Interpretation of the spectral inhomogeneity in the 10TV region in terms of a close source

Experimental data show spectral irregularities in 10 TV regions, which can be interpreted as a close source or a special transport feature.

In this paper, we consider the possibility of interpreting the experimental spectral inhomogeneity as the contribution of a single point instantaneous source in the isotropic diffusion approximation.

The emission spectrum of the source is represented by the function:

$$Q(R,t,r)=R^{-\gamma_0}\left(1+\left(R/R_{ref}\right)^{\omega_0}\right)^{-\delta\gamma/\omega_0}\delta(t-t_0)\,\delta(r-r_0)$$

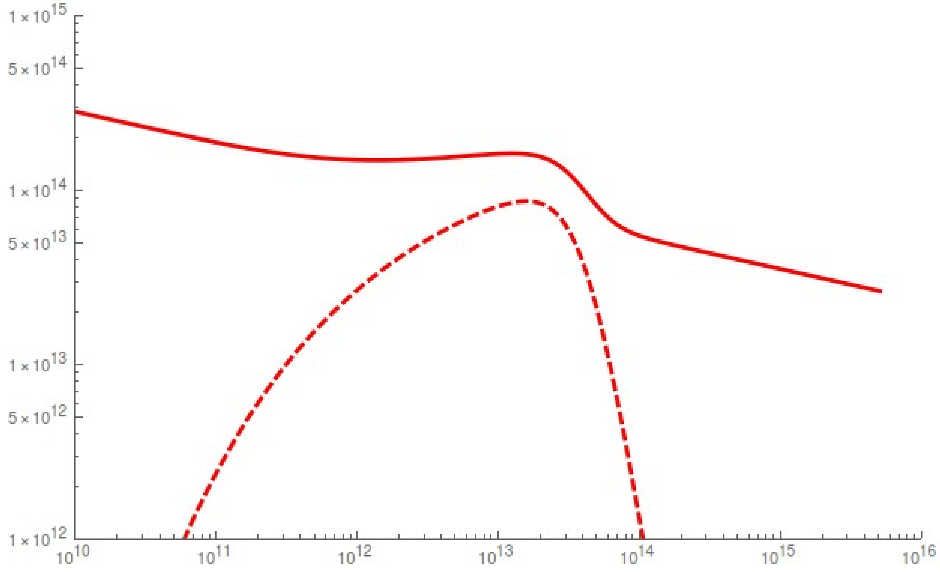
The spectrum of all CR elements in the source has the same shape in terms of rigidity and differs only in the absolute intensity.

Equation describing the evolution of the CL concentration in the diffusion approximation:

$$\frac{\partial N}{\partial t}-\nabla\,(D\nabla\, N)=Q(R,t,r)$$

Where $D\,[R] = D_0\,(R/R_0)^{\delta}$, $D_0 = 4{,}3{*}10^{28}$ cm^2 /s $\delta = 0{,}395$, $R_0 = 4{,}5$ GV

The model signal represents the sum of the background flux and the flux from the source, obtained as a solution to the diffusion equation $F_{summ} = F_{bgr}(R) + F_{star}(R)$



Penalty method

A feature of this work is the simultaneous consideration of a set of existing direct experiments that measure element-by-element spectra and reveal the elemental structure of inhomogeneity and the spectrum of all particles measured by HAWC.
The HAWC experiment has a significantly higher statistical reliability than direct experiments with high systematic errors. To account for this type of data, the penalty method was applied with a two-dimensional correlation function μ = aR + b

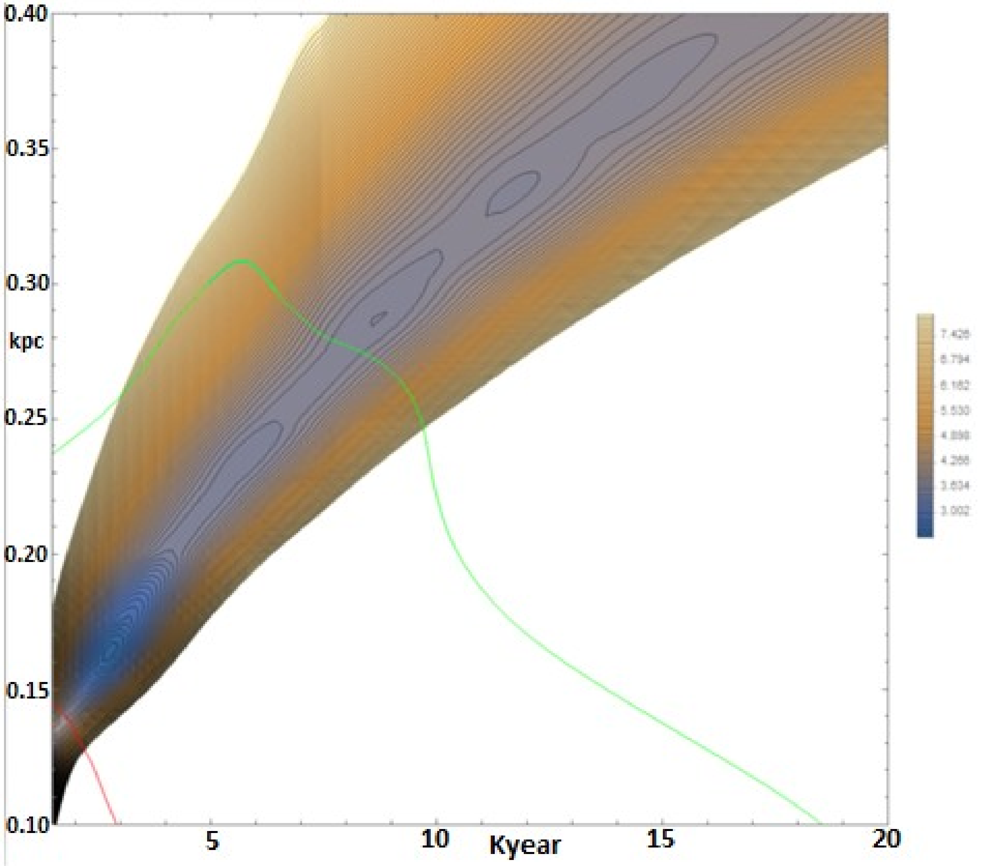
$$\chi^2(\xi,\alpha)=\Sigma_i \frac{\left(F_i\left(1+\Sigma_j \frac{\partial \mu_i}{\partial \alpha_j}\Delta\alpha_j\right)-P_i(\xi)\right)^2}{\delta_i^2\left(1+\Sigma_j \frac{\partial \mu_i}{\partial \alpha_j}\Delta\alpha_j\right)}+\Sigma_i \Sigma_j \Delta\alpha_i \Delta\alpha_j (A_s)_{ij}^{-1}$$

$$A_s=\begin{bmatrix} \sigma 1^2 & \rho\sigma 1 \sigma 2 \\ \rho\sigma 1 \sigma 2 & \sigma 2^2 \end{bmatrix} \quad \sigma_1=\frac{B}{(AB-C^2)} \quad \sigma_2=\frac{A}{(AB-C^2)} \quad \rho=\frac{-C}{AB}$$

where δ-relative systematic error

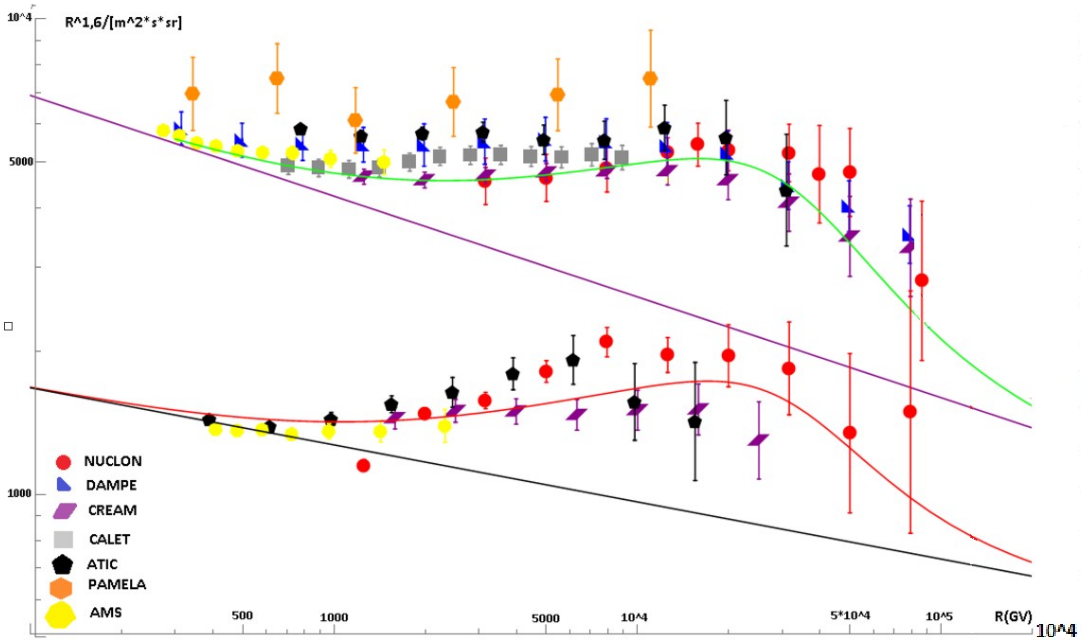
$$A=\sum_i^n \frac{E_i^2}{\sigma_i^2} \quad B=\sum_i^n \frac{1}{\sigma_i^2} \quad C=\sum_i^n \frac{E_i}{\sigma_i^2}$$

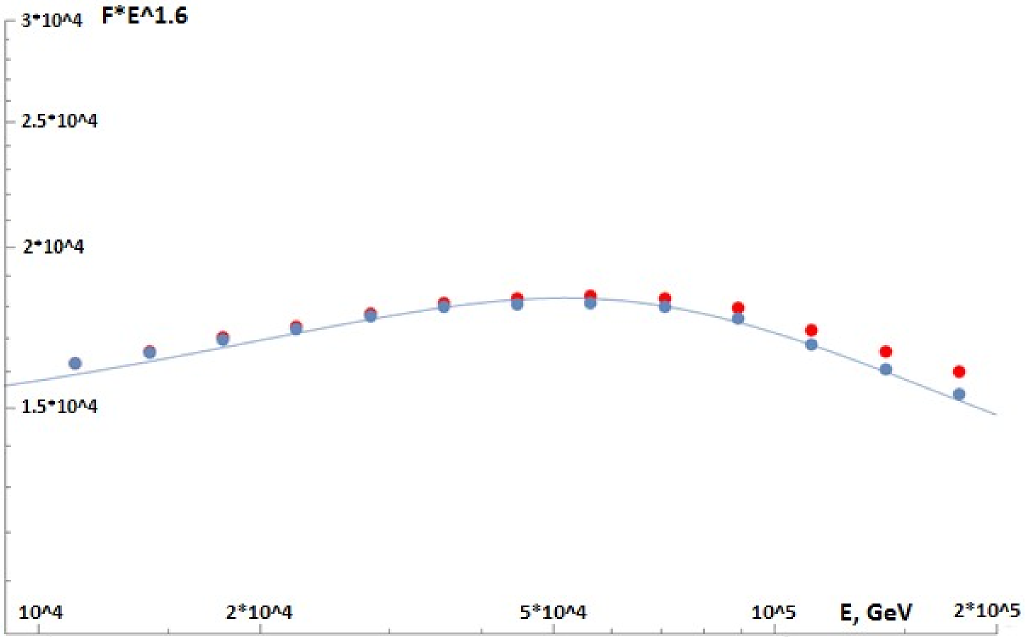
Localization of a hypothetical source in distance-age coordinates, color denoted xi2



red line power limit 10^50 erg
green line power limit 10^51 erg

Best fit experimental data





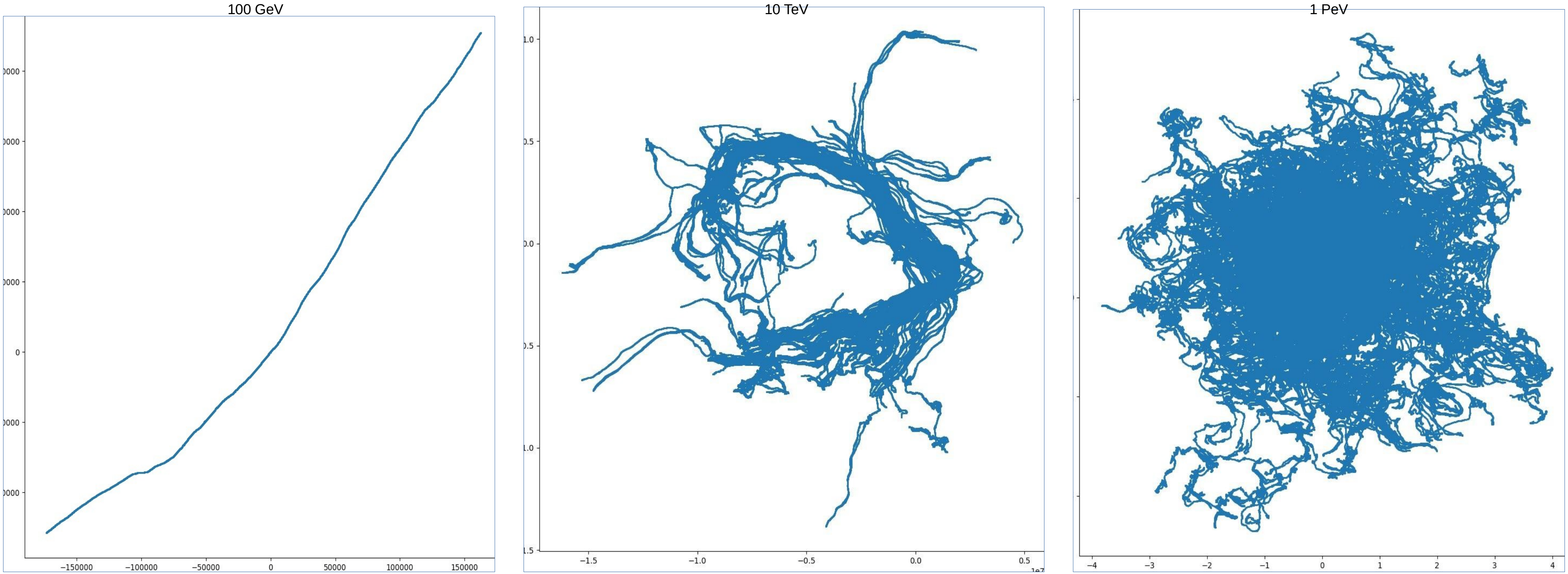
Predictive model of pectra P and He for a source with minimum Xi2 ~ 3 at a distance of 170 parsecs and an age of 4000 years and experimental data

Predictive model of all particle spectra for a source with minimum Xi2 ~ 3 at a distance of 170 parsecs and an age of 4000 years and experimental data.

Red point -HAWC data

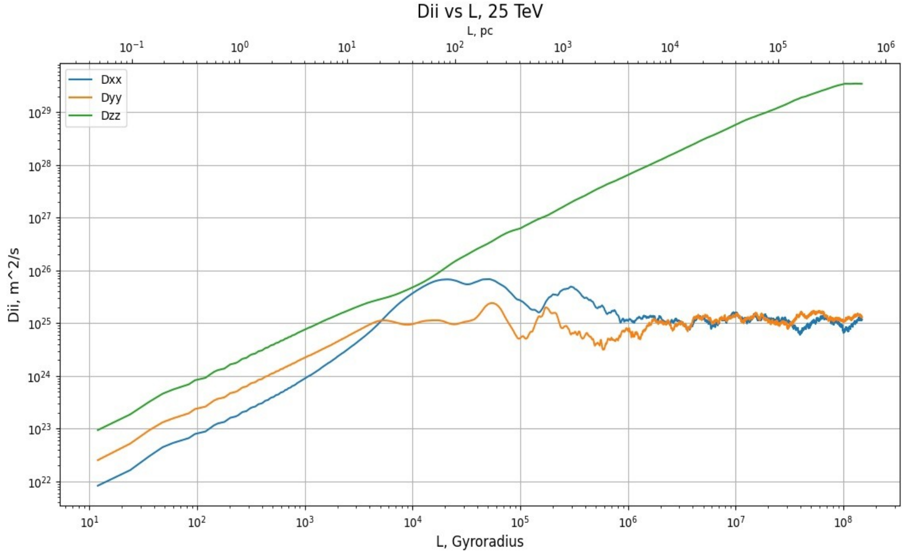
Blue point- HAWC data multiplied by the correlation function

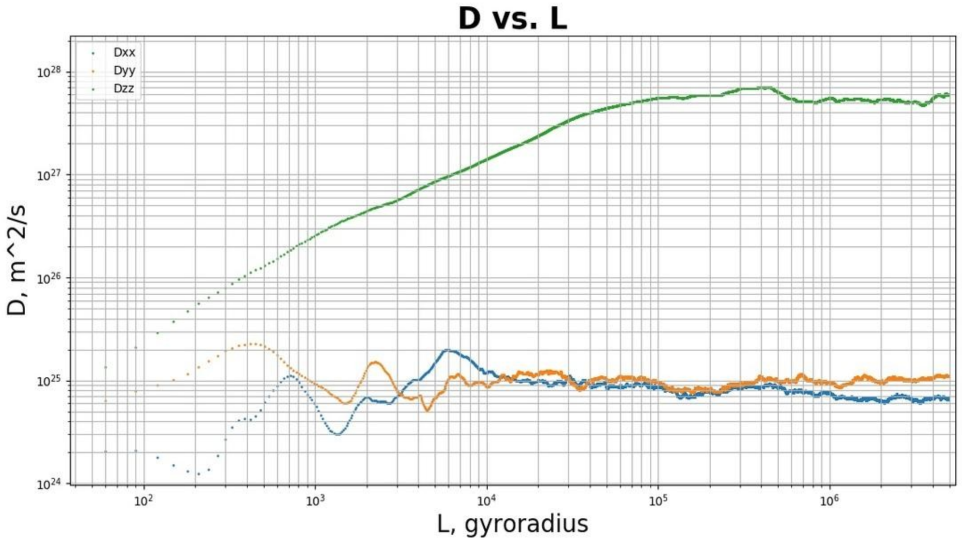
Calculation of particle trajectories in the generated magnetic field



Trajectories of particles with energies of 100 GeV (not to scale), 10 TeV and 1 PeV in turbulent magnetic field Brandom at Bmean =0. From these trajectories it can be seen that for energies below 10 TeV the anisotropy *is determined by the local field*

Calculation of transport coefficients to refine the position of the source and take into account the anisotropy





Diffusion coefficients for protons 25 TeV (left) and 1 PeV(right) as a function of the path L (in gyroradii), calculated in the configuration Brms = 6muG and Bmean = 6muG (directed along the Z axis). Significant anisotropy of transport coefficients is visible, this will be taken into account in the next work. It is also worth paying attention to the fact that the transport coefficient along the regular field behaves in a superdiffusion manner at small ranges, when the transverse transport already demonstrates diffusion behavior.

This feature will be taken into account in future work.

Conclusion

A model of the contribution of a single point source-flash to the background spectrum of CR in the approximation of diffusion without energy losses and fragmentation is proposed to explain the nature of the observed spectral inhomogeneity of CR.

For the first time, the model takes into account the combination of direct experiments that measure the spectra of elements separately and the HAWC experiment that measures the spectrum of all particles. To take into account the data of the ground-based experiment, the penalty method was applied with a two-dimensional correlation function

The model demonstrates reasonable agreement with experimental data at the source energy up to 10^{51} erg, localizes the position of a hypothetical source in the distance-time space in a narrow region of phase space, and also predicts the most likely area of existence of such a hypothetical source at 0.1 – 0.2 kpc and an age of 1 to 5 thousand years.

Transport coefficients were calculated for a wide energy range (25 TeV-10PeV) in a realistic magnetic field with configuration regular field 6 μG + 6 μG random field distributed over the Kolmogorov spectrum in the range from 100 astronomical units to 100 parsecs. Significant anisotropy of diffusion coefficients is shown

It should be noted that the optimal source is obtained quite young, so the approximation of the source-flash for its description is not very accurate, and given that the isotropic diffusion for these energies is a very rough approximation, the presented results should be considered preliminary, and in the subsequent work we assume to take into account the anisotropy of the diffusion tensor and the evolution of the supernova remnant at the Sedov-Taylor stage. Thus, it is demonstrated that the explanation of the observed spectral inhomogeneity of the CR near 10 TV in terms of magnetic rigidity by the contribution of a single remnant of a close supernova to the observed cosmic ray fluxes is possible.