Fermi-LAT detection of two high galactic latitude gamma-ray sources, Fermi J1049.7+0435 and J1103.2+1145

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ABSTRACT

During a search for gamma-ray emission from NGC 3628 (Arp 317), two new unidentified gamma-ray sources were discovered, Fermi J1049.7+0435 and J1103.2+1145. The detections were made using data from the Large Area Telescope (LAT), on board the Fermi Gamma-Ray Space Telescope, in the 100 MeV to 300 GeV band during the period between 2008 August 5 and 2012 October 27. Neither detection is coincident with any source listed in the second Fermi-LAT (2FGL) catalog. Fermi J1049.7+0435 is at Galactic coordinates (l, b) = (245:34, 53:27), (α12000, δ12000) = (162:43, 4:60). Fermi J1103.2+1145 is at Galactic coordinates (l, b) = (238:85, 60:33), (α12000, δ12000) = (165:81, 11:75). Possible radio counterparts are found for both sources, which show flat radio spectra similar to other Fermi-LAT detected active galactic nuclei, and their identifications are discussed.

Key words: BL Lacertae objects: general – galaxies: active – gamma rays: galaxies

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1. INTRODUCTION

The Second Fermi Large Area Telescope (LAT) source catalog (2FGL; Nolan et al. 2012) includes as many as 1873 sources, but initial attempts to identify counterparts at other wavelengths resulted in 575 sources remaining unidentified. The 2FGL catalog is based on the first 24 months of LAT observation since its launch in 2008, but the LAT has now accumulated more than 5 yr of high-energy gamma-ray data almost flawlessly, presenting the possibility of finding new sources that were too faint to be detected in the first 2 yr of data or showed flaring activity after the catalog was created.

In this paper, we report on two new gamma-ray sources serendipitously discovered in the constellation Leo and discuss possible counterparts based on radio observations.

2. ANALYSIS

Our original goal was to search for gamma-ray emission from NGC 3628 (Arp 317), one of the three galaxies called the “Leo Triplet”, for which possible starburst activity has been reported based on XMM observations (Tüllman et al. 2006). Five years of archival data from Fermi-LAT have been analyzed using the Fermi Science Tools supplied by Fermi Science Support Center (FSSC 2013, Fermi Science Tools v9r23p1). The energy range used in the present analysis was from 100 MeV to 300 GeV. “Source” class events detected at zenith angles smaller than 100° were used for analysis, assuming the “P7SOURCE_V6” instrument response function along with the standard analysis pipeline suggested by FSSC. The significance of the gamma-ray signal has been estimated using a maximum likelihood method with the help of the gtlike program (which we used in the binned mode) included in the tools. The data periods for this studies span from 2008 August 4 to 2012 October 27.

For NGC 3628 (Arp 317) the test statistic, TS, returned by gtlike is consistent with zero, indicating that there is no evidence of gamma-ray emission. Thus we calculated upper limits to gamma-ray flux from NGC 3628 of 1.4(1.3) × 10−9 cm−2 s−1, at 95% confidence level (CL), above 100 MeV for the period 2008 August 4 to 2010 July 31 (2010 July 31 to 2012 October 27). This translates to a gamma-ray luminosity upper limit of 2.5(2.3) × 1038 erg s−1 assuming a distance of 12 Mpc, which is derived as the median of eight measurements ranging from 6.7 to 14.2 Mpc (NED 2012).

During the study of NGC 3628, we noticed two rather bright gamma-ray sources in the field of view centered on NGC 3628 and within a radius of 15° (Nishimichi & Mori 2013). These detections are not coincident with any source listed in the 2FGL catalog (Nolan et al. 2012) or in the third EGRET catalog (3EG, Hartman et al. 1999). Figure 1 shows a gamma-ray countmap of this area. The positions for these sources were estimated using the gtcontmap program which calculates the TS value assuming an unknown source at various positions in the field of view of interest, and the maximum TS values were obtained for the positions shown in Table 1. The errors of the positions are conservatively estimated as the radius at which the TS value drops to the half value.

Figures 2 and 3 show the TS maps around the new sources for the half-year period when the TS value takes the maximum, which is consistent with the assumed of point sources. The average fluxes, power-law indices, and TS value for the entire analyzed period (from 2008 August 27 to October 10, 2013) are (3.68 ± 0.36) × 10−8 cm−2 s−1 (>100 MeV), −2.60 ± 0.07 and TS = 332 for J1049.7+0435; (2.35 ± 0.30) × 10−8 cm−2 s−1 (>100 MeV), −2.55 ± 0.09 and TS = 196 for J1103.2+1145.

Figures 4 and 5 show the time variation of the gamma-ray fluxes of the newly detected sources in half-year bins. For these plots we added data until 2013 October 10. One can see in the one-day period between 2008 August 5 and 2012 October 27. Neither detection is coincident with any source listed in the 2FGL catalog. Fermi J1049.7+0435 is at Galactic coordinates (l, b) = (245:34, 53:27), (α12000, δ12000) = (162:43, 4:60). Fermi J1103.2+1145 is at Galactic coordinates (l, b) = (238:85, 60:33), (α12000, δ12000) = (165:81, 11:75). Possible radio counterparts are found for both sources, which show flat radio spectra similar to other Fermi-LAT detected active galactic nuclei, and their identifications are discussed.

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3. DISCUSSION

The variability both sources display at gamma-ray energies suggests that they are more likely to be active galactic nuclei (AGNs) than members of other populations of identified...
Figure 1. Gamma-ray countmap around the NGC 3628 region. The map is created in a 0.1° grid and smoothed for the data during 2008 August 5 to 2013 July 3. 2FGL sources are annotated, and two new gamma-ray sources are marked as “Unknown_1” (J1103.2+1145) and “Unknown_2” (J1049.7+0435).
(A color version of this figure is available in the online journal.)

Table 1
Best Positions of New Sources

| Name            | $\alpha_{\text{J2000}}$ (deg) | $\delta_{\text{J2000}}$ (deg) | $\ell_{\text{II}}$ (deg) | $\psi_{\text{II}}$ (deg) | Error Radius (arcmin) |
|-----------------|-------------------------------|-------------------------------|---------------------------|---------------------------|------------------------|
| J1049.7+0435    | 162.43                        | 4.60                          | 245.34                    | 53.27                     | 51                     |
| J1103.2+1145    | 165.81                        | 11.75                         | 238.85                    | 60.33                     | 66                     |

Figure 2. Test statistics map around the J1049.7+0435 region for the period from 2011 October 27 to 2012 April 27 where the TS value is the highest (TS = 222).
(A color version of this figure is available in the online journal.)

Figure 3. Test statistics map around the J1103.2+1145 region for the period from 2013 April 27 to 2013 October 27 where the TS value is the highest (TS = 197).
(A color version of this figure is available in the online journal.)
Figure 4. Time variation of gamma-ray flux of J1049.7+0435 in half-year bins for the period from 2008 August 5 to 2013 October 10. The triangles are upper limits (95% CL).

Figure 5. Time variation of gamma-ray flux of J1103.2+1145 in half-year bins for the period from 2008 August 5 to 2013 October 10. The triangles are upper limits (95% CL).

by, e.g., Edwards (2005), radio spectral indices determined from single dish observations are affected by steeper-spectrum radio lobes in some sources, which disguise the presence of a flat-spectrum radio core.)

We have therefore searched for potential counterparts in the Green Bank 6 cm (GB6; Gregory et al. 1996) catalog and determined spectral indices between 20 cm and 6 cm using the NRAO VLA Sky Survey (NVSS; Condon et al. 1998) catalog.

The closest GB6 radio source to J1049.7+0435 is GB6 J1050+0432, with an angular separation of 7
degree. The source has a flux density of 99 ± 10 mJy at 4.8 GHz, and the corresponding 20 cm source, NVSS J105010+043251, has a flux density of 101.2 mJy, yielding a spectral index α (where S ∝ ν^{α}) of 0.0. Two fractionally brighter GB6 sources have both larger angular offsets and significantly steeper spectra: GB6 J1049+0505, 113 mJy, 30’ separation, α = −0.8; GB6 J1051+0449, 101 mJy, 29’ separation, α = −0.9. We note that the GB6 and NVSS flux densities were made some years apart, and so these spectral indices should be taken as representative values rather than absolute measurements. As this declination range is also covered by the Parkes–MIT–NRAO (PMN) equatorial survey (Griffith et al. 1995), we can compare the GB6 value with that of PMN J1050+0432, which has a 4.8 GHz flux density of 98 ± 12 mJy.

For J1105.2+1145, the closest GB6 source is GB6 J1103+1158, with an angular separation of 14’. The source has a 4.8 GHz flux density of 306 ± 27 mJy, with the corresponding 20 cm source, NVSS J110303+115816, having a flux density of 262.6 mJy, resulting in a spectral index of 0.1. Other relatively bright GB6 sources in the area are further away and with steeper spectral indices: GB6 J1103+1114, 116 mJy, 31’ separation, α = −0.7; GB6 J1104+1103, 277 mJy, 46’ separation, α = −0.8. A Seyfert 1 galaxy, Mrk 728, is 0.89 from J1103.2+1145 and is not likely the counterpart. GB6 J1103+1158 corresponds to the quasar SDSS J110303.52+115816.5, which lies at a redshift of 0.912 (Schneider et al. 2007). Furthermore, the quasar has been detected in the Very Long Baseline Array Calibrator Survey (VLBI) observations (Petrov et al. 2005), confirming the presence of a compact core in this radio-loud AGN. Cataloged radio positions and flux densities for the two sources are tabulated in Table 2.

We have additionally made snap-shot observations of J1049.7+0435 and J1103.2+1145 (at their NVSS positions) with the Australia Telescope Compact Array at several epochs, as part of an ongoing program to monitor gamma-ray sources (Stevens et al. 2012) with the measured flux densities are listed in Table 3. The observations at 17 GHz and 38 GHz were preceded by a pointing scan on a nearby bright compact source to refine the global pointing model. Data were processed in Miriad in the standard manner. Flux density calibration was bootstrapped to the standard ATCA flux density calibrator, PKS 1934–638. Errors are conservatively estimated as 5% at lower frequencies and 10% at highest frequencies, including statistical and systematic errors, with the latter dominating.
GB6 J1050+0432 has brightened considerably, by a factor of 2.7, since the GB6 and PMN observations (which date back to the late 1980s and early 1990s), and has an inverted spectrum with \( \alpha \sim 0.25 \), strengthening the case for an association with J1049.7+0435. Note also the increased gamma-ray flux in the latest half-year (Figure 4).

GB6 J1103+1158 is a little fainter than the cataloged GB6 value; however, the ATCA observations confirm that the spectral index remains flat, at \( \alpha \sim -0.1 \), up to 38 GHz. There is no evidence of significant variability over the four months spanned by these observations; however, comparison with the GB6 flux density indicates the presence of longer timescale variability.

We have also examined the ASDC Sky Explorer (ASDC; ASDC 2012) and NASA/IPAC Extragalactic Database (NED; NED 2012) for other possible counterparts, but we did not find any good candidates nearer than the radio sources mentioned above.

In light of the above facts, we tentatively identify both gamma-ray sources with the radio sources mentioned above. Petrov et al. (2013) make a detailed consideration of the utility of radio observations in finding counterparts to unidentified Fermi sources. The associations proposed here would be strengthened by improved gamma-ray localizations, and/or evidence of contemporaneous multi-wavelength flaring, and, in the case of GB6 J1050+0432, with VLBI observations to determine whether the source contains a compact, parsec-scale radio core.

### 4. CONCLUSIONS

A search for gamma-rays from NGC 3628 (Arp 317), for which possible starburst activity has been reported, found no evidence for >100 MeV emission. However, two new GeV sources, Fermi J1049.7+0435 and J1103.2+1145, have been found near the Leo Triplet region using Fermi LAT archival data spanning five years. The fluxes for both sources increase over the 5 yr period; thus, they are not included in 2FGL catalog. Their flux variability and spectral indices are compatible with those of gamma-ray detected AGNs. Based on angular separation, radio flux density, and spectral index, we associate J1049.7+0435 with GB6 J1050+0432 and J1103.2+1145 with the quasar GB6 J1103+1158. Further multiwavelength studies are required to confirm these identifications.

Finally, looking forward to the release of the third Fermi-LAT catalog, we note that the 15° radius (0.2 sr) field studied here has yielded two previously uncataloged sources. Although the small number statistics result in extrapolations with large uncertainties, this suggests (ignoring further improvements in analysis software and background models) that there might be ~100 new extragalactic sources with $|b| > 10^\circ$ in the 3FGL catalog.

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