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Mid-infrared selection of dusty AGN

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Abstract. We present results from the spectroscopic follow-up of a sample of candidate obscured AGN selected in the mid-infrared from the Spitzer First Look Survey. Our selection allows a direct comparison of the numbers of obscured and unobscured AGN at a given luminosity for the first time, and shows that the ratio of obscured to unobscured AGN in an 8μm-selected sample with infrared luminosities corresponding to low luminosity quasars is $\approx 1:1$ at $z \sim 0.5$. Most of our optically-faint candidate obscured AGN have the high-ionization, narrow-line spectra expected from type-2 AGN. We discuss techniques for selecting such samples at longer infrared wavelengths to reduce the selection bias against highly-obscured and high redshift objects inherent in our IRAC-based selection technique.

Spitzer is changing the way we select and study samples of dust-obscured AGN. A combination of sensitivity and observing efficiency allows it to rapidly map regions of several square degrees to limits which are deep enough to find luminous AGN at cosmological distances. In particular, we are able to select members of the previously elusive type-2 (i.e. obscured) quasar population. This population is interesting both from the point of view of allowing a correct accounting for accretion onto black holes, and for helping us to understand whether obscured and unobscured quasars are related through orientation or evolution. It may also help us understand the links between quasars and galaxy formation.

Despite some success with samples selected in the hard X-ray (e.g. Norman et al. 2002), and from the Sloan Digital Sky Survey (SDSS) (Zakamska et al. 2004), there is still no consensus on the number densities and luminosity distribution of the hidden quasar population, particularly at high (quasar-like) luminosities.

In Lacy et al. (2004; hereafter Paper 1) we presented a technique for selecting obscured AGN using only mid-infrared colours. The advantage of this technique is that type-1 and type-2 AGN can be selected using the same criteria, removing the uncertainty involved when type-1 and type-2 objects are selected in different ways. Our technique is also capable of selecting Compton-thick AGN (such as NGC1068). Thus we may well be able to probe higher obscuring columns than hard X-ray surveys, though this is yet to be directly established. In Lacy et al. (2005; hereafter Paper II) we showed optical spectra demonstrating that our selection technique is indeed effective at finding obscured AGN. Other work also shows that AGN selection through mid-infrared Spitzer colors is both reliable and effective (Stern et al. 2004; Hatziminaoglou et al. 2005). In this paper we summarize the results of our program so far, discuss the selection of a sample of type-1 quasars matched in mid-infrared luminosity and redshift, and the SEDs of our type-2 quasars from optical to radio wavelengths.

1. The quasar-2 sample

The initial selection of the obscured AGN sample in Paper I included estimates of photometric redshifts. Paper II used optical spectra to refine the redshifts of the objects which had photometric redshifts > 0.3 and were thus likely to be sufficiently luminous to be classed as type-2 quasars. Table 1 summarizes our obscured quasar sample.

Table 1. Properties of 8μm-selected quasar-2s

Object	z	$S_{8\mu m}$ (mJy)	$\lg(L_{5\mu m}$ $(\mathrm{WHz}^{-1}))$	Nature of optical spectrum
SSTXFLS J171106.8+590436	0.462	1.38	23.71	high-ionization, narrow lines
SSTXFLS J171115.2+594906	0.587	5.09	24.30	starburst spectrum
SSTXFLS J171147.4+585839	0.800	1.83	24.30	high-ionization, narrow lines
SSTXFLS J171313.9+603146	0.105	4.65	22.90	high-ionization, narrow lines
SSTXFLS J171324.3+585549	0.609	1.30	23.85	high-ionization, narrow lines
SSTXFLS J171804.6+602705	0.43?	1.18	23.71	single narrow emission line
SSTXFLS J171831.6+595317	0.700	1.22	24.27	high-ionization, narrow lines
SSTXFLS J171930.9+594751	0.358	1.57	23.56	high-ionization, narrow lines
SSTXFLS J172050.4+591511	?	3.63	-	featureless red continuum
SSTXFLS J172123.1+601214	0.325	3.71	23.89	high-ionization, narrow lines
SSTXFLS J172328.4+592947	1.34?	1.69	25.12	single broad emission line
SSTXFLS J172458.3+591545	0.494	1.18	23.85	high-ionization, narrow lines

1.1. Comparison with a sample of type-1 quasars

We have selected a matched sample of type-1 quasars in the XFLS field from the SDSS DR1 quasar catalogue using the same mid-infrared selection criteria as our type-2 sample, and a redshift range of $0.3-0.8$. Their mid-infrared colors are significantly bluer than the type-2 sample, showing that extinction in the IRAC mid-infrared bands is important for our type-2 objects. This suggests that selection at longer wavelengths still, e.g. 24μm, will be necessary to find the most obscured objects.

The SEDs of the type-1 quasars are (as expected) very similar to those of our type-2s at infrared wavelengths. There is some evidence for a slightly higher median radio luminosity for the type-2s, and a slightly higher median narrow line luminosity, but the statistical significance of these trends is low. In the near-infrared and optical the type-2 SEDs are, of course, much redder than those of the type-1s, and they show a lot of variation in their SEDs. Further near-infrared data is required to separate the AGN and host galaxy contributions to the near-infrared emission.

2. Selection at 24μm

Our present 8μm-based selection is biased against the most heavily obscured objects, where extinction may be high even in the mid-infrared. There is also a bias against high redshift objects as the rest-frame near-infrared is redshifted into the observed mid-infrared. Not only is there a large k-correction on the mid-infrared torus emission as it falls off at short wavelengths, but also the contribution from starlight in the host galaxy starts to become important. We can alleviate this problem by selecting at 24μm, using two techniques. Martinez-Sansigre et al. (2005) use 24μm sources which are also radio-detected with radio

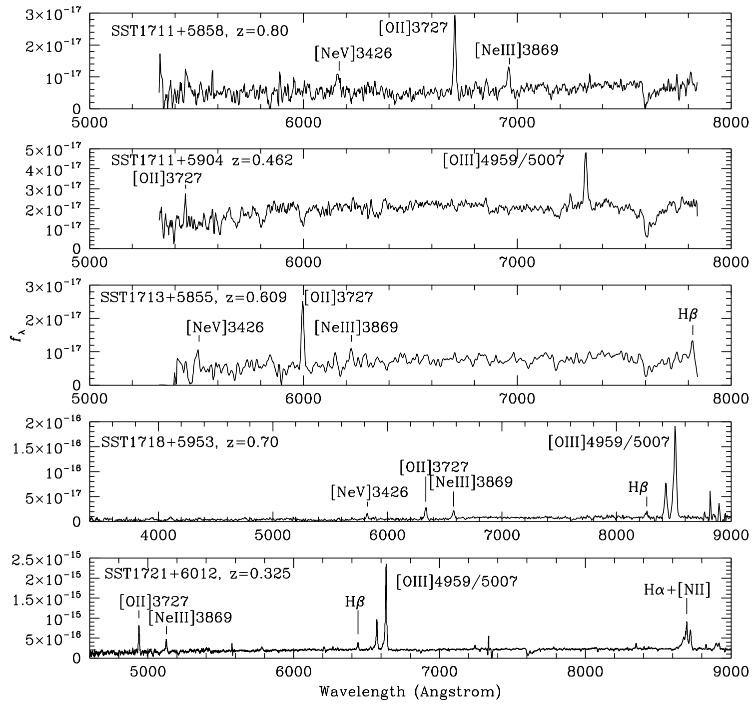

Figure 1. Representative spectra of some of our type-2 quasars.

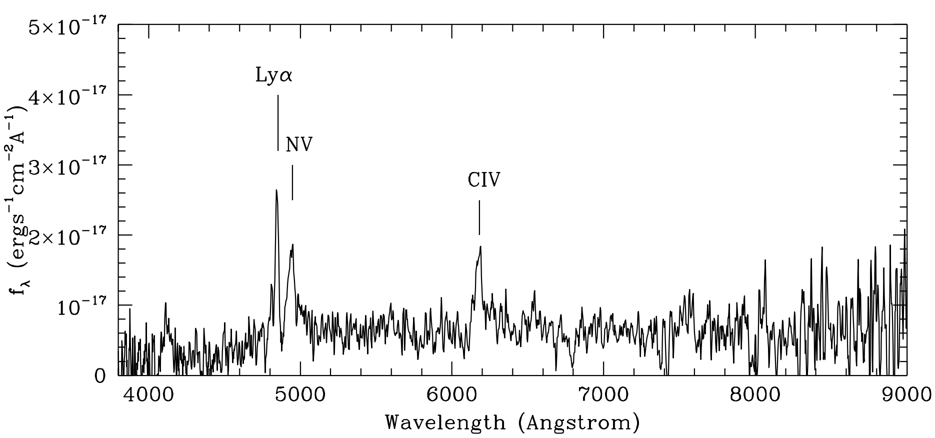

Figure 2. A $z = 2.99$ obscured quasar discovered using IRAC color selection in a 24μm flux-limited sample. The Lyα line has a FWHM $\approx$ 1400 kms^{-1}, and the Nv and Civ FWHM are 3200 and 2600 kms^{-1}, respectively. The linewidths of the high ionization lines are thus intermediate between type-1 and type-2 quasars, though the continuum level is significantly lower than that of type-1 objects with similar 24μm fluxes.

fluxes brighter than the far-infrared – radio correlation for star-forming galaxies and also faint in IRAC (to ensure high redshift). This selection has allowed us to find several examples of high redshift ($1.5 < z < 4.2$) type-2 quasars. We have also tried using the IRAC-based color selection, but on a sample flux-limited at 24μm rather than 8μm. Preliminary spectroscopy suggests that this small change in selection technique seems to have significantly improved our sensitivity to high redshift objects (Fig. 2).

3. The "type-3" population

Besides the obvious type-2 quasars, with high-ionization emission lines, our surveys have also found objects with either no emission lines, or emission lines with ratios characteristic of starbursts rather than AGN. Similar objects have been found by Leipski et al. (2005) using their ISO-2MASS color-based selection, who name these "type-3" AGN. Whether these are true AGN, or starburst interlopers in the AGN selection remains unclear, though IRS spectroscopy may yield important clues. If they are AGN, the narrow-line region must either be non-existent, completely shielded by dust around the AGN, or obscured by dust further out in the host galaxy than the usual nuclear dust emission, perhaps associated with starburst activity. This latter possibility is particularly interesting in the light of theories in which AGN start off in a dusty/starburst phase and evolve into unobscured objects (e.g. Sanders et al. 1988).

4. How many obscured quasars are there?

Our estimates for the total number of obscured quasars still span a large range, due to the difficulty in accounting for the selection effects of the different techniques we have used to find them, and the possibility of the dependence of the ratio of type-2s to type-1s on luminosity. However, both Martinez-Sansigre et al. (2005) and Lacy et al. (2005) are able to place a lower bound on the ratio of type-2s to type-1s of 1:1 at bolometric luminosities corresponding to low-to-moderate luminosity type-1 quasars ($-22.5 \lesssim M_B \lesssim -25$), and Martinez-Sansigre et al. suggest that this ratio could be as high as 3:1.

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