CANGAROO, PRESENT STATUS AND FUTURE

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For the CANGAROO Collaboration

1. Introduction

CANGAROO (Collaboration between Australia and Nippon for a GAmma-Ray Observatory in the Outback) aims to study the properties of V E (very high energy) gamma-ray sources by utilizing the atmospheric Cherenkov technique with a 3.8-m single-dish telescope located at Woomera, South Australia (136 degree E, 31 degree S, and 160 m a.s.l.). Since 1992, CANGAROO has observed various objects: pulsars, their nebulae, SNRs, and AGN in the southern sky. Unpulsed TeV gamma-ray emissions from three EGRET pulsars/nebulae (Crab, Vela, and PSR B1706−44) and from a shell-type SNR (SN 1006) were detected, and a preliminary positive DC signal from a non-EGRET pulsar (PSR B1509−58) was recently reported.

CANGAROO Cherenkov telescope has contributed to V E gamma-ray astronomy with its good-quality 3.8-m mirror and high resolution imaging camera of $0.^\circ 12$ square × 256 PMT pixels (ara *et al.*, 1993). The 3.8-m reflector of parabolic shape originally used for lunar ranging was re-coated with aluminum in Oct. 1996 to improve the reflectivity. Consequently the threshold energy was reduced by a factor of ∼2. A new telescope with a larger reflector (7 m in the first stage and will be extended to 10 m later) is now under construction and is scheduled to commence operations in 1998 at Woomera. It will develop the CANGAROO observations to multi-hundred-GeV-energy region.

2. Results of the Observations - *Hops!* of the CANGAROO

In Table 1, galactic and extra-galactice targets of our observations are listed. We usually spend about 20 hours of observations for each target, then a similar amount of observations is repeated to confirm the promising result. The galactic objects have been intensively studied taking advantage of the location in

Table 1. Observed targets (of published data only).

target	threshold (TeV)	flux (unpulsed) (10^{-12}cm^{-2}s^{-1})	obs. time (hrs) on source	distance
Crab	7	0.80 ± 0.11 (1)	61(+60)[a]	2.0 kpc
Vela	2.5(1.3)[b]	$2.9 \pm 0.4 \pm 0.5$ (2)	174(+33)[a]	0.5 kpc
PSR B1706−44	2(1.5)[b]	3.5 ± 1.1 (3),(5)	125(+27)[a]	1.8 kpc
PSR B1509−58	1.5	3.1 ± 0.8 (4)	96	4.2 kpc
PSR B1055−52	2	< 0.95 (5)	79	1.5 kpc
SN 1006	1.7	$4.6 \pm 0.6 \pm 1.4$ (6)	60	2.0 kpc
Cen A	2	< 1.5 (5)	75	z=0.002
EXO 0423−084	2	< 1.1 (7)	26	z=0.039
PKS 2005−489	2	< 1.1 (7)	41	z=0.071
PKS 2316−423	2	< 1.1 (7)	19	z=0.055

(a) data taken in 1997, to be analyzed.
(b) threshold energies changed before and after the recoating (Oct. 1996).
reference (1)Tanimori, 1998a (2)Yoshikoshi, 1997 (3)Kifune, 1995 (4)Sako, this workshop (5)Susukita, 1997 (6)Tanimori, 1998b (7)Roberts, 1997

the southern hemisphere, and these new TeV sources in the southern sky have been discovered so far. On the other hand, detections of the extra-galactic objects have not been successful in spite of our observations of several targets for years (Roberts *et al.*, 1997). A variety of new targets observed in 1997 are: the galactic center, Fornax A, 2EG J1746−2852 and 2EG J1811−2339 (EGRET unidentified sources), and GRB 970402.

igher threshold energy but larger detection area for the Crab pulsar is achieved by observations at the large zenith angle (53°- 60°). That enables us to enjoy a good sensitivity in the energy region ranging 7 - 50 TeV, and it was found the spectrum of the Crab nebula extends over the range by one power law index of -2.53 ± 0.18 with no apparent cut-off (Tanimori *et al.*, 1998a).

As shown in Table 2, all the four pulsars positively detected by CANGAROO are accompanied by the extended non-thermal X-ray sources, which is suggestive of plerionic activities, and all have high values (within the top 5 among the known pulsars) of $\dot{E}/4\pi d^2$, where $\dot{E}$ and d are spin down luminosity and distance of the pulsar, respectively. The TeV luminosity (1 - 10 TeV) are calculated from the detected photon flux, assuming a power law index of -2.5 and isotropical emission. The estimated luminosities correspond to $10^{-2.5}$- 10^{-4} of the total rotation energy losses. These unpulsed V E emssions are considered to be up-scattered by the relativistic electrons in the pulsar driven nebulae, which

Table 2. Parameters of the observed pulsars. Preliminary estimations of unpulsed TeV gamma-ray luminosities are also shown.

target	log $\dot{E}$ ^{c}	log$L_{X(\mathrm{nebula})}$ ^{d}	log$L_{\gamma 1-10\mathrm{TeV}}$ ^{e} (preliminary)	log $\dot{E}/4\pi d^2$ ^{f}
Crab	38.65	37.18 [8]	34.5	-6.0
Vela	36.84	34.08 [8]	33.1	-6.6
PSR B1706−44	36.53	33.32[10]	34.2	-8.1
PSR B1509−58	37.26	34.80 [9]	34.6	-8.1
PSR B1055−52	34.48	32.30 [8]	< 33.4	-10.0

(c) spin down power in erg s^{-1}. (d) X-ray luminosity of accompanied nebula (erg s^{-1}). (e) unpulsed TeV gamma-ray luminosity (erg s^{-1}) deduced from the photon flux in Table 1 by the normalization to E_γ= 1 - 10 TeV (see the text). For the Crab pulsar, the measured spectrum of the Whipple group in 0.5 - 8 TeV (Carter-Lewis *et al.*, 1997) results in ~34.6 for the same definition. (f) spin down power available in one str, at the distance of d (cm). *reference* (8)Shibata, 1998 (9)Tamura, 1996 (10)Finley, 1998

may produce synchrotron radiations in X-ray wavelength. Therefore the relevant fluxes of non-thermal X-ray and TeV gamma-ray from a plerion gives us information on the photon energy density and the magnetic field density in the emssion region. Except for the Crab pulsar ($\sim$ 300μG), the estimated magnetic fields are as low as several μG which is also the case with SN 1006 (Tanimori *et al.*, 1998b).

3. CANGAROO II - *Steps forward!*

In 1998, CANGAROO will have a new 7-m imaging Cherenkov telescope at Woomera, near the present 3.8-m telescope. The reflector is composed of 60 spherical mirrors on a parabolic frame. The spherical mirrors of 80-cm diameter are made of Carbon Fiber Reinforced Plastic. The diameter of our light collecting dish can be extended from 7 m to 10 m by adding more mirrors on the frame. On the focal plane at the focal length of 8 m, an imaging camera of 512 PMTs of 1/2" is installed, covering about 3° as the total FOV in diameter. Arrays of light collecting cones will be attached to the camera to improve the acceptance.

Figure 1 shows estimated sensitivities for the new 7-m telescope. According to a simulation, a threshold energy of ~200 GeV is available, and an observation of 100 hours, for example, gives the minimum detectable (5σ) energy flux of $\sim 10^{-12}$erg $cm^{-2}s^{-1}$, an improvement by more than one order. If TeV emission is about the same fraction of the total pulsar spin down luminosity as we have detected, we can expect to detect V E gamma-rays from those pulsars whose $\dot{E}/4\pi d^2 \geq 10^{-10}$(erg $cm^{-2}s^{-1}$). The highest ~40 pulsars in $\dot{E}/4\pi d^2$ value pass

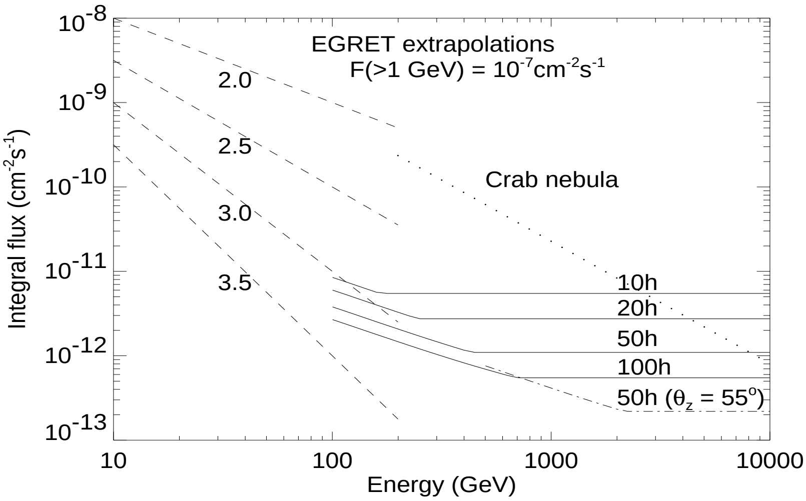

Fig. 1. Minimum detectable flux (5σ) estimated from a simulation. Detection at EGRET sensitivity is extrapolated for reference, by power law spectra of different indices.

this criteria, of which more than half can be observed by CANGAROO at the zenith angle less than 30°. V E detectin from ten of pulsars will greatly proceed the systematic study of pulsar driven nebulae and emission mechanisms.

4. CANGAROO III - *Jumps!*

With addtional three more telescopes to the 7-m (10-m) CANGAROO II telescope, an array of four Cherenkov telescopes of a 10-m dish has recently been proposed. Further study for another leap of CANGAROO is now under way.

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