Very High Energy Gamma-ray Observations of the Galactic Center with the CANGAROO-II telescope

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Abstract

The Galactic Center has been observed with the CANGAROO-II atmospheric Cherenkov telescope in 2001 and 2002. We have analyzed the data with a likelihood method to discriminate gamma-ray events from background cosmic-ray events using image parameters. The details of the analysis method and the preliminary results are presented.

1. Introduction

Observations of the Galactic Center are being actively pursued at radio, sub-millimeter, infrared, X-ray and gamma-ray wavelengths. They indicate that the central region contains (amongst other components) a super massive black hole, diffuse hot gas and a supernova remnant. The review of Melia and Falcke provides an excellent summary of the latest results [11].

Emission of high energy gamma-rays from the Galactic Center region still remains to be fully exploited, when compared with observations in the lower energy region. EGRET detected a GeV gamma-ray source at the Galactic Center [9]. However, it is not yet clear that whether it is a point source or a diffuse source. Various theories have suggested for the origin of the high energy emission: the accretion disk around the massive black hole [8], the radio arc [13] or supernova remnants [10]. If the high energy radiation continues up to the sub TeV gamma-rays region or has a cut-off in the spectrum in the TeV gamma-ray region, observations with the Imaging Air Cherenkov Telescopes (IACTs) will provide important information to help determine the radiation mechanism.

On the other hand, from point of view of particle physics, annihilation of putative dark matter neutralinos might be the origin of the gamma-rays from the Galactic Center. A substantial density enhancement near the center and neutralino annihilation rate larger than that predicted previously give IACTs a chance of detecting a gamma-ray signal in the 100 GeV–10 TeV region [2].

In the northern hemisphere, the Whipple group and the HEGRA group have reported upper limits on the gamma-ray fluxes at 3.1 TeV [7] and 4.5 TeV [1], respectively.

pp. 2517–2520

We observed the Galactic Center with the CANGAROO-II telescope for two years. Observations from the southern hemisphere have an advantage owing to the higher elevations of the Galactic Center than possible from the northern hemisphere, i.e., a lower energy threshold is expected.

2. Observation

The CANGAROO-II telescope is a 10m IACT near Woomera, South Australia ($31°06'S, 136°47'E$,160m asl). The imaging camera has 552 pixels, each of which subtends an angle of 0.115°, with a total field-of-view of 2.8 degrees. Details of the telescope are given elsewhere [12].

We observed the Galactic Center in July 2001 and July–August 2002. Both ON-source and OFF-source observations were carried out, with a total observation time of about 120 hours for each.

3. Analysis and results

For every event, information on relative arrival time (TDC) and the number of photoelectrons (ADC) is recorded for each PMT. The PMTs are calibrated with a blue LED flasher before each observation. Flat fielding and time-walk corrections are carried out using this data.

The noise reduction and the selection of clustered images, which enhance Cherenkov photon images of showers, were carried out as pre-selection processes. The procedures are (1) pixels must have pulse heights greater than $\sim$ 3.3 photoelectrons, (2) pixels must be triggered within 40 ns of the timing center of the event, and (3) the image includes only pixels each of which is adjacent to at least five hit pixels.

After the pre-selection, we rejected the data in which the shower rate is less than 2 Hz in order to exclude data affected by cloud or dew on the mirrors. The remaining observation time was 71 hours for the ON-source data and 53 hours for the OFF-source data, respectively. Table 1 shows the observation times after pre-selection. The OFF-source time in 2002 was less than ON-source mostly because of troubles with the GPS recording module.

Table 1. Observation time of the Galactic Center after pre-selection.

	ON-source	OFF-source
2001	20.3 hrs	20.9 hrs
2002	50.3 hrs	31.8 hrs
all	70.6 hrs	52.8 hrs

The typical image expected from gamma-rays has a compact and elliptical shape with its major axis presumably oriented towards the center of field of view. In contrast, Cherenkov images from hadron cosmic-ray showers are much more irregular and randomly oriented in the focal plane. The difference between images produced in gamma-ray and cosmic-ray showers can be quantified by Monte Carlo simulations (for gamma-rays) and OFF-source data (for cosmic rays).

Our imaging analysis was based on the method of likelihood analysis [4] using image parameters [6]. This analysis gives a signal-to-noise (S/N) ratio and an acceptance better than those by the standard method [3]. The image parameters strongly depend on the energy of initiating shower. Therefore, a two-dimensional (2D) likelihood analysis [5] was used to take this effect into account. The Probability Density Functions (PDF) for gamma-rays and protons were made for "Length" and "Width". We define the Likelihood ratio (L) as

$$L \equiv \frac{Prob(\gamma)}{Prob(\gamma) + Prob(proton)},$$

where Prob(γ,proton) means the product of each PDF ("Length" and "Width"), for gamma-rays and cosmic-ray protons, respectively. The PDF for cosmic-ray protons was made using the OFF-source data. The L for cosmic-ray protons peaks at zero and that for gamma-rays peaks at 1. In this analysis, we accepted events with $L > 0.4$ after a "Distance" cut of $0.2 < Distance < 1.2$ and E-ratio< 0.25. E-ratio is the ratio of number of photoelectrons in another clusters to that in the maximum cluster [4].

The "Alpha" (image orientation angle) distributions, obtained after the above selections, are shown in Fig. 1. The histograms were normalized by OFF-source events with $\alpha > 30°$. The observation in 2001 has shown a considerable excess around $\alpha \sim 0°$, possibly indicating gamma ray signal with an energy threshold of about 400 GeV [12]. The data from the observation in 2002 year are added to analysis and now under study to correct for the effects due to noisy pixels etc.

4. Discussion and Conclusion

We have made observation of the Galactic Center region with the CANGAROO II telescope in the two years of 2001 and 2002. The data are analyzed with the 2D-Likelihood method. The preliminary results shows that alpha distributions of OFF-source data (2002) have possible systematic effects and it is still under investigation. Updated results of analysis will be presented in the conference, as well as about how different intensity and spatial extent of different radiation mechanisms of the Galactic Center emission.

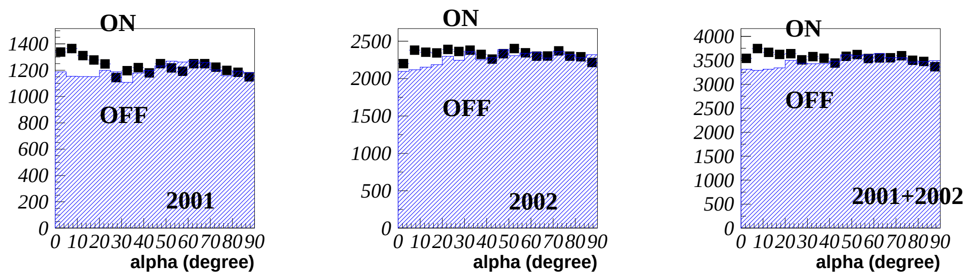

Fig. 1. Image orientation angle ("Alpha") distributions (from the left, 2001 data, 2002 data and all data). The points with statistical error bars are those for the ON-source runs and the hatched histograms are for the OFF-source runs. The normalization was carried out using events with $\alpha > 30°$.

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