Constrains on the Galactic magnetic field from the two-dimensional correlation function of AGASA events

Gustavo Medina Tanco,[1] Masahiro Teshima,[2] and Masahiro Takeda[3]
(1) Instituto Astronomico e Geofisico, Univ. of Sao Paulo, CEP 05508-900, Brazil
(2)Max-Planck-Institute for Physics, Foeringer Ring 6, 80805 Munchen, Germany
(3) The Institute of Physical and Chemical Research, Saitama 351-0198, Japan

Abstract

AGASA has recently shown the results of a two-dimensional correlation analysis in Galactic coordinates of the arrival directions of CR events above 10^{19} eV. This analysis shows an interesting signature in the form of a linear correlation between galactic latitude and longitude difference for pairs of events at small angle separations ($< 10^o$). The linear feature is significant up to the 3 σ level and is present at several energy bins above 10^{19} eV, preserving a constant inclination in the $\Delta l - \Delta b$ plane over that energy range. This feature can be interpreted as the result of the coherent deflection of UHECR over the observed sky by a large scale Galactic halo and disk magnetic field. This result may have important implications for the identity of the UHECR particles as well as for the nature their sources and spatial distribution inside the GZK sphere. The structure and intensity of the Galactic magnetic field, in particular, can be constrained from these observations. In the present work, we depict a galactic magnetic field consistent with this scenario and make predictions for the Auger Observatory observing the Southern sky.

1. Introduction

The analysis of the AGASA data above 10^{19} eV suggests the presence of two kinds of clustering.

First, the data set above 4×10^{19} eV, with 59 events, contains the well known five pairs and one triplet with maximum separation of 2.5^o, the expected angular resolution of the experiment times $\sqrt{2}$ [1]. The significance of this clusters is confirmed by the application of self correlation analysis (introduced by [2]).

The AGASA collaboration has also extended this kind of analysis to two dimensions [3]. The difference of arrival directions in galactic coordinates were calculated for every pair of events in the data sample, and vector density maps were constructed in the Δl - Δb plane. A tilted linear pattern is obtained, showing clustering of events on a preferential orientation for a wide area of sky. The

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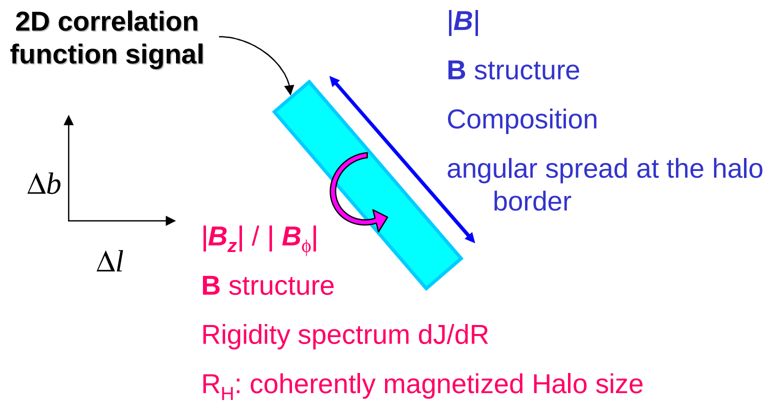

Fig. 1. Schematic representation of the information encoded in the 2D correlation function signal.

clustering extends to scales of approximately 5^o, i.e, larger than the AGASA resolution scale. The pattern appears at energies above 10^{19} eV, and is also present at several individual energy bins of 0.1 dex.

The latter clustering is physically highly significant due to its richness of clues about the nature of the UHECR and the structure of the galactic and intergalactic magnetic fields (see figure 1). A consistent picture is difficult to obtain unless one assumes that the linear feature in the two dimensional correlation function is the result of: (a) charged UHECR particles, (b) a large scale regular component of the magnetic field extending through the Galactic plane and halo, (c) the existence of at least a few relatively nearby point sources of UHECR and (d) a relatively low intergalactic magnetic field between those nearby sources and the border of the Galactic halo.

Points (a) and (b) are necessary to produce a differential bending of particle trajectories as a function of rigidity. Point (b) is also necessary to produced this bending on a regular way over a large fraction of the sky as consider by the AGASA group in its analysis ($90 < l < 180^o$ and $-60 < b < 60^o$)). Point (c), is necessary because pairs of aligned particles responsible for the linear excess in the correlation function at Earth must have pointed to almost the same direction of the sky at their arrival to the border of the magnetized Galactic halo. It is likely that groups of several particles per point source impinge the halo. Furthermore, in order to preserve the statistical significance of the observed signal, particles of different energies originated in the same source must arrive with very small deflections among them, $\sim 1^o$, which justifies statements (c) and (d).

An exciting possibility is that, taking the previous scenario as a working hypothesis, the correlation between arrival directions of UHECR can be used to constrain the large scale regular component of the Galactic magnetic field.

Alvarez-Muñiz et al. [6] have also analyzed UHECR source scenarios in relation to this signal.

2. Implications for the galactic magnetic field

Although the grand design of the magnetic field of external galaxies is rather easy to observe [4,5], the Galactic magnetic field structure is not clear due to our location inside the system.

Nevertheless, despite previous claims in support of ring and axi-symmetric (ASS) models, evidence seems to be accumulating in favor of the existence of a thin disk with bi-symmetric (BSS) structure with possibly several inversions. This is somewhat unexpected, since inversions are almost never observed in external galaxies, and simple dynamo models tend to grow faster axi-symmetric modes. Therefore, reversals could be relics of a chaotic seed field. Based on rotation measurements of a large database of southern pulsars Han [7] has recently argued in favor of the existence of a thick disk, or halo, toroidal component enveloping the thin disk with odd symmetry with respect to the galactic plane and without inversions, superimposed with a poloidal component pointing Northward in the solar vicinity. This features are consistent with the signature of an A0 dynamo acting in the halo.

We have performed orbit integrations of charged nuclei testing several topologies for the galactic magnetic field, including full (that is extending from the Galactic disk into the Halo) axi-symmetric and bi-symmetric structures and also the combination of a thin bi-symmetric disk field with a larger scale A0 dynamo component.

The same number of particles as in the AGASA sample above 10^{19} eV were tracked through the Galactic field between the halo border and the detector. The sample was divided in two sub-samples, an isotropic background and a varying number of extragalactic point sources with different multiplicities.

The two dimensional correlation function was reconstructed for every trial searching for a match with AGASA's.

Good fits can be achieved for two different models: (a)A bi-symmetric disk component with even symmetry with respect to the Galactic plane, decaying exponentially over the plane up to a galactocentric distance of 20 kpc, vertical scale hights $z_1 = 300$ pc and $z_2 = 4$ kpc, plus a dipolar component pointing towards the South Galactic Pole at the solar circle and with an intensity of 0.3 μG. (b) A bi-symmetric model as in case (a)but constrained to a thin disk (half-thickness ~ 100 pc), immersed in a thick disk-halo axi-symmetric field with odd symmetry with respect to the Galactic plane, extending also up to a galactocentric distance of ~ 20 kpc and a dipolar component with amplitude of 0.3 μG pointing towards the North Galactic Pole at the solar circle. Model (b) is consistent with the GMF suggested by Han [7] based on rotation measurements of pulsars and

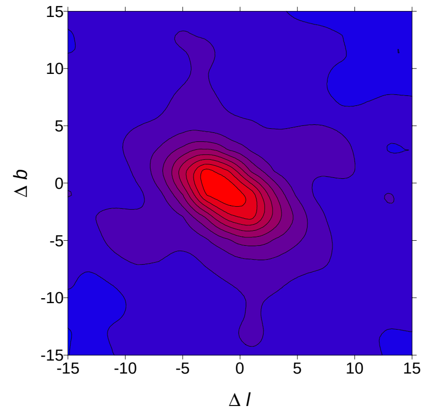

Fig. 2. 2D correlation function signal for GMF model (a).

extragalactic sources.

3. Conclusions

The 2D correlation function observed by AGASA can be well explained assuming protons propagating through the currently most plausible galactic magnetic field scenario, as suggested by rotation measure observation of pulsars and extragalactic radio sources. This also implies the presence of few point nearby sources, and severely restricts the intensity of the intergalactic magnetic field in the immediate vicinity of our Galaxy.

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4. References

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