TeV Gamma-ray Observations of Southern AGN with the CANGAROO 3.8m Telescope

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ABSTRACT

Since 1992 the CANGAROO 3.8m imaging telescope has been used to search for sources of TeV gamma-rays. Results are presented here for observations of four Southern Hemisphere BL-Lacs - PKS0521-365, PKS2316-423, PKS2005-489 and EXO0423-084. In addition to testing for steady DC emission, a night by night burst excess search has been performed for each source.

THE CANGAROO IMAGING ATMOSPHERIC CHERENKOV TELESCOPE

The CANGAROO 3.8m imaging telescope is located near Woomera, South Australia (longitude 137°47′E, latitude 31°06′S, 160m a.s.l). The reflector is a single 3.8m diameter parabolic dish with F1 optics. The imaging camera consists of a square packed array of 10mm × 10mm Hamamatsu R2248 photomultiplier tubes. The tube centers are separated by 0.18°, giving a total field of view (side-side) of ~3°. The current gamma-ray energy threshold of the 3.8m telescope is estimated to be ~1.0 TeV. Prior to mirror recoating in November 1996 (which includes all data presented in this paper) the energy threshold was somewhat higher (~2.0 TeV). For a more detailed description of the 3.8m telescope see Hara et al. 1993.

DATA SAMPLE

PKS2316-423 (RA = 23°19′05.8, Dec= −42°06′48″, z= 0.055) is a BL-Lac object associated with a parent elliptical galaxy. It has previously been studied over a wide range of wavelengths. Emission from radio through to x-ray wavelengths is consistent with synchrotron radiation from electrons with $E > 10^{13}$eV (Crawford and Fabian 1994). PKS2316-423 is not detected by the EGRET telescope on the CGRO. The CANGAROO 3.8m telescope observed PKS2316-423 during July 1996, for a total of 26 hours on-source data and 25 hours off-source data.
PKS0521-365 (RA=05h22m57.8, Dec=−36°27'03", Z=0.055) is a radio selected BL-Lac. It was first detected as a strong radio source more than 30 years ago. PKS0521-365 was viewed by the EGRET experiment on the CGRO during 1992 from May 14 to June 4. A point source, consistent with the position of PKS0521-365 was detected at a statistical significance of 4.3 \( \sigma \). The integral source flux above 100MeV was \((1.8 \pm 0.5) \times 10^{-7}\) photons cm\(^{-2}\)s\(^{-1}\). The hardness of the EGRET photon spectrum and the proximity of the source make PKS0521-365 a candidate source for detectable levels of TeV gamma-ray emission. PKS0521-365 has been observed by the CANGAROO 3.8m telescope for three consecutive years between 1993 and 1995. The CANGAROO raw data set consists of 52 on/off pairs with a total of 89 hours of on-source and 84 hours of off-source data.

PKS2005-489 (RA=20h09m25.4, Dec=−48°49'54", z=0.071) is an x-ray selected BL-Lac. X-ray measurements of PKS2005-489 by EXOSAT show extremely large flux variations on timescales of hours (Giommi et al. 1990). PKS2005-489 is not detected by EGRET. We have observed PKS2005-489 during August 1993 and during August/September 1994 obtaining 41 hours of on-source and 38 hours of off-source data.

EXO0423-084 (RA = 04h25m50.7, Dec=−08°33'43", z= 0.039) was detected at x-ray wavelengths by EXOSAT. The associated galaxy, MCG 01-12-005, is a radio source free of emission lines. This, along with the high X-ray luminosity (\(>10^{43}\) ergs s\(^{-1}\)) makes EXO0423-084 a candidate BL-Lac object (Giommi et al. 1991). If this source is a BL-Lac, it would be the third closest such object known (after Mkn 421 and Mkn 501), and the closest in the southern hemisphere. This source was observed during October of 1996 for a total of 19 hours on-source and 18 hours off-source data.

ANALYSIS

Prior to image analysis each data set is subjected to data integrity checks and photomultiplier gain/pedestal correction. Images that are sufficiently large (> 4 tubes and > 20 photoelectrons) are parameterized after Hillas (1985). The gamma-ray selection domains for the 3.8m telescope are defined as

\[
0.5^\circ < \text{Distance} < 1.1^\circ \\
0.01^\circ < \text{Width} < 0.08^\circ \\
0.1^\circ < \text{Length} < 0.4^\circ \\
0.4 < \text{Concentration} < 0.9 \\
\text{Alpha} < 10^\circ
\]

These cuts, based on Monte Carlo simulations, reject 98% of the background cosmic ray triggers while retaining 40% of the gamma-rays. For each source the total data set has been tested for gamma-ray emission. The significance of the on-source excesses have been estimated using a method based on the maximum likelihood method of Li and Ma (1983). In the total data set for each source no significant excess is seen for those events in the gamma-ray domain. The calculated excesses are 

\[-0.91\sigma \text{ (PKS2005-489)}, +0.22\sigma \text{ (PKS2316-423), } -0.99\sigma \text{ (EXO0423-084)} \text{ and } -0.27\sigma \text{ (PKS0521-365).}

Upper limits to steady DC emission have been calculated after Protheroe (1984) and are shown in the scatter plot in figure[1]. We have also searched our data set for gamma-ray emission on a night by night basis. In general our observations of a source consist of a long (several hours) on-source run, with a similar length off-source run, offset in RA to provide the same coverage of azimuth and zenith. The burst search has been performed by calculating the on-source excess for each pair of on/off observations each night. In cases where there is no matching off-source run, an equivalent off-source run from another night is used. Figure[2] shows the distribution of on-source excess significances for all four sources. There is
no evidence for gamma-ray bursts on the timescale of \( \sim 1 \) night for any of the sources. The most significant nightly excess (from PKS0521-365) has a nominal significance of 3.7\( \sigma \) but after allowing for the number of searches performed this significance is reduced to less than 3\( \sigma \). The 2\( \sigma \) upper limits to gamma-ray emission for each observation are shown in figure 1.

**CONCLUSION**

Analysis of CANGAROO data shows no evidence for steady DC or burst emission of TeV gamma-rays from the BL-Lacs PKS0521-365, PKS2005-489, PKS2316-423 and EXO0423-084. A sensible comparison at TeV energies between these sources and the proven TeV sources Mkn421 and Mkn501 depends upon the nature of the gamma-ray emission above the threshold of CANGAROO. If we assume that the gamma-ray emission from Mkn421 and Mkn 501 extend up to 10TeV with an integral spectral power law of index -1.0, we can compare the expected fluxes with the upper limits shown in figure 1. Under these assumptions the integral quiescent fluxes above 2TeV are:

- Mkn421 \( F(>2\text{TeV}) \sim 2.1 \times 10^{-12} \) photons cm\(^{-2}\)s\(^{-1}\) (for measurement taken from Dec. 1993-April 1994) Kerrick et al. 1995.
- Mkn501 \( F(>2\text{TeV}) \sim 1.0 \times 10^{-12} \) photons cm\(^{-2}\)s\(^{-1}\) (Catanese 1995)

If any of these sources reported in this paper were capable of providing a steady DC flux at the level of Mkn 421 it would be detectable by CANGAROO, albeit at low significance. We would not expect to see a source of similar flux to Mkn501. Observations by Whipple of Mkn421 have shown that it is capable of extremely energetic bursts on timescales of hours to days. A burst with \( F(>250\text{GeV}) \sim 4.0 \times 10^{-10} \) photons cm\(^{-2}\)s\(^{-1}\) (\( F(>2\text{TeV}) \sim 4.0 \times 10^{-11} \) photons cm\(^{-2}\)s\(^{-1}\) for a -1.0 spectral index and maximum photon energy of 10TeV) lasting two hours would be easily detectable by CANGAROO at a significance of around 13\( \sigma \).

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Fig. 2: Distribution of the significances of night by night excesses for all sources.

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