Low-Ionization BAL QSOs in Ultraluminous Infrared Systems

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Abstract. Low-ionization broad absorption line (BAL) QSOs present properties that cannot generally be explained by simple orientation effects. We have conducted a deep spectroscopic and imaging study of the host galaxies of the only four BAL QSOs that are currently known at $z < 0.4$, and found that all four objects reside in dusty, starburst or post-starburst, merging systems. The starburst ages derived from modeling the stellar populations are in every case a few hundred million years or younger. There is strong evidence that the ongoing mergers triggered both the starbursts and the nuclear activity, thus indicating that the QSOs have been recently triggered or rejuvenated. The low-ionization BAL phenomenon then appears to be directly related to young systems, and it may represent a short-lived stage in the early life of a large fraction of QSOs.

1. Introduction

Broad absorption line (BAL) QSOs comprise $\sim 12\%$ of the QSO population in current magnitude-limited samples. The standard view is that the BAL 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.

An even rarer class comprising only $\sim 1.5\%$ of all radio-quiet QSOs in optically-selected samples, the low-ionization BAL (hereafter lo-BAL) QSOs, pose serious problems to orientation-based models. Lo-BAL QSOs have considerably different broad emission line properties, are substantially redder than non-BAL QSOs, and are intrinsically X-ray quiet (Weymann et al. 1991; Sprayberry & Foltz 1992; Green 2001). In addition, the radio properties of lo-BAL QSOs may indicate that no preferred viewing orientation is necessary to observe BAL systems in the spectra of quasars since BALs are present in both flat and steep spectrum quasars, i.e., objects that are presumably viewed along the jet axis and at high inclination respectively (Brotherton 2001; Becker et al. 2000; Gregg et al. 2000). Thus lo-BAL QSOs are thought to constitute a different
class of QSOs, having more absorbing material and more dust (Voit et al. 1993; Hutsémekeers et al. 1998).

2. A Sign of Youth?

An intriguing possibility is that the lo-BAL phenomenon may represent a stage in the early life of QSOs, either in the form of young QSOs “in the act of casting off their cocoons of gas and dust” (Voit et al. 1993; see also Egami et al. 1996, and Hazard et al. 1984), or as the result of outflows driven by supermassive starbursts (Lípari 1994; Shields 1996).

We have carried out deep Keck spectroscopic observations of the host galaxies of the four lo-BAL QSOs that are currently known at z < 0.4: PG 1700+518 (Canalizo & Stockton 1997), Mrk 231 and IRAS 07598+6508 (Canalizo & Stockton 2000), and IRAS 14026+4341 (Canalizo & Stockton 2001, in preparation). These objects have nuclear properties that are relatively rare in the classical QSO population (e.g., Boroson & Meyers 1992; Turnshek et al. 1997): (1) strong Fe II emission, with the flux ratio Fe II λ4570/Hβ ≥ 1, and (2) very weak or no [O III] emission (see Table 1). In addition, we have found the following properties in the low redshift sample: (3) every lo-BAL QSO resides in an ultraluminous infrared galaxy (ULIG; i.e., log Lir/L⊙ ≥ 12); (4) they have a small range in far infrared (FIR) colors, intermediate between those characteristic of ULIGs and QSOs; (5) the host galaxies show signs of strong tidal interaction, and they appear to be major mergers (Fig. 1); (6) spectra of their host galaxies (Fig. 2) show unambiguous interaction-induced star formation, with post-starburst ages ≤ 250 Myr.

The spatially resolved spectra of the hosts clearly show a concentration of material towards the central regions in timescales that are consistent with the dynamical age for the tidal interaction (Canalizo & Stockton 2000; Table 1). Thus, it is clear that there has been a recent flow of gas towards the central regions which fueled the centrally concentrated starbursts in each of these objects. Moreover, there is strong evidence that these QSOs have been recently fueled (either for the first time, or simply rejuvenated). In agreement with this scenario, Mathur et al. (2001) find that the X-ray flux of the lo-BAL QSO PHL 5200 is highly absorbed with a very steep power-law slope of $\alpha = 1.7 ± 0.4$ (compared to the mean slope for non-BAL QSOs of $\alpha = 0.67 ± 0.11$). Such a

| Object Name | Redshift | log Lir/L⊙ | REW$^a$ | Fe II/ [O III] | Tail(s) | Dyn. | Sb. |
|-------------|----------|-------------|---------|---------------|---------|------|-----|
| IRAS 07598+6508 | 0.1483 | 12.41 | 0 | 2.6 | 50 | 160 | 30 |
| Mrk 231 | 0.0422 | 12.50 | 0 | 2.1 | 35 | 110 | 40 |
| IRAS 14026+4341 | 0.3233 | 12.77 | 0 | 1.0 | 37 | 120 | TBD |
| PG 1700+518 | 0.2923 | 12.58 | 2 | 1.4 | 13 | 40 | 85 |

$^a$ Rest equivalent width (REW) in Å

$^b$ Tail lengths in kpc, assuming $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$ and $q_0 = 0.5$

$^c$ Dynamical and starburst ages in Myr
steep slope may be the result of a high accretion rate close to the Eddington limit, which may in turn be indicative of a recent fueling of the black hole (i.e., a young QSO).

3. Proposed Model

Our results support those interpretations of the lo-BAL phenomenon which imply young systems. Here we propose a model that accounts for the observed properties in the four low-redshift lo-BAL QSOs. A major merger between galaxies of similar mass triggers intense bursts of star formation. As the gas concentrates in nuclear regions, the QSO activity is ignited. Along with the gas, dust is concentrated in the central 1 or 2 kpc, resulting in a dust-enshrouded QSO. The dust cocoon shields the narrow line region from the ionizing radiation coming from the central continuum source. The resulting low ionization parameter and the dusty environment increases the relative prominence of Fe II emission. A lo-BAL phase comes next, consisting of widespread outflows whereby the QSO expels the shroud of gas and dust (e.g. Voit, Weymann, & Korista 1993). As the ionizing photons are able to escape through holes on the cocoon poked by the outflows, nuclear and extended [O III] appear. A cocoon with holes may explain the different lightpaths in some BAL QSOs inferred from polarimetric studies, where some continuum is seen to escape without passing through dust (e.g. Hines & Wills 1995). Powerful QSOs, especially powerful radio sources, are able to break through the dust cocoon more rapidly, and this is why we do not see many strong radio-loud quasars in cocoon phase (Canalizo & Stockton 2001; Gregg et al. 2000).

4. Biases and Future Work

What keeps the evidence from having more weight is the fact that the sample of lo-BAL QSOs at $z < 0.4$ is incomplete and may be significantly biased. Only a fraction of low-redshift QSOs have been observed in the UV (where the BAL features are evident), and these observations have different biases. For example, Turnshek et al. (1997) conducted an HST FOS survey of low-z BALs in a sample of QSOs with weak [O III] (and strong Fe II). These two properties have an unusually high incidence in young IR-loud QSOs (Canalizo & Stockton 2001). The Turnshek et al. sample may then be biased towards young objects. We are therefore obtaining further spectroscopic and high resolution imaging observations of the host galaxies of BAL QSOs at somewhat higher redshifts (for which the BAL features appear in the optical).

The possibility that the lo-BAL phenomenon represents a short phase in the early life of QSOs is of great interest because it could potentially provide a method to answer one of the fundamental questions regarding QSOs, namely, how long does the QSO activity last? Determining the ages of starbursts that are related to the fueling of QSOs in a sample of objects could place limits on the duration of the BAL phase. This, along with an estimate of the fraction of QSOs go through a lo-BAL phase (as seen from our line of sight) would place upper limits on the mean lifetime of the QSO activity.
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References

Becker, R. H., White, R. L., Gregg, M. D., Brotherton, M. S., Laurent-Meuleisen, S. A., Arav, N. 2000, ApJ, 538, 72
Bruzual A., G. & Charlot, S. 1996, unpublished [ftp://gemin i.tuc.noao.edu/pub/charlot/bc96]
Brotherton, M. S. 2001, this volume
Canalizo, G., & Stockton, A. 1997, ApJ, 480, L5
Canalizo, G., & Stockton, A. 2000, AJ, 120, 1750
Canalizo, G., & Stockton, A. 2001, ApJ, 555, 719
Egami, E., Iwamuro, F., Maihara, T., Oya, S., Cowie, L. L. 1996, AJ, 112, 73
Green, P. J. 2001, this volume
Gregg, M. D., Becker, R. H., Brotherton, M. S., Laurent-Meuleisen, S. A., Lacy, M., White, R. L. 2000, ApJ, 544, 142
Hazard, C., Morton, D. C., Terlevich, R., & McMahon, R. 1984, ApJ, 282, 33
Hines, D. C., & Wills, B. J. 1995, ApJ, 448, L69
Hutsemékers, D., Lamy, H., & Remy, M. 1998, A&A, 340, 371
Lípari, S. 1994 ApJ, 436, 102
Mathur, S., Matt, G., Green, P. J., Elvis, M., & Singh, K. P. 2001, ApJ, 551, L13
Shields, G. A. 1996, ApJ, 461, L9
Sprayberry, D. & Foltz, C. B. 1992, ApJ, 390, 39
Voit, G. M., Weymann, R. J., Korista, K. T. 1993, ApJ, 413, 95
Weymann, R. J., Morris, S.L., Foltz, C.B., & Hewett, P.C. 1991, ApJ, 373, 23
Figure 1. Adaptive Optics and HST images of the host galaxies of low-redshift lo-BAL QSOs. Every host galaxy shows signs of recent strong tidal interaction.
Figure 2. Stellar populations in the host galaxies of low-z lo-BAL QSOs. Panels display Keck LRIS spectra of the host galaxies of 3 of the lo-BAL QSOs in rest frame (solid trace). Superposed are the best fitting models (dotted traces), consisting of the sum of an underlying old stellar population model and a young instantaneous starburst model (Bruzual & Charlot 1996). For details, see Canalizo & Stockton 1997. We have recently obtained Keck ESI spectroscopy of the fourth object, IRAS 14026+4341, which shows a large H II region ~ 2''5 North of the nucleus, as well as several post-starburst regions with populations similar to those of the other three objects (Canalizo & Stockton 2001, in preparation).