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Redshift Distribution and Luminosity Functions of Obscured and Unobscured Quasars

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Abstract. We have undertaken a spectroscopic survey of luminous AGNs and quasars selected in the mid-infrared from Spitzer IRAC surveys. Mid-infrared selection is much less biased with respect to obscuration than optical techniques, and hence enables the discovery of obscured quasars as well as normal, unobscured ones. Our survey is designed to include brighter 24 micron sources over wider areas and also to go to much lower fluxes limits in more limited spatial regions to allow us to disentangle dependences on redshift and luminosity. We have used 4m class telescopes to obtain spectra of the brighter 24 micron targets (targeting high luminosity objects at low z), and 8m class telescopes to identify lower luminosity high-redshift obscured quasars by targeting the fainter 24 micron targets. Fron this survey we have been able to compile a statistically complete sample of $\sim$ 500 AGN, both obscured and unobscured, over a large range of redshift and luminosity. We find that obscured objects outnumber unobscured AGN with an obscured fraction ranging from $\sim$90% to $\sim$50%. For the most luminous quasars, the number densities of unobscured quasars peaks at $z \sim 2.8$, and for the obscured objects, the peak may be at slightly higher redshift.

1. Introduction

AGN are almost certainly powered by accretion onto a supermassive black hole (SMBH), and in the nearby universe every massive galaxy harbors a SMBH with a mass proportional to the mass and velocity dispersion of the stellar bulge (e.g. Magorrian *et al.* 1998). It has become clear that most bulge dominated galaxies may have gone through an active quasar phase, and indeed models of galaxy formation can reproduce these scaling relations when quasar feedback is included (e.g. Croton *et al.* 2006, Bower *et al.* 2006). In one formulation (e.g. Hopkins *et al.* 2008), major mergers trigger star formation and quasar activity, and then feedback from the powerful AGN blows off enveloping dust, heats halo gas and stops star formation. Incorporation of feedback allows fitting of the scaling relations and stops overproduction of massive galaxies that otherwise occur at the bright end of the galaxy luminosity function. This is comparable to the ultraluminous infrared galaxy (ULIRG) merger sequence outlined by Sanders *et al.* (1988) at low z, in which the major merger results in a dusty, starforming ULIRG, which may evolve to an obscured quasar phase, which then evolves to a unobscured quasar phase, and finally results in an inactive SMBH in a merged elliptical galaxy. In all of these scenarios, there are key phases in which there is a AGN obscured by dust, and the relationship between the obscured and unobscured AGN is evolutionary. This leaves us with some outstanding questions about obscured AGN: What role do they AGN play in galaxy evolution? Are they a stage in the lifecycle of quasars, or generic objects viewed at a particular range of angles? Is our census of AGN and quasars complete?

Powerful obscured quasars (also called Type 2 quasars) are now being selected through X-ray emission, wide field infrared surveys or optical spectroscopic surveys like SDSS (e.g. Norman *et al.* 2002, Zakamska *et al.* 2005). In the mid-IR, quasars are selected using Spitzer IRAC and WISE colors from large area, moderate depth mid-IR surveys (Lacy *et al.* 2004, 2007, Stern *et al.* 2005, Donley *et al.* 2012). Selection on the mid-IR should be roughly isotropic, allowing selection of obscured and unobscured quasars matched in mid-infrared flux where the torus SED is dominated by dust emission.

2. Our survey

In order to address some of these questions, we have been working on identifying, with optical and infrared spectroscopy, a sample of obscured and unobscured quasars closely matched in AGN luminosity, selected in the mid-infrared where the SED is dominated by nuclear dust emission. Having samples well-matched on a isotropic measure of the nuclear luminosity allows us to explore the relationships between the different classes of objects.

We have selected fields that have extensive multiwavelength coverage, including some fields in the south to allow follow-up with ALMA. The survey consists of several subsamples with nested flux density limits at 24 μm ranging from 0.6 - 8mJy. Bright 24 μm sources, which typically have strong emission lines, were followed up using 4m-class telescopes (Palomar, Blanco, SOAR), and faint sources with 6 - 8m telescopes (MMT/Hectospec, Gemini/GMOS). We followed up spectroscopically on 786 candidates, and were able to to determine type and redshifts with good confidence for 672. Details of the survey and the catalog of all the objects are published in Lacy *et al.* (2013).

3. Results

To derive statistically useful results for the redshift distribution and luminosity function, we make a 90% complete sample, in which we go down in 24 micron flux in each subsample until the point where $<$ 90% of the targets would be identified. Overall we have been very successful: in the 10 subsamples that are around 90% complete, we have about 479 confirmed AGN from z = 0 to z = 4.27. We find that half of the AGN found are more luminous than the Seyfert/quasar luminosity divide, and the obscured objects (reddened Type 1 and Type 2 quasars) outnumber the unobscured (Type 1 quasars) over the whole Luminosity-z plane (Fig. 1).

In Fig. 2, we show the obscured fraction. We find the fraction of obscured objects varies from 90% at Seyfert luminosities down to ∼50% at high luminosities. At low luminosity (and low z) most obscured AGN seem to be Type 2, with A_V ¿ 5 to the broad line region, while at high luminosity (and high z) most are of more moderate obscuration and are reddened Type 1s. This implies the kind of obscuration may be different, with the low z obscuration consistent with a viewing angle to a dusty torus, while at high z the type

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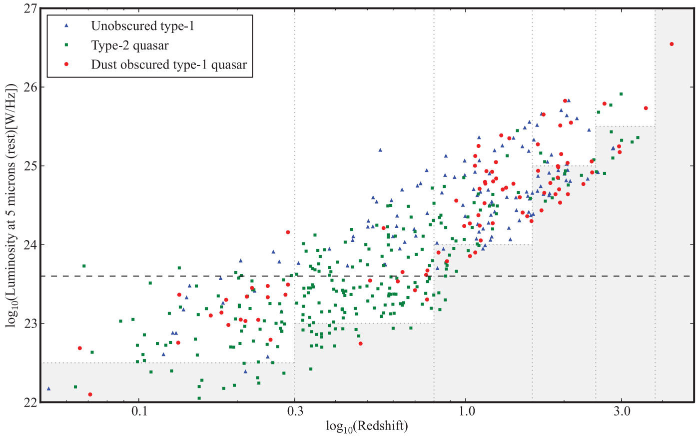

Figure 1. Rest 5 μm luminosity of mid-IR selected AGNs vs redshift for the 90% complete sample. Green symbols are spectroscopically identified Type 2 objects; red symbols are reddened Type 1s, and blue are unobscured, Type 1 objects. The dashed line shows the quasar– Seyfert divide. Vertical lines indicate the bins used in deriving the binned luminosity functions; shaded regions are not included in binned LFs but are included in parametric fits.

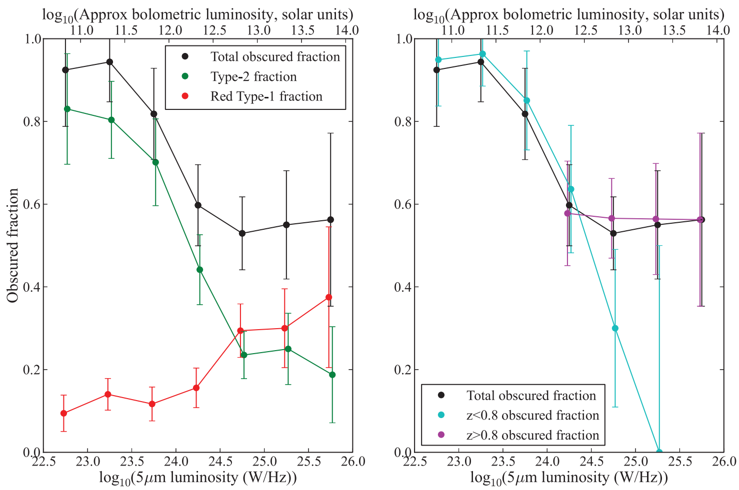

Figure 2. The obscured fraction as a function of luminosity and redshift

of moderate obscuration seems more consistent with dusty hosts and the evolutionary merger scenario.

We find that, compared to the optically selected and hard X-ray selected luminosity functions, the mid-IR selected function contains more low luminosity AGN, and more high z AGN as well, while agreeing at intermediate redshifts and luminosities. This implies that a census of AGN based on optical selection, or even hard (2 – 10 KeV) xray selection will not be complete.

In Fig. 3, I show the number densities of the most luminous of our quasars as a function of redshift for all levels of obscuration. For these quasars, number densities of the unobscured objects seem to be peaking at around z of 2.5, while the obscured objects may be peaking at slightly higher redshifts. Up to z $\sim$ 2, we see a trend for a decreasing fraction of obscured quasars with luminosity and redshift- this is roughly consistent with results from X-ray studies. At z $>$ 2, the obscured fraction may be rising again- roughly

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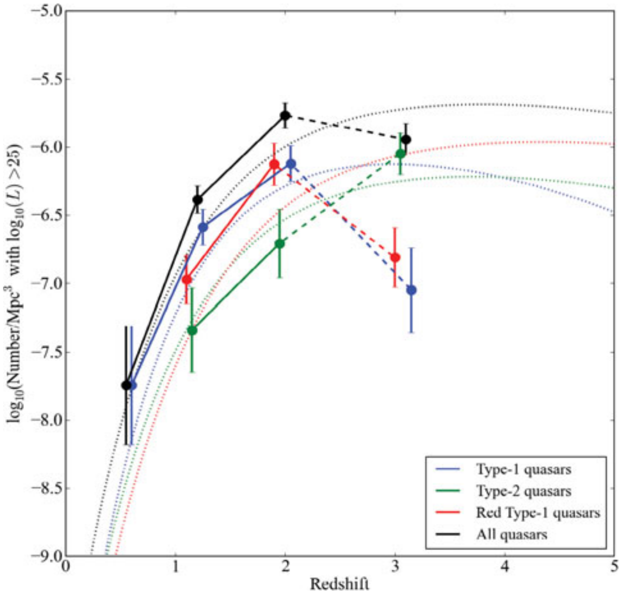

Figure 3. Number densities of quasars of all levels of obscuration with $L_{5\mu m} > 10^{32}$ergs^{-1}, corresponding to a bolometric luminosity $\approx 10^{13} L_{\odot}$) as a function of redshift.

consistent with the joint quasar/galaxy formation models in which mergers trigger quasar activity in dusty hosts at high z (e.g. Hopkins *et al.* 2008). However, the numbers of objects at the high z end are still low.

4. Implications

With this project, we have greatly increased the number of type 2 quasars known, and have identified an easy and reliable method of finding samples of type 1 and type 2 AGN selected on a roughly isotropic property. This is a unique sample of powerful quasars at redshifts from 0 to 4, about half of which are so deeply obscured that they would not have been detected in X-ray surveys. The discovery of this large population of obscured quasars changes fundamentally our view of quasar demographics, and is roughly consistent with models of joint quasar/galaxy formation in which quasars spend a significant portion of their lives in an obscured state (e.g. Sanders *et al.* 1988, Hopkins *et al.* 2008).

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