Observations of Candidate $z \sim 1.54$ Quasar Host Clusters

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Abstract. We present new data on several $z = 1.54$ radio-loud quasar fields from a sample of 31 at $z = 1−2$ in which we have previously identified an excess population of predominantly red galaxies. Narrow-band Hα observations detect five candidate galaxies at the quasar redshifts in three fields totaling $10.156''$, a surface density $\sim 30$ times higher than in previous surveys, even targeted ones. SCUBA observations of three fields detect at least one candidate quasar-associated galaxy. Many galaxies with SEDs indicating considerable dust are not detected, but the limits are only sufficient to rule out hyperluminous infrared galaxies. Finally, quantitative photometric redshifts and SED fits are presented for one “J-band dropout” galaxy with $J−K > 2.5$ which is confirmed to be very dusty ($E(B−V) \simeq 0.5$) and background to the quasar at $\geq 99.9\%$ confidence.

1. Introduction

It is of considerable interest to identify structures of galaxies at $z > 1$ to study the evolution of both galaxies and galaxy clusters. Radio-loud quasars (RLQs) are obvious signposts around which to search for clusters at $z > 1$. In Hall & Green (1998; hereafter HG98) we presented imaging of 31 RLQs at $z = 1−2$ which revealed an excess population of predominantly red galaxies. Most candidate excess galaxies’ SEDs are consistent with them being at the quasar redshifts and red due to high age or metallicity, but some are consistent with being heavily dust-reddened galaxies, and/or background galaxies at $z > 2.5$. Here and in Hall et al. (1999) we present new observations of these fields and further analyses of existing data which strengthen many of our previous conclusions.
2. Narrow-band H$\alpha$ Imaging

In the past few years, narrow-band surveys have typically yielded a few detections per survey of H$\alpha$ emitters at $z > 1$ (see Teplitz, McLean & Malkan 1999). Our RLQ fields make promising targets for narrow-band searches for H$\alpha$ emission at the quasar redshifts. We would hope to detect galaxies whose SEDs suggest they are dust-reddened and thus possibly actively star-forming and not to detect galaxies whose SEDs suggest they are old and dust-free.

We observed Q 0835+580 with IRTF using a circularly variable filter (CVF), Q 2149+212 with CFHT using a special narrow filter, and Q 2345+061 with both. There is a $>3\sigma$ detection in each of the three fields and two $3\sigma$ detections in the Q 2345+061 field. Q 0835+580 (H$\alpha$1) is an unremarkable faint blue galaxy with SFR$_{H\alpha}$=14.7±2.5 $M_\odot$ yr$^{-1}$. Based on $U$-band data for this field, we estimate SFR$_{FUV}$=5.3±0.3 $M_\odot$ yr$^{-1}$, in good agreement with SFR$_{H\alpha}$ given the various uncertainties (e.g. no correction for dust extinction has been made to either value). None of the nine very red galaxies within 20$''$ of Q 0835+580 were detected in H$\alpha$, strengthening the case for them being red due to age or metallicity instead of dust (if they are at the quasar redshift).

In the Q 2345+061 field, the candidate H$\alpha$ emitter seen with IRTF (SFR$_{H\alpha}$ = 4.9±0.1 $M_\odot$ yr$^{-1}$) is not confirmed with CFHT, but the IRTF CVF is three times wider than the CFHT narrow-band filter. If the H$\alpha$ excess observed with IRTF is real, the line must lie outside the CFHT filter. Conversely, the two $3\sigma$ detections (SFR$_{H\alpha}$=1.8±0.4 $M_\odot$ yr$^{-1}$) are seen with CFHT but not IRTF. However, given the relative widths of the filters, lines of the strength seen in the CFHT data could be present but lost in the noise in the IRTF data.

Five detections over 10.156$''$ in these three fields (all among our top ten cluster candidates) gives a surface density of 0.5±0.3 $arcmin^{-2}$, ~30 times higher than previous shallower surveys, even targeted ones. The deep CFHT H$\alpha$ images show that there are only three quasar-associated galaxies with star formation rates of $>2$ $M_\odot$ yr$^{-1}$ within fields ~1 Mpc wide centered on Q 2149+212 and Q 2345+061. This is a lower limit which neglects extinction and the velocity dispersion of the clusters, but it illustrates the potential of deep wide-field narrow-band data in studying star formation rates in high redshift clusters.

3. Sub-millimeter Mapping

The presence of a number of galaxies with SEDs strongly indicative of substantial dust reddening in our RLQ fields (see HG98) suggested that they might be detectable sub-mm sources. Thus we observed the fields of Q 0835+580, Q 1126+101, and Q 2345+061 with SCUBA on the JCMT. The reduced jigggle maps were cross-correlated with the beam map and correlation coefficients measured; a high value was required to accept any potential source as real.

Q 2345+061 was detected at 2.8$\sigma$, and Q 1126+101 at 3.4$\sigma$. Only one other source, dubbed Q 1126+101 (SM1), is securely detected, but the limits on our relatively short exposures can only rule out luminosities >10$^{13}$ $L_\odot$ for galaxies at the quasar redshifts. Q 1126+101 (SM1) has two possible counterparts. The closest is a candidate quasar-associated red galaxy with $K = 19.4$, $r - K = 5.7$, $z - J = 3.4$ and $J - K = 2.7$. The next closest has a moderate $r - K$ and with
\( K = 17.7 \) is almost certainly foreground to the quasar. Photometric redshifts and spectral types for the objects may help determine which ID is most plausible.

4. Photometric Redshifts and Spectral Types

We are calculating photometric redshifts and spectral types for objects in \( z > 1 \) quasar fields with multicolor imaging data to verify the existence of excess galaxies at the quasar redshifts or beyond, investigate such galaxies’ SEDs, and remove secure foreground objects from consideration for future spectroscopy. To compute photometric redshifts, a solar metallicity GISSEL model with synthetic Kurucz spectra (Bruzual & Charlot 1996) was calculated for ages 0–20 Gyr and \( z = 0–4 \) assuming either an instantaneous burst or a constant SFR and with dust added using the Calzetti (1997) extinction law for ten values of \( E(B-V) \) from 0 to 1.6. Fluxes were computed and compared to observations to construct \( \chi^2 \) contour plots in age-\( z \) space for each value of \( E(B-V) \) for each SFR scenario.

We present preliminary results on one object. Q 1126+101 (425) was studied since it is the brightest “J-dropout” \( (J-K > 2.5) \) in its field and it has a very red \( z-J > 2.7 \). For either a constant SFR or instantaneous burst (the latter being shown in Figure 1), the lowest \( \chi^2 \) is given by \( E(B-V) \sim 0.5 \). With \( z_{ph} = 3.5 \pm 0.5 \), the object is background to the \( z = 1.54 \) quasar at \( > 99.9\% \) confidence for all \( E(B-V) < 0.7 \). For a constant SFR, the very red colors of Q 1126+101 (425) require \( E(B-V) > 0.5 \) at any \( z \) to remain younger than the universe in any reasonable cosmology. The required dust is consistent with its \( J-K \) color being redder than that of HR10, the prototypical dusty ERO (Extremely Red Object). However, the prediction of HG98 that this particular object would be at the quasar redshift seems to be erroneous. Instead, it appears to be a member of the other J-band dropout population proposed in HG98, namely galaxies at \( z \geq 2.5 \) which have red \( J-K \) colors due to the redshifted 4000Å break.

5. Conclusion

These and other observations (Hall et al. 1999) are good evidence for galaxy overdensities around \( z > 1 \) RLQs, and for a population of red galaxies at \( z \geq 2.5 \). If confirmed by spectroscopy with 8-m class telescopes, it may prove worthwhile to extend RLQ host cluster searches to \( z > 2 \) by searching for “J-dropout” galaxies.

References

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Figure 1. $\chi^2$ contour plots for instantaneous burst fits to the SED of object Q 1126+101 (425). Each panel corresponds to a different $E(B - V)$, starting with 0 at top left and increasing downward to 0.6 at the bottom of the first column and 1.6 at the bottom of the second. The asterisk shows the point with minimum $\chi^2$ in each panel. From smallest to largest, the error contours enclose the 90, 99 and 99.9% probability regions respectively. Note that the contours are drawn for each panel independently relative to the minimum unReduced $\chi^2$ for that panel, which is printed in the bottom right corner.