A preliminary study on the effect of the latitude on the measurement of the UHECR spectrum

RITA C. ANJOS¹, VITOR DE SOUZA¹

¹Instituto de Física de São Carlos, Universidade de São Paulo, São Carlos, Brazil.
rita@ursa.ifsc.usp.br, vitor@ifsc.usp.br

Abstract: Recent high precision measurements of the Ultra High Energy Cosmic-ray spectrum have been done by the Hires, Pierre Auger and Telescope Array Observatories. The agreement between the published spectra is remarkably good despite the possibility that each experiment is exposed to a different source population. If the highest energetic particles are not all heavy and if the magnetic field strength is not extreme quasi-linear propagation of particles from source to Earth is a reasonable assumption. In this work we evaluate the effect of different source population visible from different latitudes in the measured energy spectra. We simulated the propagation of particles in the Universe given a chosen composition and source distribution and studied the energy spectrum arriving on Earth.

Keywords: ultra high energy cosmic rays, spectrum, latitude effect.

1 Introduction

Ultra high energy cosmic rays consist of relativistic charged particles with energies above 10¹⁸ eV. They propagate through the universe and are deflected by magnetic fields. Moreover they lose energy interacting with radiation fields, like cosmic microwave background (CMB) and infrared radiation (IR) [1].

Regarding the spectrum measurement the experiments on Earth can be described by an exposure function [2] which reflects the efficiency of the detector. The relative exposition is a function of the latitude of the detector array (λ) and the source declination (δ). There are observed differences in the flux of UHECR spectrum from the recent observations [3, 5, 6]. It has been shown that the differences in flux can be explained by energy shifts within the estimated systematic uncertainty of each experiment [6].

We investigate in this paper the possible contribution of latitude of the experiment in the measurement of the spectrum. Given a source distribution, each latitude on Earth offers an unique observational time. As an example, we used the catalogue of quasars and active galactic nuclei from Veron-Cetty&Veron [8]. We propagated protons and iron nuclei from the source in this catalogue to Earth and calculated the corresponding measured energy spectrum for several latitudes on Earth.

2 Simulations

The propagation of the particles from the sources to Earth were done using the CRPropa (v. 2.0) program [3]. CRPropa is one of the most complete public software to model the propagation of nuclei in the extragalactic media considering the most relevant particle interactions and radiation backgrounds. We have considered an emission power law spectrum dn/dE ∝ E⁻α, with α = 2.4, Emin = 10¹⁸ eV and Emax = 10²¹ eV. For each source 50,000 particles were simulated. The particles were propagated in one dimension and energy losses were considered [10].

The Veron-Cetty&Veron Catalogue has 1857 sources with redshift z < 0.05. As a example, figure 1 in Hammer-Aitoff projection in Galactic coordinates show the sources that can be observed at latitudes ± 25º.

2.1 Exposure function

The exposure of the observatory to the sources is a function of the latitude. A detector at latitude λ has continuous operation with constant exposure in right ascension. We consider that the observatory as 100% efficiency for zenith angles smaller than 60º. If the latitude is fixed, the exposure is only a function of declination (δ) [2]:

ω(δ) = \frac{1}{π} [\sin α_m \cos λ \cos δ + α_m \sin λ \sin δ], \quad (1)

where λ is the latitude of the detector array, θmax is the zenith angle cut and

α_m = \begin{cases} 0, & \text{for } \xi > 1 \\ \pi, & \text{for } \xi < -1 \\ \cos^{-1} \xi, & \text{otherwise} \end{cases} \quad (2)

with

ξ = \frac{\cos θ_{max} - \sin \lambda \sin δ}{\cos \lambda \cos δ}. \quad (3)

Table 1 shows the values of λ and θmax chosen.

<table>
<thead>
<tr>
<th>Latitude North (λ°)</th>
<th>Latitude South (−λ°)</th>
<th>θmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>-25</td>
<td>60</td>
</tr>
<tr>
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<td>-35</td>
<td>60</td>
</tr>
<tr>
<td>45</td>
<td>-45</td>
<td>60</td>
</tr>
<tr>
<td>55</td>
<td>-55</td>
<td>60</td>
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</tbody>
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Table 1: Values of λ and θmax.
**Figure 1:** Hammer-Aitoff projection in Galactic coordinates. Left: AGNs from North with latitude $\lambda = 25^\circ$. Right: AGNs from South with latitude $\lambda = -25^\circ$.

**Figure 2:** Histograms of number of sources multiply by theirs weights versus distance. Left: Northern Latitudes. Right: Southern Latitudes.

**Figure 3:** Propagated spectra obtained assuming a AGNs at latitude $\pm 25$ and $\gamma = 2.4$. Left: Iron with $E_{\text{max}} = 26.10^{21}$ eV Right: Proton with $E_{\text{max}} = 10^{21}$ eV.
Figure 4: Propagated spectra obtained assuming a AGNs at latitude ± 35 and γ = 2.4. Left: Iron with $E_{\text{max}} = 26.10^{21}$ eV Right: Proton with $E_{\text{max}} = 10^{21}$ eV.

Figure 5: Propagated spectra obtained assuming a AGNs at latitude ± 45 and γ = 2.4. Left: Iron with $E_{\text{max}} = 26.10^{21}$ eV Right: Proton with $E_{\text{max}} = 10^{21}$ eV.

Figure 6: Propagated spectra obtained assuming a AGNs at latitude ± 55 and γ = 2.4. Left: Iron with $E_{\text{max}} = 26.10^{21}$ eV Right: Proton with $E_{\text{max}} = 10^{21}$ eV.
3 Results

Figures 2 show the distribution of distances for all sources in the used catalogue. The distance was weighted by the exposure of the considered latitude. It is clear that closer to the equator the main contribution in the total measured flux is from distance source. For an observatory closer to the poles, the contribution of nearby sources is almost as important as the distance ones.

The propagated energy spectra considering the exposure of each latitude are presented in figures 3-6. The propagated spectra were obtained assuming pure proton and pure iron source compositions.

Figures 3-6 show clearly the difference between propagation from North and South for proton and iron composition. This difference grows with the increase of latitude. This happens because the number of AGNs observed by South and North at the same time decrease.

4 Conclusions

In conclusion, we have reported a preliminary study on the latitude influence on the measured flux of UHECR. We shown that for a given source distribution the absolute flux measured depends on the latitude of the experiment.

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References