Extreme BAL Quasars from the Sloan Digital Sky Survey

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**Abstract.** The Sloan Digital Sky Survey has discovered a population of broad absorption line quasars with various extreme properties. Many show absorption from metastable states of Fe II with varying excitations; several objects are almost completely absorbed bluewards of Mg II; at
least one shows stronger absorption from Fe\textsuperscript{II\*} than Fe\textsuperscript{II}, indicating temperatures $T > 35000$ K in the absorbing region; and one object even seems to have broad H\textbeta absorption. Many of these extreme BALs are also heavily reddened, though 'normal' BALs (particularly LoBALs) from SDSS also show evidence for internal reddening.

1. Introduction

The Sloan Digital Sky Survey (York et al. 2000) is using dedicated instruments on a 2.5m telescope (Gunn et al. 1998) to image $10^4$ deg$^2$ of sky to $\sim 23$\,m in five bands (Fukugita et al. 1996) and obtain spectra of $\sim 10^5$ galaxies and $\sim 10^5$ quasars selected primarily as outliers from the stellar locus. Its area, depth, and selection criteria make SDSS effective at finding unusual quasars. The first data release (Stoughton et al. 2001, in prep.), contains $\sim 4500$ spectroscopically confirmed quasars, including $\sim 200$ BALs, a few percent of which have extreme properties of one sort or another. All these extreme BALs are LoBALs, which show absorption from both low- and high-ionization transitions, instead of the more common HiBALs with only high-ionization absorption. Full analysis is underway (Hall et al. 2001, in prep.), but already these objects confirm the existence of a population of extreme BALs, as suspected from previous discoveries of individual extreme BALs (Becker et al. 1997, Djorgovski et al. 2001).

2. BAL Quasars With Fe\textsuperscript{II\*} Absorption

The rare LoBAL quasars with absorption from metastable excited states of Fe\textsuperscript{II} (Fe\textsuperscript{II\*}) have been dubbed FeLoBALs (Becker et al. 2000; Hazard et al. 1987; Menou et al. 2001). They are valuable because photoionization modelling of them can constrain $n_e$ in the BAL clouds (e.g. de Kool et al. 2001). Fig. 1a shows a spectacular example, SDSS 1723+5553, with absorption
from over twenty transitions in at least a dozen elements. Fig. 1b compares SDSS 1723+5553 to two lower-z FeLoBALs with [O\textsc{ii}] emission line redshifts. Both low-z objects show Fe\textsc{ii}\* absorption blueward of 2414Å and 2632Å from states up to \(\sim\)1 eV above ground, but SDSS 1125+0029 also shows absorption near 2500 Å from even more excited levels. In both low-z objects, the Mg\textsc{ii} BAL absorption apparently extends 2000 km s\(^{-1}\) redward of the systemic \(z\).

Some SDSS FeLoBALs show very abrupt drops in flux near Mg\textsc{ii} \(\lambda\lambda 2796,2803\) (e.g. SDSS 0300+0048 in Fig. 2a). SDSS 0300+0048 has associated Mg\textsc{ii} absorption at \(z=0.8916\), at least 4 narrow Ca\textsc{ii} H\&K absorption systems located 2350 to 3900 km s\(^{-1}\) blueward of the Mg\textsc{ii} system, and broad Ca\textsc{ii} absorption extending a further 2000 km s\(^{-1}\) blueward. Broad, near-total Mg\textsc{ii} absorption is associated with the highest-z Ca\textsc{ii} system, but broad Fe\textsc{ii}\* absorption is associated instead with the strongest Ca\textsc{ii} system, at slightly lower \(z\). Fig. 2b shows SDSS 1730+5850, which is clearly a higher redshift analogue of SDSS 0300+0048. Our spectrum extends farther into the UV for this \(z\approx2\) object, and shows a weak recovery at C\textsc{iii}\(\lambda\lambda 1908\) but essentially zero flux below Al\textsc{iii}\(\lambda\lambda 1670\). Quasars such as these at \(z \geq 2\) will obviously be greatly underrepresented in optical surveys.

3. BAL Quasars With Fe\textsc{iii} Absorption

Fig. 3 shows SDSS 2215–0045, a LoBAL at \(z=1.47548\) (measured from associated Mg\textsc{ii} absorption, as with SDSS 0300+0048). Its absorption troughs are unusual for a LoBAL: they are very broad, detached, and strongest near the high velocity end rather than at low velocity. By comparison to SDSS 1723+5553 (Fig. 1), we initially identified the strong trough at \(\lambda_{\text{obs}}\approx4900\) Å as C\textsc{iii}h. However, the implied abundance of C\textsc{r} relative to Mg is implausible, and the expected corresponding Zn\textsc{ii} is missing. We now believe this absorption is due to Fe\textsc{iii} (multiplet UV 48), with additional Fe\textsc{iii} (UV 34) absorption at \(\lambda_{\text{obs}}\approx4500\) Å, redward of Al\textsc{iii}. Since Fe\textsc{ii} absorption is weak or absent, the large Fe\textsc{iii}/Fe\textsc{ii} ratio suggests that the BAL clouds in this object have \(T>35000\) K, sufficient to collisionally ionize Fe\textsc{i} to Fe\textsc{iii}. Fe\textsc{iii} absorption is seen in several other SDSS LoBALs (e.g. Fig. 4) and in a few previously known LoBALs, but nowhere as strongly (alone or relative to Fe\textsc{ii}) as in SDSS 2215–0045. Note the different
spectral slopes blueward & redward of ~2400 Å, indicating reddening which must occur outside the BAL region since dust cannot survive long at $T > 35000$ K.

4. **A LoBAL With Broad Hβ Absorption**

Fig. 4 shows an optical (Keck) plus NIR (UKIRT) spectrum of SDSS 0437-0045 which reveals a strongly absorbed quasar with $z = 2.74389$ from [O III]. The absorption extends 2900 km s$^{-1}$ redward of this $z$ (cf. Fig. 2b). Even more remarkable is the probable presence of Hβ absorption nearly $10^4$ km s$^{-1}$ wide and of REW~100 Å. Hβ absorption in AGN has previously been seen only in NGC 4151 (Anderson & Kraft 1969; Sergeev et al. 1999), but with $\leq 1000$ km s$^{-1}$ width and $\leq 3$ Å REW. This object is also unusual because the Fe II trough at ~2070 Å has been seen to vary with nearly unprecedented amplitude and speed.

5. **Heavily Reddened BAL Quasars**

SDSS has found evidence for a population of red quasars (Richards et al. 2001), and BALs in general are redder than the typical quasar (Menou et al. 2001), but for the most extreme objects the reddening is unambiguous. Fig. 5 shows SDSS 1456+0114, an extremely reddened LoBAL (and FIRST source) at $z = 2.367$ (measured from weak C IV, the only broad line visible). Several other similar objects have been found by SDSS, but with even weaker broad emission. Since
Figure 4. Optical-NIR spectra of SDSS 0437−0045 at $z=2.74389$. Strong lines are labeled at the expected wavelengths for emission (top) and absorption (bottom). Note the nearly complete absorption near the expected wavelength of C iv, and the probable broad Hβ absorption.

Figure 5. SDSS 1456+0114, an extremely reddened LoBAL at $z=2.367$. 
reddening does not affect equivalent widths, this may indicate that in these objects the broad line region is even more heavily reddened than the continuum. This would be quite plausible if most of the continuum light in those objects is scattered light, a hypothesis which can easily be tested with polarization data.

6. Discussion

‘Well, that was disturbing.’ —Fred Hamann, after this talk at the meeting.

We prefer to view these objects as invigorating. The area and depth of SDSS, plus its simple selection of quasar candidates as outliers from the stellar locus, makes it efficient at finding quasars with unusual properties. Moreover, the discovery of typically several examples of each type of extreme LoBAL quasar presented here means that a population of extreme LoBAL quasars exists and that only now, with SDSS, are we beginning to sample the full range of properties that exist in BAL outflows, and thus around quasars on the whole.

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