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Very high energy gamma-ray observations of the Galactic plane with the CANGAROO-III telescopes

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We have searched for very high energy gamma-ray emission from two points ($l = -19^\circ.5$ and $l = +13^\circ$) on the galactic plane ($b = 0^\circ$) using the CANGAROO-III stereoscopic observation system in 2004. Stereo analysis using 2-fold coincidence data was performed, which aims for the measurement of the diffuse component flux and also allows a search for unknown point sources in the field of view. No significant excess associated with the galactic plane was found for either region. Assuming that the gamma-ray spectrum is a single power law between a few GeV and 600 GeV, upper limits to the spectral index were obtained: -2.17 and -2.12 for the $l = -19^\circ.5$ and $l = +13^\circ$ regions, respectively. A search was made for point sources in the $l = -19^\circ.5$ region, with no source with a statistical significance exceeding 4σ being found in the field of view. Typical flux upper limits of about 20% of the Crab nebula flux were obtained in that region.

1. Motivation for this work

The Galactic plane is one of the brightest MeV-GeV gamma-ray sources, and gamma-ray emission profile and spectra were accurately measured up to a few tens of GeV by satellite experiments such as EGRET detector on the CGRO.

Since MeV-GeV gamma-rays from the galactic plane are thought to originate from the interaction between the galactic cosmic rays and the interstellar matter/photons, gamma-ray flux can be estimated well quantitatively

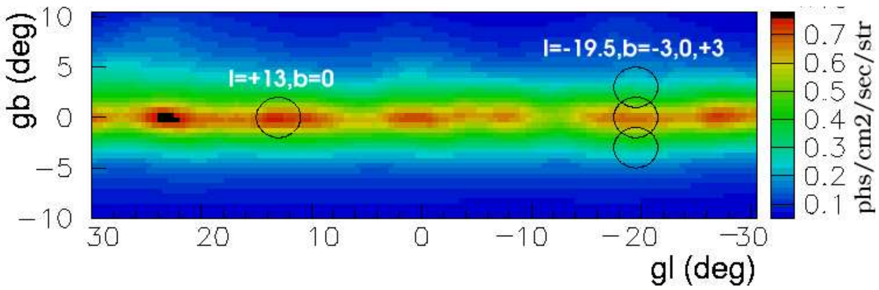

Figure 1. EGRET diffuse emission model and CANGAROO-III target points.

using radio/optical measurement data. In this context some authors constructed diffuse gamma-ray emission model([3],[7] etc.) and among those, the model by Hunter[7] showed good agreement with the EGRET measurement in the MeV region both for spatial and spectral features. But for above 1 GeV, the measured flux showed a 60% excess over the model, although the spatial features were reproduced well. The spectral index measured between 1 GeV to 30 GeV (-2.45 [10] on average) was also rather harder than that expected from the cosmic-ray protons and this discrepancy has become known as the "GeV excess" problem.

One possibility for the origin of the GeV excess is that cosmic-ray spectrum adopted in the model calculation is not suitable as the Galactic average. One of the most straight-forward tests of this hypothesis for the GeV excess is to measure the spectral shape more precisely over a more broader energy range. Thus very high energy gamma-ray measurements become important in this context, and the observation by the CANGAROO-III (C-III, hereafter) stereoscopic system in 2004 and its results are reported here.

2. Observations and analysis methods

We selected a few points on the galactic plane as "target points" rather than make a low sensitivity search over a larger area of galactic longitude. The target points were chosen to meet the following conditions: 1.) Coincident with local emission maxima of the EGRET diffuse emission model on the Galactic plane ($b = 0°$). (See Fig. 1), 2.)A minimum observation zenith angle at the C-III site of less than 20 degrees, 3.)No bright star within the FOV, and 4.)No known TeV gamma-ray sources within the FOV. Thus two points, $(l, b) = (-19°.5, 0°.0)$ and $(+13°.0, 0°.0)$, were adopted.

Since in this case the expected extent of the emission region in galactic latitude is comparable to the field of view, a scanning observation is the most preferable method of obtaining an emission profile in this direction. Thus the $l = -19°.5$ region was observed in this way with a scan point interval of $3°.0$(See Fig. 1). Each scan point was observed for 15 minutes and then the tracking point was switched. However, for the $l = +13°$ region, the conventional long ON-OFF observation mode was adopted since the variation of the optical brightness in the scanning path was rather large. All the selected OFF-source positions were well away from the Galactic plane, by more than 10 degrees.

Observations were made at zenith angles less than 45 degrees, which leads to energy threshold of 600 GeV for the newer telescopes. In this paper only two-fold coincidence data (T2-T3, T2-T4) are treated. Total amounts of the analyzed ON-source data are: 10.6 hours ($l = -19°.5$, T2-T3), 6.3 hours ($l = -19°.5$, T2-T4), 8.0 hours ($l = +13°$, T2-T3), 8.5 hours($l = +13°$, T2-T4), respectively. Details on the performance of the C-III stereoscopic system and data analysis for a point source will be appeared in [9] and [4] etc.

As for these galactic plane data, two types of analysis method were applied: measurement of diffuse component flux and survey of unknown point sources. The former was applied both for $l = -19°.5$ and $l = +13°$, testing

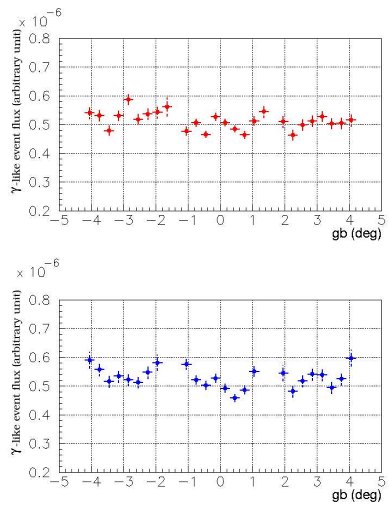

Figure 2. Latitude profile of gamma-ray like events for $l = -19°.5$ region. Upper:T2-T3, Lower:T2-T4.

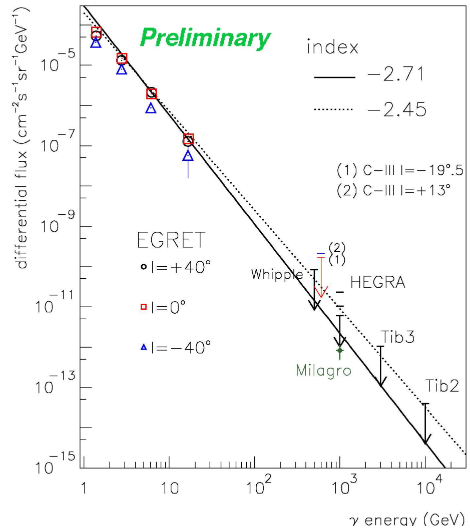

Figure 3. Comparison of the CANGAROO-III upper limits and other measurements. ([1],[2],[5],[8],[13])

gamma-ray like event excess of ON-source data to OFF-source one. As for $l = -19°.5$, $b = \pm 3°$ regions are treated as OFF. Gamma-ray flux averaged within radius of 1.2 degree from the center of field of view is treated as “Flux”, after sensitivity variance correction within the field of view. Since this source can be thought as a extended source, normalization of ON/OFF source observation data was performed using number of proton-like events. The latter survey was applied only for $l = -19°.5$ region, defining ON/OFF-source position within the field of view (This method is based on the HEGRA method[1]), but for detail on the analysis, see [11]) etc.

3. Results

Diffuse component As for the diffuse emission component, no significant signal excess associated with the plane was found both for $l = -19°.5$ and $l = +13°$ region. Figure 2 shows the gamma-ray like event profile in the latitude direction for $l = -19°.5$ data. 2-sigma upper limits on the flux level (systematic errors in the derivation of the flux is also considered here) were imposed from the C-III measurements and preliminary results are shown in Fig. 3, superimposed to the other measurement results. Under the assumption that gamma-ray spectra has a single power-law form between the GeV and sub-TeV regions, spectral index upper limits were obtained to be 2.17 for the $l = -19°.5$ region and 2.12 for the $l = +13°.0$ region using EGRET data and C-III flux upper limits. On the other hand, measurements of the northern region and the spectral indices obtained from TeV/sub-TeV measurements are: -2.31 (Whipple [8], upper limit), -2.5 (HEGRA [1], upper limit), -2.6 (Milagro [5], 4.5σdetection). Thus assuming the emission mechanism is identical at the observed points, our upper limits are consistent with previous results.

One more thing to be considered is the existence of unknown and unresolved point source within the field of view. In fact, the H.E.S.S. team recently reported the results of a detailed galactic plane survey [6], finding unidentified VHE point source in the field of view of the $l = +13°$ region (HESS J1813-178) with a flux level of $\sim 5\%$ of the Crab nebula. This flux can be converted to $\sim 3.8 \times 10^{-12}$ phs/cm^2/sec/sr/GeV at 600 GeV, when averaged over a 1.2 degree radius, which is below the C-III upper limit. Thus the above results are also consistent with this new result.

Comparison with the hypothesis Pohl & Esposito [12] constructed a model with an enhanced inverse Compton component to explain the GeV excess, with a hard spectral index of -2.0 for the cosmic-ray electron component. In their model the IC component exceeds the π^0 component near 50 GeV with a gamma-ray spectral index harder than -2.0. In the few hundred GeV region the Klein-Nishina effect does not strongly affect the IC flux and power-law nature of the gamma-ray flux should be maintained up to this region. A power-law extrapolation of their model to the few hundred GeV region exceeds the upper limit imposed by the upper limits of the C-III observations. Unless there is a break in the electron injection spectrum between 50 GeV and 600 GeV, our results place constraints on such enhanced IC models, consistent with the Whipple [8] and HEGRA [1] results.

Survey of unknown point sources Though there are 5 pulsars, 6 SNRs, and 2 EGRET point sources within the field of view of 3.0 deg, we found no strong point source whose significance exceeds 4-sigma associated/unassociated to them. Typical 2-sigma upper limit of the flux within the field of view was obtained to be $\sim 20\%$ of the Crab flux.

4. Summary

The CANGAROO-III stereoscopic observation system was completed in March 2004, and two carefully selected regions of the galactic plane were observed the new array with an energy threshold of 600 GeV. No significant signal associated with the galactic plane was found and, assuming the gamma-ray spectrum can be described by a single power law between a few GeV and 600 GeV, upper limits to the spectral indices of diffuse emission component of 2.17 and 2.12 were obtained for the $l = -19^\circ.5$ and $l = +13^\circ$ region, respectively. No strong point source ($> 4\sigma$) was found in $l = -19^\circ.5$ region survey. Typical flux upper limits of about 20% of the Crab nebula flux were obtained by this measurement.

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