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New Flux Upper Limits of Diffuse TeV Gamma Rays from the Galactic Plane Observed with the Tibet Air Shower Array

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The flux upper limits of the diffuse gamma rays, from the inner and outer Galactic planes, are found to be decreased by factors of 4.0∼3.6 for 3∼10 TeV, respectively, by using the simulation results of effective area ratios for gamma-ray and cosmic-ray induced showers in the Tibet air shower array. In our previous work, the flux upper limits were deduced only from the flux ratio of air showers generated by gamma rays versus cosmic rays. As a result the source electron spectral index for inverse Compton should be steeper than 2.2 and 2.1 for the inner and outer Galactic planes, respectively.

1. Introduction

Diffuse gamma rays in MeV∼GeV region from the inner Galactic (IG) and outer Galactic (OG) planes observed by EGRET [1] show a sharp ridge both along the IG and OG planes. The EGRET flux is about 3 times higher than *COS B* data [2] in several GeV, although the flux is consistent with the conventional calculation [3] in $E \leq 1$ GeV. The EGRET excess above 1 GeV has been tried to explain by some models; a hard source electron spectrum of index β=2.0 by Pohl & Esposito (1998) [4], hard proton spectra by Mori [5] and Webber (1999) [6], and an additional secondary electrons and positrons raising from the cosmic-ray collisions with ISM by Strong et al. (2004) [7].
In higher energy region theoretical calculations have been given by Porter & Protheroe (1997) [8] and Tateyama & Nishimura (2001) [9] for the inverse Compton (IC) gamma rays, and by Berezinsky et al. (1993) [10] for $\pi^0 \rightarrow 2\gamma$ process through cosmic-ray interaction with ISM. The most experimental data in higher energy region gave only flux upper limits except the data by Milagro [11] at 1 TeV. Not only the absolute flux but also the flux upper limit are both important for restriction of theoretical models. In this paper, using the difference of detection area of the Tibet array between gamma rays and galactic cosmic rays, we revised and made low the flux upper limits in our previous paper [12].

2. Simulation of effective areas for gamma rays and cosmic rays

Shower size of primary gamma induced showers is about three times larger than galactic cosmic-ray induced ones in average at the depth of 606 g cm^{-2} of the Tibet array for multi-TeV energy region. Hence, the effective area of the array is larger to gamma rays than cosmic rays. The simulation results of the effective area of the

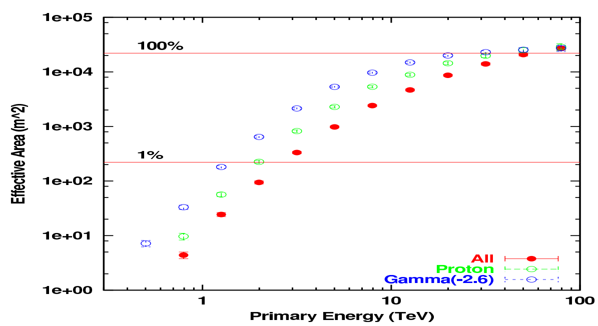

Figure 1. Effective areas of the Tibet III for primary gamma rays, protons and cosmic rays from the IG plane.

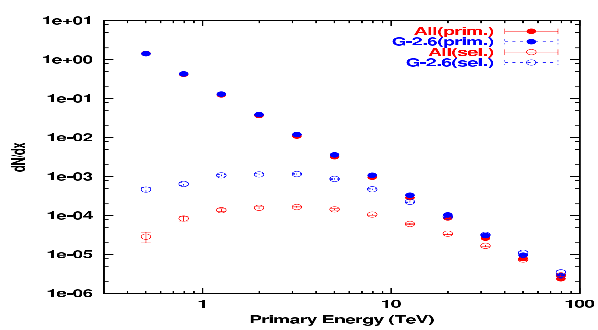

Figure 2. Distribution of triggered events for cosmic rays and gamma rays with β=2.6 from the IG plane.

Tibet III array is shown in Figure 1 for primary gamma rays, protons and cosmic rays from the direction of the IG plane. In this figure we can see the effective area ratio to be about 7 in multi-TeV region.
Figure 2 shows differential energy spectra of triggered gamma induced showers and cosmic-ray induced ones, assuming both spectral index of 2.6. We can see the mode energy of triggered gamma rays is 1.5∼2.0 times smaller than cosmic rays for the same trigger condition. The average advantage factor of the effective area for gamma rays is 4.0 for $E_{\rm mode} \simeq 3$ TeV and 3.6 for 10 TeV in average of gamma-ray spectral indices of $\beta = 2.2 \sim 2.8$. In this paper the mediate value β=2.5 is employed because of its weak dependence on the spectral index. The significance of the excess sigma (σ), in the Table 1, of TeV gamma rays from the IG and OG planes implies a simple formula of $(E - B)/\sqrt{B}$, where E is the on-plane event number and B is the background number of events estimated from neighboring bins around the on-plane. Those evaluated values in the previous paper [12] are tabulated together with the simulated effective area ratio of gamma vs. cosmic rays and the revised upper limits with a small change of β from 2.4 to 2.5.

Table 1 Effective area ratio and gamma-ray flux upper limits.

Array of data taken with	Tibet III		Tibet II	
$E_{\rm mode}$	3 TeV		10 TeV	
Inner or Outer Galactic plane	Inner	Outer	Inner	Outer
Significance of excess (σ)†	+2.52	+0.25	+1.71	-0.63
Flux ratio of gamma rays versus cosmic rays† $I_\gamma(\text{at } 1\,\sigma)/I_{\rm CR} \equiv 1/\sqrt{B}$ $(\times 10^{-4})$	1.95	1.16	2.43	1.45
99%C.L. upper limit in the original (β=2.4)† $E_\gamma^2 dN(>E_\gamma)/dE_\gamma$ ($\times 10^{-3}$cm^{-2}s^{-1}sr^{-1}MeV)	9.6	3.3	4.0	1.3
Effective area (γ/CR) ratio of the Tibet array $S_{\rm eff}(\gamma)/S_{\rm eff}$(CR)	**4.0**	**4.0**	**3.7**	**3.7**
99%C.L. revised upper limit with β=2.5 $E_\gamma^2 dN(>E_\gamma)/dE_\gamma$ ($\times 10^{-3}$cm^{-2}s^{-1}sr^{-1}MeV)	**2.6**	**0.88**	**1.2**	**0.37**

The rows with † are referred to the original paper by Amenomori et al. (2002) [12]

3. New flux upper limits of TeV gamma rays from IG and OG planes

The present simulation, giving a larger effective area of the Tibet array for gamma rays than the galactic cosmic rays, makes low the flux upper limits of diffuse gamma rays by a significant factor, as given in Table 1. The original data in the previous paper [12] at 3 TeV were obtained by the Tibet III array (7.5 m spacing) with inner area of 22,050m^2, and at 10 TeV by the Tibet II array (15 m spacing) with 28,350m^2.
Figure 3 show the revised flux upper limits, for IG (left) and OG (right) planes, at $E_{\rm mode}$=3 TeV (T3': new and T3: old for Tibet III array) and at 10 TeV (T2': new and T2: old for Tibet II array) together with the previous upper limits [12]. In these left and right figures the EGRET data [1] of the Galactic latitude width of $|b| \leq 2°$ are shown, and also shown the upper limits by Whipple (W) [13] with 99.9% C.L. and HEGRA (H) [14] with 99% C.L., though both at a small sky region around the Galactic longitude of $l = 40°$, and HEGRA-AIROBICC (Ha) [15]and CASA-MIA (C-A) [16] both with 90% C.L.. Theoretical curves are given by Porter and Protheroe (1997) [8] (PP2.0 and PP2.4 in figures), and by Tateyama and Nishimura (2003) [9] (TN 2.0 and TN2.4), where 2.0 and 2.4 are assumed source electron spectral indices. Theoretical curves arising from $\pi^0 \rightarrow 2\gamma$ decay are also given by Berezinsky et al. (1993) (BGHS) [10].

4. Summary

When the observed gamma-ray spectra with the spectral index of 2.5 is adopted as described in the section 2, the revised results can give a strong suggestion that the spectral indices of source electrons for the inverse

Compton (IC) are steeper than 2.2 in the IG plane and also smaller than 2.1 in the OG plane in comparison with the theoretical calculations of IC. The theoretical flux of diffuse gamma-rays raising from cosmic rays - ISM collisions is much small. [10]

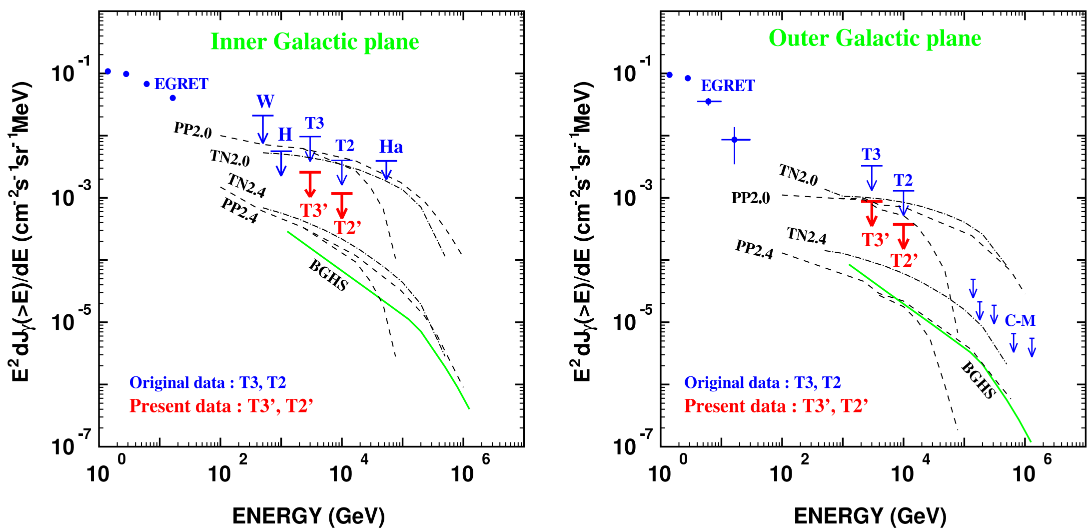

Figure 3. Diffuse gamma rays from the IG plane (left figure) of $20° \leq l \leq 55°$, $|b| \leq 2°$, and the OG plane (right figure) of $140° \leq l \leq 225°$, $|b| \leq 2°$.

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References

[1] S. D. Hunter et al., ApJ, 481, 205 (1997).
[2] H. Mayer-Hasselwander et al., A&A, 105, 164 (1982).
[3] C. D. Dermer, A&A, 157, 223 (1986).
[4] M. Pohl and J. A. Esposito, ApJ, 507, 327 (1998).
[5] M. Mori, ApJ, 478, 225 (1997).
[6] W. R. Webber, Proc. 26th Int. Cosmic-Ray Conf. (Salt Lake City), 4, 97 (1999).
[7] A. W. Strong, I. V. Moskalenko and O. Reimer, ApJ, 613, 962 (2004).
[8] T. A. Porter and R. J. Protheroe, J. Phys. G, 23, 1765 (1997).
[9] N. Tateyama and J. Nishimura, Proc. 28th Int. Cosmic-Ray Conf. (Tsukuba), 4, 2285 (2003).
[10] V. S. Berezinsky, T. K. Gaisser, F. Halzen and T. Stanev, Astropart. Phys., 1, 281 (1993).
[11] R. Atkins et al., preprint, arXiv:astro-ph/0502303 vl (2005).
[12] M. Amenomori et al., ApJ, 580, 887 (2002).
[13] S. LeBohec et al., ApJ, 539, 209 (2000).
[14] F. A. Aharonian et al., A&A, 375, 1008 (2001).
[15] F. A. Aharonian et al., Astropart. Phys., 17, 459 (2002).
[16] A. Borione et al., ApJ, 493, 175 (1998).