The Effect of Compton-Getting Correction on Galactic Cosmic Rays Anisotropy

G. Adagba[1], J. Augustine[2], B.G Ayantunji[3]

[1]Department of Physics, Benue State University, P.M.B 102119, Makurdi, Benue State, Nigeria

[2]Department of Chemistry, Benue State University, P.M.B 102119, Makurdi, Benue State, Nigeria

[3]National Space Research and Development Agency, Abuja
Corresponding author: *domgrace1[at]gmail.com*

Abstract: ***The relative motion of the solar system through the local plasma frame can introduce a dipole anisotropy also known as Compton-Getting (CG) effect. This effect can alter galactic cosmic ray (GCR) anisotropy data if not corrected. Here, CG anisotropy was modeled using a theoretical approach while data from the research team at Cosmic Rays Observatory in (IZMIRAN Moscow), Russia was used to test the mini model. Our results showed that GCR anisotropy modeled with CG demonstrated a strong spurious anisotropy in Geocentric Solar Ecliptic (GSE) coordinate rotating with the Earth particularly, the equatorial anisotropy. The result showed that, the decrease is mostly affected in the x and y direction because their amplitude was affected most. And the recovery time was longer in the x axis after the decrease. The amplitude of the uncorrected GCR anisotropies were higher and after CG was removed, the amplitude became lower and smoother. Our results also showed that GCR anisotropy modeled with CG inclusive showed higher magnitudes in the GSE coordinate rotating with the Earth particularly, the equatorial anisotropy. The results with CG correction do not exhibit this feature. Our conclusion is that GCR anisotropy data should be corrected for CG effects before using in analysis.***

Keywords: cosmic rays, Compton-Getting, anisotropy, solar system, sun

1. Introduction

Galactic cosmic rays (GCRs) measured on Earth are known to be modulated in the heliosphere by an expanding solar wind (Ihongo and Wang 2016). Modulation of GCRs is governed by the convection of solar wind, inward diffusion of GCRs on the irregularities of heliospheric magnetic field (HMF), drift on the regular HMF and adiabatic cooling of GCRs particles due to extension of SW. GCRs intensity detected near Earth contains the various long- and short-term quasi-periodic variations (Gabici, 2012; Kudela and Sabbah, 2016; Chowdhury et. al, 2016; Bazilevskaya et al., 2014; Ihongo and Wang 2016and Modzelewska et. al. 2019). These variations are referred as “anisotropies’’

The anisotropy of GCRs has also been investigated by several authors. For example, Cane (2000)observed that, CMEs cause depressions in the cosmic ray intensity both locally, when an observer is inside the interplanetary structure (ejecta) and remotely, if the ejecta is energetic enough to create an interplanetary shock to which the observer is magnetically connected. After the shock and ejecta have passed, the intensity gradually recovers as particles diffuse in around the shock. Also, in their studies; Tortermpun et. al. (2018), developed a technique to determine the Galactic cosmic ray anisotropy during a Forbush decrease using data from worldwide network of neutron monitors for a single event.

Ihongo et al. (2019), also modeled GCR anisotropy using a technique initially developed by Tortermpun, *et al.* (2018), alongside normalized count rates from NM stations. Their results revealed an anti-correlation between $\delta_{\parallel}$and $\delta_{\perp}$. They showed that, there is often an increase in the perpendicular anisotropy ($\delta_{\perp}$) at times with stronger fluctuation in $\Delta B_{rms.}$

However, it wasn’t clear whether the aforementioned models accounted for Compton-Getting factor. Thus; this study aims at calculating the effect of Compton-Getting factor and testing the mini-model with data.

2. Rationale and Methodology

The anisotropy of cosmic ray fluxis given by (Ihongo, *et al* 2019);

$$\delta = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad (1.1)$$

where I_{max} and I_{min} are the maximum and minimum observed cosmic ray intensities respectively.

Also, the Earth’s frame anisotropy is defined as;

$$\xi = \delta + \chi \quad (1.2)$$

where ξ is Earth frame anisotropy, χ is Compton – Getting anisotropy and δ is the First order anisotropy.

Thus, the first order anisotropy is given as,

$$\delta = \xi - \chi\,(P) \quad (1.3)$$

So, the first order anisotropy values were obtained directly from the research team at IZMIRAN, Russia for the April, 2013 Forbush Decrease event.

The Compton – Getting Anisotropy is defined as (Ihongo, *et al* 2019)

$$\chi(P) = -\gamma\,(P)\frac{u}{v} \quad (1.4)$$

Licensed Under Creative Commons Attribution CC BY

where u is the solar wind velocity relative to an observer and v is the particle speed which is equal tothe speed of light (c)

$$\gamma(P) = \frac{d \log (f)}{d \log (P)} \qquad (1.5)$$

f is phase density of the particles and P is the particle's rigidityThus γ (P) is evaluated from

$$f \propto \frac{\Phi}{(vp^2)} \qquad (1.6)$$

where Φ is the differential rigidity spectrum of cosmic ray protons. For the purpose of this work, Φ is taken from Aguilar et al. (2015).Where v is the velocity of the particles and p is the momentum of the particles.

Consequently, Compton-Getting anisotropy was calculated using equation (1.4). The difference between anisotropy in the earth's frame and Compton-Getting anisotropy was also evaluated from equation (1.3) MATLAB 2018 version was used to implement the analysis and the results obtained from our analysisis presented in section 3.

3. Results and Discussion

3.1 Results

The results presented here shows anisotropy calculated with Compton-Getting factor inclusive (figure 1a) and anisotropy calculated with Compton-Getting factor removed (figure 1b).

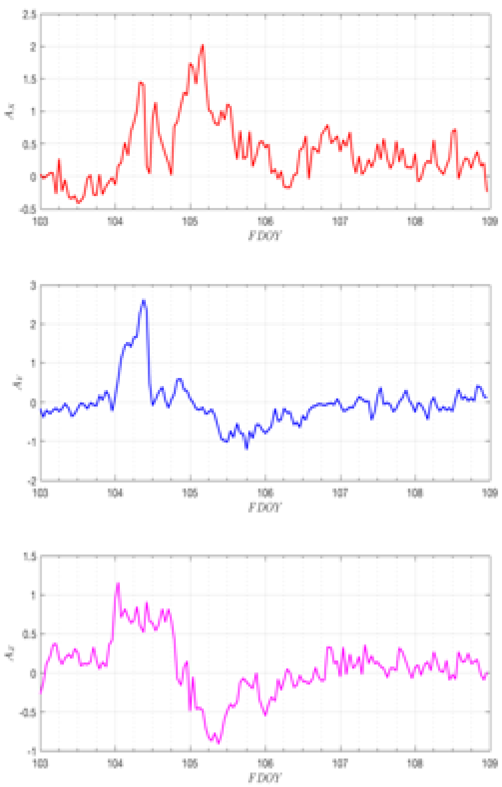

Figure 1 A: Anisotropies with CG inclusive

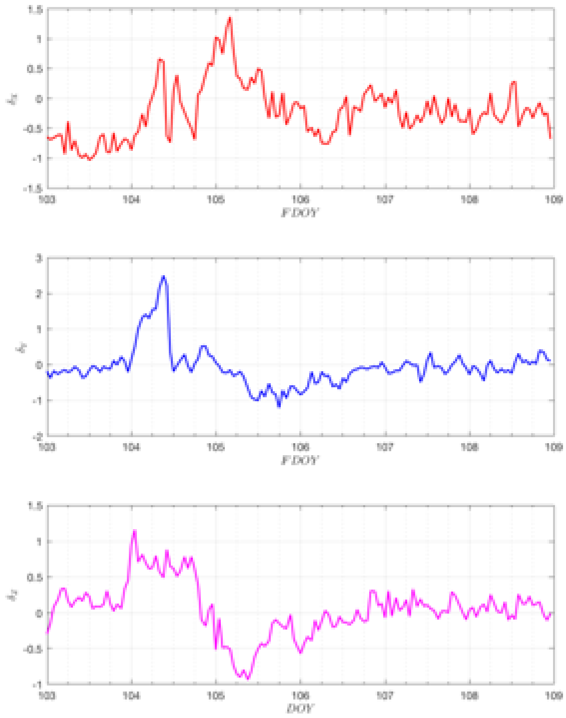

Figure 1b: Anisotropies with CG removed

3.2 Discussions

Variations in the distribution of Galactic cosmic rays (GCRs) can provide useful information on the properties of the solar wind plasma and interplanetary magnetic field (IMF) that complement in situ measurements (Tortermpun et. al 2018, Ihongo et al. 2019). Deviations from isotropy have been a key tool to identify the origin of the primary type of cosmic rays at low energies. It is suggested that Compton–Getting effect can play a similar role at ultra-high energies: If at these energies the cosmic ray flux is dominated by sources at cosmological distances, then the movement of the Sun relative to the cosmic microwave background frame induces a dipole anisotropy at the 0.6% level (KachelrieB M. and Serpico P.D. 2006).

Consequently, the anisotropic part of GCRs flux, reflected in the solar diurnal variation (≈24 hours wave) can be influenced by Compton-Getting effect if not corrected. For example, figure (1a), shows GCR anisotropy calculated with CG factor inclusive. Our result shows a clear increase in the anisotropy magnitude of about 0.6% in the x-axis in line with (KachelrieB M. and Serpico P.D. 2006), while there is a corresponding decrease of 0.6% in magnitude in the x-axis for case where the Compton-Getting factor was removed figure (1a). This trend is mostly observed in the x and y direction because their amplitudes were affected most.

The sharp curve in the y-axis may suggest that the IZMIRAN anisotropy data were not corrected for Compton-Getting effects. This is evident in figure (1a) where the amplitude of the uncorrected GCR anisotropies were higher in figure (1a) and after CG was removed, the amplitude became lower and smoother in figure (1b). Our results also show that GCR anisotropy modeled with CG inclusive showed higher magnitudes in the Geocentric Solar Ecliptic (GSE) coordinate rotating with the Earth particularly, the

Licensed Under Creative Commons Attribution CC BY

equatorial anisotropy. The GSE system has its X-axis pointing from the Earth toward the Sun and its Y-axis is chosen to be in the ecliptic plane pointing towards dusk (thus opposing planetary motion).

However, it is observed that the anisotropies in the z-axis appears to be unaffected. This may be due to the fact that perpendicular diffusion in the upstream region reduces the effect of Compton-Getting anisotropy because there are in opposite direction (Ming Zhang, 2005).

In summary, Galactic Cosmic Ray anisotropy calculated with Compton-Getting effect inclusive can influence the magnitude of the anisotropies as seen from the results.

4. Summary

The relative motion of the solar system through the local plasma frame can introduce a dipole anisotropy also known as Compton-Getting (CG) effect. This effect can alter galactic cosmic ray (GCR) anisotropy data if not corrected. Our conclusion is that GCR anisotropy should be corrected for CG effects before been used in analysis.

References

[1] Bazilevskaya, G., Broomhall, A.M., Elsworth, Y., Nakariakov, V.M. 2014, A combined analysis of the observational aspects of the quasi-biennial oscillation in solar magnetic activity. Space Sci. Rev.186 (1–4), 359
[2] Cane H. (2000) Coronal Mass Ejections and Forbush Decreases. Space Science Reviews 93: 55-77, 2000.
[3] Chowdhury, P., Kudela, K., Moon, Y.J.: 2016, A study of heliospheric modulation and periodicities of galactic cosmic rays during Cycle 24. Solar Phys.291 (2), 581
[4] Gabici, S. (2012) "Gamma Ray Astronomy and the Origin of Galactic Cosmic Rays". Laboratoire Astro Particule et Cosmologie (APC) – Paris, France.
[5] Ihongo, G.D., Wang, C.HT. The effects of solar wind on galactic cosmic ray flux at Earth. Astrophys Space Sci 361, 44 (2016). https://doi.org/10.1007/s10509-015-2628-5
[6] Ihongo, G. D., Ruffolo, D., Sáiz, A., Tortermpun, U., Bieber, J. W., & Chian, A. C.-L. (2019). Galactic Cosmic-Ray Anisotropy during Forbush Decreases: Evidence for Diffusive Barriers and Large-Scale Flow. Proceedings of Science (ICRC 2019). Vol. 1084 pp 1-7.
[7] Kachelrie B M. and Serpico P.D. 2006 ''The Compton–Getting effect on ultra-high energy cosmic rays of cosmological origin'' Physics Letters B 640 (5-6); 225-226
[8] Kudela, K., Sabbah, I. 2016, Quasi-periodic variations of low energy cosmic rays. Sci. China, Technol. Sci.59 (4), 547
[9] Ming Zhang, 2005. The compton-getting effect of energetic particles with an anisotropic pitch-angle distribution: an application to voyager 1 results at ~85 AU'' The Astrophysical Journal, 624:1038–1048.
[10] Modzelewska, R., Iskra, K., Wozniak, W. et al. (2019). Features of the Galactic Cosmic Ray Anisotropy in Solar Cycle 24 and Solar Minima 23/24 and 24/25. Sol Phys 294, 148
[11] Tortermpun, U., Ruffolo, D. & Bieber, J. W. (2018). Galactic Cosmic-Ray Anisotropy During the Forbush Decrease Starting 2013 April 13. The Astrophysical Journal Letters. Vol. 852 pp. L26.

Licensed Under Creative Commons Attribution CC BY