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Distant Radio Galaxies in the Near IR
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We are carrying out a program of near IR imaging and spectroscopy of radio galaxies with redshifts of 1.5 and greater. One of its principal goals is to constrain the ages and star formation histories of massive galaxies at early epochs.

The radio galaxies are drawn from the survey of 1Jy class sources by McCarthy et al (1989) and McCarthy (1990). The sample contains 18 radio galaxies with redshifts greater than 2 and an additional 10 objects with $1.5 < z < 2.0$. The redshifts were obtained from long slit spectra with the CTIO 4m. While the galaxies are quite faint ($r \sim 21 - 24.5$) all have Lyman α emission with rest frame equivalent widths of 100 - 1000Å. Multicolor photometry in the g,r,i and J,H,K bands has been obtained with the 2.5-m Du Pont Telescope on Las Campanas and with the Hale 5m telescope at Palomar. We have recently obtained near IR spectra, using the 4m telescopes at KPNO and CTIO, of a few objects with the goal of determining the Lyman $\alpha/H\alpha$ ratio and hence the reddening.

One of the key questions in the interpretation of the spectra of distant radio galaxies is whether they contain a single roughly coeval stellar population or a number of distinct populations. Presently, the only observational signature of two distinct components would be differences in the near IR (rest-frame visible) and rest-frame UV morphologies. The rest-frame UV morphologies of radio galaxies with $z > 1$ are highly irregular and are strongly aligned with the radio source axes. A crucial question is whether or not the near IR morphologies are also aligned with the radio axes. While observations of $z \sim 1$ galaxies from the 3CR catalog reveal a few cases of aligned morphologies in the K band (e.g. Chambers et al 1987; Eisenhardt et al 1989), many objects do not (Rigler et al 1990). Our high signal-to-noise ratio K images of Molonglo radio galaxies with $z > 2$ show very few cases of convincing K band alignments. Comparison with our optical images reveals a trend for the morphologies to become more compact at longer wavelengths, supporting the view that these systems contain two stellar populations with distinct star formation histories.

We use Bruzual's (1984) spectral synthesis code, as modified to include AGB stars by Chokshi and Eisenhardt to constrain the ages and star formation histories of our $z > 1.5$ sample. We adopt Lilly's 'Old galaxy + burst' paradigm for fitting the broad band spectral energy distributions. The old component is modeled as a single burst with a duration of 1 Gyr. The young component is taken as a zero age burst and has a nearly flat spectrum in F_ν units. The best fit is achieved by varying the time since the initial burst and the fractional contribution of the young component. The age of the old component is most sensitive to the colors longward of 4000Å rest, whereas the amplitude of the burst is constrained by the level of the far UV flux density. In figure 1 we show the fit to one of the reddest galaxies in our sample. These red objects are of the most interest from a cosmological standpoint as they provide the strongest constraints on the redshift of formation. For 0156-252, shown below, we derive a lower bound on the age for the compact red component of

2.8Gyr. The age required to fit the J, H and K colors of the compact core alone is well in excess of 3 Gyr. The implied redshift of formation is quite high even in the most conservative cosmologies. For $H_0 = 50$, $q_0 = 0.1$ the minimum formation redshift is 6, while for a $H_0 = 50$, $q_0 = 0.5$ universe, the implied redshift of formation is greater than 20. Roughly 15% of the $z > 2$ galaxies in our sample have extremely red colors. These galaxies, with r-K colors redder than 6.5 are also quite overluminous at K, the brightest object having $K=16.8$ at $z=2.01$.

Such extremely red spectral energy distributions and large luminosities suggest that highly obscured non-stellar sources may contribute to the light at long wavelengths. The only observational handle that we have on reddening comes from comparing emission lines arising from different levels of a single ionic species. The recent increase in sensitivity of near IR spectrographs has made it possible to measure $H\alpha$ and the [NII]6548,6584 lines in the H and K windows at redshifts of ~ 1.5 and ~ 2.4 . We have now detected $H\alpha$ emission in four galaxies with redshifts of roughly 2.4. From these we determine the $Ly\alpha/H\alpha$ ratios. The observed ratios are typically 3 – 4.5, while the case B ratio is 8.75. The implied spatially uniform reddening is rather small, $E(B-V) = 0.1 - 0.15$. The strong $H\alpha$ emission contributes roughly 15% of the light at K, also making the galaxies appear redder than their true colors. The net result of the two effects is that the galaxies are roughly 0.7 magnitudes bluer in the rest-frame than observed. While this does reduce the implied ages slightly, it does not change the basic conclusion that these galaxies contain an old stellar population. Our near IR spectra fail to reveal a broad component to the $H\alpha$ line, which must be present if an obscured quasar dominates the K band flux. Higher S/N $H\alpha$ spectra will allow us to place a better constraint on the contribution of an AGN to the near IR colors. Based on the data that we have at the present it appears that the distant radio galaxies contain a population with an age of 1 Gyr or more at redshifts in excess of 2. These objects imply an early formation epoch for AGN host galaxies. Our approach, which is based on light from stellar photospheres leads us to essentially the same conclusions reached by Turner (1990) from fueling and collapse time scales in $z > 4$ quasars.

Figure 1. The SED of 0156-252 at a redshift of 2.02. The filled symbols refer to the compact near-IR core while the open symbols contain all of the light. The dotted line is a 2.8 Gyr old Bruzual C model. The solid line is the sum of this old galaxy SED and a zero age burst population.

