CANGAROO PROJECT AND VERY HIGH ENERGY GAMMA RAY ASTRONOMY

TADASHI KIFUNE
Institute for Cosmic Ray Research, University of Tokyo, Kashiwa-no-ha 5-1-5, Kashiwa, Chiba 277-8582, Japan

The CANGAROO Project and the results are discussed as well as about the present status of TeV γ-ray astronomy. The observation through the shortest wavelength of electromagnetic radiation is so far considerably influenced by the results from other bands. A fair, unbiased outline of the non-thermal, high energy Universe seen at TeV γ-rays remains to be seeked for.

1 Introduction

The concept of CANGAROO (Collaboration between Australia and Nippon (Japan) for a GAmma Ray Observatory in the Outback) is traced back to the observation of supernova 1987A for VHE (very high energy) γ-ray emission by the project JANZOS (Japan, Australia and New Zealand Observation of SN 1987A)[1]. While observation was attempted by the "primitive drift scan mode" of spherical mirrors, a suggestion was *kindly* given to utilize a telescope which had been in use for optical bands in National Astronomical Observatory of Japan. The telescope of 3.8m diameter has good quality of focusing air Čerenkov lights and thus well matches imaging air Čerenkov technique. It was timely and fortunate to CANGAROO that the Whipple group made a success of the firm detection of TeV γ-rays from the Crab nebula[2] by using the IACT (imaging air Čerenkov telescope) of 10m size, demonstrating the break-through of VHE γ-ray astronomy. It was also almost simultaneous with the launching of the Compton Gamma Ray Observatory (CGRO).

CANGAROO observation started in 1992 at the site near Woomera town located in the *outback*, the deserted dry area in the central inland of Australia. Observation in the southern hemisphere can enjoy many putative Galactic sources of VHE γ-rays, which are presumably to be found near the Galactic Centre. The EGRET (Energetic Gamma Ray Experiment Telescope) of CGRO provided us with the candidate objects for VHE γ-ray observation. Most of the observation time of CANGAROO has been, at least at the beginning, thus spent in the Galactic EGRET sources such as the Crab nebula.

2 Current status: Phase I, II and III of CANGAROO project

The observation by using the 3.8m telescope continued until 1998 (the phase of CANGAROO I). The threshold energy of detectable γ-rays is $1 \sim 3$ TeV varying with the time because of the deterioration of the reflectivity of the telescope mirror or the improvement by recoating the aluminum surface. A telescope of 7m diameter then came to construction, and was in operation during the period from May 1999 to Janurary 2000 (CANGAROO II). The collection of air Čerenkov lights is made with 60 spherical mirrors of 80cm diameter; a composite mirror system similar to other contemporary IACTs, however by challenging to use plastic mirrors. The telescope was scaled up after a year by adding 54 more mirrors of 80cm diameter, increasing the area of light collection to 10m diameter aperture, and in operation since April 2000. Another telescope of 10m diameter will be installed at the beginning of 2002. In the phase of CANGAROO III, the full system of the four 10m telescope as total is scheduled to commence operation in 2003.

So far, the observation with the 7m/10m telescope has been spent mostly in confirming the earlier results during CANGAROO I period, rather than challenging to many new objects. Signals, from Crab, PSR 1706-44, RXJ 1713-39 and so on, are used to calibrate the performance of the new telescope and to improve the operation conditions, as well as to obtain the energy spectrum of those sources down to a few hundred GeV energies.

3 Objects observed by CANGAROO and summary of results

Table 1: Summary of CANGAROO I observation

	Evidence of VHE emission	Upper limit or Unpublished	Examples of the objects which are not observed by CANGAROO
Pulsar	Crab PSR 1706-44 Vela pulsar (PSR1509-58?)	PSR 1055-52 PSR 1259-63	Geminga ....
Supernova	SN 1006 RXJ1713-39	W28	SN 1987A many others
AGN, galaxies		PKS2155-304 PKS2005-304 etc. Cen A	LMC/SMC etc.
Others		Galactic Center Vela X-1 Cen X-3	SS433 or jet objects Galactic Black Holes etc

The VHE γ-ray sources discovered by CANGAROO are listed in Table 1. In order to establish the TeV signal, at $\sim$ 1TeV threshold of CANGAROO I, presumably of a flux as large as or less than the Crab flux of $\sim 10^{-11}$ cm^{-2} s^{-1}, it is necessary to accumulate data during 50 - 100 hrs, which has limited the number of observation targets to handful objects. The CANGAROO observation was started by choosing as targets the Galactic identified sources of EGRET detection, *i.e.* the Crab pulsar/nebula and other γ-ray pulsars. On the other hand, the EGRET sources, which may be associated with SNR (supernova remnants), were considered no less important and as "standard sources"[3] of VHE γ-rays, since they are very likely to be the site of acceleration of cosmic rays and they are considered to have energy spectrum extending to TeV region and even higher emergies. However, TeV γ-rays have been detected not from the COSB/EGRET source 2CG006-00/2EGJ1801-2312 or SNR W28 [4,5], but positively from the SNRs, such as SN 1006 [9] and RXJ1713-39 [10] that are, interestingly, not the EGRET sources. The Table 2 summarizes implication of CANGAROO results with new questions to be addressed as noted in the 3rd column. The signals of TeV γ-rays are explained by electron progenitor more likely than protons. The comparison of TeV γ-ray with X-ray flux, by attributing them to, respectively, inverse Compton and synchrotron radiation of $\sim$ 100TeV electrons, suggests that the magnetic field in the emission region is $\sim 1\mu$G, which is as weak as the interstellar field. The 7m/10m telescope of CANGAROO II and III will provide us with the energy spectrum from a few hundred GeV to 10 TeV, giving a clue to clarify emission mechanism of VHE γ-rays.

Table 2: Results and what remains to study

object *references*	results	note
Crab [8]	unpulsed spectrum up to $\sim$ 50 TeV	cutoff energy? large zenith angle technique
PSR 1706-44 [6]	unpulsed B $\sim$ a few μG	compact nebula ?
Vela pulsar [7]	unpulsed displaced from pulsar position?	birth place of pulsars ?
SN 1006 [9]	North East Shell	South East ? extended ?
RXJ 1713-39 [10]	probably extended	
PSR 1509-58 [11]	marginal	soft spectrum ?
All the objects	electron progenitor weak (except Crab) magnetic field disimilar to GeV sources consistent with unpulsed/persistent signal	"entire' energy spectrum ? more detailed spectrum near 1 TeV ? compact or extended ?

It is to be noted that CANGAROO has not so far been successful in detecting VHE γ-rays from blazars. However, it is also worth attemting to challenge to northern objects from the southern hemisphere. CANGAROO I has detected $\geq$10 TeV γ-rays[8] from the Crab nebula at large zenith angles of $\geq 53°$, and we have recently made an attempt to observe Mrk 421 and 501 at even larger zenith angles of $\sim 80°$.

4 Summary and discussions

The CANGAROO Telescope of 7m/10m diameter are so far, with the first priority, used to confirm the earlier results from the sources, such as Crab, PSR 1706-44, RXJ 1713-394 etc., and to provide the operation conditions of the new telescope. From the same data, we can expect that the energy spectrum down to a few hundred GeV will be determined possibly to reveal a change of the power index of the spectrum. The characteristics of VHE point sources show interesting disimilarities to features of GeV γ-ray emission, as noted in Table 3. The summation of the fluxes over the EGRET Galactic sources is given in the bottom two lines of the Table 3, which may suggest, when compared with the VHE case from a few number of VHE sources, that a considerable number of VHE sources are still hidden from observation.

Observations so far done are limited in a handful number of sources, and thus our understanding of VHE sky is incomplete; very much likely to be "biased" to what we have known from GeV γ-rays and X-rays etc. The γ-rays from the Galactic disk includes all the contribution from unknown sources. The diffuse emission as well as the extragalactic one thus can be useful to draw *an entire picture* of VHE γ-ray sky. However, the diffuse emission still remains to be detected by IACT technique. "A fairer view of VHE sky" will hopefully become available by a system of four IACTs (CANGAROO III), as well as by the contemporary projects of VERITAS, H.E.S.S. and MAGIC and other projects of the next generation.

Table 3: Characteristics of TeV γ-ray sources in comparison with GeV sources

	100 MeV - 10 GeV	100 GeV - 10 TeV
pulsar	from pulsar magnetosphere 6 objects (modulated with pulsar spin)	from pulsar nebula 3 objects (unmodulated signal)
supernova remnant (shell type)	several associated with unidentified sources	3 objects
X-ray binarires	1 objects (transient)	1? objects
unidentified sources	165 objects	not searched
blazar	75 objects	nearby 2∼6? objects
normal galaxy	1 objects	0 objects
gamma ray burst	5 objects	1? objects
typical intensity of point sources	$\sim 10^{-11}$ erg cm^{-2} s^{-1}	$\sim 10^{-11}$ erg cm^{-2} s^{-1}
Galactic plane	6×10^{-8} erg s^{-1} sr^{-1}	not detected yet ($6 \times (10^{-10} \sim 10^{-9})$ erg s^{-1} sr^{-1} ?)
extragalactic diffuse	$\sim 1 \times 10^{-8}$ erg cm^{-2} s^{-1} sr^{-1}	difficult to observe
$\sum_{\lvert b \rvert < 20^\circ}$ (Intensity of Sources)	(inferred from EGRET catalog)	(difficult to estimate)
pulsars	$\sim 2.5 \times 10^{-9}$ erg cm^{-2} s^{-1}	$\geq 10^{-11}$ erg cm^{-2} s^{-1}
others	$\sim 5 \times 10^{-9}$ erg cm^{-2} s^{-1}	$\geq 10^{-11}$ erg cm^{-2} s^{-1}

References

1. I.A. Bond *et al*, *Phys. Rev. Lett.* **61**, 2292 (1988).
2. T.C. Weekes *et al*, Ap J **342**, 379 (1989).
3. T. Kifune in *Proc. of Kofu Conference; Astrophysical Aspect of the Most Energetic Cosmic Rays*, ed. M Nagano and F Takahara (World Scientific, Singapore, 1991) p240.
4. T. Kifune *et al*, Proc. of 23rd Int. Cosmic Ray Conf. (Calgary) **1**, 444 (1993).
5. G.P. Rowell *al*, Astron. Astrophys. **359**, 337 (2000).
6. T. Kifune *et al*, Ap J Lett **438**, L91 (1995).
7. T. Yoshikoshi *et al*, Ap J Lett **487**, L65 (1997).
8. T. Tanimori *et al*, Ap J Lett **492**, L33 (1998).
9. T. Tanimori *et al*, Ap J Lett **497**, L25 (1998).
10. H. Muraishi *et al*, Astron Astrophys **354**, L57 (2000).
11. T. Sako *et al*, Ap J **537**, 422 (2000).