Observations of PSR 1706−44 with CANGAROO-II telescope

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Abstract. The PSR 1706−44 has been observed with the CANGAROO-II 10m telescope in Woomera, South Australia. The total observation time was about 30 hours each for both ON-source and OFF-source data. The energy threshold was estimated to be around 400 GeV by Monte Carlo simulations. The preliminary result of the detected gamma-ray flux around 1 TeV was consistent with previous results.

1 Introduction

The pulsar PSR 1706−44 is a young neutron star with a period of 102 ms and a large spin-down luminosity of 3.0×10^{36} erg $\cdot$ s^{-1}. It was originally discovered by Johnston et al. (1992) during a high-frequency radio survey of the southern Galactic plane. PSR 1706−44 was detected as a pulsed GeV gamma-ray source by EGRET aboard the CGRO (Thompson et al., 1992). Following this, the CANGAROO group detected TeV gamma rays from the region of the pulsar using the CANGAROO 3.8m telescope (Kifune et al., 1995). The detected TeV gamma rays were unpulsed. The unpulsed TeV gamma-ray emission ($\geq$300 GeV) was confirmed by the Durham Mark 6 telescope (Chadwick et al., 1998). In the X-ray band only weak unpulsed components were detected by ASCA (Finley et al., 1998) and ROSAT (Becker et al., 1995). A faint nebula around the pulsar was reported by these X-ray observations, and if a synchrotron nebula exists, it is very faint and the magnetic field strength seems to be the same order of that in the Galaxy. The energy density of the Cosmic Microwave Background (CMB) far exceeds that of synchrotron radiation in the nebula. In such a circumstance, high energy gamma rays are expected to be emitted by Inverse Compton (IC) scattering of high energy electrons with the CMB photon. Because the energy density of CMB is constant in all space and well-known, the energy spectrum of IC radiation of PSR 1706−44 can be predicted fairly quantitatively using its synchrotron spectrum. However, a theoretical model based on the IC process can predict only less than one tenth of observed TeV gamma-ray emission due to the faint

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X-ray emission from this nebula (Aharonian et al., 1997). They proposed the different positions of the TeV and X-ray emissions in the nebula system.

In 1999 the new CANGAROO-II 7m telescope observed PSR1706−44, and the differential spectrum above 700 GeV (Tanimori et al., 2001) was obtained. This data indicated a possible break of the spectrum around 1 TeV which is predicted from the IC model. To investigate this more closely, observations covering a wide energy range are essential and we have observed the pulsar again in 2000 using the expanded 10m CANGAROO-II telescope.

2 Observations

We observed PSR 1706−44 in June and July 2000 with the CANGAROO-II 10m telescope. The details of the 10m telescope are described in elsewhere (Kubo et al., 2001; Mori et al., 2001). Observations are summarized in Table 1.

Observations each night were carried out both for gamma rays from the target source (ON-source), and for background cosmic rays (OFF-source). The direction of PSR 1706−44 is Right Ascension (R.A.) 257.°43, and declination −44.°48. We have observed PSR 1706−44 near its culmination at a zenith angle of $\sim$ 18 °. Usually, the telescope tracks the target object at the center of the ON-source field of view. In these observations, the camera center was shifted from PSR 1706−44 by 0.°1, since bright stars exist near to PSR 1706−44, especially η Sco (magnitude 3.4) which is 1.°4 from the pulsar. The OFF-source observation tracks the same declination as that of the ON source with an offset R.A., since the threshold energy of gamma-rays depends on the source elevation. Considering the weather and humidity, only data taken under good conditions were used. Calibration runs were done in every observation to measure the relative gains of the photomultipliers (PMTs) using the 20ns wide light pulses emitted from a blue LED located at the center of the reflector.

3 Analysis procedure

The imaging camera of CANGAROO-II has 552 pixels consisting of half-inch PMTs. The camera measures both number of photoelectrons (ADCs) and arrival times (TDCs) in each tube. The online event trigger requires more than 4 PMTs to detect at least $\sim$ 3 photoelectrons. The trigger condition favors air shower events against accidental events caused by the night sky background and/or electronic noise. The arrival time measurement in each PMT is useful for distinguishing marginal events from accidental ones. Each event is corrected for the time jitter using the LED calibration data, and the averaged arrival time is adjusted. After these calibrations, we selected the events within 40 nanoseconds from the center of the arrival timing distribution. Since the night sky background deforms imaging parameters, a "cluster" cut is applied to remove PMTs triggered due to the night sky background or electronic noise. We selected PMTs exceeding $\sim$ 3.8 photoelectrons and having more than 4 adjacent hits.

Atmospheric Cherenkov telescopes detect not only gamma rays but also a huge amount of cosmic rays as air shower events. The cosmic ray background should be rejected further by the analysis. The "Imaging Technique" (Hillas, 1985) has proven to be a powerful method for rejecting background

Table 1. Observation time of PSR 1706−44 with CANGAROO-II during 2000.

	ON		OFF	
	observed	analyzed	observed	analyzed
June	24h49m	10h42m	19h10m	8h12m
July	25h37m	16h54m	28h59m	13h30m
Total	50h26m	28h36m	48h 9m	21h42m

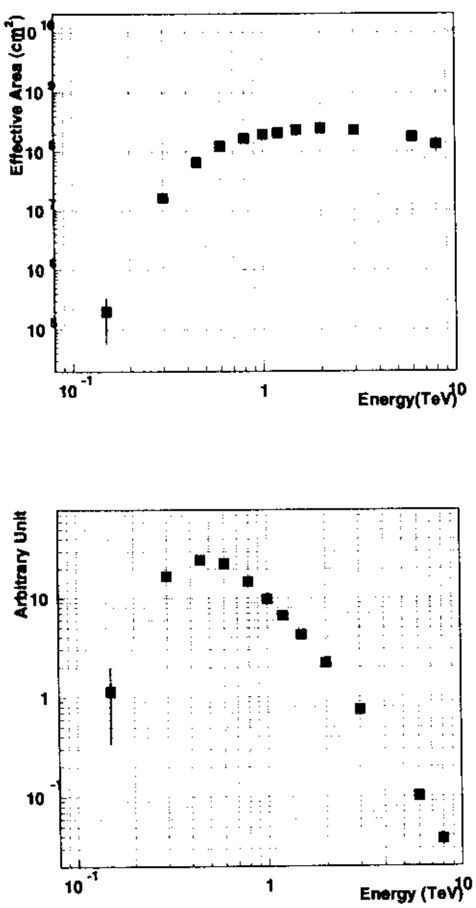

Fig. 1. Simulated effective area (upper) and spectrum (lower) for gamma rays for the PSR 1706−44. Differential power index is −2.5.

events. In this analysis, "Distance", "Length", "Width", and "Alpha" were used. In order to avoid systematic effects when applying the image parameter cuts, we used the maximum likelihood method (Enomoto et al., 2001) to enhance gamma-ray like events. For each event, the probabilities for gamma-ray like events and proton like events were calculated, respectively, where each probability was defined as a multiplication of each probability density function (PDF) obtained from the distribution of the imaging parameter. The PDFs for gamma rays and for protons are calculated using simulated gamma-ray events and OFF-source events, taking into account the energy dependence of the imaging parameters. Then the log-likelihoods for gamma rays (L_g) and protons (L_{BG}) are obtained from those PDFs as follows

$$L_g = \Sigma log(Prob_g)$$

and

$$L_{BG} = \Sigma log(Prob_{BG}),$$

where $Prob_g$ and $Prob_{BG}$ mean the PDFs for gamma rays and protons, respectively.
Using those log-likelihood, gamma-ray like events can be enhanced, and proton like events are suppressed. In this analysis, we selected the events satisfied with both $L_g > 5.8$ and $L_{BG} < 8.0$.

4 Simulation

The Monte Carlo simulations both of gamma-ray and proton air showers are carried out using the GEANT 3.21 (CERN, 1994). In this simulation, atmospheric and detector conditions were included. The gamma-ray showers were simulated in the energy range from 150 GeV to 8 TeV with the initial differential power of −2.5. and the protons were simulated in the energy range from 300 GeV to 12 TeV with power index of −2.7. Showers were simulated from a zenith angle of 18 °. Figure 1 shows the effective detection area and the simulated spectrum for gamma rays for PSR 1706−44 as a function of energy. From this figure, the energy threshold was estimated to be around 400 GeV which was defined as the maximum point of the accepted spectrum.

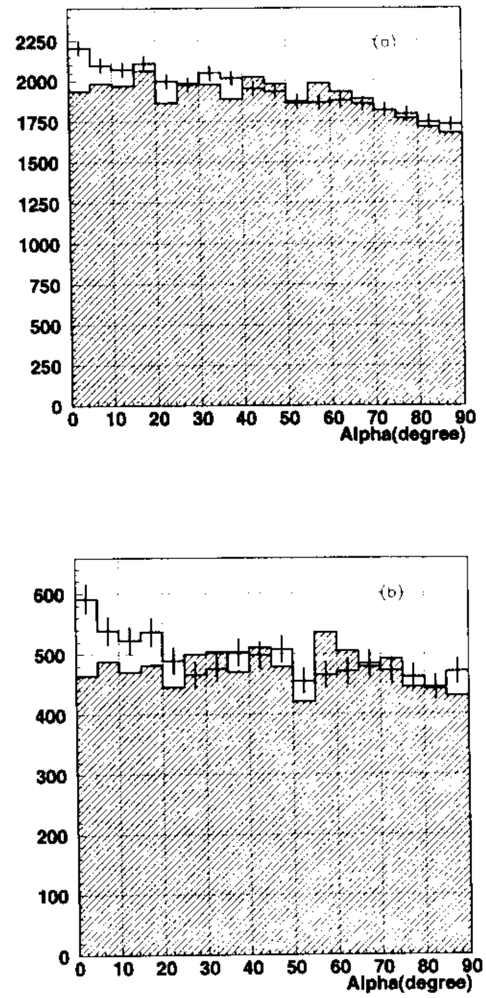

Fig. 2. Preliminary "Alpha" distribution of PSR 1706−44 in each energy for ON sources (the solid line) and OFF source (the hatched histograms); (a) > 400 GeV and (b) 800 GeV – 1.1 TeV.

5 Result and Discussion

Figure 2 shows the preliminary "Alpha" distribution of PSR 1706−44 in two energy bands. The energy range is > 400 GeV (Fig. 2-a) and 800 GeV to 1.1 TeV. (Fig. 2-b). Normalization has been done comparing the number of ON and OFF source events at 30° < alpha < 90° . The significance of the excess was calculated for alpha < 15°. The number of excess events was (a) 486 ± 111 (4.4 σ) and (b) 232 ± 58 (4.0 σ).

The preliminary TeV gamma-ray spectrum of PSR1706−44 between 400 GeV to 4 TeV, with statistical errors, is shown in Fig 3. The obtained differential fluxes are converted to integral fluxes for the comparison with other data. An $E^{-2.0}$ line, with arbitrary normalization factor, is also shown as a guide. Below the 1 TeV, this gamma-ray flux deviates from this solid line and seems to have an energy break near 1 TeV. The obtained result is consistent with previous results all the energy and the prediction of the IC process in the scattering of CMB (Aharonian et al., 1997).

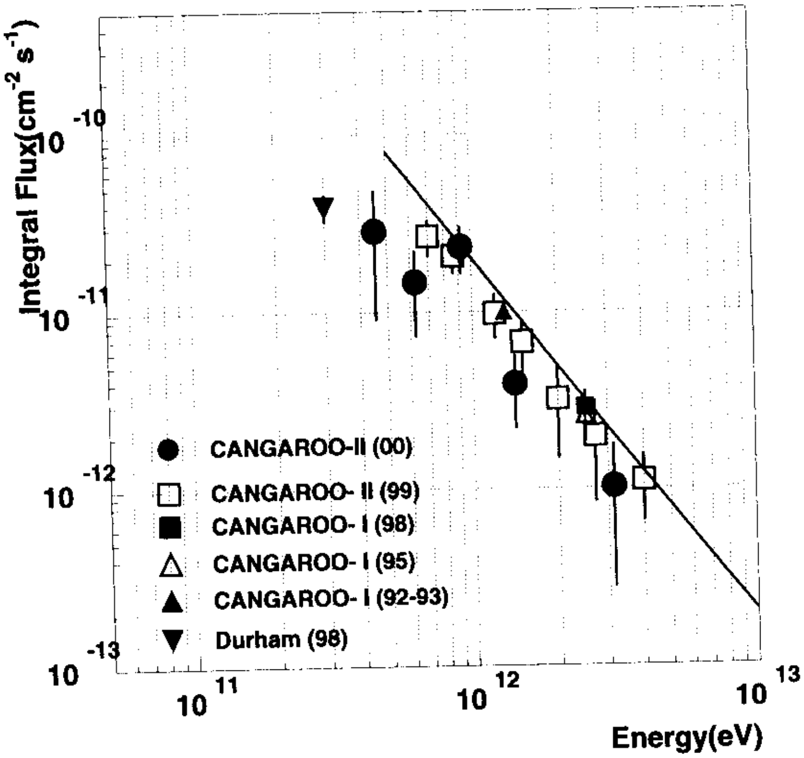

Fig. 3. Preliminary integral flux with statistical errors from PSR 1706−44. Power index is −2.5. The results of CANGAROO-II 10m telescope in 2000 are plotted by the closed circle, those of CANGAROO-II 7m telescope in 1999 (the open square), those of CANGAROO-I 3.8m telescope in 1998 (the closed square), 1995 (the open triangle), 1992–93 (the closed triangle), and the integral flux of Durham in 1998 (the closed reverse triangle). The solid line is an $E^{-2.0}$ spectrum with an an arbitrary normalization factor for comparison.

6 Conclusion

We have observed PSR1706−44 in June and July 2000 with the CANGAROO-II 10m telescope. The likelihood method has been applied and the detected gamma-ray signal exceeds 4.4 σ. The integral flux beyond 400 GeV is consistent with the previous results, although this result is preliminary. In 2001, we will take additional data using the CANGAROO-II 10m telescope.

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