# Recent Results from CANGAROO-III

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**Abstract**. The CANGAROO-III telescope system for very-high-energy γ-ray astrophysics consists of four 10-m atmospheric Cherenkov telescopes located near Woomera, South Australia. We have been observing southern-sky objects since March 2004. Here we report on the status of the system and some recent results from CANGAROO-III observations.

## 1. Introduction: CANGAROO-III telescopes

CANGAROO, Collaboration of Australia and Nippon for a GAmma Ray Observatory in the Outback, has studied southern sky gamma-ray sources for 10 years by Imaging Atmospheric Cherenkov Telescopes located near Woomera, South Australia (31°S, 137°E). Our latest telescope array, CANGAROO-III, has been operational since March 2004 with 10-m mirror and stereoscopic coincidence to achieve higher sensitivity compared to the previous (10-m later) single telescope (CANGAROO-II).

The CANGAROO-III stereoscopic system consists of four optical telescopes. Each telescope has a prime-focus segmented parabolic reflector with 57 $m^2$ light collecting area and nanosecond-order time accuracy. The prime mirror consists of 114 spherical mirrors mounted on a parabolic frame with a focal length of 8m [1].

The first telescope, T1, which was originally the CANGAROO-II telescope [2] and upgraded later, is not used for recent observations due to its smaller field of view and higher energy threshold. The second, third, and fourth telescopes (T2, T3, and T4) have identical cameras and data-acquisition systems [3]. Inter-telescope stereoscopic trigger system, which was introduced in December 2004, enables n-fold stereoscopic coincidence (usually we use 2-fold). The telescopes are located at the east (T1), west (T2), south (T3) and north (T4) corners of a diamond with sides of 100m [4].

## 2. Analysis method

Here, we briefly describe CANGAROO-III analysis procedures, recent observations and results. More details about analysis procedures can be found in [5].

First, every PMT images for each telescope are cleaned by removing isolated hit-pixels and reduced into image moments, which indicate the incident gamma-ray direction [6]. Then the direction is determined event by event as the point from which three images can be seen narrowest.

Second, we use Fisher discriminant (hereafter FD) [7] to Discriminate gamma-ray evens from hadronic events. We calculate a linear combination of image moments:

$$FD = \vec{\alpha} \cdot \vec{P}$$

where $\vec{P} = (W2, W3, W4, L2, L3, L4)$ are energy-corrected widths and lengths for the T2, T3 and T4 and α is a constant vector. FD should show particular one-dimensional distribution for given P distribution. $P_{signal}$ and $P_{background}$ will be best separated when

$$\vec{\alpha} = \frac{\vec{\mu}_{sig} - \vec{\mu}_{BG}}{\vec{E}_{sig} - \vec{E}_{BG}}$$

Finally we calculate the number of gamma-ray like events by one-parameter fitting assuming $FD_{signalregion} = x\, FD_{gamma} + (1-x)\, FD_{background}$, where x is a fraction of gamma-ray signals.

## 3. Recent observations and results

Recent CANGAROO-III observations and results are summarized in table 1, which contains four detections and nine upper limits.

### 3.1. Extragalactic sources

3.1.1. *PKS2155-304.* [8] A nearby blazer PKS 2155-304, which was first detected in TeV gamma-rays by Durham group in 1999, is a time-variable TeV source. HESS group reported historically high TeV flux in 2006 July. Just after HESS alert we began follow-up observations and continued to August 2006. We detected gamma-ray excess. The 8 hour time difference between CANGAROO-III site and H.E.S.S. site provide better time coverage of flux monitoring.

3.1.2. *Abell 3667 and Abell 4038.* [9] Clusters of Galaxies are candidate sites of the origin of ultra high energy cosmic rays. Some theories predict TeV gamma-ray emission from Clusters of Galaxies by proton-photon and proton-proton interaction. We picked up two targets from the Abell Catalogue; Abell 3667 and Abell 4038. We obtained 2-sigma upper limits on their integral fluxes, which limit model parameters.

3.1.3. *Centaurus A.* [10] We observed a nearby Active Galactic Nuclei, Centaurus A for 10 hours in 2004. We found no gamma-ray excess above 420 GeV over one-degree radius from the pointing centre. This is consistent with the HESS result in 2004. Obtained flux upper-limit implies that Centaurus A is darker in TeV gamma-ray than expected from optical luminosity, assuming gamma-ray/optical ratio is same to our galaxy.

3.1.4. *SN1987A.* [11] There is a prediction of TeV gamma-ray from SN1987A Increasing with time after explosion. We observed this target by CANGAROO-II in 2001 and by CANGAROO-III in 2004 and 2006. We had no excess in 2001, 2004 and 2006, including some other candidate sources in this region of Large Magellanic Cloud. Thought the predicted flux is under our sensitivity now, next generation Cherenkov telescope array such as CTA is expected to detect gamma-ray signals from SN 1987A near future.

### 3.2. Galactic sources

3.2.1. *MSH15-52.* [12] TeV gamma-ray emission from Pulsar Wind Nebula MSH15-52 was detected by HESS group in 2004. We had follow-up observations by CANGAROO-III from April 2006 to June and took 48.6 hours data and 582 excess events. Morphology and flux were consistent with H.E.S.S.

3.2.2. *HESS J1804-216.* [13] This source was found by HESS galactic plane survey in 2004. We had follow up observation by CANGAROO-III from 2006 June to August. We had 62.5 hours data and 920 excess events. Morphology and flux ware consistent with H.E.S.S.

**Table 1.** Summary of recent results from CANGAROO-III.

| Detection | Target | Category | Comment | Obs hours [hours] | |
|---|---|---|---|---|---|
| **Detection** | MSH15-52 | PWN? | PSR 1509-58 | 48.6 | [12] |
| **Detection** | PKS2155-304 | Blazer | z=0.117 | 10.5 | [8] |
| **Detection** | HESS J1804-216 | UnID | HESS source | 62.5 | [13] |
| **Detection** | HESS J1303-631 | UnID | HESS source | 35 | [14] |
| **Upper limit** | Abell 3667 | Clusters of Galaxies | z=0.055 | 29.7(On) / 23.7(Off) | [9] |
| **Upper limit** | Abell 4038 | Clusters of Galaxies | z=0.028 | 23.8(On) / 17.7(Off) | [9] |
| **Upper limit** | Centaurus A | AGN | z=0.0018 | 10 | [10] |
| **Upper limit** | ω Centaurus | Globular Cluster | | 10 | [10] |
| **Upper limit** | SN1987A | SNR | LMC | 10.5 (2004) / 21.8 (2006) | [11] |
| **Upper limit** | SNR N157B | SNR | LMC | 21.8 | [11] |
| **Upper limit** | 30 Dor C | SNR | LMC | 21.8 | [11] |
| **Upper limit** | LMC X-1 | X-ray binary | LMC | 21.8 | [11] |
| **Upper limit** | PSR B0540-69 | Pulsar | LMC | 21.8 | [11] |

## 4. Conclusion

We summarized recent CANGAROO-III results, which were obtained by the CANGAROO-III standard analysis. There were four detections and nine upper limits, including confirmations of H.E.S.S. results.

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