Modeling a Kolmogorov-Type Magnetic Field in the Galaxy and its Effect on an Extragalactic Isotropic Flux of Ultra High Energy Cosmic Rays

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Abstract. A model of turbulent galactic magnetic fields was developed in which, the type of turbulence were considered to be Kolmogorov. We tested the effect of this model on an isotropically distributed flux of ultra high energy cosmic ray in the extragalactic space. To do this, a giant Galactic halo (radius of $\sim 100\text{ Mpc}$) was considered. Regular and random components of the Galactic Magnetic Fields were considered to have the mean observed relevant values and also satisfy a Kolmogorov field type. The deviation from isotropy then were calculated considering the propagation of ultra high energy protons in such a magnetic field and results were discussed to show how isotropic is the flux of ultra high energy cosmic rays in the extragalactic space. It is seen that considering an isotropic flux of ultra high energy cosmic rays in the intergalactic space for different choices of galactic magnetic field is not consistence with the distribution of observed ultra high energy events.

1. Introduction

The strength of Galactic and Extragalactic Magnetic Fields (GMF and EGMF) are possible to be estimated considering different observational techniques. In fact, most of our knowledge about magnetic fields in the outer space is obtained through studying different interactions between matter, waves and magnetic fields within the stellar atmospheres and in Interstellar (IS) and Intergalactic (IG) spaces. Extensive works were done to map [1] the magnetic fields of galaxies and also modeling their fields theoretically or numerically.

Where, physical processes such as Zeeman effect [2] are mostly used to study MFs within the galaxies, on the stellar atmosphere and in more dense regions of the Galaxy; Faradey Rotation (FR) [3] is widely used to evaluate mean values of MF strengths along the line of sight and is applicable both in the IS and IG spaces with low matter densities. In 1951, it was suggested that the gas in Orion nebula was turbulent with a Kolmogorov regime [4], but this suggestion later was challenged by other theories which essentially questioned the existence of a pervasive turbulence in the ISM [5]. Up to 1980s, many physical processes and observations were discussed considering a uniform ISM (for a good review see [6]) and the turbulence was more usually accepted at small scales. In 1980s experimental evidences were in the favor of large scale turbulence and compression from interstellar turbulence was considered as one of the main mechanisms of cloud-formation [7].
In a special case, MF models are important at large distances when an Ultra High Energy Charged Particle (UHECP) travels to the Earth from its source. But, considering a top-down model to discuss about the origin of Ultra High Energy Cosmic Rays (UHECR), no special direction is possible to be considered for their sources. To examine this assumption, we studied a case of isotropically distributed flux of UHECR in IG space. We considered our Galaxy to be a point in the universe, as always it is assumed in cosmology. In a top-down model, an observer on this point measures the same flux of UHECR in all directions and also measure the same flux when moving on a sphere which we consider to be our Galaxy. The main question is that: how isotropic is the observed flux of UHECR inside this sphere?

2. Model of Galactic Magnetic Field

We have used a previously developed model [8, 9, 10], considering a Kolmogorov turbulent regime. The Galaxy considered to be consisted of a giant halo with a radius of 100 Mpc and the thickness of disk were considered to be 0.3 kpc with the radius of 30 kpc. For the GMF in disk, we used the model of Rand and Kulkarini [11] (Model A). Out of the disk, the regular component were considered to have a bipolar structure. To compare with other results we considered the regular component of GMF from model of Harari, Mollerach and Roulet [12] (Model B). The same Galactic dimensions were applied for model B.

We considered cells of orders of 100pc in halo and 50pc in Galactic disk [13] to define the turbulent Kolmogorov regime. For both cases the random components were considered to have the strength of 3µG in Halo and 1µG in Galactic disk.

3. Isotropy v.s. Anisotropy

To study the effect of GMF on the anisotropy of the observed UHE events, we assumed a sphere with the radios of 100Mpc (i.e our Galaxy). We studied the deviation from isotropy using:

\[ \delta(\alpha, \delta)_i = \frac{N(\alpha, \delta)_i - \langle N \rangle(\alpha, \delta)_i}{\langle N \rangle(\alpha, \delta)_i}, \]

in which, \((\alpha, \delta)_i\) stands for the Galactic right ascension and declination of each bin on a sphere of radios of 100 Mpc. An initially isotropic flux of UHCR were considered to enter this sphere. We considered 100 protons enter along the radius of this sphere (i.e Galaxy) on each bin. The number of bins were considered 180×360. So the value of \(\langle N \rangle(\alpha, \delta)_i\) were considered to be 100 for each bin. The new \((\alpha, \delta)_i\), of each event then were calculated considering the propagation of each UHECR in the Galaxy and obtaining the value of its deflection angle after traveling 100 Mpc. To do this we did 6480000 run and an output of 6480000 of new \((\alpha, \delta)_i\) were produced.

At this stage we counted the number of events in each Galactic bin (i.e. \((\alpha, \delta)_i\)) and the values of \(N(\alpha, \delta)_i\) were obtained.

Now considering equation 1 it is possible to calculate the deviation from isotropy for each bin of the sky.

4. The Results

We have shown the results for model A in figure 1.

The effect of a bipolar GMF is seen in figure 1. Considering model B the situation is changed. As in model B, GMF has not a bipolar structure out of the disk, the difference of north to south is not obvious like model A (figure 2).

The interesting result is that, considering an extragalactic origin of CR particles, an initially homogeneous and isotropic flux wont be observed isotropic inside the Galaxy. In fact, degrees of clustering maybe observed due to the turbulent behavior of the fields. And this may distorted our studies about the origin of UHECR.
Figure 1. Deviation from Isotropy for EG protons with energies ranged in $10^{18-19}$. The region of Inner Galaxy is mapped in which the deviation is multiplied by 100. Model A of GMF was used.

Figure 2. Deviation from Isotropy for EG protons with energies ranged in $10^{18-19}$. The region of Inner Galaxy is mapped in which the deviation is multiplied by 100. Model B of GMF was used.

Other simulations shows that at higher energies the deviation from isotropy is smaller. Whilst for protons with energies in the range of $10^{18-19}$ eV the assumption of an isotropic extragalactic flux does not seem possible, for protons with energies of $10^{19-20}$ eV this assumption depends on the Galactic magnetic field model, and for particles with energies of $10^{20-21}$ eV the assumption seems possible.

Anyhow, it does not mean that for the highest energies a top-down model is verified but at least one may consider the observed flux is not affected but the Galactic magnetic field.
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