Optical Spectroscopic Survey of a Sample of Unidentified Fermi Objects

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Abstract

We present optical spectroscopy secured at the 10 m Gran Telescopio Canarias of the counterparts of 20 extragalactic γ-ray sources detected by the Fermi satellite. The observations allow us to investigate the nature of these sources and to determine their redshift. We find that all optical counterparts have a spectrum that is consistent with a BL Lac object nature. We are able to determine the redshift for 11 objects and set spectroscopic redshift limits for five targets. The optical spectrum is found featureless for only four sources. In the latter cases, we can set lower limits on the redshift based on the assumption that they are hosted by a typical massive elliptical galaxy whose spectrum is diluted by the nonthermal continuum. The observations allow us to unveil the nature of these gamma-ray sources and provide a sanity check of a tool to discover the counterparts of γ-ray emitters/blazars based on their multiwavelength emission.

Key words: BL Lacertae objects: general – galaxies: distances and redshifts – gamma rays: galaxies – techniques: spectroscopic

Supporting material: data behind figure

1. Introduction

High energy observations from space, like those performed by the EGRET (Thompson et al. 1993), the AGILE (Tavani et al. 2009), and the Fermi (Atwood et al. 2009) missions, among others, offer us a prime tool for selecting the peculiar class of active galactic nuclei (AGNs) known as blazars. In essence, blazars derive their extreme properties from relativistic flux amplification due to bulk motions of the nonthermal emitting plasma toward the observer. This combines with the tendency of such plasmas to “inverse-Comptonize” lower energy photons in the medium, in producing very intense fluxes of photons in the high-energy regime, hence offering a rather unique method for their selection. The recent release of the 8 year Fermi survey catalog (3FGL, Acero et al. 2015) includes 3033 detected sources, a large fraction of which are either identified or suspected blazars. Indeed, more than 1000 of the 3FGL objects are already confirmed blazars.

One of the clear advantages of such high-energy observations, compared to other analyses based on broadband colors (e.g., radio to optical to X-ray, etc.), is that they provide us with a simple flux-limited and all-sky complete selection method, with good statistics. The penalty to pay for this comes from the poor angular resolution (the error box with a radius of the order of 5–10 arcminutes). Although the Fermi-LAT observatory is greatly improving it through the continuous signal addition over the years, the task remains challenging if we consider that one-third of the 3FGL lastly released source catalog is still unassociated with counterparts in other frequency bands. Preliminary searches of these unassociated/ unidentified gamma-ray sources (henceforth UGS) by various authors (Massaro et al. 2012; Mirabal et al. 2012; Acero et al. 2013; D’Abrusco et al. 2013; Doert & Errando 2014; Landi et al. 2015; Paiano et al. 2017a) found clear indications that the large majority of them are AGNs of the blazar class.

This UGS source population then represents a very important and new component of the high-energy sky, and may hide new classes of AGNs or even new unknown high-energy phenomena. It is then of utmost interest to perform a full investigation of these sources.

Of course, achieving a good level of completeness in the gamma-ray source identification is of primary importance for any statistical analyses of the samples. For instance, this is needed for understanding the physical differences between the two main blazar classes, the BL Lac objects (BLL) and the Flat-Spectrum Radio Quasars (FSRQ), to check the origin for such different spectral properties (BLLs showing very weak or absent emission lines in the optical, instead FSRQs with prominent lines), as well as the distributions of the two populations in spacetime and their cosmological evolution ( Ghisellini et al. 2017).

Progress in the identification of sources from the various Fermi releases has been quite slow through the years (e.g., Massaro et al. 2016): the effort for source identification has essentially been balanced by the increasing depth of the catalogs with time, and the higher required sensitivity for the follow-up. While refined techniques have been implemented for preliminary associations of the sources via multiwavelength analyses based on WISE data (D’Abrusco et al. 2013; Massaro & D’Abrusco 2016), broadband studies of the Spectral Energy Distributions (SED; Paiano et al. 2017a), or via complementary radio data ( Petrov et al. 2013; Nori et al. 2014; Schinzel et al. 2015; Giorelli et al. 2016), the fundamental bottleneck in this process is set by the required optical spectroscopic characterization of the sources. Even assuming that a substantial part of the missing objects are
observed spectroscopically to a sufficient depth, the spectral analysis and interpretation might turn out to be overwhelmingly difficult. To account for this, the *Fermi* collaboration has defined a new class of sources, the blazar candidates of uncertain type (BCU\(^7\)), that is, sources showing SEDs characteristic of the blazar population, but without spectroscopic confirmation of their nature. These are very numerous in the 3FGL and 3LAC\(^8\) catalog classification and represent the second largest population among the γ-ray AGN emitters.

From this point of view, the two blazar populations, BLLs and FSRQs, behave very differently from one another. The emission lines in FSRQs are relatively easy to catch based on even moderate quality spectra, also allowing a relatively easy and secure redshift measurement. This is good because FSRQs are typically high redshift objects and of high luminosity. Instead, this very often becomes prohibitive for the BLL class, whose weakness of the emission lines makes their identification, and particularly the redshift measurement very challenging. So far, 4 m or lower class telescopes have been used for such observations (Sbarufatti et al. 2005, 2006a, 2006b; Shaw et al. 2013; Massaro et al. 2014; Paggi et al. 2014; Landoni et al. 2015; Ricci et al. 2015; Álvarez Crespo et al. 2016a, 2016b; Marchesini et al. 2016), which contributed to the classification of a large number of the optical counterparts, but only a small fraction of them were able to derive a redshift for BLLs.

With all of this in mind, in 2015 we started an observational program, aimed to significantly improve the spectroscopic study of blazars, and the BLLs in particular, using observations at the 10 m class telescope, the Gran Telescopio de Canarias (GTC). In previous works, we provided high signal-to-noise (S/N) ratio optical spectra for a sample of 15 TeV BLL and 7 TeV candidates with unknown or uncertain redshifts (Paiano et al. 2017b) and of 10 BLLs detected by the *Fermi* satellite for which previous observations suggested that they are at relatively high redshifts (Paiano et al. 2017c).

The present paper is intended to be the first in a series devoted to the UGSs detected by the *Fermi* satellite. While these are rarely very faint sources in the optical (typical magnitudes ranging from 17 to about 20th mag.), the weakness of the absorption and/or emission features require high S/N spectra to detect and identify them.

We believe that, with such an approach, the elusive nature and mysterious cosmological significance of the BLL population could be effectively addressed. Is their low-redshift confinement simply due to a selection bias, favoring the line-emitting FSRQ at higher redshifts? Which are the statistical properties of the population, like the luminosity functions, and how do they compare to those of the host galaxies? Our strategy is to provide fundamental spectroscopic data to address these issues.

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\(^7\) The 3LAC sources classified as blazar candidates of uncertain type are categorized into three sub-types: the BCU-I sources where the counterpart has a published optical spectrum but is not sensitive enough for a classification as an FSRQ or a BL Lac; the BCU-II objects with the counterpart lacking an optical spectrum, but a reliable evaluation of the SED synchrotron-peak position is possible; the BCU-III sources for which the counterpart is lacking both an optical spectrum and an estimated synchrotron-peak position but shows blazar-like broadband emission and a flat radio spectrum.

\(^8\) The 3LAC catalog is the third catalog of AGNs detected by the *Fermi*-LAT (Ackermann et al. 2015).

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In Section 2, we describes our sample and its main properties. In Section 3, we present the data collection and the reduction procedure. In Section 4, we show the optical spectra of each object, underlying their main features, and discuss their redshift. In Section 5, we give detailed notes on individual objects and finally, in Section 6, we summarize and discuss the results.

In this work, we assume the following cosmological parameters: \(H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}\), \(\Omega_L = 0.7\), and \(\Omega_m = 0.3\).

### 2. Sample Selection

About 30% of the γ-ray sources reported in the 3FGL catalog are unassociated with sources at other frequencies. These may be due either to the lack of high-energy observations at other frequencies or to the presence of multiple sources in the large γ-ray error box. The active campaign provided by the *Swift* satellite (Gehrels 2004) allows us to detect X-ray sources within the error box of the γ-ray emission. We use these data to identify new X-ray sources as candidates for the γ-ray emission.

We selected a sample of UGSs from the 3FGL catalog following the criteria below.

1. The source is not associated in the 2FGL or 3FGL and in other gamma-ray catalogs (i.e., the EGRET, AGILE).
2. Target coordinates outside the Galactic plane \(|b| \geq 20^\circ\); this avoids the very crowded and confused region of the sky where the diffuse background is stronger and difficult to model. This also favors the selection of extragalactic sources.
3. The objects should be well observable from the La Palma site (\(\alpha > -20^\circ\)).
4. Presence of at least one X-ray source detected within the UGS error box. In case that more than one X-ray source is detected within the *Fermi* error box, we select the one that is coincident with a radio source.

The total number of the UGSs in the 3FGL catalog that satisfy only the first three criteria is 238 and, as of today, for \(~180\) objects there are *Swift* pointings with an integration time greater than 2000 s. Only for 60 of them, the observations revealed a detection of an X-ray source inside the 3FGL error box.

Following previous works (Stephen et al. 2010; Takahashi et al. 2012; Acero et al. 2013; Takeuchi et al. 2013; Landi et al. 2015), we search for X-ray emission inside the 3FGL error box (typically of a few arcmin). If an X-ray source is detected (with detection error circles \(\sim 5\) arcsec), the next step is to search for likely counterparts of these X-ray sources in radio, infrared, and optical, in order to determine a positional association (an example is given in Figure 1). To further constrain the association, we also build its multil wavelength SED by combining the available measured data fluxes at different wavelengths and to select blazar-like objects (for details, see Paiano et al. 2017a, [PFS]).

The obvious next step to single out the counterpart of the UGS is to obtain spectroscopic observations of the candidate optical counterpart.

In this paper, we present the results for one-third of the full sample (see Table 1). Note that the sample includes six sources classified as blazar candidates of uncertain type (BCU) and two BLLs that were unassociated in the 2FGL. For these sources, no optical spectra were available or their redshift was very uncertain.
3. Observations and Data Reduction

The observations were obtained in service mode between 2015 December and 2016 May at the GTC using the low resolution spectrograph OSIRIS (Cepa et al. 2003). The instrument was configured with the grism R500B, in order to cover the spectral range 3600–8400 Å, and with a slit width = 1.2".

The observation strategy and the data reduction followed the same procedure as reported in the Paiano et al. (2017b). For each source, three individual exposures were obtained that were then combined into a single average image, in order to perform optimal cleaning of cosmic rays and of CCD cosmetic defects. Detailed information on the observations are given in Table 2.

Data reduction was carried out following standard IRAF\(^\text{10}\) procedures for long slit spectroscopy with bias subtraction, flat fielding, and bad pixel correction. Individual spectra were

\(^9\) http://www.gtc.iac.es/instruments/osiris/osiris.php

\(^{10}\) IRAF (Image Reduction and Analysis Facility) 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.
cleaned of cosmic-ray contamination using the L.A. Cosmic algorithm (van Dokkum 2001).

Wavelength calibration was performed using the spectra of Hg, Ar, Ne, and Xe lamps. Spectra were corrected for atmospheric extinction using the mean La Palma site extinction table.11 For each source, during the same observation night, we observed a spectro-photometric standard star in order to perform the relative flux calibration on every spectrum. The absolute flux calibration was possible thanks to the availability of a direct image of the source obtained as part of target acquisition. The average spectra were then calibrated to have the flux at 4750 Å equal to the photometry found for the targets (see Table 2).

11 https://www.ing.iac.es/Astronomy/observing/manuals/
Finally, each spectrum has been dereddened for the Galaxy contribution, applying the extinction law by Cardelli et al. (1989) and assuming the $E(B - V)$ values taken from the NASA/IPAC Infrared Science Archive.\footnote{https://irsa.ipac.caltech.edu/applications/DUST/}

Figure 2. Spectra of the UGSs obtained at GTC. Top panel: flux-calibrated and dereddered spectra. Bottom panel: normalized spectra. The main telluric bands are indicated by ⊙, the absorption features from interstellar medium of our galaxies are labeled as IS (Inter-Stellar). The data used to create this figure are available.

4. Results

The flux-calibrated optical spectra of the optical counterparts of 20 γ-ray sources are presented in Figure 2 and can be accessed at the website http://www.oapd.inaf.it/zbllac/. In order to emphasize weak emission and/or absorption features,
we also show the normalized spectrum. This was obtained by dividing the observed calibrated spectrum by a power-law fit ($F \propto \lambda^n$) of the spectral continuum, excluding the telluric absorption bands. These normalized spectra were used to evaluate the S/N in a number of spectral regions (see Table 3).

All spectra were carefully inspected to find emission and absorption features. When a possible feature was found, we determined its reliability by checking that it was present on the three individual exposures (see Section 3 for details). We were able to detect spectral lines for 16 targets: in particular, we
found absorption lines due to the host galaxy: Ca II (3934 Å, 3968 Å), G-band (4305 Å), Mg I (5175 Å), and Na I (5893 Å) for 11 objects. We observed the emission line due to [O II] (3727 Å) and [O III] (5007 Å) from 3FGLJ0049.0+4224, 3FGLJ0305.2–1607, 3FGLJ1049.7+1548, and 3FGLJ1704.1+1234 and the absorption lines attributed to Mg II (2800 Å) intervening systems in the spectra of 3FGLJ0338.5+1303, 3FGLJ0644.6+6035, 3FGL J1129.0+3758, 3FGLJ1511.8-0513,
and 3FGLJ2115.2+1215, which allow us to derive a spectroscopic lower limit of the redshift. See details in Figure 3 and Table 4.

For four targets, the observed spectra are completely featureless. Based on the assumption that all BLLs are hosted by a massive elliptical galaxy, one may look for faint absorption features from the starlight (Sbarufatti et al. 2006b), provided that the SNR and the spectral resolution are sufficiently high. Following the scheme outlined in Paiano et al. (2017b), in these cases, it is possible to set a lower limit to the redshift based on the minimum equivalent width (EW) that can be measured in the spectrum (see Table 3).

5. Notes for Individual Sources

3FGL J0049.0+4224: The analysis of Swift-XRT data reveals one X-ray object ($F = 5.7 \times 10^{-14} \text{erg cm}^{-2} \text{s}^{-1}$) in the 3FGL error box that is spatially coincident with the optical source SDSS J004859.42+22351 (z = 19.9) and the radio source NVSS J004859.4+22350. Our optical spectrum is characterized by a power-law (PL) emission ($\alpha = -0.16$) with a signature of dilated galaxy starlight typical of BLL. We clearly detect stellar absorption features identified as Ca II (3934 Å, 3968 Å), G-band (4305 Å), and Mg I ($\lambda$5175), and two weak emission lines due to [O II] (3727 Å) and [O III] (5007 Å) at the redshift $z = 0.302$. This confirms the blazar nature of this γ-ray source (see Figures 2 and 3).

3FGL J0102.1+0943: This source is proposed to be associated to the optical source SDSS J010217.09+094409 as a high-synchrotron-peaked blazar at a redshift of 0.4–0.5 (Paiano et al. 2017a). Our optical spectrum is dominated by PL emission ($\alpha = -0.10$). We find a weak signature of a Ca II break at $\sim$5700 Å (see Figure 3), yielding a tentative redshift of 0.42.

3FGL J0239.0+2555: Through the XRT data analysis, we find only one X-ray source within the 3FGL error box with a flux at the same level of the γ-ray emission flux (see Figure 1). We propose the spatially coincident object SDSS J023853.1+255407 (g = 20.2) as the likely optical counterpart for this source (see Figure 4). Our optical spectrum for this source is clearly dominated by a PL emission ($\alpha = -0.39$) and doublet absorption features (6231 Å, 6286 Å) are detected. If identified as Ca II (3934 Å, 3968 Å), the redshift is 0.584. Note that the red component of this doublet is partially contaminated by the telluric band at 6280 Å.

3FGL J0305.2–1607: This γ-ray emitter is associated with the radio source PKS 0305-16 and classified as BCU-II in the 3LAC catalog, but no optical spectrum for this target is available in the literature. The GTC optical spectrum clearly exhibits absorption features of the overall stellar population superimposed onto the nonthermal emission. In particular, we detect absorption lines of...
Ca II (3934 Å, 3968 Å), G-band (4305 Å), Mg I (5157 Å), and Na I (5893 Å) at $z = 0.311$, and moreover an emission line due to [O II] ($L = 6.2 \times 10^{40} \text{ erg s}^{-1}$) indicative of modest star formation (Gilbank et al. 2010).

Figure 3. Close-up of the normalized spectra around the detected spectral features of the UGSs obtained at GTC. Main telluric bands are indicated as ⊕, spectral lines are marked by line identification.

3FGLJ 0338.5+1303: In the 3LAC catalog, the source is associated with the radio loud active galaxy RX J0338.1+1302 and classified as BCU-II. The optical spectrum of this object exhibits a featureless continuum except for a clear absorption
line at 3867 Å with an EW = 3.0 Å. If attributed to Mg II (2800 Å), we can set a spectroscopic redshift lower limit of 0.382. A featureless spectrum for this object was also reported by Marchesini et al. (2016). Note that the absorption line is also present in their published spectrum but it was not noted and identified.

3FGL J0409.8−0358: The optical counterpart of this source was identified with a BLL by Massaro et al. (2015) on the basis of

Figure 3. (Continued.)
the featureless optical spectrum. We obtain a much better S/N spectrum and we confirm that it is lineless. We can set a lower limit of the redshift of $z > 1.1$, following the procedure reported in Paiano et al. (2017b).

3FGL J0644.6+6035: This object is a UGS in the 3FGL. The optical counterpart of this γ-ray source was proposed to be WISE J064459.38+603131.7 and classified as a blazar at $z = 0.358$ (Paggi et al. 2014). Based on the new 3FGL error...
box and the analysis of the Swift data, we propose the X-ray source XRT J064435+603850 as the likely counterpart for the Fermi emitter. Our optical spectrum confirms the blazar nature of the candidate and a prominent intervening absorption system of Mg II (2800 Å) is detected at 4425 Å, setting a redshift lower limit of the object at $z > 0.581$.

3FGL J0937.9−1435: We found an X-ray emission within the 3FGL error box (XRT J093754−143350) that is coincident with the optical source USNOB0754−0223141. The same association was also proposed using IR objects from the WISE survey (Massaro et al. 2013). The optical spectrum shows a characteristic nonthermal emission with the signature of a host galaxy. We detect Ca II (3934 Å, 3968 Å), G-band (4305 Å), Mg I (5157 Å), and Ca+Fe (5269 Å) at $z = 0.287$.

3FGL J0952.8+0711: Based on XRT data, the most plausible optical counterpart is the source SDSS J095249.57+071329.9 ($g = 18.9$). No optical spectra are found in the literature. Our optical spectrum is clearly dominated by nonthermal power-law emission and we are able to detect faint absorption features of Ca II (3934 Å, 3968 Å) and G-band (4305 Å) at $z = 0.573$. It is worth noting that from the SDSS data in the environment of this source there are two galaxies (projected distance <300 kpc at $z = 0.573$) that exhibit the same redshift of the target.

3FGL J1049.7+1548: In the 3FGL, this object is classified as UGS. However, the source was associated to the optical counterpart SDSS J104939.35+154837.6 by Paggi et al. (2014) who propose a redshift $z = 0.327$ based on Ca II (3934 Å, 3968 Å) absorption lines. On the other hand, a better quality optical spectrum was obtained by the SDSS Boss survey, suggesting a redshift $z = 1.452$. Given the large inconsistency, we obtain a high SNR spectrum for this object that confirms the redshift of $z = 0.3271$ (see Figures 2 and 3).

In addition to the Ca II absorption doublet, we detect a possible faint [O III] emission. The source was found $\sim 1$ mag brighter than observed by SDSS.

3FGL J1129.0+3758: This source is classified as UGS in the 3FGL catalog with a flux of $F_{1−100 \text{GeV}} = 6.99 \times 10^{-10}$ ph cm$^{-2}$ s$^{-1}$. Paiano et al. (2017a) proposed as an optical counterpart the source SDSS J112903+375665 with $g = 20.3$, classifying it as a blazar at high redshift ($z \sim 1.4−1.8$). This object is located at $\sim 5$ arcsec west of a $g = 14$ star. In its optical spectrum, there are many clear absorption features in the spectral range between 4000 Å and 6000 Å. The strongest one, at 6189 Å, is a doublet that is consistent with an intervening absorption system due to Mg II (2800 Å) at redshift $z = 1.211$. This is also clearly present in the SDSS spectrum. For the other features (see Table 4), no clear identification is found. It is worth noting that some of them are close to stellar lines, such as He, Mg I (5157 Å), and Ca+Fe (5269 Å), but the level of contamination of our spectrum by the presence of the bright star is negligible, since the slit intersects only marginally the stellar flux. In addition to the spectral lines, the continuum also appears somewhat unusual: at $\lambda > 5000$ Å, the continuum emission is rather flat, while at shorter wavelengths a rise of the flux is noted, suggesting a thermal component. The SDSS spectrum shows a similar shape.

3FGL J1222.7+7952: The spectrum of the optical counterpart (Massaro et al. 2015) for this $\gamma$-ray source failed to detect any spectral features and the redshift remained undetermined. Our better SNR spectrum clearly shows the Ca II (3934 Å, 3968 Å) and other lines (see Table 4) characteristic of stellar population at $z = 0.375$.

3FGL J1340.6−0408: An optical spectrum of the counterpart of this $\gamma$-ray object was obtained by Ricci et al. (2015) who found it featureless. In our new spectrum, we detect a weak absorption doublet (EW $= 0.4 A$ Å) at $\sim 4300$ Å and other weak absorptions. These lines are all consistent with a redshift of $z = 0.223$ (see Figures 2 and 3).
We obtain the optical spectrum of the X-ray counterpart source XRTJ141133-072253, likely associated with the γ-ray emitter (see Figure 4), with a moderate S/N ratio. No emission or absorption lines are detected; however, the BLL nature of the source is confirmed.

3FGLJ 1411.4−0724: We obtain the optical spectrum of the X-ray counterpart source XRTJ141133-072253, likely associated with the γ-ray emitter (see Figure 4), with a moderate S/N ratio. No emission or absorption lines are detected; however, the BLL nature of the source is confirmed.

3FGLJ 1511.8−0513: The source is classified as a BCU-III and associated with the radio source NVSSJ151148-051345 in the 3LAC catalog. The optical spectrum of Álvarez Crespo et al. (2016a) was found featureless. We obtain a high S/N ratio (~200) spectrum that exhibits a marked nonthermal featureless
### Table 5
Summary of the Proposed Blazar Classification by the Broadband SED Tool (PFS)

| 3FGL Name        | Counterpart Name | 3FGL SED Classification | 3FHL | AGN Class Proposed | Redshift from PFS | Classification and Redshift from Spectroscopy |
|------------------|------------------|-------------------------|------|--------------------|-------------------|-----------------------------------------------|
| 3FGL J0049.0+4224 | SDSSJ004859+422351 | UGS                     | y    | HSP                | 0.4–0.6            | BLL, 0.302                                    |
| 3FGL J0102.1+0943 | SDSSJ010217+094409 | UGS                     | n    | HSP                | 0.4–0.5            | BLL, 0.42                                    |
| 3FGL J0239.0+2555 | SDSSJ023853+255407 | UGS                     | n    | HSP                | 0.3–0.5            | BLL, 0.584                                    |
| 3FGL J0305.2–1607 | PKSJ0302-16       | BCU-II/HSP              | y    | HSP                | 0.5–0.6            | BLL, 0.312                                    |
| 3FGL J0338.5+1303 | RXJ0338.4+1302    | BCU-II/HSP              | y    | HSP                | 0.3–0.6            | BLL, >0.382                                   |
| 3FGL J0409.8–0358 | NVSSJ040946-040003 | BLL/ISP                | y    | ISP                | 0.2–0.7            | BLL, >0.7                                    |
| 3FGL J0644.6+6035 | USNOB1506-016241  | UGS                     | n    | HSP                | 0.2–0.5            | BLL, >0.581                                   |
| 3FGL J0937.9–1435 | USNOB0754--0223141| UGS                     | n    | HSP                | 0.3–0.4            | BLL, 0.287                                    |
| 3FGL J0952.8+0711 | SDSSJ095249+071329| UGS                     | n    | HSP                | 0.4–0.5            | BLL, 0.574                                    |
| 3FGL J1049.7+1548 | SDSSJ104939+15483 | UGS                     | n    | HSP                | 0.3–0.4            | BLL, 0.326                                    |
| 3FGL J1129.0+3758 | SDSSJ112903+375656| UGS                     | n    | LSP                | 1.4–1.8            | BLL, >1.21                                   |
| 3FGL J1222.7+7952 | USNOB1698-0045483 | UGS                     | y    | HSP                | 0.3–0.5            | BLL, 0.375                                    |
| 3FGL J1340.6–0408 | NVSSJ134042–041006| BCU-II/HSP              | n    | HSP                | 0.3–0.4            | BLL, 0.223                                    |
| 3FGL J1411.4–0724 | USNOB0826–0334743 | UGS                     | y    | HSP—ISP            | 0.3–0.6            | BLL, >0.7                                    |
| 3FGL J1511.8–0513 | SDSSJ151148–051345| BCU-III                 | y    | HSP                | 0.1–0.2            | BLL, >0.45                                    |
| 3FGL J1704.4–0528 | USNOB0845–0308445 | UGS                     | y    | HSP                | 0.3–0.4            | BLL, >0.7                                    |
| 3FGL J1704.1+1234 | SDSSJ170409+123421| UGS                     | y    | HSP                | 0.2–0.4            | BLL, 0.452                                    |
| 3FGL J2115.2+1215 | SDSSJ211522+121802 | UGS                     | y    | HSP                | 0.4–0.6            | BLL, >0.497                                   |
| 3FGL J2246.2+1547 | NVSSJ224604+154437| BCU-II/ISP              | y    | ISP                | 0.3–0.8            | BLL, >0.7                                    |
| 3FGL J2346.7+0705 | TXS2344+068       | BCU-II/HSP              | y    | ISP—HSP           | ~0.2               | BLL, 0.171                                    |

**Note.** Column 1: the 3FGL name; Column 2: name of the counterpart; Column 3: Fermi SED classification as reported in the 3FGL and 3LAC catalogs (UGS = unassociated gamma-ray source, BCU = active galaxy of uncertain type, BLL = BL Lac object type, HSP = the high-synchrotron-peaked sources peak ($\nu_{\text{syn-peak}} > 10^{28} \text{ Hz}$), ISP = the intermediate-synchrotron-peaked sources ($10^{26} < \nu_{\text{syn-peak}} < 10^{28} \text{ Hz}$), and LSP = the low-synchrotron-peaked sources ($\nu_{\text{syn-peak}} < 10^{26} \text{ Hz}$)); Column 4: presence of the target in the third catalog of hard Fermi-LAT sources (3FHL, The Fermi-LAT Collaboration 2017); Column 5 and Column 6: classification and redshift range (within 2σ); Column 7: classification and spectroscopic redshift found in this work.

The optical counterpart confirms the BLL nature of the source and exhibits a pure featureless spectrum. We can set a lower limit of the redshift of $z > 0.7$ (see Table 3).

3FGL J2346.7+0705: In the 3LAC catalog, this source is associated with the radio source TXS 2344+068 and classified as BCU-II. There is a quasi-featureless optical spectrum provided by the SDSS survey that, depending on the Data Release, proposed two different redshift values ($z = 0.171$ and $z = 5.06$). In our spectrum, we detect weak absorptions of CaII (3934 Å, 3968 Å), G-band (4305 Å), and MgI (5157 Å), corresponding to a redshift of 0.171, superimposed on the nonthermal continuum.

6. Discussion and Conclusions

We secured optical spectra of the counterparts of 20 UGSs detected by the Fermi satellite with the aim to investigate the nature of these sources and to determine their redshift. For all of these objects, the optical spectrum was either not previously known or secured with modest S/N, not allowing clear spectral features to be detected (see, e.g., Massaro et al. 2016, and references therein). This allows us to classify the optical counterparts of the UGS sample and to derive their redshift or its lower limits.

The optical spectrum of all of these objects is characterized by a typical power law arising from the nonthermal emission. For 11 sources, we found absorption and emission lines, allowing us to determine their redshift, while for five targets we set spectroscopic lower limits by the detection of absorption lines from intervening systems. The optical spectrum is entirely...
featureless for only four sources in spite of the good S/N. For these objects, we can set lower limits of the redshift based on the minimum equivalent width of absorption features expected from their host galaxy as discussed in Paiano et al. (2017b).

The measured redshifts are in the range between 0.2 and 0.6 for most of the sources in the sample. One object (3FGL J1129.0+3758) is found at \( z > 1.2 \), while four sources, with featureless spectra, are likely at \( z > 0.6 \). Out of 20 objects, 14 are detected by the Fermi satellite at energies above 10 GeV (see the Third Catalog of Hard Fermi-LAT Sources (3FHL), Ajello et al. 2017). Therefore, they are candidates to be good TeV targets for the Cherenkov telescopes. Given their redshift (of ~0.4 average), these offer a good opportunity to increase the number of blazars at \( z > 0.2 \) detected at VHE energies (\( E > 100 \) GeV) suitable to probe the UV-optical EBL attenuation in their TeV spectra.

The optical spectra and redshifts reported allow us to test a recently published tool for blazar recognition and classification (PFS, see the details in Paiano et al. 2017a). This, based on analyses of the Spectral Energy Distributions and luminosities of blazars, also provides us with rough estimates of the redshift (see Table 5). Now, considering the 16 objects of our sample with spectroscopic redshift measurements or lower limits, for about 50% the estimated redshift by PFS turns out to be in agreement within the 2\( \sigma \) uncertainties with the redshift measurement, and for the remaining sources, 30% of them are in agreement within 3\( \sigma \). Altogether, these results support the fair effectiveness of the PFS blazar recognition tool to unveil and roughly characterize blazars among the numerous population of the UGSs detected by the Fermi satellite.

Finally, we note that, although the optical spectra were obtained with a large aperture telescope and modern instrumentation, for four sources, their spectra are still featureless, thus preventing redshift measurements. This will likely remain unknown until the advent of the next generation of extremely large telescopes, such as E-ELT13 and TMT.14

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**Facility:** GTC-OSIRIS, (Cepa et al. 2003).

**Software:** IRAF (Tody 1986, 1993).

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13 http://www.eso.org/sci/facilities/elt/
14 http://www.tmt.org/

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