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Upper limit of diffuse gamma rays from galactic plane using the data with Tibet II and HD Arrays
The Tibet ASγ Collaboration

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Abstract.

Signals of diffuse gamma rays from the galactic plane are searched using both the Tibet-II array and high density (HD) array data with mode energy 10 TeV and 3 TeV, respectively. No significant signal is found both from inner Galaxy (IG) for $20° \leq l \leq 55°$ near the galactic center and outer Galaxy (OG) $140° \leq l \leq 225°$ around the anti-galactic center both with $|b| \leq 5°$. Then the flux upper limits with 90% c.l. are obtained as 1.30×10^{-10} cm^{-2} s^{-1} sr^{-1} from IG and 4.05×10^{-11} cm^{-2} s^{-1} sr^{-1} from OG at 10 TeV, and also 2.34×10^{-9} cm^{-2} s^{-1} sr^{-1} from IG and 2.24×10^{-10} cm^{-2} s^{-1} sr^{-1} from OG at 3 TeV, respectively. The present data seem to exclude the inverse Compton model in an extreme case of assumed flat spectrum of power index 2.0 of injected local electrons.

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1 Introduction

Flux of diffuse gamma rays, showing a sharp ridge along the galactic plane, obtained by the EGRET at energy region around 1 GeV (Hunter et al.,1997) is considered to be dominantly $\pi° - 2\gamma$ decay origin due to cosmic-ray interaction with interstellar matter. The flux in lower energy region is substantially not inconsistent with calculation (Dermer,1986), although the EGRET data is about factor 3 higher than COS B data (Mayer-Hasselwander et al.,1980). In detail calculation in higher energy region, the flatter proton spectrum of power index 2.45 (Mori,1997) or 2.25 (Webber,1999) is necessary to explain the EGRET flux from the inner Galaxy (IG) near the galactic center.

Theoretical calculations have been done for gamma-ray flux in TeV-PeV region due to cosmic-ray proton interaction with interstellar matter for inner galactic (IG) and outer galactic (OG) planes (Berezinsky et al.,1993), and for IG plane (Ingelman and Thunman,1997). On the other hand, locally accelerated primary electrons or cosmic-ray secondary electrons have been noticed to generate not only bremsstrahlung gamma rays due to interaction with gas but also inverse Compton gamma rays due to interaction with soft photons (Porter and Protheroe,1997; Tateyama and Nishimura,2001).

However, TeV region gamma rays have not been successfully detected from the galactic plane. Flux upper limits were given by surface detector array groups as Utah-Michigan (Matthews et al.,1991), CASA-MIA (Borione et al.,1995) at 300 TeV region and Tibet group (Amenomori et al.,1997a) at 10 TeV region. Only the Tibet group gave the upper limits for both IG near the galactic center and OG around the anti-galactic center. These flux upper limits at 10 TeV were obtained by analysis of 1990∼1993 data with the Tibet I array, the small one constructed at Yangbajing (90.°53E, 30.°11N, 4300m a.s.l.) in Tibet,China

Tibet II array, enlarged from the Tibet I, and HD array with 4 times higher detector density, within the Tibet II, were constructed in 1994∼1996. In this paper, the analysis and results of 1997∼1999 data obtained with the Tibet II array at mode energy 10 TeV, and the HD array at 3 TeV, are described. Method of the present analysis is almost same as the previous one (Amenomori et al.,1997a).

2 Data Analysis and Results

Because the experimental apparatus and performance of the Tibet II and HD arrays are described somewhere (Amenomori et al.,1997b; Amenomori et al.,1999), their details are abbreviated in this paper, except for nearly same angular resolution of $\sim 1°$ for both the Tibet II array at 10 TeV and HD array at 3 TeV.

The number of used air shower events obtained by the Tibet II array is 5.44×10^9 events after pre-analysis of arrival directions, about 8.9 times larger than the Tibet I data analysed before at same mode energy 10 TeV, and the HD array data is 3.12×10^9 events, 5.1 times larger also, although the mode energy is 3 times lower.

These air shower events are assigned to the sky regions, from which they arrived, of 10° width 36 belts along the galactic plane as shown in Fig.1 for IG and Fig.2 for OG. Declination is limited as $-10° \leq \delta \leq 20°$ for IG and $-10° \leq \delta \leq 60°$ for OG.

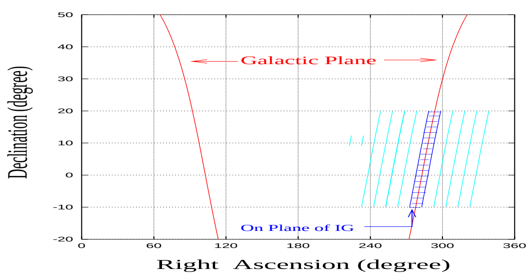

Fig. 1. 10° width belts in right ascension along the galactic plane for IG near the galctic center.

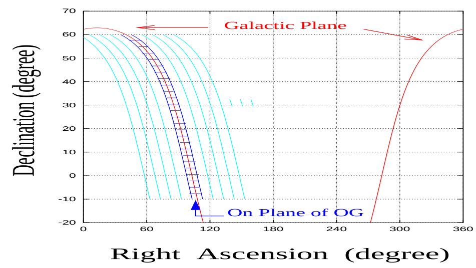

Fig. 2. 10° width belts in right ascension along the galactic plane for OG around the anti-galactic center

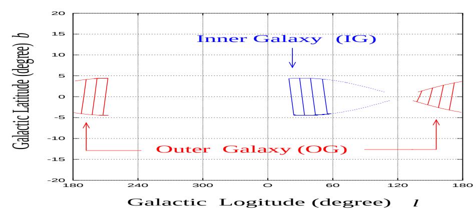

Fig. 3. IG and OG areas in the galactic coordinates corresponding to the shaded belts in figures 1 and 2.

The declination limits of on-plane belts in the equatorial coordinates are roughly corresponding to galactic longitude ranges $20° \leq l \leq 55°$ for IG and $140° \leq l \leq 225°$ for OG both with $|b| \leq 5°$ in the galactic coordinates, respectively. These zones in the galactic coordinates are shown by shaded areas in Fig. 3.

Figure 4 shows an example of distribution of number of events in 36 curved belts of right ascension. Imhomogeneity of cosmic-ray intensity, seen in this figure, with an amplitude

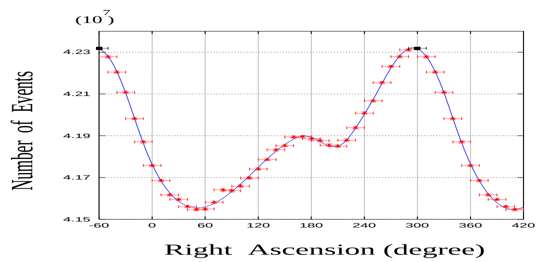

Fig. 4. Distribution of number of events in 36 curved belts for IG in the Tibet II data.

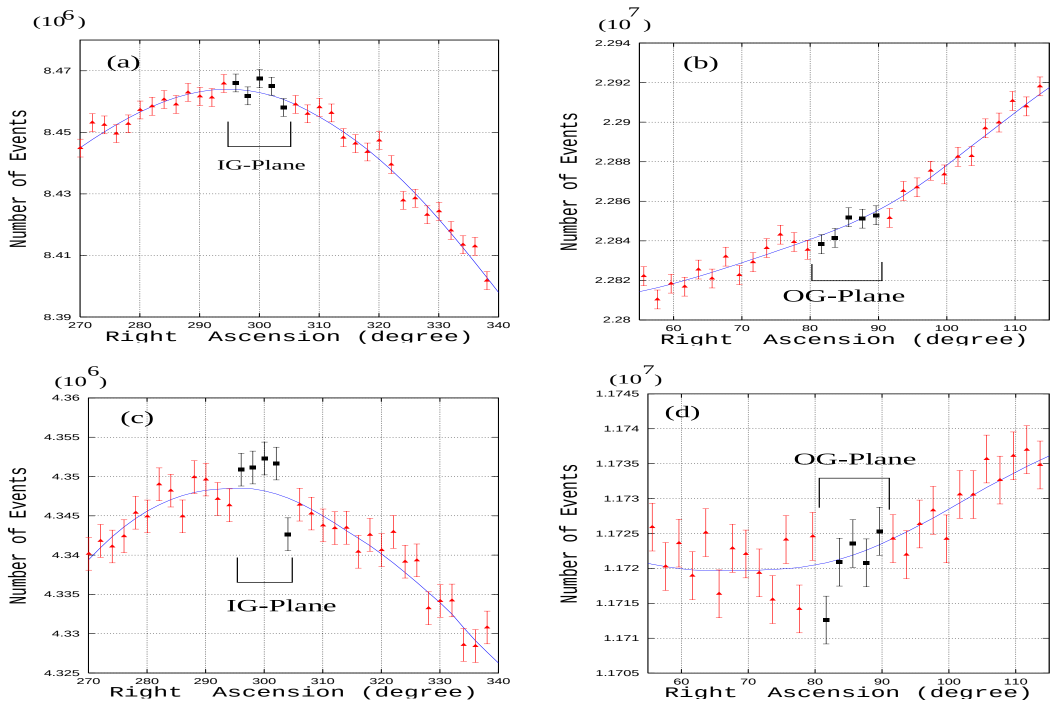

Fig. 5. Distributions of number of events in the right ascension range 70° or 60° around the inner and outer galactic planes, IG (a) and OG (b) for the Tibet II data, and also IG (c) and OG (d) for the HD data.

less than ±1% is due to systematical origin such as a slight inclination of the site of about 1° at Yangbajing and due to some long time loss of the observation. The solid line implies the best fit curve to the number distribution in the smaller width belts of 2° bin in right ascension, except for nearest five belts on the galactic plane, although nine belts were excepted in the previous work (Amenomori et al.,1997a). So, this curve is considered to be the background intensity of cosmic rays. Then, we can examine the excess of the on-plane data from the estimated background curve, and calculate its significance simply by $(E - B)/\sqrt{B}$, where E is the number of on-plane events and B the background estimated above from the number of off-plane events. Here, the horizontal axis means the right ascension at $\delta = 30°$, the zenith at Yangbajing site, of each belt.

The detail distributions around the galactic plane are shown in figures 5(a) and 5(b) for IG and OG in the Tibet II data, and also in figures 5(c) and 5(d) for IG and OG in the HD data. Thus obtained excess significance and upper limit, because of no significant signals being seen, of each part of the galactic plane are tabulated in the Table for the Tibet II and HD data.

Table

Array E_{mode}	Inner or outer G	Significance	Upper limit (90% C.L.) $\mathrm{cm^{-2}s^{-1}sr^{-1}}$
II	IG	+0.81 σ	1.30×10^{-10}
10 TeV	OG	–0.66 σ	4.05×10^{-11}
HD	IG	+1.81 σ	2.34×10^{-9}
3 TeV	OG	–0.89 σ	2.24×10^{-10}

3 Summary and Discussions

As given in the Table no significant excess is found, though +1.81 σ is a little high at 3 TeV for IG of the HD data. The upper limits with 90% confidence level in this table are calculated, for simplicity, in comparison with the galactic cosmic-ray intensities at zenith at Yangbajing site (30°N) for OG and at zenith angle 17.5° for IG, although both the previous results were deduced from a comparison with the vertical cosmic-ray intensity at Yangbajing. Results are shown in Fig. 6 for IG and Fig. 7 for OG, respectively, together with the previous results (Amenomori et al.,1997a). The figure 7 includes also the upper limits by Whipple (labeled by **W**) for

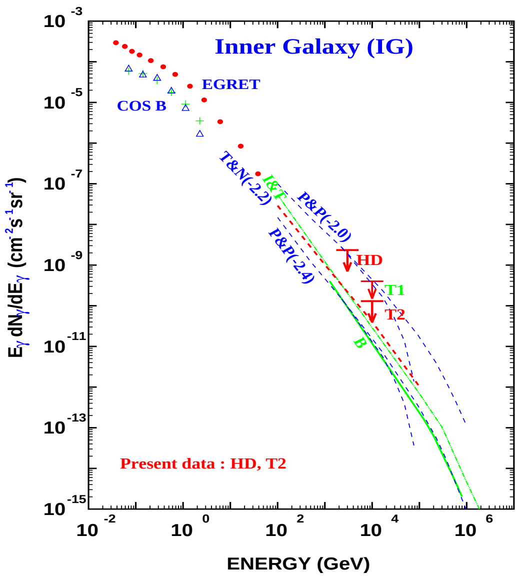

Fig. 6. Diffuse gamma rays from IG (inner galxy). Present data are labeled by T2 and HD, and also T1 is the Tibet I data previously analyzed. Theoretical curves are labeled by initials of the first author or first and second authors names.

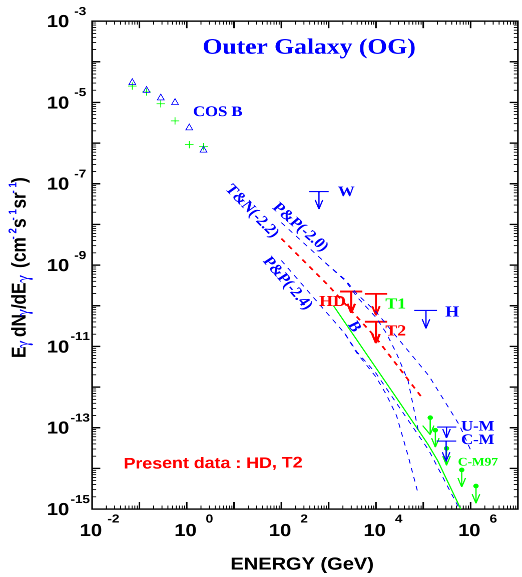

Fig. 7. Diffuse gamma rays from OG (outer galaxy). The marks and labels are same as Fig6. Marks **W**, **H**, **U-M**, **C-M** and **C-M97** are described in the text.

Taurus Giant Molecular Cloud (Reynolds et al.,1993) and by HEGRA (labeled by **H**) for the sky region apart from the galactic plane to search for isotropic metagalactic gamma-ray component (Karl et al.,1995), and also COS B data (Paul et al.,1978) and EGRET data (Hunter et al.,1997). The present upper limit at 10 TeV is suppressed by a factor 3 for IG and a factor 5 for OG than the previous one (Amenomori et al.,1997a). The upper limits at 3 TeV are given first as the surface detectors, but these are not so effective to examine the theories because of the poor statistics due to small area of the HD array. Any way, the present data seem to exclude the inverse Compton model with an extreme flat spectrum of power index 2.0 for injected local electrons, considering both the theoretical curves labeled by **P & P** (Porter and Protheroe,1997) and by **T & N** (Tateyama and Nishimura,2001) in Fi.6..

The HD array was enlarged to Tibet III array with about 7 times larger area in 1999 and is completed to about 9 times area than the HD one in 2002 (Amenomori et al.,2001). Then, the detectable upper limit will be decreased further more than factor 3 in a few years.

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