OPTICAL SPECTROSCOPIC OBSERVATIONS OF BLAZARS AND γ-RAY BLAZAR CANDIDATES IN THE SLOAN DIGITAL SKY SURVEY DATA RELEASE NINE

F. Massaro1,2, N. Masetti3, R. D’Abrusco4, A. Paggi4, and S. Funk5

1 Yale Center for Astronomy and Astrophysics, Physics Department, Yale University, P.O. Box 208120, New Haven, CT 06520-8120, USA
2 Dipartimento di Fisica, Università degli Studi di Torino, via Pietro Giuria 1, I-10125 Torino, Italy
3 INAF-Istituto di Astrofisica Spaziale e Fisica Cosmica di Bologna, via Gobetti 101, I-40129, Bologna, Italy
4 Harvard-Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge, MA 02138, USA
5 SLAC National Laboratory and Kavli Institute for Particle Astrophysics and Cosmology, 2575 Sand Hill Road, Menlo Park, CA 94025, USA

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ABSTRACT

We present an analysis of the optical spectra available in the Sloan Digital Sky Survey data release nine (SDSS DR9) for the blazars listed in the ROMA-BZCAT and for the γ-ray blazar candidates selected according to their IR colors. First, we adopt a statistical approach based on Monte Carlo simulations to find the optical counterparts of the blazars listed in the ROMA-BZCAT catalog. Then, we crossmatched the SDSS spectroscopic catalog with our selected samples of blazars and γ-ray blazar candidates, searching for those with optical spectra available to classify our blazar-like sources and, whenever possible, to confirm their redshifts. Our main objectives are to determine the classification of uncertain blazars listed in the ROMA-BZCAT and to discover new gamma-ray blazars. For the ROMA-BZCAT sources, we investigated a sample of 84 blazars, confirming the classification for 20 of them and obtaining 18 new redshift estimates. For the γ-ray blazars, indicated as potential counterparts of unassociated Fermi sources or with uncertain nature, we established the blazar-like nature of 8 out of the 27 sources analyzed and confirmed 14 classifications.

Key words: galaxies: active – quasars: general – methods: statistical – radiation mechanisms: non-thermal – surveys

Online-only material: color figures

1. INTRODUCTION

According to the well-assessed unification scenario of active galactic nuclei (AGNs; e.g., Antonucci 1993; Urry & Padovani 1995), blazars are radio-loud sources, featuring compact radio cores combined with a “flat” radio spectrum that extends from frequencies below ∼1 GHz (e.g., Massaro et al. 2013a, 2013b; Nori et al. 2014) up to the sub-millimeter band (e.g., Giommi et al. 2012). They are characterized by a variable, non-thermal continuum and exhibit a typical double-bumped spectral energy distribution (SED), and represent the largest known population of γ-ray sources (e.g., Abdo et al. 2010a; Ackermann et al. 2011), proving to be the most relevant contribution to the γ-ray sky. In particular, blazars are classified as BZBs if the rest-frame equivalent width of their optical features is lower than 5 Å (Stickel et al. 1991; Stocke et al. 1991; Laurent-Muehleisen et al. 1999; Landoni et al. 2013).

As was recently discovered using the WISE all-sky survey (Wright et al. 2010), blazars show peculiar infrared (IR) colors (Massaro et al. 2011b), mostly due to their non-thermal continuum, which allowed us to distinguish them from other classes of active galaxies (e.g., D’Abrusco et al. 2012; Massaro et al. 2012a). This IR property was also interpreted as being due to the lack of observational signatures from a dusty torus in the case of BZBs (e.g., Plotkin et al. 2012).

The variable, non-thermal emission of both BZBs and BZQs, extending from radio up to TeV energies, is interpreted as arising from high-energy particles accelerated in a relativistic jet oriented along the line of sight, whereas relativistic effects amplify both their luminosity and the amplitude of their variability (Blandford & Rees 1978; Giommi et al. 2013).

Recently, we searched for blazar-like objects as potential counterparts to the unidentified γ-ray sources (UGSs) observed with Fermi (Abdo et al. 2010a; Nolan et al. 2012) using several methods based on the IR colors alone (Massaro et al. 2012b, 2012c; D’Abrusco et al. 2013) or combined with other multifequency observations, such as radio (Massaro et al. 2013d) or observations of their X-ray properties (Paggi et al. 2013). We also explored the use of low radio frequency observations (i.e., below ∼1 GHz) as an alternative possibility to find blazar-like counterparts (e.g., Massaro et al. 2013a; Nori et al. 2014) for the UGSs listed in the second Fermi-Large Area Telescope (LAT) catalog (2FGL; Nolan et al. 2012) in addition to other multifequency analysis (e.g., Mirabal & Halpern 2009; Ackermann et al. 2012; Cowperthwaite et al. 2013; Masetti et al. 2013). All of these investigations provided several lists of gamma-ray blazar candidates which must be confirmed and classified via optical spectroscopy.

Here, we investigate the optical spectra of two blazar samples which lie in the footprint of the spectroscopic catalog of Sloan Digital Sky Survey data release 9 (SDSS DR9; Ahn et al. 2012). The first sample includes all the ROMA-BZCAT sources that have an uncertain classification, uncertain redshift estimates,
or have been classified as BL Lac candidates due to the lack of an optical spectrum in the literature (Massaro et al. 2011a).

The second sample lists all the \(\gamma\)-ray blazar candidates which were identified as potential counterparts of UGSs in our previous analyses and for which SDSS spectra are now available. This study is complementary to ongoing spectroscopic campaigns planned to investigate blazar optical properties (e.g., Sbarufatti et al. 2005; Sbarufatti et al. 2009; Plotkin et al. 2010; Paggi et al. 2014).

The paper is organized as follows. In Section 2, we present the statistical approach adopted to determine the optical counterparts of the ROMA-BZCAT sources in the SDSS DR9 catalog, while in Section 3 we describe the samples considered in our analysis. In Section 4, the results of the spectroscopic analysis are illustrated, while, finally, Section 5 is devoted to our summary and conclusions. For our numerical results, we use cgs units unless stated otherwise.

2. SPATIAL ASSOCIATIONS

The ROMA-BZCAT was mainly compiled based on radio, optical, and X-ray surveys, and the blazar coordinates reported are not uniform. The positional accuracy is generally less than \(<1\,\text{''}\) but it could reach \(~5\,\text{''}\), corresponding to the typical uncertainty on the radio positions of the NVSS, for those sources with radio flux densities close to the survey limit (Condon et al. 1998). Since the positional uncertainties for each source are not reported in the ROMA-BZCAT we adopted the following statistical approach to identify the SDSS optical counterparts of the ROMA-BZCAT blazars.

First, we computed the total number of ROMA-BZCAT blazars that lie within the SDSS footprint, corresponding to 1820 sources. For each blazar, we counted the total number of optical counterparts in the SDSS \(N(R)\) present within circular regions of a variable radius \(R\) in the range between \(0\,\text{''}\) and \(10\,\text{''}\). To be conservative in our analysis, in the \(N(R)\) calculation, we only included SDSS sources with the following flags: CLASS_OBJECT (i.e., mode) and CODE_MISC (i.e., clean), both equal to 1.

We then created 100 mock realizations of the ROMA-BZCAT by shifting each blazar position in a random direction of the sky by a fixed length of \(30\,\text{''}\). The shifts used to create the mock ROMA-BZCAT catalogs were chosen to be not too distant from the original ROMA-BZCAT locations and within the SDSS footprint. This guarantees that we will obtain fake catalogs with a sky distribution similar to the original ROMA-BZCAT and we will crossmatch each fake catalog and the SDSS taking into account the local density distribution of the optical sources. The total number of blazars in each mock realization is also preserved equal to that of the ROMA-BZCAT sources in the SDSS footprint. For each mock realization of the ROMA-BZCAT we counted the number of associations with the SDSS occurring at angular separations \(R\) smaller than \(10\,\text{''}\). Then, we computed the mean number \(\lambda(R)\) of these fake associations, averaged over the 100 mock ROMA-BZCAT catalogs, verifying that \(\lambda(R)\) has a Poissonian distribution. Increasing the radius by \(\Delta R = 0\,\text{''}/2\), we also calculated the difference \(\Delta \lambda(R)\) as

\[
\Delta \lambda(R) = \lambda(R + \Delta R) - \lambda(R),
\]

In Figure 1, we show the comparison between \(\Delta N(R)\) and \(\Delta \lambda(R)\). For radii larger than \(R_A = 1\,\text{''}/8\), the \(\Delta \lambda(R)\) curve superimposes that of \(\Delta N(R)\), indicating that ROMA-BZCAT-SDSS cross-matches could occur by chance at angular separations larger than \(R_A\). Thus, we choose \(1\,\text{''}/8\) as the maximum angular separation between the ROMA-BZCAT and SDSS positions at which we consider the optical source a reliable counterpart of the blazar in the ROMA-BZCAT.

Finally, the chance probability of spurious associations \(p(R_A)\) was calculated as the ratio between the number of real associations \(N(R_A)\) and the average of those found in the mock realizations of the ROMA-BZCAT \(\lambda(R_A)\), corresponding to a value of \(~1\%\) (see also Maselli et al. 2010; Massaro et al. 2011b, D’Abrusco et al. 2013, for additional details on \(p(R_A)\)).

3. SAMPLE SELECTION

We adopted the \(R_A\) value of \(1\,\text{''}/8\) to search for the optical counterparts of the blazar-like sources in our two samples within the available spectra of the SDSS DR9 to confirm the source nature, and whenever possible to estimate the redshift. Then, we analyzed two samples of sources in the footprint of the SDSS DR9 and using optical spectra available defined in the following manner.

1. The total number of ROMA-BZCAT sources with an optical counterpart in the SDSS DR9 spectroscopic catalog within \(R_A = 219\). Among these sources there are 50 blazars with an uncertain redshift estimate and an additional 34 sources classified as BL Lac candidates for which optical spectra were not available in the literature while ROMA-BZCAT v4.1 was being prepared. These 84 ROMA-BZCAT sources, with a unique correspondence in the SDSS DR9 spectroscopic catalog within \(1\,\text{''}/8\), constitute our first sample investigated.

2. The second sample lists 15 blazar-like sources with uncertain classification and/or uncertain \(z\) estimates included in the 2FGL (Nolan et al. 2012) and in the Second Fermi-LAT AGN Catalog (2LAC; Ackermann et al. 2011), plus an additional 12 sources identified as potential counterparts of UGSs according to their peculiar IR colors in our recent analyses (e.g., Massaro et al. 2012a, 2012b, 2013c). All 27 of these sources also have a unique correspondence in the SDSS DR9 spectroscopic catalog within \(1\,\text{''}/8\).
4. RESULTS

We visually inspected all of the optical spectra available for the sources in our samples in order to avoid misleading classifications due to artifacts from the SDSS automatic analysis, and if necessary, for example, to confirm a redshift estimate, we downloaded and analyzed the raw data.

We remark that for the BZB classification, we adopted the criterion described in Laurent-Muehleisen et al. (1999), measuring the rest-frame equivalent widths of the emission and/or absorption lines whenever they are detectable above the continuum (see also the recent analyses performed by Sbarufatti et al. 2006; Landoni et al. 2013). In addition, we also adopted the criterion developed by Massaro et al. (2013c)
to classify BL Lac objects based on SDSS ($u-r$) color, which supersedes the criterion based on the Ca H&K break contrast originally introduced by Stocke et al. (1991). Thus, for each source, we computed the absorption-corrected ($u-r$) color equal to $(u-r)_{\text{obs}} - 0.81 \times A_{\text{r}}$, where $A_{\text{r}}$ is the Galactic extinction in the $R$ band, and we considered only those sources with $(u-r) < 1.4$ to be BL Lac objects (see also Maselli et al. 2013). We only assign a BZB classification to sources having both a “featureless” spectra and a ($u-r$) color lower than 1.4.

### 4.1. ROMA-BZCAT Blazars

In the first sample of 84 ROMA-BZCAT blazars with SDSS DR9 spectra, we found that there are 3 BZQs, all associated with Fermi sources in 2FGL and 2LAC (Nolan et al. 2012, Ackermann et al. 2011) with an uncertain $z$ estimate. Our analysis of their optical SDSS spectra allowed us to confirm both their nature and their redshift. In addition to these BZQs, there are 47 sources out of the 84 listed in the first sample classified as BZB according to the ROMA-BZCAT but with an uncertain redshift estimate. We found that 9 of them have good SDSS spectra from which we obtained a $z$ measurement. Unfortunately, none of these 9 are detected in the $\gamma$-rays.

The remaining 34 sources out of the 84 objects in the first sample are indeed classified as BL Lac candidates, with 5 of them associated with Fermi sources in the 2LAC. We confirmed the BL Lac nature for 20 of these sources, including all the Fermi sources, and provided a new redshift estimate for 6. The remaining 14 sources were classified as normal galaxies (8) or type 2 Seyfert galaxies (5) according to the criteria described in Winkler (1992), plus 1 source that still has an uncertain nature mostly resembling a type 2 AGN.

All of our results are summarized in Tables 1 and 2, where we report the ROMA-BZCAT and the SDSS names, together with the results of our analysis (i.e., classification and redshift estimates when possible) and their ($u-r$) colors. Blazars that are associated with Fermi sources are also indicated. Uncertain values of redshifts are indicated with a question mark (?); they are due to the poor signal to noise of a few SDSS archival spectra or to the presence of only a single emission/absorption feature. Then, in Figure 2, we show the optical spectrum of one of the BL Lac classified from our analysis together with two cases of wrong classifications and a quasar.

| Name       | Counterpart | Class | SDSS Class | Redshift | Redshift | $u-r$ | Classification |
|------------|-------------|-------|------------|----------|----------|------|----------------|
| BZBJ0026-0005 | J002608.37-000547.0 | BL Lac | Sy2 | 0.107 | 0.106 | 2.16 | no |
| BZBJ0109+1816* | J010908.17+181607.5 | BL Lac | Sy2 | 0.145 | ? | 0.7 | yes |
| BZBJ0253-0124 | J025315.60-012405.3 | BL Lac | ? | ? | 0.67 | yes |
| BZBJ0754+4423* | J075446.66+442350.7 | BL Lac | Sy2 | 0.145 | 0.24 | 7.33 | no |
| BZBJ0814+0856 | J081421.66+085706.1 | BL Lac | galaxy | 0.23? | 0.24 | 7.33 | no |
| BZBJ0829+1754 | J082904.82+175415.8 | BL Lac | Sy2 | 0.089 | 0.0895 | 2.12 | no |
| BZBJ0831+5400 | J083100.36+540023.2 | BL Lac | Sy2 | ? | 0.0617 | 3.06 | no |
| BZBJ0839+4015 | J083903.08+401545.6 | BL Lac | galaxy | 0.194 | 0.1941 | 2.43 | no |
| BZBJ0905+4705 | J090536.44+470546.3 | BL Lac | type2 | 0.174 | 0.1736 | 2.33 | no |
| BZBJ0912+4235 | J091227.22+423545.1 | BL Lac | galaxy | 0.266 | 0.2662 | 4.0 | yes |
| BZBJ0933+0003 | J093310.57+000323.5 | BL Lac | ? | ? | 0.45 | yes |
| BZBJ0944+5557 | J094441.47+555752.9 | BL Lac | ? | ? | 0.93 | yes |
| BZBJ1007+5023 | J100710.44+502356.4 | BL Lac | Sy2 | 0.133 | 0.1326 | 1.87 | no |
| BZBJ1057+2303 | J105723.09+230318.7 | BL Lac | ? | 0.379 | 0.3782 | 1.07 | yes |
| BZBJ1058+2817 | J105829.89+281746.3 | BL Lac | ? | 0.4793 | 0.4793 | 0.89 | yes |
| BZBJ1100+4210 | J110020.99+421051.3 | BL Lac | galaxy | 0.323 | 0.3229 | 1.75 | no |
| BZBJ1110+3539 | J111056.83+353907.2 | BL Lac | galaxy | 0.61? | 0.61? | 0.72 | yes |
| BZBJ1111+3452 | J111130.90+345203.2 | BL Lac | ? | 0.212 | ? | 0.42 | yes |
| BZBJ1152+2837 | J115210.70+283721.3 | BL Lac | ? | 0.4412 | 0.4412 | 1.17 | yes |
| BZBJ1153+3823 | J115310.70+382721.3 | BL Lac | Sy2 | ? | 0.4098 | 0.99 | no |
| BZBJ1224+2239 | J122401.03+223939.5 | BL Lac | ? | 0.4821 | 0.4821 | 0.88 | yes |
| BZBJ1226+2604 | J122604.12+260427.9 | BL Lac | galaxy | 0.176 | 0.1761 | 2.0 | no |
| BZBJ1243+3627* | J124312.73+362743.9 | BL Lac | ? | ? | 0.45 | yes |
| BZBJ1253+3826 | J125300.95+382625.7 | BL Lac | ? | 0.372 | 0.3707 | 1.08 | yes |
| BZBJ1311+0853 | J131155.76+085340.9 | BL Lac | ? | 0.469 | 0.4694 | 0.85 | yes |
| BZBJ1314+2348* | J131445.80+234826.7 | BL Lac | ? | 0.15? | 0.15? | 0.72 | yes |
| BZBJ1341+3716 | J134138.66+371644.8 | BL Lac | galaxy | 0.17 | 0.1745 | 2.93 | no |
| BZBJ1404+2701 | J140436.82+270141.0 | BL Lac | galaxy | 0.136 | 0.1383 | 2.67 | no |
| BZBJ1410+2820* | J141029.56+282055.6 | BL Lac | ? | ? | 0.58 | yes |
| BZBJ1426+2415 | J142645.52+241523.0 | BL Lac | ? | 0.055? | 0.055? | 0.4 | yes |
| BZBJ1437+4717 | J143716.14+471726.3 | BL Lac | galaxy | ? | ? | 0.68 | yes |
| BZBJ1219+0035 | J121940.67+003527.4 | BL Lac | galaxy | 0.425 | 0.4264 | 0.1 | no |
| BZBJ2227+0037 | J222758.13+003705.4 | BL Lac | galaxy | ? | ? | 0.76 | yes |
| BZBJ2319-0116 | J231952.83-011626.8 | BL Lac | galaxy | 0.2835 | 0.2835 | 1.72 | no |

Notes. Column (1) ROMA-BZCAT name. Column (2) SDSS name of the optical counterpart. Column (3) ROMA-BZCAT classification. Column (4) SDSS spectroscopic classification based on our analysis. Column (5) Redshift estimate derived from our analysis. Question mark indicates uncertain estimates. Column (7) $u-r$ color. Column (8) Classification flag: (yes) marks sources that have been classified on the basis of our analysis.
4.2. γ-Ray Blazar Candidates

The second sample of γ-ray blazar candidates, selected according to our IR-based procedures and having SDSS spectra available, lists 27 sources. Fifteen blazar-like sources were already present in 2LAC but with uncertain classification or uncertain redshift estimates. Among these source, we found seven with quasar-like optical spectra and classified as BZQs, also two with new $z$ estimates, seven BZBs including two sources with measured redshifts, and one misclassified object: SDSS J122011.88+020342.2, associated with 2FGLJ1219.7+0201, which appears to be a Seyfert galaxy rather than a BZQ.

For 2FGLJ1023.6+3947, associated with the SDSS J102333.50+395312.7 source, we obtained a redshift of 1.3328 instead of the value 1.254 reported in 2LAC, and for the BL Lac object SDSS J110021.05+401928.0, counterpart of 2FGLJ1100.94+4014, we were not able to find any optical feature to confirm the 2LAC redshift of 0.225. Among these 15 sources, SDSS J222329.57+010226.6 is associated with an AGN of uncertain type, 2FGLJ2223.4+0104, and was selected in Cowperthwaite et al. (2013) as a γ-ray blazar candidate and which we confirmed as a BL Lac at unknown redshift.

The remaining 12 sources were all selected as γ-ray blazar candidates in our previous analyses of their IR colors (Massaro et al. 2012b, 2013a, 2013c; Paggi et al. 2013). We found that 3 sources, all with new $z$ estimates, out of the 12 have a quasar-like spectrum, similar to those of the BZQs, plus one that is uncertain due to a noisy SDSS spectrum (i.e., SDSS J015852.77+010132.8). Then there are 4 confirmed BL Lac objects while the remaining 4 sources are indeed contaminants of the association methods (1 star and 4 Seyfert galaxies).

All of these results are reported in Table 3 in the same order discussed above.

5. SUMMARY AND CONCLUSIONS

We performed an analysis of the archival optical spectra present in SDSS DR9 (Ahn et al. 2012) for two samples of blazars and γ-ray blazar candidates to confirm their nature, and whenever possible to estimate their redshifts.

First, we adopted a statistical approach to find the SDSS optical cross-matches of the sources in our sample. Then, we analyzed a first sample of 84 blazars listed in the ROMA-BZCAT as BL Lac candidates or as BL Lac objects and flat spectrum radio quasars with uncertain redshift estimates, and a second sample of 27 γ-ray blazar candidates selected according to their peculiar IR colors or with uncertain classification (e.g., D’Abrusco et al. 2013, Massaro et al. 2013c, 2013d, and references therein).

Based on the SDSS spectra, we confirmed the redshifts for three flat-spectrum radio quasars (all γ-ray sources detected by Fermi) and measured $z$ for the nine additional BL Lacs investigated. Then, we have been able to classify 34 BL Lac
We found a total of 11 BZBs (2 with new redshift estimates) and 11 BZQs with new redshift estimates for 2 of them. The remaining 5 sources did not appear to have the typical blazar-like optical spectrum. All of our results are summarized in Table 4.

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### Table 4

| Source Name | SDSS Counterpart | SDSS SDSS Classification | SDSS Redshift | Classification Flag |
|-------------|------------------|--------------------------|---------------|---------------------|
| 2FGL0302.3-0108 | J032345.62+011146.1 | BL Lac | | yes |
| 2FGL0924.0+2819 | J093015.52+281525.1 | QSO | 0.7442 | yes |
| 2FGL0950.1+4554 | J095101.82+455320.0 | BL Lac | 0.3994 | yes |
| 2FGL1017.0+3531 | J101810.97+354239.4 | QSO | 1.2280 | yes |
| 2FGL1023.6+3947 | J102333.50+395312.7 | QSO | 1.3328 | yes |
| 2FGL1100.9+4014 | J110021.05+401928.0 | BL Lac | | yes |
| 2FGL1019.7+4121 | J122011.88+410234.2 | Sy1.8 | 0.2402 | no |
| 2FGL1222.4+4043 | J122254.54+413157.5 | QSO | 0.9642 | yes |
| 2FGL1301.6+3331 | J130118.4+332701.2 | QSO | 1.0084 | yes |
| 2FGL1310.9+4006 | J131016.47+003801.2 | BL Lac | | yes |
| 2FGL1351.4+1115 | J135120.84+114530.0 | BL Lac | | yes |
| 2FGL1332.7+4725 | J133245.24+472222.6 | QSO | 0.6687 | yes |
| 2FGL1442.0+4352 | J144207.15+434836.7 | BL Lac | | yes |
| 2FGL1522.0+4348 | J152419.61+433639.2 | QSO | 2.1677 | yes |
| 2FGL2223.4+0104* | J222329.57+010226.6 | BL Lac | 0.297 | yes |

Notes. Column (1) Source name. Column (2) SDSS name of the optical counterpart. Column (3) SDSS spectroscopic classification based on our analysis. Column (4) Redshift estimate derived from our analysis. Question mark indicates uncertain estimates. (+): 2FGL2223.4+0104 is the source indicated by Cowperthwaite et al. (2013). Column (6) Classification flag: (yes) marks sources that have been classified on the basis of our analysis.

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### Table 3

| Source Name | SDSS Counterpart | SDSS SDSS Classification | SDSS Redshift | Classification Flag |
|-------------|------------------|--------------------------|---------------|---------------------|
| 2FGL0302.3-0108 | J032345.62+011146.1 | BL Lac | | yes |
| 2FGL0924.0+2819 | J093015.52+281525.1 | QSO | 0.7442 | yes |
| 2FGL0950.1+4554 | J095101.82+455320.0 | BL Lac | 0.3994 | yes |
| 2FGL1017.0+3531 | J101810.97+354239.4 | QSO | 1.2280 | yes |
| 2FGL1023.6+3947 | J102333.50+395312.7 | QSO | 1.3328 | yes |
| 2FGL1100.9+4014 | J110021.05+401928.0 | BL Lac | | yes |
| 2FGL1019.7+4121 | J122011.88+410234.2 | Sy1.8 | 0.2402 | no |
| 2FGL1222.4+4043 | J122254.54+413157.5 | QSO | 0.9642 | yes |
| 2FGL1301.6+3331 | J130118.4+332701.2 | QSO | 1.0084 | yes |
| 2FGL1310.9+4006 | J131016.47+003801.2 | BL Lac | | yes |
| 2FGL1351.4+1115 | J135120.84+114530.0 | BL Lac | | yes |
| 2FGL1332.7+4725 | J133245.24+472222.6 | QSO | 0.6687 | yes |
| 2FGL1442.0+4352 | J144207.15+434836.7 | BL Lac | | yes |
| 2FGL1522.0+4348 | J152419.61+433639.2 | QSO | 2.1677 | yes |
| 2FGL2223.4+0104* | J222329.57+010226.6 | BL Lac | 0.297 | yes |

Notes. Column (1) Source name. Column (2) SDSS name of the optical counterpart. Column (3) SDSS spectroscopic classification based on our analysis. Column (4) Redshift estimate derived from our analysis. Question mark indicates uncertain estimates. (+): 2FGL2223.4+0104 is the source indicated by Cowperthwaite et al. (2013). Column (6) Classification flag: (yes) marks sources that have been classified on the basis of our analysis.

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Table 3: Association of γ-Ray Blazar Candidates (00-24 HH)
Participating Institutions are the American Museum of Natural History, Astrophysical Institute Potsdam, University of Basel, University of Cambridge, Case Western Reserve University, University of Chicago, Drexel University, Fermilab, the Institute for Advanced Study, the Japan Participation Group, Johns Hopkins University, the Joint Institute for Nuclear Astrophysics, the Kavli Institute for Particle Astrophysics and Cosmology, the Korean Scientist Group, the Chinese Academy of Sciences (LAMOST), Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Ohio State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.

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