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0FGL J1830.3+0617: A FERMI BLAZAR NEAR THE GALACTIC PLANE

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ABSTRACT

We present a multiwavelength study of the unidentified *Fermi* γ -ray source 0FGL J1830.3+0617, which exhibits variability above 200 MeV on timescales of days to weeks. Within the *Fermi* 95% confidence error contour lies B1827+0617, a radio source with spectral index $\alpha = 0.09$ between 1.4 and 4.85 GHz. The flat spectral index and flux density of 443 mJy at 4.85 GHz are consistent with the bulk of *Fermi* sources associated with blazars. It is also detected in the 0.3 – 10 keV band by *Swift*. Optical imaging in 2009 May identifies B1827+0617 at $R \approx 16.9$, and shows that it is at least 2 magnitudes brighter than on the Palomar Sky Survey plates. Contemporaneous optical spectroscopy acquired during this high state finds a weak emission line that we attribute to Mg II $\lambda 2798$ at redshift $z = 0.75$, supporting a flat spectrum radio quasar (FSRQ) classification. The variability characteristics and radio properties together indicate that 0FGL J1830.3+0617 at Galactic latitude $b = +7.^\circ 5$ is a blazar. Blazar identifications of three additional low-latitude *Fermi* sources, 0FGL J0643.2+0858, 0FGL J1326.6–5302, and 0FGL J1328.8–5604, are also suggested.

Subject headings: gamma rays: observations – X-rays: individual (Swift J1830.1+0619)

1. INTRODUCTION

The complete identification of samples of high-energy (> 200 MeV) γ -rays sources remains as one of the outstanding challenges in modern astrophysics. The main difficulty arises from the limited angular resolution (from a few arcminutes to degrees) that can be achieved at GeV energies, which allows for multiple candidate counterparts within the γ -ray error circles. Overcoming the positional obstacles, the EGRET instrument (Thompson et al. 1993) managed to identify blazars and pulsars as the dominant contributors to the γ -ray source population (Hartman et al. 1999). However, despite significant observational efforts, more than half of the sources catalogued by EGRET remained unidentified (Thompson 2008).

During its first months of operation, the *Fermi* Gamma-ray Space Telescope (*Fermi*) has improved the sensitivity and angular resolution achieved by EGRET, regaling the high-energy community with an improved view of the GeV sky (Abdo et al. 2009a). Of the 205 most significant sources reported in the Bright Gamma-ray Source List (0FGL), 168 have been associated with blazars, pulsars, high-mass X-ray binaries, radio galaxies, pulsar wind nebulae, supernova remnants, a globular cluster, and the LMC. Among the 0FGL sources, 37 have no obvious counterparts at other wavelengths.

Multiwavelength observations play a powerful role in the ultimate goal of producing definite identifications for all γ -ray emitters. In particular, the absence of obvious counterparts for 18% of γ -ray sources in the 0FGL admits the possibility that there are additional types of γ -ray emitters (Montmerle 1979) or even potentially exotic phenomena (Baltz et al. 2007). It is only through dedicated multiwavelength programs that the likelihood

of new types of γ -ray emitters can be assessed.

Previous multiwavelength studies of γ -ray sources without obvious counterparts have yielded some noteworthy results. For example, Mirabal & Halpern (2001) identified the X-ray counterpart of 3EG J1835+5918 as the second member of a much larger population of radio-quiet pulsars that has been recently confirmed by *Fermi* (Abdo et al. 2009a). Multiwavelength efforts also suggested the emergence of a class of γ -ray sources associated with radio galaxies (Mukherjee et al. 2002; Combi et al. 2003).

Building on the improved localizations and sensitivity achieved by *Fermi*, we have started a dedicated multiwavelength program to investigate the nature of unidentified sources in the 0FGL. In a parallel effort, Bassani et al. (2009) suggested a probable association of *Fermi* source 0FGL J2001.2+4352 with a BL Lac object. In this Letter, we report the association of 0FGL J1830.3+0617, a low Galactic latitude source at $(\ell, b) = (36.^\circ 158, +7.^\circ 543)$, listed as having photon flux $1.7 \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$ above 100 MeV, with the flat-spectrum radio quasar (FSRQ) B1827+0617. The organization of this paper is as follows. In §2, we describe multiwavelength observations of B1827+0617. In §3 we discuss the implications of our results. Finally, conclusions are presented in §4.

2. OBSERVATIONS

2.1. Radio

A number of archival radio observations have covered the field of 0FGL J1830.3+0617. An examination of the NRAO VLA Sky Survey (NVSS) source catalog reveals only one source within the 95% confidence level radius derived by *Fermi*. NVSS J183005.90+061916.4 is listed as an unresolved source of flux density 397 mJy at 1.4 GHz (Condon et al. 1998). In order to provide a map of the entire field, we generated a radio finding chart from the 1995 February 27 VLA observation using the postage stamp image server available on the NVSS World Wide

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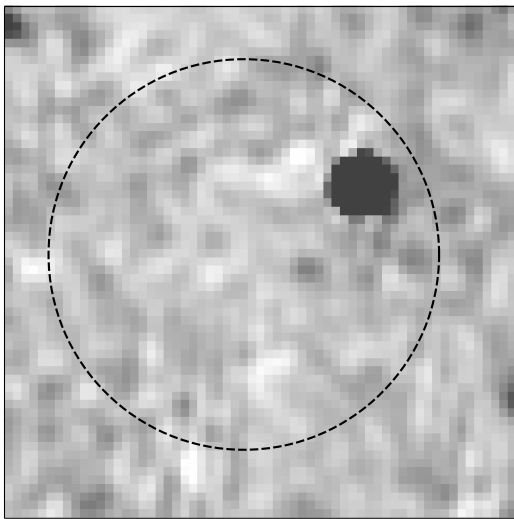


FIG. 1.— NVSS postage stamp image of 0FGL J1830.3+0617 at 1.4 GHz overlain with the 5.8 radius *Fermi* error circle derived by Abdo et al. (2009a). The bright source corresponds to NVSS J183005.90+061916.4 (B1827+0617). The field is $15' \times 15'$.

Web⁴. Figure 1 shows the 1.4 GHz image and the localization of NVSS J183005.90+061916.4 within the *Fermi* error circle. A corresponding source GB6 J1830+0619 (B1827+0617 herein) was also detected with a flux density of 443 mJy at 4.85 GHz in the Green Bank 4.85 GHz northern sky survey carried out during 1986 November and 1987 October (Gregory et al. 1996). We accordingly estimate a spectral index $\alpha = 0.09$ between 1.4 and 4.85 GHz, defined as $S_\nu \propto \nu^\alpha$. Given the resulting spectral index, we classify B1827+0617 as a flat-spectrum ($\alpha > -0.5$) radio source.

2.2. X-rays

The X-Ray Telescope (XRT) on board the *Swift* observatory (Gehrels et al. 2004) observed the field of 0FGL J1830.3+0617 on 2009 May 20 UT for a total of 580 s of useful exposure in photon counting (PC) mode. For the data reduction, we used grades 0–12 and version 3.3 of the *Swift* software. As in the radio observations, a single source, Swift J1830.1+0619, was detected with *xrtcentroid* within the *Fermi* error circle at (J2000.0) R.A.=18^h30^m05.^s8, decl.=+06°19'12" with a 6" uncertainty, consistent with the position of B1827+0617. X-ray counts were extracted from a circular region with a 20 pixel radius (47"). The background was extracted from a source-free region with similar radius. The count rate obtained from the observation is $(5.3 \pm 0.8) \times 10^{-2} \text{ s}^{-1}$. Although the source contains only 31 photons, Swift J1830.1+0619 is detected at a 5.5 σ level of significance. Because of the limited number of photons detected, no spectral fitting was attempted. Using WebPIMMS⁵, we estimate an absorbed flux in the 0.3–10 keV band of $(2.2 \pm 0.3) \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ assuming a power law spectrum with $\Gamma = 2.0$ and a Galactic H I column

density $N_{\text{H}} = 2.4 \times 10^{21} \text{ cm}^{-2}$ as obtained from the nH tool⁶. We note that N_{H} is consistent with Galactic absorption derived assuming an optical extinction $E(B - V) = 0.46$ (Schlegel et al. 1998) and the standard conversion $N_{\text{H}}/E(B - V) = 5.0 \times 10^{21} \text{ cm}^{-2} \text{ mag}^{-1}$ (Savage & Mathis 1979).

2.3. Optical

Optical identification of B1827+0617 was made during 2009 May 25 and May 29 UT using the RETROCAM imager (Morgan et al. 2005) mounted on the MDM 2.4 m Hiltner Telescope. Images in Sloan *g, r, i, z* were taken, and the *r*-band image is shown Figure 2. Magnitudes were measured using a 1.5" radius aperture centered at the optical position of the object at coordinates (J2000.0) R.A.=18^h30^m05.^s95, decl.=+06°19'16".2 in the USNO-B1.0 astrometric system. An approximate *R* magnitude was derived using USNO magnitudes of nearby stars. In this system, stars A and B in Figure 2 have *R* = 18.4 and *R* = 18.8, respectively.

On both nights, B1827+0617 was found at *R* \approx 16.9. It is clear that this is brighter by at least 2 magnitudes in comparison with any of the Palomar Sky Survey plates obtained in 1950, 1990, and 1993. Visual inspection shows that B1827+0617 was definitely fainter than star B on the Digitized Sky Survey image from the 1993 May 27 plate, also shown in Figure 2. Therefore, reporting here a > 2 mag high state in 2009 is rather conservative.

In addition to the optical imaging, we used the Boller & Chivens CCD spectrograph (CCDS) mounted on the MDM 2.4 m telescope to acquire spectra of B1827+0617. The setup used provides $3.1 \text{ \AA pixel}^{-1}$ dispersion and $\approx 8.0 \text{ \AA}$ resolution with a 1" slit. Observations consisted of three 1200 s integrations obtained on 2009 May 25 UT under photometric conditions. The spectra were processed using standard procedures in IRAF⁷ and a final spectrum was generated by combining the three individual exposures. The wavelength scale was established by fitting a set of polynomials to Xe lamp spectra. A Hg-Ne lamp was also used to verify the wavelength calibration. Finally, we derived the flux calibration from observations of the spectrophotometric standard Feige 34 (Stone 1977) observed at comparable telescope pointing to B1827+0617.

Galactic reddening is a significant factor in this line of sight at Galactic coordinates $(\ell, b) = (36^\circ 158, +7^\circ 543)$. Therefore, we produced a final dereddened spectrum using an extinction correction of $E(B - V) = 0.46$ for these coordinates derived from the dust maps of Schlegel et al. (1998). Figure 3 shows the resulting dereddened, wavelength- and flux-calibrated spectrum of B1827+0617. A single weak emission line at 4892 \AA can be identified with Mg II $\lambda 2798$ at a redshift of $z = 0.75$ by process of elimination, considering other expected QSO emission lines that are not seen for alternative identifications. In addition, the weak, broad shelf to the red of Mg II, with a maximum at 5600 \AA , is due to the blend of Fe II multiplets that commonly contribute to the feature

⁶ <http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3nh/w3nh.pl>

⁷ IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

⁴ Available at <http://www.cv.nrao.edu/nvss/postage.shtml>

⁵ <http://heasarc.gsfc.nasa.gov/Tools/w3pimms.html>

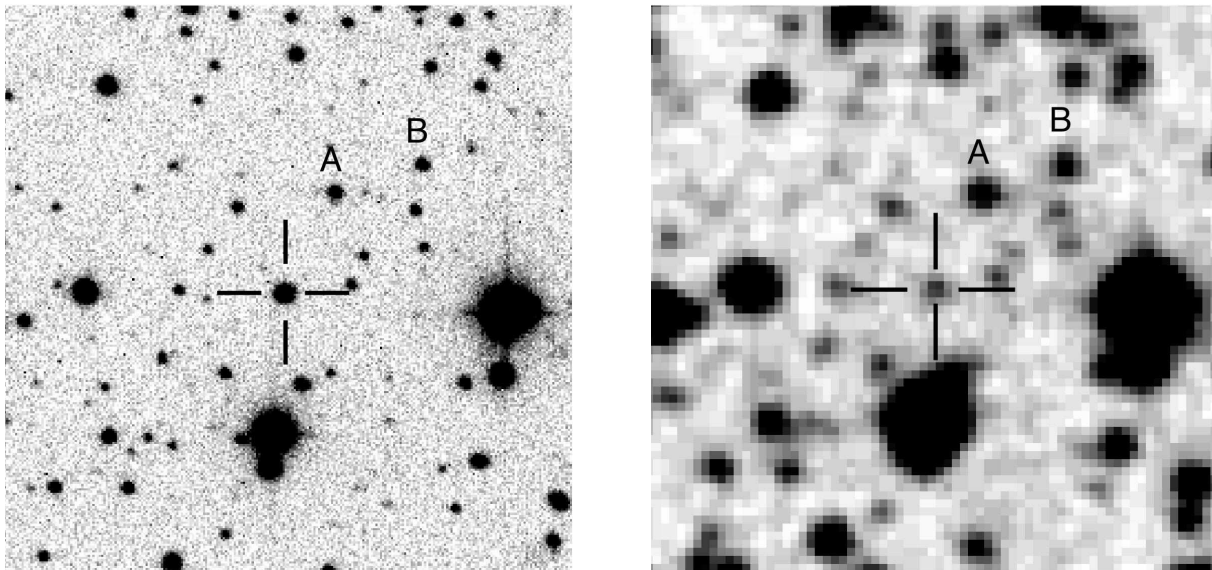


FIG. 2.— *Left*: RETROCAM r -band image obtained with the MDM 2.4 m telescope on 2009 May 29 UT at a scale of $0''.259 \text{ pixel}^{-1}$. The field is $70''$ across. North is up, and east is to the left. The optical counterpart of B1827+0617, at coordinates (J2000.0) R.A.= $18^{\text{h}}30^{\text{m}}05.^{\text{s}}95$, decl.= $+06^{\circ}19'16''.2$, is marked with a cross. Comparison stars A and B have USNO-B1.0 magnitudes $R = 18.4$ and $R = 18.8$, respectively, while B1827+0617 has $R \approx 16.9$. *Right*: Digitized Palomar Sky Survey red plate ($1'' \text{ pixel}^{-1}$) of the same field from 1993 May 27 UT.

known as the small blue bump in QSO spectra. As is often the case in blazars, these and other emission lines may become more prominent in the spectrum when the continuum declines to a low state.

3. DISCUSSION

A typical γ -ray error circle contains several radio and X-ray sources to contend with. The field of 0FGL J1830.3+0617 is rather simple in that a single radio/X-ray source, B1827+0617, emerges as the only counterpart candidate. Optical photometry shows that B1827+0617 is at least 2 magnitudes brighter than its historical level as seen on sky survey plates. Interestingly, there is also

evidence for variability of 0FGL J1830.3+0617 in *Fermi* observations between 2008 August 4 and 2008 October 30 (Abdo et al. 2009a). Multiwavelength variability and periods of enhanced activity are typically observed in γ -ray blazars (Abdo et al. 2009b).

Turning our attention to the radio band, archival measurements indicate a spectral index of $\alpha = 0.09$ between 1.4 and 4.85 GHz. In order to compare the radio properties of B1827+0617 with proposed blazar associations in the 0FGL (Abdo et al. 2009a), we culled measurements from the Green Bank (GB6) catalog at 4.85 GHz (Gregory et al. 1996), the 4.85 GHz Parkes-MIT-NRAO (PMN) survey catalogue (Griffith & Wright 1993), and the 1.4 GHz NVSS catalog (Condon et al. 1998). For sources classified as blazars (Abdo et al. 2009a), flux densities were assembled and a spectral index α (where $S_\nu \propto \nu^\alpha$) computed between 1.4 and 4.85 GHz. We show in Figure 4 the radio spectral index distribution as a function of the flux density at 4.85 GHz for 100 *Fermi* blazars. Clearly, the results indicate that the radio properties of B1827+0617 are in accord with the flux densities and flat spectral indices of typical blazars.

The association of B1827+0617 with 0FGL J1830.3+0617 is further supported by the optical spectrum of B1827+0617, which indicates a redshift $z = 0.75$. The presence of a single emission line in the optical spectrum accompanied by a flat-spectrum radio spectral index is consistent with a FSRQ blazar.

Statistically, as many blazars are expected to be located near the Galactic plane as anywhere else (Mukherjee et al. 2000; Halpern et al. 2001; Sguera et al. 2004). Indeed, by extrapolation, *Fermi* should detect 20–25 blazars at $|b| \leq 10^\circ$ (Abdo et al. 2009b). Thus far, five blazar associations are reported in the 0FGL at $|b| \leq 10^\circ$. In addition, 0FGL J0910.2–5044 at $b = -1.8^\circ$ (Cheung et al. 2008; Landi et al. 2008) is likely associated with a blazar (Sadler 2008). The new identification of 0FGL J1830.3+0617 confirms the

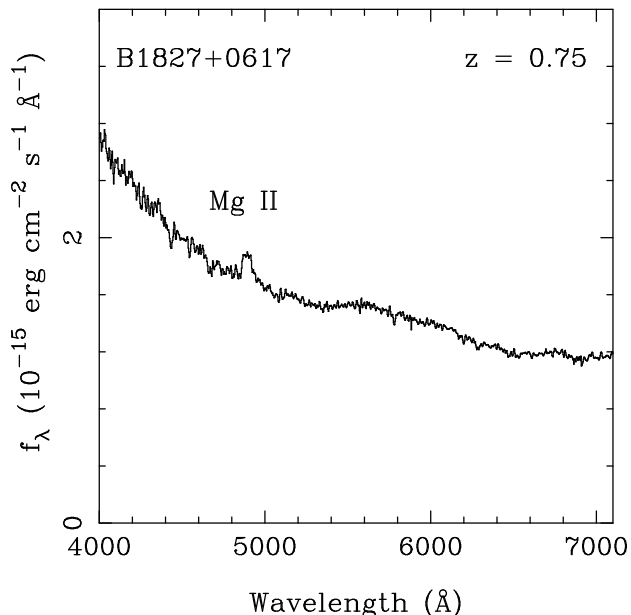


FIG. 3.— Spectrum of B1827+0617 obtained on 2009 May 25 UT, dereddened assuming $E(B - V) = 0.46 \text{ mag}$ (Schlegel et al. 1998). The single emission line Mg II $\lambda 2798$ at $z = 0.75$ is indicated.

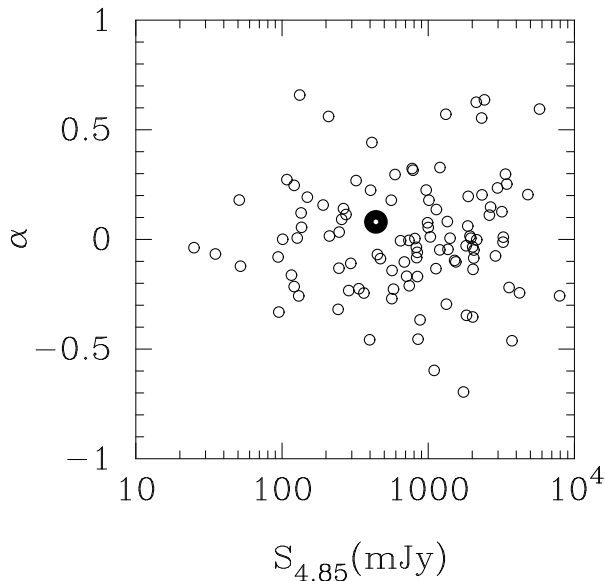


FIG. 4.— Spectral index α between 1.4 and 4.85 GHz as a function of flux density at 4.85 GHz $S_{4.85}$ for 100 blazars detected by *Fermi* (Abdo et al. 2009a). B1827+0617 is indicated by the large filled circle.

expectation of additional *Fermi* blazars within the zone $-10^\circ < b < 10^\circ$. A blazar classification for B1827+0617 using the BZCAT (Massaro et al. 2009), CRATES (Healey et al. 2007), or CGRaBS (Healey et al. 2008) catalogs was most likely missed because such surveys only aim for uniform sky coverage at $|b| \geq 10^\circ$. We anticipate that several additional “unidentified” *Fermi* sources at low Galactic latitude can be associated with known flat-spectrum radio sources. Among our proposed identifications (Figure 5) are 0FGL J0643.2+0858 = PMN J0643+0857 (Griffith et al. 1995; Petrov et al. 2006), 0FGL J1326.6–5302 = PMN J1326–5256 and 0FGL J1328.8–5604 = PMN J1329–5608 (Griffith et al. 1995; Massardi et al. 2008).

4. CONCLUSIONS

We have presented radio, optical, and X-ray observations of the field of the unidentified *Fermi* source 0FGL J1830.3+0617. Only a single plausible counterpart, B1827+0617, is detected within its 95% error circle. In the absence of other alternatives, we have argued that the B1827+0617 is most likely associated with 0FGL J1830.3+0617. A blazar identification of the *Fermi* source is supported by its flat spectral index between 1.4 and 4.85 GHz, as well as the detection of optical/ γ -ray variability. The optical spectrum of B1827+0617 has a single emission line that we identify with Mg II $\lambda 2798$ at $z = 0.75$, which supports a FSRQ blazar classification for this source. The radio properties of B1827+0617 are compatible with known *Fermi* blazars in the 0FGL. These findings suggest that the proposed blazar association is largely secure. Additional identifications of *Fermi* blazars at low Galactic latitude with known radio sources can proceed in the same manner as for high-latitude sources. Ultimately, the unequivocal identification of γ -ray blazars will depend strongly on the detection of contemporaneous variability in γ rays and at least one additional energy band.

Independent of the γ -ray strategies, it is crucial to move ahead with dedicated multiwavelength programs of both identified and unidentified *Fermi* sources. These efforts may prove successful in sorting out the presence of novel classes of γ -ray emitters. Such multiwavelength studies will increase in complexity as the *Fermi* mission continues to unveil the full distribution of GeV sources in the sky to even fainter flux levels.

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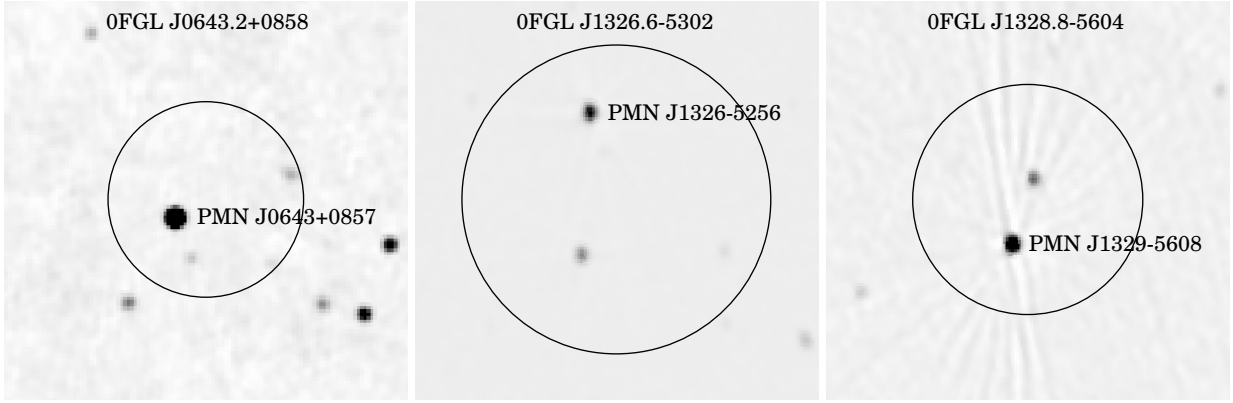


FIG. 5.— Radio images of unidentified *Fermi* sources with error circles from Abdo et al. (2009a). Proposed flat-spectrum radio source identifications are indicated (see text for radio references). Each image is 0.5° across. 0FGL J0643.2+0858 is from the 1.4 GHz NVSS, while the two southern sources are from the 843 MHz Sydney University Molonglo Sky Survey (Bock et al. 1999)