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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 in southern hemisphere using an imaging air Cherenkov telescope at Woomera, South Australia (136^{o}.47'E, 31^{o}.06'S). Since 2002, we have constructed three 10m telescopes for the stereo observation. The first 10m one built in 1999 was designed for a single mode observation, which has a narrow field of view of 2^{o}.8 (designated T1). New three ones (T2, T3, and T4) have the same cameras (4^{o} F.o.V) 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 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 [1]. They are aligned on a parabolic frame with f=0.77, i.e., a focal length of 8m. Four telescopes 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 cameras of those three telescopes consist of 427 3/4inch photo-multipliers aligned in hexagonal shape [2]. 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]. Summary of the observations for AGNs will be also presented in this conference [6].

Here we report the present status of the analyses for three targets RX J0852.0-4622, PSR1706-44, and SN1006. RX J0852.0-4622 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 J0852.0-4622 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].

2. Observations

RX J0852.0-4622 was observed in 2004 January and February by stereo mode using T2 and T3. Observation was carried out with the wobble mode, in which the telescopes tracked the position of a $\pm 0^{o}.5$ 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. After the coarse selections, 1204 minutes data was available. We used the Northwest rim as a target point in the wobble mode. The observation of SN1006 was carried out in 2004 May by stereo mode using T2, T3 and T4. Due to the two brighter stars (magnitude 3.4 and 2.8) near the SNR inside the FoV, 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 FoV cause a different acceptance 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 FoV 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 northeast rim (α=225 ^{o}.971,δ=-41 ^{o}.758 J2000) where we reported the TeV gamma-ray emission rotated with the radius of a $0^{o}.25$ around the SNR center. 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. 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

For all analyses described here, the two telescopes of T2 and T3 were used. For a stereo event, timing coincidence of two telescopes within ± 100μs was required in analysis. Then for each telescope, we required the minimum deposited photoelectron in each photo-multiplier (PMT) with > ~6 p.e. and the clustering of at least 5 adjacent hit PMTs. Also timing concentration of hit PMTs within ±~25ns, the removal of the cloudy condition, and the elevation angle cut with $>60^o$ were applied.

HESS showed the extended TeV gamma ray emission from RX J0852.0-4622 over about 1^o circle region. In order to estimate the background, we used the data of the Vela region, which is only about 3 degree far from this target, and observed at the same time. For the data passing through above coarse selection, we applied the Fisher Discriminant method to estimate the content of gamma ray like events. In this method, effectiveness of the parameters for the gamma ray like event selection is evaluated using the simulation, and we can optimize the weights of the parameters in estimating the probability of gamma ray like events. Here we used two parameters, “Length” and “Width”. Detail of it is described elsewhere [15]. Finally the content of gamma-ray events was obtained with about 7 σ in the wide range θ^2 distribution around the SNR center (Fig.1) by the comparing the Fisher Discriminant values between the background region and on-region.

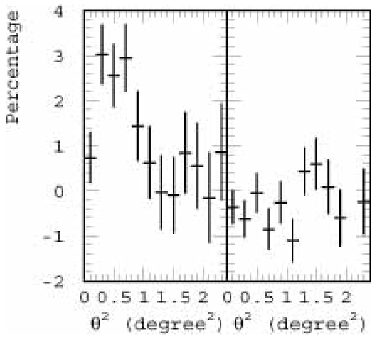

Fig 1 Preliminary θ^2 distribution around RX J0852.0-4622 center

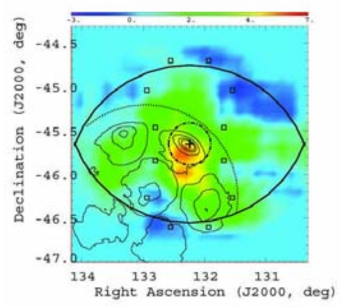

Fig 2 Preliminary morphology of gamma ray like events

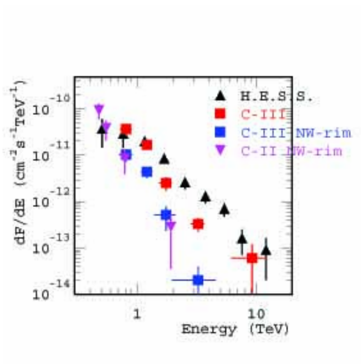

Fig 3 Preliminary differential fluxes

Figure 1 indicated that the gamma-ray emission extends over 1^o radial circle. The Vela region was used as a background region. Figure 2 shows the morphology of gamma ray like events. Te region inside the solid arcs shows the maximum acceptance region, which is an overlap of the two FoVs by the wobble mode. Also the one-degree arc from the SNR center is indicated by the dotted line. The strong gamma-ray emission from the NW rim is obviously seen, which was first reported by the CANGAROO-II. Furthermore we re-estimated the gamma ray like events using the region outside the maximum acceptance in Fig.2 as a background region, and obtained flux and morphology were consistent with the above results. This maximum acceptance region covers about a half of the whole SNR, and the integrated flux above 0.81 TeV is about 60% of the H.E.S.S., which seems explainable due to our coverage of the SNR. The differential flux obtained from this region is plotted in Fig.2 with H.E.S.S. result. Our spectrum looks slightly softer than that of H.E.S.S. Also since CANGAROO-II observed only the gamma rays around the NW-rim as shown dot-dashed circle in Fig.3, we extract gamma ray like events within the stereo angular resolution of $0^o.23$ radius and obtained differential flux are potted in Fig.4 with the CANGAROO-II result. The both results seem consistent with statistical errors. Here possible systematic error of 25% is estimated mainly due to the background subtraction and positional ambiguities of acceptance. Therefore, the accuracy of the power index is too poor to compare with that of the NW-rim and the half region of the SNR.

For SN1006 data, after applying the first step cut mentioned above, the likelihood method are applied to reduce the hadron like events, where "Length" and the distances between the intersection point and the center of the shower image (IP-distance) were used. Figure shows the preliminary θ^2 distribution around the NE rim point where TeV gamma ray emission was reported by CANGAROO-I [11]. In this time there is not seen any peaks around this point. Very preliminary integral upper limit with 2σ level is ~3x10^{-12}cm^{-2}s^{-1} above ~500GeV. Also for PSR1706-44 data was also examined using the simple square cuts for Length and IP-distance, and the preliminary θ^2 distribution around the pulsar position was obtained as shown in Fig.5 There is not seen any peak, and very preliminary integral upper limit with 2σ level is ~5x10^{-12}cm^{-2}s^{-1} above ~600GeV. Independently Fisher Discriminant was applied for both data, and their results were consistent with those in Figs.4 and 5.

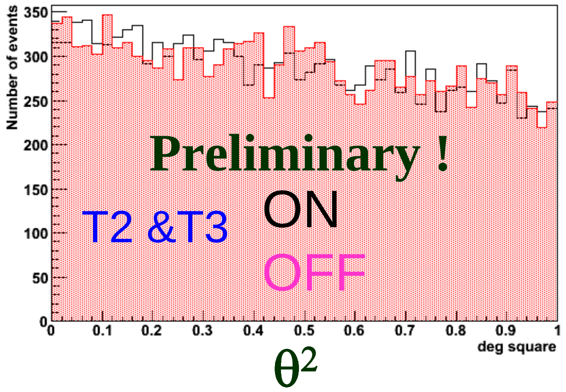

Fig 4 Preliminary θ^2 distribution of SN1006 above ~500GeV

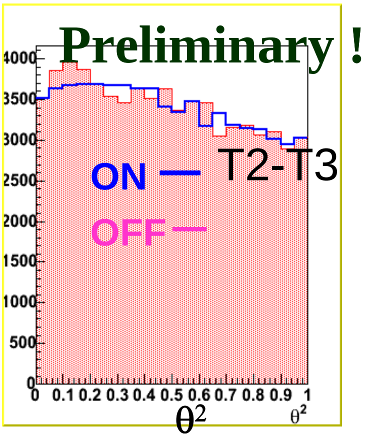

Fig 5 Preliminary θ^2 distribution of PSR 1706-44 above ~600GeV

Now we are analyzing the data using three telescopes, and also fixing the analysis method to the likelihood or Fisher Discriminant. Another preliminary results on the radio galaxy, Cen-A, and the Galactic disk emission are reported separately [17,18] in this conference.

References

[1] S.Kabuki.et al., Nucl. Instr. & Meth. A 500, 318 (2003).
[2] A.Kawachi et al., Astropart. Phys. 14, 261 (2001)
[3] R.Kiuchi et al., 29 th ICRC, Pune(2005)
[4] T.Yoshikoshi et al., 29 th ICRC, Pune(2005)
[5] T.Nakamori et al., 29 th ICRC, Pune(2005)
[6] Y.Sakamoto et al., 29 th ICRC, Pune(2005)
[7] H.Katagiri et al., Astrophys. J. 619, L163 (2005)
[8] F.Aharonian et al., Astron. & Astrophys.437, L7 (2005)
[9] T.Kifune et al., Astrophys. J. 438, L91 (1995)
[10] P.M.Chadwick et al., Astropart. Phys. 9, 131 (1998)
[11] T.Tanimori et al., Astrophys. J. 497, L25 (1998)
[12] F.Aharonian et al., Astron. & Astrophys.437, 135 (2005)
[13] F.Aharonian et al., Astron. & Astrophys.432, L9 (2005)
[14] K.Nishijima et al., 29 th ICRC, Pune(2005)
[15] R.Enomoto et al., submitted
[16] Khelifi et al.,AIP Conf. Proc. 745:High Energy Gamma Ray Astronomy 745, 335(2005)
[17] S.Kabuki et al., 29 th ICRC, Pune(2005)
[18]M.Ohishi et al., 29 th ICRC, Pune(2005)