VLT Observations of Two Unusual BAL Quasars

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Abstract. Among the unusual broad absorption line quasars being found by the Sloan Digital Sky Survey (SDSS) are objects with much stronger absorption in Fe\textsc{iii} than Fe\textsc{ii}. These unusual line ratios require a high density in the outflow ($n_{\text{H}} \geq 3 \times 10^{10} \text{ cm}^{-3}$). They should also appear for only a limited range of outflow column densities, which explains their rarity. Previously we suggested that the Fe\textsc{iii} line ratios were also affected by a resonance; we now believe this is an artifact of structure in the underlying Fe\textsc{ii}+Fe\textsc{iii} pseudocontinuum. The SDSS is also discovering objects with absorption in rarely seen transitions such as He\textsc{i}. VLT+UVES high-resolution spectra of one such object, the mini-BAL quasar SDSS 1453+0029, show that it has two He\textsc{i} absorption systems with considerably different properties separated by only 350 km s\textsuperscript{−1}.

1. A Luminous Fe\textsc{iii}-dominant BAL Quasar

Broad Absorption Line (BAL) quasars show absorption from gas with blueshifted outflow velocities of typically 0.1c. About 10% of quasars exhibit BAL troughs, usually attributed either to an orientation effect such that all quasars have BAL outflows covering $\sim$10% of the sky, or a phase of $\sim$100% covering lasting $\sim$10% of the typical quasar lifetime. Understanding BAL outflows is necessary since the BAL outflow mass loss rates seem comparable to the accretion rates required to power quasars. Unusual BAL quasars delineate the full range of physical conditions and parameter space spanned by BAL outflows. The Sloan Digital Sky Survey (York et al. 2000; www.sdss.org) has discovered populations of unusual low-ionization broad absorption line quasars (‘LoBALs’), many of them ‘FeLoBALs’ with absorption from excited Fe\textsc{ii} or Fe\textsc{iii} (Hall et al. 2002).

One population of unusual BAL quasars has unprecedented line ratios which are the reverse of those seen in previously known objects; namely, LoBALs with stronger absorption in Al\textsc{iii} than Mg\textsc{ii} and FeLoBALs with weak or no Fe\textsc{ii} absorption but with Fe\textsc{iii} even stronger than Mg\textsc{ii} (Fig. 1a). The CLOUDY modeling of de Kool et al. 2002 (his Figs. 6-7) shows that these ratios can be produced in a high density outflow ($\log n_{\text{H}} \geq 10.5 \text{ cm}^{-3}$ for ionization parameter $U \simeq -2$) with column density $N_{\text{H}}$ in a narrow range ($\sim$0.2 dex) such that a partially ionized zone of Fe\textsc{ii} and Mg\textsc{ii} — typically present in AGN broad emission

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Figure 1. UVES spectra of the Fe\textsc{iii}-dominant BAL quasar SDSS 2215-0045, a) compared with a model for its unabsorbed spectrum, and b) showing various absorption troughs on the same velocity scale.

line regions — does not exist in the BAL outflow along our line of sight, but a Fe\textsc{iii}+Al\textsc{iii} zone does. The high densities and narrow range in $N_H$ required to reproduce the observed line ratios explains why these objects are so rare. The SDSS has recently found a quasar with a narrow Fe\textsc{iii}-dominant absorption system for which high-resolution spectra could test this explanation. Unfortunately, the most luminous Fe\textsc{iii}-dominant BAL quasar known, SDSS 2215-0045, cannot test this model since a VLT+UVES spectrum shows no narrow features. However, the UVES spectrum does reveal that C\textsc{iv} and Si\textsc{iv} emission are as weak as Al\textsc{iii}. This might be due in part to a weak absorption trough at $\sim 4000 \text{ km s}^{-1}$ in addition to the main trough at $\sim 15000 \text{ km s}^{-1}$ (Fig. 1b, blue arrows).

The Fe\textsc{iii} UV48 $\lambda 2080\text{ Å}$ absorption in SDSS 2215-0045 appears stronger than the UV34 $\lambda 1910\text{ Å}$ absorption, which is unphysical. In Hall et al. 2002 this was attributed to a previously unknown resonance populating the lower term of UV48, but we now believe it is due to a complicated underlying continuum. As seen in Fig. 1a, the unabsorbed continuum of 2215-0045 (thin dotted red line) can be estimated as a power law plus Fe\textsc{ii}+Fe\textsc{iii} emission (using the extreme Fe emitter SDSS 0923+5745 as a template), all reddened by $E(B-V)=0.06$. Due to the strong emission at 1800 Å and the lack of emission at 2000 Å, the observed spectrum (heavy line) appears consistent with saturated Fe\textsc{iii} UV48 and UV34 absorption with 35% partial covering. The lower-ionization Mg\textsc{ii} absorption has smaller partial covering, which is typical. The Fe-emission template is not a perfect fit (e.g., 2215-0045 has weaker Mg\textsc{ii} and C\textsc{iii}] emission than the template), but it shows the spectrum can be fit without invoking a new Fe\textsc{iii} resonance.
2. A Reddened Mini-LoBAL Quasar

Traditionally, objects with troughs <2000 km/s wide, or with absorption solely within 3000 km/s of the quasar redshift, have not been classified as BAL quasars. However, numerous studies have shown that both `mini-BALs' and many narrow associated systems also arise in the central regions of AGN. Thus in Hall et al. (2002) we suggested an alternative to the traditional balnicity index which does not discriminate against narrow intrinsic absorbers. The physics of AGN outflows are more easily studied with such objects, since in BALs most doublet transitions are blended and cannot be used to infer the physical conditions or other parameters of the outflow. For example, studies of numerous intrinsic AGN outflows have shown that the troughs are usually saturated. In such cases, the trough depth in high-resolution spectra yields that ion's covering factor as a function of velocity. Then, knowing the relative strengths of the various transitions observed, interesting conclusions can be drawn by examining the spectra.

An excellent example is the reddened, extreme-Fe\textsuperscript{ii} emitting, mini-LoBAL quasar SDSS 1453+0029, which has $z=1.2899\pm0.0008$ from an ISAAC near-IR spectrum (Fig. 2). Broadly speaking, this object has two He\textsuperscript{i} absorption systems within a more extensive (in velocity space) set of Mg\textsuperscript{ii} absorption systems. This He\textsuperscript{i} absorption arises in an excited state populated by recombination (He\textsuperscript{ii} + e$^-$ $\rightarrow$ He\textsuperscript{i} + $\gamma$). Thus this He\textsuperscript{i} absorption traces the column density of He\textsuperscript{ii}, which yields a lower limit on $N_H$ since hydrogen is completely ionized in He\textsuperscript{ii} regions. Component A in SDSS 1453+0029 appears to have equally strong He\textsuperscript{i}\textsuperscript{λ}3188 and He\textsuperscript{i}\textsuperscript{λ}3889 absorption (Fig. 3). Since the latter transition is intrinsically much stronger, this means that He\textsuperscript{i}\textsuperscript{λ}3889 is saturated. The covering factor of the He\textsuperscript{i} ($\sim$50\%) is less than that of Mg\textsuperscript{ii} ($\sim$85\%) by inspection. Component B has He\textsuperscript{i} line ratios consistent with He\textsuperscript{i}\textsuperscript{λ}3889 being at most only slightly saturated, but its velocity-dependent covering factor reaches a maximum $\sim$90\% while that of Mg\textsuperscript{ii} is only $\sim$60\%. Thus, He\textsuperscript{i} and Mg\textsuperscript{ii} absorption can behave very differently, even over small velocity ranges, and even when the two components are very likely in physical proximity as indicated by their nearly identical velocities.

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Figure 2. Optical & VLT+ISAAC NIR spectra of the mini-LoBAL 1453+0029. The narrow Hα z agrees with the UVES absorption z.

Figure 3. Important transitions in the UVES spectrum of 1453+0029.