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QSOs, BALQSOs AND HYPERLUMINOUS INFRARED GALAXIES

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QSOs, BALQSOs & Hyperluminous Infrared Galaxies

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Abstract. The broadband linear polarization of BALQSOs is compared with that of non-BALQSOs, *IRAS*-selected QSOs and Hyperluminous Infrared Galaxies (HIGs). We confirm that BALQSOs as a class are more highly polarized than non-BALQSOs, but are less polarized than the *IRAS*-QSOs and HIGs. We also find that BALQSOs have $\log(L_{IR}/L_{opt})$ intermediate between the non-BALQSOs and *IRAS*-QSOs/HIGs.

Since the far-IR emission is probably emitted isotropically, we suggest that these properties are naturally explained if all QSOs contain a torus of dusty gas which surrounds the central ionizing continuum. The distinction between the three types of objects results primarily from viewing the systems at different orientations: objects viewed face-on will appear as non-BALQSOs without significant optical attenuation or obscuration [i.e. small $\log(L_{IR}/L_{opt})$] and low polarization; highly inclined objects will be heavily obscured in the optical and highly polarized. Objects viewed at latitudes which just graze the surface of the torus will show intermediate polarization and $\log(L_{IR}/L_{opt})$, and absorption from material ablated from the torus.

1. Introduction

Approximately 12% of radio-quiet QSOs have blue-shifted broad absorption lines (BALs) from resonant transitions. Typically, these are from Lyα, Si IV and C IV, but about 15% of BALQSOs show absorption from low-ionization species such as Al III, Mg II and Na I. High-ionization BALs are often nearly black but some have residual emission attributable to the blue wing of the associated emission line. This, and the fact that the emission-line properties of non-BALQSOs and BALQSOs are very similar, suggests that the BAL region (BALR) lies beyond the broad emission line region and only covers about 10%−15% of the sky as seen from the central source (e.g. Turnshek 1988; Weymann et al. 1991; Hamman et al. 1993). Although this picture is attractive, it is still uncertain whether all radio-quiet QSOs contain BALRs, or whether they constitute a separate population with large covering factors (e.g. Boroson & Meyers 1992).

On a related question, the *IRAS* mission has clearly shown that, even though dust and reddening were first thought to be negligible in QSOs, the spectral energy distributions of QSOs are dominated by emission from dust heated by the central continuum source (e.g. Sanders et al. 1989). *IRAS* also revealed reddened QSOs (*IRAS*-QSOs) which were missed in previous UV/optical surveys, and it

found galaxies with infrared luminosities and "warm" far-IR colors comparable to luminous QSOs [$\log(L_{IR}/L_{\odot}) \geq 12$; $0.25 \leq F_{\nu}(25\mu m)/F_{\nu}(60\mu m) < 3$][1]. Are these *IRAS*-QSOs and Hyperluminous Infrared Galaxies (HIGs) also separate populations, or are they perhaps normal QSOs viewed through the dust which radiates in the far-IR? Recent observations of the polarization of *IRAS*-QSOs and HIGs strongly suggest that they would be indistinguishable from typical luminous QSOs if viewed from different directions (e.g. Wills et al. 1992; Hines 1994; Hines et al. 1995; Wills & Hines herein). This implies that all QSOs contain dust distributed nonuniformly around the nucleus, and is likely contained in a structure similar to the dusty torus envisioned for the lower luminosity Seyfert galaxies. If all QSOs contain a BALR, then the dusty torus would naturally provide a resevoir for BAL material (e.g. Weymann et al. 1991; Voit, Weymann & Korista 1993).

2. The BALQSO Polarization Survey

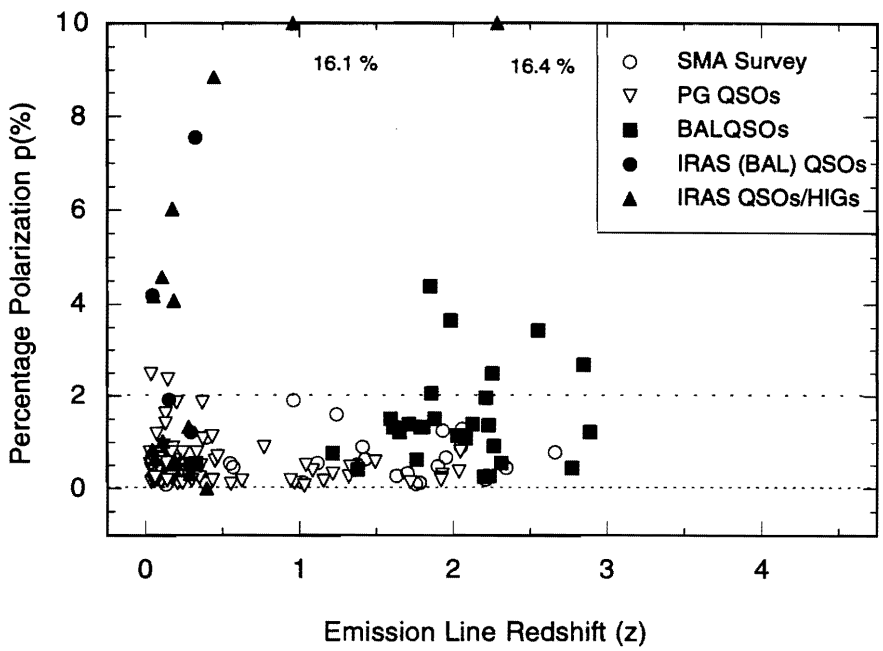

Figure 1. Results of our broadband polarization survey of BALQSOs compared with (radio quiet) non-BALQSOs, *IRAS*-BALQSOs, and *IRAS*-QSOs/HIGs. The measurements have been corrected for statistical bias (Wardle & Kronberg 1974). BALQSOs, including those *IRAS*-QSOs which show BALs, have polarizations which are in general intermediate between non-BALQSOs and *IRAS*-QSOs/HIGs. Note that the elevated polarizations of BALQSOs are not simply caused by observing at shorter rest wavelengths.

[1]We assume a cosmology in which $H_o = 100$ km s^{-1} Mpc^{-1} and $q_o = 0.5$.

Stockman, Moore & Angel (1984; hereafter SMA84) showed that radio quiet QSOs typically have low polarizations ($p \leq 1\%$). Importantly, the 2 objects with $p \geq 3\%$ in their sample were both BALQSOs, suggesting that BALQSOs may tend to be more highly polarized than non-BALQSOs. To further investigate the geometry of BALQSOs and their connection with IRAS-QSOs and HIGs, we have undertaken a broadband polarization survey of 40 QSOs selected according to the criteria that they be classified as BALQSOs (as defined in Weymann, Carswell & Smith 1981), are accessible from northern observatories ($\delta \geq -30°$), and are bright enough to obtain a good polarimetric S/N in a reasonable time.

Measurements were obtained in "white light" ($\sim 0.32 - 0.90\mu$m) over the span 1978−1996 using the Octopol & Two-Holer polarimeters at the 60, 61 & 90-inch telescopes of Steward Observatory, and the Breger photopolarimeter at the 82-inch telescope of McDonald Observatory. Integrations were sufficient to provide an accuracy of $\sigma_p \leq 0.62\%$ for all 40 objects, and $\sigma_p \leq 0.5\%$ for 28 objects, giving a 4σ detection for $p = 2.5\%$ and 2.0%, respectively.

Eight of the BALQSOs in our sample show significant polarization above 2%; 4 have $p \geq 3\%$. This suggests that 20% of BALQSOs have rather high polarization ($p \geq 2\%; p/\sigma_p \geq 4$), compared with only 2 of 115 (radio-quiet) non-BALQSOs in our control sample, and confirms the earlier impression that BALQSOs are more highly polarized than non-BALQSOs (Figure 1). Even for $p \leq 2\%$, BALQSOs are on average more polarized than non-BALQSOs. Using a two-tailed K-S test, the probability that these samples of non-BALQSOs and BALQSOs were drawn from the same polarization distribution is 1.2×10^{-5}. Interestingly, one of the two polarized non-BALQSOs shows "associated" C IV absorption (Smith et al. 1997).

We have obtained detailed spectropolarimetry for the highly polarized BALQSOs, the results of which are discussed in by Schmidt, Hines & Smith elsewhere in these proceedings. We find that the scattering regions cannot be much larger than the line-emitting regions, and that the BAL clouds are more efficient at absorbing direct light than scattered light. This implies that the scattering takes place in a region that is much larger than the central engine. The degree of polarization in some BAL troughs ($p \sim 10\%$) requires rather extreme geometries similar to those invoked for *IRAS*-QSOs & HIGs, and implies that the continua of BALQSOs are diluted by direct nuclear emission.

3. Comparison with *IRAS*-QSOs & HIGs

IRAS-QSOs and HIGs appear no more IR-luminous than energetic non-*IRAS*-selected QSOs, and have typical values of $\log(L_{IR}/L_{opt})$ when their optical luminosities are corrected for extinction. Therefore, the *apparent* $\log(L_{IR}/L_{opt})$ is probably a good indicator of attenuation of UV/optical light in our direction. In the dusty torus model, $\log(L_{IR}/L_{opt})$ also provides an indication of the inclination of the system (e.g. Hines 1994; Hines et al. 1997). [Note that any line-of-sight attenuation of optical light increases the apparent $\log(L_{IR}/L_{opt})$, so elevated $\log(L_{IR}/L_{opt})$ does not necessarily imply occultation by the torus itself (see also the contribution by Goodrich).]

Figure 2 and Table 1 compare the polarization distributions of non-BALQSOs, BALQSOs and *IRAS*-QSOs/HIGs. The observed polarization tends to follow the

Table 1. Observed Properties of non-BALQSOs, BALQSOs and *IRAS*-QSOs/HIGs

Object	Median P(%) (range)	$<L_{IR}/L_{opt}>$ (range)
non-BALQSOs	0.5	7 (0.3 – 17)
BALQSOs	1.2 (0.1 – 4.4)	11 (7 – 17)
IRAS-QSOs/HIGs	2.7 (0.1 – 16.4)	199 (48 – 370)

apparent value of $\log(L_{IR}/L_{opt})$. Since the increase of the *apparent* $\log(L_{IR}/L_{opt})$ is caused by higher attenuation of the UV/optical (i.e., viewing the system at higher inclination), the increase in polarization is caused by decreased dilution from direct direct light *and* by increased scattering angles. [We assume that the available far-IR observations of BALQSOs are representative of the class.] These results suggest that BALQSOs are rather typical QSOs, but are viewed at intermediate latitudes such that our line of sight skims the obscuring torus.

4. The BALR as the Skin of the Torus

Our sample provides sufficient information to constrain the geometry of the BALR within the dusty torus model. There is strong evidence that the angle through which central continuum light can escape is defined by the opening in the torus itself (e.g. Wills et al. 1992; Storchi-Bergmann, Wilson & Baldwin 1992; Hines et al. 1997). Direct imaging of scattering cones, images of QSO host galaxies, intrinsic *vs.* apparent $\log(L_{IR}/L_{opt})$, and the relative number of HIGs compared with high-luminosity QSOs [$\log(L_{IR}/L_{\odot}) > 12$] indicate that the half-opening angles of the scattering cones, and hence of the dusty torus, tend to fall in the range $30° \lesssim \theta_c \lesssim 60°$.

The inferred covering factor of BAL material as seen from the central continuum source is $c(all) \sim 12\%$ and $c(low) \sim 1\%$ for all BALQSOs and low-ionization BALQSOs, respectively. For $\theta_c = 50°$, the "skin" of low-ionization absorbing material would subtend $\sim 3°$ above the torus as viewed from the central source. It is therefore easy to envision how light scattered within the open pole of the torus could miss the majority of the absorbing material (e.g. Hines & Wills 1995; Cohen et al. 1995; Goodrich & Miller 1995; and Figure 3). This is also illustrated by the spectropolarimetry results presented by Schmidt, Hines & Smith and the contributions by Ogle and Cohen.

A potential problem with the Unified Scheme for BALQSOs has been the implied abruptness of the "turn-on" of high polarization and appearance of BALs (Goodrich herein). As illustrated in Figure 3, this is naturally explained if the BAL material is indeed confined to the skin of the torus. The geometry also provides high column densities along very restricted sight-lines.

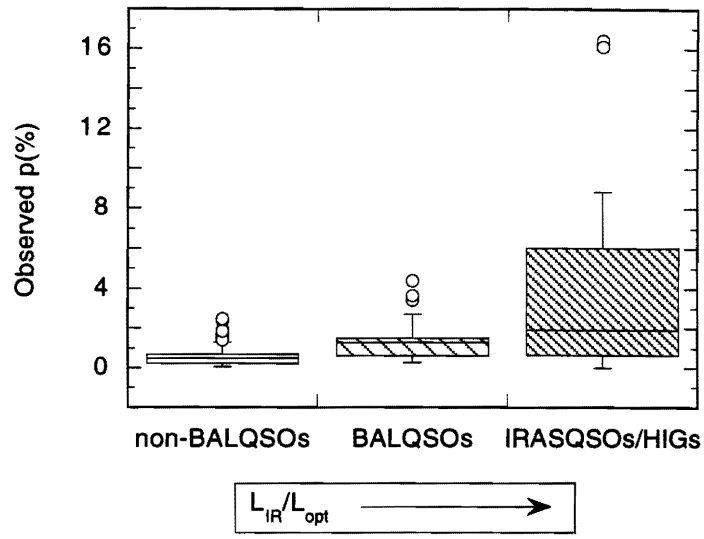

Figure 2. Polarization distributions for non-BALQSOs, BALQSOs and *IRAS*-QSOs/HIGs. Boxes enclose 50% of the data for each group with the median value displayed as a horizontal line. Vertical "error bars" represent minimum and maximum limits excluding outliers which are more than 1.5 times the value of the upper edge of the box.

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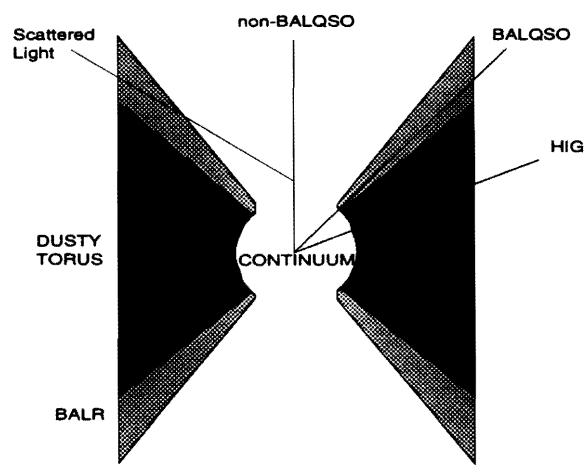

Figure 3. Geometry of the dusty torus and BALR.

References

Boroson, T.A., & Meyers, K.A. 1992, ApJ, 397, 442

Cohen, M.H., et al. 1995, ApJ 448, L77

Goodrich, R.W., & Miller, J.S. 1995, ApJ, 448, L73

Hamman, F., Korista, K.T., & Morris, S.L. 1993, ApJ, 415, 541

Hines, D.C. 1994, Ph.D. Thesis, University of Texas

Hines, D.C., & Wills, B. J. 1993, ApJ, 415, 82

Hines, D.C., & Wills, B. J. 1995, ApJ, 448, L72

Hines, D.C. et al. 1995, ApJ, 450, L1

Hines, D.C., et al. 1997, ApJ, submitted.

Low, F.J., Cutri, R.M., Kleinmann, S.G., & Huchra, J.P. 1989, ApJ, 340, L1

Pier, E.A. & Krolik, J. H., 1993, ApJ, 418, 673

Sanders, D.B. et al. 1989, ApJ, 347, 29

Smith, P.S., Schmidt, G.D., Allen, R.G., & Hines, D.C. 1997, ApJ, in press

Stockman, H.S., Moore, R.L., & Angel, J.R.P. 1984, ApJ, 279, 485

Stockman, H.S., Angel, J.R.P., & Hier, R.G. 1981, ApJ, 243, 404

Storchi-Bergmann, T., Wilson, A.S., & Baldwin, J.A. 1992, ApJ, 396, 45

Turnshek, D.A., 1988, in STScI Symp. 2, QSO Absorption Lines: Probing the Universe, eds. J.C. Blades, D. Turnshek, & C. Norman (Cambridge: Cambridge Univ. Press)

Voit, G.M., Weymann, R.J., & Korista, K.T. 1993, ApJ, 413, 95

Wardle, J.F.C, & Kronberg, P.P. 1974, ApJ, 194, 249

Wills, B.J. et al. 1992, ApJ, 400, 96

Weymann, R.J., Carswell, R.F., & Smith, M.G., 1981, ARA&A, 19, 41

Weymann, R.J., Morris, S.L., Foltz, C.B., & Hewett, P.C. 1991, ApJ, 373, 23

Young, S. et al. 1995, MNRAS, 281, 1206

5. Questions

K. Korista: If the extra Fe II emission in these sources is from the torus, then it must be very high density ($>10^{10}$ cm^{-3}) otherwise the [Fe II] line spectrum would come booming through, which is not observed. Comments?

D. Hines: Although we have not detected polarization differences between the Fe II and other broad emission lines, the apparently stronger Fe II emission in BALQSOs may be related to the "attenuated" view of the continuum. The Fe II gas may not be physically associated with the torus, but instead arise from dense (matter bound) blobs closer to the central source. The blobs would be highly ionized at the inner face and less ionized behind, with perhaps dust persisting on the back side away from the continuum source. If these blobs share the same angular momentum as the torus, they would better present their low-ionization emission at higher inclinations.

M. Yun: If the IR is optically thin, then there should be no orientation dependence. If it is optically thick, then a face-on system would appear IR luminous. A more significant effect may be the photon processing volume (i.e. 10^{10} $M_\odot$ of molecular gas surrounding the QSO in ULIRGs). If the model is correct, large $\log(L_{IR}/L_{opt})$ objects should be low-luminosity QSOs.

D. Hines: In all these objects there are clear lines of sight to the unobscured nucleus: revealed directly in QSOs, or by high ionization narrow line spectra and QSO-like scattered spectra in HIGs. Also, the extreme IR luminosities of HIGs alone qualify them as QSO-2s. If the inner regions of the torus are optically thick, then face-on systems will have larger infrared luminosities, but will also reveal the optical nucleus (e.g. Pier & Krolik 1993). The apparent $\log(L_{IR}/L_{opt})$ is much more strongly affected by extinction of optical light which can vary by orders of magnitude as a function of orientation.