Monitoring Quasar Colour Variability in Stripe 82

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Abstract

Broad Absorption Line (BAL) trough variability is predominantly due to cloud motion transverse to our line of sight. The rate at which the variability occurs indicates the velocity of the cloud, which can provide constraints on the cloud's distance from the central source. This requires detailed spectroscopy during a variability event. Such spectra have proven elusive, suggesting either the timescale of variability is too short to be caught, or too long to notice until a sufficient amount of time has passed. Photometric monitoring of BAL quasar colours may potentially be used as an early warning system to trigger time resolved spectroscopic monitoring of BAL variability. Towards this end, we present an analysis of both BAL and non BAL colour variability using time series photometry from Stripe 82 in the Sloan Digital Sky Survey.

1. Stripe 82

A small section of sky observed by the Sloan Digital Sky Survey (SDSS) known as Stripe 82 (S82) was specifically targeted for multiple photometric observations.

Coverage: 22h 24m < R.A. < 04h 08m | Dec | < 1.27
~290 square degrees

S82 has been observed over 50 times with time-resolution ranging from 3 hours to 8 years.

There are 9275 spectroscopically confirmed quasars in the SDSS Data Release 7 (DR7) located in S82. These were sorted into BAL and non-BAL quasars based on the classifications done in Gibson et al. (2005) and Allen et al. (2011) (DR5 and DR6, respectively).

2. Finding a signal

We use the time-series nature of the S82 photometry to extract a signal of higher variability among BAL quasars colours. Depending on the redshift, a given BAL trough may occur in any of the SDSS standard passbands. Nearly all BAL quasars exhibit absorption due to the C_{IV} doublet at λλ 1548.203, 1550.770 ÅÅ, and therefore we build our preliminary study around this transition.

Using the possible range of blueshift (-3000 km s^{-1} to -25 000 km s^{-1}) in a BAL trough and the wavelength range of the SDSS filters, we have sorted the quasars of S82 into redshift bins based on where the C_{IV} trough will occur. The following table lists the redshift ranges of the bins, the filter in which we expect to observe a C_{IV} trough, and the colour we will use to measure the change in that trough's absorption strength.

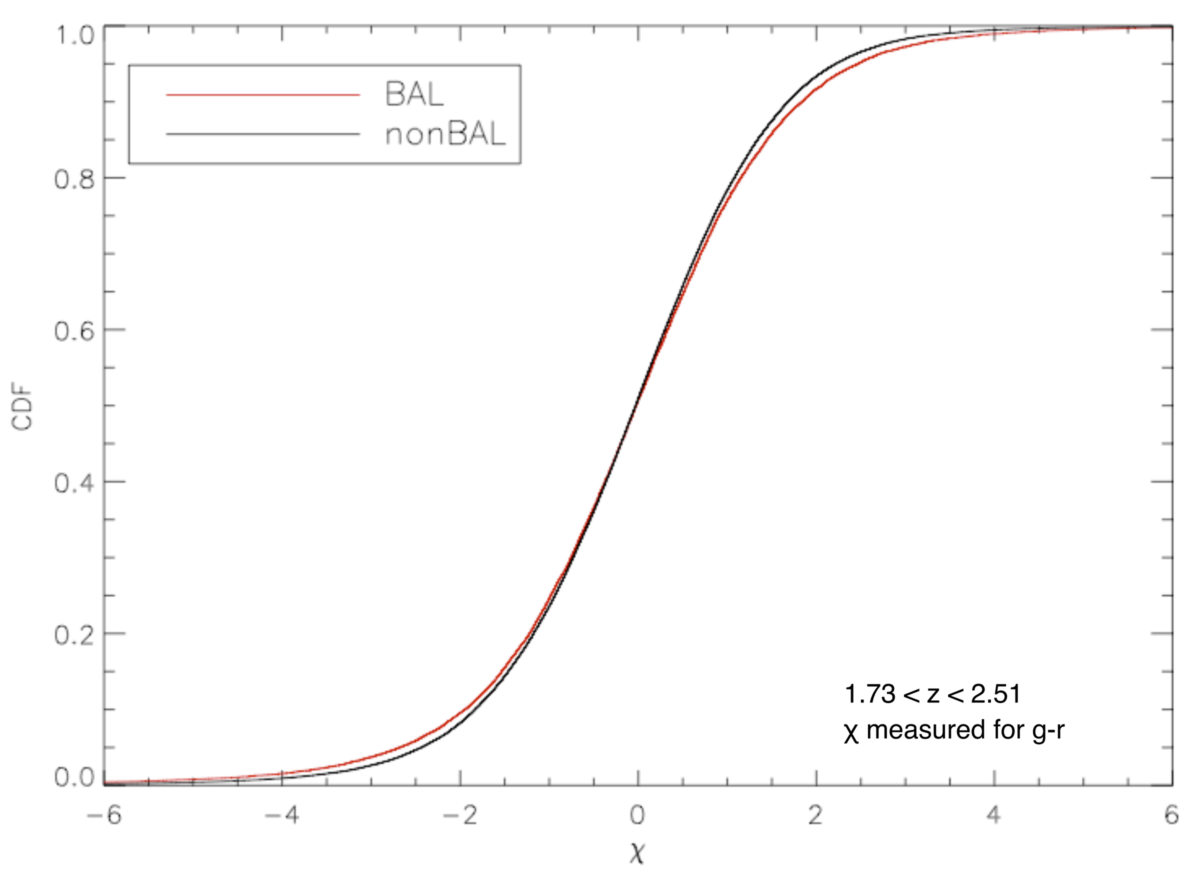
z_{range}	BALs	nonBALs	BAL fraction	SDSS filter	colour stat.
$0.00 < z < 0.92$	5	1722	0.0028	none	N/A
$0.92 < z < 1.51$	21	2803	0.0074	u	u-g
$1.51 < z < 1.73$	100	1112	0.083	u and g	u-r and g-r
$1.73 < z < 2.51$	333	2215	0.13	g	g-r
$2.51 < z < 2.82$	46	327	0.12	g and r	g-i and i-r
$2.82 < z < 3.40$	61	311	0.16	r	r-i
$3.40 < z < 3.79$	21	86	0.20	r and i	r-z and i-z
$3.79 < z < 4.35$	13	60	0.18	i	i-z
$4.35 < z < 4.82$	0	13	0.00	i and z	i-z and r-i
$z > 4.82$	0	6	0.00	z	i-z
Total:	600	8655			

We quantified the overall variability of a given colour in the S82 quasars using the χ distribution:

$$\chi_i = \frac{c_i - c_0}{\sigma_i}$$

where: c_i is the ith colour in a series
σ_i is the uncertainty in colour
c_0 is the mean colour

While all quasars are naturally variable, we expect BAL quasars to be additionally variable due to bulk motions of absorbing gas moving transverse to our line of sight. Therefore, BALs in a given redshift bin should exhibit **larger** values of χ than non-BAL quasars of the same bin.

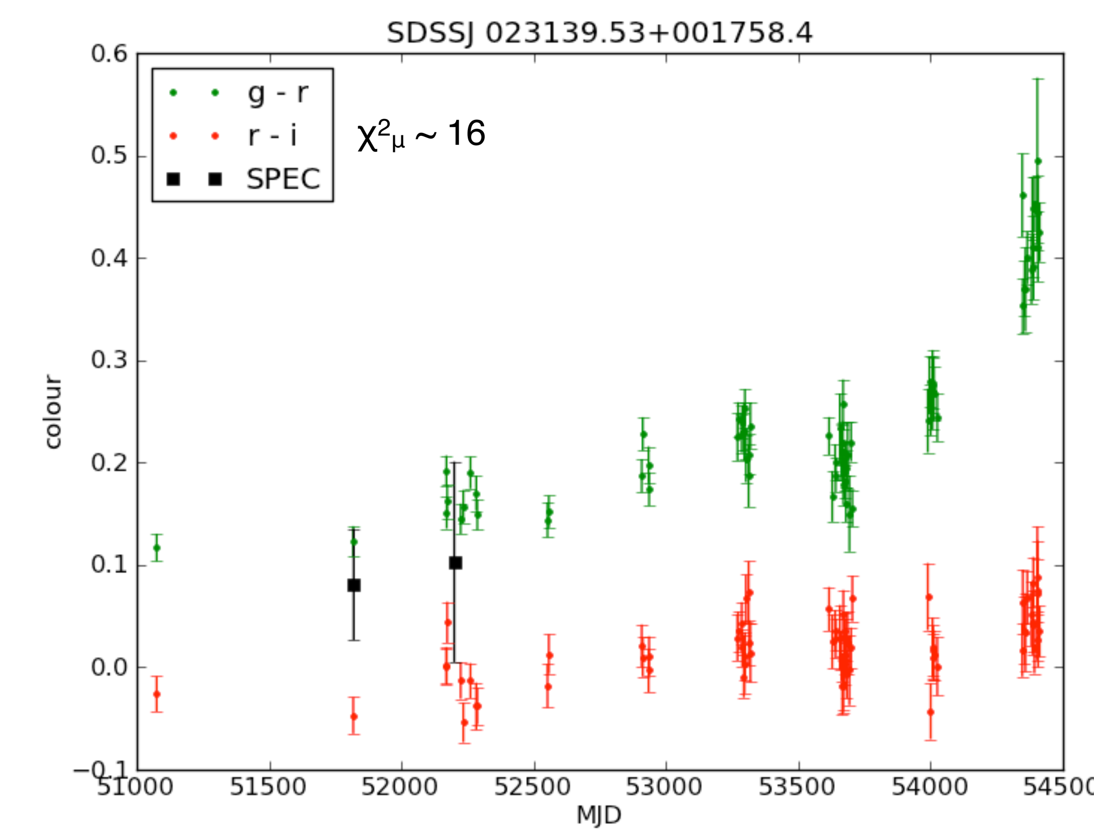


To test this, we used the Kolmogorov-Smirnov test with Kuiper variant to determine if the Cumulative Distribution Function of individual χ values of BALs vs. non-BALs in a given redshift bin (and thus, for a given colour) are significantly different. For comparison, in the same redshift bin, we do the same test on a different colour, where we do not expect variability due to a C_{IV} trough. The table below shows the probability that the BALs and non-BALs (for both test and comparison colours) are drawn from the same distribution, and at what confidence level.

z_{range}	test	confidence	compare	confidence
$0.92 < z < 1.51$	(u-g) 0.0007	4σ	(g-r) 0.005	2.8σ
$1.73 < z < 2.51$	(g-r) 10^{-15}	$\infty\sigma$	(r-i) 0.0003	3σ
$2.82 < z < 3.40$	(r-i) 10^{-13}	$\infty\sigma$	(i-z) 0.4	$< 1\sigma$
$3.79 < z < 4.35$	(i-z) 0.3	$< 1\sigma$	N/A	N/A

3. Preliminary Results

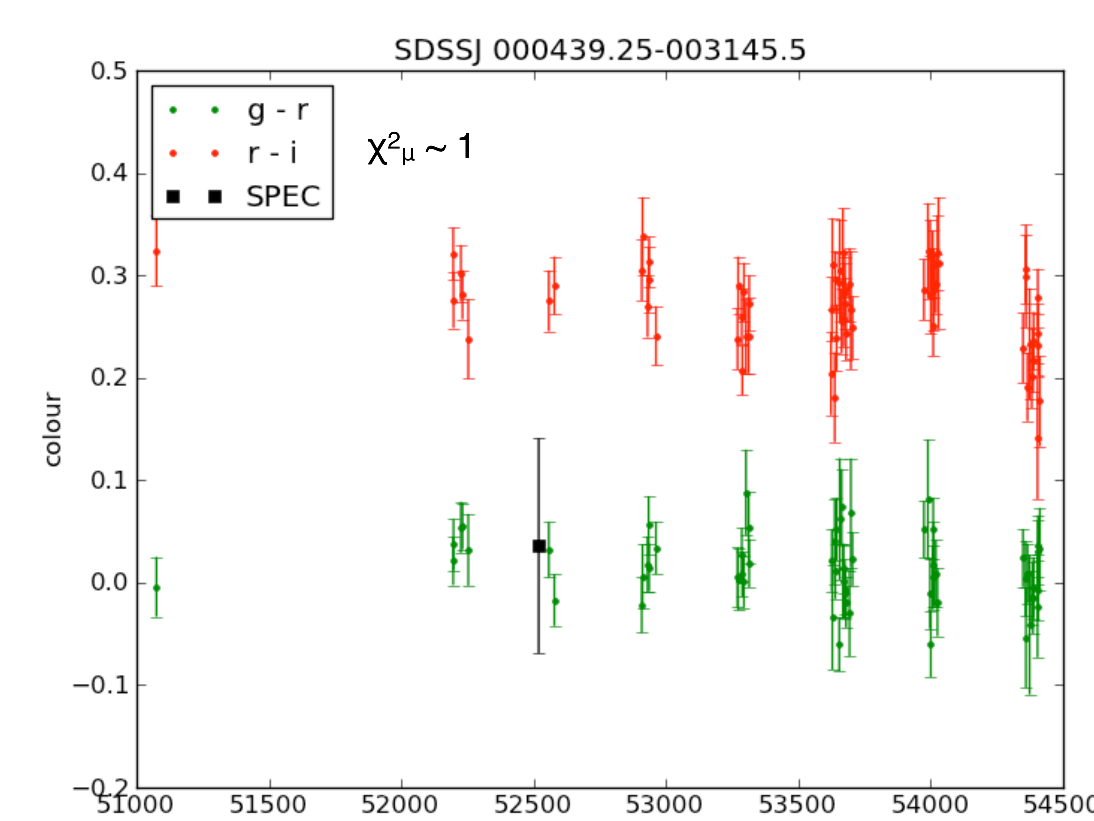
We target objects that exhibit large values of reduced χ^2_μ, these are expected to have a more variable colour than those with a reduced χ^2_μ value close to 1.

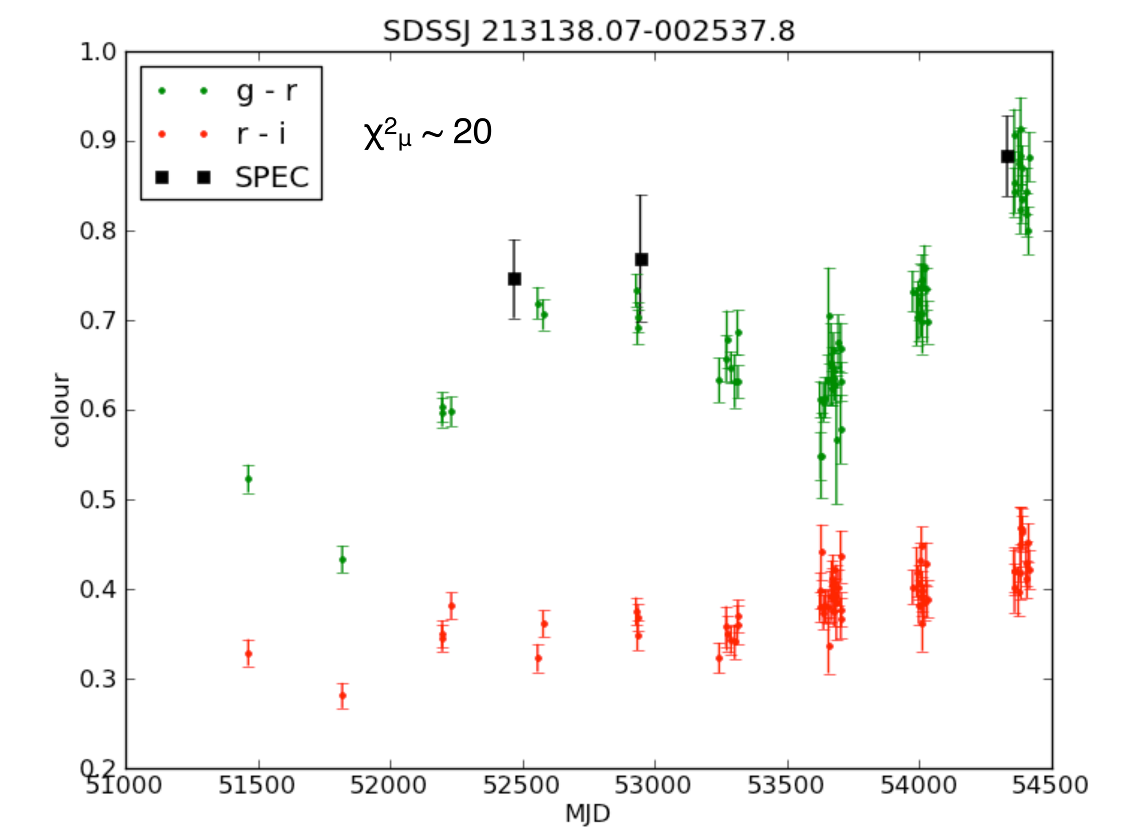


The **above** plots all the S82 photometric measurements for the labeled **BAL** quasar, which exhibits a large value for χ^2_μ. This object is at z=2.375, so a C_{IV} trough is expected to be in the g filter. A clear change in g-r is observed near MJD=54250, compared to r-i where no major change occurs. Black data points label the g-r colour as estimated by spectra taken of the object at the indicated MJD.

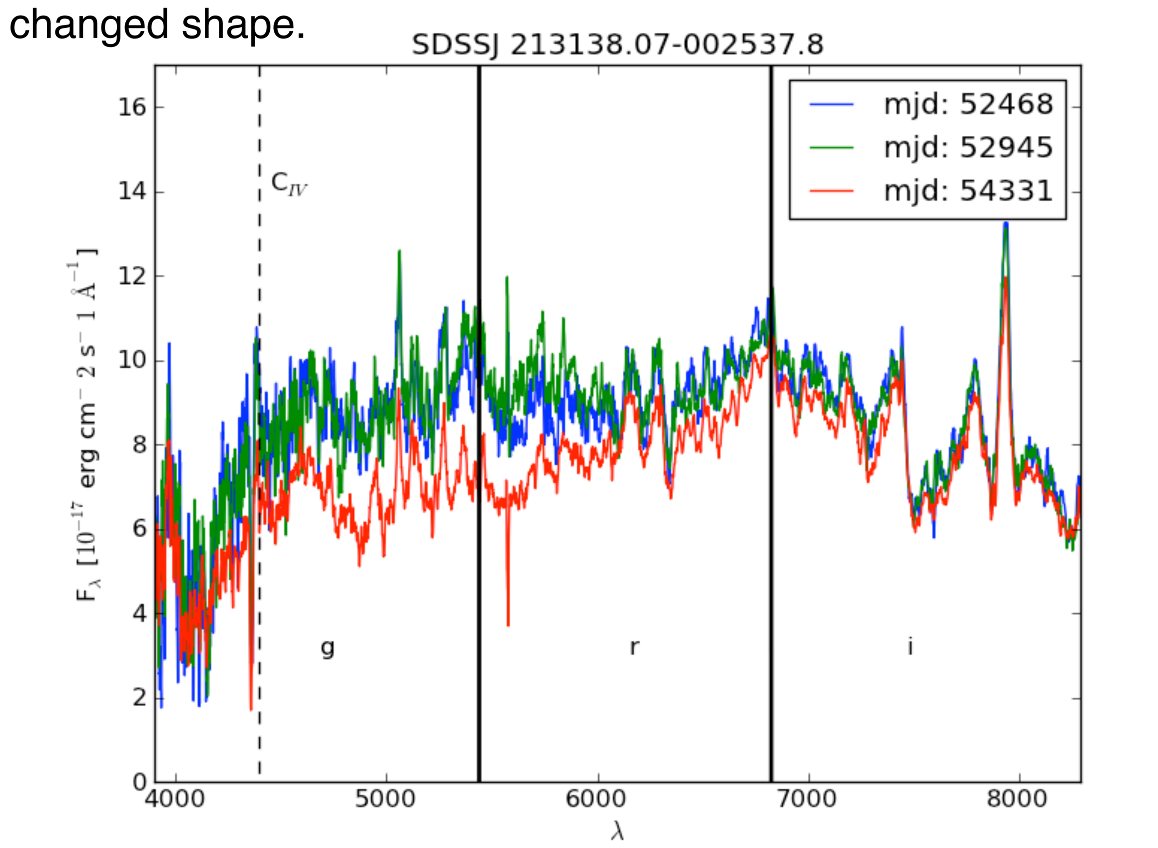
It is clear the method of estimation for the filter magnitudes from the spectra does not (always) match well to the photometrically measured magnitudes.

The plot **below** displays photometric measurements for a **non-BAL** quasar with little colour change over the data set. Such a low χ^2_μ indicates no significant deviation from the mean colour. This object is at z=1.853.





The object studied in the above and below plots is at z=1.837, and was indicated to be one of the most highly variable by its χ^2_μ. It is clear g-r has changed while r-i has stayed reasonably stable. Fortunately, this object also has 3 spectra taken on MJDs that straddle the timeframe over which the g-r colour change occurred. Not all the loss of flux in g is due to the change in the C_{IV} trough observed, but the trough has clearly changed shape.



4. Conclusions & Future Work

The S82 photometry provides an excellent test bed to compare colour variability in different types of quasars. We have shown BAL colour to be more variable than non-BAL quasars colour, a feature attributed to the variable nature of absorption troughs. Such a result hints towards a photometric monitoring program that would trigger spectroscopic followup and coverage when a colour begins to vary. We have yet to analyze all redshift bins listed. We also plan to analyze the timescale over which BALs vary using these data.

References

Gibson et al., 2009, ApJ, 692, 758
Allen et al., 2011, MNRAS, in-press arXiv:1007.3991
Macleod et al., 2011, in-prep