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Recent status of the analyses for stereoscopic observations with the CANGAROO-III telescopes

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CANGAROO-III is an array of four 10m-diameter imaging atmospheric Cherenkov telescopes to search for sub-TeV gamma-rays from celestial objects in collaboration with Japanese and Australian institutions, which is located in southern hemisphere (Woomera, South Australia). Three of four telescopes were made with the same design for stereo observation. We have started observations in stereo mode using those three telescopes since March 2004.
We report the recent status of the analyses for stereo observations including several targets of which our previous data are inconsistent with the recent HESS results.

1. Introduction

The CANGAROO project began in 1992 to investigate TeV gamma-ray astronomy in southern hemisphere using an imaging air Cherenkov telescope at Woomera, South Australia (136°.47'E, 31°.06'S). Since 2002, we have constructed three 10m imaging telescopes for the stereo observation. The first 10m telescope built in 1999 was designed for a single mode observation, which has a relatively narrow field of view of 2.8 degree (designated T1). New three telescopes (T2, T3, and T4) have the same cameras of which field of view is a relatively wide of 4 degree for the stereo observation. In 2003 March, we started a stereo observation using the two 10m telescopes (T2 and T3), and since 2004 April the stereo observation using three 10m telescopes (T2, T3, and T4) has been continuing. Each 10m telescope has a 10m diameter reflector consisting of 114 spherical mirror segments with the diameter of a 80cm and the curvature radius of 16.4m on average, which are made of Fiber Reinforced Plastic (RFP) as the base material[1]. They are aligned on a parabolic frame with f=0.77, i.e., a focal length of 8m. The 10m telescopes including T1 are located on the corners of a diamond, of which distances of T2 - T3 and T2-T4 , T3-T4 are 100m, 100, and 170m respectively. The camera of those three telescopes consist of 427 3/4inch photo-multipliers aligned in hexagonal shape with a field of view of 4 degree [2]. Both timing and integrated charge of signals of all PMTs are measured by multi Timing digital converters and analog to digital converters. Calibration of the camera was carried out using the LED system in every observation. Also the total performance of the telescopes including the light collection efficiencies are monitored using measured cosmic muon ring events. Details of the calibration for the mirror and the analysis of the cosmic muon events are presented in this conference [3,4].

Since the start of the stereo observation, more than ten objects have been observed by stereo observation. The Crab nebula was observed every year in order to study the stereo analysis method, which will be reported in this conference [5]. Table1 summarizes the target list observed by the CANGAROO-III stereo telescope system. Summary of the observations for AGNs will be presented in this conference [6].

Here we report the present status of the analyses for three targets RX J0852.0-46.22, PSR1706-44, and SN1006. RX J0852.0-46.22 was observed at first by the CANGAROO-II single 10m telescope (T1) [7] and sub TeV gamma-ray emission from the intense X-ray emission region with about 1/10 of the Crab flux level, and recently HESS group detected sub TeV gamma rays from the whole SNR region with the similar flux to the Crab by stereo observation [8]. TeV gamma-ray emission from PSR1706-44 was reported by CANGAROO-I in 1995 [9] and also the Durham group reported the detection of TeV gamma ray emission in 1998 [10]. Also the TeV gamma-ray emission from SN1006 northwest rim was reported by CANGAROO-I in 1998 [11]. However, recently the HESS group reported the severe upper limits for TeV gamma ray emissions for both PSR1706-44 and SN1006 by stereo observation in both sub TeV and TeV regions, which are about one order below our reported fluxes. Then we concentrated the observation time of the CANGAROO-III telescopes for those two targets by stereo observation. Also RX J0852.0-46.22 was observed by stereo observation in order to investigate the difference of the fluxes between CANGAROO-II single telescope observation and HESS stereo observation [12,13]. Recently result on the Vela by CANGAROO-III stereo observation has been submitted [14], of which result of CANGAROO-I was inconsistent with the severe upper limit by the HESS group [15].

Table 1. Target list observed by stereo observation,. In some targets, observation time includes off-source time.

Target name	Obs. Time (hrs)	Target name	Obs. Time (hrs)
47 Tuc	13.6	RCW 86	38.6
NGC 253	33.8	SN1006	40.7
Crab	53.9	PSR 1509-58	63.0
SN1987A	13.6	PSR 1706-44	36.9
RX J0852.0-4622	46.1	RX J1713.7-3946	44.0
Mrk 421	8.1	Kepler SNR	23.7
PSR 1259-63	20.6	Sgr A*	23.4
Cen A	21.7	Galactic disk	66.0
ω Cen	21.4	W44	17.4
M83	13.3	PKS 2155-304	43.9

2. Observations

RX J0852.0-4622 was observed in 2004 January and 2004 February by stereo mode using two telescopes of T2 and T3. Observation was carried out with the wobble mode, in which the telescopes tracked the position of a ±0.5degree north and south apart from the X-ray intense emission point in the northwest rim of the SNR (α=132^{o}.245,δ=-45^{o}.65 J2000) alternatively in 20minute interval. In total, we observed 2197 minutes in the wobble. After the coarse selections based on the weather and telescope system conditions, 1204 minutes data was available for the analysis. We used the X-ray maximum emission point as a target point in the wobble observation. In this pointing, the field of view of the telescopes with the diameter of 4 degree enabled us to analyze more than 2/3 of the whole SNR by stereo analysis method including the whole northwest rim, the strongest non-thermal X-ray emission region in the SNR. Also we could take an off –region in the northern part of the field of view where only a small part of SNR was included.

The observation of SN1006 was carried out in 2004 May by stereo mode using three telescopes of T2, T3 and T4, where T4 was already available since 2004 April. Due to the two brighter stars (magnitude 3.4 and 2.8) near the SNR inside the field of view, we adopted the long on-off mode observation. In wobble mode two dead regions (several PMTs were turned off when a star passing) in the field of view cause a different acceptance of the field of view for on and off regions, which may result in some unexpected systematic errors. On the other hand, a long on-off observation mode give us the same field of view by removing the same regions as the dead regions in the on –source by two bright stars at the off-line analysis. The telescopes were tracked at the center of the SNR (α=225^{o}.592, δ=-41^{o}.897 J2000), and then the northwest rim (α=225^{o}.971,δ=-41^{o}.758 J2000) where we reported the TeV gamma-ray emission rotated with the radius of a 0.25degree around the SNR center, and we have a relatively flat acceptance for the whole SNR with the diameter of about 0.5 degree. We observed for 1786 minutes and 1883 minutes for on-source and off –source regions, respectively. After the coarse selection, about 1625 minutes for on-source and 1738 minutes for off –source data remained for the off-line analysis.

The observation of PSR1706-44 was carried out in 2005 June by stereo observation of above three telescopes, and also we adopted the long on-off mode observation by the same reason as that for SN 1006 (a bright star of magnitude 3.4 near this target in the field of view). The telescopes tracked the position of this pulsar (α=257^{o}.42,δ=--44^{o}.48 J2000) . We observed about 1780 minutes for on source and 1725 minutes for off –source, respectively. After the same coarse selections, about 1330 minutes and 1300 minutes on-source and off –source data were used for the off-line analysis.

For those three objects, three telescopes were operated independently. The hit timings of all telescopes were collected to the T2 telescope, and T2 on-line system recorded the time differences of the triggers generated by T3 and T4. Therefore stereo observations of the coincidences between T2 & T3, T2 &T4, and three telescopes are available, where the hit of T2 was required for the stereo observation. Event rates after the stereo requirement (at least two telescopes out of three have a typical shower image) was about 10Hz at the zenith. About 50% of the stereo events include three telescopes hits. Since 2004 December, we have started the hardware stereo trigger system, which selected the stereo events in which at least any two telescopes hits within several hundred ns (detail will be presented by in this conference [16]).

3. Analysis & Conclusion

Analyses for those three objects are ongoing, and we will present the status of the analyses including some results at the conference and final version of the proceedings. Results on the radio galaxy, Cen-A, and the Galactic disk emission are reported separately [17,18] in this conference.

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