THE TWICE-OVERLOOKED, SECOND FANAROFF-RILEY II BROAD ABSORPTION LINE QUASAR LBQS 1138–0126

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ABSTRACT

We report the correct classification of an overlooked Fanaroff-Riley class II radio-loud quasar with broad absorption lines, only the second such object so identified. The rare properties of this quasar, LBQS 1138–0126, are twice overlooked. First, LBQS 1138–0126 was found in the Large Bright Quasar Survey but only noted as a possible broad absorption line quasar without additional follow-up. Later, LBQS 1138–0126 was rediscovered and classified as a radio-loud broad absorption line quasar but not recognized as an FR II radio source. We describe the radio, absorption line, and optical polarization properties of LBQS 1138–0126 and place it in context with respect to related quasars. In particular, spectropolarimetry shows that LBQS 1138–0126 has high continuum polarization increasing from 3% in the red (rest-frame 2400 Å) to over 4% in the blue (rest-frame 1650 Å), essentially confirming the intrinsic nature of the absorption. The polarization position angle rotates from ~30° in the red to ~0° in the blue; the radio lobe position angle is ~52° for comparison. LBQS 1138–0126 is additionally notable for being one of the most radio-loud broad absorption line quasars and for having low-ionization broad absorption lines as well.

Key words: quasars: absorption lines — quasars: general — radio continuum — techniques: polarimetric

1. INTRODUCTION

Some 10%–20% of optically selected quasars display broad, blueshifted, ultraviolet absorption lines from highly ionized species (e.g., C iv—HiBAL quasars), with a smaller fraction also showing absorption from very low ionization species (e.g., Mg ii—LoBAL quasars). A decade ago, no formally radio-loud broad absorption line (BAL) quasars were known despite searching for such objects (e.g., Stocke et al. 1992). This strong anticorrelation seemed to be a clue to explaining the apparent bimodal distribution of radio-loudness in quasars (which is very much less apparent in new samples selected using deep radio surveys; see, e.g., White et al. 2000).

In the mid 1990s, with the advent of large-area, deep radio surveys like the NVSS (Condon et al. 1998) and FIRST (Becker, White, & Helfand 1995), radio-loud BAL quasars began to be found. Becker et al. (1997) found the first such source, FIRST J1556+3517, by matching optically red point sources with FIRST radio sources; corrections for dust reddening and the possibility of beaming at radio frequencies leave this quasar straddling the traditional borderline between radio-loud and radio-quiet quasars (Najita, Dey, & Brotherton 2000). Additional follow-up to the FIRST survey found more radio-loud BAL quasars by matching radio sources to the Automated Plate Measuring Facility catalog (Becker et al. 2000, 2001) and the Sloan Digital Sky Survey (SDSS; Menou et al. 2001). Over 50 BAL quasars have now been identified using radio selection techniques.

The largest and brightest sample of radio-selected BAL quasars is that of Becker et al. (2000), which comprises ~27 BAL quasars from the FIRST Bright Quasar Survey (White et al. 2000). Their radio properties can tell us some things that cannot be learned from optically selected BAL quasars. First, a wide range of radio spectral indexes are present, including both flat and steep spectra; unified radio models (e.g., Orr & Browne 1982) would indicate that therefore a range of orientations are present. Second, the radio sources are almost all compact (90%), whereas a matched parent population from the FIRST Bright Quasar Survey (FBQS) consists of only 60% compact sources. This is similarly contrary to the idea that BAL quasars are simply normal quasars seen edge-on. Properties at other wave bands are also inconsistent with BAL quasars being edge-on quasars (e.g., Brandt & Gallagher 2000).

Were it not for these results, the discovery of a powerful edge-on Fanaroff-Riley type II (FR II; Fanaroff & Riley 1974) radio source that is also BAL quasar, FIRST J101614.3+520916 (hereafter FIRST J1016+5209; Gregg et al. 2000), might have been taken as supporting evidence for an edge-on geometry. The once popular notion of such an edge-on geometry was motivated by spectropolarimetry (e.g., Ogle et al. 1999) and by theoretical expectations for winds arising from accretion disks (e.g., Murray et al. 1995; Konigl & Kartje 1994). Instead, Becker et al. (2000) and
Gregg et al. (2000) interpret BAL quasar radio properties to indicate that BAL quasars are young, evolving quasars, moving from dusty objects with high covering fractions and high accretion rates to becoming more typical quasars.

Brotherton et al. (1998) found five radio-loud BAL quasars by matching color-selected quasar candidates from the 2dF Quasar Survey (e.g., Croom et al. 2001) against radio sources in the NVSS. These were of particular interest because their blue colors ensured minimal dust reddening, which can artificially enhance the radio-loudness by making an object appear optically weak relative to its radio emission. Also of interest was that the observed targets were taken from a large optically selected sample, making possible statistical comparison with the Large Bright Quasar Survey (LBQS; Foltz et al. 1989; Hewett et al. 1991; Chaffee et al. 1991; Morris et al. 1991; Francis et al. 1992; Hewett, Foltz, & Chaffee 1995). The 2dF-NVSS cross match indicates that approximately one in 500 bright blue quasars should be seen in an observed-frame optical spectrum as a radio-loud BAL quasar. With the LBQS coming in at ~1000 quasars, it would be likely to find one or two such objects but not too surprising to not find any.

An error labeling the coordinates of one of the five radio-loud BAL quasars from Brotherton et al. (1998) prevented identification with the correct radio source (Brotherton et al. 2002). Likewise, this error prevented identification with a previously discovered quasar, LBQS 1138–0126 (Hewett et al. 1991), which had only been noted as being a possible BAL quasar but had not been followed up on in either the optical or radio. We show in this paper that LBQS 1138–0126 is not only a BAL quasar, it is also a powerful FR II radio source, only the second such BAL quasar found.

2. DATA

In addition to the 4000–9000 Å spectrum presented by Brotherton et al. (1998), the original LBQS spectrum (Hewett et al. 1991) is also available that covers shorter wavelengths, including the C iv λ1549 transition. Additionally, radio data is publicly available from several surveys, including radio maps from the FIRST survey (Becker et al. 1995). Finally, we describe new spectropolarimetry obtained from European Southern Observatory’s Very Large Telescope (VLT).

2.1. Radio Observations

A search on the NASA Extragalactic Database (NED) shows that LBQS 1138–0126 is present in several radio surveys in addition to the NVSS, which indicates a radio flux density of 252 mJy at 1.4 GHz and a radio-loudness of log R* = 3.0 (Brotherton et al. 2002). This already makes LBQS 1138–0126 competitive for the title of the most radio-loud BAL quasar known.

In the Texas 365 MHz Survey (Douglas et al. 1996), LBQS 1138–0126 is reported to have a flux density of 658 ± 49 mJy. In the Parkes-MIT-NRAO (PMN) Survey (Griffith et al. 1995), LBQS 1138–0126 is reported to have a flux density of 69 ± 11 mJy at 4.85 GHz. The flux measurements at the three frequencies indicate a radio spectral index of α = −0.7 (Sν ∝ ν^α) from 365 MHz to 1.4 GHz, steepening to α = −1 from 1.4 to 4.85 GHz. LBQS 1138–0126 is a strong, steep-spectrum radio source consistent with optically thin synchrotron from a lobe-dominated FR II source.

The high resolution of the 1.4 GHz FIRST survey (Becker et al. 1995) provides morphological information. We have used the FIRST survey cutout server to extract an image of LBQS 1138–0126 at ~5° resolution. Figure 1 shows this image as a contour map. We clearly see a double-lobed radio structure at a position angle $\theta \sim 52^\circ$, with a bridge of radio flux between. A spur from the northeastern source into this bridge corresponds to the marked optical position of LBQS 1138–0126, although from this map we cannot reliably extract a distinct core flux. The core flux does appear to be no more than a tenth of the lobe flux and probably significantly less, making the source “edge-on” in unified radio schemes (e.g., Orr & Browne 1982).

2.2. Spectropolarimetry

We obtained spectropolarimetric observations of LBQS 1138–0126 on UT 2002 May 8 using the PMOS mode of the FORS1 spectrograph (Appenzeller et al. 1992) on the Melipal unit of the VLT. Conditions were nearly photometric with ~0.7” seeing. The observations were split into four 300 s exposures, each at a different orientation of the half-wave plate (0°, 22.5°, 45°, 67.5°). We used the 600B grism with a 1.0” wide slit oriented north-south, resulting in a spectral resolution of 5.0 Å (FWHM).

We reduced the data using the standard IRAF procedures. We extracted the spectra with an identical 3.6” wide aperture for the $o$- and $e$-rays, and resampled all eight individual spectra ($o$- and $e$-rays for the four half-wave plate positions) to the same linear dispersion (1.166 Å pixel$^{-1}$) in
3. ANALYSIS AND RESULTS

3.1. BALs in the LBQS 1138–0126 Spectrum

Brotherton et al. (1998) classified LBQS 1138–0126 as a BAL quasar on the basis of broad but shallow absorption troughs from Al iii and Mg ii. Typically, these low-ionization BALs, when present, are weaker and lower velocity than high-ionization BALs (e.g., Voit, Weymann, & Korista 1993). The original LBQS spectrum and our new VLT spectrum cover the C iv λ1549 region (not present with the Brotherton et al. 1998 wavelength coverage) and reveal a significantly deeper BAL trough (Fig. 3).

The original LBQS spectrum has higher signal-to-noise ratio (S/N) than the VLT spectrum in the immediate region of the C iv λ1549 BAL, although the VLT spectrum has the best S/N at longer wavelengths that includes the Al iii λ1863 BAL. The C iv λ1549 BAL is present in both HiBAL quasars and LoBAL quasars and provides the most commonly measured standard for comparison of absorption-

line properties. Weymann et al. (1991) defined the “BAL-nicity index” (BI)—a complex measurement of the detachment, depth, and velocity span of an absorption feature—in order to distinguish real BALs from blends of associated absorbers (especially) in low-resolution, low-S/N spectra. In recent years, detailed studies of individual objects have shown that a significant number of absorbed quasars with zero BALnicity nevertheless possess intrinsic outflows (e.g., Becker et al. 2000). For this reason, Hall et al. (2002) have created a new index similar to the BI, called the “absorption index” or AI, that provides a wider measurement range to include such lower velocity outflows.

We find that the C iv λ1549 BAL trough, based on the LBQS spectrum, possesses a small but positive BALnicity index, BI = 900 ± 300 km s\(^{-1}\). The uncertainty is quite large given the low S/N and depends critically on continuum choice and assumed redshift (we assume z = 1.266). The uncertainty we quote indicates the range of values we find for different assumptions rather than formal fitting errors. The absorption index is AI = 3000 ± 300 km s\(^{-1}\). The conservative definition of BI would indicate that we certainly have a BAL quasar in LBQS 1138–0126, and this is supported by the deep C iv trough and velocity span of some ~5000 km s\(^{-1}\) detached ~2000 km s\(^{-1}\) from the C iv λ1549 peak. The low-ionization BAL troughs (Al iii, Mg ii) cover a very similar velocity range (approximately −2000 to −8000 km s\(^{-1}\)) but are much shallower.

If there is any doubt regarding the BAL quasar designation for LBQS 1138–0126, they should be dispelled by our polarization results. Only about one in a hundred optically selected quasars without intrinsic absorption shows any significant optical polarization greater than 1% (e.g., Berriman et al. 1990). The frequency is similar for radio-loud quasars with extended, lobe-dominated steep-spectrum radio structures (e.g., Visvanathan & Wills 1998 and references within). BAL quasars, especially those showing absorption
from low-ionization species and red colors, are significantly more often highly polarized than unabsorbed quasars (Brotherton et al. 2001a and references therein). The only other quasar class exhibiting such high levels of continuum polarization are beamed radio-loud quasars (blazars), which possess a large contribution of optical synchrotron emission; the radio structure of LBQS 1138–0126 rules out a blazar designation.

### 3.2. Reddening in LBQS 1138–0126 and Radio-Loudness

Despite the fact that LBQS 1138–0126 has an ultraviolet excess ($U - B_r = -0.7$), the continuum shape is clearly redder than that of the average radio-selected quasar. Its selection was assisted by the presence of C IV $\lambda$1549 emission in the $U$ band. The Galactic reddening is only $E(B-V) = 0.017$ mag in this direction (Schlegel, Finkbeiner, & Davis 1999), so local Galactic dust is not the cause. For the LBQS, Sprayberry & Foltz (1992) showed that LoBAL quasars were on average reddened by $E(B-V) = 0.1$ mag for a Small Magellanic Cloud extinction law (Prevot et al. 1984) compared with the LBQS as a whole. Comparison with the radio-selected composite FBQS spectrum (Brotherton et al. 2001b) indicates that the continuum of LBQS 1138–0126 is consistent with intrinsic reddening (at the redshift of the quasar) of 0.35 mag for a Small Magellanic Cloud extinction law, which well matches the average result of Sprayberry & Foltz (1992). The effective observed $B$-band flux would then be enhanced by a factor of $\approx 2.8$ to correct for this level of extinction. The intrinsic radio-loudness would then decrease, because of the intrinsically brighter optical continuum, to $\log R^a = 2.5$. This value would still place LBQS 1138–0126 among the most radio-loud BAL quasars known.

### 4. DISCUSSION

It is clear that LBQS 1138–0126 is a powerful double-lobed FR II radio source, and that the optical/UV spectrum contains both high-ionization and low-ionization BALs. The high continuum polarization makes a very strong statistical argument that the absorption lines are broad and intrinsic and we are not being misled by the low resolution of our spectra. These properties lead to the conclusion that LBQS 1138–0126 is an FR II BAL quasar, only the second such object so identified after FIRST J1016+5209 (Gregg et al. 2000).

We also note the existence of the less luminous, low-redshift quasar PKS 1004+13 (Wills, Brandt, & Laor 1999) that is a strong candidate for having BALs and is soon to have a definitive UV spectrum obtained with the Hubble Space Telescope. One other BAL quasar from Brotherton et al. (1998), UN J1053–0058, is seen to be a very core-dominated radio triple in FIRST survey images. The spatial extent of the triple is approximately 45', corresponding to a projected size of 550 kpc at $z = 1.55$ for our adopted cosmology. Hutsemékers & Lamy (2000) report an optical polarization of 1.89%, with a position angle some 20°–30° from being perpendicular to the radio axis. The large radio core dominance (an observed core-to-extended 1.4 GHz flux ratio of about 12) would indicate that the radio core, and the radio-loudness, is artificially enhanced by relativistic beaming. Therefore, UN J1053–0058 is perhaps best identified as a beamed radio-quiet quasar rather than as an intrinsically luminous radio-loud quasar (see Falcke, Patnaik, & Sherwood 1996; Falcke, Sherwood, & Patnaik 1996). We focus the remaining discussion on quasars like LBQS 1138–0126 and FIRST J1016+5209.

How similar are LBQS 1138–0126 and FIRST J1016+5209? Table 1 compares their properties. The similar small BIs, modest reddening, high polarization, and radio luminosity in particular stand out. Also similar is the fact that both have optical polarization position angles intermediate between those parallel or perpendicular to the large-scale radio structure. The comparison of the angular size is strongly affected by adopted cosmology, although both sources appear to be relatively large (at least several hundred kiloparsecs). Significant differences include the presence of low-ionization BALs in LBQS 1138–0126 but not FIRST J1016+5209 and the smooth single trough structure of LBQS 1138–0126 compared with the jagged multiple trough structure in the BALs of FIRST J1016+5209, which also spans a much larger velocity range. We note that among radio-quiet BAL quasars there exists a wide range of trough structures that have so far not been found to clearly correlate with other properties.

Gregg et al. (2000) proposed and discussed an evolutionary sequence for LoBAL quasars to evolve into HiBAL quasars and then into radio-loud quasars with associated absorption that is the remainder of the once smooth BAL outflow. The formally radio-loud BAL quasars from Becker et al. (2000) with compact radio structures would be the youngest (most recently fueled) sources, perhaps themselves closely related to gigahertz-peak sources (GPSs) and

| Parameter | LBQS 1138–0126 | FIRST 1016+5209|
|-----------|----------------|----------------|
| R.A. (J2000.0) | 11 41 11.56 | 10 16 14.3 |
| Decl. (J2000.0) | -01 43 07.7 | 59 09 16 |
| z | 2.66 | 2.45 |
| $B_r$ | 18.56 | 20.2 |
| $R^a$ | 17.74 | 18.6 |
| $S_{2500}$ (mJy) | 658 | 846^a |
| $S_{4300}$ (mJy) | 252 | 131.1 |
| $S_{8400}$ (mJy) | 69 | 44 |
| Lobe peak-to-peak distance (arcsec) | 21 | 45 |
| Total projected size (kpc) | 250 | 600 |
| Lobe-lobe axis P.A. (deg) | 52 | 146 |
| Continuum Pol. P.A. (deg) | 0 to 30 | 85 to 75 |
| Continuum Pol. (%) | 4 to 3 | 2.5 to 2 |
| C IV $\lambda$1549 BI (km s$^{-1}$) | 900 | 2400 |
| Intrinsic $E(B-V)$ (mag) | 0.11 | 0.27 |
| $M_B$ | $-26.4$ (−26.9) | $-25.7$ (−26.8) |
| $\log L_{2500}$ (ergs s$^{-1}$ Hz$^{-1}$) | 34.4 | 34.5 |
| $\log R^a$ | 3.0 (2.5) | 3.4 (2.7) |

*Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

^a From Brotherton et al. 2002 or measured here, for $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$ and $q_0 = 0$. Quantities in parentheses correspond to dereddened values.

^b Taken from Gregg et al. 2000 and converted to our adopted cosmology.

Note: Quantities of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

^c $B_r$ in the case of LBQS 1138–0126, POSS $O$ in the case of FIRST 1016+5209.

^d POSS $E$ in the case of FIRST 1016+5209.

^e Also from the Texas survey; Douglas et al. 1996.
compact steep spectrum (CSS) radio-loud quasars (e.g., O’Dea 1998). Next in the progression is LBQS 1138–0126, in which the radio jet has escaped the nuclear regions but low-ionization BALs are still visible and dust is still present along the line of sight. FIRST J1016+5209 is the next stage as the LoBAL features vanish and the HiBAL features begin to break up. The final stage before being regarded as a normal, unabsorbed radio-loud quasar is represented by PKS 1157+014, an object once put forward and rejected as a radio-loud BAL quasar for which variability has provided proof of the intrinsic nature of its rather narrow absorption features (Aldcroft, Bechtold, & Foltz 1997).

The polarization properties of LBQS 1138–0126 are similar to those of other highly polarized BAL quasars (e.g., Ogle et al. 1999). The polarization mechanism is widely thought to arise from asymmetric scattering, since other likely mechanisms can be ruled out with high-quality spectropolarimetry for individual objects. In particular, the rise in the polarization toward shorter wavelengths is very common and can be attributed to a decreasing amount of dilution from direct light more reddened than the scattered light path or as a signature of dust scattering (e.g., Hines et al. 2001). Less commonly seen in polarized BAL quasars is a significant rotation of the polarization position angle, although it appears (e.g., QSO 2359–1241; Brotherton et al. 2001a). Such a rotation can be ascribed to multiple scattering light paths with different amounts of reddening or different polarization efficiencies as a function of wavelength (e.g., in the case of dust scattering). Such complex scattering geometries might be expected for young, highly accreting objects with large covering fractions, as opposed to a simpler scattering geometry as seen in edge-on Seyfert 2 and radio galaxies for which the polarization position angle is perpendicular to system (jet) axes (Antonucci 1993).

LBQS 1138–0126 is not especially red or faint and was easily found using optical selection techniques. The radio emissions are strong and detected in multiple surveys. The key elements in making the classification of a radio-loud FR II BAL quasar are having an optical spectrum covering the C iv λ1549 region and matching optical properties with radio properties. Given the statistics of Brotherton et al. (1998) and Menou et al. (2001) selecting BAL quasars by optical techniques and matching to radio surveys, the SDSS should turn up an entire population of quasars similar to LBQS 1138–0126. The small number statistics and the possible existence of as yet unidentified biases make a precise estimate impossible, but we might expect 100–200 FR II BAL quasars to be identifiable from combining information from SDSS discovery spectra and the FIRST survey. This might seem like a large number of sources, but these still appear to be rare objects requiring very large surveys to discover in significant numbers. Such a sample would permit quantitative tests and development of the evolutionary hypothesis of Gregg et al. (2000).

5. SUMMARY

The properties of LBQS 1138–0126, now properly recognized, mark it as the second FR II BAL quasar so far discovered after FIRST 1016+5209. This quasar shows both low and high-ionization BALs, as well as the high continuum polarization (3%–4%) characteristic of LoBAL quasars. The position angle of the luminous radio lobes differs from the polarization position angle by 50°–70°. Modest reddening of the optical/ultraviolet continuum reduces the radio-loudness from log R* = 3.0 to 2.5, still one of the most radio-loud BAL quasars known and one of only two confirmed BAL quasars with a large double-lobed radio structure.

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