DETECTION OF VHE GAMMA-RAYS FROM PSR1509-58

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1. Introduction

Evidence of particle acceleration can be obtained through non-thermal emission from accelerated particles. Recently, the *ASCA* satellite has found X-ray synchrotron nebulae around many pulsars (Kawai and Tamura, 1996). Accelerated electrons/positrons, which emit synchrotron X-rays in such objects, are expected to produce inverse Compton radiation in the Very High-Energy gamma-ray region. VHE gamma-ray observations provide us with important information about the environment around pulsars.

PSR B1509-58 is located near the center of the SNR MSH15-52. The pulsar has a young characteristic age of ~1700 years and a large spin down energy loss rate of 1.8×10^{37} ergs s^{-1}. A synchrotron X-ray nebula has been found to exist around the pulsar (Seward et al., 1983). Moreover, *ASCA* found a jet-like structure extending from the pulsar (Tamura et al., 1996). Using the X-ray results, VHE gamma-ray emission from the nebula was predicted by du Plessis et al. (1995). The expected flux is within the sensitivity of the CANGAROO telescope.

When the polar cap model is applied, due to the photon splitting process caused by the strong surface magnetic field, a cut-off of a pulsed emission around MeV energies is predicted by Harding, Baring and Gonthier (1997). We examine our data for the periodicity in the signal as well.

2. Observation

The 3.8m telescope of the CANGAROO (Collaboration between Australia and Nippon (Japan) for a GAmma-Ray Observatory in the Outback) is located at Woomera, South Australia (136°47′E, 31°6′S and 160m a.s.l.). Čerenkov photons emitted from an extensive air shower originated by a primary gamma-ray or a cosmic ray are collected with the parabolic mirror of 3.8m diameter and detected with the imaging camera at the focal plane. The details of the camera and the telescope are described in Hara et al. (1993).

The telescope was pointed at the pulsar PSR B1509-58 (right ascension $15^h13^m55^s.62$ and declination $-59^\circ\ 08'\ 08''.9$ (J2000)) in 1996 and 1997. The pulsar (ON source) as well as the offset regions having the same declination as the pulsar but different right ascension (OFF source) were observed for equal amounts of time each night under moonless conditions. The total observation times for ON (OFF) source directions are $53^{\rm h}35^{\rm m}$ ($50^{\rm h}30^{\rm m}$) and $42^{\rm h}44^{\rm m}$ ($41^{\rm h}09^{\rm m}$) in 1996 and 1997, respectively. The selected durations after omitting the data during cloudy sky conditions are $40^{\rm h}32^{\rm m}$ ($42^{\rm h}10^{\rm m}$) and $32^{\rm h}08^{\rm m}$ ($32^{\rm h}08^{\rm m}$). Because the mirror was recoated in October 1996, the threshold energy is estimated to be 1.5 TeV for the 1997 observations although it was 4.0 TeV for the 1996 observations.

3. Analysis and Results

Shower images obtained at the focal plane are fitted as ellipses and the conventional image parameters (Hillas, 1985) are derived. The parameter ranges used to enhance the gamma-ray signals were determined from Monte Carlo simulations and are: $0^\circ\!.6 <$ distance $\leq 1^\circ\!.3$, $0^\circ\!.04 <$ width $\leq 0^\circ\!.09$, $0^\circ\!.1 <$ length $\leq 0^\circ\!.4$, $0.35 <$ concentration ≤ 0.70 and alpha $\leq 10^\circ$. To remove the incomplete images near the edge of the camera, images with centroids located $< 1^\circ\!.05$ from the center of the camera are selected. It was also required that the number of hit tubes ≥ 5 and the number of photoelectrons ≥ 20.

The distributions of the orientation angle (alpha) after all the cuts are shown in Figure 1. For the 1996 data, a normalization factor of 0.961 was used to multiply the OFF source counts to account for the differences in the observation times. Although there is no significant excess of the ON source counts over the OFF source seen in the 1996 data, the 1997 data clearly shows an excess, indicating the existence of a gamma-ray signal with a statistical significance of 4.1σ at $\alpha \leq 10^\circ$. The corresponding upper limit and flux are calculated as,

$$\mathrm{F}_{3\sigma}(\mathrm{E} \geq 4.0\,\mathrm{TeV}) \leq 2.0 \times 10^{-12}\ \mathrm{cm}^{-2}\mathrm{s}^{-1} \qquad \text{(1996 data)}$$

$$\mathrm{F}(\mathrm{E} \geq 1.5\,\mathrm{TeV}) = (3.1 \pm 0.8) \times 10^{-12}\ \mathrm{cm}^{-2}\mathrm{s}^{-1} \qquad \text{(1997 data)}$$

assuming a differential energy spectral index of -2.5. The upper limit and the error in the flux are estimated based on the numbers of the observed counts. The threshold energies are defined as those at which the *detected* differential photon flux becomes maximum in the Monte Carlo calculations. If we change the assumption of the differential energy spectrum index as -2.5 ± 1.0, the corresponding threshold energies are estimated to change $\sim \pm 30\%$.

For the 1997 data, a map of the statistical significance in the $2° \times 2°$ field of view centered on the pulsar position is shown in Figure 2 with 66% and 91% error circles obtained using Monte Carlo calculations. The maximum excess is found at 0°.11 away from the pulsar position with 4.9 σ. This value decreases $\sim 4.0\sigma$ when the penalty of the source search was considered. Furthermore, the excess position is still within the error circle of the pulsar, so we can conclude that the emission position is consistent with the pulsar position.

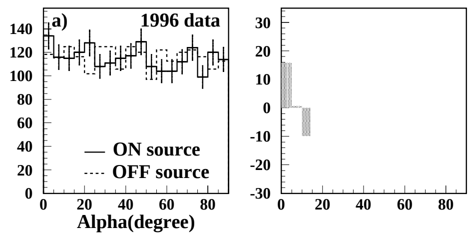

Table 1. Results of period analysis. χ^2 are obtained for the histograms with 20 bins.

Observation Period	χ^2	Z_2^2 test Z	P(>Z)	H-test H	P(>H)	flux upper limit (3σ) ($\times 10^{-12} cm^{-2} s^{-1}$)
1996	17.0	3.18	0.53	3.18	0.28	1.6
March 1997	31.4	6.65	0.16	6.28	0.08	6.4
April 1997	14.1	1.43	0.83	0.65	0.77	3.3
May 1997	16.2	0.90	0.92	0.71	0.75	2.6

the nebula around the pulsar PSR B1509-58. Indeed, the flux from the nebula predicted by du Plessis et al. (1995) agrees with our results if the magnetic field strength in the nebula is $\sim 6\ \mu$G. This value of the magnetic field strength is consistent with the one obtained from the equipartition between the magnetic field and the particle energy densities.

This is the first evidence of VHE gamma-ray emission from the vicinity of a non-EGRET pulsar. For the further study of the pulsar environment, it is important to observe pulsars having X-ray synchrotron nebulae in VHE energy range.

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