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 ~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 Lyα 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.

Key words: quasars; absorption systems – quasars; infrared – galaxies; high redshift

1 INTRODUCTION
The selection of high redshift galaxies on the basis of their colours has been a growth industry over the last 5 years. Much of this work has concentrated on the selection of high (z>3) redshift objects through ‘dropout’ techniques. Such methods have had considerable success (eg. Steidel et al. 1999). 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 Ω 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 (eg. Hu & Ridgway 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 eg. Cohen et al. (1999), or Rigopoulou et al. (in preparation). Red objects need not be old, though. An alternative explanation is that they are heavily obscured, and may contain either a redened AGN or massive starburst (eg. Dey et al., 1999, Egami et al., 1996). In this context it is interesting to note that several of the objects found in recent deep submm surveys have been identified with very red objects (Smail et al., 1999; Clements et al., in preparation).

Finding emission from the putative galaxies responsible for metal and damped-Lyα absorption line systems has been the goal of numerous observational programmes. At low redshift there has been considerable success in identifying the galaxies responsible for MgII absorption systems (Bergeron & Boisse, 1991; Steidel et al., 1997. At higher redshifts, interest has mostly focussed on the damped-Lyα absorption systems. Searches for line emission from such objects (eg. Bunker et al. 1999; Wolfe et al. 1992) has met with varying success (Leibundgut & Robertson, 1999). Fewer observers have looked in the continuum, but there have been some successes there as well. For example, Aragon-Salamanca et al. (1996) found close companions to 2 out of 10 quasars...
with damped absorbers in a K band survey. As yet there has been no spectroscopic confirmation of these identifications, but the broad characteristics of these objects, and the small fraction of damped absorbers detected, is consistent with plausible models for the evolution of the galaxies responsible (Mathlin et al., in preparation). Meanwhile, Aragon-Salamanca et al. (1994) looked for counterparts to multiple CIV absorbers lying at z ∼ 1-1.6, also using K band observations. They found an excess of K band objects near to the quasars, consistent with their being responsible for the CIV absorption. Once again, there is no spectroscopic confirmation of the assumed redshifts.

The present paper presents the first results of a programme aimed at finding quiescent objects at high redshift (z ∼ 2-2.5) using optical/IR colour selection techniques. Among the targets observed in an initial test programme was the radio loud quasar 1550-2655, selected as an example radio loud object. The rest of the paper is organised as follows. Section 2 describes our observations, data analysis and presents the results. Section 3 discusses these results and examines three possible origins for the red objects we have found to be associated with 1550-2655. Finally we discuss and present the results. Section 3 discusses these results and examines three possible origins for the red objects we have found to be associated with 1550-2655. Finally we draw our conclusions. We assume ΩM = 1, ΩΛ = 0 and H0 = 100 km s⁻¹ Mpc⁻¹ throughout this paper.

2 OBSERVATIONS AND RESULTS

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 Lyα 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, and the reality of this object was investigated by subtracting off what would appear to be a red companion object — apparently an extension in K, but absent in the R band image. The optical observations, in R band, were conducted in service mode on 20 August 1997 using the SUSI imager. This provides high resolution images, with a pixel size of 0.13″. A total integration time of 3600s was obtained on the source. This integration time was broken up into 12 subintegrations of 300s each, whose relative positions were shifted by up to 40″ in a semi-random jitter pattern. These images were bias subtracted, flat fielded using a sky flat made on the twilight lamp OFF image. A residual gradient going from left to right across the sky, then aligned and median combined to produce the final PSF image was scaled to match that in the quasar image, and then the two images were subtracted. The companion was marginally resolved, having a size of roughly 1.5 x 1 arcseconds, and is situated ∼ 2 arcseconds from the quasar. Its position is shown in Figure 1a. Seeing was measured to be marginally subarcsecond on the final image.

The infrared data was obtained using the K′ filter on the SOFI infrared imager on 12 July 1998. The 3600s of integration were obtained in 60 one minute sub-integrations which themselves were the result of six 10s integrations. The 60 one minute sub-integrations were shifted relative to one another in a random 15″ dither pattern to allow for sky background determination and subtraction. The flat field was obtained using a standard lamp ON — lamp OFF dome flat. The data were reduced using the Eclipse package by Nick Devillard (1997). The algorithms used for reducing dithered infrared data in this package are detailed in Devillard (1999). In summary, the package allows for flat fielding with the prepreared flat, and conducts sky subtraction using a running average of 10 offset images. It then identifies sources on each image and uses a correlation technique to calculate the offsets between them. The separate subintegartions are then offset and combined to produce the final image. Seeing was measured in the final image to be ∼ 0.9″.

Photometric calibration used the Landolt standard (Landolt, 1992) PG1633+099C in R band, and the faint IR standards P499E and S875C at K′ (Cassali & Hawarden, 1992). Galactic extinction was corrected using values obtained from the NASA Extragalactic Database (NED).

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 matched images were 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. To qualify for detection, an object had to have a 1.5σ significance flux in 10 connected pixels in the K′ band image (i.e. ∼ 5σ significance overall). 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 ∼ 20.5.

The catalogue was then searched 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 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 was marginally resolved, having a size of roughly 1.5 x 1 arcseconds, and is situated ∼ 2 arcseconds from the quasar. Its position is shown in Figure 1a. Seeing was measured to be marginally subarcsecond on the final image.

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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 - \( \sim 4 \pm 1.5 \text{ arcmin}^{-2} \) as opposed to the supposed global value of \( \sim 1 \pm 0.3 \text{ arcmin}^{-2} \) (Cohen et al. 1999). 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 \( \sim 26 \text{kpc} \) 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 \( \sim -24 \) to -25, ie. about L\(^*\) (using the luminosity function of Mobasher et al., 1993 and converting to the assumed cosmology). This calculation of course ignores K-corrections, but these are expected to be quite low in the K-band. Cowie et al (1994) calculate K-corrections at \( z=2.1 \) to be less than 1 for all morphological classes from E to Irr. We also note that these results are not dissimilar to those of Francis et al. (1997) who 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, or brighter then, those of the objects discussed here. It is interesting to note that the Francis et al. objects are all Ly\( \alpha \) emitters. If the present red objects have simi-
4.3 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 & Ridgway, 1994), known as HR10. This was found in the field of a $z \approx 3.79$ 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. (1999), 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.

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