Recent CANGAROO Observations of Galactic Objects

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Abstract

Since June 2000, the CANGAROO project has extensively observed galactic sources using the CANGAROO-II 10-m Cherenkov telescope. The observatory location in Woomera, South Australia enables us to observe nearby objects of interest at good observing conditions such as smaller zenith angles, i.e. with lower energy thresholds, than those in the northern hemisphere. The two year observation history of Galactic objects is summarized here.

1. Introduction

Following the successful operation of the CANGAROO-I 3.8-m telescope in 1992–1998, the CANGAROO project commenced observations in 2000 with a 10-m imaging Cherenkov telescope, called as CANGAROO-II telescope (Mori et al. 2001; Tanimori et al. 2001), located at the same observatory in Woomera, South Australia (136°47′ E, 31°06′ S, 160 m a.s.l.). We have concentrated on exploring the southern sky which is rich in various Galactic objects, in the sub-TeV to multi-TeV energy range. In this paper, we summarize the observed targets into the following three sections with the citations to the recent papers.

2. Supernova Remnants

The first detection of very high energy gamma-rays from a shell-type SNR, SN 1006 (Tanimori et al. 1998b) supports the existence of high energy particles in the SNR claimed by the previous non-thermal X-ray detection (Koyama et al. 1995). The discovery favors an assumption that shell type SNRs are one of the most powerful particle acceleration sites in the Galaxy, are possible origins of the cosmic rays, and are good candidates of TeV emitters. We have chosen four galactic SNRs for our observation targets, SN 1006, RX J1713.7−3946, RX J0852.0−4622, and RCW 86, which are of shell type and are characterized by detections of non-thermal X-rays. Some basic parameters of these SNRs are presented in Table 1. The sources have been tracked to the points where the non-thermal X-rays show the largest intensity.

High energy gamma-ray emissions from the two SNRs, SN 1006 and RX J1713.7−3946, have been confirmed as the previous results of the CANGAROO-I 3.8-m telescope (Tanimori et al. 1998b; Muraishi et al. 1999). With the increasing sensitivity of the CANGAROO-II 10-m telescope (Asahara et al. 2003), the energy spectra of the two sources have been deduced in the wider energy range. The TeV energy spectrum of RX J1713.7−3946 cannot be interpreted by a simple Synchrotron Inverse Compton emission model including the multi-wavelength

Table 1. The basic parameters of the observed SNRs with the CANGAROO-II telescope. Observation time (2000–2002) T includes cloudy weather conditions.

Object name	Distance (kpc)	Age (year)	T:ON/OFF (hour)	Reference
SN 1006 (NE rim)	2	1E3	75/65	(Hara 2002)
RX J1713.7−3946 (NW rim)	6[1]	1[0.2]E4	68/64	(Enomoto 2002)
RX J0852.0−4622 (NW point)	0.5	1E3	41/36	(Katagiri 2002)
RCW 86 (SW rim)	3[1]	1[0.2]E4	79/73	(Watanabe 2002)

spectrum information (Enomoto et al. 2002), while the spectrum of SN 1006 is well fitted to a spectrum of Inverse Compton scattering by the same electrons emitting Synchrotron X-rays, with a reasonable parameter of the magnetic fields, about 4 μ Gauss (Hara et al. 2001; Tanimori et al. 2001). We have repeatedly observed RX J0852.0−4622 and RCW 86 and the details of the observations, the analyses of these two SNRs are described in Katagiri et al. (2002) and Watanabe et al. (2002), respectively.

3. Rotation-powered pulsars/nebulae

Since the Crab (nebula) is the first established TeV gamma-ray source and has become a standard candle in the TeV energy range, rotation-powered pulsars are also supposed to be good candidates of TeV emitters. Pulsed and unpulsed emissions from the Crab pulsar were detected by *EGRET*, however, no pulsed emission has been detected above the 100 GeV region. The observational results suggest that high energy gamma-rays are originated from the nebula, as relativistic particles of the pulsar wind are injected into the nebula. We have chosen target pulsars according to the $\dot{E}/d^2$, where $\dot{E}$ denotes spin-down luminosity and d is distance to the pulsar. $\dot{E}$ is assumed to be related with the driving force of pulsar winds. The Crab pulsar is the first in the $\dot{E}/d^2$ rank and four of the five highest pulsars in the rank have been observed by the CANGAROO-II telescope; the Crab pulsar, the Vela pulsar, PSR B1509−58, and PSR B1706−44 (Table 2). For the Vela pulsar as well as the Crab pulsar, pulsed and unpulsed emissions were detected by *EGRET*, and pulsed emission only for PSR B1706−44. They have been claimed or suggested to be positive in very high energy gamma-ray detection (Tanimori et al. 1998a; Yoshikoshi et al. 1997; Sako et al. 2000; Kifune et al. 1995;

Table 2. The basic parameters of the observed rotation-powered pulsars using the CANGAROO-II telescope. P represents the pulse period, $\dot{E}$ the spin-down luminosity, and d the distance. Observation time (2000–2002) T includes cloudy weather conditions.

Object name	P (msec)	$\dot{E}$ (erg/sec)	d (kpc)	T:ON/OFF (hour)	Reference
Crab	33.5	4.5E38	2.0	57/53	(Okumura 2002)
Vela	89.3	7.0E36	0.25	76/72	
PSR B1706−44	102.5	3.4E36	1.8	94/90	(Kushida 2002)
PSR B1509−58	150.7	1.8E37	4.2	32/34	
PSR J1420−6048	68.2	1.0E37	7.7[2]	30/24	

Chadwick et al. 1998). PSR J1420−6048 has recently joined our target list as a newly discovered pulsar with a large $\dot{E}/d^2$ value comparable to the other targets. Correlation with a gamma-ray source, GeV J1417−6100/3EG J1420−6038 has been discussed for this pulsar. The Crab data has been used to check the telescope performance including calibrations and analyses and the obtained spectrum is consistent with the previous reports within 15% in the absolute energy scale (Okumura et al. 2002). The gamma-ray spectrum of PSR B1706−44 around 1 TeV has been measured using the data spanning two years (Kushida et al. 2001). The recent *Chandra* observation of PSR B1706−44 exhibits a compact nebula in contrast with the complicated feature of the Crab nebula, thus different emission mechanisms may be responsible to TeV gamma-rays from these pulsars (Kushida et al. 2002).

4. Other objects

There remain some other Galactic objects in our target list besides the previous two classes; a massive black hole at our Galactic center (Tsuchiya et al. 2002), a nearby micro quasar with a bipolar jet, SS 433 (Hayashi et al. 2002), and a binary system PSR B1259−63/SS 2883 (Table 3). A fast rotating pulsar PSR B1259−63 and a Be star SS 2883 consists a binary system in a highly eccentric ($e = 0.87$) orbit, and the orbital modulation of radio and non-thermal unpulsed X-ray have been detected. The orbital period is 3.4 year and we observed the binary about 47 and 157 days after the recent periastron. Upper limits at the 0.2–0.5 Crab level have been obtained which constrain the outflow parameters of the Be star (Kawachi et al. 2002).

Table 3. The basic parameters of the remaining observation targets of our galaxy using the CANGAROO-II telescope. Observation time (2000–2002) T includes cloudy weather conditions.

Object name	Distance (kpc)	T: ON/OFF (hour)	Reference
Galactic Center	8	134/129	(Tsuchiya 2002)
SS 433 (Western lobe)	5	86/81	(Hayashi 2002)
PSR 1259−63/SS 2883 binary	1.5	24/22	(Kawachi 2002)

5. Summary

With the CANGAROO-II 10-m Cherenkov telescope located in Woomera, South Australia, the CANGAROO project has observed the southern sky in the sub-TeV to multi-TeV energy range for two years. SNRs of non-thermal X-ray detection, rotation-powered pulsars of large $\dot{E}/d^2$ value, and other galactic unique objects including our Galactic Center have been selected as observation targets. TeV gamma-rays from two SNRs (SN 1006 and RX J1713.7−3946) and two rotation-powered pulsars (the Crab pulsar and PSR B1706−44) have been detected and detailed study of the energy spectra has been performed. Upper limits have been obtained for PSR B1259−63 binary at the two orbital phases in the post-periastron period. The analyses are on-going for other targets and results will be presented soon.

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