Broad Absorption Line Variability in Radio-Loud Quasars

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We investigate broad absorption line (BAL) variability within a sample of 41 radio-loud quasars (RLQs), selected from SDSS/FIRST data to span a wide range of radio and BAL properties. We have obtained 28 new Hobby-Eberly Telescope (HET) spectra to compare to earlier Sloan Digital Sky Survey (SDSS) data, and we also incorporate archival coverage (primarily dual-epoch SDSS) for a total set of 50 pairs of BAL equivalent width measurements. In general, only modest changes in the depth of segments of absorption troughs are observed, akin to those seen in prior studies of BAL RQQs. Also similar to previous findings for RQQs, the RLQs studied here are more likely to display BAL variability on longer rest-frame timescales. These results suggest that the mechanism of BAL production within this sample of RLQs may be similar to that of the comparison BAL RQQs. BAL variability in RLQs does not obviously depend upon their radio luminosities or radio-loudness values. However, there is a tendency toward greater fractional BAL variability within lobe-dominated (i.e., more edge-on) RLQs, which may be qualitatively consistent with a disk-wind origin for the absorbing outflow.

Sample characteristics

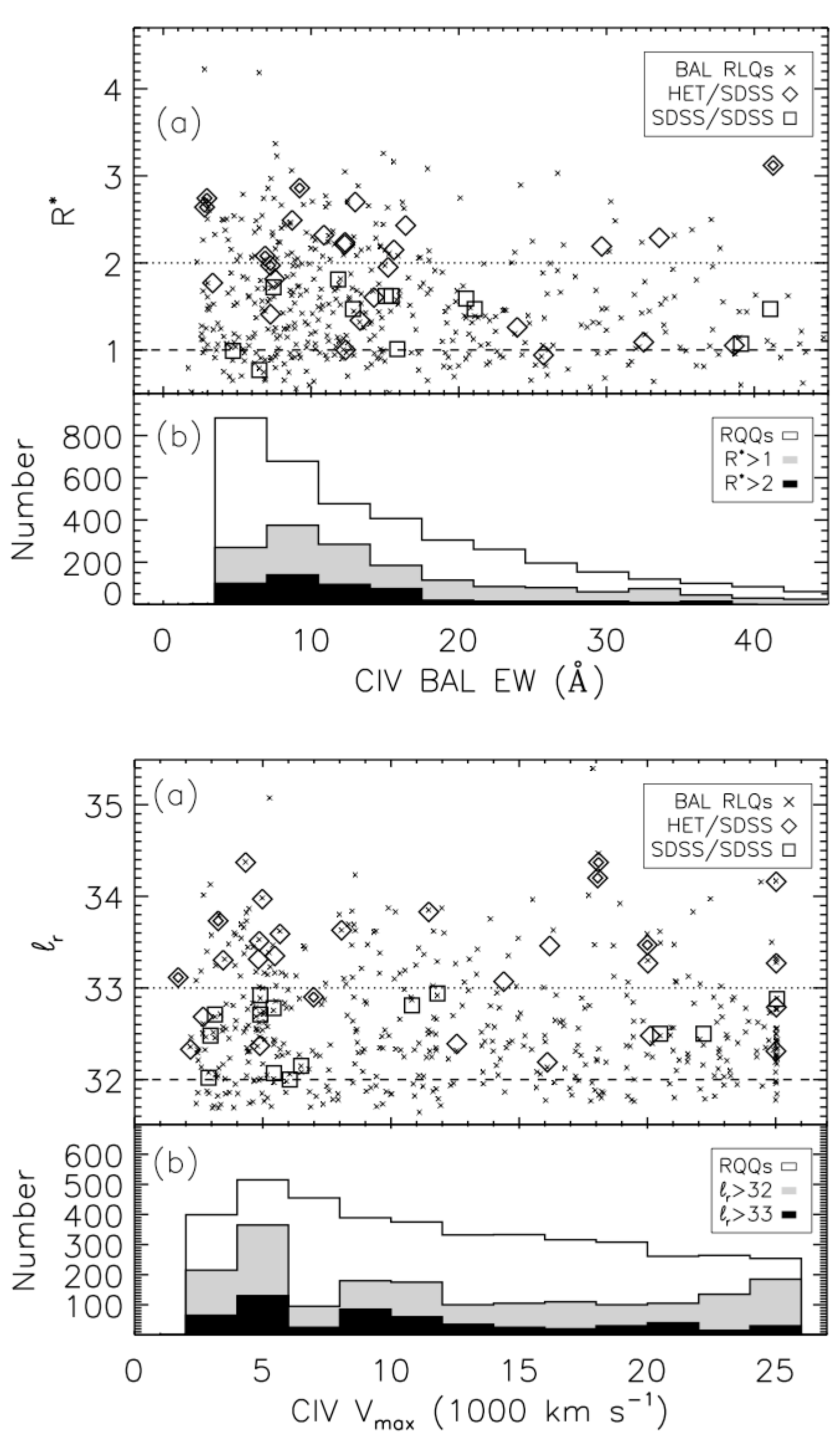


Figure 1: CIV BAL EW (top) and v_{max} (bottom) absorption properties versus R* and ℓ_r. Histograms show distribution for RQQs and for categories of RLQs (the latter shown x5 for clarity).

- To help test whether outflows in BAL RLQs are similar to those in BAL RQQs, we carried out the first systematic study of BAL variability in RLQs.
- Selection is from SDSS BAL quasar catalogs (Trump et al. 2006; Gibson et al. 2009) cross-matched to FIRST 1.4 GHz radio data.
- Obtained 28 new HET spectra; with archival data, have 50 pairs of BAL EWs for 41 RLQs.
- Sample is representative of BAL RLQs in general, spans a wide range in radio loudness and luminosity, and includes a substantial fraction of objects with large EWs or maximum velocities.
- Includes both core-dominated (34) and lobe-dominated (7) RLQs.
- Sample is mostly HiBALs; LoBALs may have distinct properties (White et al. 2007).

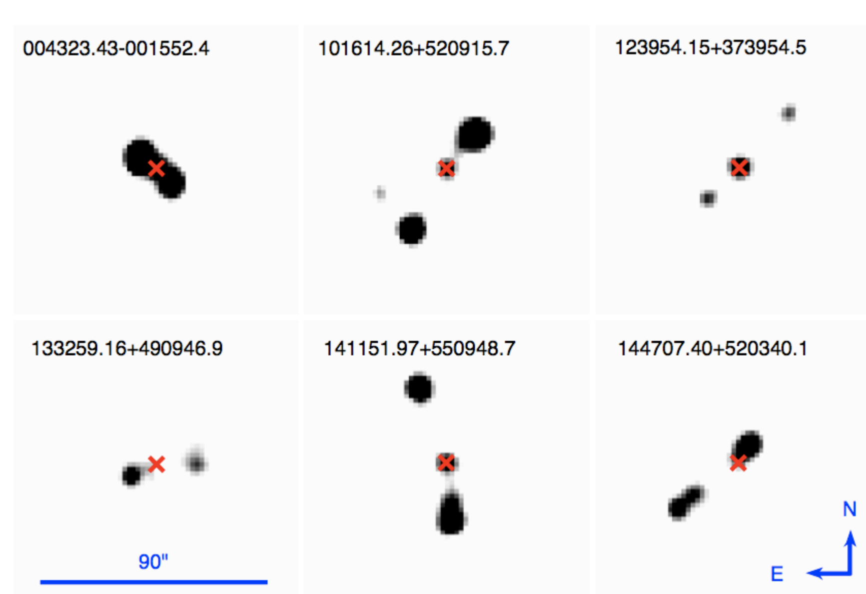


Figure 2: FIRST maps of lobe-dominated BAL RLQs.

RLQs versus RQQs

- Compare variability in our BAL RLQs to prior studies of BAL RQQs (Barlow 1993; Lundgren et al. 2007; Gibson et al. 2009, 2010; see also Capellupo et al. 2011)
- Construct a subsample of RQQs with timescales consistent with the distribution of RLQ separations.

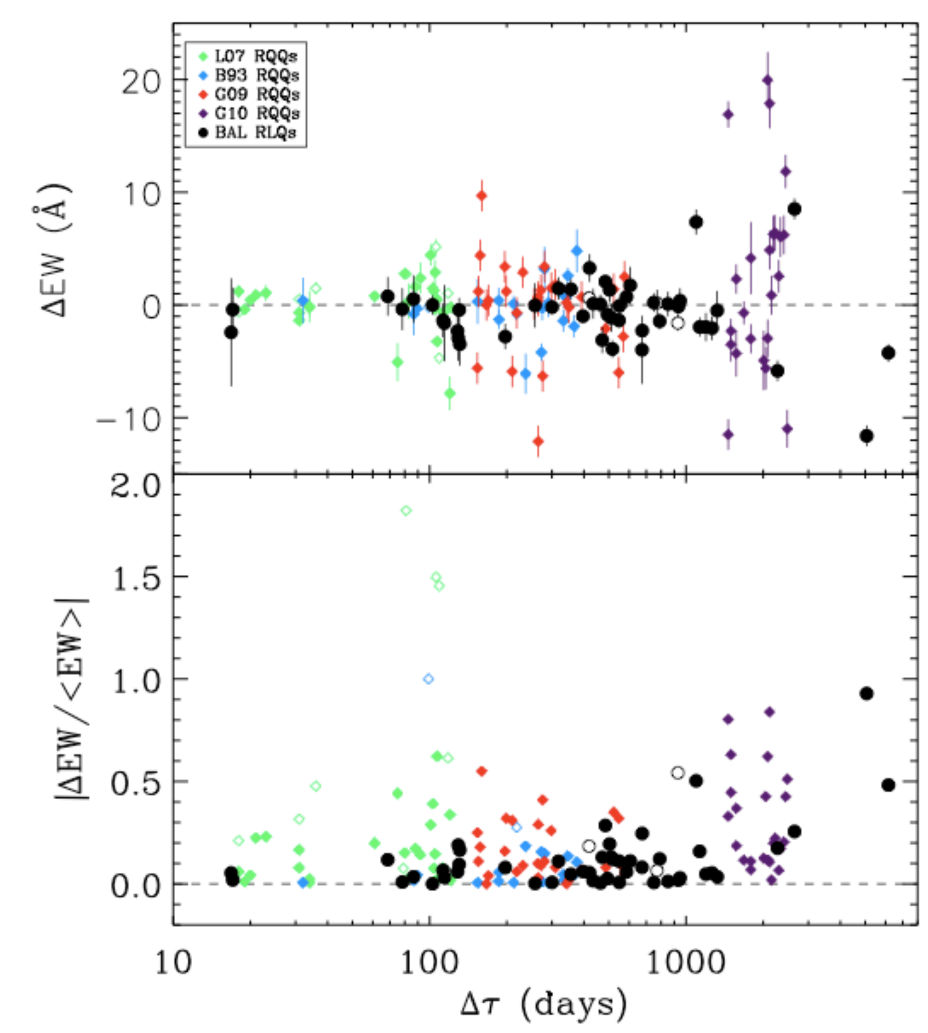


Figure 5: Change in BAL EW (top; expressed as absolute fraction, bottom) versus rest-frame timescale for RLQs and RQQs.

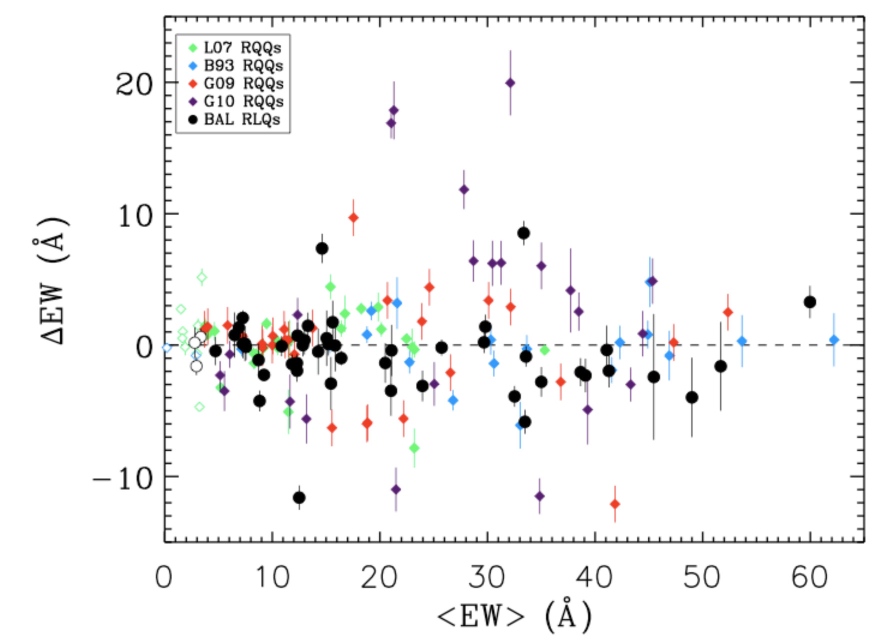


Figure 6: BAL ΔEW versus <EW>

- |ΔEW/<EW>| is significantly correlated with Δτ, and the mean |ΔEW/<EW>| is 0.17±0.04 (0.07±0.01) for Δτ>500d (<500d) for RLQs.
- The corresponding mean values for matched BAL RQQs are somewhat greater (0.13±0.02 and 0.29±0.04, respectively), but the full distributions of |ΔEW/<EW>| are consistent.
- Both RLQs and RQQs show a positive correlation between |ΔEW| and <EW> but a negative correlation between |ΔEW/<EW>| and <EW> (Spearman coefficients of 0.3 and -0.3, significance >0.95). This is due to BALs varying within segments of absorption troughs.

Measuring BAL variability

- HET observations carried out using the Low-Resolution Spectrograph, typically with the g2 grating and a 1.5" slit which provides a spectral resolution of ~850.
- HET/LRS data reduced in IRAF following standard methods. The flux was normalized (with an implicit correction for reddening) through fitting the continuum as a low-order Chebyshev polynomial (as was applied similarly to each associated SDSS spectrum).
- The CIV emission line was modeled as a Voigt profile (including a linear residual continuum term) and divided out prior to measuring BAL properties.
- We determine the EW for each spectrum, and check pairs of spectra for significant variability. We also assess and constrain any changes in velocity within BAL regions.

Figure 3: Left: example of CIV emission-line modeling and BAL EW measurement and variability assessment for J141546.24+112943.4. Right: additional illustrations of BAL variability including archival data (top: PG 1004+130, IUE+HST; bottom, 101614.26+520915.7, Keck+HET)

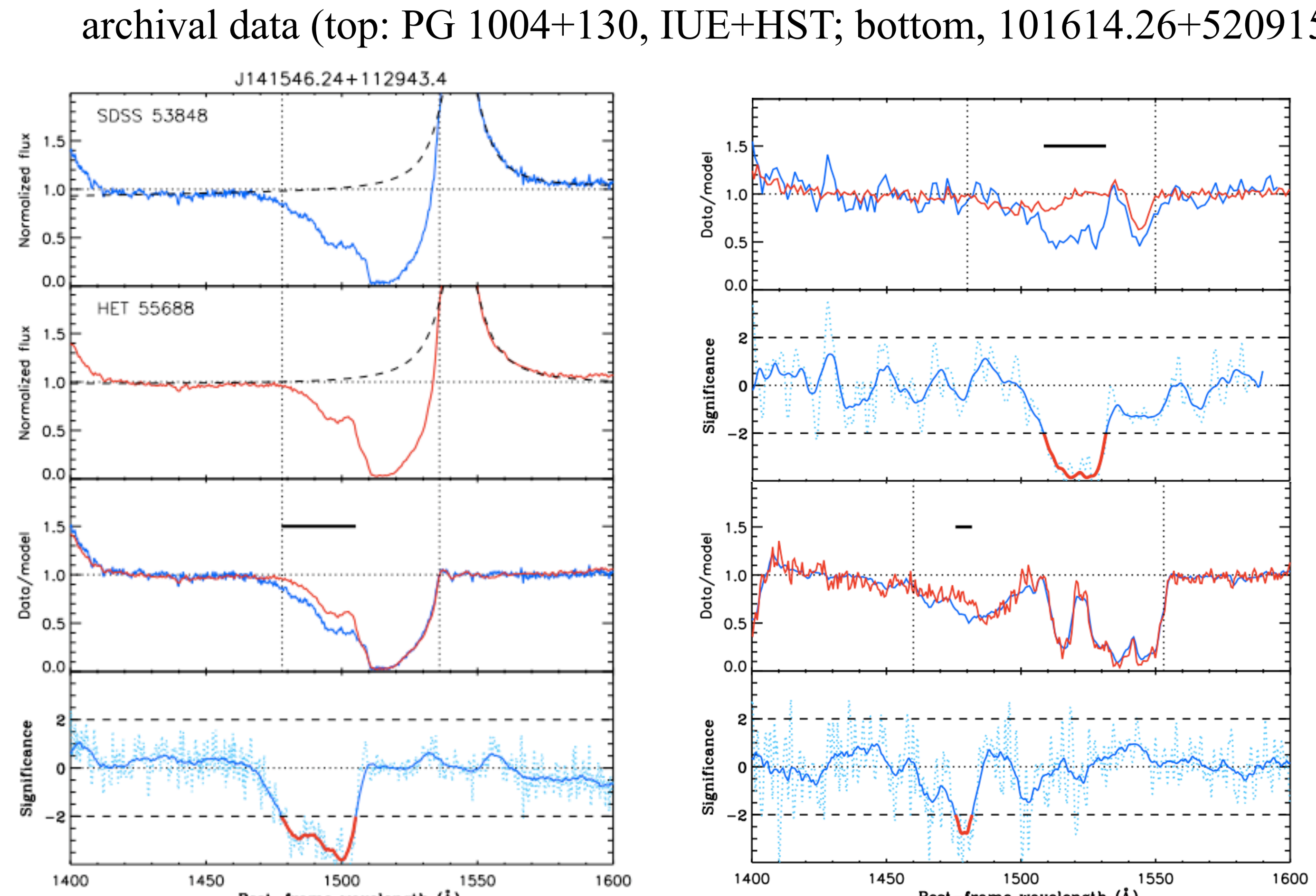
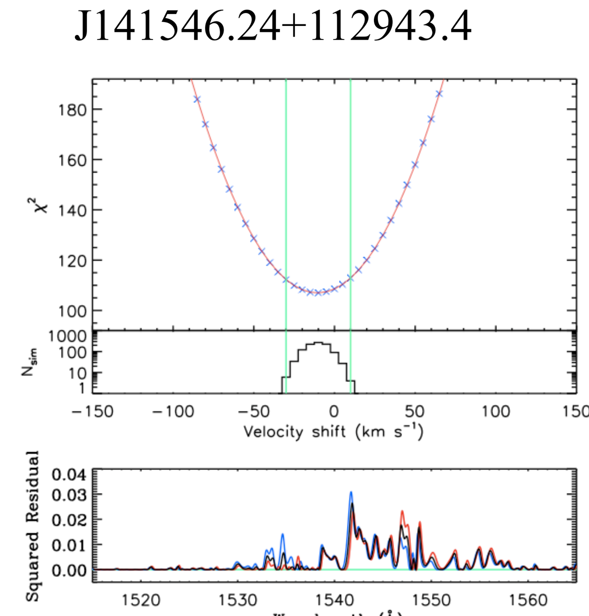


Figure 4: example check of velocity shift, here consistent with zero for J141546.24+112943.4



Trends with radio properties

- The full sample shows no significant correlations between |ΔEW| or |ΔEW/<EW>| and either ℓ_r or R* (Spearman significance <0.9, absolute value of coefficients<0.3).
- Even omitting three long-separation measurements for the lobe-dominated PG 1004+130, the mean |ΔEW/<EW>| is 0.23±0.07 for lobe-dominated RLQs, higher than the 0.07±0.01 for core-dominated RLQs.
- Other examples known (Hall et al. 2011) but due to potential influence of Δτ and <EW>, more objects are needed to confirm enhanced BAL variability in lobe-dominated RLQs.

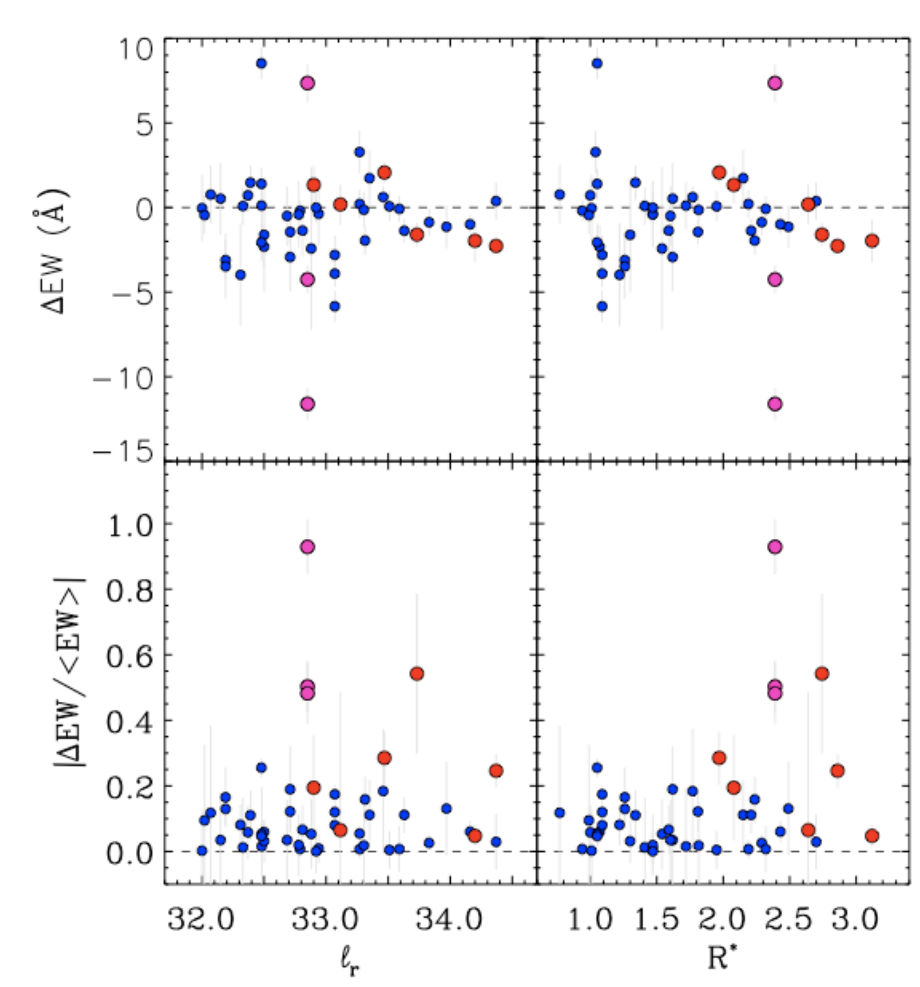


Figure 7: BAL variability as a function of radio loudness and luminosity, for core-dominated (blue) and lobe-dominated (red) RLQs. The lobe-dominated PG 1004+130 (magenta) has long-separation archival coverage.

Barlow, T. A. 1993, Ph.D. Thesis
Capellupo et al. 2011, MNRAS, 413, 908
Gibson et al. 2009, ApJ, 692, 758
Gibson et al. 2010, ApJ, 713, 220
Hall et al. 2011, MNRAS, 411, 2653
Lundgren et al. 2007, ApJ, 656, 73
Trump et al. 2006, ApJS, 165, 1
White et al. 2007, ApJ, 654, 99

The Hobby-Eberly Telescope (HET) is a joint project of the University of Texas at Austin, the Pennsylvania State University, Stanford University, Ludwig-Maximillians-Universitat Munchen, and Georg-August-Universitat Gottingen. The HET is named in honor of its principal benefactors, William P. Hobby and Robert E. Eberly.