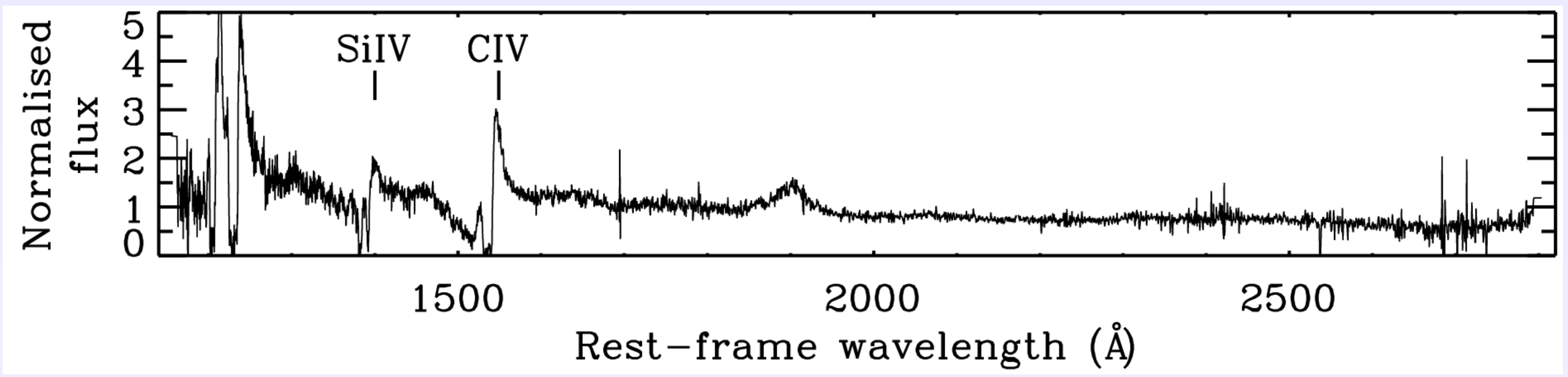
A dramatic increase in the fraction of BALQSOs at the epoch of rapid black hole growth

James T. Allen[1*], Paul C. Hewett[1], Natasha Maddox[2], Gordon Richards[3], Vasily Belokurov[1]
[1]Institute of Astronomy, University of Cambridge [2]Astrophysikalisches Institut Potsdam [3]Department of Physics, Drexel University *email: jta@ast.cam.ac.uk

MNRAS in press
arXiv:1007.3991

1. Introduction

Broad absorption line quasars (BALQSOs) offer an opportunity to directly trace the kinematics of quasar outflow systems, but analysis has been hampered by a poor understanding of their physical origins. By definition, a BALQSO exhibits blueshifted absorption, with outflow velocities and velocity widths of thousands or tens of thousands of km s^{-1} (Weymann et al. 1991). The energies required imply that the absorbing material is accelerated by the quasar central engine during high Eddington ratio fuelling episodes.



Example BALQSO spectrum from the SDSS. The deep, broad absorption troughs bluewards of SiIV λ1403 and CIV λ1551 are clear indicators of outflowing material, accelerated to thousands of km s^{-1} by the quasar central engine.

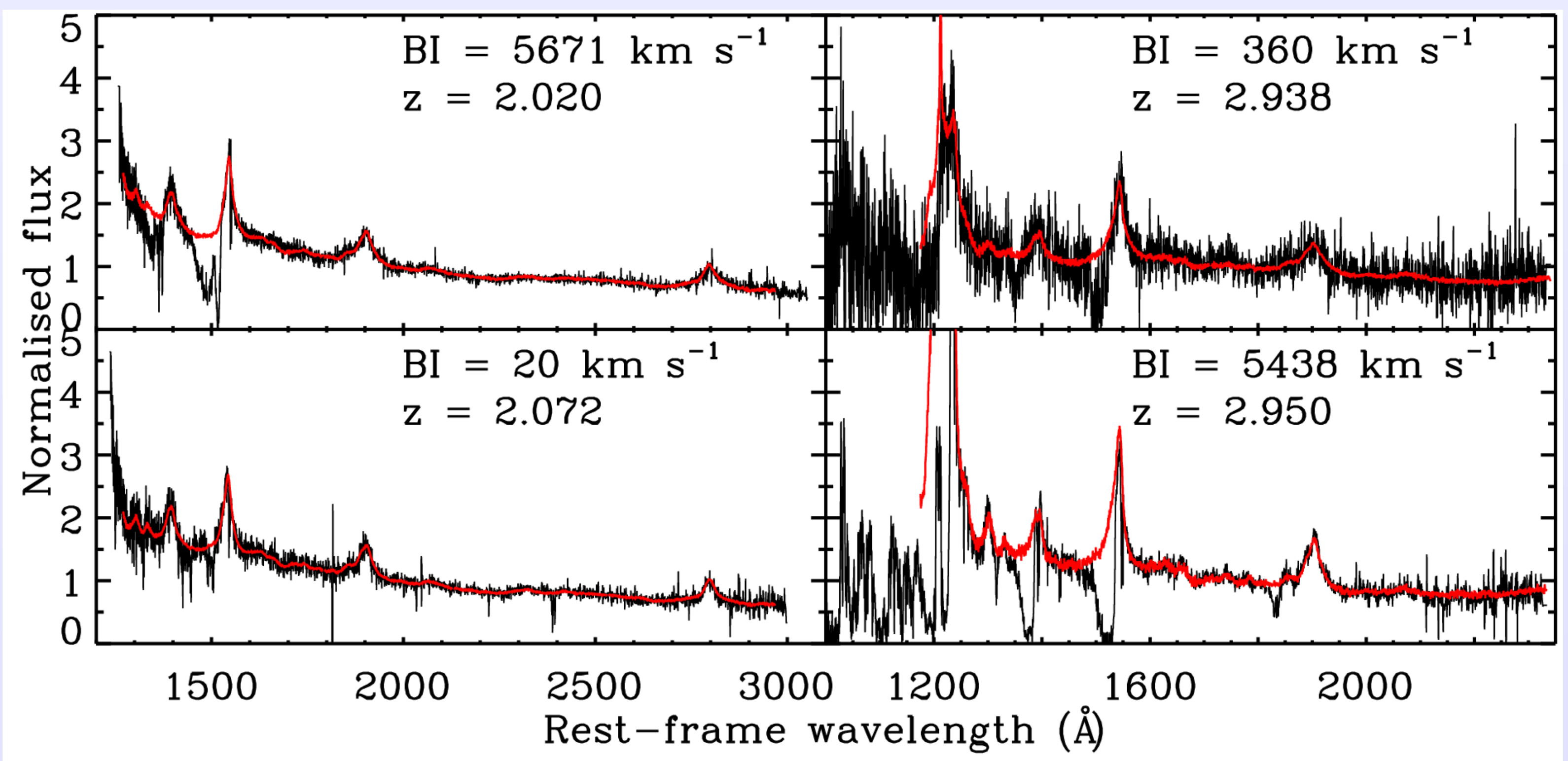
BAL systems with a great variety of profiles are seen in 10-20% of optically-selected quasars (Gibson et al. 2009; Scaringi et al. 2009). It is often suggested that this fraction reflects the fractional solid angle coverage of BAL systems in individual quasars, but it is also possible that this coverage varies greatly between quasars. In particular, evolutionary models predict a higher covering factor during periods of particularly rapid fuelling. Distinguishing between these models would shed light on the physical origins of BAL systems and their relationship to the fuelling episodes that drive them.

A BALQSO fraction that varied with redshift would be a clear indicator that the solid angle coverage of BAL systems depends on one or more physical properties of the quasar. We have measured the BALQSO fraction from a new catalogue based on the SDSS DR6 spectroscopic survey. BALQSOs were identified based on a reliable new continuum fitting procedure (§2). A careful analysis of selection effects was undertaken, regarding both our BALQSO detection procedure (§3) and the SDSS itself (§4). Preliminary results (§5) show a large increase in BALQSO fraction at high redshift, hinting at a link between BAL systems and rapid black hole growth.

2. Detecting BALQSOs: continuum fits

In order to identify regions of broad absorption, which are often relatively shallow, accurate estimates of the unabsorbed continuum level are required. We have generated such estimates using the novel technique of non-negative matrix factorisation (NMF; Lee & Seung 1999, 2000; Blanton & Roweis 2007). NMF is a blind source separation technique, in which a large number of input spectra are decomposed into a much smaller number of component spectra. The components can then be applied to create reconstructions of the continua of further sets of spectra.

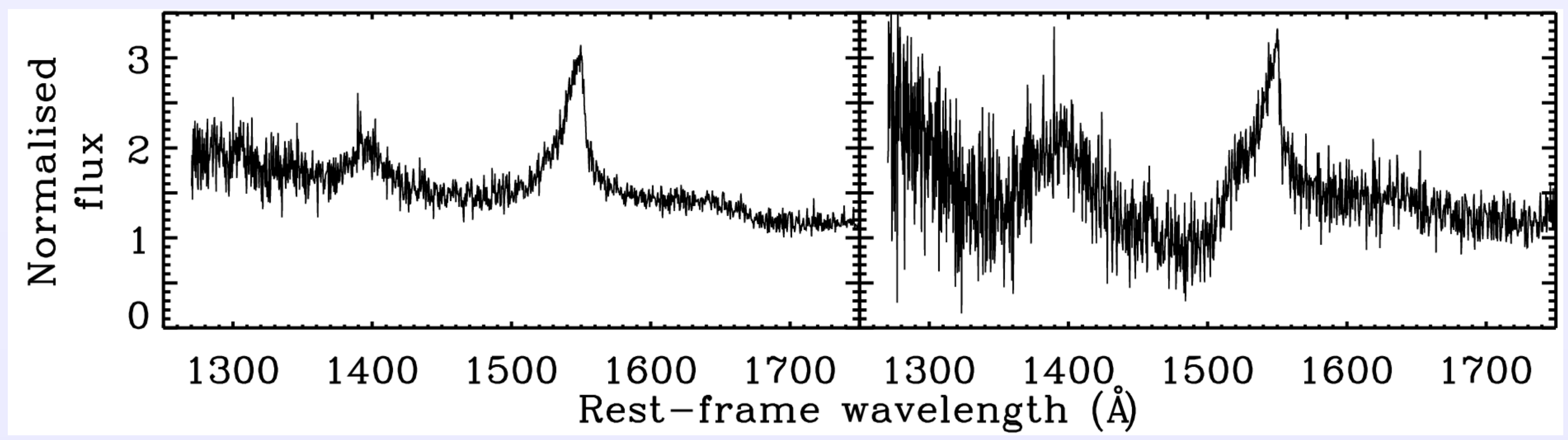
In this way we have generated reconstructions of the unabsorbed continua of 93 400 observations of 86 773 quasars, finding BAL systems in 3547 quasars. The continuum fits to all spectra, in the CIV emission and absorption region, will be released online.



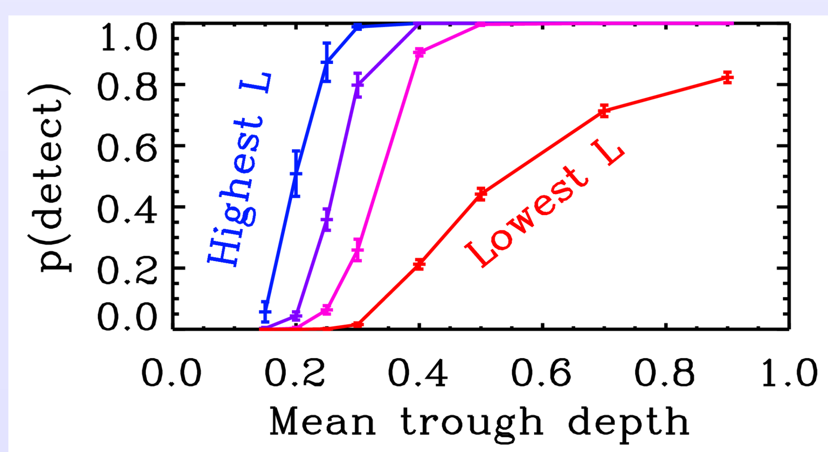
Examples of NMF reconstructions of BALQSOs. In each panel the black line shows the observed spectrum and the red line shows the reconstruction. Redshifts and balnicity index (BI) values are as shown. The NMF procedure accurately reconstructs the quasar spectra for a wide range of physical and observational properties.

3. CIV BALQSO detection probability

Even for a perfect continuum reconstruction, BALQSO systems are not detected if the noise in the observed spectrum brings some pixel values too close to the unabsorbed continuum. The strong correlation between noise and physical properties such as redshift make it crucial that the detection probability be quantified.



Generation of a synthetic BALQSO to calculate the detection probability. Left panel: input non-BAL quasar spectrum. Right panel: same spectrum after insertion of BAL troughs and additional noise. In this case the initial signal-to-noise ratio of 17.0 is degraded to 6.1. With known BAL properties, such spectra can be used to test the success of the NMF procedure in identifying BALQSOs.

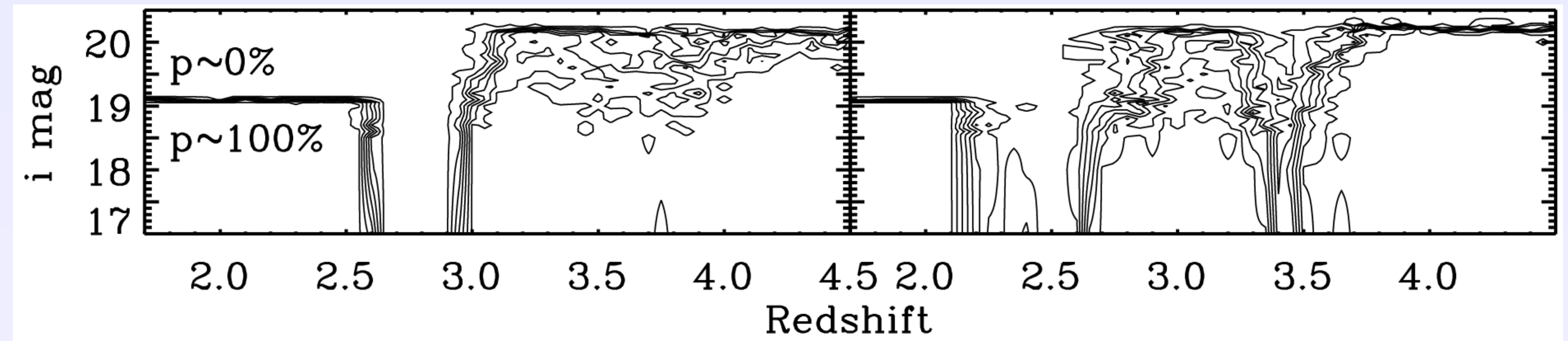


CIV BALQSO detection probabilities for redshift $2.0 \leq z < 2.1$, as a function of mean trough depth and luminosity, L. For deep troughs in high-luminosity quasars all BALQSOs are recovered, but this is not the case for shallow troughs and fainter quasars.

We have measured the detection probability by inserting BAL troughs with known properties into non-BAL quasar spectra, as shown above, and processing the resulting synthetic BALQSO spectra with our standard continuum fitting procedure. Noise properties were varied by adding SDSS sky spectra. Typical results are shown to the left. Knowing the detection probability as a function of redshift, luminosity and BAL properties, we can correct the BALQSO fraction for the undetected BALQSOs.

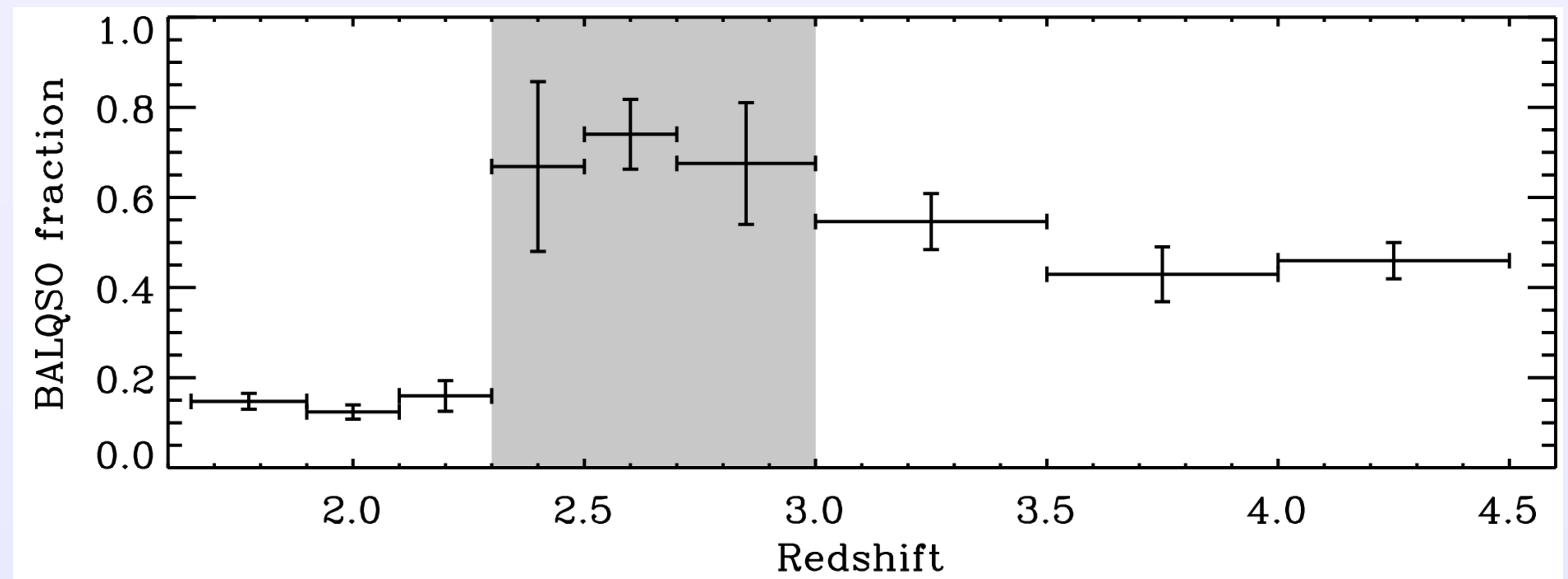
4. SDSS completeness

Candidate quasars for the SDSS spectroscopy were chosen on the basis of their broadband colours, but these colours are affected by the presence of BAL systems and associated dust, so the completeness of the survey is different for BALQSOs and non-BAL quasars. We have tested the target selection algorithm using model quasar spectra with a wide range of BAL properties (including non-BAL), levels of dust, and intervening absorbers. The resulting completeness values allow us to apply a redshift-dependent correction to the observed BALQSO fraction.



Completeness contours in redshift-magnitude space for a non-BAL quasar (left) and a BALQSO with BI = 4124 km s^{-1} (right). Each has E(B-V) = 0 and Lyman limit absorbers at the systemic redshift. The SDSS completeness is different for BALQSOs and non-BAL quasars, necessitating a correction to the BALQSO fraction.

5. Results



Redshift evolution of the BALQSO fraction in high-luminosity quasars, showing a marked increase at high redshift. In the shaded redshift region the systematic errors (not shown) become large.

The above figure shows the redshift evolution of the intrinsic CIV BALQSO fraction. The BALQSO fraction is considerably higher at $z>3.0$ than at $z<2.3$; at intermediate redshifts the systematic errors become large and the results are less reliable. The redshifts at which the BALQSO fraction is highest are also the redshifts at which black hole growth is believed to be most rapid, hinting at a link between BAL systems and fuelling episodes in which the black hole grows rapidly.

6. References

Blanton M. R., Roweis S., 2007, AJ, 113, 734
Gibson R. R., et al., 2009, ApJ, 692, 758
Lee D. D., Seung H. S., 1999, Nat, 401, 788
Lee D. D., Seung H. S., 2000, ANIPS, 13, 556
Scaringi S., et al., 2009, MNRAS, 399, 2231
Weymann R. J., et al., 1991, ApJ, 373, 23