Mid-infrared properties and color selection for X-ray detected AGN

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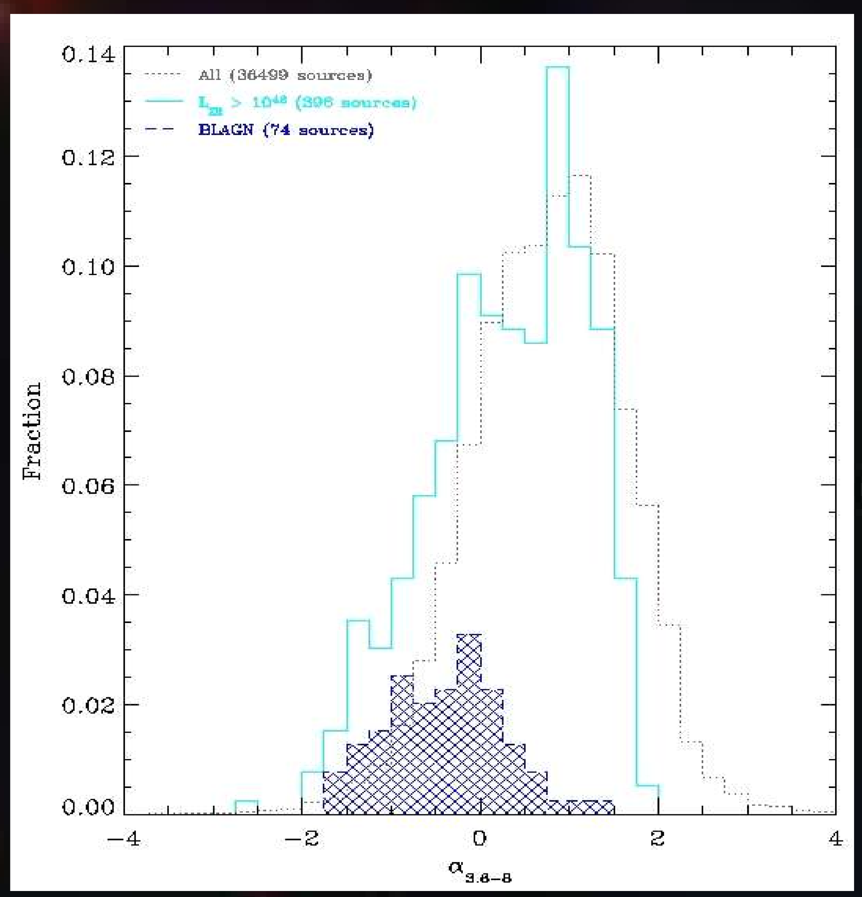
Abstract

We present the mid-infrared colors of X-ray-detected AGN and explore mid-infrared selection criteria. Using a statistical matching technique, the likelihood ratio, over 900 IRAC counterparts were identified with the more than 1000 published X-ray sources in the Chandra Deep Field-South and Extended Chandra Deep Field-South. Most X-ray-selected sources have IRAC spectral shapes consistent with power-law slopes, $f_\nu \propto \nu^\alpha$, and display a wide range of colors, $-2 \le \alpha \le 2$. Although X-ray sources typically fit to redder (more negative α) power-laws than non-X-ray detected galaxies, more than 50% do have flat or blue (galaxy-like) spectral shapes. Roughly a fourth of the X-ray selected AGN detected at 24 μm show monotonically red (negative α) power-laws through 24 μm. This could be the subset of our sample whose infrared spectra are dominated by emission from the central AGN region. Most IRAC color selection criteria fail to identify the majority of X-ray selected AGN, identifying only the luminous AGN and those displaying broad lines at optical wavelengths. Thus some forms of infrared selection may be efficient (yieldings a high fraction of AGN) but they are incomplete (many bona fide AGN are missed).

IRAC Power Law SEDs

Each source with detections in all 4 IRAC channels was fit with $f_\nu \propto \nu^\alpha$: 94% of all sources and 97% of the X-ray-selected AGN had acceptable fits by power laws (X^2, p=0.05).



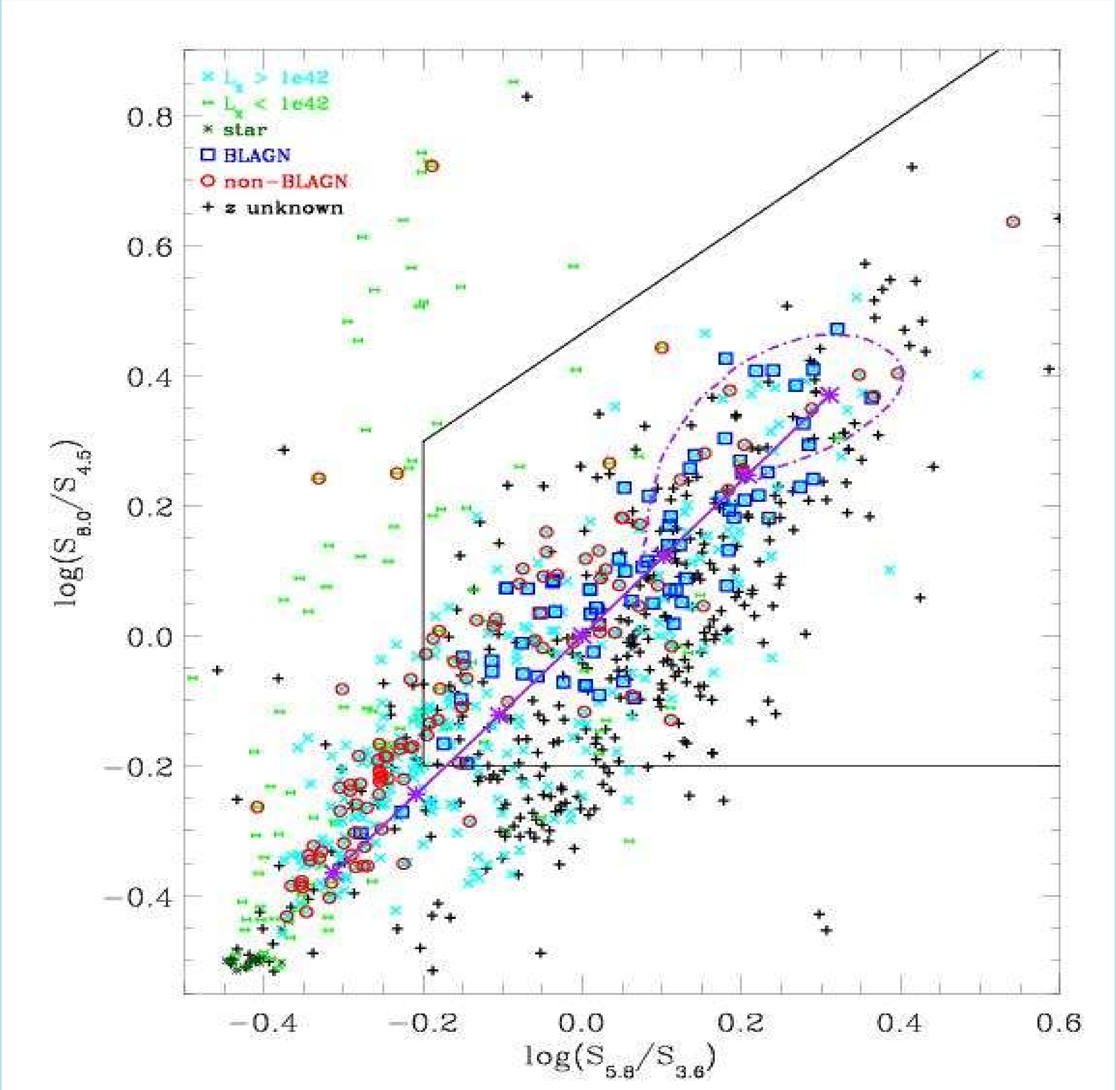
Left: Histograms for $\alpha_{3.6-8\mu m}$: all IRAC sources (black), X-ray-selected AGN (light blue), and Broad-Line AGN (dark blue hatched). Within the short wavelength baseline of the IRAC camera, nearly all of our sources are consistent with power laws, especially considering their photometric uncertainties.

X-ray-selected AGN and galaxies share a similar range in power law slopes, but have distinct distributions (KS test; P=0.0014). Galaxies are bluer as a whole than the AGN population, even excluding the broad-line objects which have the reddest slopes. Yet, over half (62%) of X-ray-selected AGN have positive slopes similar to the bulk of the galaxy population.

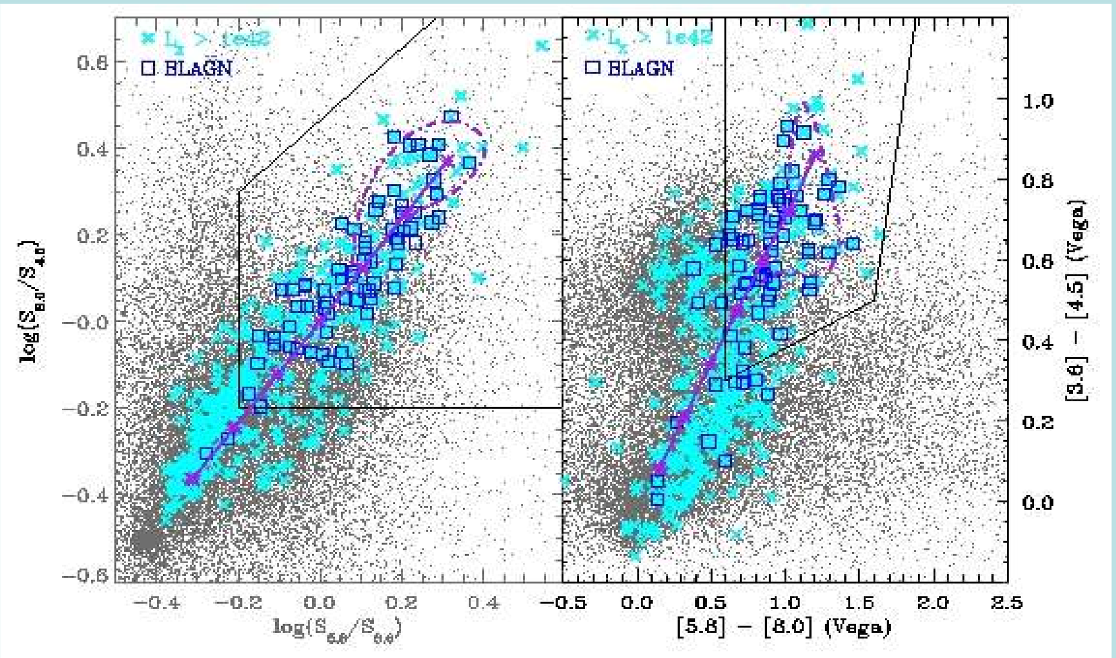
Mid-infrared SEDs

AGN mid-IR spectra, powered by hot dust, are typically are red power laws ($f_\nu \propto \nu^\alpha$, $\alpha \approx -1$; Elvis et al 1994). Most galaxies appear blue at 3.6–8.0μm because stellar spectra are declining. The 24 μm band is sensitive to all warm dust emission in galaxies, making both AGN and star forming galaxies easily detectable (Treister et al. 2006; Egami et al. 2004; Le Floc'h et al. 2004).

Color-Color Selection

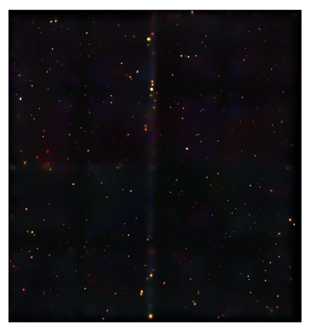


Above: Color-color selection (after Lacy et al. 2004) selects 97% of Broad-Line AGN but only 58% of X-ray-selected AGN. A similar selection region (after Stern et al. 2005; left below) still selects the majority (77%) of Broad-Line AGN, but only 40% of X-ray-selected AGN.



In deep IRAC surveys, the Lacy selection box [Left] is not as efficient as the Stern selection box [Right]: 18% of all sources (11,000 galaxies) lie within the box compared to under 10% (5,000 galaxies). **Although many AGN have redder colors than the bulk of the galaxy population, the entire X-ray-selected AGN population is not well separated from the rest of the galaxies.**

Multi-wavelength data in MUSYC ECDF-S

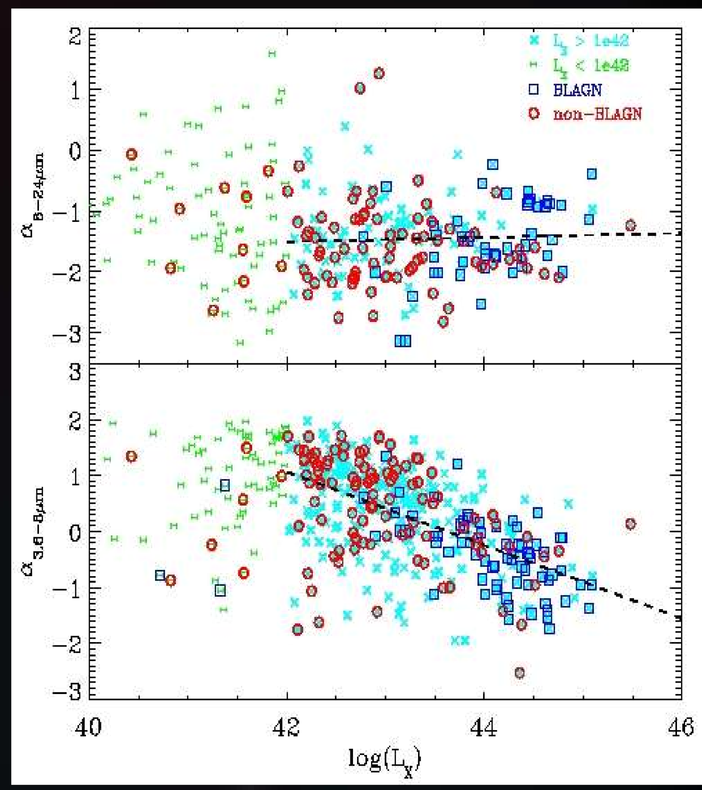


X-ray: We combine the ~300 arcmin² very sensitive central Chandra Deep Field-South (CDF-S; Giacconi et al. 2002) with the ~1100 arcmin² Extended Chandra Deep Field-South (ECDF-S; Lehmer et al. 2005, Virani et al. 2006). *We create a new unified MUSYC X-ray point source catalog from the individual published point source catalogs.*

Mid-IR: The **S**pitzer **I**RAC / **MU**SYC **P**ublic **L**egacy in **E**-CDFS is a public Deep IRAC Survey (Damen et al. 2008, in prep.) complementing the existing deep IRAC and MIPS data on the central region of this field (Dickinson et al. 2003). The IRAC data cover 3–8 μm to 5σ limiting depths of 24.4 (3.6 μm), 24.0 (4.5 μm), 22.2 (5.8 μm) and 22.2 (8.0 μm) in AB magnitude. We also combine the wide SWIRE 24 μm catalog (Lonsdale et al. 2003), which yields counterparts with AB magnitudes down to 19, with the deeper data in the central area, finding counterparts in the central region up to 3 magnitudes deeper.

X-ray Luminosity:

- **Top:** Beyond the observed 8 μm band, there is no trend of spectral shape ($\alpha_{8-24\mu m}$) with X-ray luminosity; X-ray galaxies of all luminosities contain varying amounts of warm dust.
- ***Bottom:*** *At a given L_X, X-ray sources fit a large range of $\alpha_{3.6-8\mu m}$;* Varying contributions from the host galaxy (stars and cool dust) could cause the different IRAC slopes.



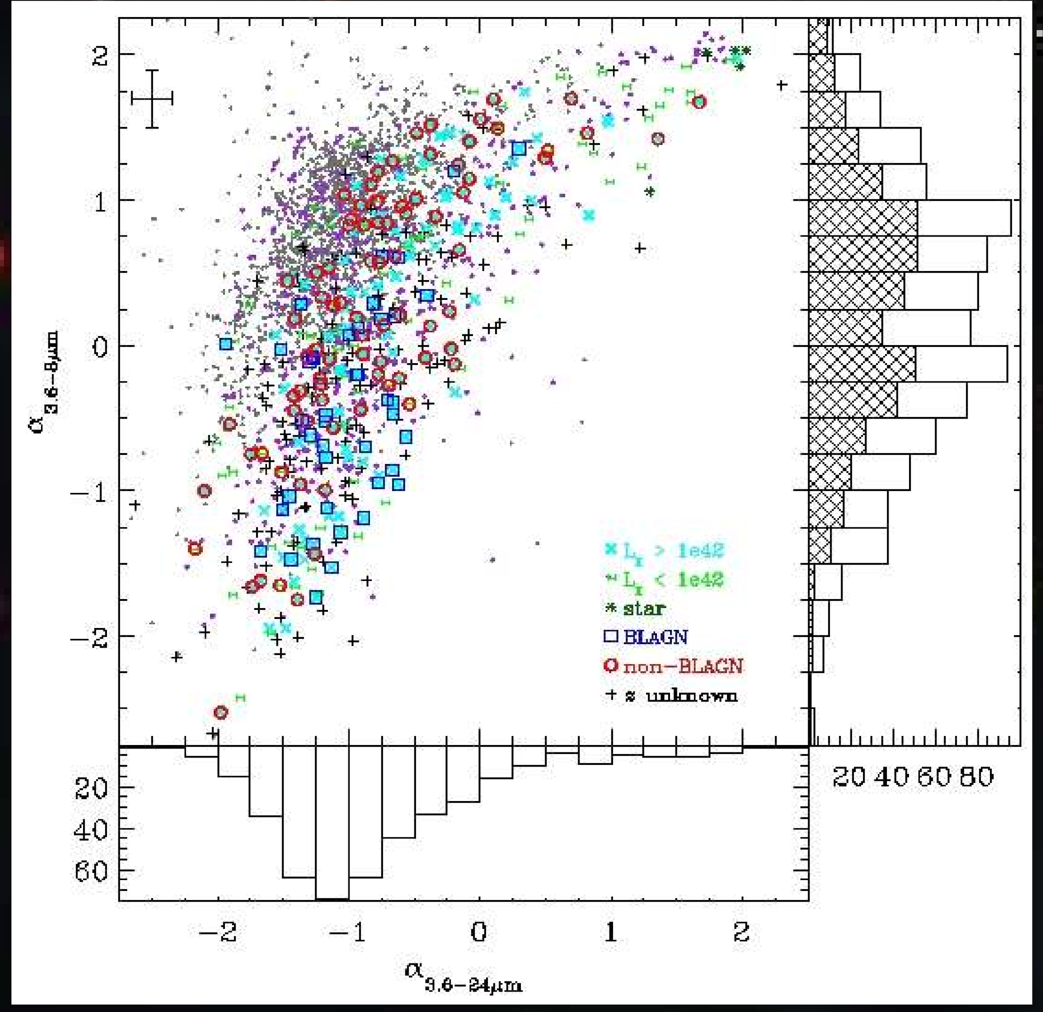
Host Galaxies:

From their location on color-color plots (and $\alpha_{3.6-8\mu m}$), we find *the mid-infrared light in many moderate luminosity AGN is consistent with being dominated by emission from stars and cool dust in the host galaxy.* This agrees with the findings of other X-ray selected samples (e.g., Franceschini et al. 2005; Barmby et al. 2006) and with the similar mid-infrared luminosity distributions of low luminosity AGN and non-X-ray detected galaxies (Treister et al. 2006).

$L_x=10^{42.8}$ergs/s

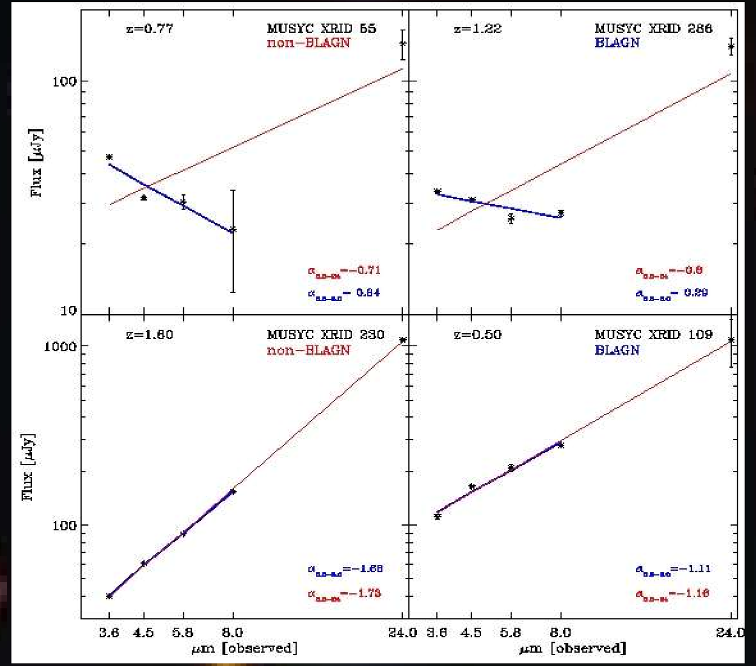
GEMS images of Host Galaxies in the ECDF-S

$L_x=10^{42.5}$ergs/s



3-24 μm Data:

Left: The X-ray-detected sources span a large range of $\alpha_{3.6-8\mu m}$ but they are nearly uniformly red in $\alpha_{3.6-24\mu m}$. In this figure we include all sources whether or not their spectral shape is consistent with a power law. The histogram of $\alpha_{3.6-24\mu m}$ peaks below -1, with 90% of X-ray-selected AGN detected at 24 μm having $\alpha_{3.6-24\mu m} < 0$. This histogram is quite distinct from the histogram of the best-fit $\alpha_{3.6-8\mu m}$ where a very broad peak extends from $\alpha_{3.6-8\mu m} \approx 0$ to +1.



Top: For many sources $\alpha_{3.6-8}$ is much bluer than $\alpha_{3.6-24}$.

Bottom: For ~30% of our X-ray sources, power-law fits to 3.6-8 μm are consistent with those from 3.6-24 μm.

Conclusions

- **25-30% of the X-ray-selected AGN fit red power laws ($\alpha_{3.6-8} < 0$ & $\alpha_{3.6-24} < 0$) and tend to be the most luminous of the X-ray sources. These sources, and their Compton-thick counterparts undetected at X-ray wavelengths, are the best candidates for infrared selection techniques.**
- **Mid-infrared selection techniques miss a significant fraction of AGN when the high column densities significantly dim the central power-law emission and/or emission star burst activity significantly dilutes the continuum emission from AGN activity.**

References:

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