Disentangling AGN and star formation activity in high redshift (Ultra) Luminous Infrared Galaxies

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MOTIVATION

Our aim is to determine the relative contributions from active galactic nucleus (AGN) and star formation activity to the infrared spectral energy distribution (SED) in high redshift dusty galaxies. We collated a large sample of 151 ULIRGs and LIRGs in the GOODS-N and ECDFS fields with deep *Spitzer* mid-IR spectroscopy and photometry from 1-500 µm. The mid-infrared spectrum contains distinct signatures from both star formation and AGN activity; we performed spectral decomposition (for details see Pope, A., *et al*. 2008, ApJ, 675, 1171) to determine how much of the mid-IR luminosity was produced by star formation and how much was due to an AGN (see figure 1 below); sources with more than 50% mid-IR luminosity due to a power law component are hereafter referred to as AGN while the sources whose mid-IR luminosity is dominated by star formation are referred to as starbursts. We then combine the mid-IR spectral decomposition with the far-IR photometry to further disentangle the influence of the AGN and starburst on the IR SED in order to explore the relative growth of stellar mass and black holes in high redshift dusty galaxies.

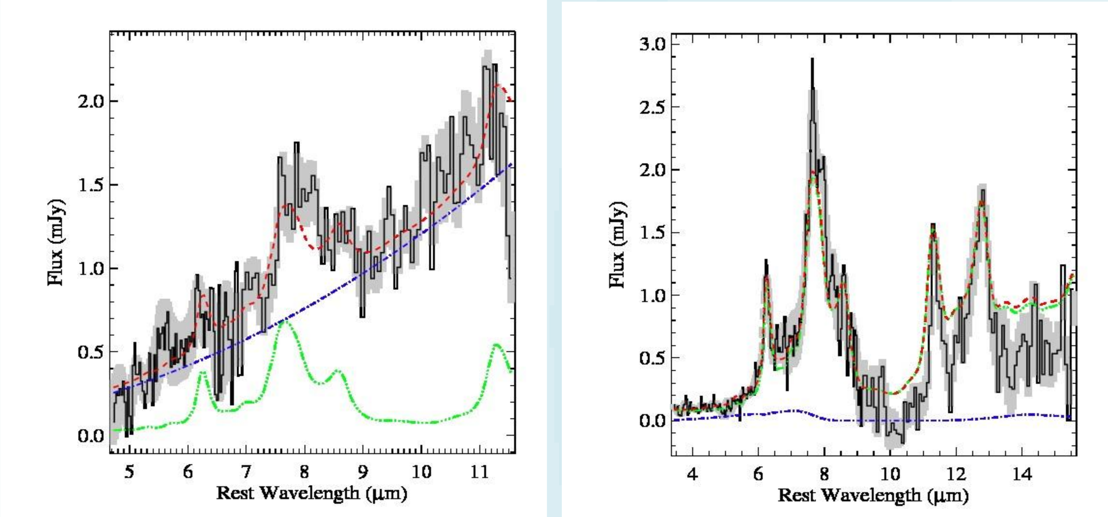


Figure 1 Sample mid-IR spectra of a source dominated by AGN emission (left) and a source dominated by star formation (right). The red dashed curves show the best-fit SED which is made up of an extincted power-law component (blue-dashed line) and an extincted starburst template (green-dashed line). The relative contributions of each component to the overall fit determines whether a galaxy is dominated by AGN or star formation activity in the mid-IR.

COMPOSITE SPECTRAL ENERGY DISTRIBUTIONS

We divided our sample into four subsamples:

1) Star forming galaxies at low redshift (z < 1.5; 37 sources)

2) Star forming galaxies at high redshift (z > 1.5; 30 sources)

3) AGN dominated systems (> 50%) that exhibit a 9.7 µm silicate absorption feature (18 sources)

4) AGN dominated systems (> 50%) with a featureless power-law spectrum in the mid-IR (10 sources)

We include photometry from near-IR, *Spitzer*/IRAC and MIPS, and *Herschel* PACS and SPIRE (from the GOODS-*Herschel* Key Program, PI David Elbaz, see Elbaz, D., *et al*. 2011, submitted, arXiv:1105.2537) with the mid-IR spectroscopy to create composite SEDs for each subsample. In making the composite SEDs, we normalized each galaxy to a portion of the mid-IR spectrum and excluded any galaxies that didn't possess a full range of data. At far-IR wavelengths, we fit a two temperature modified blackbody model and attached the fit to the stacked spectrum to create a composite spanning the full IR wavelength range. We calculate the effective temperature of this two temperature component model by calculating a luminosity weighted average of each temperature component.

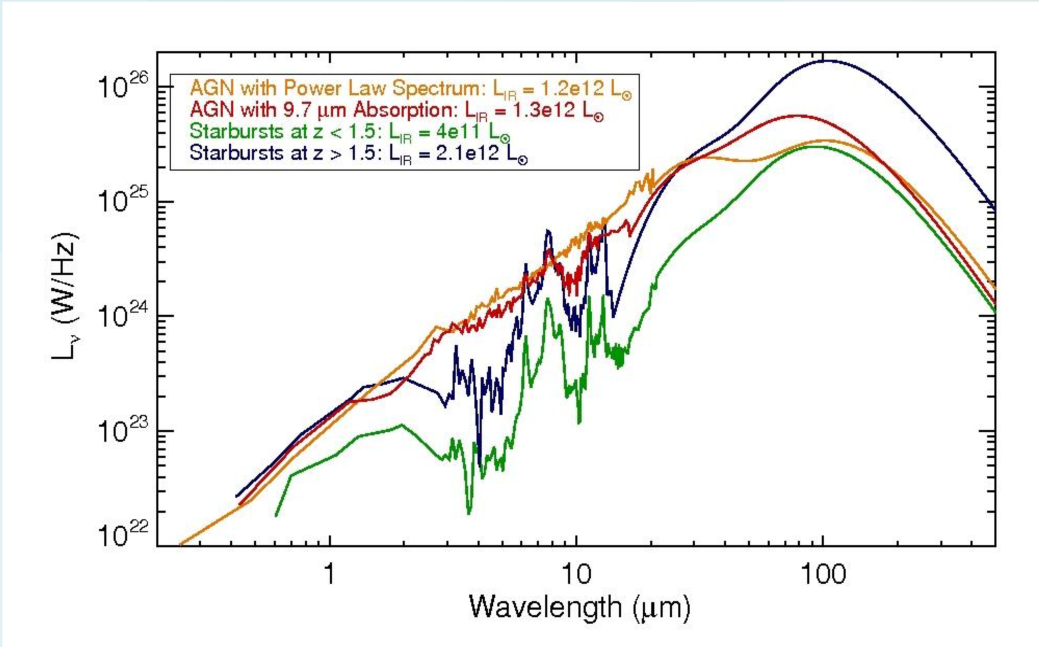
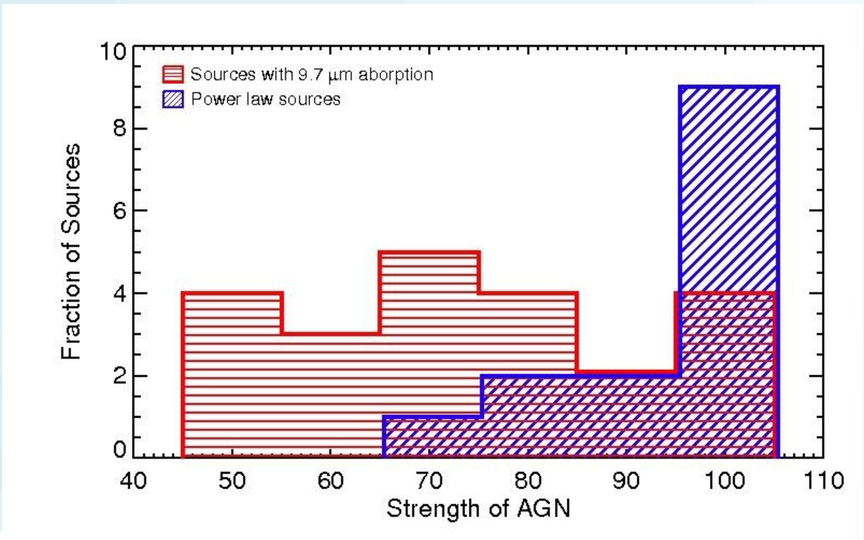


Figure 2 Comparison of the composite IR SEDs created from the four subsamples of galaxies. The individual subsamples and composites are discussed below.

AGN

Figure 3 Sources whose mid-IR spectrum was dominated by an AGN continuum were further divided according to whether they exhibited 9.7 µm silicate absorption. The majority of the sources completely dominated by AGN emission (> 95 %) exhibit a featureless power law spectrum, whereas sources with a silicate absorption feature are more uniformly distributed according to the strength of the AGN.



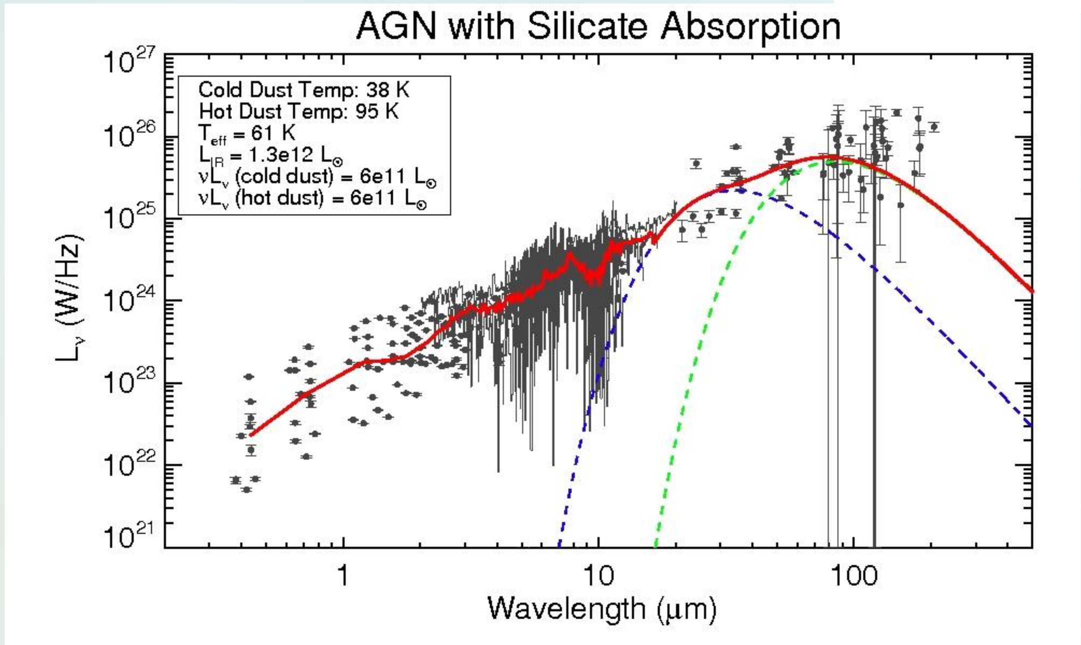
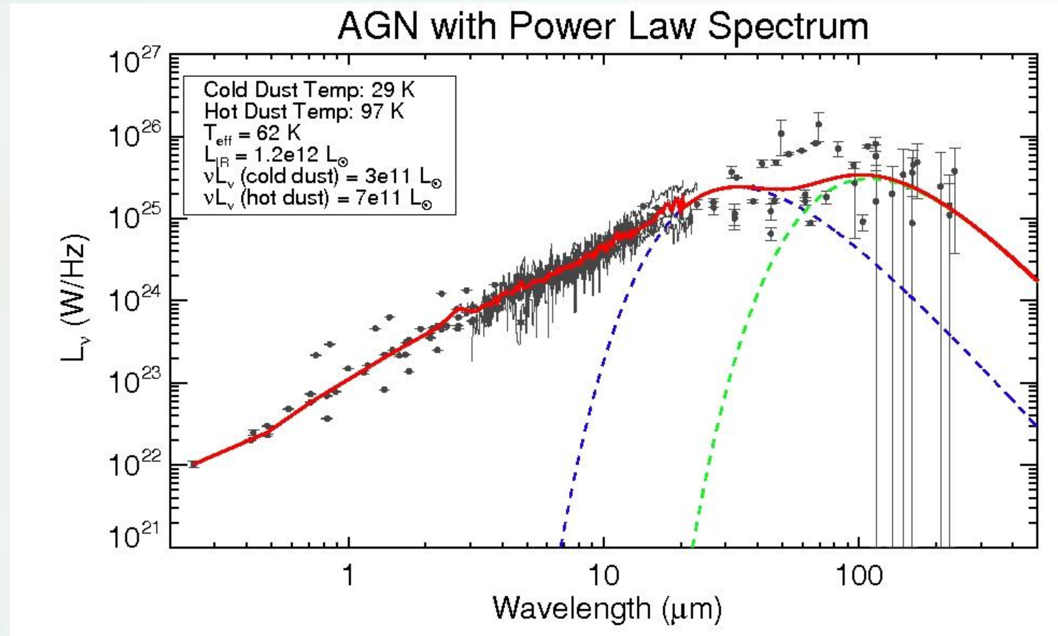


Figure 4 Composite SED created from galaxies with mid-IR spectra dominated by AGN emission (> 50%) that exhibit the 9.7 µm silicate absorption feature (18 sources). The relative contributions of the hot and cold dust components were determined by integrating under the modified blackbody for each dust temperature from 8-1000 µm.

Figure 5 Composite SED created from galaxies with mid-IR spectra dominated by AGN emission (> 50%; 10 sources). The power-law nature of the individual spectra and composite SED from the near-IR to ~ 20 µm is apparent. This is the only composite where the contribution from the hot dust dominates over the cold dust.



STARBURSTS

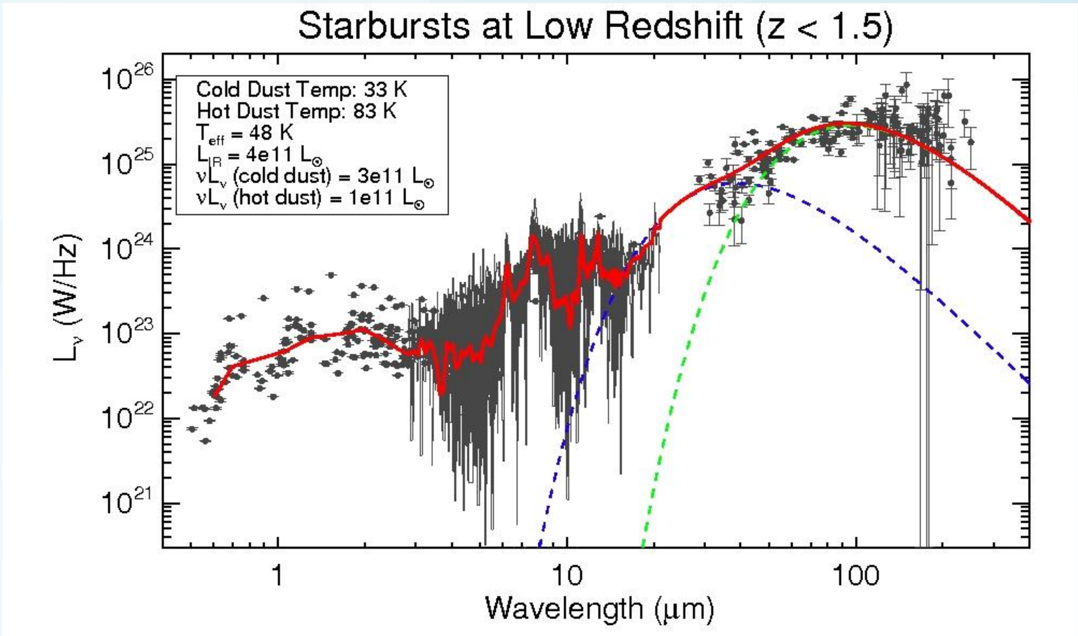
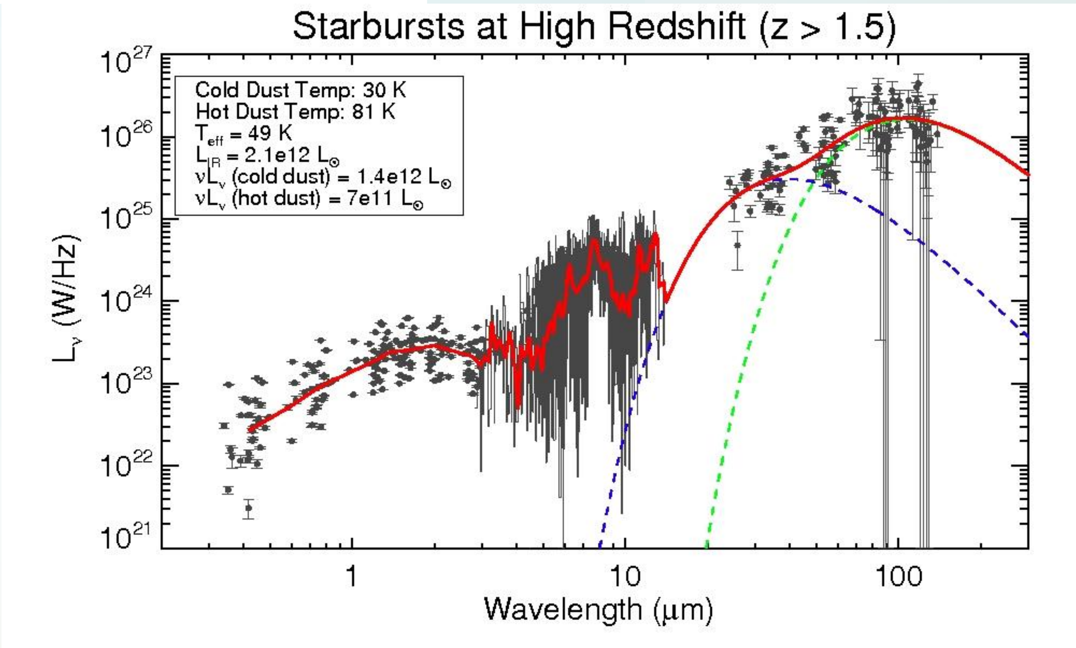


Figure 6 Composite SED created from galaxies with mid-IR spectra dominated by star formation emission (> 50%) below a redshift of 1.5. Composite was created from 37 sources.

Figure 7 Composite SED created from starburst galaxies above a redshift of 1.5. Composite was created from 30 sources.



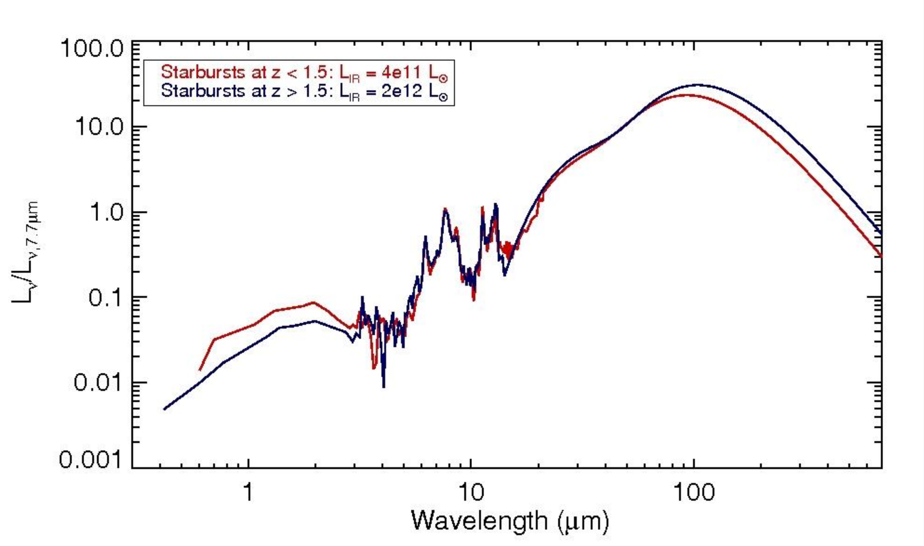


Figure 8 Comparison of the starburst composite SEDs for z < 1.5 and z > 1.5. The shape of the mid-IR PAH spectrum exhibits no evolution from high redshift to low redshift. The low redshift starburst composite has a lower average L_{IR} (by a factor of three); therefore, as expected, we see slightly more emission in the stellar bump at near-IR wavelengths and slightly less dust emission in the far-IR.

COLOR-COLOR DIAGNOSTICS

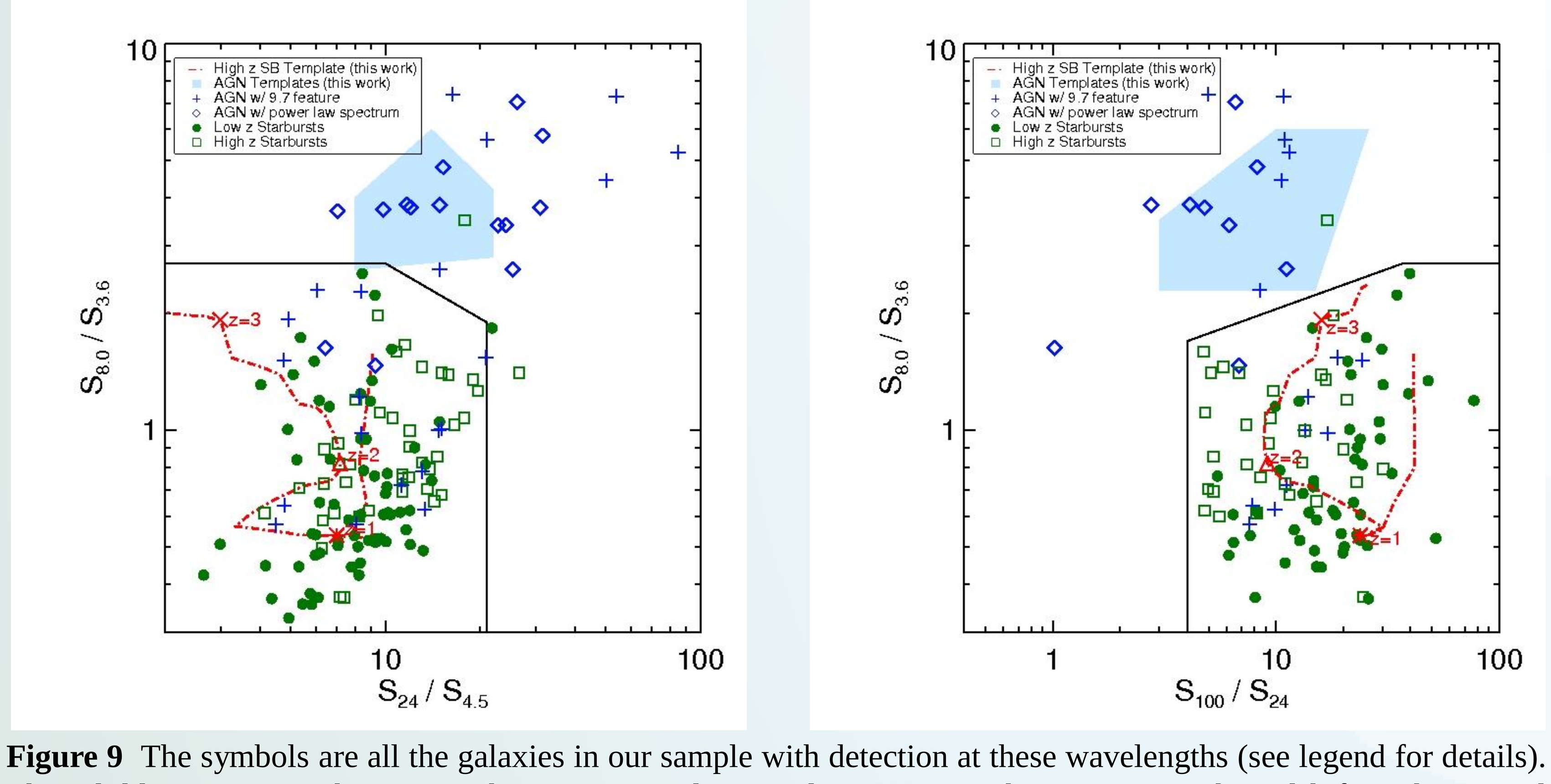


Figure 9 The symbols are all the galaxies in our sample with detection at these wavelengths (see legend for details). The solid lines separate the regions that contain predominantly AGN or starburst sources. The redshift tracks created from the AGN composite SEDs in figures 4 and 5 above as well as the tracks of Mrk 231 exhibit little evolution and are shown as the blue shaded region. The redshift track created from the high z starburst SED template in figure 7 is shown as the red dashed line. The low z and high z starbursts separate nicely following the tracks, especially when including the 100 µm fluxes (right). While several AGN dominated sources lie in the region primarily occupied by starburst sources (contamination is 13% for plot on the left and 11% for plot on the right) there is little contamination by starburst sources in the upper part of the graph primarily occupied by AGN. The color-color plot using far-IR *Herschel* data (on right) does a slightly better job of separating sources (58% of AGN lie outside the starburst region as opposed to 54% for the plot on the left) than using mid-IR *Spitzer* colors alone. Both plots are a robust diagnostic for separating AGN and starburst sources at high redshift since they have been calibrated with spectroscopy.

SUMMARY

- We have combined deep photometry from 3.6 – 500 µm with *Spitzer* mid-IR spectroscopy for 151 (U)LIRGs in order to explore the relative contribution of AGN and star formation activity to the total IR emission.
- We perform spectral decomposition on the mid-IR spectrum of each source to determine whether the mid-IR luminosity is dominated by a power law (sources we designate AGN) or star formation (sources we designate starbursts).
- We find no significant difference in the SEDs (stellar bump, PAH features, dust temperature) between starburst systems at z < 1.5 (L_{IR} = 4e11 $L_\odot$) and z > 1.5 (L_{IR} = 2.1e12 $L_\odot$)
- AGN dominated galaxies with a pure power law spectrum are dominated by a hot dust component whereas AGN with silicate absorption have a significant cold dust component.
- We find slightly warmer (~ 10 K) effective average dust temperatures for AGN classified galaxies than for starbursts.
- We define new color-color diagnostic plots for separating AGN and starburst systems in the absence of spectroscopy.