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AN EXCESS OF Mg II ABSORBERS IN BL LACERTAE OBJECTS

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ABSTRACT

Three Mg II absorbers are presented, one of which is new ($z = 1.340$ in S5 0454+844), bringing the total number of Mg II systems in the 1 Jy radio-selected BL Lac sample to 10. Five of the 10 absorption systems are at $W_\lambda > 1$ Å; this is a factor of 4–5 greater than the number expected based upon quasar sight lines and is 2.5–3 σ greater than the expectation value. Interpretations of this possible excess include either that some of the Mg II absorbers might be intrinsic to the BL Lac or that there is a correlation between the presence of absorbing gas in the foreground and the nearly featureless spectra of these BL Lac objects compared to quasars. Such a correlation can be created by gravitational microlensing as suggested by Ostriker & Vietri. The similarity between the optical spectra of BL Lac objects with Mg II absorption and the spectrum of the γ-ray burst source GRB 970508 suggests that models of γ-ray bursts as microlensed AGNs should be investigated.

Subject headings: BL Lacertae objects — gamma rays: bursts — gravitational lensing — quasars: absorption lines

1. INTRODUCTION

BL Lac objects are thought to be low-luminosity radio galaxies (Fanaroff-Riley 1974 class 1 sources, hereafter FR 1's) whose jet synchrotron and inverse-Compton emissions are Doppler-boosted (Blandford & Rees 1978; Urry & Padovani 1995). The detailed properties of many (but not all) BL Lac objects are consistent with this scenario, including (1) their presence in luminous early-type host galaxies (Abraham, Crawford, & McHardy 1992; Wurtz, Stocke, & Yee 1996) in poor clusters of galaxies (Wurtz et al. 1997), (2) low-luminosity extended radio structures that often (but not always) resemble FR 1's (Antonuuci & Ulvestad 1985; Murphy, Browne, & Perley 1993; Perlman & Stocke 1993), and (3) overall spectral energy distributions (Sambruna, Maraschi, & Urry 1996) and luminosity functions (Urry & Padovani 1995) consistent with Doppler-boosted FR 1 energy distributions and luminosity functions. The multiwavelength properties of X-ray selected BL Lac objects (XBLs; Stocke et al. 1991) are especially well-described by the beamed FR 1 model. However, many of the radio-selected BL Lac objects (RBLs) have somewhat different properties, which include overall energy distributions similar to flat radio spectrum quasars (Padovani, Giommi, & Fiore 1997), weak, often broad emission lines similar to quasars but not seen in FR 1's (Stickel, Fried, & Kühr 1993, hereafter SFK; Rector & Stocke 1998, hereafter RS), and extended radio structures more luminous than that of FR 1's (Antonucci & Ulvestad 1985). Also, the $\langle V/V_{max} \rangle$ values for the XBLs and RBLs are widely different (Perlman et al. 1996; RS). Sambruna et al. (1996) explain these differences as caused by RBLs and XBLs being selected from different portions of the overall luminosity function. However, Stickel (1988a, 1988b), Narayan & Schneider (1990), and Stocke, Wurtz, & Perlman (1995) have presented individual examples suggestive of microlensing of background AGNs by stars in foreground galaxies (Ostriker & Vietri 1986). If a significant fraction of RBLs are not beamed FR 1's, but rather microlensed quasars, this can also explain the above differences. However, no convincing individual case of a microlensed BL Lac object has been brought forth as yet.

In this Letter we present statistical evidence for a significant excess of Mg II absorption systems in the complete RBL sample drawn from the 1 Jy survey (Kühr et al. 1981). The original sample consisted of 34 sources and was augmented with three new sources by Stickel, Meisenheimer, & Kühr (1994). New redshift information based upon improved optical spectroscopy by us (RS) and Lawrence et al. (1996) leave only four 1 Jy BL Lac objects without firm or tentative redshifts or lower limits on redshift due to Mg II absorbers. A total of 10 Mg II absorption systems have been found so far in the 1 Jy sample.

2. OBSERVATIONS

In order to improve the redshift information in the 1 Jy BL Lac sample, we obtained new spectroscopy of 1 Jy BL Lac objects at the 2.1 m telescope of the Kitt Peak National Observatory and at the Multiple Mirror Telescope Observatory (MMTO). The 2.1 m spectra spanned 4000–8000 Å at 8.4 Å resolution; the MMTO spectra included 3200–7500 Å at 7.4 Å resolution. Targets included all 1 Jy objects with no or uncertain redshift. While the complete spectroscopy will be presented elsewhere (RS), here we show a portion of a 2.1 m spectrum of S5 0454+844, the MMTO spectrum of PKS 2029+121, and the MMTO spectrum of PKS 0138−097. The proposed redshift of 0454+844 was based upon the detection of a single absorption line at ~6550 Å by Lawrence et al. (1996), which they identified as Na "D" at $z = 0.112$. Our spectrum in Figure 1 resolves this line into the Mg II doublet at $z = 1.340$. This lower bound on the redshift makes this object the most distant now known in the 1 Jy sample and alters the apparent speed of its jet from subluminal to superluminal (i.e., $\beta_{app}h > 1.9c$, where $H_0 = 100\ h$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$; Gabuzda & Cawthorne 1996). The MMTO spectrum of 2029+121 (Fig. 2) reveals emission lines of C IV, C III] and Mg II at $z = 1.215$ with foreground Mg II, Mg I, Fe II/Mn II λλ2600, 2606, and Fe II λ2382 absorption at $z = 1.117$. Stickel & Kühr (1993) first detected the intervening Mg II absorption system and suggested $z_{em} = 1.223$ based upon only broad Mg II and a tentative detection of C III]. The strength of the newly detected C IV line (rest $W_\lambda = 18$ Å) and the Mg II line (rest

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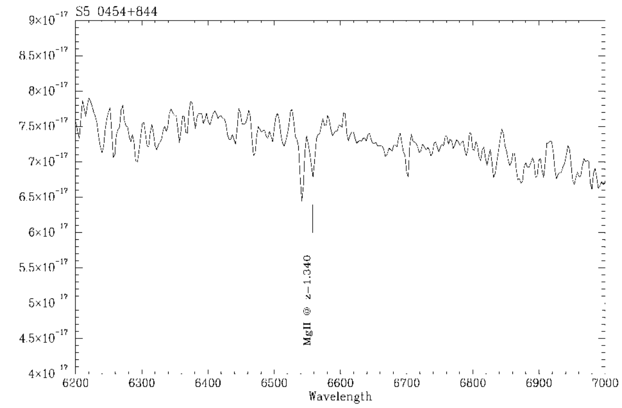

FIG. 1.—Portion of the KPNO 2.1 m spectrum of S5 0454+844 showing the resolution of the absorption line previously detected in a 5 m spectrum by Lawrence et al. (1996) into the Mg II doublet at $z = 1.340$.

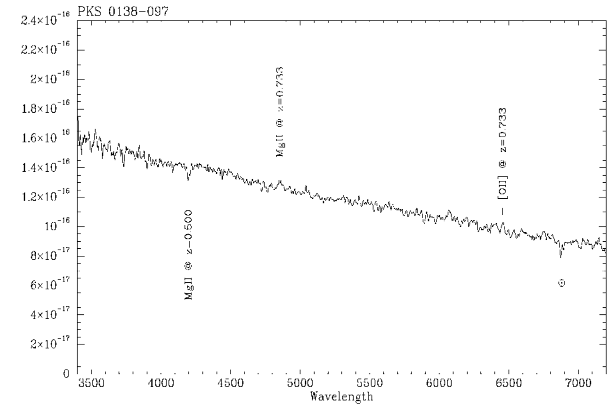

FIG. 3.—MMTO spectrum of PKS 0138−097 showing the previously known Mg II absorber at $z = 0.500$ (SFK) and the new emission-line redshift of $z = 0.733$ from Mg II and possible [O II]. A 2.1 m spectrum (RS) confirms the Mg II and [O II] emission, while detecting [Ne V] in addition at the same redshift.

$W_\lambda = 8$ Å) raises some doubts about classifying this object as a BL Lac object, although other BL Lac objects have been observed with similarly large W_λ emission lines at some epochs (e.g., 1 Jy 1308+326; SFK). Our new MMTO spectrum of 0138−097 (Fig. 3) confirms the Mg II absorption doublet previously found by SFK at $z = 0.500$ and detects for the first time the emission-line redshift of $z = 0.733$ based upon weak Mg II and [O II]. Our 2.1 m spectrum of the same object (see RS) detects Mg II, [O II] and [Ne V] emission as well as Ca II H and K in absorption, confirming this redshift.

3. ANALYSIS

The new redshift information in Lawrence et al. (1996) and RS added to the SFK data yields the following redshift statistics for the 37 member 1 Jy sample: 23 objects with firm redshifts, five objects with tentative redshifts, four objects with only lower bounds on redshift due to the presence of Mg II absorption, and five objects with only featureless spectra to date. Of the objects with firm or tentative redshifts only 16 contribute to the redshift path in which Mg II absorptions could be found because 12 1 Jy BL Lac objects are at $z < 0.4$. Four other 1 Jy BL Lac objects (0820+225, 1144−379, 1519−273, and 2150+173) have not been well enough observed to support a limiting equivalent width (W_λ) of less than several angstroms and so do not contribute to the observed Mg II path length either. Thus, a total of 21 of the 37 1 Jy BL Lac sample contribute to the Mg II absorption path length.

Table 1 lists the known Mg II systems in the 1 Jy sample, including 10 systems total in nine different objects with five systems at $W_\lambda > 1$ Å. It is noteworthy that nearly half (four of nine) of the well-observed 1 Jy BL Lac objects without observable emission lines possess Mg II absorbers. Table 1 includes the well-known absorption system in AO 0235+164 at $z = 0.524$ (Wolfe & Wills 1977; Wolfe et al. 1978) and the foreground Mg II absorber due to the lensing galaxy in the "Smallest Einstein Ring" source B0218+357 (Browne et al. 1993).

The absorption data in Table 1 can be used to compute a Mg II line density based upon the total Mg II path length observed in the entire 1 Jy sample. As mentioned above, 21 of the full 37 objects contribute to the redshift path, and most (15), but not all, of these have firm redshift information. For those few without firm redshifts, we have estimated "best redshifts" on the basis of (1) a single emission-line detection (e.g., from SFK or RS) and (2) extended radio source angular size and luminosity (RS; Murphy et al. 1993; Antonucci & Ulvestad 1985). In addition, for these same sources we set firm upper and lower bounds to the redshifts using (1) the Mg II absorbers; (2) the absence of "host galaxy" in optical images (SFK) setting $z_{min} = 0.2$; and (3) the absence of "Lyα forest" absorption in

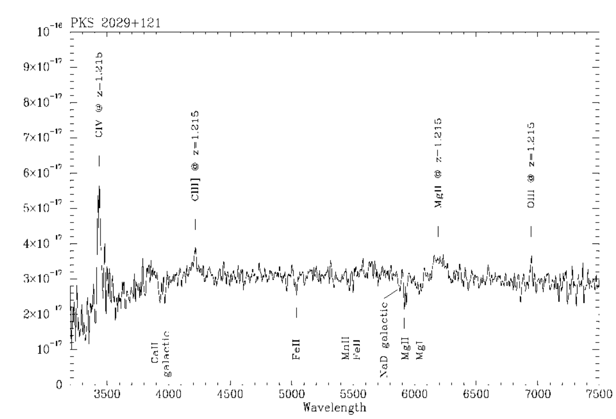

FIG. 2.—MMTO spectrum of PKS 2029+121 showing the C IV, C III] and Mg II emission at $z = 1.215$, Mg I, Mg II doublet, Mn II λ2606, Fe II λ2600, and Fe II λ2382 at $z_{abs} = 1.117$ and Galactic Na I "D" and Ca II H and K absorption.

TABLE 1
Mg II ABSORPTION SYSTEMS IN 1 Jy BL LACERTAE OBJECTS

Object	z_{em}	z_{abs}	W_λ (2796 Å) (Rest Frame)	Reference
0118−272	...	0.559	0.8	1
0138−097	0.733	0.500	0.3	2
0218+357	0.94:	0.685	1.8	3
0235+164	0.94	0.852	0.4	4
		0.524	2.4	
0426−380	...	1.030	1–1.3	5
0454+844	...	1.340	0.4	2
0735+178	...	0.424	1.1	6
1308+326	0.996	0.879	0.4	7
2029+121	1.215	1.117	1.5	2

REFERENCES.—(1) Falomo 1991; (2) this Letter; (3) Browne et al. 1993; (4) Wolfe & Wills 1977; (5) SFK; (6) Carswell et al. 1974; (7) Briggs & Wolfe 1983.

IUE spectra of three objects, setting $z_{max} = 1.0$ (Lanzetta, Turnshek, & Sandoval 1993). In the four objects lacking *IUE* spectra z_{max} was set by the wavelength range of the available spectra.

None of these spectra were obtained with the specific purpose of detecting absorption lines but rather broad, low-contrast emission lines so that moderate resolution spectroscopy (6–18 Å) was employed. Therefore, only large W_λ Mg II absorption could have been detected over the entire Mg II path length for a typical BL Lac spectrum (e.g., those in SFK). For example, the spectrum from SFK in which the Mg II absorber in 0426−380 was discovered finds a total observed W_λ of ∼4 Å yielding a rest-frame W_λ of 1–1.3 Å for the blue component alone (depending on doublet ratio). Since there are other possible absorptions in the SFK spectrum of 0426−380 at nearly the same W_λ, a rest-frame W_λ limit close to 1 Å is indicated. Some spectra have considerably lower W_λ limits than this one (e.g., those reobserved by Lawrence et al. 1996 or RS because previous spectra had no detectable emission or absorption features), but others are quite comparable, so that a 1 Å limit is the best that can be claimed for the sample. Indeed, this limit may be even overly optimistic for some of the spectra.

With these points in mind, the total path length for Mg II absorption in the 1 Jy sample is 8.1 unit redshifts with a firm lower bound of 6.8 and maximum value of 11.6. Using the number of Mg II absorbers with $W_\lambda > 1$ Å in Table 1, the number density per unit redshift in the 1 Jy sample is $dN/dz = 0.62 \pm 0.30$, where the uncertainty is the quadratic sum of the uncertainty in the path length and the sampling statistics.

We compare the above value to the results of the large Mg II absorption line survey of Steidel & Sargent (1992), who observed 103 quasars and detected 111 Mg II systems, with 36 having $W_\lambda > 1$ Å. The best-fit evolution model for the greater than 1 Å sample of Steidel & Sargent (1992) is $N(z) = (1 + z)^{2.24}$, with a mean redshift for these absorbers at $z = 1.31$. Thus, the $W_\lambda > 1$ Å absorbers are mostly detected at higher redshift than the emission-line redshift for all of the 1 Jy BL Lac objects. Weighting the number expected at each redshift by the observed path length of the 1 Jy sample we find an expectation value for the number density of Mg II absorbers in the 1 Jy sample of $dN/dz = 0.14$ systems per unit redshift. Thus, the observed number of high W_λ Mg II system is a factor of 4–5 times greater than the number expected based upon quasar sight lines, although the uncertainty is large owing to the sampling statistics. Because we have found five BL Lac objects out of 21 with observed Mg II absorption where only 1 was expected, the binomial probability of this occurrence is 0.4% (i.e., 3 σ). If the maximum observed path length of 11.6 is used the probability increases to 1.5% (2.5 σ).

4. DISCUSSION

The only previous mention of the possibility of an excess of Mg II absorbers in BL Lac objects is a brief comment in Weymann, Carswell, & Smith (1981) that J. Miller (1997, private communication) "...found Mg II absorption in what appeared to be an unusually high percentage of such objects." We confirm Miller's observation with the present statistics based only on the high W_λ absorbers in the 1 Jy. But as seen in Table 1, there are a number of lower W_λ absorbers already found in the 1 Jy despite the absence of a concerted effort to find them. This excess could have one of two possible causes:

1. Since four of the 10 systems occur in objects lacking emission-line redshifts, these Mg II systems could be intrinsic to the BL Lac. Aldcroft, Bechtold, & Elvis (1994) have reported an excess of large W_λ "associated" Mg II absorbers in radio-loud quasars. If these four absorbers are associated, this could reduce the excess quoted above but not eliminate it entirely since three of the five $W_\lambda > 1$ Å systems are clearly foreground to the BL Lac. Therefore, associated absorbers plus small number statistics could account for the excess. However, this idea does not explain the correlation between very featureless spectra and Mg II absorbers. Nor does the 1 Jy sample contain a single confirmed associated absorber (i.e., $z_{em} \approx z_{abs}$).

2. For some reason there is a correlation between the presence of a Mg II absorber along the sight line with a background source whose characteristics are those of a BL Lac object (i.e., a radio-loud AGN with a featureless or nearly featureless optical spectrum). This possibility fits under the general hypothesis proposed a few years ago by Ostriker & Vietri (1986, hereafter OV) in which the characteristics of a BL Lac object are created by the microlensing effect. OV required the background AGN to be an optically violently variable quasar in order to understand all the most extreme characteristics of BL Lac objects. But the current statistics do not require all BL Lac objects to be microlensed, only those that show the large W_λ Mg II absorbers (although the list in Table 1 is certainly not complete since the entire path length foreground to all BL Lac objects has not been observed).

We are aware that there are ample observations (e.g., host galaxies, extended radio powers, optical spectra) that strongly support the beamed FR 1 hypothesis for low-*z* BL Lac objects, objects that do not contribute to the Mg II path length. It is the high-*z* ($z > 0.5$) BL Lac objects that are most discrepant in their properties, many of which have higher radio power levels than FR 1's and weak, quasar-like emission lines in their optical spectra (e.g., see Fig. 2); suggesting that many high-*z* BL Lac objects may belong to an intrinsically different population (or populations). This issue will be discussed in detail in RS.

Two of the BL Lac objects in Table 1 have already been suggested as gravitationally lensed sources. The case for 0218+357 is clearly made in Patnaik et al. (1993) and Browne et al. (1993). The case of AO 0235+164 is more problematical since there is no obvious second image and the extended radio structure is too faint for its morphology to be determined. But the variable foreground H I absorption is difficult to understand without some gravitational microlensing (Wolfe et al. 1978; Wolfe, Davis, & Briggs 1982). Abraham et al. (1993) have used high-resolution ground-based imaging to place stringent limits on the presence of any second image and use these limits to argue against the microlensing hypothesis since, by their estimation, any significant microlensing must be accompanied by macrolensing that would produce an observable second image (Merrifield 1992). However, Narayan & Schneider (1990) pointed out that these constraints are relaxed if the foreground galaxy has low surface mass density. A test of the microlensing hypothesis for BL Lac objects in Table 1 would involve the identification of the Mg II absorber galaxy as a low surface brightness galaxy like a late-type spiral or irregular. This type of galaxy is quite different from the types of galaxies found by Steidel (1995) to be the Mg II absorbers (i.e., $L > 0.1L^*$ normal galaxies) in his quasar sample.

In this proposed scenario, BL Lac objects with foreground Mg II absorbers are microlensed by stars associated with the absorbing gas. The background AGN is a radio-loud quasar with normal emission-line properties but the action of the foreground stellar screen is to preferentially amplify the continuum emission region relative to the broad-line region, creating an optical spectrum like that in Figure 3. Microlensing also explains the correlation between the presence of the Mg II absorber and the very featureless BL Lac spectra.

If this hypothesis is correct, the largest unanswered question is why AGNs with "featureless" spectra are always radio loud (Stocke et al. 1990). Also, if this hypothesis is correct, conclusions concerning BL Lac objects that have relied upon complete 1 Jy sample properties must be reevaluated (e.g., Urry & Padovani 1995).

Finally, we note the great similarity between the BL Lac spectrum of PKS 0138−097 shown in Figure 3 and the optical spectrum of the γ-ray burst source GRB 970508 recently obtained by Metzger et al. (1997). This similarity and the abundance of BL Lac objects amongst known, bright γ-ray sources suggests that the transient gravitational microlensing of AGNs could account for γ-ray bursters. If γ-ray bursts are lensed AGNs, this would greatly reduce the intrinsic energy requirements of the γ-ray bursts through both relativistic beaming and gravitational lensing.

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