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The Polarization Properties of Broad Absorption Line QSOs: Observational Results

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Abstract. Correlations between BAL QSO intrinsic properties and polarization have been searched for. Some results are summarized here, providing possible constraints on BAL outflow models.

1. Introduction

From 1994 to 1999 we have obtained broad-band linear polarization measurements for a sample of approximately 50 Broad Absorption Line (BAL) QSOs using the ESO 3.6m telescope at La Silla (Chile).
On the basis of this sample plus additional data compiled from the literature, possible correlations between BAL QSO intrinsic properties and polarization have been searched for. Here we present some of our most interesting results, updated with recent data.

2. Analysis and results

A careful distinction between BAL QSO subtypes has been made. In addition to the BAL QSOs with high-ionization (HI) absorption features only, we have distinguished BAL QSOs with strong (S), weak (W), and marginal (M) low-ionization (LI) absorption troughs (Hutsemékers et al. 1998, 2000 for details).
Several indices are used to quantify the spectral characteristics: the balnicity index (BI) which is a modified velocity equivalent width of the C IV BAL, the detachment index (DI) which measures the degree of detachment of the absorption trough relative to the emission line, the maximum velocity $v_{\max}$ in the C IV BAL, and the power-law index α of the continuum.
Although most BAL QSOs are radio-quiet, some of them appear radio-moderate, and radio-to-optical flux ratios $R^\star$ were also collected.
Correlations and sample differences were searched for by means of the usual statistical tests. Survival analysis was used for censored data (mainly $R^\star$). While the study of polarization was our main goal, correlations between different in-

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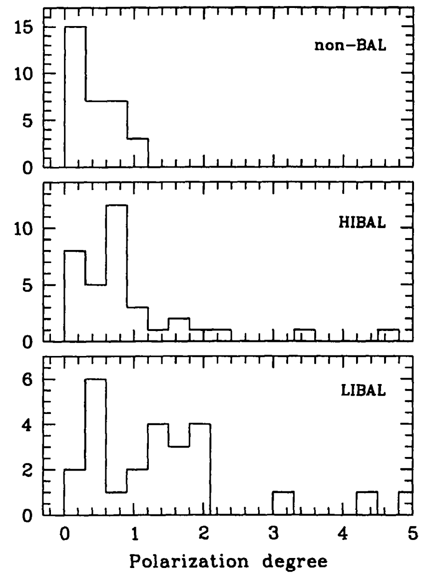

Figure 1. The distribution of the polarization degree p_0 (in %) for the three main classes of QSOs. LIBAL QSOs contain the three sub-categories, i.e. strong, weak and marginal LIBAL QSOs. Data are from H1998, S1999, L2000, O2000 (a LIBAL QSO with p_0=7.5 and the unclassified BAL QSOs are not represented here)

dices have also been considered.
Results presented by Hutsemékers et al. (1998, 2000; H1998, H2000) are updated with polarimetric data from Schmidt & Hines (1999; S1999), Lamy & Hutsemékers (2000; L2000), and Ogle et al. (2000; O2000). Only polarimetric measurements with $\sigma_p \leq 0.4\%$ are taken into account, such that the debiased polarization degree p_0 has a typical uncertainty σ_p = 0.2-0.3%. The radio-loud BAL QSOs recently discovered in the FIRST survey (Becker et al. 2000; B2000) are included in the present study.

• Evidence for polarization differences between low- and high-ionization BAL QSOs
The distribution of the polarization degree p_0 for the three main classes of QSOs is illustrated in Fig. 1. We can see that the bulk of QSOs with $p_0 > 1.2\%$ belong to the sub-class of LIBAL QSOs. Note that not all LIBAL QSOs are highly polarized. As a class, HIBAL QSOs appear less polarized than LIBAL QSOs and more polarized that non-BAL QSOs. They seem to have intermediate properties. All these differences are statistically significant ($P_{\text{K-S}} \geq 99\%$).

• The correlation between the balnicity and the slope of the continuum
In addition to their higher polarization, it is seen from Fig. 2 that most LIBAL QSOs have also larger balnicities and more reddened continua than HIBAL QSOs. Considering the whole BAL QSO sample (i.e. HI+LI BALs), a significant ($P_\tau \geq 99\%$) correlation is found between the balnicity index BI and the slope of the continuum. Since LIBAL QSOs as a class are more reddened and

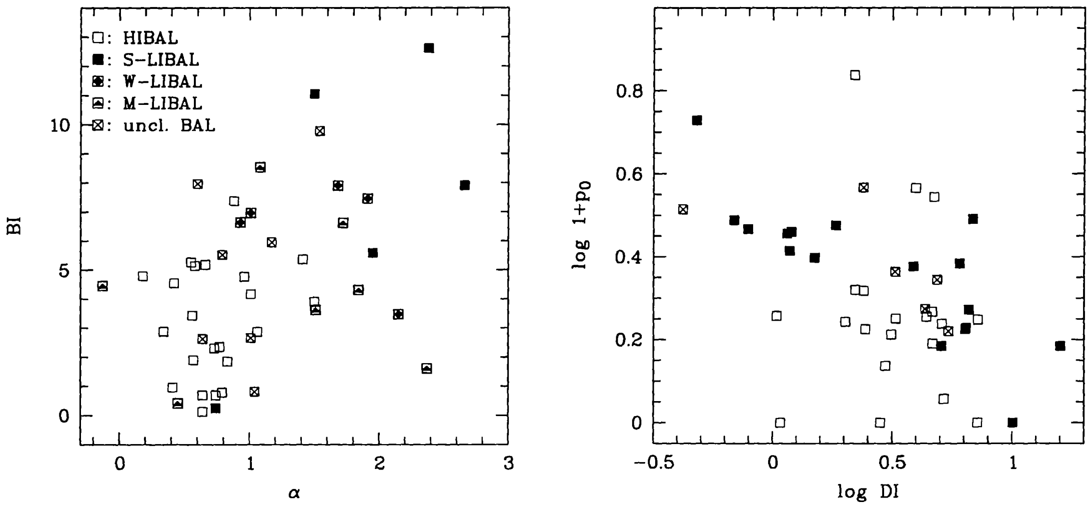

Figure 2. **Left**: the correlation between the balnicity index BI (in 10^3 km s^{-1}) and the power-law index α ($F_\nu \propto \nu^{-\alpha}$). The 3 subcategories of LIBAL QSOs are distinguished here. Data and objects are from H1998, L2000, H2000. **Right**: the correlation between the polarization degree p_0 (in %) and the line profile detachment index DI. The correlation is especially apparent for the LIBAL QSOs (filled squares). Data from H1998, S1999, L2000

more polarized than HIBAL QSOs, it also results a correlation between the power-law index and the polarization, although less convincing.

• The correlation between the polarization of the continuum and the line profile detachment index

Among several possible correlations of the polarization with spectral indices like the balnicity index, the equivalent width and the velocity width of C IV and C III], the only significant ($P_\tau \geq 99\%$) correlation we found is a correlation with the line profile detachment index, quite unexpectedly. Fig. 2 illustrates the correlation between the polarization degree p_0 and the line profile detachment index DI for all BAL QSOs of our sample. The correlation is especially apparent and significant for the LIBAL QSOs. It indicates that the BAL QSOs with P Cygni-type line profiles (DI$\ll$) are the most polarized.

• The absence of correlation between the polarization and $R^\star$

If the higher polarization of BAL QSOs as a class is due to an attenuation of the direct continuum with respect to the scattered one –at least in some objects– (Goodrich 1997), then we expect the polarization to be correlated with the radio-to-optical flux ratio. In Fig. 3, the BAL QSO polarization p_0 is plotted against the radio-to-optical flux ratio $R^\star$. No correlation is seen, as confirmed by the statistical tests. Note that the distribution of $R^\star$ is not found to differ between the HIBAL and LIBAL subsamples

• The absence of correlation between the terminal velocity and $R^\star$

In order to investigate the claimed anticorrelation between the terminal velocity of the flow and the radio-to-optical flux ratio (Weymann 1997), we have plotted

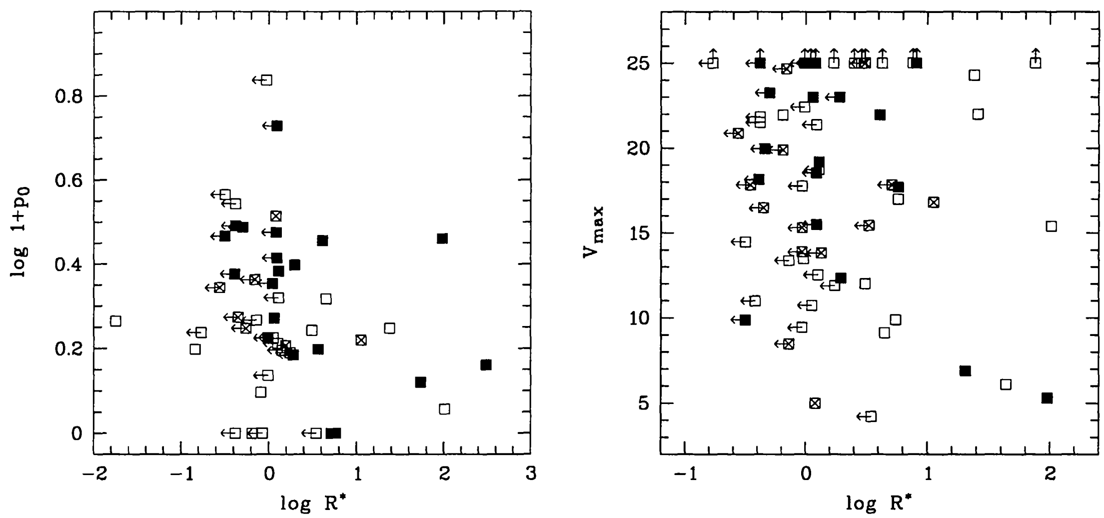

Figure 3. **Left**: The polarization degree p_0 plotted against the radio-to-optical flux ratio $R^\star$. Data are from H2000. **Right**: the maximum velocity v_{max} in the C IV BAL (in 10^3 km s^{-1}) is plotted against the radio-to-optical flux ratio $R^\star$. Data from H2000, B2000. In both figures, open squares represent HIBAL QSOs, filled squares LIBAL QSOs, and squares with a cross unclassified BAL QSOs, while arrows indicate censored data points

in Fig. 3 the maximum velocity v_{max} in the C IV BAL against the radio-to-optical flux ratio $R^\star$. No correlation is found, as confirmed by the statistical tests.

3. Conclusions

Our results show that polarization is correlated with BAL QSO line profiles and types, emphasizing the extreme behavior of LIBAL QSOs already reported by several studies. These results could provide constraints on the BAL outflow models and geometry. As discussed by Hutsemékers et al. (1998), they are consistent with the Murray et al. (1995) disk-wind model.

References

Becker, R. et al. 2000, ApJ 538, 72 [B2000]

Goodrich, R. 1997, ApJ 474, 606

Hutsemékers, D., Lamy, H., Remy, M. 1998, A&A 340, 371 [H1998]

Hutsemékers, D., Lamy, H. 2000, A&A 358, 835 [H2000]

Lamy, H., Hutsemékers, D. 2000, A&AS 142, 451 [L2000]

Murray, N. et al. 1995, ApJ 451, 498

Ogle, P. et al. 2000, ApJS 125, 1 [O2000]

Schmidt, G., Hines, D. 1999, ApJ 512, 125 [S1999]

Weymann, R. 1997, ASP Conf 128, 3