A measurement of the diffuse TeV gamma ray emission from the Galactic Plane with ARGO-YBJ experiment

L.L. MA[1], ON BEHALF OF THE ARGO-YBJ COLLABORATION
[1] *Particle & Astrophysics Center, Institute of High Energy Physics, CAS*
llma@ihep.ac.cn

Abstract: The diffuse gamma ray produced by the interactions of the cosmic rays with the interstellar medium and radiation fields in the Galaxy can be used to probe the cosmic rays spectral and the density of the interstellar medium through out the whole Galaxy. ARGO-YBJ experiment can survey the large regions of the Northern hemisphere sky with its large field of view and long observation time. Therefore, ARGO-YBJ experiment is ideal for the study of diffuse gamma ray from Galactic plane at TeV range. The spatial distribution and the flux of the diffuse gamma ray for the Galactic longitude between 25° and 110° are calculated. The energy spectra of the region with $|db| < 2^\circ$ and $25^\circ < dl < 65^\circ$ and the Cygnus region are also calculted.

Keywords: diffuse gamma ray, Galactic Plane, extensive air shower, ARGO-YBJ

1 Introduction

The diffuse γ ray is produced by the interactions of the energetic cosmic rays with the interstellar medium and radiation fields in the Galaxy. Cosmic ray nuclei interact with the nuclei in the interstellar medium producing π^0s which decay into γ-rays immediately. While cosmic ray electrons or positrons can produce γ-rays by inverse Compton scattering with the radiation field. Therefore, the diffuse γ ray provides the information about the density and energy spectra of cosmic rays of the Galaxy. Furthermore, the study of the diffuse γ ray can shed light on the origin and propagation of galactic cosmic rays.

In addition, due to the high density of the interstellar medium and gases on the Galactic plane, the diffuse γ-ray has a clear structure along it, therefore, the diffuse γ ray is a background for the signals from point source, influencing the position and flux of the point source, and also a background of the faint isotropic extragalactic diffuse γ ray. So the studies of the diffuse γ ray from Galactic plane will be helpful to the study of point sources and the isotropic extragalactic diffuse γ rays.

However, the identification of the truly diffuse γ ray emission is not an easy work, due to the contamination of the weak but numerous unresolved point sources.

In the GeV range, the results of the diffuse γ ray are mainly provided by satellite experiments. The results of SAS-2[1] and COS-B[2] γ ray satellites show the noticeable correlations between the few GeV γ ray flux and the density of the interstellar medium. The EGRET satellite with its high quality data from the Galactic plane discovered the well known "GeV excess", which results in new theoretical studies of the diffuse γ rays[3]. The recently launched Fermi satellite has mapped the γ ray sky up to 100 GeV with high accuracy after its 2 years operation. However, the well known "GeV excess" is not confirmed by Fermi/LAT[4].

In the hundred GeV or TeV range, due to its low flux, the observation of γ ray can only depend on the ground-based detectors. However, most of the ground-based detectors can only provide upper limits of the diffuse γ ray due to the limitation of their sensitivities. The first result of the TeV diffuse γ ray emission is provided by HESS experiment, which detected the signals of diffuse emission from the Galactic Center Ridge and concluded that the signals correlate with the giant molecular clouds[5]. Unlike the IACT expriments, the EAS detectors have large field of view which are suitable for scan of the Galactic Disk. the Milagro experiment has detected a signal of diffuse emission above 3.5 TeV from a large region of the Galactic plane (Galactic longitudes $30^\circ < dl < 110^\circ$) indicating the existence of the TeV excess[7].

The ARGO-YBJ experiment with a large field of view has been operated almost four years. The significance of Crab can reach 16σ[16]. In this paper, the data of ARGO-YBJ experiment are analyzed to study the diffuse γ emission from the Galactic Plane.

2 The ARGO experiment

The ARGO-YBJ located in Tibet, China at an altitude of 4300 m a.s.l., is the result of a collaboration among Chinese and Italian institutions and is designed for very high energy γ-ray astronomy and cosmic ray observations. The detector consists of a single layer of Resistive Plate Chambers (RPCs), which are organized in a modular configuration. The basic module is a cluster (5.7 m $\times$ 7.6 m), composed of 12 RPCs (2.850 m $\times$ 1.225 m each). The RPCs are equipped with pick-up strips (6.75 cm $\times$ 61.80 cm each) and the logical OR of the signal from 8 neighboring strips constitutes a logical pixel (named "pad") for triggering and timing purposes. 130 clusters are installed to form a carpet of about 5600 m^2 with an active area of $\sim$93%. This central carpet is surrounded by 23 additional clusters ("guard ring") to improve the reconstruction of the shower core location. The total area of the array is 110 m $\times$ 100 m. More details about the detector and the RPC performance can be found elsewhere[8].

The RPC carpet is connected to two independent data acquisition systems, corresponding to two different operation modes, referred to as the shower and the scaler modes[9]. Data used in this paper refers to the shower mode, in which the ARGO-YBJ detector is triggered when at least 20 pads in the entire carpet detector are registered within 420 ns. The high granularity of the apparatus permits a detailed spatial-temporal reconstruction of the shower profile and thus the incident direction of the primary particle. The arrival time of the particles is measured by Time to Digital Converters (TDCs) with a resolution of approximately 1.8 ns. In order to calibrate the 18,360 TDC channels, an off-line method[10] has been developed using cosmic ray showers. The calibration precision is 0.4 ns and the procedure is applied every month[11].

The central 130 clusters began taking data in June 2006, and the "guard ring" was merged into the DAQ stream in November 2007. The trigger rate is $\sim$3.5 kHz with a dead time of 4% and the average duty cycle is higher than 86%.

3 Data analysis

The ARGO detector has been operated almost four years stably, the data collected between November 2007 and January 2011 are analyzed. In the data selection, only events with a zenith angle less than 50° and *npad* more than 20 are used, therefore, the observation sky region corresponds to to $-15^\circ < \delta < 75^\circ$ in declinations, and the energy is greater than 100 GeV. The details of the data selection criteria can be seen from [12]. The number of excess events are calculated by the background estimation method called direct integration which is described in[12] in detail.

The regions of the Galactic disk of longitudes $25^\circ < dl < 110^\circ$ (the inner Galactic plane) and $130^\circ < dl < 230^\circ$ (the outer Galactic plane) are in the field of view of ARGO-YBJ detector. The inner Galactic plane is near the Galactic Center, therefore, the γ ray emission of the inner Galactic plane should be stronger than the one of the outer Galactic plane due to its high density of the interstellar medium and gases. In order to minimize the background, only inner Galactic plane is selected to study the diffuse γ ray emission from the Galactic plane. The selected region contains the famous Cygnus region ($65^\circ < dl < 85^\circ$) which contains many star formation regions, high mass stars and molecular clouds. Considering the peculiarity of the Cygnus region, the study is carried out seperately in three consecutive phases by dividing the Galactic longitude into ($25^\circ < dl < 65^\circ$,$65^\circ < dl < 85^\circ$,$85^\circ < dl < 110^\circ$).

The ARGO-YBJ detector can not discriminate between the γ-ray and cosmic rays effectively, so the large scale anisotropy of cosmic rays affects the background estimation of the diffuse γ ray seriously due to its large scale. The ratio between the number of observed events and that of the background of the up and down regions of the studied regions is used as the intensity of the anisotropy of cosmic rays of the studied region. In order to avoid the affects of the emission from the Galactic plane, the regions of Galactic latitude lower than 3° are excluded during the anisotropy estimation. The significance of the studied region is estimated by Li-Ma formula[13].

Within the region studied in this paper, ARGO detector has detected two sources (MGROJ1908+06[14], TeVJ2032+4130[15]), both with a significance 6σ [16]. In order to get rid of the effect of the two point sources and considering the angular resolution (1.5°) of the ARGO detector, the neighborhood in boxes centered around the sources $2^\circ\times 2^\circ/\cos(\delta)$ are excluded in our analysis. The regions of other TeV sources detected by other experiments but not detected by ARGO are included in the analysis. The effects of the un-detected sources are discussed in the Discussion section.

4 Results

In the inner Galactic Plane with $25^\circ < dl < 110^\circ$, $|db| < 2^\circ$, a significance with 8.3σ is obtained. After deducting the regions around the TeV sources, the significance is still 7.8σ. However, no significance excess can be seen from the outer Galactic Plane. So the inner Galactic Plane is studied in detail including the flux distribution along the Galactic latitude, longitude and the energy spectrum.

Figure 1 shows the flux profiles with Galactic longitude ($25^\circ < dl < 110^\circ$) along the Galactic latitude with $|db| < 15^\circ$ of the inner Galactic plane. In the plot, each dot indicates 1° width of the Galactic latitude. The blue dots indicate the point sources' flux with energy around 1TeV. From figure1 the point sources concentrate on the Galactic plane with latitude lower than 1°, and the effects to the diffuse emission is about 25%. In order to compare with results of the Fermi diffuse model[6], the flux profile around 100 GeV predicted by the model is also shown in figure1 by the red line. It is indicated that the flux profile and the

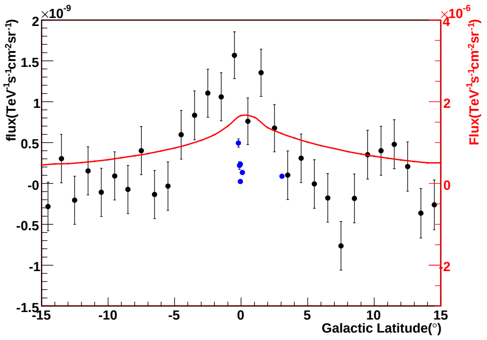

Figure 1: The flux profile along the Galactic latitude of the emission around 1 TeV from the inner Galactic plane shown by the black dots. The blue dots indicate the point sources' flux with energy around 1 TeV. The red line shows the flux predicted by Fermi diffuse model.

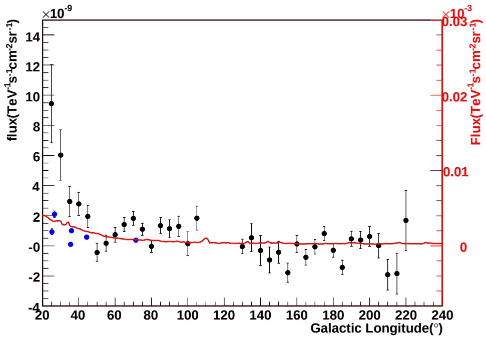

Figure 2: The flux profile along the Galactic longitude of the emission around 1 TeV shown by the black dots. The blue dots indicate the point sources' flux with energy around 1 TeV. The red line shows the flux predicted by Fermi diffuse model.

model share a similar structure by comparison. The intensities of the flux become smaller as absolute latitude value increase.

When calculating the flux distribution along the Galactic longitude, the thickness of the Galactic plane with latitude lower than 2° which are used in the Milagro's analysis[7] are chosen.

Figure 2 shows the flux profiles within $|db| < 2^\circ$ along the Galactic longitude. In figure 2, each dot indicates a 5° width bin in Galactic longitude. The point sources' fluxes and the prediction of Fermi model around 100 GeV are also shown by the blue dots and red line, respectively. As can be seen from figure 2, the affects of the point sources to the flux profile along the Galactic longitude is about 30%. After deducting the effects of the point sources, the flux profiles and the prediction of Fermi model again take on the similar structure. The intensities of the flux profiles becomes smaller become smaller as the longitude degree of the region increases away from Galactic Center.

The significances and fluxes of the two intervals with Galactic latitude lower than 2° are listed in table 1. The contributions of point sources are not subtracted.

The energy spectra of the γ ray emission of the first two regions are shown in figure 3. The upper plot shows the region with $25^\circ < dl < 65^\circ$, $|db| < 2^\circ$, while the bottom one shows the region with $65^\circ < dl < 85^\circ$, $|db| < 2^\circ$. The red dots indicate the results of ARGO, while the blue one indicates the results of Milagro. The contributions of the point sources have been subtracted.

The energy spectra are fitted by a power low function. The fitted flux of the two region at 1 TeV are $9.9 \pm 3.7 \times 10^{-10}$ and $13.2 \pm 4.9 \times 10^{-10}$ with index -2.9 ± 0.4 and -3.0 ± 0.3, respectively. The flux of Milagro are higher than those of the ARGO's, which was found through comparison of their results.

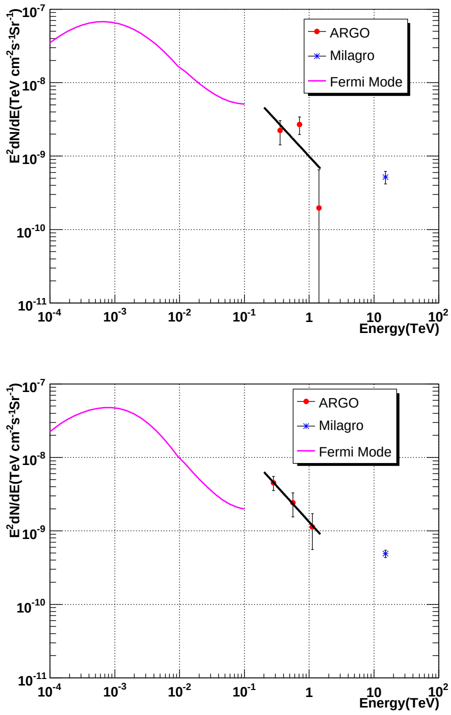

Figure 3: The energy spectra of the γ ray emission from Galactic plane. The upper plot shows the results of the region $25^\circ < dl < 65^\circ$, $|db| < 2^\circ$, while the bottom one shows the result of the region $65^\circ < dl < 85^\circ$, $|db| < 2^\circ$. The red dots indicate the results of ARGO, and the blue one shows the results of Milagro. The black line are the fitted results using a power low. The predictions of Fermi model at lower energy are shown as the pink line.

In order to compare with the Fermi diffuse model, the predicted energy spectrum are also shown by the pink line in the two plots.

Region($\|db\| < 2^\circ$)	Significance(σ)	flux($10^{-10}TeV^{-1}cm^{-2}s^{-1}sr^{-1}$)
$25^\circ < dl < 65^\circ$	5.59	9.9 ± 3.7
$65^\circ < dl < 85^\circ$	5.7	13.2 ± 4.9

Table 1: Sigficances and fluxes of the three parts of the Galactic plane.

5 Discussion

The flux profiles along the Galactic longitude,latitude and the energy spectra have been presented in the last section. In order to estimate the effects of calculation of the large scale anisotropy, the size of the up/down regions used to calculate the intensity of the anisotropy is changed from 5° to 10° in Galactic latitudes. The differences of the significance caused by the change is less than 10%.

In addition, the effects of point sources have to be considered. In the studied region, ARGO experiment has detected two sources (MGROJ1908+06[14], TeVJ2032+4130[15]) which have been subtracted when calculating the flux profiles and the energy spectra. However, despite the rich γ ray sources of the Galactic disk, but the fluxes of most of them are lower than the sensitivity of ARGO experiments. So it's difficult for ARGO to detect the weak sources due to its sensitivity and angular resolution. Though the fluxes of the weak sources are very low, taking their large amout into account, , the affects of the un-detected sources can not be neglected.

The IACT telescopes such as HESS and MAGIC with its better sensitivities than ARGO detector can detect sources with 1% Crab flux. Until now, there are other six TeV sources (HESSJ1837-069[17], HESSJ1841-055, HESSJ1857+026, HESSJ1858+020[18], HESSJ1912+101[19], Cyg X-1[20]) discovered in the studied region. The first five sources are located in the first region, and the last one in the Cygnus region. The effect of the point sources in the first region is about 28% at low energy, and at higher energy, the effect becomes larger (>50%) due to the hard energy spectra of the sources. In the second region, the effect of the Cyg X-1 is very little due to its soft spectrum and its location at the edge of the studied region.

From figure 3 it can be seen that, even subtracting the fluxes of the six detected TeV sources, the fluxes of ARGO are still higher than the extrapolation of the Fermi diffuse model, which may be caused by the weak and numerous point sources.

6 Conclusion

After subtracting the TeV sources, an excess with significance 7.8σ from inner Galactic plane can be seen. So the excess observed can be considered as the diffuse emission. In order to study the properties of the diffuse emission, the flux profiles along the Galactic latitude and longitude are calculated. Both of them have a structure similar to Fermi diffuse model. The energy spectra of the regions with $25^\circ < dl < 65^\circ$ and $65^\circ < db < 85^\circ$ and $|db| < 2^\circ$ are calculated. The flux of milagro is higher than the extrapolation of ARGO's results by comparison. In addition the effects of the TeV point sources are discussed. In the region with $25^\circ < dl < 65^\circ$, $|db| < 2^\circ$, the effects of the point sources is about 30% due to the high density of the point sources.

7 Acknowledgments

This work is supported in China by NSFC (No.10120130794), the Chinese Ministry of Science and Technology, the Chinese Academy of Sciences, the Key Laboratory of Particle Astrophysics, CAS, and in Italy by the Istituto Nazionale di Fisica Nucleare (INFN). We also acknowledge the essential supports of W.Y. Chen, G. Yang, X.F. Yuan, C.Y. Zhao, R. Assiro, B. Biondo, S. Bricola, F. Budano, A. Corvaglia, B. D'Aquino, R. Esposito, A. Innocente, A. Mangano, E. Pastori, C. Pinto, E. Reali, F. Taurino and A. Zerbini, in the installation, debugging and maintenance of the detector.

References

[1] C.E. Fichetal et. al., APJ, 1975, **198** 163
[2] H.Mayer-Hasselwander et. al. A&A, 1982 bf 105 164
[3] S. D. Hunter, et. al., APJ, 1997, **481** 205
[4] T. A. Porter, et. al. 31th ICRC, 2009, arXiv:0907.0294v1 [astro-ph.HE]
[5] F. Aharonian et. al., Nature, 2006, **436** 695
[6] http://fermi.gsfc.nasa.gov/ssc/data/access /lat/ring_for_FSSC_final4.pdf
[7] A. A. Abdo et. al., APJ, 2008, **688** 1078
[8] G. Aielli, et. al., 2006, Nucl.Instrum.Meth.A, **562**,92
[9] G. Aielli, et. al., 2008, Astrop. Phys., **30** 85
[10] H. H. He et. al., 2007, Astrop. Phys., **27** 528
[11] G. Aielli, et. al., 2009a, strop. Phys., **30** 287
[12] R. Fleysher, et. al., 2004, APJ, **603** 355
[13] T. P. Li, Y. Q. Ma, 1983, APJ, **272** 317
[14] A. A. Abdo, et. al. 2009, APJ, **703** L185
[15] J. Albert et. al., 2008, APJ, **675** L25
[16] Bartoli. B., et al. 2011, ApJ, 734, 110
[17] F.Aharonian et. al., APJ, 2006, **636**:777
[18] F.Aharonian et. al., A&A, 2007, **477**:353
[19] F.Aharonian et. al., A&A, 2008, **484**:435
[20] J.Albert et. al., APJ, 2007, **665**:L51