Serendipitous Discovery of a BAL QSO at $z = 2.169$

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ABSTRACT

We report the serendipitous discovery of a BAL QSO at $z = 2.169$, located 41$''$ southwest of 3C 48. We present Keck LRIS spectroscopy covering rest frame 1500 Å to 2300 Å. The C IV BAL has three components and it extends to outflow velocities of at least 12,000 km s$^{-1}$.

The BAL QSO has an intervening low-ionization metal-line absorption system at $z = 1.667$ which is likely to be a damped Ly$\alpha$ absorber. HST images show extended luminous material around the QSO, which could be either the host galaxy or the intervening system.

Subject headings: quasars: absorption lines

1. Introduction

Broad Absorption Line Quasi Stellar Objects (BAL QSOs) form a rare class comprising $\sim 12\%$ of the QSO population at moderate to high redshift (Foltz et al. 1990). The standard view, based largely on estimates of upper limits to resonant scattering by the BAL clouds, is that such clouds have a small covering factor as seen from the QSO nucleus, implying that essentially all radio-quiet QSOs would be classified as BAL QSOs if observed from the proper angle. However, BAL QSOs appear to be found more frequently among those with enhanced far-IR emission, strong Fe II emission, and/or weak or absent [O III] narrow emission lines (Low et al. 1989; Boroson & Meyers 1992; Turnshek et al. 1997). While the strong Fe II emission might be due to an orientation effect, it seems unlikely that the other properties mentioned would have a strong dependence on viewing angle.

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One interpretation of the BAL phenomenon running counter to the standard unified view is that these QSOs are very young and are ejecting their gaseous envelopes at very high velocities following the initial turn-on of the AGN (Hazard et al. 1984). In particular, the high incidence of low-ionization BAL QSOs in IRAS-selected, luminous QSOs, along with the reddening from dust in these objects, suggests that this subclass, at least, may comprise transition objects between ultraluminous infrared galaxies and the classical QSO population (Lípari 1994, Voit et al. 1993, Egami et al. 1996).

In principle, characterization of the host galaxies of sufficiently large samples of normal radio-quiet QSOs and BAL QSOs might tell us whether the BAL phenomenon is mostly due to orientation or mostly due to intrinsic properties. Here we report the chance discovery of a BAL QSO at moderately high redshift, for which HST imaging already exists. We found the QSO in the field of the quasar 3C 48 as part of a Keck spectroscopic program studying the host galaxies of low redshift QSOs (Canalizo & Stockton 1997, 1998). The only previous mention of this object in the astronomical literature is its identification as a “star” by Kirhakos et al. (1995). It is because of its proximity to 3C 48 that it is present on HST WFPC archival images, and, as we shall describe, it does show some extended emission.

2. Observations and Data Reduction

Spectroscopic observations of the host galaxy of 3C 48 were carried out on 1996 October 13 with the Low-Resolution Imaging Spectrometer (LRIS) on the Keck II telescope. We used a 600 groove mm\(^{-1}\) grating blazed at 5000 Å to obtain a dispersion of 1.24 Å pixel\(^{-1}\) and a useful wavelength range of 4600–7200 Å. One of our slit positions happened to include a stellar object to the south of 3C 48. The slit (1′′ wide, projecting to ∼5 pixels on the Tektronix 2048×2048 CCD) was centered ∼1′′ 5 E of 3C 48, with a PA of 14°, as indicated on Fig. 1. The spectrum of what we will refer to as the BAL QSO 0134+3253 fell 41′′ below that of the host galaxy of 3C 48. The total exposure time was 60 minutes.

The spectra were reduced with IRAF, using standard reduction procedures. After dark, bias and flat field correction, the images were background subtracted to remove sky lines. Wavelength calibrations were made using the least-mean-squares fit to identified lines in a comparison spectrum. The spectra were flux calibrated using spectrophotometric standards from Massey et al. (1988). The distortions in the spatial coordinate were removed with the apectract routines.

WFPC2 images of the 3C 48 field were obtained from the HST data archive. The images used in this analysis included two 1400 s exposures in the F555W filter and two 1700 s exposures in the F814W filter. In each case, 3C 48 was centered on the PC1 detector and the BAL QSO fell near pixel coordinates (308, 244) in the WFC2 detector. Most cosmic rays were removed by subtracting one of the frames (“image 2”) from the other frame obtained with the same filter (“image 1”), then thresholding the difference at a 3σ level, setting points above this threshold to the median.
of the difference image. Pixels near the position of the peak of the QSO were excluded from this process. The corrected difference image was then added back to image 2, giving a corrected version of image 1. The few cosmic rays within the relevant region that escaped this process were removed manually with the IRAF task \textit{imedit}. The procedure was repeated, interchanging the images, to correct image 2, and the two corrected images for each filter were averaged.

In order to study extended luminous material around the QSO, we subtracted a model point-spread function (PSF). This PSF was based on a star of similar brightness to the QSO, located 15$''$ away. While the WFPC2 shows significant field variations in the PSF, at the detection level of the QSO features of the PSF beyond a radius of 0$''$.4 are insignificant compared with the noise. We found we could achieve a good match simply with a slight adjustment of the ellipticity of the PSF model.

Finally, the field including 3C 48 and the BAL QSO was imaged with a notched $H + K'$ filter on 1997 October 2 with the UH QUIRC camera (Hodapp et al. 1996) on the University of Hawaii 2.2 m telescope. The total exposure time was 50 minutes, and we used standard IR reduction procedures.

3. Results and Discussion

3.1. The BAL QSO

The field of the QSO is shown in Fig. 1. The redshift of the QSO, determined from the He II and C III] broad emission lines, is $z_{\text{QSO}} = 2.169$. The coordinates, measured from the HST archival images, are $\alpha_{J2000} = 01^h 37^m 40^s.67$ and $\delta_{J2000} = 33^\circ 08' 56''.8$. From these same images, we obtain $m_{F555W} = 21.14$ and $m_{F814W} = 21.28$. Kirhakos et al. (1994) give $m_g = 21.2$.

Figure 2 shows the observed frame spectrum of the BAL QSO. The only trough evident in this region is C IV, which shows at least three components and outflow velocities extending to $-12000$ km s$^{-1}$. The trough is superposed on the emission line, and the red edge is around $+1,000$ km s$^{-1}$, as can be seen clearly in Fig. 2.

Unfortunately, Mg II $\lambda$2800 did not fall within our observed range, so we cannot determine whether this is a low-ionization BAL QSO. Weymann et al. (1991) found that the continua of low-ionization BAL QSOs are substantially redder than those of high-ionization BAL QSOs and non-BAL QSOs, presumably due to higher amounts of dust (Sprayberry & Foltz 1992). This BAL QSO appears reddened with respect to the Faint Object Spectrograph composite QSO spectrum (Zheng et al. 1997), but this reddening could be due to the intervening metal-line absorption system described in §3.2. There are hints of Fe II and Fe III emission superposed on C III] + Al III, and a possible weak trough bluewards of this feature, both of which are common in low-ionization BAL QSOs.
3.2. A Damped Ly$\alpha$ Absorber at $z_{\text{abs}} = 1.667$?

Figure 2 shows several unresolved absorption features, which we identify as arising from an intervening low-ionization metal-line system at $z_{\text{abs}} = 1.667$. Table 1 gives the line identifications and measured equivalent widths. The absorption features are unusually strong, with Al III and Fe II rest-frame equivalent widths being of strength similar to or greater than that seen in the relatively rare damped Ly$\alpha$ systems (e.g. Lu et al. 1996). We have performed a single-component curve-of-growth analysis on the five Fe II lines ($b = 30$ km s$^{-1}$), yielding an estimated Fe II column density of $\log N(\text{Fe II}) = 14.8$ cm$^{-2}$. Assuming a solar metallicity ($\log N(\text{Fe})/N(\text{H}) = -4.49$, Anders & Grevesse 1989), this implies the absorber has an H I column density of $N(\text{H I}) = 2 \times 10^{19}$ cm$^{-2}$. This is likely to be a damped Ly$\alpha$ absorber since the metallicity of such systems is typically $\approx 10\%$ solar (Pettini et al. 1997). Furthermore, the fact that Fe depletes readily onto dust in H I gas and our selection of a conservatively high Doppler value in the curve-of-growth analysis both add to the likelihood that this H I column density estimate is low by a factor of at least 10.

Low-ionization QSO metal-line absorption systems have been identified with the gaseous halos of luminous galaxies (Bergeron & Boissé 1991; Steidel 1993) with large absorption cross sections, $D \approx 100$ kpc ($H_0 = 75$). The damped absorbers, however, are believed to arise from the inner disk regions (few 10s of kpc) of the same absorbers based on their H I column density (Wolfe et al. 1986), mass density (Wolfe 1987), metallicity, and asymmetric absorption profile kinematics (Prochaska & Wolfe 1997). Attempts to image high-redshift damped Ly$\alpha$ absorbers have met with limited success, presumably due in part to the close proximity of the intervening system to the QSO image. High-spatial-resolution HST images have recently revealed candidate galaxies within a few arcsec of the QSO for several moderate-redshift ($0.4 < z < 1$) damped Ly$\alpha$ absorbers (Le Brun et al. 1997), but the absorbers appear to be morphologically diverse. The interpretation of extended structure associated with this QSO is therefore likely to be confused if indeed the intervening $z_{\text{abs}} = 1.667$ system arises from a damped Ly$\alpha$ absorber lying very near the QSO line of sight.

3.3. Extended Luminous Material: Intervening System or Host Galaxy?

Figure 3 shows the extent and distribution of the faint, extended luminous material around the QSO, from the HST archival images. In both the F555W and F814W images, the overall impression is of a roughly elliptical morphology, with a major axis at position angle $\sim 25^\circ$, and a center offset slightly to the SW from the QSO. There is evidence for a discrete object, or at least a luminosity peak, $\sim 0^\prime.7$ NE of the QSO, present in both images but most obvious in the F814W image. The southern edge of the ellipse appears to form an arc-like feature (Fig. 3b), but this impression is dependent on only a few crucial pixels and could easily result from noise fluctuations.

By interpolating over the central $0^\prime.4$ region of our PSF-subtracted images (Fig. 3b and d), we can obtain a conservative estimate of the magnitudes of the extended component alone. We
find $m_{F555W} = 23.8 \pm 0.1$ and $m_{F814W} = 24.1 \pm 0.1$ in 2.6-diameter apertures, where the errors include only measurement uncertainties. If the luminosity were due to stars at the redshift of the possible damped absorber ($z = 1.667$), the slope of the spectral-energy distribution at rest-frame 2000–3000 Å, compared with Bruzual & Charlot (1997) models, indicates that it would likely be dominated by a stellar population with an age of $\sim 2.5 \times 10^8$ years for solar metallicity, or roughly twice this age for 20% of solar metallicity. On the other hand, if we are observing stars in the QSO host galaxy, at $z = 2.169$, the corresponding ages of the dominant population at rest-frame 1800–2500 Å would be $\sim 5 \times 10^8$ and $\sim 7.5 \times 10^8$ years, respectively.

We do not detect any extension in our deep, ground-based $H + K'$ image. This image has a 1-$\sigma$ detection threshold of $\sim 5 \times 10^{-20}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$ arcsec$^{-1}$. For a 2-$\sigma$ detection, our surface-brightness limit (in $f_\lambda$) is essentially the same as that for the F814W filter, although we lose some additional detection efficiency because we are looking in the wings of the QSO profile. In any case, our failure to detect the extension in the IR is consistent with the stellar populations inferred above and would be inconsistent with the presence of any additional red component that would dominate either of these populations by a factor of $\sim 5$ or more in the observed IR (rest-frame 6000–7000 Å).

Thus, we cannot distinguish between an intervening or host-galaxy origin for the extended material in terms of our current knowledge of its SED. A galaxy at $z = 1.667$ dominated by a $\sim 2.5 \times 10^8$-year-old population would not be sufficiently unusual to constitute an objection to an intervening origin. We have been forced by our low S/N to deal with average colors, but inspection of Fig. 3 indicates that the peak or discrete object just NE of the QSO may be somewhat redder than the rest of the extended material. It is tempting to suggest that this object may be responsible for the intervening system, and that the more diffuse extended material may be the QSO host galaxy; but this suggestion is little more than speculation at this stage.

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Fig. 1.— The field of 3C 48 and the BAL QSO 0134+3253, from an HST WFPC2 F814W archival image. The inset shows the BAL QSO at higher contrast and 3× larger scale. The parallel lines indicate the position and orientation of the spectroscopic slit. North is up and East to the left.

Fig. 2.— See next page.

Fig. 3.— HST WFPC2 images of the extended material around the BAL QSO 0134+3253. (a) The F555W image, with a lower-contrast version in the inset. (b) The F555W image, smoothed with a Gaussian with $\sigma = 1$ pixel, and with a PSF derived from a nearby star subtracted (see text for details). (c) and (d) Like (a) and (b), but for the F814W filter.

Table 1. Absorption Features in the $z_{\text{abs}} = 1.667$ System

| $\lambda_{\text{obs}}$ | ID    | $W^{\text{obs}}_\lambda$ (Å)$^a$ | $W^{\text{rest}}_\lambda$ (Å) |
|-----------------------|-------|----------------------------------|---------------------------------|
| 4947.9                | Al III 1854.72 | 1.13                             | 0.42                            |
| 4969.9                | Al III 1862.79 | 0.76                             | 0.28                            |
| 6252.9                | Fe II 2344.21  | 2.48                             | 0.93                            |
| 6333.7                | Fe II 2374.46  | 1.43                             | 0.54                            |
| 6355.2                | Fe II 2382.76  | 2.99                             | 1.12                            |
| 6899.2                | Fe II 2586.65  | 3.29                             | 1.23                            |
| 6935.3                | Fe II 2600.17  | 2.99                             | 1.12                            |

$^a$1σ $W_\lambda$ error $\approx 120$ mÅ observed, 45 mÅ in the rest frame.
Fig. 2.— BAL QSO 0134+3253 spectrum in the observed frame. The QSO redshift from the broad emission lines is 2.169. The spectrum has been smoothed with a Gaussian filter of $\sigma = 3$ Å. The narrow absorption lines come from an intervening absorption system at $z_{\text{abs}} = 1.667$. The inset shows the C IV trough in the reference frame of the QSO. The spectrum in the inset has not been smoothed.
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