SPECTROSCOPY OF OPTICALLY SELECTED BL LAC OBJECTS AND THEIR $\gamma$-RAY EMISSION

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ABSTRACT

We present Very Large Telescope optical spectroscopy of nine BL Lac objects of unknown redshift belonging to the list of optically selected radio-loud BL Lac candidates. We explore their spectroscopic properties and possible link with gamma-ray emission. From the new observations we determine the redshifts of four objects from faint emission lines or from absorption features of their host galaxies. In three cases we find narrow intervening absorptions from which a lower limit to the redshift is inferred. For the remaining two featureless sources, lower limits to the redshift are deduced from the absence of spectral lines. A search for counterpart emission shows that six out of the nine candidates are Fermi $\gamma$-ray emitters and we find two new detections. Our analysis suggests that most of the BL Lac objects still lacking redshift information are most likely located at high redshifts.

Key words: BL Lacertae objects: general – galaxies: distances and redshifts

Online-only material: supplemental data

1. INTRODUCTION

BL Lac objects are active galactic nuclei (AGNs) characterized by strong and rapid flux variability, polarization, and either weakness or an absence of spectral emission lines. Along with flat spectrum radio quasars, BL Lac objects represent a type of radio-loud object called blazars. As proposed in the seminal paper of Blandford & Rees (1978), blazars are AGNs with relativistic jets pointing close to the direction of the observer. They are the dominant population in the extragalactic $\gamma$-ray sky at both GeV and TeV energies. At radio frequencies, BL Lac objects display strong core compact flat spectrum emissions. In the optical range, the synchrotron continuum is boosted by relativistic beaming resulting in a depression of the equivalent width of the spectral lines, especially in the high-state spectra, often making the detection of redshift a challenging task and a central issue in $\gamma$ astronomy.

The first complete surveys of BL Lac objects were performed in the radio band considering the flatness of the radio spectrum (e.g., Stickel et al. 1991) as a distinguishing feature. In X-rays BL Lac surveys were a sub-product of “complete” sky surveys (see, e.g., Stoeckle 1985, 1991). The Palomar Green survey (Green et al. 1986), aimed at building a complete list of quasars based on their colors, yielded four bright BL Lac objects. The optical spectroscopy was a necessary further step, since the commonly used criterion for defining a BL Lac is the line equivalent widths $EW \lesssim 5 \, \AA$ (e.g., Marcha et al. 1996). The detection of these weak features requires spectroscopy of adequate spectral resolution and signal-to-noise ratio ($S/N$). Observations with medium aperture telescopes provided redshifts for a number of BL Lac objects (e.g., Falomo et al. 1987b, 1987a; Falomo 1990; Stickel et al. 1993; Veron 1994; Marcha et al. 1996; Carangelo et al. 2003) but for many of these objects, in particular those with a strong nuclear component, the redshifts remained unknown. With 8 $m$ class telescopes the situation improved as demonstrated among the recent systematic spectroscopic campaigns such as our study of 69 BL Lac objects in the southern sky with ESO–VLT+FORS2, which yielded 23 new redshifts of BL Lac objects basically selected in the Giommi/Padovani list (Padovani & Giommi 1995) before the launch of Fermi (Sbarufatti et al. 2005a, 2005b, 2006a, 2006b, 2009; Landoni et al. 2013, spectra and redshifts are available in electronic form on our Web site http://www.oapd.inaf.it/zbllac/).

In the last decade in parallel with the activity related to high-energy emission, substantial progress in discovering new BL Lac objects and their redshifts has been derived from large optical spectroscopic surveys in combination with data from radio and X-ray catalogs. Plotkin et al. (2008, hereafter P08) selected 501 BL Lac candidates by combining observations from the Faint Images of the Radio Sky at Twenty-Centimeters (FIRST; Becker et al. 1995) radio survey with the Sloan Digital Sky Survey (SDSS) Data Release 5 spectroscopic data base, using the criteria of featureless or weak-feature spectra and [CaT]/H$\alpha$ depression less than 40%. A substantial fraction of sources, (~60%) lack reliable spectroscopic redshifts. Recently, using different telescopes, Shaw et al. (2013, hereafter S13) produced spectra of most of the 475 Fermi BL Lac candidates (Ackermann et al. 2011), obtaining redshifts for ~44% of the sample and constraining $z$ for nearly all remaining objects. However, in order to characterize the general properties of the BL Lac population it is highly desirable to define a homogeneous sample of BL Lac objects not biased by the properties introduced by the selection of X-ray and radio surveys. For instance, Collinge et al. (2005) compiled a large optically selected sample (386 targets) from 2860 $deg^2$ of the SDSS, chosen to have quasi-featureless optical spectra and low proper motions. Some radio-quiet sources were found, almost all without X-ray counterparts in the ROSAT All-Sky Survey (RASS; Voges et al. 1999). Plotkin et al. (2010a, hereafter P10) expanded the Collinge sample through a complex sieving procedure of SDSS DR7 (Abazajian et al. 2009), and recovered 723 purely optically selected BL Lac objects, included a fraction of 86 radio-quiet objects, the majority of which are unlikely bona fide BL Lac objects, but rather a distinct class of quasars.
with intrinsically weak emission lines (Plotkin et al. 2010b; Wu et al. 2012). Approximately ~80% of the whole P10 sample match with radio sources in the FIRST/NRAO VLA Sky Survey (Condon et al. 1998), and ~40% match with RASS X-ray sources. Spectroscopic redshifts are given for ~36% of the radio-loud subsample.

For this elusive class of objects the adopted selection criteria can affect the redshift distributions of the BL Lac objects and cause different cosmological evolution scenarios (see, e.g., the discussions in Bade et al. 1998 and Giommi et al. 2012). Radio-selected BL Lac objects seem to display a positive evolution (i.e., either the number density or the luminosity shows a decrease with cosmic time), while a negative evolution or no evolution at all was proposed for X-ray-selected objects (Rector et al. 2000; Rector & Stocke 2001; Caccianiga et al. 2002; Beckmann et al. 2003; Padovani et al. 2007; Ajello et al. 2009; Giommi et al. 2009, 2012, and references therein). A continuum trend from slightly positive-evolution low-peaked BL Lac objects to strong negative-evolution high-peaked BL Lac objects was proposed (Rector et al. 2000), and was thought to be related to the X-ray to radio flux ratio (Giommi et al. 1999, 2012). Statistics concerning the evolution of BL Lac objects suffer from redshift incompleteness, making the increase in objects with reliable redshifts from homogeneous and unbiased selections a core issue (see also Shaw et al. 2013 for a discussion).

In this paper we present optical spectroscopy of a small sample (nine targets) of BL Lac objects with unknown redshifts belonging to the P08 catalog of radio-selected BL Lac objects. We note that our sample is also entirely included in the P10 catalog of optically selected BL Lac objects. We describe our observations and analysis of spectra in Section 2 together with the new redshifts; then we search for counterparts in the Fermi Gamma-ray Space Telescope archives (Section 3). A summary and conclusions are given in Section 4.

Throughout the paper we adopt the following concordant cosmology: \( H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1} \), \( \Omega_m = 0.30 \), and \( \Omega_{\Lambda} = 0.70 \).

### 2. OPTICAL SPECTROSCOPY

#### 2.1. Sample Observations and Data Analysis

Within about 200 P08 BL Lac objects with unknown redshift, we selected a small sample of 15 with the only requirement that they be relatively bright objects \( r < 19.4 \), well observable from Paranal (Chile) ESO premises and classified as high-confidence BL Lac objects. We stress that these objects are all included among the P10 radio-loud BL Lac candidates, selected on the only basis of their optical properties, thus we can consider them to be a posteriori optically selected. We collected optical spectra of only 9 sources (see Table 1) out of 15 because of weather conditions.

Spectra were gathered with FORS2 mounted on the Antu Very Large Telescope (VLT) of the ESO in Paranal. Observations were performed with the grism 300 V and the 2" wide slit, yielding a spectral resolution at the central wavelength of \( R = \lambda/\Delta \lambda \approx 350 \) and covering 3800–8200 \( \AA \) spectral range, exploiting the better S/N of the VLT. The seeing in the nights of observations ranged from 0.5 to 1.2, with an average of ~0.9, as reported in Table 1. Standard IRAF tools were used for the data reduction. We adopted the same procedures described in previous works (e.g., Sbarufatti et al. 2005a, 2005b), including bias subtraction and flat fielding. For each target we obtained three or six individual spectra with typical total exposure times of 45 or 90 minutes, respectively, to correct for the effect of cosmic rays and provide independent checks of each signature (see Table 1). Individual spectral frames are combined by taking the median from which a one-dimensional spectrum is extracted. The wavelength calibration was achieved using the spectra of a helium neon argon lamp and typical uncertainties are ~1 \( \AA \). Spectra are corrected for Galactic reddening according to the Schlegel et al. (1998) maps and assuming \( R_V = 3.1 \) (e.g., Cardelli et al. 1989).

#### 2.2. The Optical Spectra

The extracted spectra and the normalized spectra with respect to the continuum are reported in both Figure 1 and on our previously mentioned Web site. For each spectrum the S/N is given in Table 1. The continuum was fitted with a power law, defined as \( F_{\nu} \propto \nu^{-\alpha_{\nu}} \). The resulting optical spectral indices are given in the Table 2 as \( \alpha_{\nu} \) \( (F_{\nu} \propto \nu^{\alpha_{\nu}}) \), where \( \alpha_{\nu} = 2 - \alpha_{\lambda} \) for consistency and easy comparison with the bulk of the literature. We find \( 0.73 < \alpha_{\nu} < 1.44 \) corresponding to an average value of \( \alpha_{\nu}\text{ave} = 1.17 \), consistent with both the average spectral index \( \alpha_{\nu} = 1.15 \) and the dispersion of 0.69 reported by P10.

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**Table 1**

| Source | R.A. (h:m:s) | Decl. (d:m:s) | Date | \( r \) (mag) | Exp.Time (min) | \( N \) | Seeing (arcsec) | S/N |
|--------|-------------|--------------|------|--------------|---------------|------|----------------|-----|
| J003808.50+001336.5 | 00 38 08.503 | + 00 13 36.53 | 2009 Jun 13 | 19.30 | 90 | 6 | 0.6 | 50 |
| J125032.58+021632.1 | 12 50 32.581 | + 02 16 32.173 | 2009 Jun 24 | 18.58 | 45 | 3 | 0.9 | 30 |
| J135120.84+111453.0 | 13 51 20.847 | + 11 14 53.02 | 2009 Jun 24 | 17.17 | 45 | 3 | 1.0 | 100 |
| J144052.93+061016.1 | 14 40 52.94 | + 06 10 16.2 | 2009 Jun 24 | 19.40 | 45 | 3 | 1.1 | 140 |
| J145507.44+025040.2 | 14 55 07.447 | + 02 50 40.25 | 2009 Aug 12 | 18.95 | 45 | 3 | 1.2 | 90 |
| J163716.73+131438.8 | 16 37 16.737 | + 13 14 38.80 | 2009 Aug 12 | 19.20 | 45 | 3 | 0.7 | 35 |
| J163716.73+131438.8 | 16 37 16.737 | + 13 14 38.80 | 2009 Apr 29 | 19.11 | 45 | 3 | 0.5 | 90 |
| J125032.58+021632.1 | 12 50 32.581 | + 02 16 32.173 | 2009 Apr 30 | 18.26 | 45 | 3 | 1.1 | 45 |

Notes. (a) Object ID. (b) ICRS right ascension and declination coordinates (J2000). (c) Date of observation. (e) \( r \) apparent point-spread function magnitude from SDSS DR7. (f) Total exposure time. (g) Number of collected spectra. (h) Seeing during the observation. (i) S/N evaluated as the average over the whole spectrum range, avoiding the regions affected by emission or absorption features.

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\( \Omega_r \) (Tody 1986) is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
In order to search for very weak spectral lines, we evaluated the minimum observable equivalent width (EW_{min}). Dividing the spectrum into 25 Å bins, as fully described in Sbarufatti et al. (2005b), we objectively define the EW_{min} as twice the rms of the distribution of all the observer-frame EWs measured in each bin. The absorption and emission features with EWs greater than this threshold are carefully inspected. ID labels mark the successful identifications in Figure 1 and in Table 2, where EW_{min} and line properties are also reported. For four sources we were able to obtain a redshift from the detection absorption/emission lines associated with the BL Lac host galaxy. In three cases, we observed absorption intervening features which, interpreted as Mg\,\textsc{ii} 2800, allow us to set a lower limit for the redshift. In two cases the spectrum is featureless, thus we calculated a lower limit for z using the method described by Sbarufatti et al. (2005b, 2006b). Briefly, recalling that both nonthermal jets and the host galaxy contribute to the observed flux and assuming that BL Lac host galaxies are giant ellipticals with M_{\text{host}}^{R} = -22.90 \pm 0.50 and standard absorption lines, one can infer a \( z \)-dependent relationship between the observed EW and emitted EW_{rest} = EW/(1 + z). The absence of lines puts EW < EW_{min}, providing a lower limit for z. In Table 2 we also report the upper limit of the redshift from the lack of Ly\alpha absorptions as z_{\text{upper}} = \lambda_{\text{lim}}/1216 Å - 1 + \Delta z, where \( \Delta z \) is derived.
from the probability of not detecting any absorber close to the blue limit wavelength $\lambda_{\text{lim}}$ of the spectrum, taking into account the redshift dependence of Ly$\alpha$ forest absorber density and its EW scaling (see Shaw et al. 2013, and references therein).

In the following we report further information about individual sources.

2.3. Notes on Individual Sources

J003808.50+001336.5. The spectrum shows a feature at $\lambda = 4780$ Å. We ascribed to a Mg$\text{ii} \lambda 2798$ intervening system absorption, which places the source at $z > 0.708$. This feature is, however, only detected at the 2$\sigma$ level. We also note that the Mg$\text{ii}$ doublet is unresolvable with our observations. To complement our observations we retrieved all the spectra from the SDSS. This target was observed three times from MJD 51793 to 55444 with S/N $\sim$ 10 and no reliable redshift is available.

J125032.58+021632.1. Mg$\text{ii} \lambda 2798$ and O$\text{ii} \lambda 3727$ emission lines are apparent, securing the source at $z = 0.995$. A tentative redshift of 0.953, warning-flagged for multiple equal $\chi^2$ best fits, was assigned to the source by the redshift fitting procedure in the SDSS DR9 based on a spectrum of S/N $\sim$ 10 where the Mg$\text{ii}$ feature is loosely visible and detectable. For this optically selected BL Lac candidate the rest-frame Mg$\text{ii}$ equivalent width is $\text{EW}_{\text{rest}} = 6.1 \pm 0.4$ Å, which makes its inclusion in the BL Lac class marginal. To evaluate a more physical discriminant parameter, the optical beaming factor $\delta$, as discussed by Farina et al. (2012) and Landoni et al. (2013), was calculated. This parameter quantifies the contribution of the thermal disk to the total luminosity (Decarli et al. 2011). $\delta = 6.0 \pm 3.6$ identifies the
source as a BL Lac just above the intermediate region between pure QSOs (δ ≃ 1) and BL Lac objects (δ ≃ 4) (Landoni et al. 2013).

J135120.84+111453.0. An absorption feature at λ = 4530 Å is detected. If the interpretation is in terms of a Mg II λ2798 intervening system, the redshift lower limit is 0.619. This absorption feature at λ = 4530 Å was also recently observed by Shaw et al. (2013).

J144052.93+061016.1. Our spectrum exhibits Ca II H/K λλ3934, 3968 and G-band λ4305 absorption lines from the underlying host galaxy at z = 0.396. Two optical spectra were gathered by SDSS on MJD 53494 and 55686 and the inferred redshifts are noted as unreliable. Shaw et al. (2013) detected an absorption feature λ ≃ 3685 Å, which, interpreted as Mg II, set a lower limit at 0.316.

J163716.73+134387.7. In our spectrum we detect a narrow emission line at λ = 6170 Å. This is most probably a real feature, since it clearly appears on each of the three individual spectra. It can be identified with O II λ2373 at z = 0.656. At the same redshift two absorption lines ascribed to Ca II H/K λλ3934, 3968 are apparent. In addition, the position of an absorption at λ = 7124 Å, encompassed by two H2O telluric bands, is consistent with G-band absorption at the same redshift of the other lines. Our redshift is one of the highest ever detected in the optical range using host galaxy absorption lines.

J214406.27+002853.1. Because of the featureless spectrum, a redshift lower limit of ≃ 0.34 is derived from EW_{min} = 1.36 Å. Unreliable redshifts were assigned by the SDSS.

J224448.09−000619.3. We clearly detected Ca II H/K λλ3934, 3968 absorptions at redshift z = 0.641. The position of an absorption at λ = 7057 Å in a region inside the H2O telluric bands, is consistent with G-band absorption at the same redshift as Ca II doublet wavelengths. No reliable redshift was obtained by the SDSS.

J224730.18+000006.4. We distinctly observed an absorption feature at λ = 5311 Å with an EW = +3.0 ± 0.1 Å, which was interpreted as a Mg II λ2798 intervening system setting z > 0.898. There is no evidence of the emission line feature detected by Shaw et al. (2013) at λ ∼ 5460 Å and taken as Mg II at z = 0.949. We suspect this feature to be instrumental.

Table 2

| Source                     | z         | α_v     | EW_{min} (Å) | Line ID | λ_{line} (Å) | Type | FWHM (km s^{-1}) | EW (Å) |
|---------------------------|-----------|---------|--------------|---------|--------------|------|------------------|--------|
| J003808.50+001336.5       | 0.708     | 2.7     | 1.14         | Mg II 4780 | a            | 900 + 200 | +1.6 ± 0.3       |        |
| J125032.58+021632.1       | 0.955     | 1.44    | 1.05         | Mg II 5469 | e            | 4500 + 200 | −12.1 ± 0.8      |        |
| J135120.84+111453.0       | 0.619     | 2.4     | 0.73         | Mg II 4530 | a            | 1500 + 300 | +1.0 ± 0.2       |        |
| J144052.93+061016.1       | 0.396     | 1.08    | 0.28         | Ca II 5491 | g            | 1500 + 600 | +0.4 ± 0.1       |        |
| J145507.44+025040.3       | 0.47      | 2.5     | 1.44         | featureless | ... | ... | ... | ... |
| J163716.73+131438.7       | 0.655     | 1.19    | 0.40         | O II 6170 | e            | 900 ± 100  | −0.8 ± 0.2       |        |
| J214406.27−002858.1       | 0.34      | 2.5     | 1.36         | Ca II 6523 | g            | 1100 ± 100 | +0.7 ± 0.07      |        |
| J224448.09−000619.3       | 0.640     | 0.88    | 0.35         | Ca II 6566 | g            | 800 ± 300  | +0.4 ± 0.09      |        |
| J224730.18+000006.4       | 0.898     | 2.5     | 1.27         | Mg II 5311 | a            | 1800 ± 100 | +3.0 ± 0.1       |        |

Notes. (a) Object ID. (b) Average redshift from the single lines or limits: lower limits from intervening systems or following Sbarufatti et al. (2005b) for featureless spectra; upper limits from the absence of Lyα absorptions following Shaw et al. (2013), and references therein. (c) Spectral index of the continuum, defined by F_ν ∝ ν^{−α_v}. (d) Minimum detectable equivalent width (observer frame). (e) Line identification. (f) Wavelength at the center of the feature. (g) Type of feature: e: emission line; g: host galaxy absorption line; a: intervening system absorption line. (h) FWHM of the line. (i) Line equivalent width (observer frame).
since it appears in other spectra reported by Shaw with the same spectrograph.

3. HIGH-ENERGY EMISSION OF THE SOURCES

The Fermi Second Source Catalog (2LAC; Nolan et al. 2012) lists the 1873 significant sources detected by the Large Area Telescope (LAT; Atwood et al. 2009) during Fermi’s first two years of sky survey observations. Most of them are jet-dominated AGNs. Among them, more than 400 Fermi BL Lac objects attest to their large contribution to the γ emission background among the brightest extragalactic sources. To fully describe our small sample of optically selected BL Lac objects, the detections of the target objects at high and very high energy were investigated. A comparison with TevCat (Horan & Wakely 2008) indicates that there are no TeV counterparts. This is not surprising, since measured redshifts or lower limits to the redshift are beyond the extragalactic background light horizon, with the exception of J144052.93+061016.1.

We cross-correlated the Fermi archived events available online with the positions of our sources to update them with respect to the LAT 2 release. As shown in Table 3, four of our sources were entered in the 2LAC catalog (LAT AGN Catalog; Ackermann et al. 2011). We analyzed all the available 57 month survey data from the start of Fermi activity on 2008 August 4 (MJD 54682) to 2013 April 8 (MJD 56390), with the aim of updating the values of flux and photon indices, tracing the light curves, and looking for new detections. We used the LAT Science Tools v. 9.27.1, the Instrument Response Function P7SOURCE_V6, and the corresponding background files, following standard procedures. For each source, we selected all the events of class 2 (“source” type) included in a circular region centered on the optical coordinates and with radius 10°. The final source list was determined by applying a significance threshold.

Two new γ-ray sources appeared: J125032.58+021632.1 and J163716.73+131438.8. Some targets, although included in the 2LAC, have not been detected on the basis of their γ fluxes over the entire 57 month period, but due to the variability they are found on a monthly scale. In Table 3 the integrated photon flux in the 0.1–100 GeV range or upper limit, the photon index, and Test Statistic (TS, Mattox et al. 1996) are given for the entire observation time in the central columns, while the right columns refer to monthly detections with the highest TS. We considered as valid the results of the likelihood of TS ≥ 9, corresponding to about 3σ.

In order to compare these results with the whole dataset, we have correlated the list of 637 radio-loud optically selected BL Lac objects of P10 with 2LAC, finding 125 positional coincidences, corresponding to ~20% of the objects. In the sample examined here we observed a higher percentage, possibly as a consequence of the imposed magnitude limit, and the choice of SDSS lineless objects, which can be indicative of strong beaming. We have therefore selected 194 P10 objects that are lineless and have r < 19.4, and found 69 correlations with 2LAC, corresponding to ~35%, which is consistent with our findings.

4. SUMMARY AND CONCLUSIONS

We obtained optical spectroscopy of a small sample of BL Lac objects with unknown redshifts. On the basis of the γ properties the objects appear representative of the parent sample. In one case a broad line emission was found; in others absorptions from the host galaxy or intervening material were detected. For two objects the spectrum remained featureless, and in these cases the host galaxy or intervening material were detected. For two objects the spectrum remained featureless, and in these cases the redshift should be z ≳ 0.4. New surveys have allowed us to derive the spectroscopic redshifts of a large number of BL Lac objects with high S/N spectra. Nevertheless a significant fraction of unknown z objects remains. The new redshifts are higher compared to those from recently assembled large samples (P08, P10, S13). If tentative attributions and lower limits are included, redshift medians for high-confidence BL Lac objects are 0.39 in P08, 0.43 in the P10 radio-loud subsample, 0.32 in S13, and 0.64 for our objects. Although ours is a small sample, it suggests that a significant fraction of most unknown z objects is probably at high z and significantly beamed. Larger redshift completeness fractions and homogeneous and unbiased selections could also better define the picture of cosmological evolution. A search for γ counterpart emission shows that six out of nine objects are Fermi γ-ray emitters and we also found two new detections. High z and high-beamed BL Lac objects merit a

Table 3

Fermi LAT Detections for the Target Objects

| Source | 2LAC | R.A. | Decl. | Error | Flux | Index | Time | Photon | T5m | Source |
|--------|------|------|-------|-------|------|-------|------|--------|------|--------|
| J003808.50+001336.5 Y | J0038.1+0015 | 9.542 | 0.265 | 0.217 | 1.6 ± 0.7 | −1.78 ± 0.15 | 42 | 2009 Oct 09 | 1.80 ± 0.16 | 1.74 ± 0.04 |
| J125032.58+021632.1 ... | ... | 192.578 | 2.308 | 0.095 | 2.2 ± 1.1 | −1.85 ± 0.17 | 35 | 2009 Nov 08 | 2.07 ± 0.54 | 1.93 ± 0.13 |
| J135120.84+111453.0 Y | J1351.4+1115 | 207.867 | 11.256 | 0.110 | <2 (5σ) | ... | ... | ... | ... | ... |
| J144052.93+061016.1 ... | ... | 220.248 | 6.189 | 0.099 | 9.6 ± 2.1 | 2.1 ± 0.1 | 148 | 2008 Dec 13 | 2.72 ± 1.3 | 1.93 ± 0.23 |
| J145507.44+020504.0 ... | ... | ... | ... | ... | <2 (5σ) | ... | ... | ... | ... | ... |
| J163716.73+131438.8 ... | ... | 249.37 | 13.20 | 0.12 | <2 (5σ) | ... | ... | ... | ... | ... |
| J174406.27+025858.1 ... | ... | ... | ... | ... | <2 (5σ) | ... | ... | ... | ... | ... |
| J224448.09-000619.3 ... | ... | ... | ... | ... | <2 (5σ) | ... | ... | ... | ... | ... |
| J224730.19+000006.4 Y | J2247.2−00002 | 341.811 | −0.049 | 0.152 | <2 (5σ) | ... | ... | ... | ... | ... |

Notes. (a) Object ID. (b) Fermi LAT designation in two-year catalog. (c) γ counterpart coordinates. (d) 95% error radius. (e) Integral photon flux in 0.1–100 GeV range. (f) Photon index defined as νFν ∝ ν−Γ+2. (g) Test statistic (Mattox et al. 1996). (h) Time of highest significance observation: measures derived from 30 days integration around the date (±15 days) in Column (b). (i) Highest significance photon flux. (j) Photon index of highest significance observation. (k) Highest test statistic.

http://tevcat.uchicago.edu/
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2yr_catalog/
http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/
new approach and capabilities for deriving their redshifts. In the region of $z \sim 0.1-0.7$ a very effective technique was introduced in the far-UV (1135–1800 Å) with HST+COS (e.g., Stocke et al. 2011; Danforth et al. 2010, 2013), for constraining $z$ quite stringently using intervening intergalactic medium absorbers detected in Ly$\alpha$ and in Ly$\beta$ and/or metal lines. An interesting possibility is deriving $z$ lower limits for BL Lac objects at redshift $z > 1.5$ by searching for weak and narrow Ly$\alpha$ absorption in the optical range from the ground as performed and adopted in UV spectra. Good candidates can also be found in the sample presented here. High-resolution spectroscopy combined with large-diameter telescopes is required.

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