Multifrequency Studies of Radio-Loud Broad Absorption Line Quasars

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Abstract

The origin and nature of broad-absorption line (BAL) quasars is not yet fully understood. In the `orientation scheme' all quasars present the BAL phenomenon but it is only seen in a fraction observed from a certain angle. In the `evolutionary scenario' BAL QSOs are in an early stage of their evolution before becoming normal quasars. We are currently studying a sample of radio-loud BAL QSOs to find clues for the correct scenario via a synchrotron aging analysis, Faraday rotation measures and cool dust contents.

Motivation: Unusual BAL QSO 1624+37

Our study of a sample of radio-loud BAL QSOs is motivated by the peculiar properties of 1624+37, a z=3.377 quasar discovered in a search for high-z QSOs (see Fig 1):

- It is among the most radio-luminous BAL QSOs known:

$P_{1.4\,GHz} = 5.2 \times 10^{27}$ W/Hz (H_0 = 71 km/s/Mpc, Ω_M = 0.27, Ω_Λ = 0.73)

- It has the second highest Rotation Measure among extragalactic radio sources:

$RM = -18350 \pm 570$ rad/m^2

- It is a compact GPS source with $\alpha^{4.85}_{10.5}$ = -1.04, unresolved in FIRST maps, with an angular extension $\lesssim$ 0.5 kpc.
- The FeII UV191 1787 Å emission line is very prominent
- The BAL trough is detached by 21000 km/s and extends to velocity v= - 29000 km/s

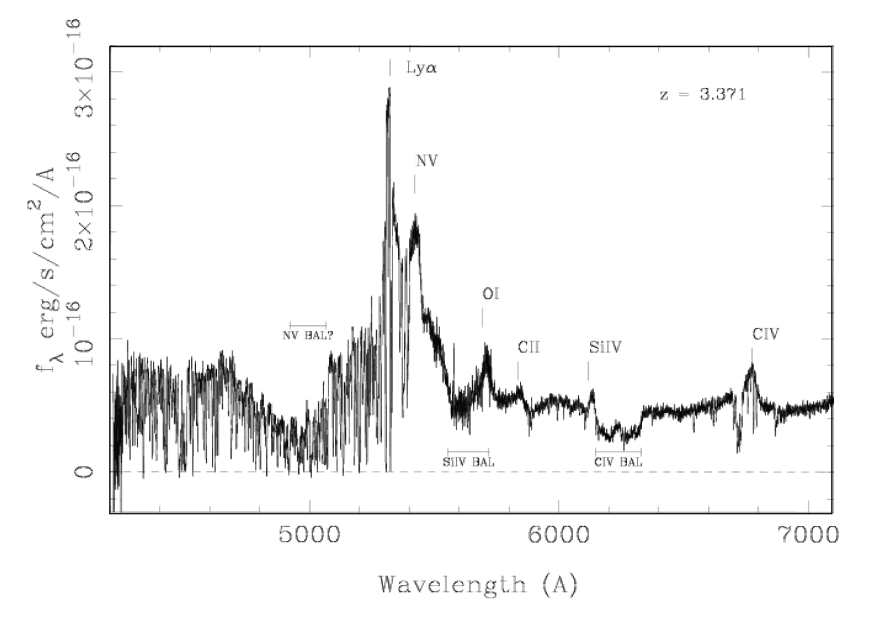

Fig 1. WHT/ISIS Optical Spectrum of BAL quasar 1624+37, showing the main features identified. A detailed study of the different absorbers can be found in Benn et al. (2006).

Evolution vs. Orientation Schemes

Orientation seem to play a role in the understanding of the BAL phenomenon. Elvis (2000) presents a simple model in which all QSOs have BAL outflows, but they are only seen viewed from a certain angle (see Fig. 2).

Other authors (e.g. Sanders et al. 2001) suggest that BAL QSOs are in an early evolutionary stage while becoming "normal" quasars.

UV/Optical and mm/sub-mm studies of radio-quiet BAL QSOs tend to favour orientation: Weymann et al. (1991), Reichard et al. (2003), Willott et al. (2003).

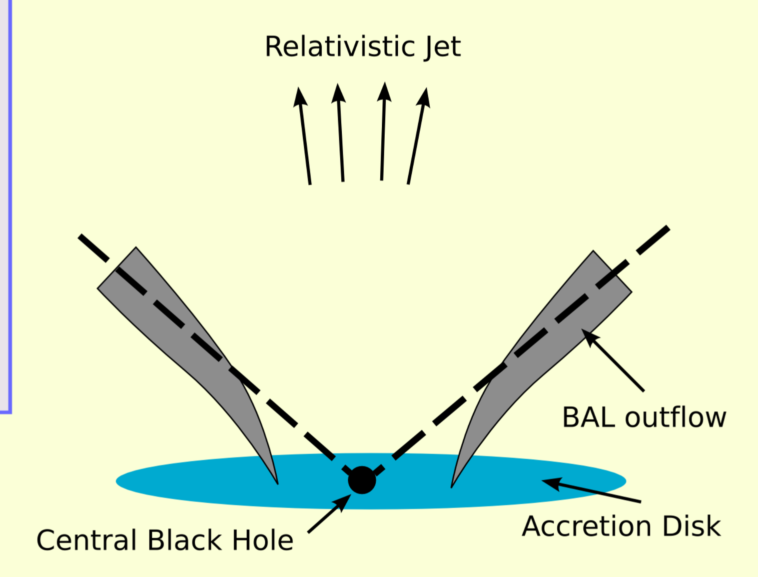

Fig 2. Schematic model from Elvis (2000). BALs are only see from certain angles.

Observational Campaign: Radio-continuum, sub-mm

We have started a radiocontinuum follow-up of a sample of 18 radio-loud BAL QSOs from the literature satisfying:

- S(1.4 GHz) > 15 mJy
- Point-like in FIRST maps.

We observed the radiocontinuum emission with the 100-m Effelsberg radiotelescope at 4.8, 8.4 and 10.5 GHz, in full polarization. JCMT/SCUBA observations have been initiated and delivered so far results for two QSOs at 350 and 666 GHz.

Fig 3. shows the Spectral Energy Distribution (SED) of 4 BAL QSOs. A few flux densities were extracted from public databases.

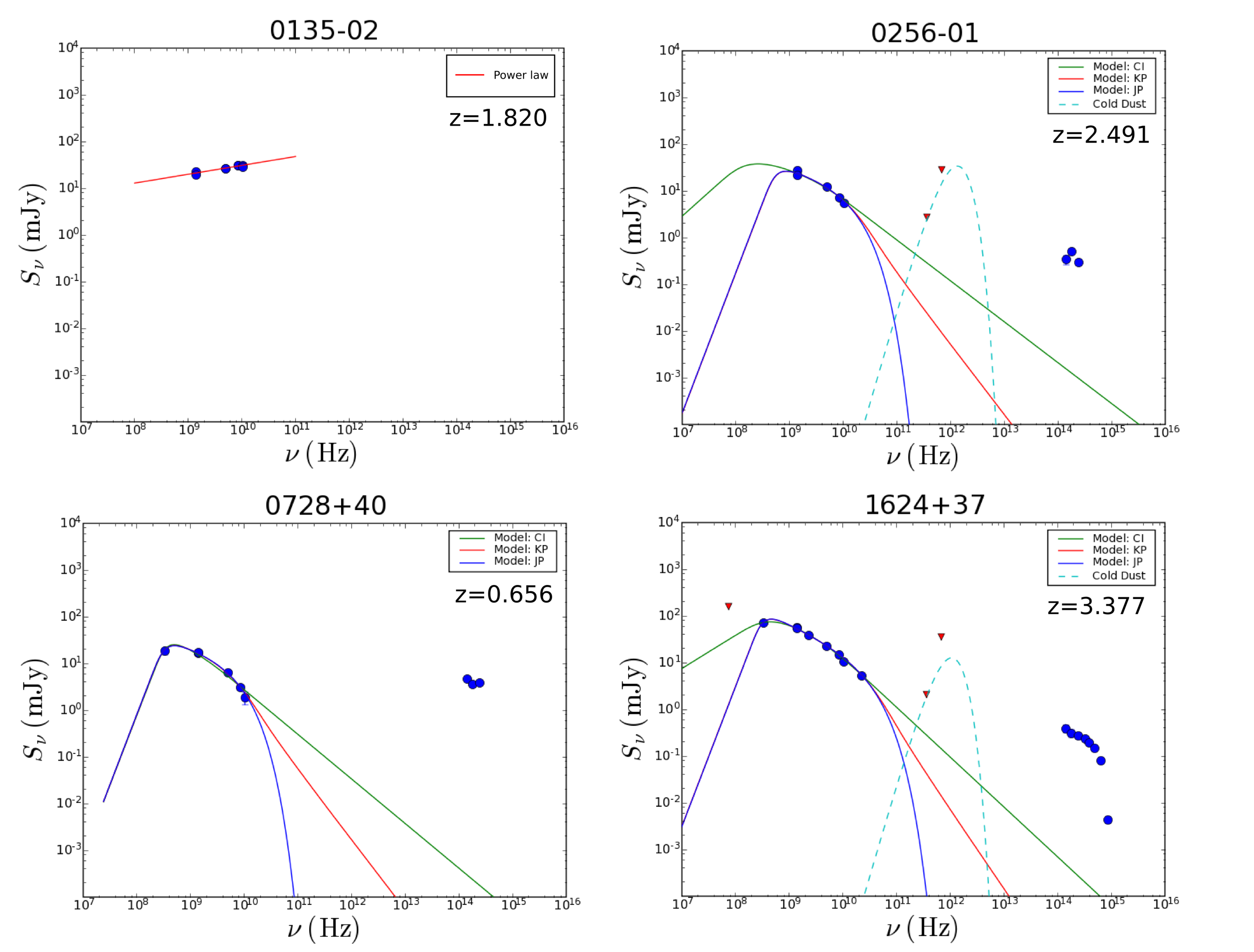

Fig 3. SEDs of 4 BAL QSOs from our sample. Blue points are flux densities and red triangles 3-sigma upper limits. Data are taken with Effelsberg, SCUBA (1624+37, 0256-01), VLA (1624+37 at 22 GHz) and collected from public catalogs (SDSS, 2MASS, FIRST, NVSS, WENSS, etc). Solid lines correspond to synchrotron models fitted to the data. The dotted lines are the maximun emission from cold dust consistent with the SCUBA upper limits.

Synchrotron aging and Cold Dust Modelling

We have fitted the data to different synchrotron emission models in order to have an estimate of the radiative age (Murgia et al. 1999) computed as follows:

$$t_{syn} = 1610 \frac{B^{1/2}}{B^2 + B_{CMB}^2} \frac{1}{\sqrt{\nu_{br}(1+z)}} \text{ Myr} \quad , \quad B_{CMB} = 3.25\,(1+z)^2\ \mu G$$

To compute the magnetic field, equipartition conditions are assumed. This simple situation is not always realistic, specially in core/jet-dominated sources showing flat spectra, like 0135-02. The particle ages depend on the break in the high frequency part of the radio spectrum, often beyond the observed range.

The fits yield radiative ages ranging from ~ 10^3 up to 10^6 years (median ~ 75000 years), being these consistent with typical radiative ages for CSS sources (e.g Murgia et al. 1999). For lobe-dominated sources this is an indicator of their youthness. For lobe/hot spot dominated ones, this value is likely to represent the age of the particles in these active regions.

As can be seen in Fig 3, SCUBA observations were non-detections, and with the upper limits we have fitted a greybody with T = 45K and emissivity spectral index 2 (using k=0.068 at 250 GHz). This yields dust masses of 5 x 10^7 (1624+37) and 8 x 10^7 (0256-01) solar masses. Dusty high-z QSOs have ~ 10^8 to 10^9 solar masses (Beelen et al. 2006), indicating that the observed BALs are not specially dust rich.

Polarization: Rotation Measures

The rotation measure (RM) provides information about the ionized medium between the synchrotron source and the observer. The measured polarization angle follows a dependence with the wavelength as follows:

$$X = X_0 + RM\ \lambda^2$$

Most of the BAL QSOs from the sample appear unpolarized at 1.4 GHz in NVSS. This is likely to be due to Faraday depolarization. In the Effelsberg bands apart from 1624+37, only 2300-10 shows fractional polarization with significance larger than 3-sigma, but the inferred RM from only 3 points is low: RM = 270 ± 10 rad/m^2. Additional high frequency VLA observations are currently being analysed which will complement the existing data and will allow more precise determination of RM.

Summary and Future work

- In spite of the caveats mentioned, a synchrotron aging analysis shows that radio-loud BAL QSOs have radiative ages consistent with those of CSS sources, implying that they are young sources if they are lobe-dominated.
- SCUBA non-detections for 2 BAL QSOs imply dust masses small compared to typical dusty high-z quasars.
- New VLA observations (15, 22 and 43 GHz) performed in A configuration are useful to (i) sample the SED region that determines the break in to improve the radiative age determination; (ii) provide additional polarization measurements at high frequencies where depolarization is less likely; (iii) improve the morphological information (resolution ~ 0.05 arcsec at 43 GHz) to classify them as lobe- or core-dominated.

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