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## **Resolved mid-infrared imaging of Seyferts: an isotropic probe of AGN luminosity**

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**Abstract.** I present results from a program of imaging local Seyferts of all types (Sy 1, Sy 2) in  $N$ -band ( $\sim 10\mu\text{m}$ ) filters with the 8-m Very Large Telescope. A total of 42 detections of point-like AGN cores in the mid-infrared are augmented with published intrinsic X-ray fluxes, and a strong mid-infrared:X-ray ( $12.3\text{-}\mu\text{m}$ :2-10 keV) luminosity correlation is found for these. The sources in which the Seyfert torus is likely to be best-resolved yield the correlation  $L_{\text{MIR}} \propto L_{\text{X}}^{1.11 \pm 0.07}$ , with a small scatter in luminosities. The fact that unobscured, obscured and Compton-thick sources all closely follow the same luminosity correlation has important implications for the structures of Seyfert cores. This suggests that resolved mid-IR continuum imaging of AGN is an accurate proxy for their intrinsic powers. Intrinsic AGN bolometric powers can then be derived free of any contamination from star formation for the very first time.

### **1. Introduction**

Space infrared (IR) missions now provide superb sensitivities as compared to their historical counterparts, or even contemporary ground-based telescopes. But they are limited in the spatial resolution that they are able to deliver. Large ground telescopes have about 10 times better angular resolving power as compared to space missions such as *Akari*. In the  $N$ -band atmospheric window ( $\sim 10\mu\text{m}$ ), telescopes such as the Very Large Telescope (VLT) provide diffraction-limited imaging. This is because the typical IR seeing at the telescope sites is  $\sim 0''.3\text{--}0''.5$  which is close to the diffraction limit of their 8-m diameter mirrors. Good angular resolution is particularly important for IR observations of galaxies, because the radiative flux from star formation (SF) activity is often able to swamp the flux from accretion on to their central active galactic nuclei (AGN).

In order to take advantage of the good resolution offered, we have begun a campaign to image the cores of Seyfert galaxies in the nearby Universe with the VISIR mid-IR imager mounted on the VLT (Lagage et al. 2004). The main results can be found in Gandhi et al. (2009, hereafter G09) and Horst et al. (2008, hereafter H08). In total, 41 local Seyferts have been detected in a variety of narrow-band filters covering the 8–13  $\mu\text{m}$  spectral regime. A point-like unresolved core is resolved in all cases (Horst et al. 2009). Because of the unprecedented angular resolution, the unresolved core fluxes are the best ones (i.e. least biased by extra-nuclear emission) available for most of these objects. As an illustration, Fig. 1 shows our VISIR high-resolution imaging of the target IC 3639, whose nuclear starburst (SB) was studied in detail by González Delgado et al. (1998) and found to have a bolometric luminosity (determined from *HST*

ultraviolet observations) similar to the total power emitted by the AGN. Our point-like mid-IR profile sharply contrasts to the over-plotted *HST* contours.

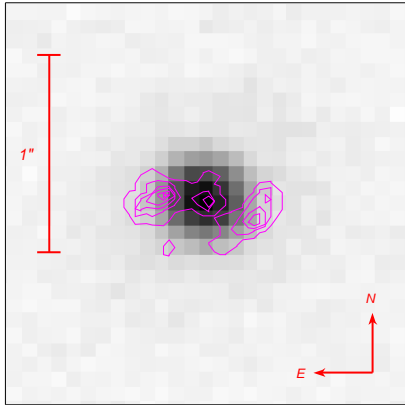


Figure 1. Image ( $2'' \times 2''$  wide) of IC 3639 centred on  $13.04 \mu\text{m}$  with the VLT/VISIR NEII.2 filter, showing the clean point-like core profile and excellent spatial resolution. With a point spread function of only  $\approx 0''.35$ , sampled at  $0''.075/\text{pixel}$ , the image is diffraction-limited for the 8-m VLT. The overlaid contours are from the ultraviolet (UV) Faint Object Camera image obtained from the *HST* archive. Bright, extended SB emission, especially the central complex of knots, is clearly visible in the UV, but not in the *N*-band.

## 2. The infrared:X-ray correlation

The next important result relates to the correlation of observed IR and X-ray fluxes (and, in turn, luminosities). Because such a IR:X-ray comparison was one of our main goals, source selection was mainly based on the availability of good X-ray measurements in the literature. Hence, our sample is not complete.

For each of our sources, intrinsic AGN X-ray fluxes, corrected for absorption, over the 2–10 keV range, were carefully selected from other published works. We found that the distribution of IR monochromatic luminosities ( $\lambda L_\lambda$  at  $12.3 \mu\text{m}$ , hereafter  $L_{\text{MIR}}$ ) is strongly correlated with the 2–10 keV intrinsic luminosity (hereafter  $L_X$ ) distribution. This is shown in Fig. 2. Here, we supplemented our sample with archival observations of NGC 1068 because it is one of the best-studied of local AGN; hence our correlation includes 42 sources in all.

Given that  $L_X$  is a measure of the intrinsic AGN accretion luminosity (e.g. Marconi et al. 2004, hereafter M04), the AGN unification scheme would predict an increase in the emitted IR power (which is a result of re-processing within dusty torus clouds) with increasing  $L_X$ . Hence, our correlation in Fig. 2 is consistent with basic aspects of unification.

It is to be emphasized that a strong correlation holds for intrinsic fluxes as well, i.e. redshift is not the dominant common factor. On the other hand, the spread of source distances ranging from  $\sim 10$ –300 Mpc does imply a correspondingly wide range of physical resolution scales at the sources. To try and make a meaningful sub selection of sources from our incomplete sample, we sorted objects based on the physical scale that is resolved in our observations, normalized to the expected torus size. The sublimation radius of the torus ( $r_{\text{sub}}$ ) scales as  $\sqrt{L_{\text{Bol}}}$  where  $L_{\text{Bol}}$  represents the source bolometric power. Furthermore, H08 identified a threshold whereby all sources with a VISIR resolution limit  $< 560 r_{\text{sub}}$  exhibit a well-defined IR:X-ray correlation, while those above this threshold have a larger spread. Of our sample of 42 sources, 22 obey this threshold limit and we designate them as ‘well-resolved’ sources, the rest being ‘less-resolved’. Fitting the luminosity correlation for the well-resolved subsample in log-space, we find:

$$\log\left(\frac{L_{\text{MIR}}}{10^{43} \text{ erg s}^{-1}}\right) = (0.19 \pm 0.05) + (1.11 \pm 0.07) \log\left(\frac{L_{\text{X}}}{10^{43} \text{ erg s}^{-1}}\right), \quad (1)$$

where the errors on the linear fit slope and intercept are  $1\text{-}\sigma$  uncertainties. This relation is plotted in Fig. 2 as the dashed curve.

### 3. Mid-infrared fluxes are isotropic

A striking aspect of the correlation in Fig. 2 is that sources with all levels of obscuration, including unabsorbed Sy 1, absorbed Sy 2 and heavily-obscured Compton-thick (with  $N_{\text{H}} > 1.5 \times 10^{24} \text{ cm}^{-2}$ ) ones, closely follow the same luminosity correlation with little dispersion. This is not expected in canonical models of radiative transfer through geometrically-thick tori in which the dust is smoothly-distributed. See, e.g. Fig. 1 of Pier & Krolik (1993), in which the emergent  $N$ -band flux varies by an order of magnitude depending on source orientation (which is related to X-ray column density in the unification scheme).

Instead, our uniform correlation finds the observed mid-IR powers of AGN to be independent of obscuration, and hence to be isotropically-emitted. How can this be accommodated within the physical scenario of a geometrically-thick torus? One possibility is that dust within the torus is not smoothly-distributed but rather possesses a high degree of clumpiness. In such ‘clumpy tori’, a few optically-thick clouds along the line-of-sight serve to observe the nucleus itself, but illuminated hot clouds around the inner torus regions are still visible statistically, effectively making the torus optically-thin around  $10 \mu\text{m}$  (Hönig et al. 2006; Nenkova et al. 2008b).

### 4. Implications: Obscured AGN, Bolometric power computations

Finding a tight correlation with little intrinsic spread has important implications. The fact that highly-obscured and Compton-thick AGN fall on the same relation means that mid-IR imaging can be used a new way to measure their intrinsic powers. As long as one can be reasonably certain that the observed IR flux is largely unbiased by SF (either from high spatial resolution imaging, or from careful spectral deconvolution of any SF components), then Eq. 1 can be used to determine the intrinsic AGN X-ray powers.

There are many works studying the conversion from X-ray powers to bolometric ones (e.g. M04) which may be used to connect  $L_{\text{MIR}}$  to  $L_{\text{Bol}}$ . With our Eq. 1 and the X-ray:bolometric conversion factors of M04, we can derive indirect mid-IR:bolometric conversion factors ( $f_{\text{Bol}}^{\text{MIR}} = L_{\text{Bol}}/L_{\text{MIR}}$ ) as a function of luminosity. Expressing in units of  $\mathcal{L} = \log(L_{\text{Bol}}/L_{\odot}) - 12$  similar to M04, we find

$$\log f_{\text{Bol}}^{\text{MIR}}(\mathcal{L}) = 1.24 + 0.16\mathcal{L} + 0.012\mathcal{L}^2 - 0.0015\mathcal{L}^3. \quad (2)$$

These mid-IR bolometric corrections span values of  $\approx 10\text{--}30$  for the range of Sy luminosities that we probe.

Our full dataset and resultant implications are discussed in G09 and H08. A short review of the campaign can be found in Horst et al. (2009b), while initial

observations and much imaging are detailed in Horst et al. (2006) and Horst et al. (2009), respectively. Our sample of 42 sources is the largest mid-IR sample of high spatial resolution imaging to date. But it still lacks completeness. We are in the process of obtaining similar resolved data for a full sample of X-ray selected AGN in order to place these findings on a firm statistical footing.

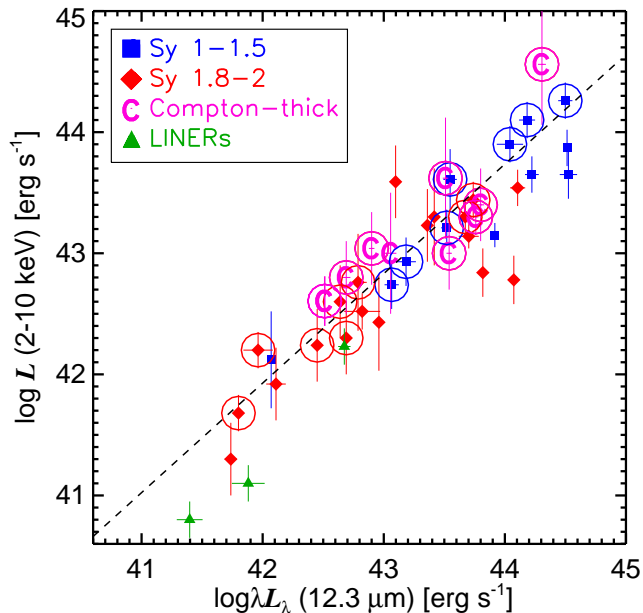


Figure 2. Mid-infrared:X-ray luminosity correlation for the sample of 42 sources from G09 and H08. The 22 objects classified as being ‘well-resolved’ are circled, and the dashed line is the fitted correlation for these (Eq. 1). See G09 for details.

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