Acceleration of BAL Outflows & Radio Loudness

Beverley J Wills

University of Texas at Austin

INTRODUCTION

There have been new insights from the X-ray, far and near UV, and optical, especially in constraining the physical parameters of individual absorbing outflows (e.g. Arav+05), new insights from spectropolarimetry (e.g. Lamy & Hutsemekers 05), an important empirical approach to understanding the pieces of the puzzle (Elvis 00), and important advances in theoretical understanding of the outflows(e.g. de Kool+00), including the interaction of outflows with the host galaxy. Still, there are some clear statistical relationships that hold important physical clues for outflows, but they are not understood. Here we update the situation for two relationships: the dependence of absorbing outflows (1) on radio-loudness, and (2) on optical luminosity of the AGN. The dependence on radio loudness shows that BAL outflows are linked directly or indirectly with magnetic fields (see e.g. Konigl & Kartje 94).

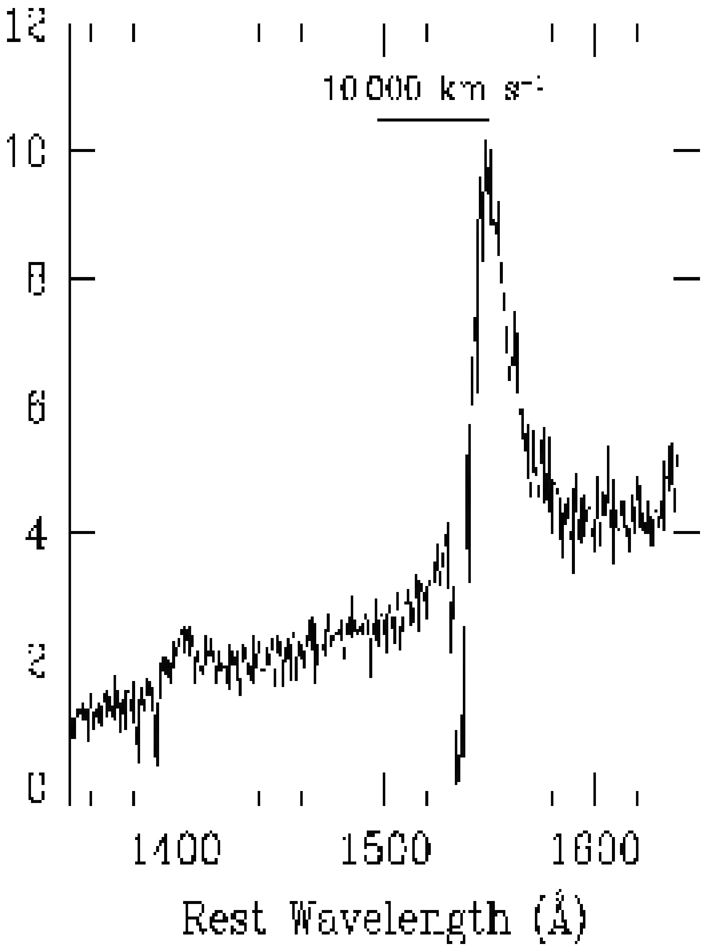
NALs and BALs

Intrinsic absorption is present in half of AGN with a range of widths, strengths (EW) and outflow velocities. Illustrated are C IV λ *1549*

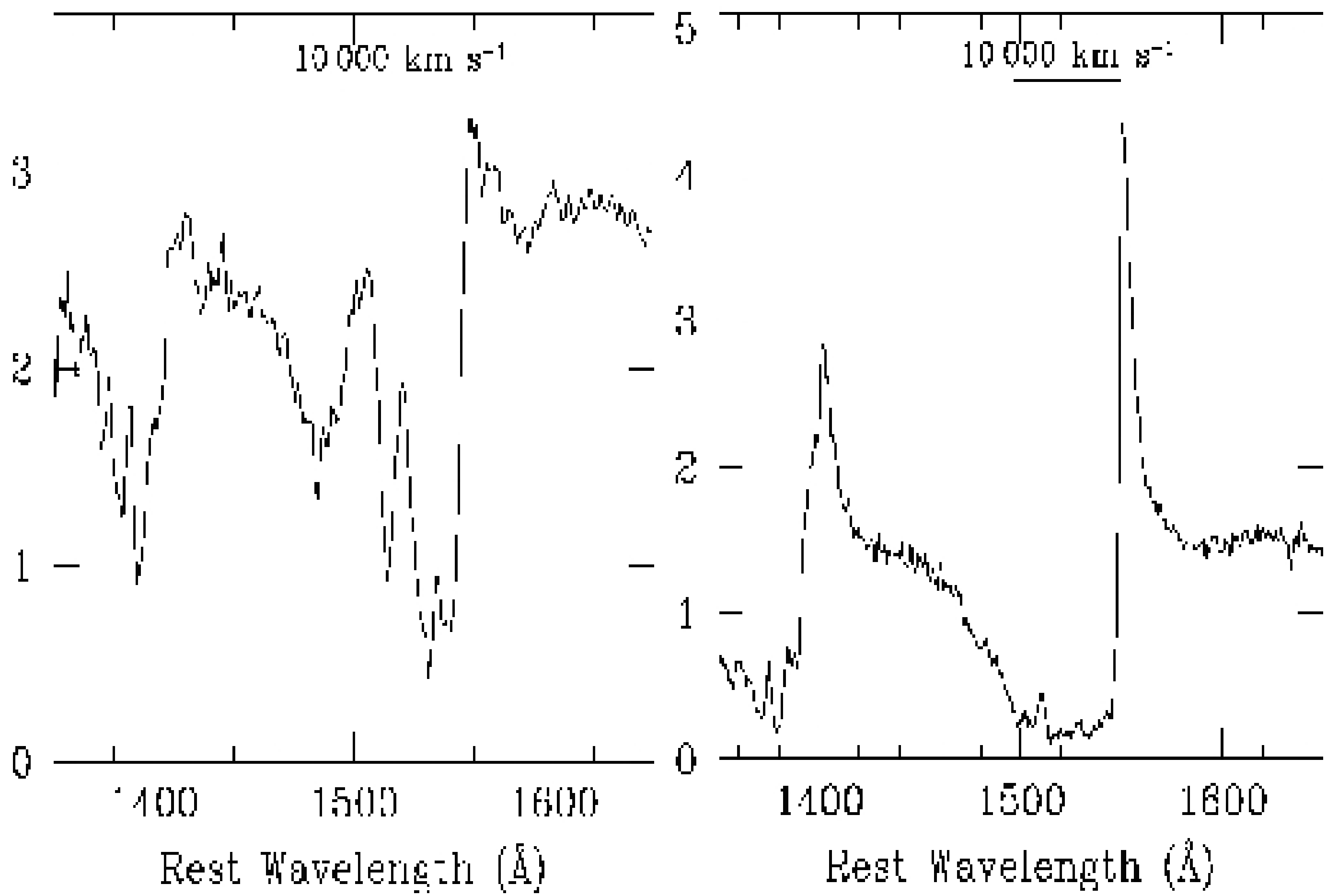
NALs: widths ~400 km/s; strong in lobe-dominant QSOs (LDQs) &

BALs: seen in >20% of luminous QSOs; vmax up to at least 0.1c.

Narrow absorption lines (NALs)



Broad absorption lines (BALs)



DATA

High quality ground-based spectra in the redshift range 1.5-3.5 allow us to access absorption from the region of the CIV λ 1549 emission line to ~1400Å corresponding to absorption blueshifts of vmax ~30,000 km/s. Using 130 BAL QSO spectra from Korista+93, Ogle+99, Becker+00,01, Menou+98, Brotherton+98, I measured:

- total rest-frame equivalent width (EW)
- difference in EW either side of 5000 km/s, normalized by the EW:
  r5b = (EW blue of 5000 km/s)-(EW red of 5000km/s)/EW
- similarly, the difference in EW: r2b, around 2000 km/s outflow velocity.
- vmax (defined at the wavelength with 5% of absorption EW to blue).
- r magnitudes, corrected for extinction and k-corrected for continuum and emission lines. From this we derive absolute blue magnitude Mbr.
- rest-frame 5GHz luminosities or upper limits, L5, from NED or FIRST flux densities.
- RL, the radio-loudness, measured by the rest-frame ratio L5/L(B) where L5 is radio luminosity at 5 Ghz, and L(B) is B-band optical luminosity. Sometimes L5 is used directly to measure radio loudness.

For comparison, I also collected similar data for NAL QSOs (Foltz+86, Baker+02), and for other absorption systems from Vestergaard 03.

BALs and Radio Loudness

Historically, BALs were thought to be strictly the domain of radio-quiet QSOs (RL<1). However, many BAL QSOs have been found in the FIRST deep radio survey at 21cm. Even after correction for reddening and the broad absorption troughs, some really are radio-loud (Becker+00, Brotherton+02, Gregg+00).

Now there's confusion: Did the earlier surveys miss something?

If BAL QSOs show properties continuous among both radio-quiet and radio-loud QSOs, the answer to the age-old question, "Is there a radio-loud - - radio-quiet dichotomy?" is likely to be "NO".

A careful comparison of the statistics (Hewett & Foltz 03, see references therein), shows that, using the historical definition of balnicity, the probability of a FIRST radio source being a BAL QSO is roughly ½ that in an otherwise equivalent optically-selected sample.

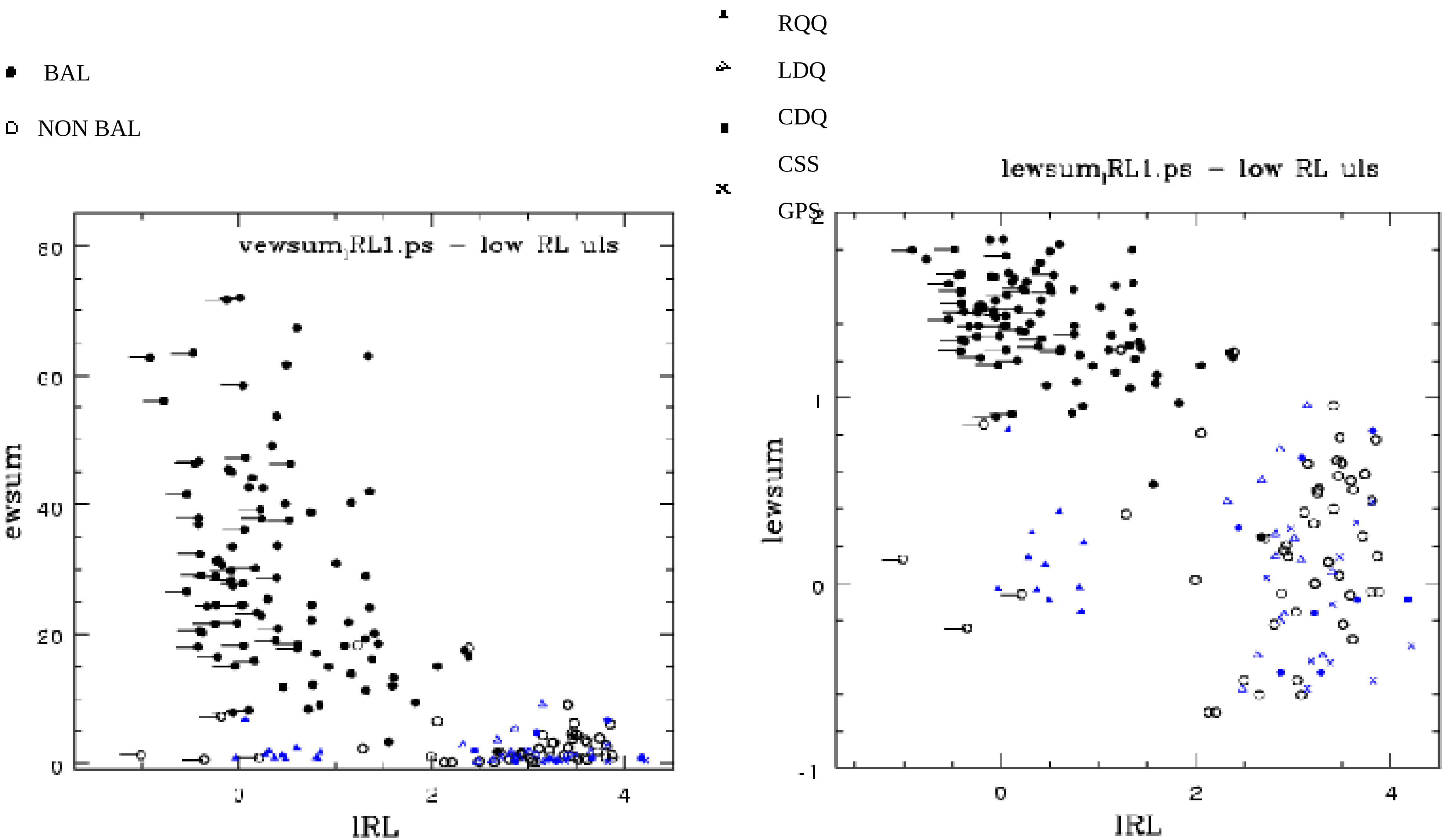
Scanning through the FIRST spectra, the resolution of the issue is very clear: FIRST BAL QSOs tend to have broken troughs and do not extend to high vmax (compare the radio-loud QSO BAL in the middle panel, and the radio-quiet QSO BAL in the right panel).

Radio-loud BAL QSOs? -ctd

This result was also found for the absorption seen in classical radio-loud QSOs (Foltz+86). Many FIRST BAL QSOs do not meet the historical definition of balnicity.

My first goal is to quantify issues related to BAL outflow & radio-loudness.

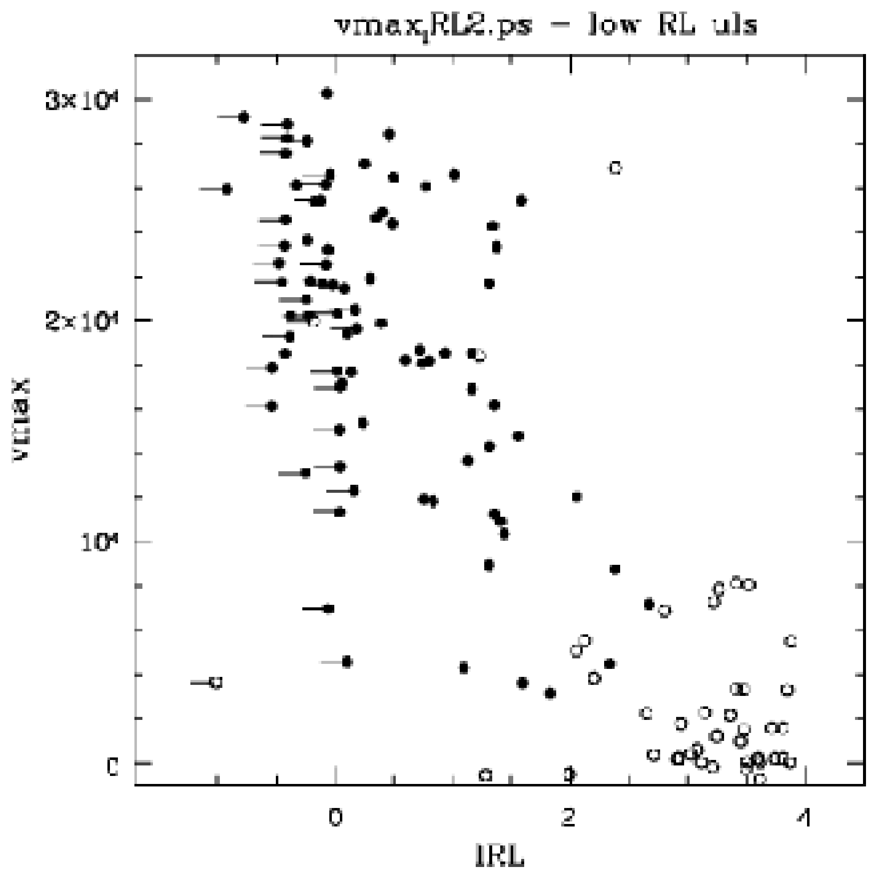
We use the absorption EW, rather than the more restrictive balnicity index (BI). Caution: EW is sensitive not only to instrinsic QSO absorption but also to absorption in the QSO host galaxy or cluster environment, and intergalactic absorption (Weymann+91).

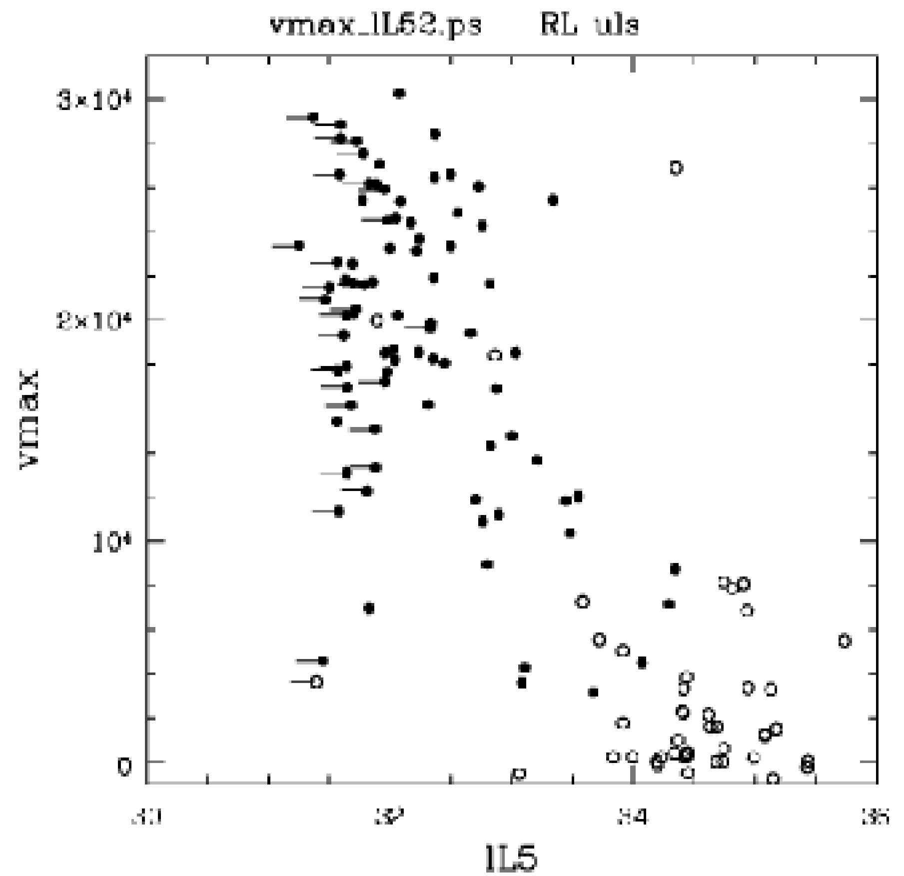


Total EW (ewsum, left) and its log (right) vs. log radio-loudness. The blue points are from Vestergaard 03 (see symbols above). The non-BALs and blue points are likely to have significant contamination from non-intrinsic systems for EW<1Å. There is a trend for smaller EW with increasing RL, and an absence of large EW for RL > 30.

Dependence of vmax on radio-loudness.

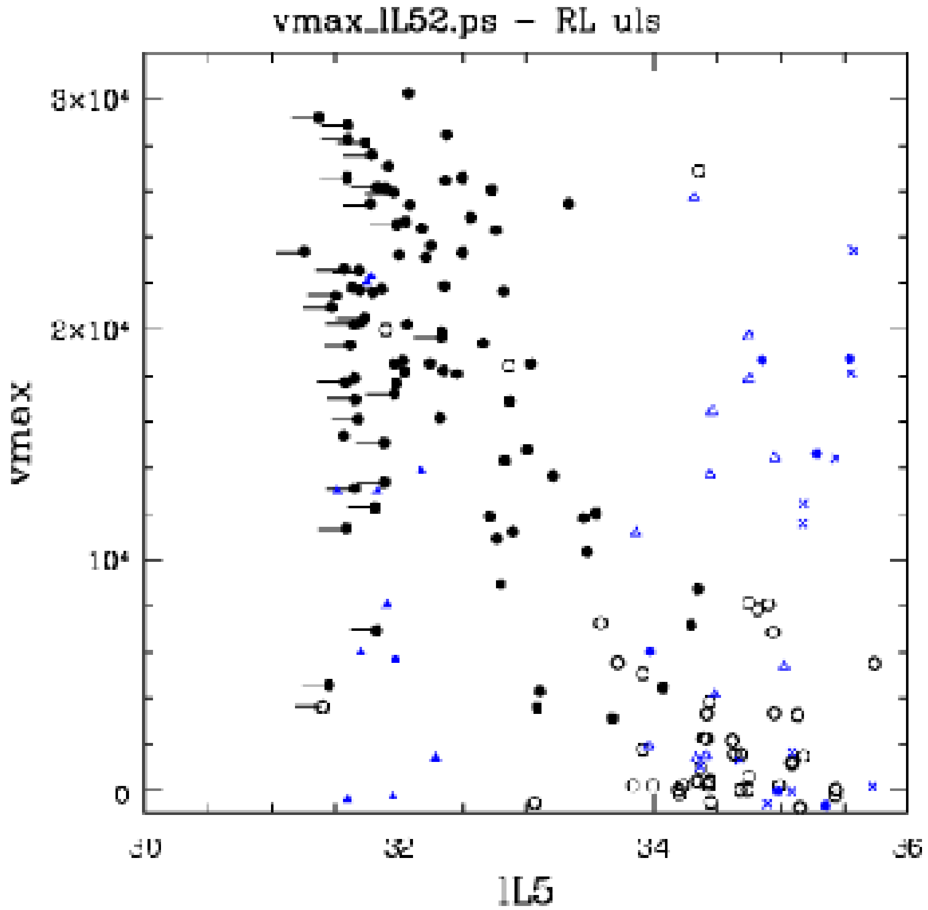
● BAL
○ NON BAL

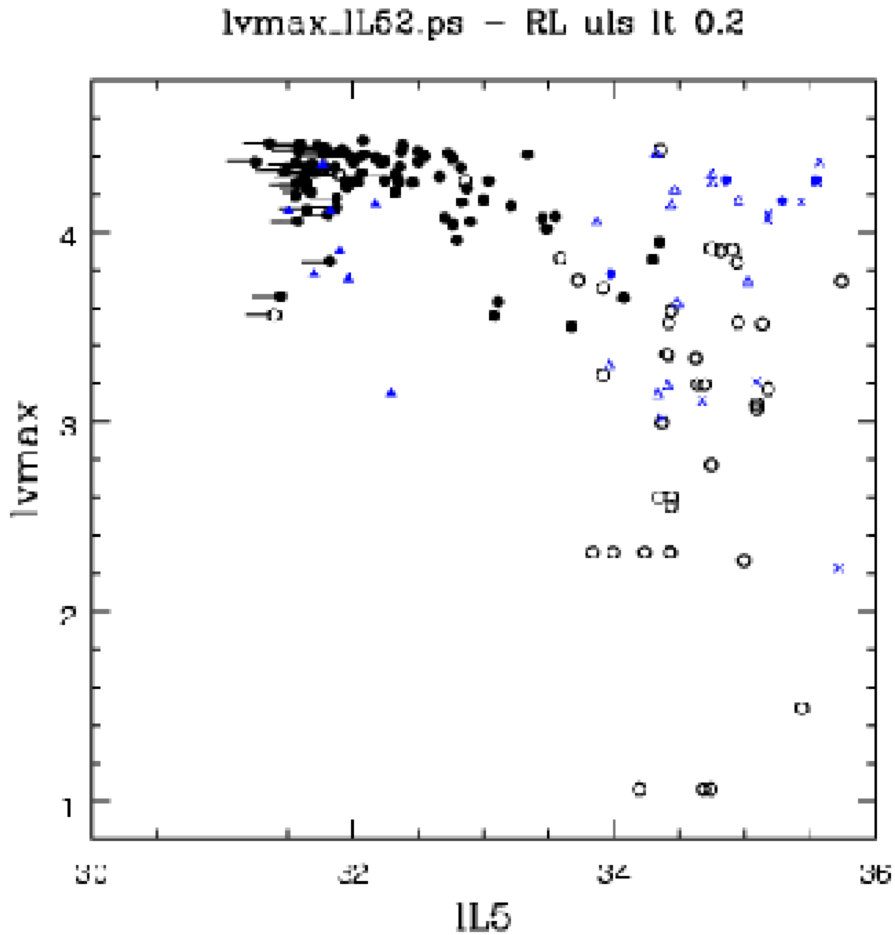




vmax (km/s) vs. log RL and log L5. RL is poorly correlated with Mbr, so either RL or L5 are good measures of radio-loudness. The trend of decreasing vmax with increasing radio loudness is evident.

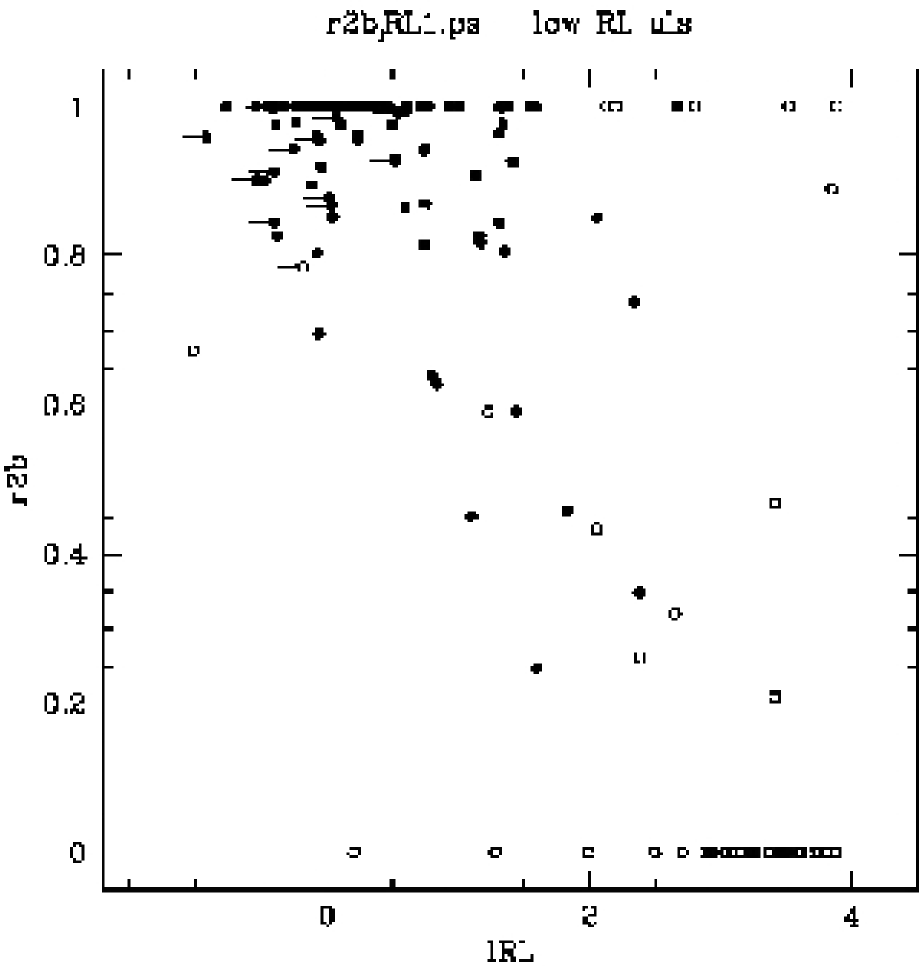
..including narrow absorption lines from Vestergaard (2003), many of which are low EW and may not be intrinsic, looks like this:

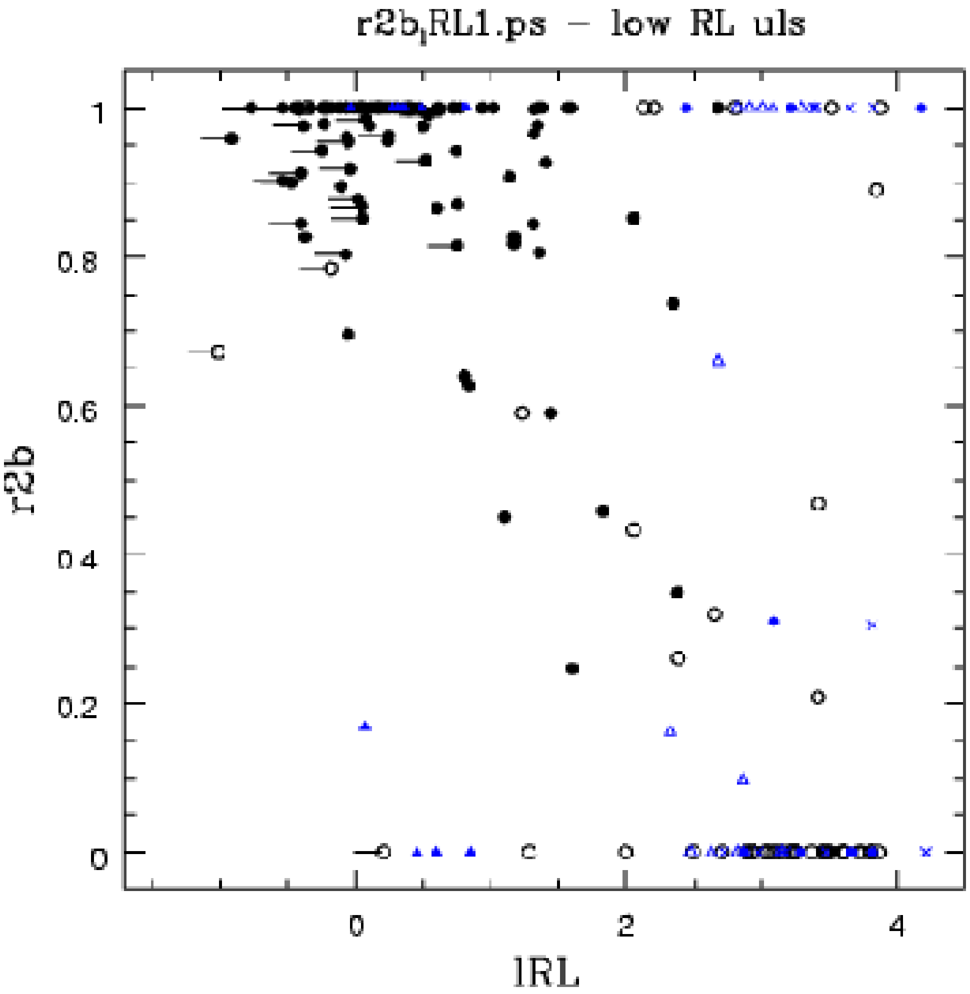




Conclusion: There's a strong inverse dependence of EW and vmax on both radio-loudness RL, and 5GHz luminosity, L5.

These plots illustrate the decreasing dominance of higher relative to lower velocity outflows (divided at 2000 km/s), as radio-loudness increases. This is clearly seen too, when one examines the individual spectra.



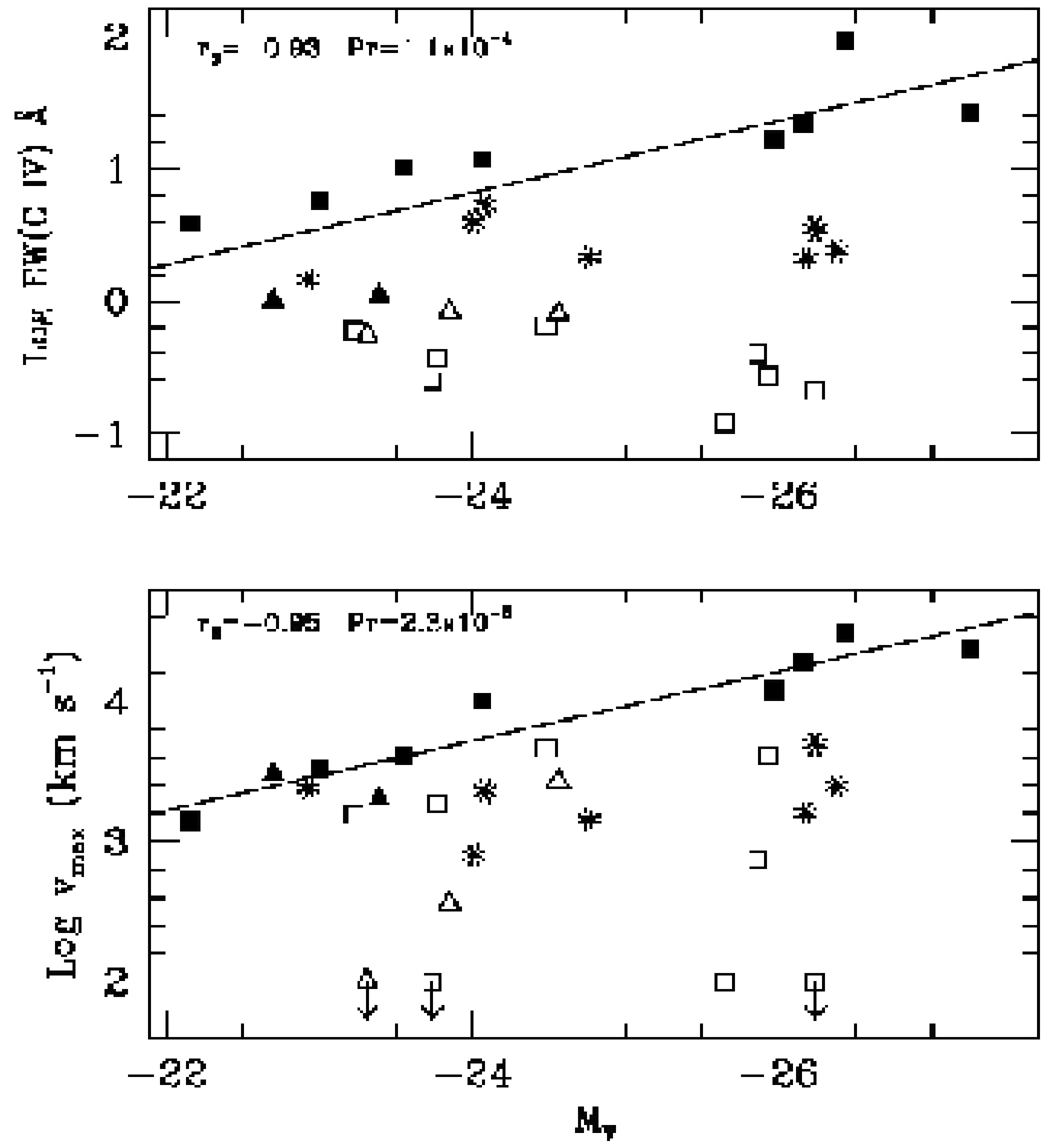


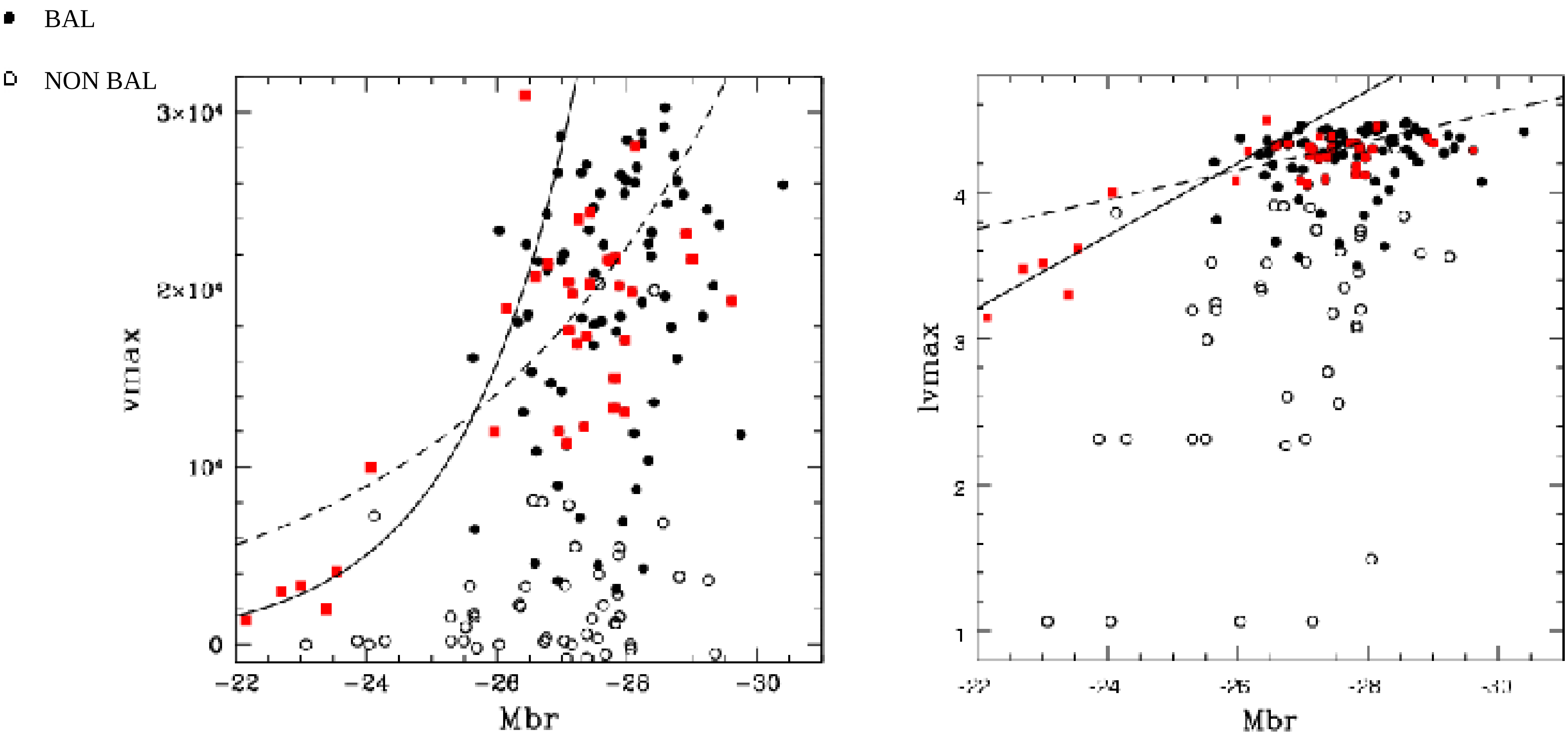
RADIATIVE ACCELERATION

For dust, lines, or bound-free absorption in optically-thin clouds, one predicts a luminosity dependence of radiative acceleration, vmax ∝ Luv^1/4.

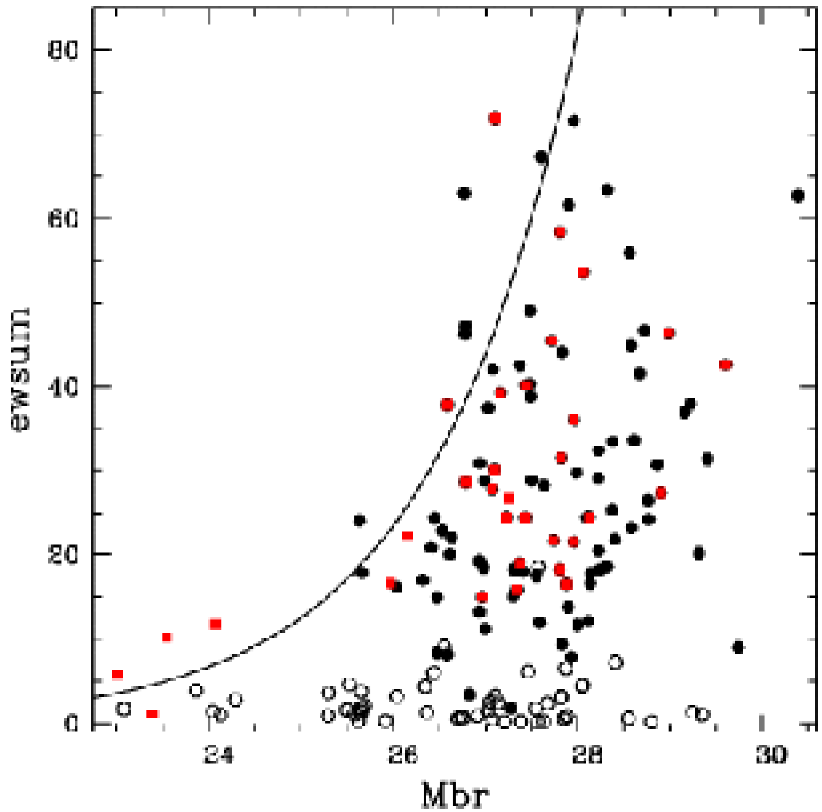
Soft-Xray weak QSOs (SXWQs) show suppression of soft X-ray flux by more than a factor 25, attributed to large columns of outflowing absorbing gas (e.g. Brandt+00, Gallagher+02). Laor & Brandt02 find, for soft X-ray weak QSOs (■), vmax ∝ Luv^0.6, and suggest that the positive slope is consistent with radiative acceleration if launching radius is L-dependent. They also determine a dependence on EW, ∝ L(uv)^0.7.

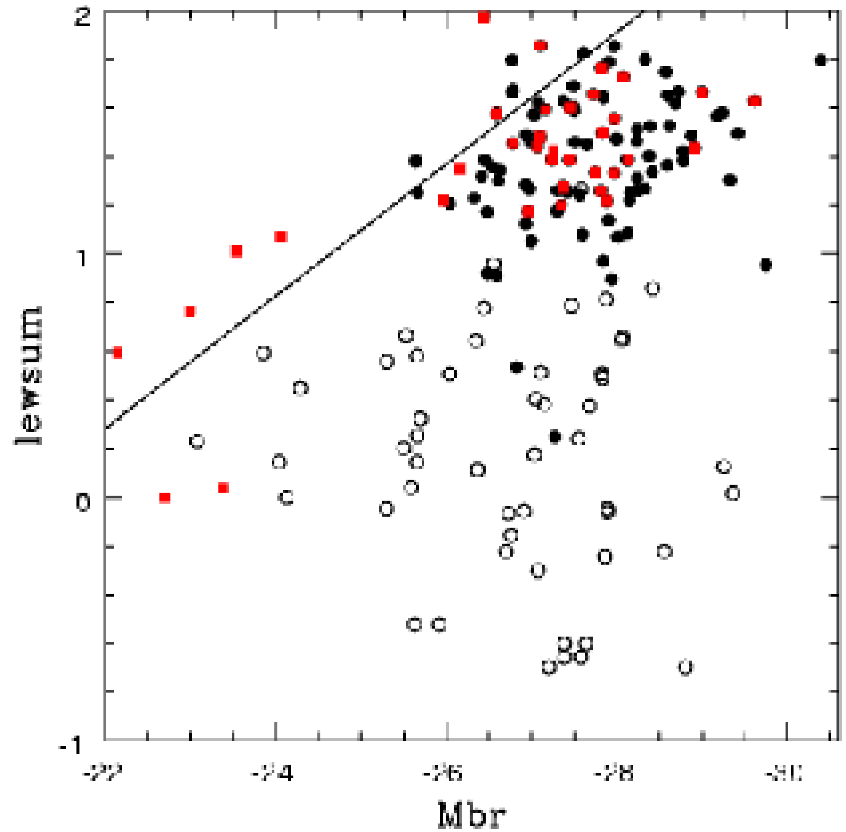
We test these dependences, because BAL QSOs are nearly always soft-X-ray weak.





vmax (left) and log vmax (right) vs. blue magnitude Mbr. The ■ represent SXWQs. Fainter than Mbr=-25 these have NALs (from Laor & Brandt 00), and the more luminous are all BALQSOs. The solid curve is from Laor & Brandt, and the dashed curve is for the predicted L^1/4 dependence. Not all the BALQSOs are as SXW as Laor & Brandts' (α < -1.85 instead of -2.0). We note that higher vmax may be beyond the observational limit (~28000 km/s).





Total EW (ewsum, left) and log (ewsum, right) vs. Mbr. Symbols as for the previous plots. The curve and SXWQ for Mbr >-25 are from Laor & Brandt 02. The curve is consistent with an upper limit to ewsum. However as previously, for the most luminous BAL QSOs, there may be more absorption beyond the 1400 rest wavelength limit.

Summary

- For BAL QSOs, there is a strong inverse dependence of vmax & EW on radio-loudness (RL & L5), with BAL QSOs of intermediate RL bridging the gap between strong BAL QSOs and the NALs common in radio-loud QSOs.
- The data are consistent with a dependence of the upper envelope of vmax and EW on optical luminosity (Mbr).

Interpretation

Inverse dependence of EW on RL and L5

Several authors find a dependence of radio-loudness on black hole mass (Mbh, determined by the virial theorem & Hβ width) of the form L5 ~ Mbh^2 or RL ~ Mbh (Franceschini+98, Lacy+01, Dunlop+03; see also Laor00).

As we find little dependence of radio-loudness on Luv, the inverse dependence of EW on RL or L may be interpreted as an inverse dependence on Mbh, or a dependence on Luv/Mbh (~L/LEdd). BAL QSOs with smaller Mbh are able to accrete at a rate closer to the Eddington limit. Statistically, RLQs with larger Mbh cannot easily accrete near their higher LEdd. The existence of high L/LEdd in high Mbh RLQs requires a very high fuelling rate.

Interpretation, ctd......

The historical occurrence of BALs only in radio-quiet QSOs is not surprising, considering the past use of the more conservative Balnicity Index (Weymann+91) rather than EW.

EW & vmax vs. RL & the radio-loud - radio-quiet dichotomy:

If these relationships are continuous with RL and lL5, then they link radio-loud and radio-quiet QSOs in a continuous distribution.

If the radio-loud and radio-quiet QSOs are distinct populations, then BAL QSOs, by virtue of these relationships, are not true radio-quiet QSOs but belong to the tail of the radio-loud QSO distribution. This might be consistent with past suggestions that BAL QSOs are stronger radio sources as a whole, compared with radio-quiet QSOs (Francis+93,Becker+00).

Orientation:

For similar RL or L5, disk wind models for absorbing outflows could lead to smaller EW and vmax away from the line-of-sight of maximum outflow.

The relationship of vmax and EW of CIV absorption with luminosity (Mbr), appears to be independent of those of vmax and EW with radio-loudness. A contrived! explanation might be that there are absorbing outflows arising from two different places, at different distances from the nucleus. In the case of the (generally) radio-quiet SXWQs, this radius may be luminosity dependent as suggested by Laor & Brandt's results. A component inversely related to radio-loudness may be launched near the inner disk, whose radius depends directly on Mbh. In this case radiative acceleration (vmax) would be independent of luminosity. But why would vmax be dependent on radio luminosity (L5)? Whatever the explanation, BAL outflows are directly or indirectly related to radio jets, hence magnetic fields (see e.g. Konigl & Kartje 1994).