OPTICAL SPECTROSCOPY OF BRIGHT FERMIG LAT BLAZARS

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ABSTRACT

We report on HET and Palomar 5 m spectroscopy of recently identified γ-ray blazars in the Fermi LAT Bright Source List. These data provide identifications for 10 newly discovered γ-ray flat spectrum radio quasars (FSRQ) and six new BL Lacs plus improved spectroscopy for six additional BL Lacs. We substantially improve the identification completeness of the bright LAT blazars and give new redshifts and z constraints, new estimates of the black hole masses and new measurements of the optical SED. Subject headings: BL Lacertae objects: general — galaxies: active — quasars: general — surveys

1. INTRODUCTION

The Fermi LAT pair production telescope has been surveying the 20 MeV–300 GeV γ-ray sky since 2008 August 11. Among the many sources being detected by this mission, blazars dominate the extragalactic sky. The first published set of these objects, the ‘LAT Bright AGN Sample’ (LBAS) based on 3 months of sky survey exposure, included 132 bright (>10%) detections at |b| > 10°. The bulk (117) of these sources have been associated with flat spectrum radio counterparts, which in turn end up being mostly well-known flat spectrum radio quasars (FSRQ) and BL Lac objects. A few additional sources are pulsars and a few remain unidentified. The associations are based on the distribution of radio and X-ray properties of the radio counterparts (CRATES; Healey et al. 2007) and the analysis allows a quantitative assessment of the probability of association.

Even before the start of the Fermi mission, it was recognized that a large sample of these blazars would be needed for source identification; in the Candidate Gamma-Ray Blazar Survey (CGRaBS; Healey et al. 2008, and references therein) we pursued optical spectroscopy of the sources selected to be most similar to the previously known EGRET blazars. This set of 1625 blazars included many sources without previous spectroscopic identification. Here we report on previously unpublished optical spectra from our CRATES/CGRaBS survey and observations for new sources from the LBAS list. The data allow classification of the blazar type and redshift solutions for the strong-lined objects. Significant redshift constraints are also obtained for the weak-lined BL Lacs. These measurements contribute ten FSRQ redshifts, one new spectroscopic redshift for a BL Lac, and 11 additional BL Lac redshift constraints. Including these new data, 91% of all LBAS sources have been spectroscopically typed, 84% have redshifts, and 70% of the BL Lac have spectroscopic redshifts. We also use our spectra to examine the black hole masses and optical continua of these blazar sources.

In this paper, we assume an approximate concordance cosmology—Ωm = 0.3, ΩΛ = 0.7, and H0 = 70 km s⁻¹ Mpc⁻¹.

2. OBSERVATIONS AND DATA ANALYSIS

2.1. HET

The bulk of the spectroscopic observations were performed with the 9.2 m Hobby-Eberly Telescope (HET) at McDonald Observatory; many of these observations were part of the CGRaBS survey (Healey et al. 2008), but additional data were taken on newly discovered LBAS sources. The HET observes in the declination range −11° < δ < +73°, and is fully queue scheduled (Shetrone et al. 2007), allowing us to receive data remotely year round and to spread the cost of inclement weather and unfavorable conditions among the observing programs. We use the Marcario Low-Resolution Spectrograph, LRS (Hill et al. 1998), with grism G1 (300 lines mm⁻¹), a 2′ slit, and a Schott GG385 long-pass filter for a resolution of R ≈ 500 between 4150 Å and 10500 Å. Typical exposures are 2 × 600 s for FSRQ objects and 2 × 900 s for BL Lac objects, with the slit placed along the parallactic angle.

2.2. DBSP

We also used the double spectrograph (DBSP) on the 5 m Hale Telescope at Palomar. The observations with a 1″ slit at the parallactic angle used a 600 line mm⁻¹ grating on the blue side, covering λ3100 – 5200 at a resolution of ~ 2.8 Å (R ~ 1450). The red camera, with a 316 line mm⁻¹ grating covers λ5200 – 9500, at a resolution ~ 5.2 Å (R ~ 1350). P200/DBSP is our primary tool for targets outside of the HET declination range (i.e. −35° < δ < −11° and +73° < δ) and provides extra spectral coverage and resolution in the blue for bright BL Lacs. Typical exposures were 2 × 600 s for FSRQs and up to 3 × 900 s for faint BL Lacs.

2.3. Analysis Pipeline

Data reduction was performed with the IRAF package (Tody, 1986) using standard techniques. Wavelength calibration was performed with a neon-argon lamp at the HET and on the red side at DBSP, and iron-argon on the DBSP blue side. For these relatively faint objects,
we employ an optimal extraction algorithm \cite{Valdes1992} to maximize the S/N.

We perform spectrophotometric calibration using standard stars from \cite{Oke1990}. In most cases the standard exposures from the data night were suitable, but at the HET, standards from subsequent nights were sometimes used. Due to differential slit losses and variable conditions between object and standard star exposures, we estimate that the accuracy of our absolute spectrophotometry is $\sim 30\%$ \cite{Healey2008}, although the relative spectrophotometry is considerably better. Spectra are corrected for telluric absorptions and visually cleaned of cosmic rays. Multiple exposures on a single target are combined into a single spectrum, weighting by S/N.

We visually identify and measure emission line equivalent widths and FWHMs and derive redshifts from these line measurements. They are listed in Table 1. Line and redshift measurement techniques are discussed in §3.1.

3. RESULTS

We present spectra for ten FSRQ objects, six new BL Lac identifications and spectra, and high S/N spectroscopy on six additional objects previously known to be BL Lacs. We present spectroscopic redshifts for all ten FSRQ, and for one BL Lac. We derive virial BH
masses for the FSRQ, and for BL Lac that lack spectroscopic redshifts, we extract significant constraints on the redshift.

3.1. FSRQ Spectra

We present ten previously unpublished FSRQ spectra with redshifts ranging from 0.227 to 1.805. These redshifts were previously listed in Abdo et al. (2009). All redshifts are confirmed by multiple emission lines and derived by cross-correlation analysis using the rvsao package (Kurtz & Mink 1998). Table 1 gives the approximate continuum fluxes at 10^{14.7} Hz (λ = 5981 Å) and spectral indices (νFν ∝ ν−α). The fluxes, as above, have uncertainties as large as 30% due to unknown slit losses. The spectral index uncertainties are estimated by fits to independent subsets of the spectral range.

The properties of strong emission lines are listed in Table 1. We are particularly interested in the broad emission lines Hβ, Mg II, and C IV, as their virialized broad components are used to make estimates of the black hole mass. For these lines, we take care to measure the Gaussian full width at half maximum (FWHM) of the broad component, avoiding contamination by other spectral features.

For Hβ, it is important to include narrow components in the line fit. We fit the continuum to a power law, and, following McLure & Dunlop (2004), we simultaneously fit broad and narrow Hβ, narrow [O III]4959 Å, and narrow [O III]5007 Å. We require rest wavelengths of narrow Hβ and the [O III] lines to match laboratory values; the broad Hβ wavelength was free. All lines are modeled with Gaussian profiles. The continuum is measured at 5100 Å.

For Mg II, we first subtract off our power law fit. Then, we subtract a template (Tsuzuki et al. 2006) of the broad Fe II complexes near 2800 Å, to minimize contamination with Mg II. We then fit the Mg II line itself with a broad−narrow Gaussian. For this line the continuum measurement is, as usual, made at 3000 Å, to avoid Fe contamination (McLure & Dunlop 2004).

C IV lines sometimes suffer strong associated absorption, but such corrections were modest for the few cases presented here. Also, for consistency with the SDSS measurements (see below) and to minimize sensitivity to associated absorbers we report here the FWHM of the actual C IV line (Shen et al. 2008).

3.2. Black Hole Mass Estimates

We can use the emission line measurements reported above to estimate black hole masses for the FSRQ objects in our sample using the empirical ‘virial’ scaling relationships (McLure & Jarvis 2002). Mass scaling relations have been applied to large samples of quasars in the past and are calibrated by reverberation mapping techniques (Vestergaard & Osmer 2009).

Continuum flux measurements were made for each line at the appropriate rest wavelength (5100 Å for Hβ, 3000 Å for Mg II, 1350 Å for C IV), and converted to continuum luminosity L_{α}, using our assumed cosmology. For two objects in our sample, J1012+2439 and J2327+0940, the C IV line is clearly present, but the spectra do not extend blue-ward enough to cover 1350 Å; for these, we extrapolate a power law fit to the continuum at longer wavelengths. We then fit the Mg II line itself with a broad−narrow Gaussian. For this line the continuum measurement is, as usual, made at 3000 Å, to avoid Fe contamination (McLure & Dunlop 2004).

Table 1: We require rest wavelengths of narrow Hβ, narrow [O III]4959 Å, and narrow [O III]5007 Å. We require rest wavelengths of narrow Hβ and the [O III] lines to match laboratory values; the broad Hβ wavelength was free. All lines are modeled with Gaussian profiles. The continuum is measured at 5100 Å.

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wavelengths. We follow Shen et al. (2008) in the calculation of the black hole masses:

\[
\log \left( \frac{M}{M_\odot} \right) = a + b \log \left( \frac{\lambda L_\lambda}{10^{44} \text{erg s}^{-1}} \right) + 2 \log \left( \frac{\text{FWHM}}{\text{km s}^{-1}} \right)
\]

where \(a = 0.505, b = 0.62\) for Mg II; \(a = 0.672, b = 0.61\) for Hβ; and \(a = 0.66, b = 0.53\) for C IV.

Masses are plotted in Figure 2 Values measured from spectra presented in this paper are indicated by filled points (species used indicated by point style). Some of the LBAS FSRQ have spectra in the SDSS archive (Schneider et al. 2007). We recovered these and measured line profiles and continuum fluxes exactly as for our new objects to obtain similar BH mass estimates (open points). For about half of these sources, SDSS published independently estimated values for \(M\) (Shen et al. 2008). We find adequate agreement, with rms differences in \(\log(M)\) of 0.04 (Hβ) and 0.14 (Mg II, C IV), comparable to the inter-species dispersion.

In general, the virial mass estimators are of limited accuracy for individual objects. As one illustration, when estimates are available for a given object from more than one species, we connect the points with a dashed line. The pipeline processing of the entire Sloan DR5 sample of optically selected quasars provides a large number of such mass estimates. In Figure 2 we show the mean and rms \(\log(M)\) values as a function of redshift. For both the \(\gamma\)-ray selected sample presented here and the optical SDSS sample, the mean mass increases with redshift, likely a simple flux bias. However, we note that the \(\gamma\)-ray sources trend about 3× lower in mass than the optically selected objects, albeit with large scatter. There are several possible origins of this trend. One possibility is that this is a result of the fainter optical limit in the follow-up to the LBAS sample. Another selection effect may be imposed by the \(\gamma\)-ray selection’s dependence on the jet flux, which, as a strong function of the viewing angle to the relativistic jet, is more weakly dependent on the underlying source luminosity and presumably black hole mass. A final possibility stems from orientation: virial estimates (Equation 1) assume isotropic velocities in the broad line region. However, blazars are known to have the jet-axis, close to the Earth line-of-sight. If the broad line region has a toroidal structure (Fine et al. 2008), then blazars will have lines with FWHM decreased by \(\langle \sin i \rangle\) and lower virial mass estimates than QSOs viewed at larger inclination angles. Larger data sets from future LAT samples should allow us to probe the reality and origin of such effects.

3.3. BL Lac Properties

We have obtained high sensitivity (\(S/N \sim 100\)) spectra of twelve LBAS BL Lacs. Following Marcha et al. (1993) and Healey et al. (2008), we adopt here the pragmatic ‘optical spectroscopic’ definition of a BL Lac as a blazar lacking emission lines with observed equivalent width greater than 5 Å and a limit on any possible 4000 Å spectral break of < 40%. For some sources in CGRaBS we have seen that, as the continuum level fluctuates, the source passes from spectroscopic BL Lac to spectroscopic FSRQ. We designate a source as a BL Lac if during any of our observations with adequate spectral range it has satisfied the spectroscopic definition. In this connection, one of the high-mass objects appearing in Figure 2 should be mentioned. This is J1058+0133, designated an FSRQ in LBAS based on a clear detection of a broad Mg II line at \(z=0.888\). However, this line has an EW of only 3.5 Å; accordingly this blazar should be formally designated a BL Lac at the epoch of the SDSS spectrum. The very strong non-thermal continuum, in fact, drives up the apparent luminosity and the BH mass estimate. This emphasizes that non-thermal continuum can artificially increase the apparent mass; the virial estimates are not calibrated for BL Lac sources.

The spectral range requirement for BL Lac designation is that the spectrum covers [\(\lambda_{\min} \text{ to } \lambda_{\max}\)] with sufficient S/N to detect at least one of the standard AGN broad emission lines — Lyα, C IV, C III, Mg II, Hβ, or Hα. In practice this means adequate S/N over \(\lambda_{\max}/\lambda_{\min} > 1.75\); this is easily satisfied for the BL Lac in our LBAS sample.

To describe the BL Lac continua, we fit the spectra to a power law, using the IRAF nfit1d routine. Most are well fit with rising (blue) power-laws, suggesting a synchrotron \(\nu F_\nu\) peak well above the optical band. J0144+2705 is, however, very red. This is confirmed by USNO B1/2MASS fluxes which rise to the J-band and flatten above 1.5μm. The Galactic extinction in the direction of this source is \(A_B = 0.3\) mag, so local absorption is unlikely to redden the source. It seems plausible that this BL Lac has a low synchrotron peak frequency \(\nu_{\max} \sim 10^{14}\)Hz. This may be tested by broader study of the SED.

The spectral indices \((F_\nu \propto \nu^{-\alpha})\) and fluxes of the BL Lac are reported in Table 2. For the continuum normalization we assume the 30% absolute spectrophotometric uncertainty noted above; for the spectral indices we again estimate the dominant systematic errors from fits to non-overlapping sections of the continuum. The continuum-normalized spectra are shown in Figures 3 & 4. These plots also label notable interstellar features e.g. Na λ5892, and the diffuse interstellar bands, or DIBs (Herbig 1993).

3.4. BL Lac Redshift Limits

The strong dominance of the non-thermal nuclear continuum in BL Lacs guarantees that the equivalent widths of any broad nuclear lines or absorption features from the host galaxy are very small. While recent work with 8 m-class telescopes has provided some redshift solutions, spectroscopic redshifts for many objects remain elusive (Sbarufatti et al 2003). Nevertheless, quantitative limits on host spectral features can be useful in extracting redshift constraints. For example, based on the lack of a Lyα forest-induced break in the HET spectra, none of our BL Lacs can have \(z > 2.41\). This rather weak bound can be improved with UV coverage beyond the HET LRS 4150 Å limit.

Also, there is good evidence, especially from HST imaging, that BL Lacs reside in relatively uniform giant elliptical hosts, with \(M \sim -22.9\) (Sbarufatti et al 2005). Analysis to limit the contribution of such a host to the observed spectrum can thus provide a lower limit on the BL Lac redshift (Sbarufatti et al 2005). We develop here a similar spectral bound on redshift, using the Ca H/K and G-band absorption features, the strongest
narrow features in the host spectrum.

We first determine the expected equivalent width of a given absorption line by measuring an elliptical template spectrum and then computing the net equivalent width in the observed host+nucleus spectrum at each redshift following Sbarufatti et al. (2006):

\[ EW_{\text{expected}} = \frac{(1 + z)EW_{h}}{1 + F_n/F_h} \]  

(2)

where \( EW_{h} \) is the equivalent width of the line in the host galaxy spectrum, \( F_{h} \) is the nuclear flux at the wavelength of that absorption line, and \( F_{n} \) is the flux of the giant elliptical host at that wavelength. \( F_{h} \) is corrected for the slit/extraction aperture losses, assuming a deVaucouleurs profile with redshift-dependent angular size set by a constant radius \( r_0 = 10 \text{kpc} \). \( F_{n} \) is the observed flux minus that expected from the host in our extraction aperture. This predicted feature strength is computed for the major absorption lines at each redshift.

We next compute the 3σ limit on narrow absorption features in the observed spectrum as a function of wavelength from the local rms of negative spectral fluctuations, after high-pass filtering to remove broad continuum features and after exclusion of zero-redshift Galactic and telluric features. We find that the line sensitivity varies considerably across the spectrum (Sbarufatti et al. 2006 assume constant sensitivity for their VLT spectra). For the HET data, limited blue sensitivity weakens the constraints below \( \sim 5000 \text{Å} \), while strong fringing (uncor-
rectable due the varying HET pupil) weakens the bounds beyond $\sim 8000$ Å. The sensitivity also varies due to the changing resolution; this is especially important for the DBSP data, although no DBSP spectra are used in the measurements of the BL Lacs presented here.

Comparison of the expected and limiting EW curves gives a lower limit on the BL Lac redshift (for the assumed standard host magnitude) whenever one absorption feature is excluded at the $3\sigma$ level. Generally the Ca features provide the strongest constraint. However, since our HET spectra are limited to $\lambda > 4150$ Å, the G-band at $\lambda = 4304$ Å is used to exclude $z \leq 0.05$. Figure 4 shows the exclusion curve for J1253+5301, where we find $z > 0.77$. The results for the BL Lac data are presented in Table 2. With our HET data, we can exclude redshifts less than $z \sim 0.5 - 0.8$. For a few particularly bright BL Lac, however, the redshift constraints are substantially weaker as the expected equivalent widths are smaller. Higher resolution, higher S/N spectra can, of course, improve these bounds.

A few objects deserve particular comment. For J1054+2210, after completing the redshift limit analysis, weak H/K and G-band features plus O II $\lambda 3727$ emission were found at redshift $z = 0.634$. This detection is confirmed by cross-correlation analysis. The measured redshift is just above the redshift bound of $z > 0.60$ given by the exclusion analysis. For J2325+3957, the EW limit analysis gave a redshift bound of $z > 0.77$. We have detected an intergalactic absorption system in this spectrum, with Mg II doublet and Fe II absorption features.
corresponding to $z$.

For the strong-line objects we present estimates of the virial black hole masses. Although such mass estimates have large uncertainties, our objects appear to have somewhat lower mass than typical for the SDSS quasar sample. Like that sample, the mean mass increases with redshift. In the one case where a BL Lac-like object has a mass measurement, the excess continuum artificially inflates the apparent black hole mass.

The spectroscopic analysis presented here for the small LBAS blazar sample will be much more powerful when applied to the full sample of LAT blazars detected during the first year sky survey, which should include 500-1000 objects. We continue to collect spectroscopic data on the LAT blazars as they are detected and plan to use the optical analysis of this larger data set to probe the evolution of the $\gamma$-ray emitting objects.

4. CONCLUSIONS

The optical spectroscopy presented here provides significant new information on some of the less well-known members of the set of the LBAS $\gamma$-ray blazars.

For all of the new FSRQ, precision redshifts are measured from the spectra. For one of the new BL Lacs, we determine the redshift spectroscopically; for the others we extract limits on the redshift from the spectrum. Continuum fluxes and spectral indices are provided that will be useful for SED plots. These measurements bring the LBAS to 84% redshift completion. For most of the unsolved BL Lacs we extract significant lower limits on the redshift. These will be helpful in modeling the $\gamma$-ray BL Lac population and evolution and in focusing redshift searches to a narrower spectral range.

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REFERENCES

Abdo et al. 2009, ApJ, in press.
Fine, S. et al. 2008, MNRAS, 390, 1413.
Healey, S. E. et al. 2007, ApJS, 171, 61.
Healey, S. E. et al. 2008, ApJS, 175, 97.
Herbig, G. H., 1995, ARA&A, 33, 19.
Hill, G. J., Nicklas, H. E., MacQueen, P. J., Tejada, C., Cobos Duenas, F. J., & Mitsch, W. 1998, Proc. SPIE, 3355, 375.
Kurtz, M. J., & Mink, D. J., 1998, PASP, 110, 934.
Marcha, M.J.M., et al, 1996, MNRAS, 281, 425.
McLure, R. J., & Dunlop, J. S. 2004, MNRAS, 352, 1390.
McLure, R. J., & Jarvis, M. J., 2002. MNRAS, 337, 109.
Oke, J. B. 1990, AJ, 99, 1621.
Sbarufatti, B., et al. 2005, AJ, 129, 559.
Sbarufatti, B. et al. 2006, AJ, 132, 1.
Schneider, D. P., et al. 2007, AJ, 134, 102.

Shen, Y., et al. 2008, ApJ 680, 169.
Shetrone, M., et al. 2007, PASP, 119, 556.
Tody, D. 1986, Proc. SPIE, 627, 733.
Tsuzuki et al. 2006, ApJ, 650, 57.
Valdes, F. 1992, in ASP Conf. Ser. 25, Astronomical Data Analysis Software and Systems I, ed. D. M.
Vestergaard, M., & Peterson, B. M. 2006, ApJ, 641, 689.
Vestergaard, M., & Osmer, P. S. 2009, ApJ, in press.