

Mid-IR Selected Quasars in the First Look Survey

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Abstract. We present a preliminary investigation of the spectral energy distributions (SEDs), and star-formation properties of a sample of Mid-IR selected Quasars. The mid-infrared SEDs of our objects are consistent with that expected from clumpy torus models. At longer infrared wavelengths, the radio to infrared ratios of several objects are consistent with those of star-forming galaxies.

1. Introduction

A central issue in the study of the formation and evolution of galaxies is the connection between the central black hole and the surrounding bulge stars. Observations of the dynamics of stars and gas in the nuclear regions of nearby galaxies suggest that the overwhelming majority of spheroidal galaxies in the local Universe contain massive black holes (BH), and that the mass of the central black hole correlates with the velocity dispersion of the stars in the spheroid (e.g. Gebhardt et al. 2000). This suggests a fundamental relation between the formation of massive BH and the stellar content of galaxies. Valid tests of the coeval growth theories are contingent upon a deeper understanding of the processes associated with the the formation of the spheroid and those close to the galactic nucleus which regulate the growth of the black hole by accretion. Such understanding can be partially gained through the study of large numbers of quasars, especially the obscured population, some members of which may represent quasars obscured by star-forming host galaxies.

2. Sample Selection

Our sample contains 77 MID-IR selected AGN (Lacy et al. 2004,2005) for which we have IRAC, and MIPS 24/70 μm data. VLA 1.4GHz and ugrizJHK data are available for the majority of the sample. The sources were selected from the Spitzer First Look Survey (e.g. Lacy et al. 2004) and from the Spitzer Wide-area InfraRed Extragalactic (SWIRE) Legacy Survey (Lonsdale et al. 2003). The sources presented here were chosen on the basis of both their IRAC colors and their MIPS 24 μm fluxes. The IRAC color selection, discussed e.g. in

Lacy et al. (2004,2005), Stern (2005) has been derived empirically, is supported by modeling of ISO spectra by Sajina et al. (2005), and adds greatly to the completeness and reliability of optical AGN selections (e.g. Lacy et al. 2006, Richards et al. 2006, Siana et al. 2006). To select the objects presented here we also required that they should have $24\ \mu\text{m}$ fluxes greater than $\sim 4\text{mJy}$. Selection based on a $24\ \mu\text{m}$ rather than the $8\ \mu\text{m}$ -based selection of Lacy et al. (2004) is a more sensitive to highly-reddened AGN, and QSO's at high redshift where the strong k-correction on the mid-infrared dust emission means that they drop out of flux-limited samples selected at shorter wavelengths. The selected sources were followed up spectroscopically, these observations are thoroughly discussed in Lacy et al. (2006). Figure 1 shows the main classes of quasars found in the MIR selected sample.

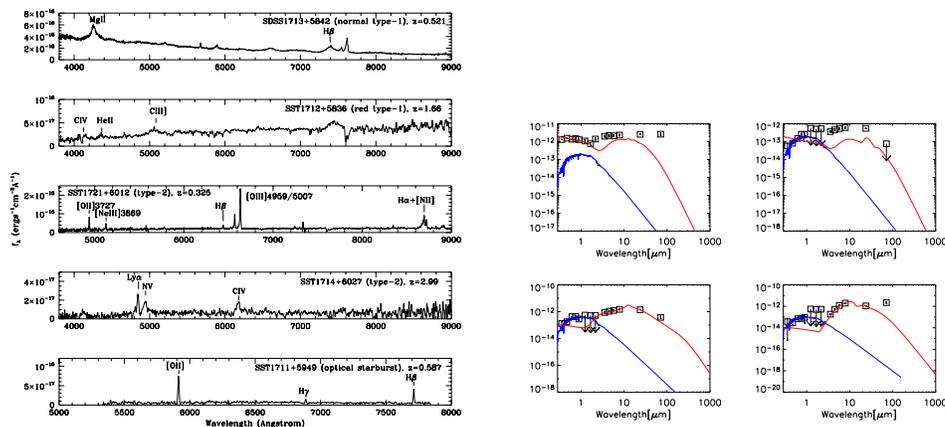


Figure 1. On the left we show five optical spectra representative of the types of AGN's detected with the MIR selection. The first panel in this figure is a typical type 1 QSO with strong permitted lines and FeII emission in the 4000-5000Å range. Panel 2 shows a reddened quasar with broad optical lines. The third and fourth plots are type 2 quasars. These are objects with high-ionization narrow emission lines and it is only recently that these type of quasars have been admitted as the bigger and brighter counterpart of Seyfert IIs (e.g. Zakamska 2003,2006). The last panel shows a type 3 source, (Leipski et al. 2005). These latter sources lack any obvious signs of AGN activity in their optical spectra. On the right we show SED's and best model fits for the spectra shown in the top figures, panels 1,2,3,and 5 respectively. The X-axis gives the observed wavelength while the Y-axis is in arbitrary units but is proportional to νF_ν . The blue curve shows the estimated host contribution from a 5 Gyr stellar population. The red curve shows the AGN-torus emission as indicated from our fits of the Nenkova et al. (2002) models.

3. Estimated Sample Properties

Modeling the SEDs We fit models of a clumpy torus developed by Nenkova et al. (2002) and our preliminary result is that they fit well our spectra, (e.g. their estimated inclinations seem to match these expected from the optical spec-

troscopy). A host galaxy contribution seems to be needed for all but a few type 1 sources.

Star formation One of the mechanisms invoked to maintain a stable torus is nuclear star formation (e.g. Wada & Norman 2002). Also, the theory of coeval and supermassive black hole growth implies that objects with accreting AGN are undergoing star-formation in the host galaxy and/or the torus. One method to obtain an indication whether massive star formation occurs in a source is to check if the IR to radio flux ratios match those of nearby non-AGN star-forming galaxies. In the local universe, star-forming sources from optically, IR or radio selected samples follow a very tight linear relation between the radio-continuum and FIR luminosities, with only a factor of two scatter around linearity over four orders of magnitude in luminosity (Condon 1992; Yun, Reddy, & Condon 2001) The radio to FIR correlation has been quantified through the q parameter, defined as:

$$q = \log \left(\frac{L_{\text{FIR}}}{3.75 \times 10^{12} \text{ W m}^{-2}} \right) - \log \left(\frac{F_{1.4}}{\text{W m}^{-2} \text{ Hz}^{-1}} \right)$$

where L_{FIR} corresponds to the FIR luminosity in solar units between 40 and 120 μm and $F_{1.4}$ is the radio flux at 1.4 GHz in $\text{W m}^{-2} \text{ Hz}^{-1}$. In a study of 2000 IRAS-selected galaxies, Yun, Reddy & Condon (2001) find a mean q value of 2.34, and that the range ($q = 1.64$ to 3) corresponds to star forming galaxies, while significantly lower q values imply that the dominant emission is from the AGN.

We estimate the restframe 60 μm luminosity using the measured, or upper-limit spectral index between 70 and 24 μm . Frayer et al. (2006) find a ratio of 2.3 between the 100 and 60 μm flux of 2.3. Condon (1992) relates the 60 (S_{60}) and 100(S_{100}) μm fluxes in Jys to the total FIR emission in W m^2 : $S_{\text{FIR}} = 1.26e - 4(2.58S_{60} + S_{100})$. We find that several of our AGNs tend to follow the FIR-radio correlation for nearby star-forming sources, as previously determined by other workers e.g. Sopp & Alexander (2001).

The 70 to 24 μm flux ratios provide another way to estimate the contribution of either host or starformation in and outside the torus to the observed emission since these values are expected to range between 0.2 and 2 for AGN sources, and an excess of 100 μm emission is seen in star forming objects (e.g. Canalizo & Stockton 2001). Figure 2b showing the spectral index at 8-24 μm plotted against that from 24-70 also suggests that the type 3 (open circles) are more likely to have an IR-excess, due perhaps to more cold dust, and star-formation.

4. Conclusions and Future Work

Initial SED modeling suggests that the emission from these objects are consistent with what is expected from clumpy torus models (Nenkova et al. 2002) with contributing light from a host galaxy with an old stellar population (~ 5 Gyr). We are currently investigating whether adding a younger population of stars changes our results. We estimate that several of our obscured sources have similar FIR to radio properties as those of star-forming nearby galaxies. Scheduled HST observations will allow us to image the host galaxies of several type 2 and

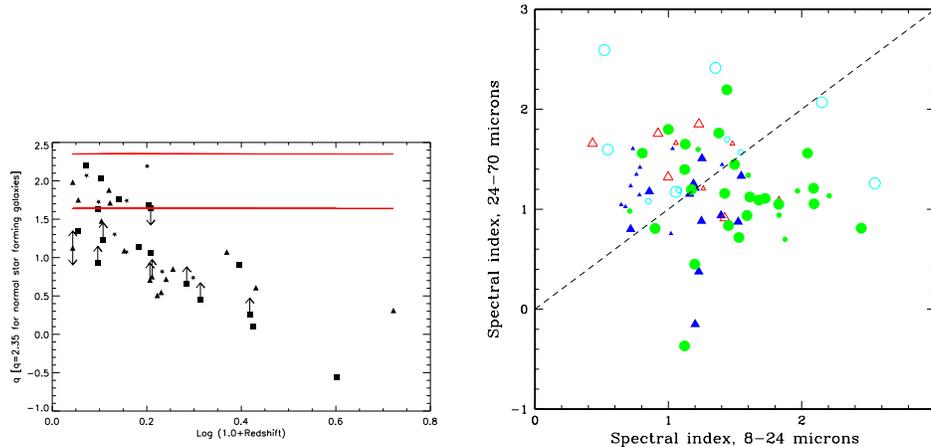


Figure 2. The estimated FIR and radio properties of MIR selected AGN with triangles, squares, and stars representing type 1, 2 and 3 quasars respectively. The plot on the left shows the q parameter versus redshift for our sample. The average q value for nearby star-forming galaxies is 2.35. The figure on the right shows the spectral index at 8-24 μm plotted against that from 24-70, with the IR-excess objects plotted above the line. Closed triangles are type-1 objects, open triangles type-2s, closed circles reddened type 1s and open circles type 3s. The smaller symbols show upper limits at 70 μm .

type 3 sources and relate them to their infrared spectra, and to observations of optically selected type-2 QSOs (e.g. Zakamska et al. 2006). Available and proposed IRS spectroscopy, together with more sophisticated model fitting, will give us further insight into the star-formation processes, origin of extinction, and physical properties of the dust associated with the AGN.

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