Red Companions to a z=2.15 Radio Loud Quasar

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Abstract. We have conducted observations of the environment around the z=2.15 radio loud quasar 1550-269 in search of distant galaxies associated either with it or the z=2.09 CIV absorber along its line of sight. Such objects will be distinguished by their red colours, R-K > 4.5. We find five such objects in a 1.5 arcmin$^2$ field around the quasar, with typical K magnitudes of $\sim$20.4 and no detected R band emission. We also find a sixth object with K=19.6±0.3, and undetected at R, just two arcseconds from the quasar. The nature of all these objects is currently unclear, and will remain so until we have determined their redshifts. We suggest that it is likely that they are associated with either the quasar or the CIV absorber, in which case their properties might be similar to those of the z=2.38 red Ly$\alpha$ emitting galaxies discovered by Francis et al. (1997). The small separation between the quasar and the brightest of our objects suggests that it may be the galaxy responsible for the CIV metal line absorption system. The closeness to the quasar and the red colour might have precluded similar objects from being uncovered in previous searches for emission from CIV and eg. damped absorbers.

1. Introduction

The selection of high redshift galaxies on the basis of their colours has been a growth industry over the last 5 years, as demonstrated by the breadth and depth of contributions to this meeting. Much of this work has concentrated on the selection of high (z>3) redshift objects through ‘dropout’ techniques. Such methods have had considerable success (see eg. C.C. Steidel’s contribution in this volume, among many others). However, many of these techniques are reliant on emission in the rest-frame ultraviolet. The UV emission from a galaxy can easily be dominated by a small burst of star formation, or alternatively obscured by a relatively small amount of dust. A population of older quiescent galaxies might thus coexist with the UV selected high redshift objects. Studies of the stellar populations in moderate redshift radio galaxies provide some support for this idea. A number of authors (eg. Stockton et al. (1995), Spinrad et al. (1997)) have shown that several radio galaxies have ages >3–5 Gyr at z~1.5,
indicating that they must have formed at \( z > 5 \). These results have even been used (Dunlop et al. 1996) to argue that \( \Omega \) must be significantly less than 1.

Old galaxies at moderate redshift, passively evolving from \( z > 5 \) to \( z = 1.5 - 2.5 \), would appear as red objects, with R-K colours >4.5. There has been considerable interest in such red objects. Much of this work has centred on red objects found in the fields of known high redshift AGN (e.g. Hu & Ridgeway (1994), Yamada et al., (1997)). A large survey of the environments of \( z = 1 - 2 \) quasars (Hall et al., 1998) finds that such associations are quite common. The present paper attempts to push such studies above \( z = 2 \). The alternative approach, to study red objects in the field, is also an active area with several surveys dedicated to or capable of finding such objects. See e.g. Cohen et al. (1998), or Rigopoulou et al. (in preparation). There are also several other contributions in the present proceedings on the subject.

We assume \( \Omega_M = 1, \Lambda = 0 \) and \( H_0 = 100 \text{ kms}^{-1}\text{Mpc}^{-1} \) throughout this paper.

2. Observations

As part of a programme to examine the role of quiescent galaxies at \( z = 2 - 2.5 \), we observed the field surrounding the radio loud quasar 1550-2655. This object lies at a redshift of 2.15 and shows signs of associated \( \text{Ly}\alpha \) absorption (Jauncey et al., 1984). Its spectrum also contains a CIV absorber at \( z = 2.09 \). Observations were made at the 3.5m ESO NTT using the SUSI optical imager for R band observations, and the SOFI infrared imager for the K band observations. We acquired a total of 4800s of integration time at R and 3600s at K. Data reduction used standard IRAF and Eclipse procedures. The observations were flux calibrated using the faint IR standards P499E and S875C for K band, and the Landolt standard (Landolt, 1992) PG1633+099C for R. Galactic extinction was also corrected.

After data reduction and flux calibration, the SUSI image, which has a resolution of 0.13\"/pixel, was rebinned to match the 0.292\"/pixel SOFI resolution, and the images were aligned. The final image was 67 by 88 arcseconds in size. The main limiting factor on this size was the small SUSI field of view and the dithering scheme used for the optical observations. We then used SExtractor to select objects detected at K and to extract their photometric properties in matched apertures in the two passbands. This matched catalogue can then easily be searched for objects with specific colour criteria. We detected a total of 75 objects in K down to a limiting magnitude of \( \sim 20.5 \).

We then searched the catalogue for candidate red objects, with R-K > 4.5. We found five such objects in the catalogue, details of which are given in Table 1. Their positions are also shown in Figure 1, which shows both the R and K band images of the quasar field.

2.1. A Red Quasar Companion

Comparison of the R and K images of the quasar itself shows what would appear to be a red companion object - apparent as an extension in K, but absent in the R band image. The reality of this object was investigated by subtracting off the unresolved quasar contribution. This was achieved by selecting a star, with no close companions, in the observed field and using this as a PSF model. The
The red associates are indicated in each image. Note their clear detections in the K image, and their non-detections in the deeper R band image.

central value of the PSF image was scaled to match that in the quasar image, and then the two images were subtracted. The companion was clearly visible in the K-band PSF subtracted image, but was entirely absent in the R-band PSF subtracted image. The companion is marginally resolved, having a size of roughly 1.5 x 1 arcseconds, and is situated ~2 arcseconds from the quasar. 

R and K magnitudes were extracted from the PSF subtracted image, indicating that the quasar companion is also red. Its details are included in Table 1.

| Object No. | Kmag      | Rmag     | R-K     |
|------------|-----------|----------|---------|
| R1         | 20.2±0.1  | >24.8    | >4.6    |
| R2         | 20.2±0.1  | >25.3    | >5.1    |
| R3         | 20.4±0.1  | >25.3    | >4.9    |
| R4         | 20.3±0.1  | >24.9    | >4.6    |
| R5         | 20.3±0.1  | >25.0    | >4.7    |
| C1         | 19.5±0.3  | >24.5    | >5.0    |

Table 1. Properties of red companions to the RLQ 1550-2655
All limits given are 3σ. The quasar companion is object C1.
3. Discussion

Until we can obtain spectroscopy for these objects, it is difficult to assess their importance or role in this system. There are three possible origins for these red objects: (1) they are associated with the quasar, lying at z=2.15; (2) they are associated with the CIV absorber at z=2.09; (3) they are foreground objects, unrelated to the quasar or CIV system. We will assess each of these alternatives in turn.

3.1. Association with the Quasar

The density of red objects in this field is surprisingly high - \( \sim 4 \) arcmin\(^{-2} \) as opposed to the supposed global value of \( \sim 1 \) arcmin\(^{-2} \) (Cohen et al. 1998). The density of red objects near to the quasar is significantly higher, with three of the red objects as well as the companion lying in a 0.25 arcmin\(^{-2} \) region near the quasar. This is certainly suggestive that there is some connection between the red objects and the AGN (or CIV system). Other studies have found a similar connection between red objects and AGN, especially radio loud AGN. Perhaps the largest survey to date is that of Hall et al. (1999) who obtained images of 31 \( z=1 - 2 \) radio loud quasars and found a significant excess of red galaxies around them. Interestingly they found two radial dependencies for this excess, one of which lies close to the quasar (\(<40''\)) and another more distant (\(40'' - 100''\)). This is perhaps reflected in the present study, with two red objects in the second class, further from the quasar, and the rest, including the close companion, within 40''. In this interpretation, the close companion would be \( \sim 26\)kpc from the quasar, and would be about 20x15 kpc in size. Hydrogen in this object might be responsible for the associated absorption seen in the quasar spectrum.

If we take the redshift of the companion galaxies to be the same as the quasar, then the implied absolute magnitudes would be quite high, \( \sim 27 \), ie. about 5 L\(^*\) (Mobasher et al., 1993). This is not without precedent. Francis et al. (1997) uncovered a group of similarly red objects at \( z=2.38 \) associated with a cluster of quasar absorption line systems. K magnitudes for these objects are similar to, if not brighter then, the objects discussed here, implying still greater absolute magnitudes. It is interesting to note that the Francis et al. objects are all Ly\( \alpha \) emitters. If the present red objects have similar properties, then such line emission would make redshift determination much easier.

3.2. Association with the CIV Absorber

Many of the same comments regarding direct association with the quasar can be made regarding association with the CIV absorber: there is an unusually high density of red objects in this region suggesting some connection between them. Of particular interest here is the closeness of the quasar companion to the quasar - only \( \sim 2'' \) away, or 26kpc at the redshift of the CIV absorber, and with a size similar to that given above. To date little is known about the nature of CIV absorbers, so the possible identification of the galaxy responsible for one is rather interesting. Previous work looking for emission lines from objects associated with damped and CIV absorbers (Mannucci et al., 1998) suggests that galaxies are more likely to cluster with absorbers than with quasars. If
correct, this would suggest that the objects found here are more likely to be associated with the absorber than the quasar.

There has been a long and largely unsuccessful history of searches for emission from absorption line systems in quasars at large redshift. These have largely concentrated on emission lines, whether Ly\(\alpha\) (e.g., Leibundgut & Robertson, 1999), H\(\alpha\), (e.g., Bunker et al., 1999), or others, though work in the infrared continuum has perhaps shown greater success (see e.g., Aragon-Salamanca et al., 1996, 1994). If the quasar companion in the present study is indeed responsible for the CIV absorption, then we may have an explanation for the failures. The object is both red and quite close to the quasar. Detection of the companion would require both good seeing (conditions for our own observations were sub-arcsecond) and observations in the near-IR as well as the ability to subtract off the quasar contribution. Sensitive infrared detectors have only recently become available at most observatories, while subarcsecond seeing is only rarely achieved. We might thus have been lucky in being able to detect the companion. New instruments, such as UFTI at UKIRT, which combines adaptive optics correction (regularly 0.5") with a superb infrared imager, can regularly make such observations. This will hopefully allow us to make significant advances in our understanding of high redshift absorption line systems.

### 3.3. Foreground Contaminants

The possibility that the red objects are at an entirely different redshift to the quasar and absorber must still be considered while we do not have confirming redshift spectra. In this context it is salutary to note the lesson of the first VRO discovered (Hu & Ridgeway, 1994), known as HR10. This was found in the field of a z=3.79 quasar, but was later shown to have a redshift of 1.44 (Graham & Dey, 1996). However, the number density of red objects in their field was 0.9 arcmin\(^{-2}\) which matches the field density of red objects discussed by Cohen et al. (1998), and is lower than that found here.

### 4. Conclusions

At present there are several deficiencies in our data. Firstly we have only obtained limits on the objects R band magnitudes. We must detect them and measure, rather than limit, their R band magnitudes before we can properly determine their colours. Secondly we must obtain spectra for the objects so that we can actually determine, rather than speculate, on their redshift. However, the results presented here suggest that a larger survey of quasar environments, both with and without absorbers, using infrared imagers with adaptive optics correction might shed new light on galaxy populations at large redshift.

**Acknowledgments.** This paper is based on observations made at the European Southern Observatory, Chile. It is a pleasure to thank Nick Devillard for his excellent Eclipse data reduction pipeline, and E. Bertin for SExtractor. I would like to thank Amanda Baker for useful discussions. This work was support in part by an ESO fellowship, EU TMR Network programme FMRX-CT96-0068 and by a PPARC postdoctoral grant.
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