The dependence of the BAL QSO fraction on redshift and quasar parameters: evidences for QSO feedback?

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1. Introduction

The relation between quasar processes and the evolution of their host galaxies is among the most interesting open issues in modern astrophysics. One of the most interesting mechanisms that can provide such connection is usually called “quasar feedback” (e.g., Cattaneo *et al.* 2009), and is thought to work through nuclear gaseous winds powered by the energetic emission of an active galactic nucleus (AGN) that can deplete the galactic environment of cold gas, eventually quenching both black hole growth and star formation. Winds are commonly observed in quasars through the detection of high-velocity structures in their spectra, among which the most commonly studied are the broad absorption lines (BALs; Weymann & Foltz 1983, Turnshek 1988). Understanding the statistics of BAL QSOs is a crucial key point in establishing what kind of relationship exists between the gas ejected in this way from the quasar and the surrounding environment of the host galaxy; this is usually inferred starting from large catalogs of quasars, such as the Sloan Digital Sky Survey (SDSS), and the corrected mean BAL QSO fraction obtained in this way ranges from ~ 16% to ~ 40% (Reichard *et al.* 2003, Trump *et al.* 2006, Knigge *et al.* 2008, Gibson *et al.* 2009, Allen *et al.* 2011). Additionally, this fraction has been recently found to strongly evolve with redshift, peaking at z ~ 2.5 (Allen *et al.* 2011). In this paper, we analyze the statistics of BAL QSOs in a sample of reddened quasars collected during a tailored search for red QSOs (Fynbo *et al.* 2013, Krogager *et al.* 2014) in which a high number of BAL QSOs has been detected. **We find that the BAL QSO fraction is strongly evolving with redshift, peaking at z ~ 2.5 where several other quantities (such as QSO space density, SFR density, gas metallicity) are also peaking or varying: this fits well into an evolutionary scenario for BAL origin.** Additionally, **the BAL QSO fraction decreases with reddening: this may be explained either by invoking the absence of “cleaning” outflows in the most reddened objects, which remain therefore enshrouded by the host halaxy's dust (e.g., Farrah *et al.* 2007), or by an orientation-dependent effect in which these objects are viewed along a line of sight that intercepts a dusty torus around the central engine but not the BAL outflows.**

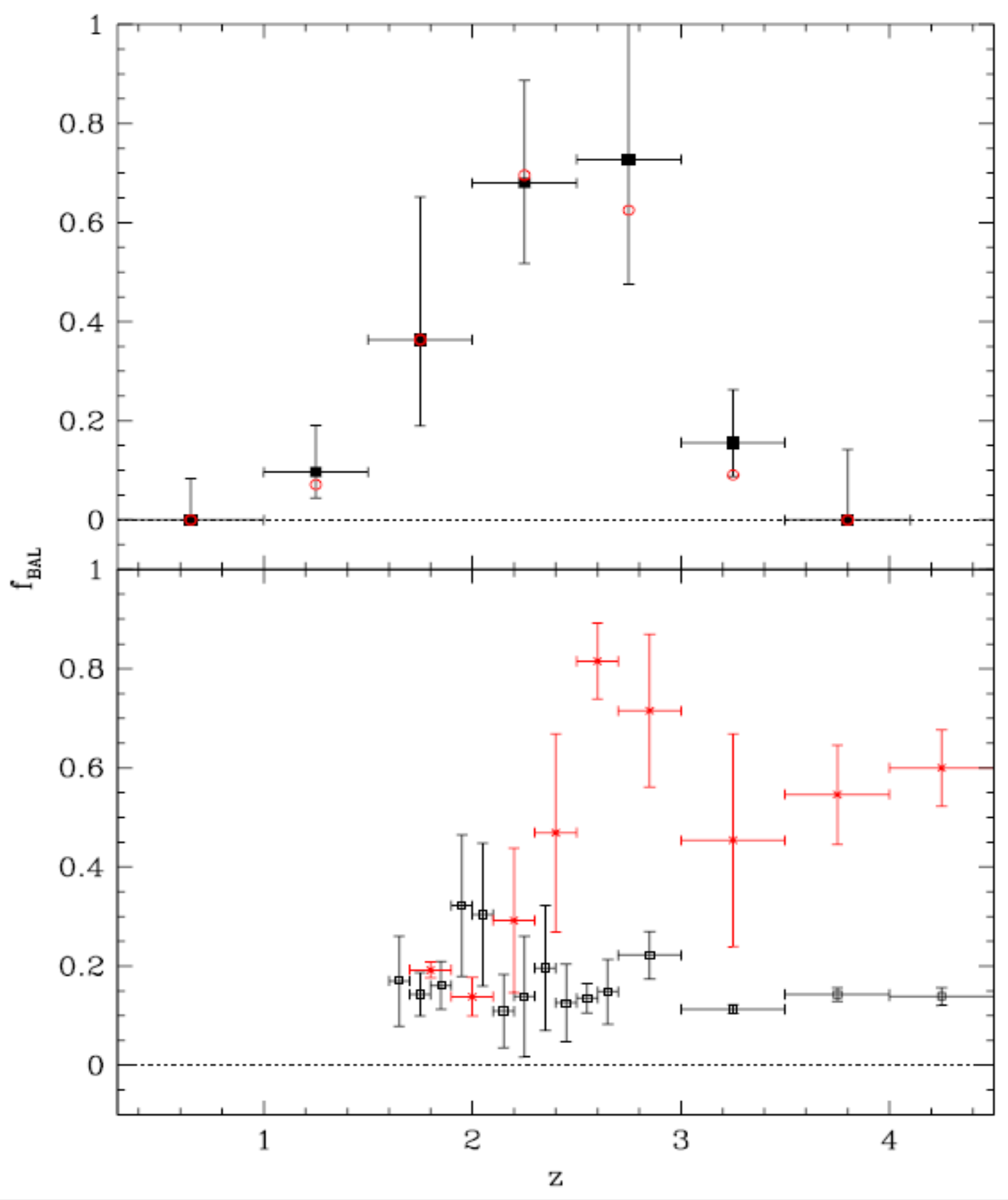
2. The *observed* BAL QSO fraction

- The sample was originally selected by looking for quasars reddened by dusty foreground absorbers in a search for damped Lyα absorption (DLAs). The color cuts were chosen in order to select very red objects. This provided a total sample of 145 QSOs so far, most of which are intrinsically reddened and show BALs.

- BAL QSOs in the sample have been identified by computing for each spectrum the classical “balnicity index” (BI; Weymann *et al.* 1991) for Si IV, C IV, Al III and Mg II:

$$BI = -\int_{3000}^{25{,}000} \left[1 - \frac{f(v)}{0.9}\right] C\, dv$$

- This provided a sample of 37 BAL QSOs, over which the dependence of the *observed* BAL QSO fraction on redshift, reddening and luminosity has been computed (Figs. 1 and 2).



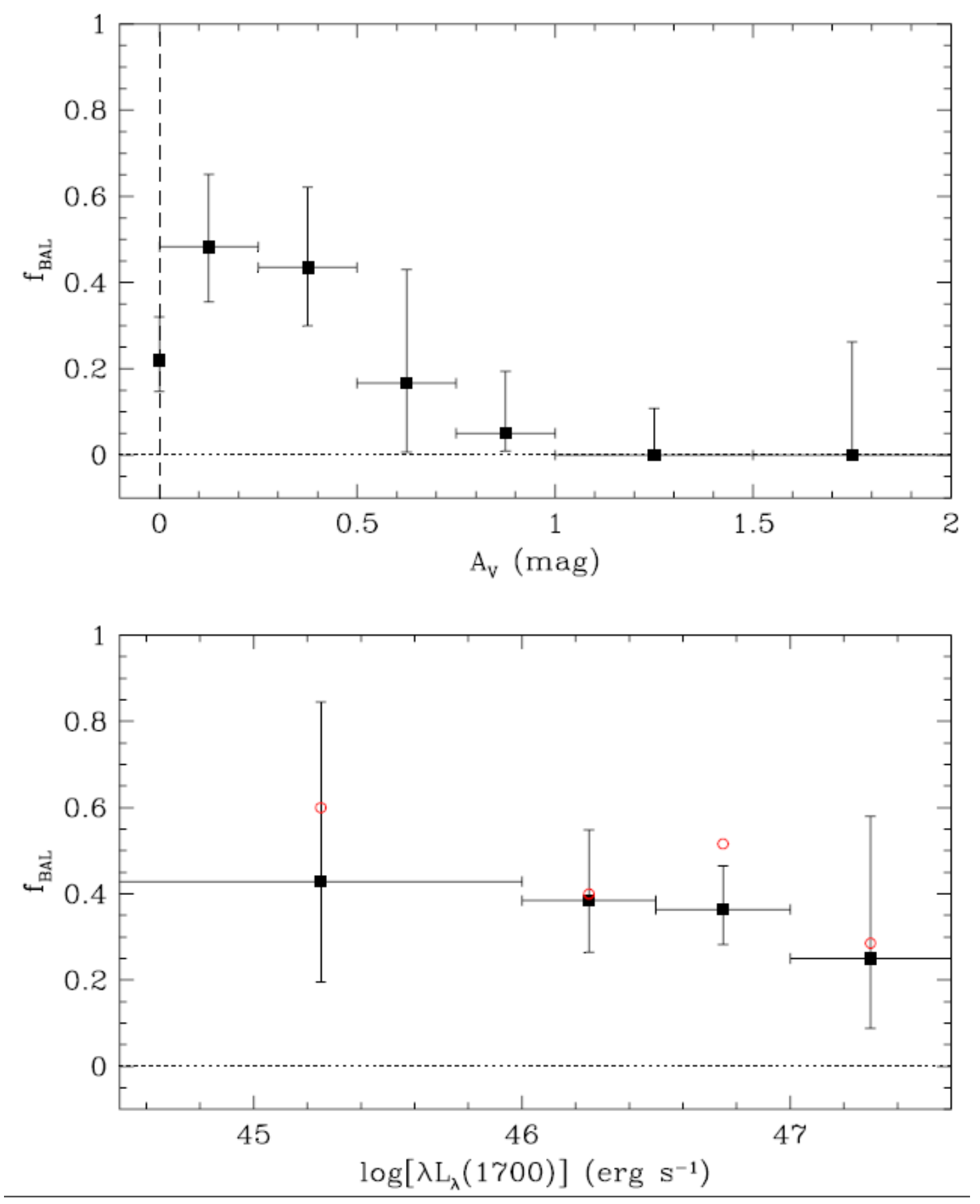


Fig. 1 – Upper panel: *Evolution with redshift of the observed BAL QSO fraction. Black dots represent the fraction computed over all the quasars, red dots are the values of the fraction for the intrinsically reddened objects alone.* Lower panel: *observed* (black) *and corrected* (red) *BAL QSO fraction from SDSS quasars (Allen* et al. *2011).*

Fig. 2 – Upper panel: *dependence on reddening of the observed BAL QSO fraction.* Lower panel: *dependence on monochromatic luminosity of the observed BAL QSO fraction. Symbols are like those shown in the upper panel of Fig. 1.*

3. Correction for selection biases

- In order to quantify the possible biases introduced by the used selection criteria, we computed the difference in QSO detection efficiency for non-BAL and BAL QSOs by producing mock spectra for both types of quasars with various levels of monochromatic luminosity, dust reddening and BAL-like absorption, and then processing them through the adopted color cuts (Fig. 3).

- The results show how our selection is less biased compared to previous results (e.g., SDSS; Figs. 4 and 5). Therefore, the shapes of the *intrinsic* BAL QSO fraction dependencies are maintained with respect to those observed.

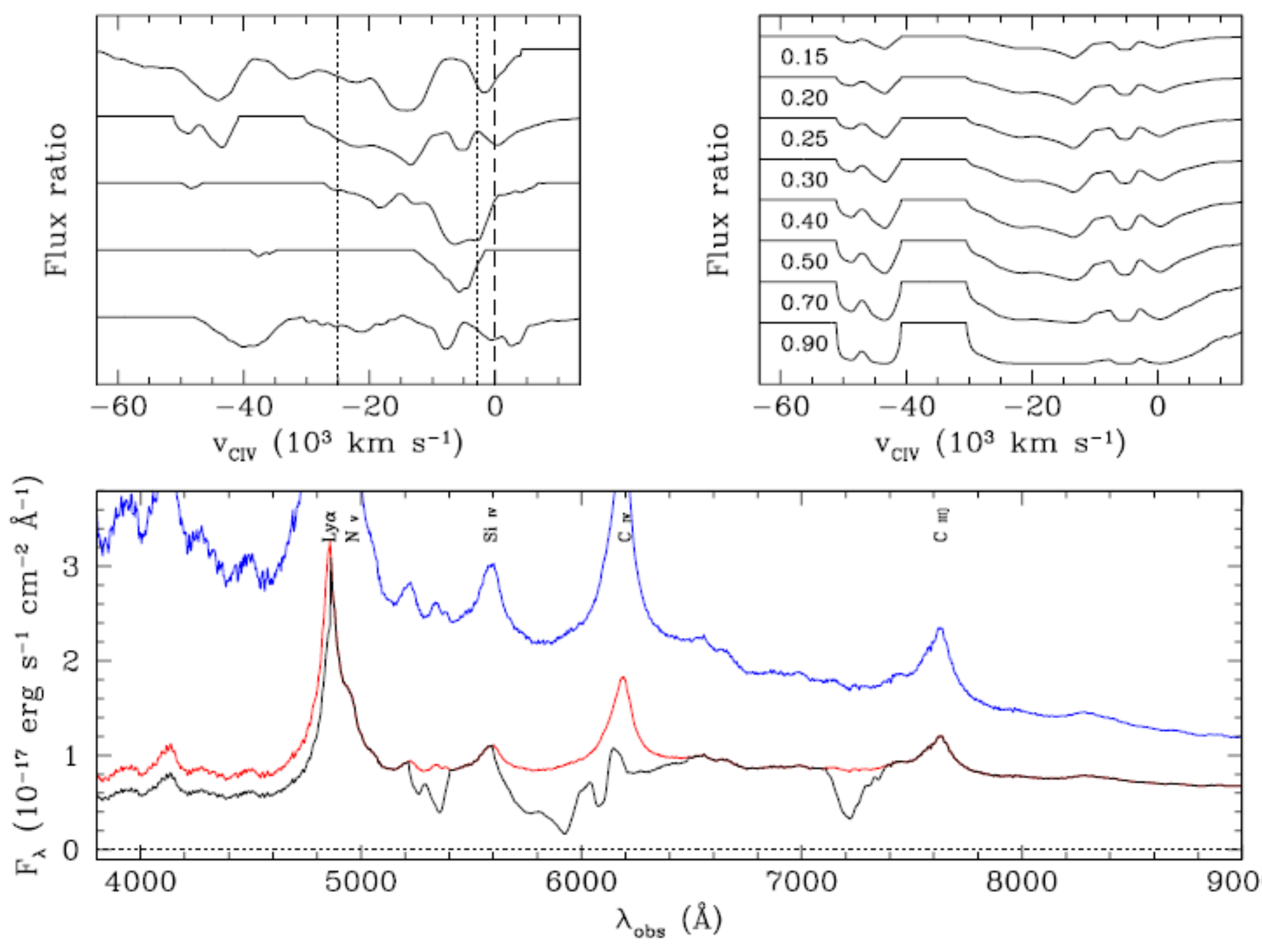
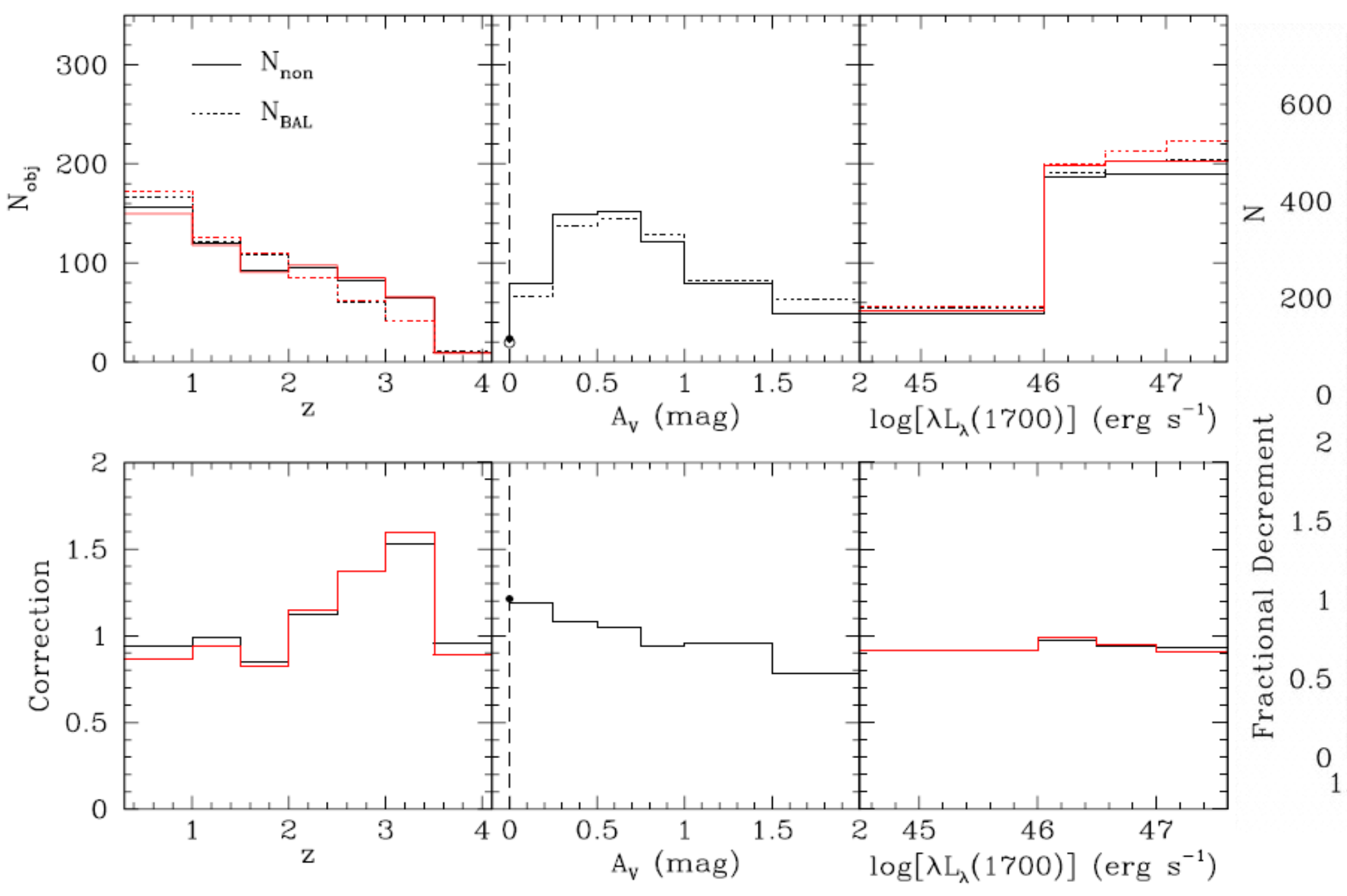
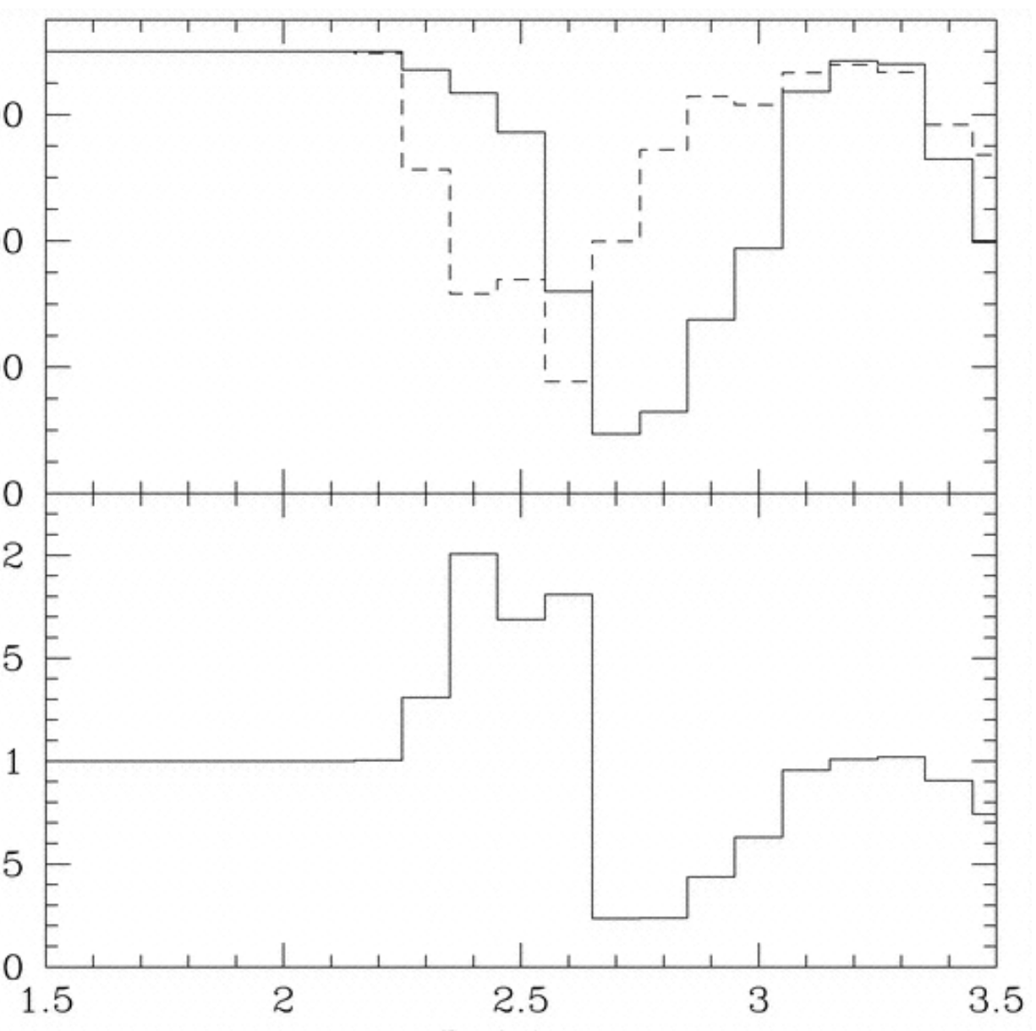


Fig. 3 (right) – Upper left panel: *High-ionization BAL profiles extracted from five BAL QSOs in our sample. C IV zero velocity (*dashed*) and intervals for BI evaluation (*dotted*) are indicated.* Upper right panel: *result of the scaling in mean depth (see Allen* et al. *2011) for the second trough in the left panel. Lower panel: example of “mock” reddened low-ionization BAL QSO at z = 3. Positions of major emission lines are indicated.*

Fig. 4 (down left) – *Upper panels: efficiency in detecting non-BAL (*continuous line*) and BAL QSOs (*dotted line*) with redshift, reddening and monochromatic luminosity, both for all simulated objects (*black*) and for intrinsically reddened spectra only (*red*).* Lower panels: *correction functions derived from the fractions of detected objects (color code as in the upper panels).*

Fig. 5 (down right) – *For comparison with our redshift correction, the correction obtained by Reichard* et al. *2003 for SDSS quasars is shown in the lower panel.*





4. The *intrinsic* BAL QSO fraction

- **The *intrinsic* BAL QSO fraction is confirmed to peak at z ~ 2.5, where several other cosmological quantities are found to peak or vary.** This fits well within an evolutionary scenario for BAL origin, in which outflows are closely related to quasar activity, star formation rate and chemical evolution of the gas in the host galaxy.

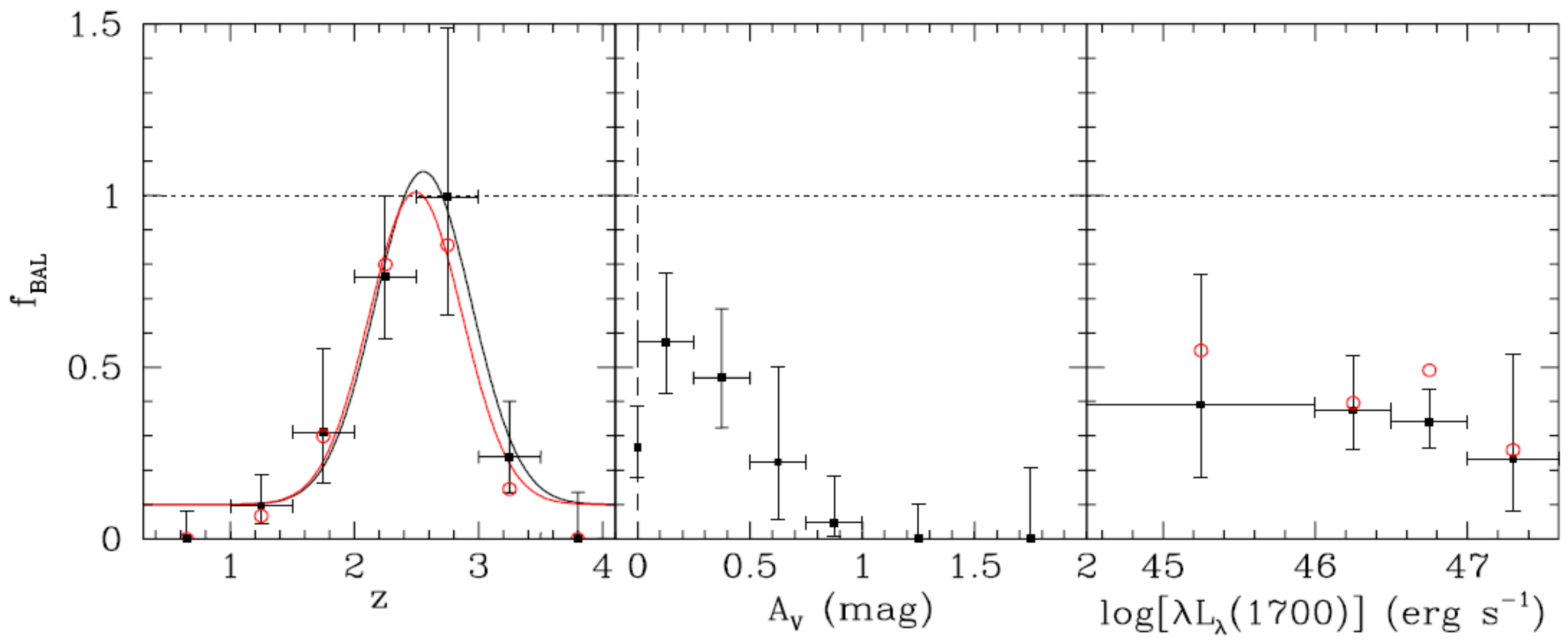


Fig. 6 – *Evolution of our corrected BAL QSO fraction in redshift, dependence on reddening and monochromatic luminosity (color code as per the upper panel of Fig. 1). Gaussian fits to the redshift evolution of the BAL QSO fraction on the total sample (*black*) and on the reddened objects only (*red*) are shown.*

- A simple Gaussian fit to the redshift evolution of the BAL QSO fraction provides the following parameters for the peak in redshift and the FWHM:

All objects	Reddened objects only
$z_{max} = 2.556 \pm 0.043$	$z_{max} = 2.494 \pm 0.042$
FWHM = 0.91 ± 0.12	FWHM = 0.88 ± 0.12

These FWHMs translate in an interval of cosmic time Δt ~ 1 Gyr (standard cosmology: $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$), which is ~ 7 to 30 times larger than typical QSO lifetimes t_Q = 30-130 Myr (Yu & Tremaine 2002).

- Additionally, the fraction peaks at A_V ~ 0.125 and moderately decreases with luminosity: the first can be interpreted either as **a lack of outflows in the dustiest objects or an orientation effect** (objects viewed through a dusty torus), while the second can provide further constraints in future structural models of BAL outflows in quasars.