Multiwavelength Observations of 3EG J2006-2321 and 3EG J0433+2908

P. M. Wallace[1], M. Eracleous[2], J. V. Foreman[1], J. P. Halpern[3], O. Reimer[4], and D. J. Thompson[4]

[1]*Department of Physics and Astronomy, Berry College, Mt. Berry, GA 30149*
[2]*Dept. of Astronomy & Astrophysics, Pennsylvania State University, University Park, PA 16802*
[3]*Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027*
[4]*Code 661 NASA Goddard Space Flight Center, Greenbelt, MD 20771*

Abstract. We present multiwavelength data for the variable EGRET sources 3EG J2006-2321 and 3EG J0433+2908. The former is listed as unidentified in the 3rd EGRET Catalog and the latter is listed as an AGN; however, as yet there has been no formal presentation of its broad-band characteristics. The most likely radio counterpart for 3EG J2006-2321 is PMN J2005-2310 (S_5=260 mJy); optical observations indicate a V=18.7 point-like counterpart with z=0.83. No X-ray counterpart has been detected, but an upper limit on the X-ray flux is derived from ROSAT data. EGRET data indicate that 3EG J2006-2321 displays strong short-term variability above 100 MeV. These data indicate that 3EG J2006-2321 is probably a blazar. For 3EG J0433+2908, the most likely radio counterpart is 87GB 0430+2859 (S_5=481 mJy). This flat-spectrum source was monitored at 2.25 and 8.3 GHz at GBI; the light curves indicate that the source is variable at these frequencies. The optical spectrum of the V=17.8 counterpart is featureless; no redshift is known. A ROSAT source, RX J0433.6+2906, is coincident with the radio position. Based on these data and the evidence that 3EG J0433+2908 is variable above 100 MeV, we confirm that this source is a member of the BL Lac subclass of AGN.

3EG J2006-2321

Gamma-ray Observations

Between 22 April 1991 and 27 September 1995, the time span covered by the 3rd EGRET catalog (Hartman et al. 1999), 3EG J2006-2321 was within 30° of the instrument axis during 9 viewing periods (VP's). In only two was it detected. During VP 5.0 (1991 July 12-26) the aspect was 28°3 and the source was detected at the 4.4σ level. Three weeks later during VP 7.2 the source was 13°6 from the instrument axis and was not detected. During VP 13.1 (1991 October 31-November 7), 3EG J2006-2321 was again detected and it exhibited transient behavior on time scales of 12 hours (Wallace et al. 2000). During this VP the source was 13°6 from the instrument axis and the overall significance of the detection was 4.8σ. There was no detection of 3EG J2006-2321 in six VP's after 13.1, although the aspect was often much less than 20°. Combining the data from the two positive detections gives the source a 95% confidence radius of 0°80. The peak flux during VP 13.1 was $(1.75\pm0.53)\times10^{-6}$

CP587, *GAMMA 2001: Gamma-Ray Astrophysics 2001*, edited by S. Ritz et al.

photons/cm^2/s and the ratio of peak to average flux is 5:1. Applying a χ^2 test to the light curve yields a variability index (McLaughlin et al. 1996) of 3.2, corresponding to a probability of 0.0006 that these data are consistent with an intrinsically nonvariable source.

Radio Observations

The NRAO/VLA Survey at 1.4 GHz (Condon et al. 1983) lists only four sources above 100 mJy within the error circle of 3EG J2006-2321. The source with the smallest separation (10.9') from the EGRET position is NVSS J200556-231028, with a 1.4-GHz flux of 302 mJy. The flux of the strongest source, NVSS J200711-233435, is slightly higher than this, at 319 mJy; this source is 23.0' from the gamma-ray position. The other two sources have weaker fluxes and are further from the gamma-ray source. Only one of five 5-GHz sources within the error circle is coincident with any of the NVSS sources: PMN J2005-2310 (S_5=260 mJy). This source is coincident with NVSS J200556-231028. This radio source is also the only one to feature a flat spectrum; its flux at 365 MHz is 260 mJy; α_r at this frequency is 0.7±02 (Douglas et al. 1996). In light of these data, we associate PMN J2005-2310 with the gamma-ray source.

Optical Observations

A CCD image in the V band centered on PMN J2005-2310 was taken at the 2.1-m telescope at Kitt Peak on 2000 June 2. A point-like optical counterpart with intrinsic V=18.7 was found within 2" of the position of PMN J2005-2310. An optical spectrum was also taken at Kitt Peak on 2000 June 2 and features a single broad Mg II 2897 Å emission line at 5129 Å, corresponding to z=0.83. This large redshift is typical of AGN.

X-ray Observations

The region surrounding PMN J2005-2310 has had little exposure to X-ray instruments. The sole data come from the ROSAT All-sky Survey; in both the Bright and Faint Source Catalogs there is no source within 30' of the radio position. This places an upper limit on the X-ray flux of the source. A typical dim source in the FSC has a PSPC count rate of ~8×10^{-13} counts/s. Assuming a power law spectrum with α=2.0, this corresponds to a flux between 0.1 and 2.0 keV of ~2.4×10^{-13} erg/cm^2/s.

Spectral Energy Distribution and Discussion

A rough SED of 3EG J2006-2321 is shown below in Figure 1. From the two-peaked profile it is evident that the distribution is consistent with a blazar identification. The conclusion of the present analysis is that 3EG J3006-3432 is probably a blazar, but in some respects it is unusual among EGRET AGN. In particular, its 5-GHz flux is much weaker than any other blazar with comparable peak gamma-ray flux. With 99.998% confidence, Mattox et al. (1997) find that the peak gamma-ray flux of EGRET blazars

is linearly correlated with their 5-GHz flux densities. They determine that the probability of EGRET detecting a radio source with S_5=260 mJy is only 0.015. This probability is a factor of 12 less than that of any other EGRET blazar (B2115-304, p=0.18). Gamma-ray sources like 3EG J2006-2321 must be uncommon. If the same fraction of blazars with S_5<1.0 Jy displayed bright (100 MeV flux > 10^{-6} photons/cm^2/s) gamma-ray flares as those with S_5>1.0 Jy, EGRET would have detected more such flares than it did. Quantitative analysis of this conclusion is underway.

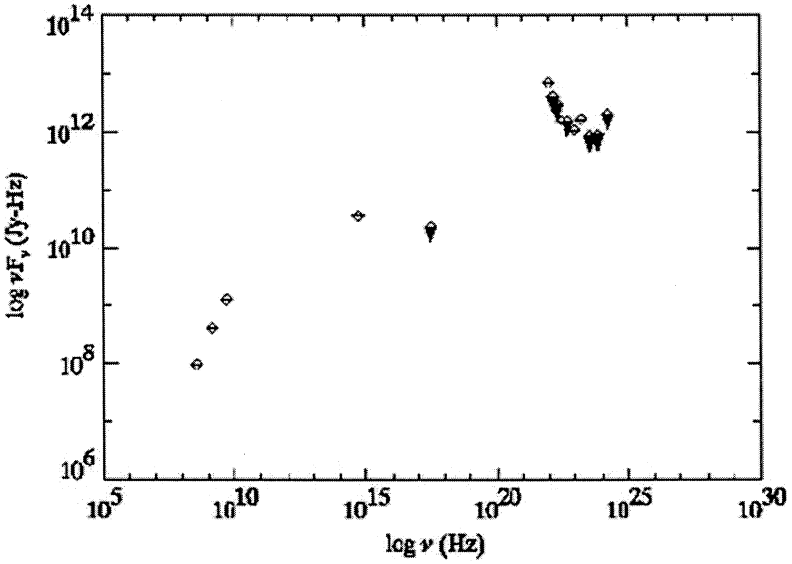

FIGURE 1. Rough spectral energy distribution for 3EG J2006-2321. Arrows indicate upper limits. The X-ray upper limit is derived from a negative detection in the ROSAT catalogs, and the gamma-ray upper limits are statistical. No error bars are shown.

3EG J20433+2908

Gamma-ray Observations

This source is listed in the 3EG catalog as an AGN; however, no formal presentation of the data to support this identification has yet been made. Over the span covered by the catalog, this source (l=170°48, b=-12°58) displays a mean high-energy gamma-ray flux of (2.20×0.28) 10^{-7} photons/cm^2/s and a power-law spectrum with α = 1.90±0.10. This is a harder spectrum than is displayed by most EGRET AGN; this source is listed in the GEV catalog. The source is well-exposed to EGRET, having been in the FOV almost 20 times from Phase 1 through Cycle 4; it has a 95% error radius of 0°18. From 1995 August 8-22 it was in a high state; its average flux during

this time was (7.57×2.21) 10^{-7} photons/cm^2/s, a factor of ~3.5 times higher than its mean flux. This high state was reported to the IAU by Lundgren et al. (1995).

Radio Observations

Dingus et al. (1995) state that the strongest flat-spectrum source within the 95% error contour, 87GB 0430+2859, is the most likely counterpart to the EGRET source. Our results from analysis of the NED database are consistent with this conclusion; there are no other flat-spectrum radio sources within the contour with S_5>100 mJy. 87GB 0430+2859 is located 7' from the gamma-ray position; the probability of this being a chance coincidence is calculated by Dingus et al. (1995) to be 0.6%. The radio source has S_5=481 mJy and α=0.2 at this frequency. In response to the high state reported by Lundgren et al. (1995), 87GB 0430+2859 was monitored at GBI at 2.25 and 8.3 GHz. Preliminary light curves display evidence of variability at these frequencies.

Infrared and Optical Observations

There is an IR source in the 2MASS database that is coincident with 87GB 0430+2859. The magnitudes in the IR bands are J=14.28, H=13.34, and K=12.50.

An optical counterpart appears in the Palomar Sky Survey within 2" of the VLA position of the radio source; its magnitude is near the POSS limit. Condon et al. (1983) optically identified this source with an extended (5") galaxy with estimated magnitude ~19; work is underway to confirm or reject this association. Several other optical photometric observations have been made of this source. On 1997 February 6, it was observed with the KPNO 2.1-m telescope and was found to have V=17.8 (Halpern et al. 1997), about 2 magnitudes brighter than in the POSS field. Another photometric point taken in 2000 December indicates R = 17.4. Optical monitoring may help to confirm the variability suggested by these numbers.

Optical/NIR spectroscopy has also been performed for this source. Two spectra have been obtained: one from 4000-7000 on 2000 February 5 at KPNO and one from 4200-10000 on 2000 November 27 at the Hobby-Eberly Telescope. Both spectra show no emission or absorption features and they rise steeply toward the red; this redness is probably due to considerable extinction at the low Galactic latitude of the source. The spectrum is typical of the BL Lac subclass of AGN.

X-ray Observations

Voges et al. (1995) report that they have found a hard X-ray source in the ROSAT All-sky Survey within 22" of the position of 87GB 0430+2859. The PSPC count rate in the 0.1-2.0 keV ROSAT band is 0.05 counts/s during 1990 August 21-23, corresponding to an energy flux of 2×10^{-12} erg/cm^2/s. This source, RX J0433.6+2906, is the only X-ray source within 1° of the radio position.

Spectral Energy Distribution and Discussion

The data presented here support the AGN identification of 3EG J0433+2908 found in the 3EG catalog. It is a variable gamma-ray source. It is a strong, flat-spectrum, variable radio source; its featureless optical spectrum is evidence that it is a member of the BL Lac subclass of blazars. Optical monitoring and polarization measurements would be useful as final pieces of evidence for this identification. A rough SED of 3EG J0433+2908 is shown below in Figure 2. From the bimodal profile it is evident that the distribution is consistent with a blazar identification.

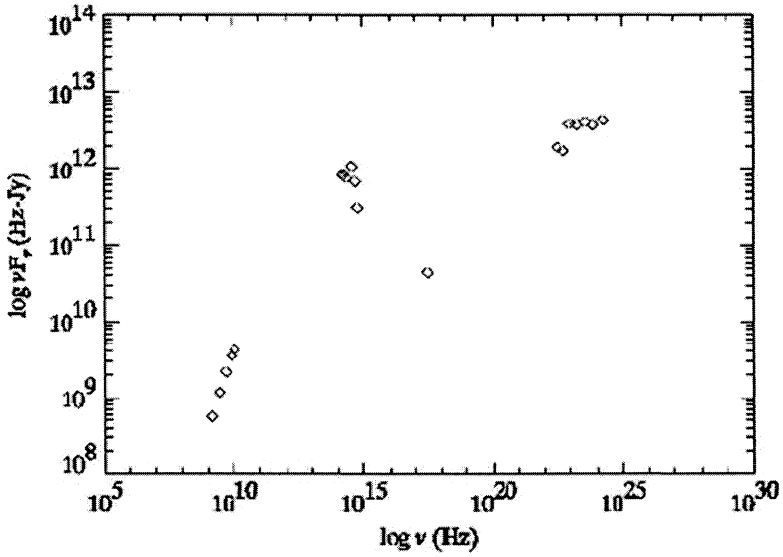

FIGURE 2. Rough spectral energy distribution for 3EG J0433+2908. No error bars are shown.

REFERENCES

1. Condon, J. J. et al. 1983, AJ, 115, 1693
2.. Dingus, B. L. et al. 1996, ApJ, 467, 589
3.. Douglas, J. N. et al. 1996, AJ, 111, 1945
4.. Hartman, R. C. et al. 1999, ApJS, 123, 79
5. Halpern, J. P. et al. 1997, IAU Circular 6639
6. Lundgren, S. C. et al. 1995, IAU Circular 6258
7. Mattox, J. R. et al. 1997, ApJ, 481, 95
8. McLaughlin, M. A. et al. 1996, ApJ, 473, 763
9. Voges, W. & Kanbach, G. 1995, IAU Circular 6264
10. Wallace, P. M. et al. 2000, ApJ, 540, 183