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Observation of TeV gamma rays from the NE-rim of SN1006 with CANGAROO-II 10m telescope

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Abstract. Observation of the North East (NE) rim of SN1006 has been carried out using the CANGAROO-II 10m telescope in April and May 2000. The observation time is 55.2 and 48.8 hours, ON- and OFF-source runs, respectively. We have confirmed TeV Gamma-ray emission from the NE-rim. The energy threshold of the observed flux is estimated to be around 1 TeV by the Monte Carlo simulation assuming the inverse Compton like spectrum. The preliminary flux is consistent with the previous result observed by the 3.8m CANGAROO telescope.

1 Introduction

As a candidate of an acceleration source of cosmic rays, the shock front of the supernova remnant is considered to be most promising. Recently, the non-thermal X-ray emission, assuming the synchrotron radiation, was observed from the supernova remnant SN1006 by ROSAT (Willingale et al., 1996) and ASCA (Koyama et al., 1995). SN1006 (G327.6+14.6) is a shell-type SNR having two northeastern and southwestern (distant from about 0.6 degree each other) rims brighten by radio and X-ray, while no apparent central engine for producing high energy particles such as a neutron star or black hole is observed inside of it. The X-ray spectrum of ASCA indicated the possibility of the high energy gamma rays due to inverse Compton scattering process with those electrons. These are strong evidences of an existence of high energy electrons accelerated up to ∼100 TeV in the shock front of this SNR.

Subsequently, TeV gamma-ray emission was detected from the North Eastern(NE) rim of SN1006 by the 3.8m CANGAROO air Čerenkov telescope, of which integral flux observed was $(4.6 \pm 0.6_{\rm stat} \pm 1.4_{\rm sys}) \times 10^{-12} {\rm cm}^{-2} {\rm sec}^{-1}$ ($E_\gamma > 1.7 \pm 0.5$ TeV) with the 7.7σ significance level (Tanimori et al., 1998). Soon TeV gamma rays were also detected from other SNR, the northwestern rim of the SNR RXJ1713.7–3946 (Muraishi et al., 2000; Enomoto et al., 2001b). This SNR was recently found by the ROSAT all-sky survey (Pfeffermann et al., 1996), and its strong non-thermal emission was detected by the ASCA (Koyama et al. , 1997) . These results have supported that the detection of high energy gamma ray from SNRs becomes a good probe for investigating the origin of cosmic rays.

On the otter hand, there is a negative result for the gamma ray emission from SN1006 at 300 GeV (Chadwick et al.,

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Period	ON (selected)	OFF (selected)
April 1 – 11	13.6 (11.2)	14.0 (11.3)
April 27 – May 11	41.6 (41.0)	33.9 (33.6)
Total	55.2 (52.2)	48.8 (44.9)

Table 1. The observation time (hours) for this analysis.

2000). We should confirm the TeV gamma-ray emission, which is one of most significant motivations of the CANGAROO-II project. Even after the confirmation of TeV gamma-ray emission from SN1006, the spectral study will tell us what kind of particles are accelerated and generate gamma rays. For example, the model based on the inverse Compton mechanism predicts the break of the gamma-ray spectrum around 1 TeV region.

With these motivations, the NE-rim of SN1006 was observed by the CANGAROO-II 10m telescope, in April and May 2000. In this observation, the telescope was pointed to the NE-rim, where TeV gamma rays were found in the previous observation. Here we report a preliminary result of this observation.

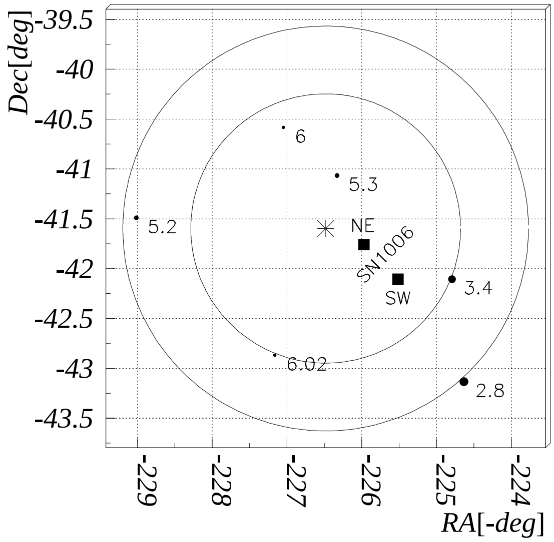

Fig. 1. Star field map around SN1006. The centre of these circles is shifted tracking position $(\mathrm{R.A., Dec}) = (+0.51°, +0.16°)$. The inner circle means the boundary of the trigger region, and the outer is that of field of view.

2 Observation

The observation was done using the CANGAROO-II 10m telescope at the near by Woomera, South Australia (136°47' E, 31°06' S). This Imaging Air Čerenkov Telescope (IACT) has 114 small mirrors on the 10.4m ϕ parabolic frame. On the imaging camera, 552 photo-multiplier tubes (1/2"ϕ PMTs) covered $2.76° \times 2.76°$ as a field of view. The charge and arrival timing are recorded by Analogue to Digital Converter (ADC) and Time to Digital Converter (TDC), respectively (Mori et al. , 1999; Mori et al., 2000; Kubo et al., 2001).

The field of view of ON-source contains two 3.4 and 2.8 magnitude stars by 0.9 and 1.7 degree from the NE-rim, respectively. In order to avoid these effects, tracking position of the telescope was shifted by $(\mathrm{R.A., Dec}) = (0.20°, 0.25°)$ or $(0.51°, 0.16°)$, from the source position (NE-rim), respectively. The total observation times were 55.2 and 48.8 hours, for ON- and OFF-source runs, respectively.

3 Analysis

3.1 Calibration

The ADC and TDC information recorded for individual PMTs were calibrated using the events triggered with a blue LED flasher before each observation. Using this data, field flattening of each PMT and correction of the time-walk effect of arrival timing were done.

3.2 Data selection

In order to keep the effects of weather conditions as small as possible, we used only the data observed in the good sky condition. This classification was done by checking the variation of the air shower rate during the observation. Then the resulted good quality data of 52.2 and 44.9 hours were obtained, for ON- and OFF-source runs, respectively (table.1).

Since SN1006 is located near the Galactic plane, the ADC value of hit pixel may include more effects due to the brighter night sky background. These noise photons possibly distort the shower image. Those effects were eliminated as following; pixels should have greater than $\sim$ 10 photoelectrons, within 25 nanoseconds from the timing centre of event, and at least four adjacent hit of pixels were required. In addition, some PMTs of which counts are quite exceeded over the averaged counts of other PMTs were removed.

3.3 Image cut

In this analysis, the NE-rim is treated as a point source from the previous result. We applied the standard image cut technique (Hillas, 1985; Weekes, 1989), and used the conventional imaging parameters of "Alpha", "Distance", "Length" and "Width". Here a new parameter of "Eratio" was adopted to select the major part of the shower in the complex image, which is the ratio between the most energetic (having the largest photoelectrons) cluster and other clusters in one image (Enomoto et al., 2001b),

$$\mathrm{Eratio} = \frac{\sum E_{\mathrm{other}}}{E_{\mathrm{max}}}. \quad (1)$$

After selecting the most energetic cluster, above image parameters were calculated only for this cluster.

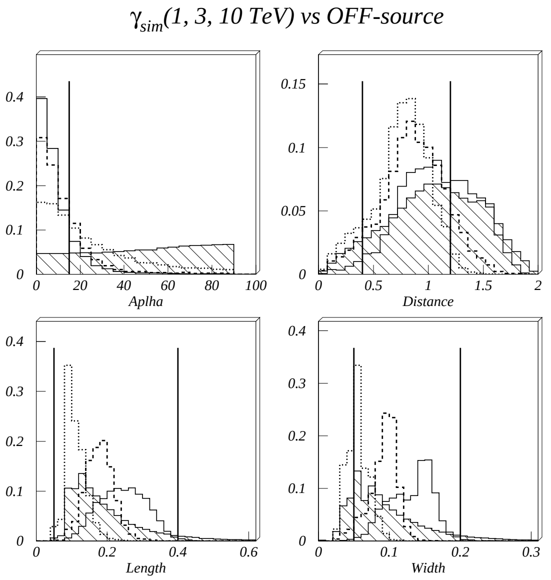

Fig. 2. The image cut criteria of gamma-ray selection. The solid line is 1TeV, the dashed one is 3TeV, the dotted one is 10TeV, respectively, by gamma-ray simulation, and the hatched histogram is OFF-source run data.

Following criteria were adopt to enhance gamma-ray events.

$$0.40 < \text{Distance} < 1.20 \quad (2)$$

$$0.05 < \text{Length} < 0.40 \quad (3)$$

$$0.05 < \text{Width} < 0.20 \quad (4)$$

$$\text{Length} < \text{Distance} \quad (5)$$

$$\text{Eratio} < 0.43 \quad (6)$$

Here energy dependences of the image parameters are not taken into account yet, and then there still remains the possibility of increasing detected gamma-ray events.

3.4 Simulation

The Monte Carlo simulation was carried out based on the above selection criteria and observation condition. GEANT 3.21 code (CERN, 1994) is used as a framework of particle tracking in the CANGAROO-II standard simulation code (Enomoto et al., 2001a). It included the details of the structure of CANGAROO-II telescope, for example, the small deformation of spherical mirrors. In addition, the atmosphere attenuation by Rayleigh scattering, the mirror reflectivity, and the quantum efficiency of PMT, are included as functions of wavelength of Čerenkov photon.

Gamma-ray events were generated in the energy range from 100GeV to 10TeV, assuming the energy spectrum of $E^{-2.3}$, which was from the previous result (Tanimori et al., 2001). The effects of the elevation angle and that of tracking offset were taken into account in the simulation. Figure 3 shows the effective detection area as a function of gamma-ray energy obtained by the simulation. The energy threshold, defined where the event rate becomes maximal, is estimated to be around 1 TeV.

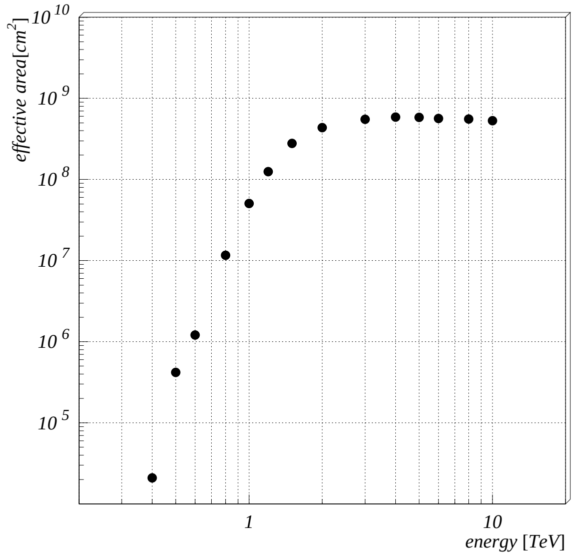

Fig. 3. Effective detection area versus gamma-ray energies.

4 Result and discussion

By the above analysis, the excess appears in the "Alpha" distribution as shown Figure 4(a). The OFF-source data was normalized to ON-source data (by using $30^\circ <$ Alpha region), and the region of $\mathrm{Alpha} < 15^\circ$ was recognized gamma-ray signals. Figure 4(b) shows the residual after subtracting the OFF-source from the ON-source, where the excess count is 568.4 ± 87.7. Its significance level is 6.5σ. Threshold energy is estimated to be about 1 TeV, which is reasonable considering the high noise cut level (∼10 photoelectrons). The integral flux of gamma ray was estimated to be $(6 \pm 1_{\mathrm{stat}}) \times 10^{-12}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ at $\sim$ 1 TeV (preliminary).

5 Conclusion

The NE-rim of SN1006 has been observed during 52.2 hours in April and May 2000, using the CANGAROO-II 10m telescope. TeV gamma-ray signals from SN1006 NE-rim were detected at the same direction reported by Tanimori et al. (1998) with 6.5σ statistical significance level. The integral flux of gamma ray observed is estimated to be $(6 \pm 1_{\mathrm{stat}}) \times 10^{-12}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ above $\sim$ 1 TeV (preliminary). This observed flux is consistent with the previous result. This is still a preliminary result, nevertheless we have certainly confirmed the gamma-ray emission from the NE-rim of SN1006.

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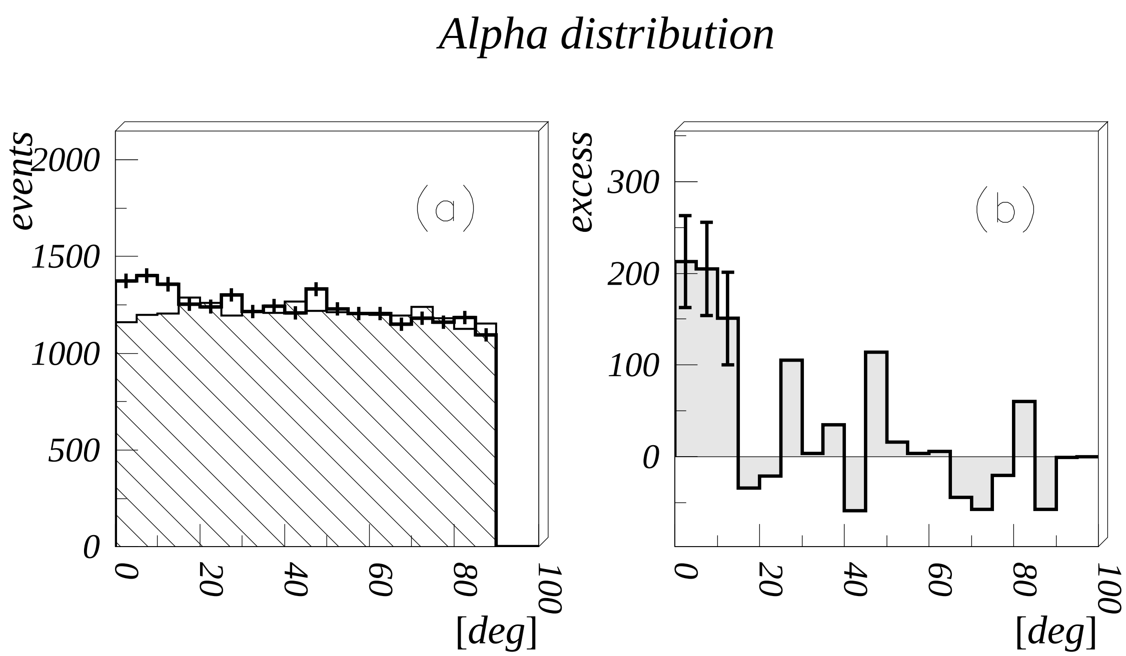

Fig. 4. "Alpha" distribution of SN1006 NE-rim (preliminary). (a) "Alpha" distribution for ON-source run (the blank histogram with error bars) and for OFF-source run (the hatched one). (b) is the background subtracted signal.

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