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## (1) TeV Observations of Pulsars and Plerions

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## (2) Recent Results and Current Status of CANGAROO



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(CANGAROO Collaboration)

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Y. Matsubara(CANGAROO Collaboration)

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Recent Status and Results of CANGAROO Collaboration

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ABSTRACT

CANGAROO 3.8m telescope was renewed by recoating its mirror in 1996, and the energy threshold was decreased near 1 TeV. The most recent results of CANGAROO observation are reported as well as the current status of CANGAROO Project. In addition to Crab, PSR B1706-44 and Vela pulsars, from which we have so far detected TeV signal, the observation by the 3.8 m telescope in 1996 and 1997 have been mostly spent on SN1006, PSR B1509-58, PSR1259-63 and some AGNs etc. The results of the latest analyses are presented on those objects.

## 1. Recoating of the Telescope

The observations of the CANGAROO collaboration were made with the 3.8m parabolic telescope (Patterson and Kifune 1992), which is located at Woomera in South Australia (136°47'E and 31°06'S). The high resolution camera, set at the prime focus, consists of small square-shaped photomultiplier tubes of 10mm × 10mm size (Hamamatsu R2248). The number of photomultipliers was 220 in 1993 and was increased to 256, in a 16×16 square, in 1995 giving a total field of view of about 3°. The details of the camera and telescope are given in Hara et al. (1993). The 3.8m reflector was constructed about 20years ago for lunar ranging, and its surface was made of aluminized duralumin (10%)and canigen plates (90%). The reflectivity was about 60% in 1992, and decreased less than 45% in 1995, which increased the threshold energy of detectable gamma rays from ~ 1.5 TeV to 2.5 TeV. In order to recover the reflectivity of the reflector, the recoating of the reflector was carried out using the big 3.9m vacuum tank of the Anglo Australian Observatory in 1996 October. In this time, the reflector was recoated by pure aluminium, and its reflective was improved to be more than 85%. The observation of the Crab just after the recoating showed the dramatical improvement of the performance of the Cangaroo telescope. The detecting rate of gamma rays from the Crab raised from 4 events/hour to 16 events/hours, from which the threshold energy was estimated to decrease a half (Sakurazawa et al. 1997).

## 2. Observation and Results

The targets observed so far years are mainly followings: Vela, PSR1259, PSR1509, Crab, PSR1055, and W28, and SN1006 for galactic sources, PKS2316-423, PKS2005-489, PKS0521-365, PKS2155-304, EXO0423-0840, and Cen-A for extra-galactic sources. Almost of the observed targets are galactic sources since the center part of our galaxy can be observed from the southern hemisphere. AGNs are usually observed in September to November during which there exists little galactic objects. All of TeV gamma-rays sources and possible ones detected by the Cangaroo so far belong to galactic source: PSR1706-44, the Crab, Vela pulsar/nebula, SN1006 (detected), and PSR1509-41 (possibly detected). Each of the detected object is mentioned in the next section.

Since distances of those AGNs are within z $\leq\sim$0.1 and three objects of them are EGRET sources, TeV gamma-rays emission could be expected from some of them theoretically. However, no emission has been detected. The upper limits of the emissions of TeV gamma rays from five AGNs observed by the Cangaroo are $\sim 1\times10^{-12}$cm$^{-2}$s$^{-1}$. The details of three AGNs (PKS2316-423, PKS2005-489 and EXO0423-0840) wii be soon published (Roberts et al. 1997). We proceed the observations for AGNs, in particular, campaign observations with detectors in multi-band.

### 2.1 Pulsar & Nebula

The new detected sources after the last Padova workshop are Vela pulsar/nebula (Yoshikoshi et al. 1997) and SN1006(Tanimori et al. 1997a). Figure 1 shows the density map of excess counts around the Vela pulsar plotted as a function of right ascension and declination, where the "star" at the origin of the map indicates the position of the Vela pulsar. The remarkable excess peak due to a gamma-ray source near the pulsar exists in this map. The position of maximum emission is offset from the pulsar to a position southeast by about 0°.13. The gamma-ray integral flux calculated for the position of the maximum excess counts is $(2.9 \pm 0.5 \pm 0.4) \times 10^{-12}$ photons $cm^{-2}$ $sec^{-1}$ above 2.5 TeV, where the first and second errors are statistical and systematic respectively. The position error for a point source was estimated to be about 0°.04 by Monte Carlo simulation, and the difference of the detected peak position from the pulsar corresponds to significance of more than 3 $\sigma$. It is interesting to compare the present result with the ROSAT soft X-ray image around the Vela pulsar (Markwardt & Ögelman 1995). In the ROSAT image, a bright spot can be found where we have detected the VHE gamma-ray signal and the region is thought to be the birthplace of the pulsar (Bailes et al. 1989). We have observed the same field of view also in 1997 using the recoated telescope to confirm the offset of the source from the pulsar. The detail of this result is described in Yoshikoshi et al. (1997).

The Crab has been an unique standard candle for TeV gamma-ray astronomy similarly to X-rays and GeV gamma-rays. From the first reliable detection of TeV gamma-rays by the Whipple group (Weekes et al. 1989), there have been reported several detections of non-pulsed gamma-rays around TeV region so far. In particular differential spectra up to 10 TeV have been presented with very good statistics from the Whipple (Lewis et al. 1997) and HEGRA groups (Aharonian et al. 1997) in this year. However, there still remains various theoretical models about the high energy phenomena in the Crab nebula, which are almost based on the Synchrotron Self Compton (SSC) model (De Jager & Harding 1992; Atoyan & Aharonian 1996). The predicted spectra for synchrotron and IC emission are sensitive to conditions within the nebula such as the magnetic field, the nature of the seed photons, and the maximum energy of high energy electrons, which allow us to test these models. In particular, all models predict that the shape of the spectrum becomes more sensitive to a change of the parameters of the nebula as the gamma-ray energy increases. Then the observation of gamma rays in the energy range above 10 TeV is the key to understanding of the IC process in the nebula.

We observed the Crab nebula in 1992 by the large zenith angle technique (Sommers & Elbert 1987), and detected gamma-rays with an integral flux of $(7.6 \pm 1.9) \times 10^{-13}$ $cm^{-2}s^{-1}$ above 7 TeV at zenith angle of $\sim$53°(Tanimori et al. 1994). Observations have been also carried out in 1994 and 1995. From three years data, the differential flux between 7 TeV and 70 TeV was obtained as shown in Fig.2, where The observed spectrum is $(2.01 \pm 0.36) \times 10^{-13}(E/7\,\mathrm{TeV})^{-2.53\pm0.18}$ $\mathrm{TeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ between 7 TeV and 50 TeV. There is no apparent cut-off less than 50 TeV. The detail of this result is described in Tanimori et al (1997b).

The gamma-ray pulsar PSR1509-58 was found by Einstein satellite in supernova remnant MSH 15-52 (Seward & Harnden 1982). This has the fifth largest $\dot{E}/d^2$ among known radio pulsars and is the second youngest pulsar following the Crab ($\sim$1700yr). Pulsed gamma-ray emission (P = 150 ms) was detected by the BATSE and OSSE experiments with a 150msec pulsar period. Although it has not been detected by the EGRET experiment (Fierro (1995) indicates a DC excess with 3 sigma level), recent X-ray observations have revealed energetic features around this pulsar. From early observations two compact nebulae are known. One is a synchrotron nebula (South Nebula) around the pulsar and the other is a thermal nebula (North Nebula), which is located 0.12 degrees from the pulsar, but the relation between these nebulae is unclear. Recent X-ray result (Tamura et al. 1996), which showed a non-thermal jet from the pulsar position toward the North Nebula, indicates an association between these nebulae. du Plessis et al. (1995) performed an observation with a 7 TeV energy threshold and set an upper limit for VHE gamma-ray emission before the discovery of the jet feature.

This pulsar was observed by the CANGAROO 3.8m telescope in 1996 and 1997. The threshold energys for this pulsar were estimated to be $\sim$ 3 TeV and 1.5 TeV for the 1996 data and 1997 data, respectively; the recoating of the mirror in 1996 decreased the threshold energy about half of previous one. Each Čerenkov image is fitted to an ellipse and image parameters, which are commonly used (e.g. Reynolds et al. 1993), are calculated. After image selection, no significant excess was seen in the distribution of alpha parameter of the data of 1996 around the pulsar and nebulae. On the other hand, a peak ($\alpha \geq 10°$) was found in the 1997 data, of which significance is about $4\sigma$ using the conventional ON-OFF Li-Ma method at the position of the pulsar. The maximum significance of this peak was obtained to be 5.3 $\sigma$ at the position of $0°.1$ south-west from the pulsar as shown in Fig.3 This discrepancy was estimated by the simulation, and can be considered to be within the statistical error. The spectrum of 1997 data seems to be steep, and it may be a reason for the no detection of TeV gamma ray in 1996 data. As mentioned above, we have an evidence of the detection of the TeV gamma-ray emission from PSR1509, although we need more significances or another observational evidences to confirm. These results are preliminary, and the analysis is still in progress.

**2.2 Supernova Remnant SN1006**

Cosmic-ray origin still remains as an outstanding problem in high-energy astrophysics. Long time, supernova remnants (SNR) have been believed to be a galactic cosmic-ray source which satisfies almost requirements as a source while there has been no direct evidence to support this. In 1995, Koyama et al(1995) reported the emission of synchrotron X-rays from the both rims in SNR SN1006. It was a first strong evidence of existence of very high energy electrons in a SNR, and also means that protons are probably accelerated by shock up to hundreds TeV. Soon some theorists predicts the detectable TeV gamma-ray emission from SN1006 due to the Inverse Compton Scattering with 2.7K microwave cosmic background photons (Pohl 1996; Mastihiadis 1996; Mastihiadis & De Jager 1996; Yoshida & Yanagita 1997). Stimulated from this result, SN1006 was observed by the CANGAROO telescope in 1996 April and June, and TeV gamma-rays ($\geq$ 3 TeV) were detected from the NE rim with the significance of 5.3 $\sigma$. The density map of the significance of a $\alpha$ peak shows the emission region extends more than the point spread function of the telescope along the ridge of the NE rim. The emission region well fits the intensity map of hard X-rays observed by ASCA in the NE rim. The source point in the NE rim giving the most significant $\alpha$ peak ($\alpha \leq 20^\circ$) was found close to the maximum flux point in the 2–10 keV band of the ASCA data. The $\alpha$ plot of the selected gamma-like events at the X-ray maximum flux point is shown in Fig.4a. Although our data suggests the emission of TeV gamma rays extends along the ridge of the NE rim, we do not yet have a reliable method to estimate the number of the gamma-ray events from an extended source. Approximating the emission as coming from a single point source at the maximum flux point in the NE rim, the integral gamma-ray flux for the 1996 observations was calculated to be $(3.0 \pm 0.54) \times 10^{-12}$ cm$^{-2}$ s$^{-1}$ ($\geq 3 \pm 1$ TeV).

In March and April 1997, an additional observation was done for 34 hours (on source) and 29 hours (off-source), and TeV gamma-ray emission was detected again as shown in Fig. 4b, where A clear peak ($\alpha \leq 20^\circ$) was seen with the significance of 7.3 $\sigma$. Thus the TeV gamma-ray emission from the NE rim of SN1006 has been confirmed. The threshold energy of detected gamma-ray events in 1997 observation was estimated to be $\sim$ 1.2 TeV due to the recoating of the mirror. Using similar approximations to the 1996 data, the gamma-ray integral flux ($\geq 1.2 \pm 0.4$ TeV) for the 1997 observation was calculated to be $(1.2 \pm 0.15) \times 10^{-11}$ cm$^{-2}$ s$^{-1}$. The data is enough to get the differential spectrum between 1 TeV and $\sim$ 7 TeV, which is now being done. The density map of the TeV gamma-ray emission and detail will be soon described elsewhere (Tanimori et al. 1997c).

## 3. Perspectives

In 1997, new targets, GRB970402, Galactic Center (SGR-A), and 2EGJ1811-2339 (EGRET un-identified source) has been observed. In particular, gamma-ray burst GRG970402 (Feroci et al. 1997) was observed about 40 hours after the detection of BeppoSAX with the position accuracy of 3'. The analyses for these objects are in progress. The Crab has been observed every year, and from last the observation at deep large zenith angle of down to 65° was carried out. Our spectrum of the Crab will covers from $\sim$ 3 TeV up to 80 TeV by combining 1996 and 1997 data. The differential spectra of SN1006, Vela and PSR1706 are also being studied, and in near future will appear.

In 1998, we will construct the new 7m telescope with the high resolution camera consisting of 516 13 mm$\phi$ phototubes near the present 3.8m telescope at Woomera. This telescope is easily extendable to a 10 m telescope by attaching small mirrors to the mirror frame. The detail of the mirror and the status of the construction are mentioned by Matsubara et al. (1997) in this workshop. By the new telescope, we will exploit new energy region around 100 GeV in the southern hemisphere.

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REFERENCES

Aharonian, A. F., et al. 1997, astro-ph/9706019
Atoyan, A. M., & Aharonian, A. F. 1996, MNRAS, 278, 525
Bails, M., *et al.* 1989, ApJ, 343, L53
Feroci, M., et al. 1997, IAU circ. No.6610
Fierro, J.M., 1995, Ph.D. thesis, Stanford University
De Jager, O. C., & Harding, A.K. 1992, ApJ, 396, 161
Hara, T., et al. 1993 Nucl. Instr. and Meth., A332, 300
Koyama, K. et al. 1995, Nature, 378, 255
Cater-Lewis, D. A, et al. 1997, astro-ph/9706145
Markwardt, C.B. & Ögelman, H. 1995, Nature, 375, 40
Mastichiadis, A., 1996, A&A, 305, L53
Mastichiadis, A. & de Jager, O.C., 1996, A&A, 311, L5
Matsubara, Y., et al. 1997 talk in this workshop
Patterson, J. R., & Kifune, T. 1992, Australian and New Zealand Physicist, 29, 58
Petry, D., et al. 1996, A&A, 311, 13
du Plessis, I., et al., 1995, ApJ, 453, 746
Pohl, M., 1996, A&A, 307, 57
Reynolds, P.T., et al., 1993, ApJ, 404, 206
Roberts, M.D., et al., in preparation.
Sakurazawa, K., et al. 1997, in Proc. 25th Int. Cosmic Ray Conf., Vol.3, 165
Sommers, P., & Elbert, J. W., 1987, J.Phys. G:Nucl. Phys., 13, 553
Seward, F. D. & Harnden, F. R., 1982, ApJ, 256, L45
Tamura, K., et al., 1996, PASJ, 48, L33
Tanimori, T., et al. 1994, ApJ, 429, L61
Tanimori, T., et al. 1997a, IAU Circ. No.6706
Tanimori, T., et al. 1997b, ApJ Lett submitted
Tanimori, T., et al. 1997b, in preparation
Weekes, T. C., et al. 1989, ApJ, 342, 379
Yoshida, T.& Yanagita, S., 1997, Proc. 2nd INTEGRAL Workshop, ESA SP-382, 85
Yoshikoshi, T., et al. 1997, ApJ, 487, L65

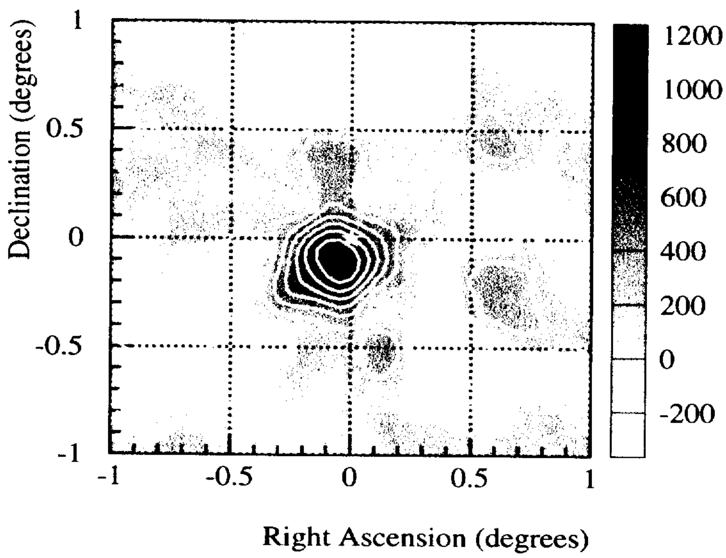


Fig. 1 A density map of excess counts around the Vela pulsar plotted as a function of right ascension and declination. The "star" indicates the position of the Vela pulsar, and the position of the maximum excess counts from the 1997 data is by the "cross".

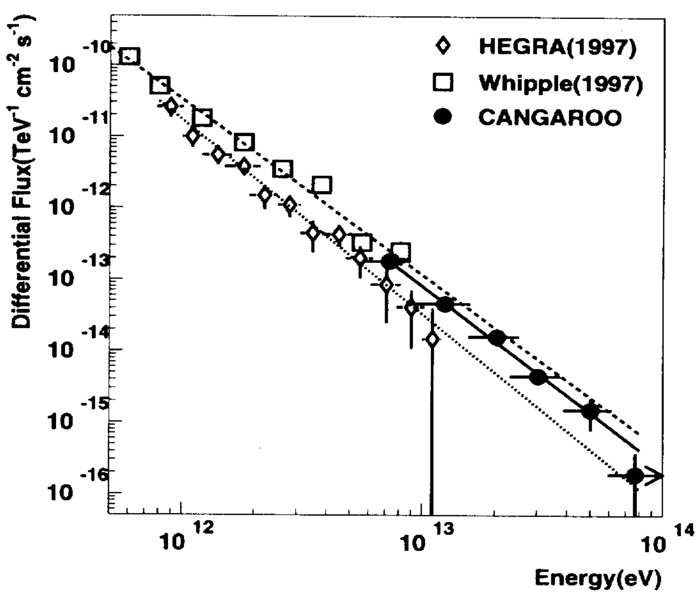


Fig. 2 The differential spectra of the present result in comparison with other experiments. The full line is the power law fit given in the section 2.1.

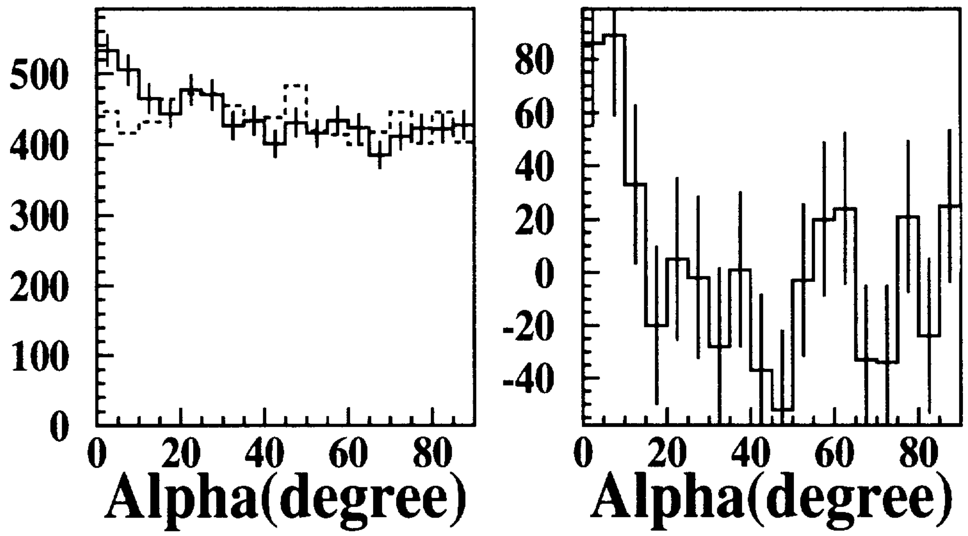


Fig. 3 The number of observed events of PSR509 as a function of the orientation angle $\alpha$ for 1997 data where on- and off-source data are indicated by the solid and dotted lines, respectively.

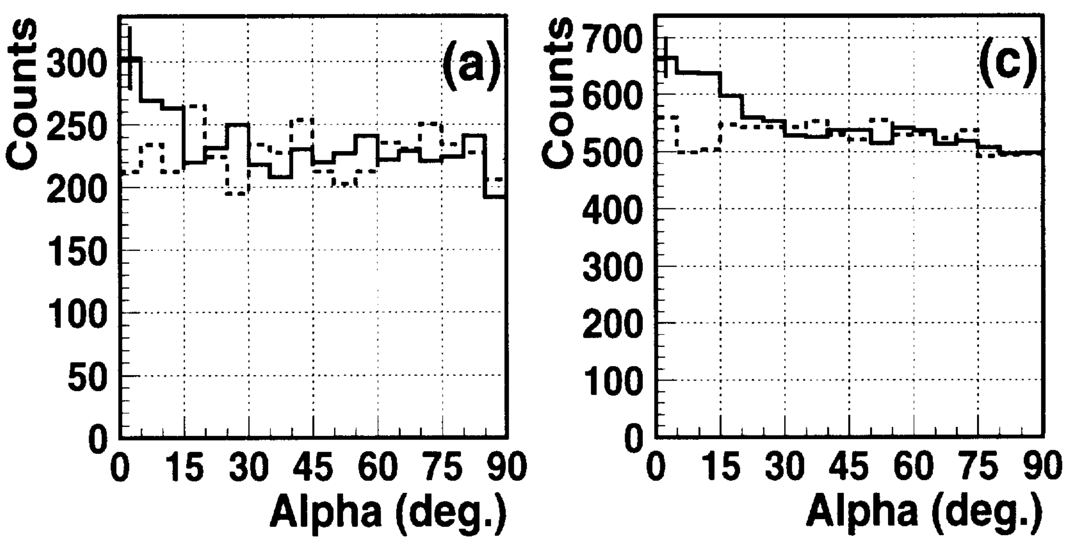


Fig. 4 (a) The number of observed events of SN1006 as a function of the orientation angle $\alpha$ for 1996 data where on- and off-source data are indicated by the solid and dotted lines, respectively. (b) The same $\alpha$ plot for 1997 data.