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Status of CANGAROO-III

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Abstract: The CANGAROO-III telescope system for very-high-energy gamma-ray astrophysics consists of four 10-m atmospheric Cherenkov telescopes located near Woomera, South Australia. The construction of the fourth telescope was completed in summer 2003, and stereoscopic observations have been in progress since March 2004. Here we report on the status of the system and some recent results from CANGAROO-III observations.

Introduction

CANGAROO is an acronym for the Collaboration of Australia and Nippon (Japan) for a GAmma Ray Observatory in the Outback. After successful operation of the 3.8m imaging Cherenkov telescope (CANGAROO-I) for 7 years, which was the first of this kind in the southern hemisphere, we constructed a new telescope of 7m diameter (CANGAROO-II) in 1999 next to the 3.8m telescope near Woomera, South Australia (136°47′E, 31°06′S, 160m a.s.l.). Then the construction of an array of four 10m telescopes (CANGAROO-III) was approved and as the first step the 7m telescope was upgraded to 10m diameter in 2000, with this becoming the first telescope of the CANGAROO-III array (T1) [21]. Results from observations with this first 10m telescope have been reported in publications (see, e.g. [21]).

In the following years, we have constructed an additional three 10m telescopes located at the corners of a diamond of 100m sides with improved mirrors, cameras and electronics. After tuning, we have started observation with the full system in stereo mode in March 2004. Here we report recent results from stereo observations with CANGAROO-III.

Analysis

Details of analysis procedure of the CANGAROO-III stereoscopic data has been given in publications [5], so we just give brief description here. First, the Hillas image parameters were calculated for each image observed by telescopes. The intersection of the major axes of the event images points to the incident direction of the gamma ray in the stereoscopic observation. Gamma-ray events can be seen as a peak near the zero point in the θ^2 distribution, where θ is an angle of the intersection point and the assumed source direction.

We apply several methods to reduce background cosmic-ray events in order to extract gamma-ray signals: the square-cut method, the likelihood method, and the Fisher discriminant method. In the square-cut methods, images of which Hillas parameters, such as *widths* and *lengths*, are within the gamma-ray domain are selected, as was done in the first firm detection of the Crab nebula by the Whipple group [19].

In the likelihood method, we proceed by making probability density functions from the histograms of image parameters for each telescope, which are defined in each energy bin, are derived from Monte Carlo simulations for gamma-rays, and from real observation data for background events. Then, a probability (P) of the event being initiated by a gamma-ray or a hadron is assigned for each event. The likelihood ratio, $\mathcal{L}$, is defined as $\mathcal{L} = P(\text{gamma-ray})/[P(\text{background}) + P(\text{gamma-ray})]$, and with a certain cut in $\mathcal{L}$ we can enrich a gamma-ray fraction of the data sample.

Another method, the Fisher discriminant method, uses a linear combination of image parameters, but their coefficients are uniquely determined by a matrix inversion, where the matrix consists of means and errors of image parameters of gamma-rays (Monte Carlo simulation) and background (real data). This method is free from cut selection bias, and now it is utilized as the standard analysis of the CANGAROO-III data.

Recent results

The result of the Crab nebula, as a standard candle in the TeV region, is reported in ref.[5] in detail. Preliminary results of PSR 1706-44 and SNR SN1006 were reported in ref.[18].

Vela pulsar and nebula [5]

The Vela pulsar was observed in January/February 2004. After basic data quality check, a total of 1,311 minutes data were used for further analysis, where the minimum elevation angle was set at $60°$. The mean elevation angle was $70.9°$, corresponding to an energy threshold of 600 GeV. The observations were carried out using the same wobble mode. In this period, T2 and T3 were in operation, and we analyzed the stereo data from these two telescopes. The resulting θ^2 distribution for the Vela pulsar position showed no significant gamma-ray signal, giving upper limits which are consistent with H.E.S.S. results [3]. Also we did not see excess from the point offset by $0.13°$ from the pulsar, which was the maximum of the excess detected with the CANGAROO-I telescope [20].

The H.E.S.S. group detected a gamma-ray excess from the Vela X nebula, extended over a $0.6°$ radius from the center of the emission [(R.A., decl.) = $(8^{\rm h}35^{\rm m}, -45°36')$, J2000] [3]. In order to analyze extended emission, we applied the following method. Gamma-ray-like events can be extracted by fitting position-by position F (Fischer discriminant) distributions under the assumption that gamma rays obey the Monte Carlo predictions, the proton background follows the average F distribution of all directions, and the total distribution is a linear combination of those two. We chose the background region to be more than $0.8°$ from the center. An excess was observed at $\theta^2 < 0.6$ deg^2 around the center of the Vela X region. The excess radius is marginally consistent with H.E.S.S. considering our angular resolution. The total number of gamma-ray-like events is 561 ± 114. Though the statistical significance is below the 5σ level, this could be supporting evidence of the H.E.S.S. detection. The differential fluxes for the excess regions are in general agreement with H.E.S.S. result.

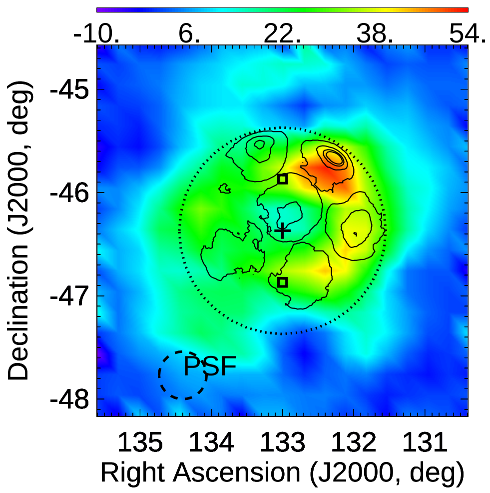

Figure 1: Excess event map around the SNR RX J0852.0-4622 obtained from the CANGAROO-III stereo observations in 2005 [6]. The vertical scale (number of events per pixel, $0.2^\circ \times 0.2^\circ$) is indicated in the top bar. The cross indicates the average pointing position, i.e., the center of the remnant and the squares the "wobble" pointing positions. The dashed circle of 0.23° shows the (1σ) point spread function. The dotted circle of 1 degree from the supernova center is also shown. Overlaid contours show X-ray intensity observed by ASCA GIS.

SNR RX J0852.0-4622 [6]

We already reported a gamma-ray signal from this SNR using observations by CANGAROO-II in 2001 and 2002 [12]. This time we applied the Fisher discriminant method to the stereo data for RX J0852.0-4622 observed in January and February 2005 using T2, T3 and T4 taken in the wobble mode. After the coarse selections, 1,129 minutes (ON) and 1,081 minutes (OFF) data were available. The excess count map is shown in Figure 1. The smoothing was carried out using the average of the center and neighboring eight pixels where the pixel size was $0.2^\circ \times 0.2^\circ$. The strong gamma-ray emission from the NW rim is obviously seen, which was first reported by CANGAROO-II [12]. The emission profile shows shell-like structure like that seen in X-rays. The differential energy spectra for the whole remnant is reasonably in agreement with that of H.E.S.S. [1]. The energy spectrum around the NW-rim was measured to be consistent with that of the whole remnant, i.e., flatter than that reported from the previous CANGAROO-II data. The difference can be partially explained by the deterioration of the hardware of the CANGAROO-II telescope.

Galaxy NGC 253

We reported the observation of diffuse gamma-ray emission from NGC253 based on data taken in 2000 and 2001 by CANGAROO-II, indicating a gamma-ray signal at 11σ level [8, 9]. H.E.S.S., however, claimed no detection from that direction [2]. We observed this source with three telescopes in 2004 using "wobble" mode in which the pointing position of each telescope was shifted in declination between ± 0.5 degree from the center of the galaxy. Analysis with 1,179 and 753 min. for ON and OFF observations, respectively, showed no significant excess from NGC 253, and we obtained upper limits for this source [10] (Fig. 2). We suspect there was a problem in the treatment of 'hot' channels in the imaging camera which led an apparent excess in the CANGAROO-II data (see [10] for details).

Blazar PKS 2155-304

In 2006 July/August, H.E.S.S. reported a large flare of this nearby ($z = 0.117$) blazar [4], and we observed this source as a Target-of-Opportunity observation. With 15 hours of data taken between July 28 and August 2, 2006, we detected a gamma-ray signal at 6.8σ level [17]. Follow-up observations between August 17 and 25 indicate the source activity had decreased. For details, see separate papers presented in this conference [17, 16].

Radio galaxy Cen A/glubular cluster ω Cen

We observed Cen A and ω Cen region in March–April 2004. The total observation times were 640 min for Cen A and 600 min for ω Cen. The analysis was carried out inside a one-degree (radius) circle from the average pointing position. We derived flux upper limits for regions containing the jet and inner lobes, the middle lobe, and portions of the outer lobes of Cen A, and center of ω Cen. The Cen A upper limits are an order of magnitude lower than previous measurements. The derived upper limits were used set constraint to the density of cold dark matter. Around the TeV region, we

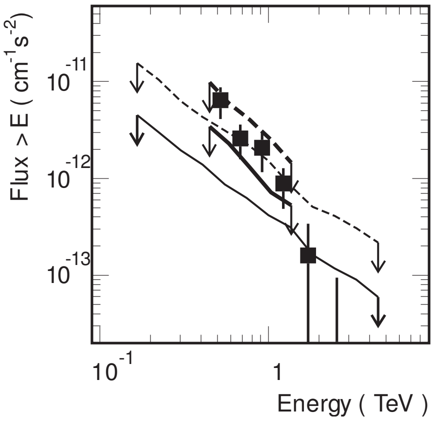

Figure 2: Upper limits on the gamma-ray flux from NGC 253 [10]. The points with error bars are the CANGAROO-II fluxes [8, 9]. The thin solid line is 99% upper limit (UL) by H.E.S.S. for point source assumption, and the thin dashed is that for 0.5 degree diffuse source [2]. The thick solid line is 2σ upper limit for this observation for point source assumption and the thick dashed line for 0.5 degree diffuse.

obtained upper limits of its density of $2M_\odot$ pc^{-3} for Cen A and $100M_\odot$ pc^{-3} for ω Cen. Note that the limit for Cen A is greater than its gravitational mass. See ref.[11] for details of this analysis.

Other sources

Reports on other sources are given in separate papers presented in this conference: PKS 2155-304 [17, 16], MSH15-52 [15], HESS J1804-216 [7], HESS J1303-631 [14], clusters of galaxies [13].

Summary

We have been carrying out stereo observations of sub-TeV gamma-rays with CANGAROO-III since March 2004. Results from stereo observations were presented: For two supernova remnants, the Vela SNR and RX J0852.0-4622, our results are consistent with the recent H.E.S.S. results. We could not confirm our detection of NGC 253 by the CANGAROO-II observations. For the flaring activity of PKS 2155-304 in July/August 2006, we detected time-varying gamma-ray flux from this source.

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