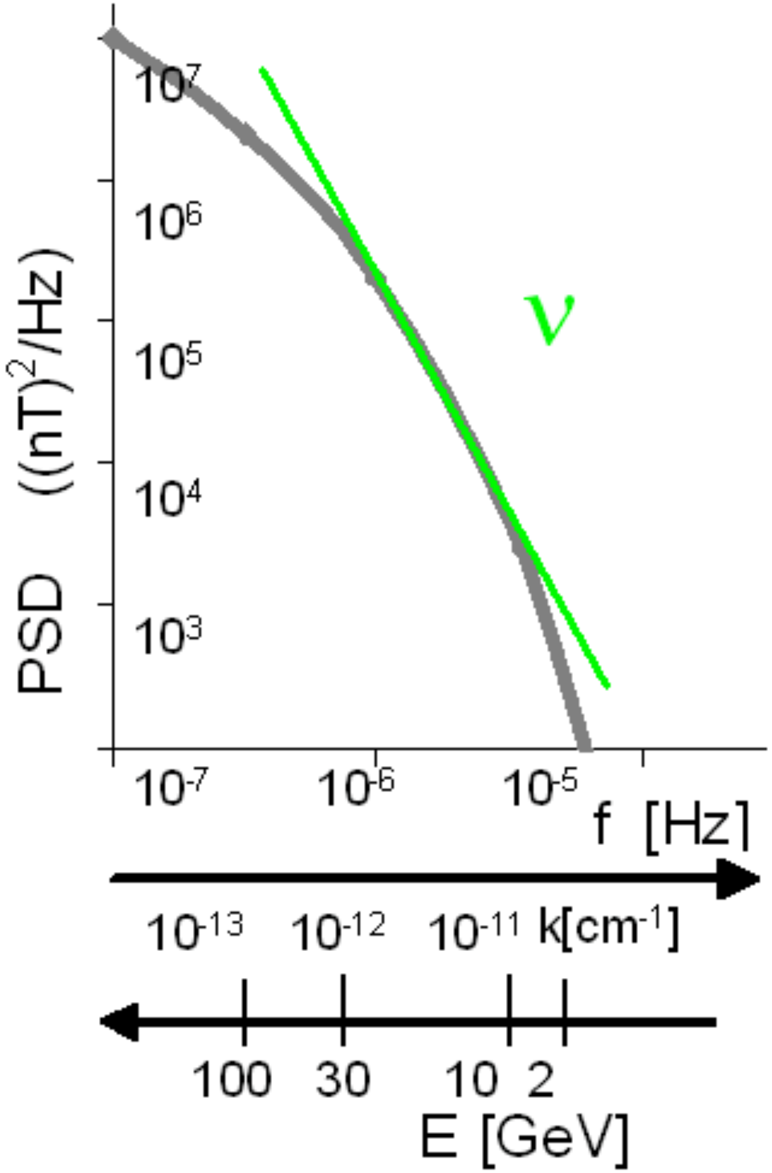
$$k \approx \frac{1}{r_L} \approx \frac{300\,B}{R}$$

$$f = \frac{V}{2\pi} k = \frac{V\,B}{2\pi\,R}$$

$$R = \frac{pc}{q}$$

$$f \propto E^{-1}$$

$$E \approx q\,R$$



f – frequency
λ- wave lenght
k- wave number
r_L- Larmor radius,
B – IMF
R – particles rigidity

[Based on: Jokipii i Coleman 1968; Jokipii, 1971]

THEORETICAL MODEL

The density N_0 of GCR is,

[illegible]

where the intensity I_0 in the LISM was taken,
[Webber and Lockwood, 2001]

[illegible]

[illegible]