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Spitzer Infrared Properties of Lyman α Emitters

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Abstract. We present results on the infrared properties of Lyman α emitters. At z=0.3 we demonstrate that our sample of 50 GALEX-identified emitters possess the same extinction properties as similarly ultraviolet-bright galaxies at the same redshift. The AGN fraction for these z=0.3 sources is low, 10-20%, and they show no correlation between Lyα flux and total infrared luminosity. At z=2.4-3.1 we discuss a sample of Lyman α blobs. Roughly two thirds of these blobs have infrared counterparts with infrared and sub-mm colors indicating they are dominated by star formation. Of the six IRS spectra taken of blob counterparts, four show PAH features. Their equivalent widths indicate two are strongly star formation dominated, while the other two are mixed sources with a significant contribution from an AGN.

1. Escaping Lyman α Emission

The discovery of Lyα emitters is now common place in the high-redshift universe. Often it is the only measurable line available and in cases of extremely high equivalent width it can be effectively the only information we possess about the galaxy. However, Lyα is a resonant ultraviolet line, both easily scattered and highly vulnerable to dust extinction. We still do not really understand the mechanism by which it escapes the galaxy, i.e., why are some galaxies Lyα emitters and others are not? It could be a function of dust extinction, orientation, or how disturbed the interstellar medium has been by either interaction or a powerful starburst.

Until the Lyα escape mechanism is understood, we will not be able to account for the likely biases in the selection of these most distant high-redshift galaxies. Studies at all wavelengths, at redshifts both high and low, are needed to address this. We focus on the infrared properties of these sources, where we can find the most powerful diagnostics for dust re-emission and the presence of an AGN.

2. Lyα Emitters at z=0.3

One of the reasons little is known about the escape mechanisms of Lyα is that, up until recently, there have been only a handful of low redshift examples(i.e., Hayes et al. 2007, Keel et al. 2005). Thanks to a GALEX sample of over 100 z~0.3 Lyα emitters (Deharveng et al. 2008, Cowie et al. 2010) this dearth of local Lyα-emitters is finally being addressed. We examine the Spitzer properties of sub-sample of 50 of

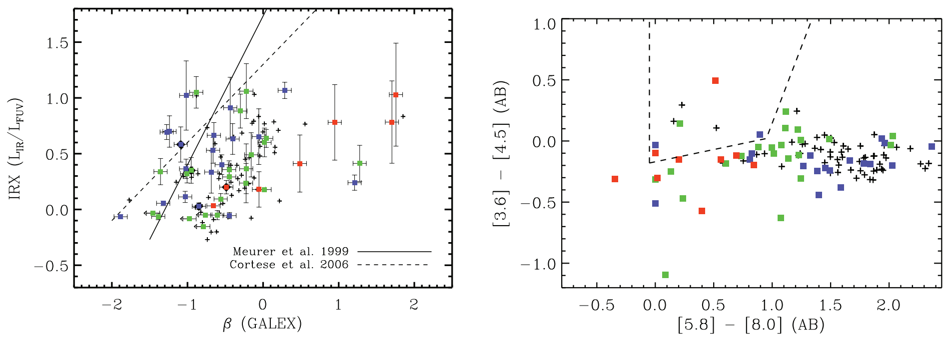

Figure 1.: Left) IRX – β Relation. The solid squares are the Lyα-emitters, while the crosses are the control sample. The lines are fits to other low redshift samples, Meurer et al. (1999), the solid line, and Cortese et al. (2006), the dashed line. Right) IRAC color-color plot to select for AGN. Symbols are the same as before. The dotted lines represent the color selection of Stern et al. (2005).

these GALEX-identified z=0.2-0.4 Lyα-emitting galaxies. We also identified a control sample of 57 non-emitting z=0.3 COSMOS galaxies, down to same NUV < 21.5.

The more dust extinction in the ultraviolet, the larger the percentage of a galaxy's total luminosity is emitted in the infrared. This principle is described by the IRX–β relation (Meurer et al. 1999), which we have plotted for our galaxies in Figure 1. Our z=0.3 Lyα emitters occupy a similar phase space to nearby, normal galaxies (i.e., Gil de Paz et al. 2007). There is no discernible difference in β or IRX between our sample galaxies and Lyα emitters. Therefore low redshift Lyα-emitting galaxies do not have less extinction or dust absorption than other ultraviolet-bright galaxies at the same redshift, meaning differences in dust extinction alone can not explain the escape of Lyα photons.

Using the IRAC color selection of Stern et al. (2005), we find that 10% of sample (5/50) has IRAC colors consistent with that of an AGN (see Figure 1). This is slightly higher than the 5% (3/57) AGN contribution found for the control sample. The Stern et al. (2005) color cut does miss some AGN, particularly those with bluer 3.6/4.5μm colors, but it is unlikely that the AGN contribution to Lyα-emitting galaxies could be much more than 20%. This AGN percentage is consistent with the estimates of Scarlata et al. (2009a), 17%, and Atek et al. (2009), 12.5%, but not Finkelstein et al. (2009), 43%. While AGNs are significant contributors to the Lyα-emitting population, they do not dominate it.

A weak Lyα – LIR Relation has been reported at higher redshifts (Colbert et al. 2006, Nilsson & Moller 2009). We see no similar correlation, not even a weak one, in the low redshift data (see Figure 2). This suggests less of a connection between the two emissions in these lower redshift, fainter sources. Alternatively, the relation seen at higher redshift is not real and will vanish with the appearance of larger and larger samples. The higher redshift samples also show a much lower ratio of $L_{Ly\alpha}$/LIR. High-redshift objects are high luminosity sources, so this would indicate that Lyα luminosity follows the same trend as the rest of ultraviolet emission, which drops as a total percentage of the total luminosity for the most infrared luminous galaxies (e.g., Martin et al. 2005).

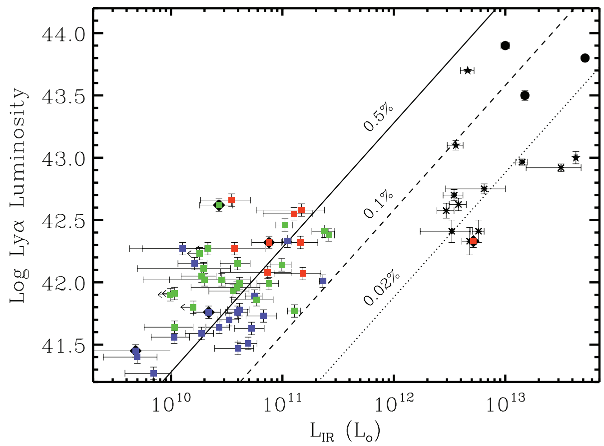

Figure 2.: Lyα – LIR Relation for z=0.3 sample. The high-redshift points are the solid circles (Colbert et al. 2006) and the stars (Nilsson & Moller 2009).

3. Lyman α Blobs at z=2.4–3.1

The Lyα blob (LAB) remains one of the great mysteries of the high redshift universe. While these extended Lyα nebulae are similar in extent (5-20″ or 50-150 kpc) and Lyα flux ($\sim10^{43-44}$ ergs s^{-1}) to high-redshift radio galaxies, blobs are radio quiet and are therefore unlikely to arise from interaction with jets. They are found almost exclusively within high-redshift galaxy over-densities (Matsuda et al. 2009, Palunas et al. 2004, Steidel et al. 2000) with none found so far at even moderate redshift (z<0.8; Keel et al. 2009), suggesting strong evolution.

With most LABs lying at the density peak of high redshift structures (Matsuda et al. 2009, Matsuda et al. 2004, Palunas et al. 2004) and with number densities comparable to galaxy clusters in the nearby and high-z universe (10^{-5}–10^{-6} Mpc^{-3}; Yang et al. 2009), it seems likely that the giant LABs are at the very least signposts for regions of massive galaxy assembly, if not the progenitors of the massive elliptical galaxies themselves. The limited *HST* imaging of these objects to date shows some evidence for interaction and merger of multiple compact objects (Chapman et al. 2004, Francis et al. 2001). The source of energy for the blobs remains a mystery, with the leading theories being escaping AGN illumination (Basu-Zych & Scharf 2004), supernova-driven superwinds (Ohyama & Taniguchi 2004), and cooling flows (Francis et al. 2001, Scarlata et al. 2009b).

3.1. Spitzer Flux Density Ratios

Mid-infrared and submillimeter imaging show that it is very common that the extended nebulae of LABs contain sources of extreme infrared luminosity. Powerful *Spitzer* 24μm and sub-mm sources have been found in dozens of LABs, and almost all the most luminous ones, (e.g., Webb et al. 2009, Colbert et al. 2006, Dey et al. 2005, Chapman et al. 2004, Geach et al. 2005, Beelen et al. 2008). Our Lyman α blob sample is spread across four different fields: J2143-4423 (z=2.39), SSA22 (z=3.1), 53w002 (z=2.38) , and the NOAO Deep Wide-Field Survey (z=2.656).

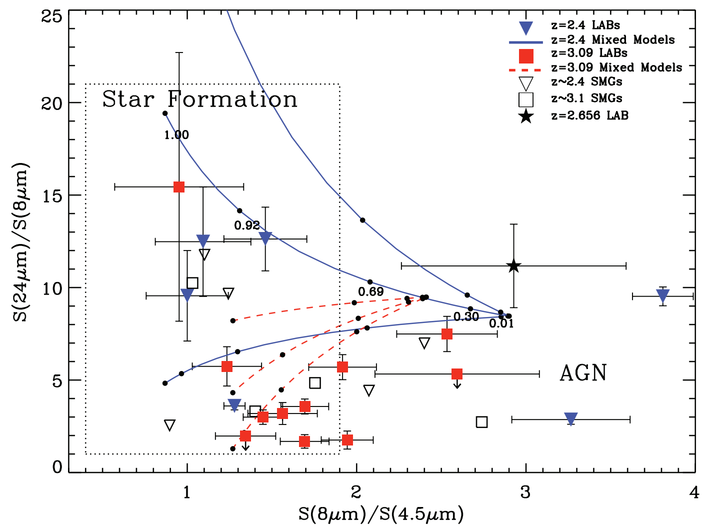

Figure 3.: Ratio of 8μm to 4.5μm versus ratio of 24μm to 8μm for our sample of Lyα blobs (solid symbols). Triangle symbols are z=2.4 sources, squares are z=3.1, and the star is at z=2.66. For comparison we also plot the sub-mm galaxies (SMGs) at similar redshifts from Pope et al. (2008) as hollow symbols and star formation. The lines are models derived from Chary & Elbaz (2001), running from star formation-dominated on the left to AGN dominated at the right. The rectangular box is from Pope et al. (2008), marking the likely location of star forming galaxies.

Plots of *Spitzer* mid-infrared IRAC colors can be powerful tools for identifying AGN and separting them from starbursts at low redshifts (Stern et al. 2005; Lacy et al. 2004). By including MIPS 24μm, one can then continue this analysis to much higher redshift (i.e., Webb et al. 2009; Pope et al. 2008). We plot all the mid-infrared sources associated with LABs that have 8μm detections in Figure 3, which is a comparison of the 24/8μm flux density ratio to the 8/4.5μm flux density ratio. The higher 8/4.5μm flux ratios are generally only obtainable by AGN, as only their SEDs should be that steep at these high redshifts (z>2). We over-plot a series of models of star formation from Chary & Elbaz (2001) mixed with the SED of an AGN (Mrk 231) to produce a range of ratios from AGN to star formation-dominated.

Nearly two thirds (59%; 10 of 17) of the LAB-associated sources fall within the star-formation rectangle. This indicates that the majority of sources associated with LABs are likely powered by starbursts. However, even an AGN dominant in the infrared can still have significant contribution from stars at rest wavelength 1μm, flattening its slope considerably, i.e. decreasing the 8/4.5μm ratio.

The combination of *Spitzer* mid-infrared with submillimetre flux densities, each being sensitive to a different temperature regime (stars, hot dust, cold dust), can also do much to reveal the likely power sources of the infrared-bright galaxies within the blobs. In Figure 4 we plot the ratio of 24μm to 850μm sub-mm versus ratio of 24μm to 8μm. All eight of the sub-mm detected components for LABs have mid-IR/sub-mm ratios consistent with star formation. An additional six of the Lyα blob components

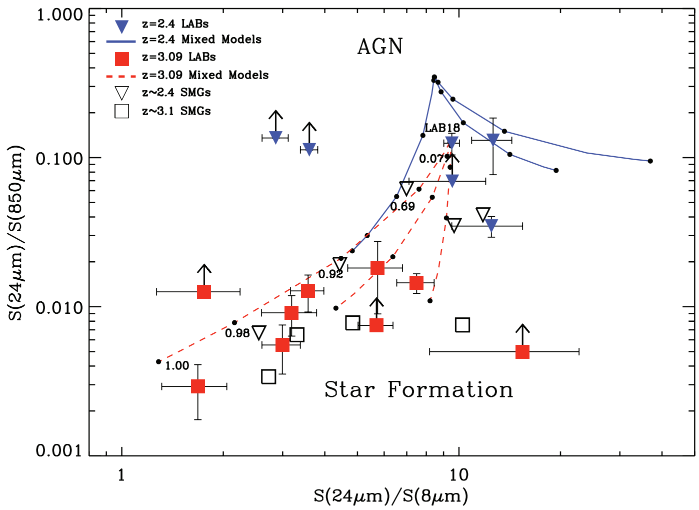

Figure 4.: Ratio of 24μm to 850μm sub-mm versus ratio of 24μm to 8μm for our sample of Lyα Blobs, symbols and models same as in FIgure 3.

are only upper limits, but only two of those are clearly outside and above the locus of star formation. This plot strongly indicates that the majority of these infrared-bright components of LABs are not powered by AGN alone.

3.2. PAH Emission in Lyman α Blobs

We targeted six infrared sources associated with LABs with *Spitzer* IRS spectroscopy. Four of the six show significant PAH features. In order to measure individual PAH emission lines, we used the IDL PAHFIT software package (Smith et al. 2007), which fits all PAH emission lines and continuum simultaneously. We plot the 6.2μm equivalent width (EW) versus the 7.7μm EW in Figure 5. The 6.2μm feature is less contaminated by nearby PAHs and silicate absorption and therefore can be less vulnerable to the continuum model chosen. Unfortunately, for most of our data the 6.2μm feature lies near the noisier wavelength edge of the LL1 IRS detector, limiting the information available for the continuum there.

The dashed lines on the figure (6.2μm EW=0.2μm and 7.7μm EW=0.8μm) are also from Sajina et al. (2007) and represent suggested dividing lines between strong-PAH (i.e. star forming) and weak-PAH sources (i.e. AGN-like). Only 25% of the Sajina et al. (2007) high-z ULIRG sample fell into the strong-PAH, as opposed to half of our sample (our two PAH-free sources are not plotted). We find star formation rates in our PAH-detected sample ranging from 420 to 2200 $M_\odot$ yr^{-1}, significantly larger than the limits we found for our two non-PAH sources which were < 130-140 $M_\odot$ yr^{-1}.

4. Summary

For the z=0.3 Lyα emitters, we find no difference in β or IRX between them and similarly ultraviolet-bright galaxies at the same redshift. Low-redshift Lyα galaxies do not

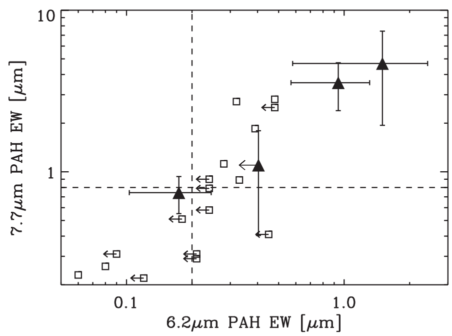

Figure 5.: 6.2 μm PAH EW vs. 7.7 μm PAH EW. Also plotted are high-z ULIRGs (hollow squares) and dashed line representing the approximate cut-off between AGN and star formation domination from Sajina et al. (2007).

have particularly different extinction or absorption than non-emitting galaxies. Using IRAC color, we find that AGN make up only 10-20% of sample. We see no Lyα-LIR correlation. The higher redshift, higher LIR emitters show a much lower ratio of $L_{Ly\alpha}$/LIR.

For the z=2.4–3 LABS, we find that roughly two thirds of their infrared counterparts are consistent with a infrared luminosity dominated by star formation. LABs resist being linked to single power source. What LABs likely all have in common is their environment: the dense, gas-rich infall zones at the centers of high redshift overdensities where the most massive galaxies are being born.

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