AN FeLoBAL BINARY QUASAR[1]

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ABSTRACT

In an ongoing infrared imaging survey of quasars at the Keck Observatory, we have discovered that the $z = 1.285$ quasar SDSS J233646.2−010732.6 comprises two point sources with a separation of $1''.67$. Resolved spectra show that one component is a standard quasar with a blue continuum and broad emission lines; the other is a broad absorption line (BAL) quasar, specifically, a BAL QSO with prominent absorption from Mg II and metastable Fe II, making it a member of the "FeLoBAL" class. The number of known FeLoBALs has recently grown dramatically from a single example to more than a dozen, including a gravitationally lensed example and the binary member presented here, suggesting that this formerly rare object may be fairly common. Additionally, the presence of this BAL quasar in a relatively small separation binary adds to the growing evidence that the BAL phenomenon is not due to viewing a normal quasar at a specific orientation but rather that it is an evolutionary phase in the life of many, if not all, quasars and is particularly associated with conditions found in interacting systems.

Subject headings: galaxies: interactions — quasars: absorption lines — quasars: general

1. INTRODUCTION

The current tally of gravitationally lensed quasars now stands at nearly 70.[8] The various searches that have contributed to this total have naturally also discovered examples of the apparently rarer phenomenon of binary quasars, of which only ∼20 systems have been documented (Mortlock, Webster, & Francis 1999; see also footnote 8). While the gravitationally lensed quasars have been intensively studied, binary quasars have not received nearly as much attention, even though binary quasars may provide invaluable insight into various aspects of the quasar phenomenon. Of particular importance are the cases in which the pair members exhibit strikingly different characteristics, perhaps making it possible to deduce what aspects of the active galactic nucleus (AGN) environment are responsible for presently little-understood quasar behavior such as radio loudness, broad or narrow absorption lines, or very red colors. In addition, physically close binaries also supply limits, statistically at least, on the timescales involved because once within approximately one galaxy radius (∼10 kpc), dynamical considerations limit the binary lifetimes (Mortlock et al. 1999).

In an ongoing infrared imaging survey of quasars at the Keck Observatory, we have discovered that SDSS J233646.2−010732.6 (hereafter SDSS 2336−0107) is a double with a separation of $1''.67$. Resolved spectra show that component A is a standard quasar with a blue continuum and broad emission lines. Component B is a broad absorption line (BAL) quasar, specifically, a BAL QSO with prominent absorption from Mg II and metastable Fe II, making it a member of the "FeLoBAL" class (Becker et al. 1997, 2000). The number of known FeLoBALs has increased dramatically in the last 5 years (Becker et al. 2000; Menou et al. 2001; Hall et al. 2002), including a gravitationally lensed example (Lacy et al. 2002) and the binary discussed here, suggesting that this type of object, once thought to be rare, may in fact be fairly common and simply overlooked in most quasar surveys. The presence of this BAL quasar in a relatively small separation binary adds to the mounting evidence that the BAL phenomenon is not simply due to viewing a normal quasar at a specific orientation but rather that it is an evolutionary phase in the life of many, if not all, quasars and is associated with conditions found in interacting systems. We adopt $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$.

2. OBSERVATIONS

SDSS 2336−0107 was first identified by the Sloan Digital Sky Survey (SDSS; York et al. 2000) using an early version of the quasar target selection algorithm (Richards et al. 2002) as a quasar with $z = 1.285$ and having modest broad absorption features (Schneider et al. 2002). It was also earmarked as an "extended" quasar in the SDSS images, meaning that it was slightly resolved. Quasars at $z \gtrsim 0.6$ are unresolved in SDSS images, so the extended nature made it a target in our imaging survey for lensed quasars at Keck Observatory.

2.1. *Infrared Imaging*

On 2001 October 30, we obtained deep imaging of SDSS 2336−0107, totaling 350 s in the K' band using the Near Infrared Camera (NIRC; Matthews & Soifer 1994) on the Keck I 10 m telescope in $0''.6$ seeing. The image scale is $0''.15$ pixel^{-1}. The reduced image reveals the double nature of SDSS 2336−0107 (Fig. 1) and three galaxies (g1, g2, and g3) in the field. Photometry of the two components was measured with DAO-

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[8] See http://cfa-www.harvard.edu/castles (C. S. Kochanek, E. E. Falco, C. Impey, J. Lehar, B. McLeod, & H.-W. Rix).
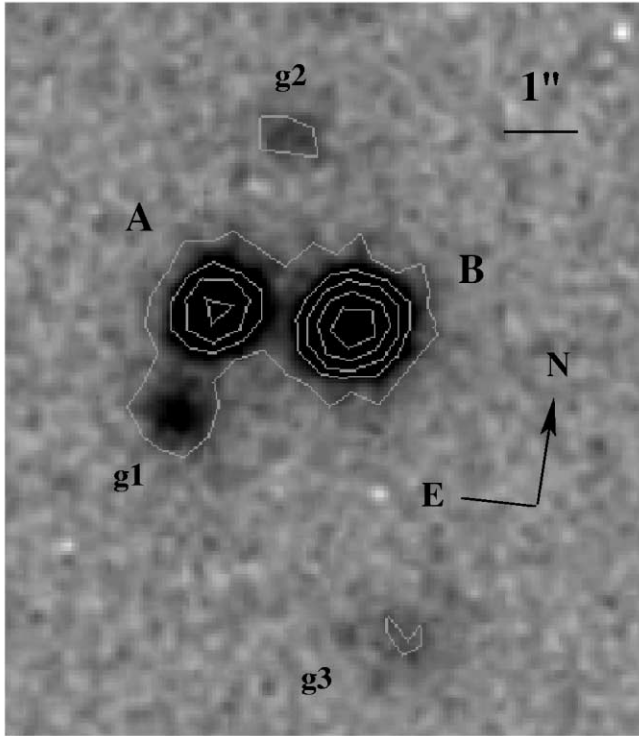
FIG. 1.—Keck NIRC K' image of SDSS 2336−0107, obtained in seeing of 0″.6; total exposure is 350 s. Components A and B are separated by 1″.67. Component B is 1.0 mag brighter than component A at 2 μm. The excess light between galaxy g1 and component A may indicate a physical connection.

PHOT/IRAF,[9] using a bright standard star as a point-spread function (PSF) model. The short-exposure standard star PSF clearly differed from the PSF of the longer exposure, dithered images of the binary quasar, so we also used component B as a PSF model, even though the wings of the PSF cannot be determined easily in this way. In both cases, the residuals after subtraction suggest that the shapes of the two components are not quite identical and that there is extended diffuse light at K' around component A, perhaps indicating that the data are just beginning to detect the host galaxies of one or both. The separation of the two components is determined to be 1″.673 in K' and 1″.681 in J.

2.2. Optical Imaging

The SDSS images were obtained in relatively poor seeing, ranging from 2″.5 in u^* to 1″.6 in r^*. Despite the seeing, the images prove adequate for photometry of the two components

using DAOPHOT/IRAF, a nearby bright star serving as the PSF model and photometric zero point. In $g^*r^*i^*z^*$, the PSF fits yield relatively small photometric errors; the separations range from 1″.5 to 1″.7, averaging 1″.623 ± 0″.074, which is consistent with a fraction of an SDSS pixel (0″.396) with the separation measured in the NIRC images, lending credibility to the extracted photometry. The redder component B is not reliably detected in u^*, but an upper limited is derived from the residuals after subtracting a single PSF at the location of component A. Table 1 lists the optical and IR photometry, corrected for Galactic reddening (Schlegel, Finkbeiner, & Davis 1998).

2.3. Echelle Spectroscopy

We obtained resolved spectra of the two components of SDSS 2336−0107 in 2002 January, using the Echelle Spectrograph and Imager (ESI; Epps & Miller 1998) on the Keck II telescope. The seeing was again 0″.6. The ESI has a dispersion of 0.15–0.3 Å pixel^{-1} over a wavelength range of 4000–10500 Å, and the 1″ slit used for these observations projects to 6.5 pixels. The 900 s exposure was obtained at an air mass of 1.33, with the slit aligned at the position angle of the components, 95°.8. The spectra show that component A is a standard quasar with broad emission lines while component B is found to be a BAL quasar, totally lacking any emission features (Fig. 2). The shape of the overall spectral energy distributions has been corrected to agree with the photometry from the SDSS images.

The redshift of component A is $z = 1.2853$ from Mg II and 1.287 from C III]; since C III] can be contaminated by Fe III, Si III], and Al III emission, we adopt the Mg II redshift. The redshift of component B is difficult to measure accurately because of the lack of emission features and the broad nature of the absorption. If we assume that the absorption feature at 6418.8 Å, which is somewhat broad and flat-bottomed, is due to the red half the Mg II doublet at 2803.5 Å, the redshift is 1.2895 Å. There is also a narrow absorption line at 6525.0 Å that, ascribed to Mg I λ2853.0, gives $z = 1.2871$, which is consistent with and perhaps more accurate than the Mg II estimate. Adopting this as the redshift of component B yields an apparent velocity difference between A and B of only ∼240 km s^{-1}. Component B also has absorption features consistent with Ca H and K at a redshift of 1.2843 (Fig. 2).

The ESI spectrum of component A reveals a Mg II–Fe II intervening absorption system at $z = 0.8041$, perhaps due to one of the faint galaxies that appear in the K'-band image (Fig. 1). There is also absorption from what may be Si I λ2515 and Ca I λ2722. The brighter galaxy (g1) is 1″.25 to the east of component A while the fainter (g2) is 2″.30 to the west, corresponding to physical impact parameters of 9.4 and 17.4 kpc, respectively.

Also weakly detected in the spectrum of component A is [O II] in emission at a wavelength corresponding to $z = 1.2882$ (Fig. 2), within 400 km s^{-1} of the emission features.

TABLE 1
BINARY QUASAR DETAILS

Component	α (J2000)	δ	Galactic A_V	z	u^*	g^*	r^*	i^*	z^*	J[a]	K[a]	M_{r^*}[b]
A	23 36 46.2	−01 07 32.6	0.114	1.2853	19.75	19.65	19.35	19.26	19.12	18.19	17.22	−23.77
B	23 36 45.1	−01 07 32.4	0.114	1.2871	>22.2	21.37	19.71	18.94	18.68	17.24	16.23	−24.72

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
[a] J and K photometry have been corrected to the AB magnitude system using zero-point offsets of 0.908 and 1.842 mag, respectively, determined from a model of Vega.
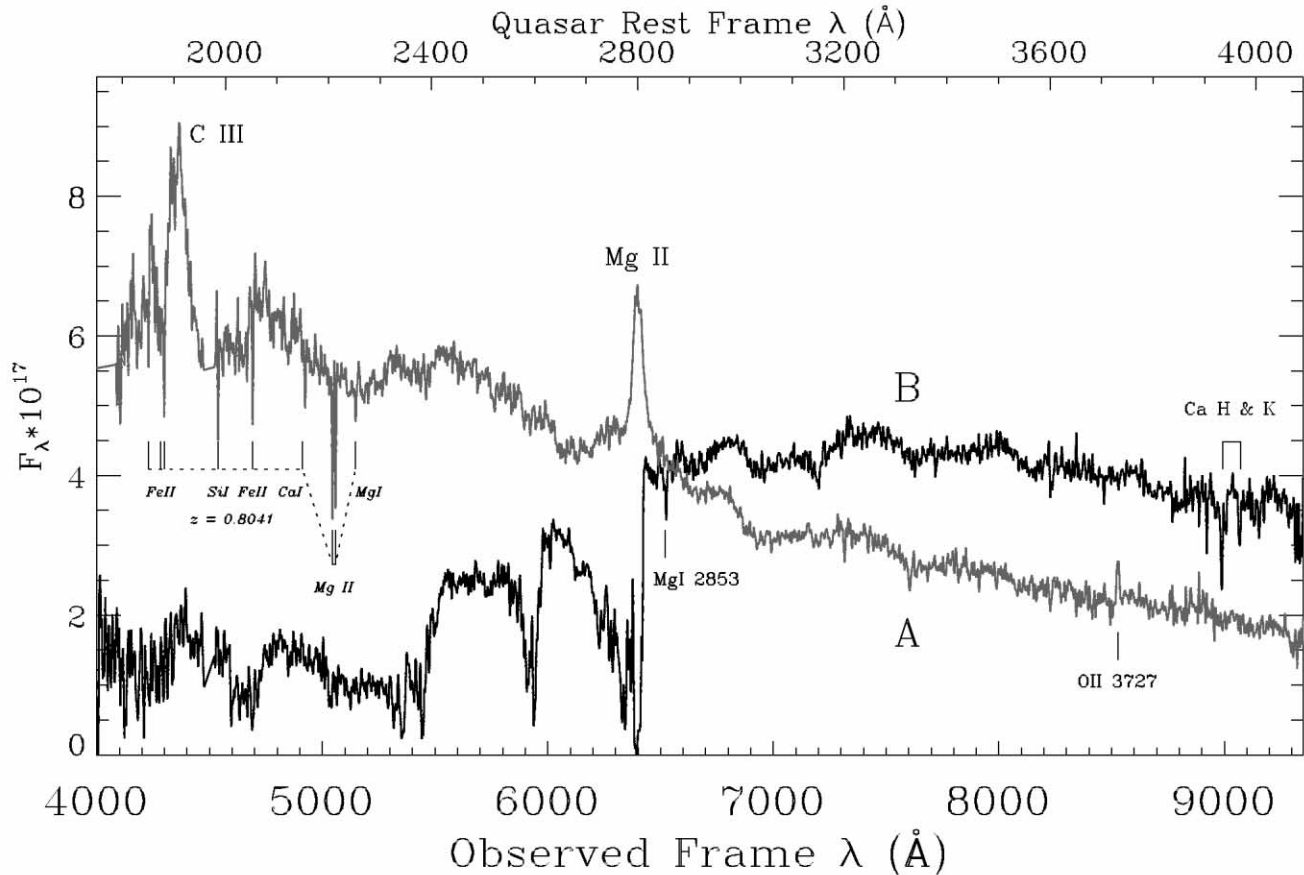[b] Computed in quasar rest frame.

Fig. 2.—Keck ESI spectra of the two components of SDSS 2336−0107 showing the striking difference in spectral appearance; component A is a typical quasar with broad emission lines and a blue continuum, while component B exhibits no emission lines whatsoever and has a relatively red spectral energy distribution.

This feature is in a region between bright sky lines and also appears on a shorter ESI exposure of SDSS 2336−0107 taken two nights previous to the data presented here, so its reality is beyond doubt. Although noisy, the [O II] feature does appear to be broadened by a few hundred kilometers per second, well in excess of the instrumental resolution.

3. DISCUSSION

Combining the redshifts with the SDSS and NIRC photometry, the absolute magnitudes of the two components can be computed in the quasar rest frame as $M_{r*}^A = -23.77$ and $M_{r*}^B = -24.72$. While not exceptionally bright, both components are luminous enough to qualify as bona fide quasars. The possibility that SDSS 2336−0107 is gravitationally lensed is immediately ruled out by the strikingly different spectra (Fig. 2) and the short time delay between the two paths. The analytic formula of Witt, Mao, & Keeton (2000) yields time delay estimates of a few months to a year for any reasonable lensing geometry. The nearly identical redshifts and tiny velocity difference, however, make it a definite binary quasar. For our adopted cosmology, the apparent separation of 1″67 translates to a physical separation of ~13.9 kpc, making SDSS 2336−0107 the smallest separation binary ever found in ground-based imaging and the second small-est ever. The smallest is LBQS 0103−2753 (Junkkarinen et al. 2001), a 0″3 (2.3 kpc) separation binary found serendipitously during an ultraviolet spectroscopy survey of BAL systems using the *Hubble Space Telescope* and the Space Telescope Imaging

Spectrograph. In LBQS 0103−2753, the brighter component is a standard high-ionization BAL quasar.

3.1. *Implications for the BAL Phenomenon*

The two binary quasars with the smallest physical separa-tions both contain a BAL member. Although this could be simply small number statistics, it is natural to speculate that the BAL features are somehow induced by the small distances between the AGN. Mass transfer onto one of the black holes would naturally result in a tidally interacting pair of galaxies where the AGNs had reached relatively small separations of less than a galactic radius. This is further evidence supporting the view that BAL features are a short-lived evolutionary phase during the life of a quasar (Becker et al. 2000; Gregg et al. 2000) rather than the result of viewing an AGN along a par-ticular line of sight. Additional support for this argument comes from Canalizo & Stockton (2001), who show that all four of the known low-ionization BAL (LoBAL) quasars with $z <$ 0.4 are in systems that exhibit tidal tails or evidence of merging, suggesting a strong link between these phenomena and the presence of BAL spectral features. The orientation picture can-not so easily account for the occurrence of BAL features in the two smallest separation binary quasars or all four low-redshift LoBAL examples, except as by chance.

If the merger/accretion origin of BALs is correct, the material directly responsible for the BAL spectral features is almost cer-tainly within tens of parsecs of the AGN and not within reach
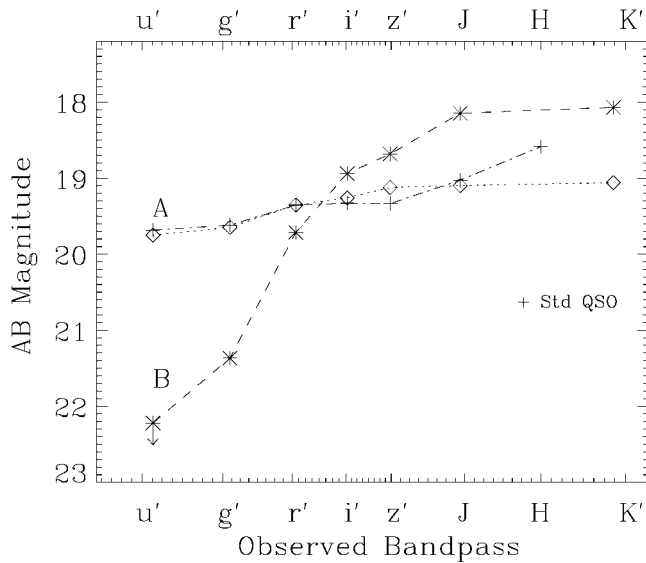
Fig. 3.—Comparative photometry of the two components showing the similarity of component A (*open diamonds, dotted line*) to a typical quasar as represented by the SDSS composite spectrum (*plus signs, dash-dotted line*) and highlighting the red spectral energy distribution of component B (*asterisks, dashed line*). The $u^*g^*r^*i^*z^*$ photometry was measured from the SDSS image of this field using PSF fitting in DAOPHOT/IRAF. The J and K' photometry from Keck/NIRC has been shifted to the AB system using constants of 0.908 and 1.842 mag, respectively.

of ground-based imaging resolution, yet mergers and tidal debris will occur over kiloparsec scales. It is then somewhat counterintuitive that it is the standard quasar component (A) of SDSS J2336−0107 that is sandwiched by the galaxies g1 and g2 in the NIRC image (Fig. 1) and that exhibits the narrow [O II] in its spectrum (Fig. 2). The K' image hints at a light bridge between g1 and component A, perhaps a real physical connection. The weak [O II] feature of component A is certainly consistent with this picture, indicating some level of star formation, quite expected for an intensely interacting system. Some or all of the [O II] could come from the material in the region between g1 and component A; the 1″ ESI slit would have entirely missed g1, though. The intervening Mg II system in the spectrum of component A (Fig. 2) could arise from g2 at an intervening location; direct spectroscopy of the galaxies in this field is required to sort out the physical relationships. The K' seeing and signal-to-noise ratio are not good enough to explore more fully the region directly between the two components, but space-based imaging would reveal details of the expected tidal interactions that may be driving the BAL behavior. If the two quasars are in the nuclei of two large galaxies separated by only ∼13.9 kpc, tidal effects should be strongly pronounced.

3.2. *Implications for the FeLoBAL Population*

Figure 3 plots the photometry of the two components, u^* through K', highlighting the contrasting color difference. Component B, the BAL, is in fact brighter in the redder bands, by ∼1 mag in J and K'. For comparison, we plot photometry synthesized from the SDSS quasar composite (Vanden Berk et al. 2001) after redshifting to $z = 1.2855$. The synthetic magnitudes have been adjusted so that r^* equals that of component A. The excess flux in H in the composite may be due to the contribution from the host starlight in the low-redshift quasar spectra that contribute to the composite in this wavelength region. The even larger excess in the BAL component is prob-
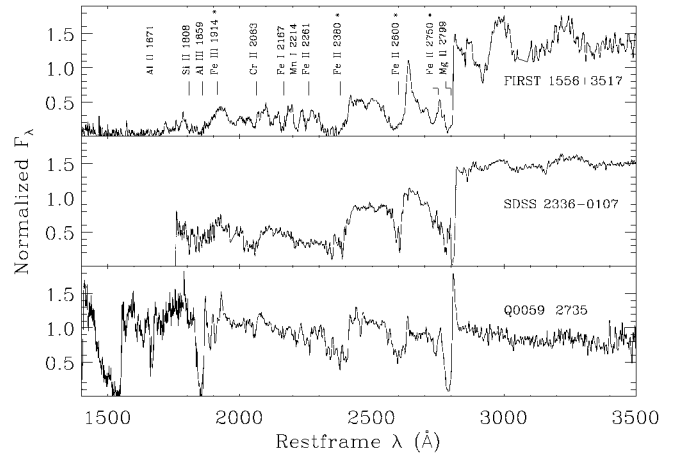

Fig. 4.—Spectrum of the FeLoBAL member of SDSS 2336−0107 (component B) compared with FIRST J1556+3517 and Q0059−2735. Locations of prominent absorption features are marked; an asterisk indicates a metastable transition.

ably a combination of starlight and "back warming" from dust extinction. There is evidence that FeLoBALs are heavily reddened (Hall et al. 1997; Najita, Dey, & Brotherton 2000) and may be associated with young galaxies and star formation (Egami et al. 1996).

Perhaps the most intriguing finding is that component B is an FeLoBAL, a quasar with low-ionization broad absorption from Mg II plus broad and narrow absorption from metastable states of Fe II. In Figure 4, the spectrum of component B is compared with two other FeLoBALs, J1556+3517 (Becker et al. 1997) and the original of the class, Q0059−2735 (Hazard et al. 1987). The spectrum of SDSS 2336−0107 B exhibits strong Fe II at 2380, 2600, and 2750 Å. The broad Mg II absorption depresses the spectrum blueward to at least 2630 Å, or −18,000 km s^{-1} in the quasar rest frame. While not quite as red as J1556+3517, SDSS 2336−0107 B has essentially no emission lines whatsoever.

There is now one FeLoBAL quasar (SDSS 2336−0107) known among the 15 binary QSO systems and one FeLoBAL (J1004+1229; Lacy et al. 2002) among the ∼70 known gravitationally lensed quasars. These statistics argue strongly that FeLoBALs must be much more common than their presently cataloged population suggests. Lacy et al. (2002) discuss the details of red quasar luminosity functions and lensing probabilities, but not with regard to FeLoBALs in particular. With one FeLoBAL in ∼70 lensed quasars and one among 40 quasars in ∼20 binary systems, the simplest explanation is that from 1% to a few percent of quasars are FeLoBALs or, alternatively, that the FeLoBALs phase lasts for a similar percentage of the total quasar lifetime. The very red spectral energy distribution and the weak or completely absent broad emission lines (Fig. 1) make these objects extremely difficult to find, especially at redshifts ≳2.5, where the Mg II absorption edge moves into the J band. An IR-selected sample of quasars is needed to better gauge the frequency of FeLoBAL numbers, but evidence is mounting (Becker et al. 1997; Lacy et al. 2002; Hall et al. 2002) that they are much more common than suspected even just a few years ago when the rather blue example of Q0059−2735 was the only one known (Hazard et al. 1987).

4. CONCLUSIONS

A deep imaging survey of BAL quasars and a control sample of non-BAL quasars, from the ground or space, is needed to

document the frequency of each in systems that show tidal interactions, which would be a more comprehensive version of the work done by Canalizo & Stockton (2001). If BAL-ness is explained simply by viewing an ordinary quasar along a line of sight that skims the "dusty torus" (Weymann et al. 1991), then the two populations should appear with equal frequency in merging or interacting systems. If BAL features are produced by conditions created in mergers, and if orientation plays less or no role, then they will be more common in chaotic systems with tidal tails and other signs of host galaxy interactions. Dynamical modeling of the tidal effects may help constrain the timescales of various quasar phases.

FeLoBALs may be a common feature of the AGN landscape, especially if there are Seyfert-type luminosity class analogs to the brighter objects now being unearthed. If FeLoBALs are indeed common, then infrared sky surveys that reach deeper than the Two Micron All Sky Survey (2MASS), such as those being undertaken with *SIRTF*, will turn up numerous examples along with other extreme BAL phenomena in quasar and galaxy luminosity objects. The FeLoBAL-like Hawaii 167 (Cowie et al. 1994) was discovered in just such a survey. Such surveys are needed to provide more accurate estimates of the extremely red quasar population, especially at redshifts above 2.5 where such objects are essentially invisible in the optical.

[10] The SDSS Web site is http://www.sdss.org.

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