Covering Factor of AGN at $z \sim 1$

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The dusty torus in the Active Galactic Nuclei (AGN) has a major impact on the physical characteristics of AGN. In this proceeding we measure the covering factor (CF) which is defined as the fraction of the AGN's central light obscured by the dusty torus. It is often estimated from a ratio of AGN's infrared and bolometric luminosities ($L_{\rm IR}$ and $L_{\rm BOL}$, respectively). Based on a sample of 9030 AGN at $0.7 \leq z \leq 1.1$ selected from the SDSS database with auxiliary IR and UV measurements, we confirm the existence of the tight correlation between $L_{\rm IR}$ and $L_{\rm BOL}$, and we estimate the median value of CF for this sample to be 0.65±0.16. Possible explanations of $L_{\rm IR}$ and $L_{\rm BOL}$ correlation are discussed.

1 Introduction

The Active Galactic Nuclei (AGN) after many years of research still pose questions that are hard to answer. The most widely accepted description of an AGN structure is provided by the so-called unification scheme (Antonucci & Miller, 1985; Urry & Padovani, 1995). One of the major elements of an AGN in this scheme is the dusty torus. Simple models describe the torus as the donut-like shape made of dust (ie. Torres & Anchordoqui, 2004). The torus surrounds the Super Massive Black Hole (SMBH) at the radius of the subparsec scale (Suganuma et al., 2006; Koshida et al., 2014). Recent studies suggest that the structure of the torus might be more complex and that it can be directly linked with the Broad Line Regions (BLR) and accretion disk (Czerny & Hryniewicz, 2011). The covering factor (CF) is a parameter describing the fraction of obscuration of the quasar SMBH by the dusty torus. In the earlier studies (Hamann et al., 1993) CF has been defined as the ratio of the solid angle between SMBH and torus to 4π ($CF = \Omega/4\pi$). However, CF according to this original definition is difficult to be derived from the observations. Currently, an estimator of the CF defined as the ratio between $L_{\rm IR}$ and $L_{\rm BOL}$ is often used, i.e. $CF = L_{\rm IR}/L_{\rm BOL}$ (Maiolino et al., 2007; Gu, 2013). Two assumptions are necessary for this definition to be firmly related with the original definition of the CF: 1) $L_{\rm IR}$ is dominated by the hot dust emission from the torus and depends on the amount of radiation captured from the accretion disc, 2) $L_{\rm BOL}$ accounts for the majority of the disc luminosity. Thus their ratio is expected to be directly proportional to the CF. Both $L_{\rm BOL}$ and $L_{\rm IR}$ are directly linked to the torus's physical properties. In this work we analyse the relation between the $L_{\rm IR}$ and $L_{\rm BOL}$ and discuss possible explanations of its form.

2 Data

To study correlation between $L_{\rm IR}$ and $L_{\rm BOL}$, photometric data from five different surveys were cross-matched. The optical data were taken from the newest Sloan

Digital Sky Survey data release (SDSS DR16Q, Lyke et al. (2020)). To concentrate on the mid-redshift range, the redshift range of $0.7 \leq z \leq 1.1$ was chosen. To cover the spectral range from IR to UV the cross-match with Wide-field Infrared Survey Explorer (WISE, Wright et al. 2010), Galaxy Evolution Explorer (GALEX, Martin et al. 2005) and UKIRT Infrared Deep Sky Survey (UKIDSS, Lawrence et al. 2007) was performed, with the cross-matching radius of 2 arcsec (3 arcsec for GALEX). Only sources with observations in all filters in all these five catalogs were used. The final sample of 9,030 quasars was derived. The data were corrected with the Cardelli extinction law (Cardelli et al., 1989), using the dust maps by Schlegel et al. (1998).

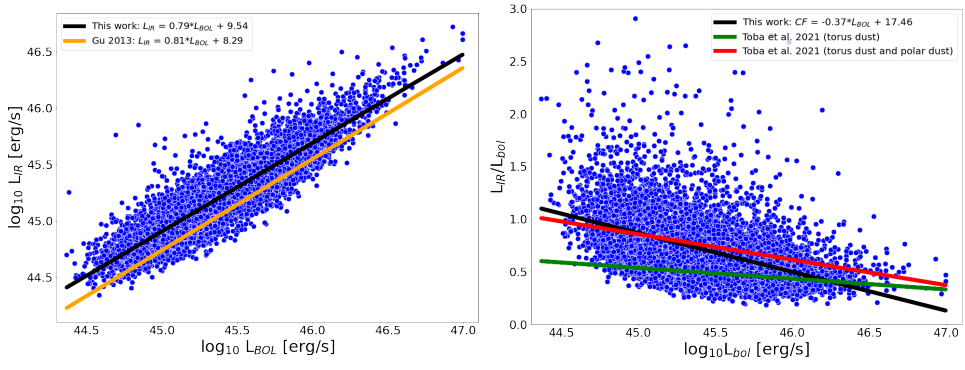

Fig. 1: *Left*: Relation between $L_{\rm IR}$ and $L_{\rm BOL}$ in logarithmic space for $z \sim 1$ SDSS quasars (represented by blue dots). The black line is the fitted regression line, whose equation is shown in the top-left corner. The orange line is the regression line found by Gu (2013). *Right*: Relation between the covering factor and the $\log_{10}$ $L_{\rm BOL}$ for the same quasar sample. The black line is the fitted regression line, whose equation is shown in the top-right corner. The green line is the regression from Toba et al. (2021) fitted to the model with torus dust only, while the red line is the sum of regressions fitted to torus dust and polar dust models separately.

3 Results and discussion

To calculate $L_{\rm IR}$ and $L_{\rm BOL}$, the spectral energy distribution (SED) for each object was constructed. $L_{\rm IR}$ and $L_{\rm BOL}$ were computed as the integrals of monochromatic luminosities between 7μm and 1 μm and 1 μm and 0.11 μm, respectively. Monochromatic luminosities at $L_{7\mu\rm m}$, $L_{1\mu\rm m}$, $L_{0.11\mu\rm m}$ were estimated from the interpolation between two nearest filters. Left panel of Fig. 1 shows the relation between so-obtained $\log_{10}$ $L_{\rm BOL}$ and $\log_{10}$ $L_{\rm IR}$. Both luminosities are well correlated, with the corresponding linear regression line described by the equation given on the plot. We obtained similar trend to Gu (2013) but systematically shifted toward higher $L_{\rm IR}$. The corresponding median value of the CF for our sample is 0.65 ± 0.16.

This correlation can be explained by the majority of the torus IR emission coming from reprocessing of the illumination from the inner accretion disk, as shown by synthetic modelling of the AGN SED (Stalevski et al., 2016) and the detailed SED fitting for small samples (Zhuang et al., 2018; Toba et al., 2021). Simulations suggest that the ratio of luminosities is not linearly related with the "true" covering factor because reprocessing is a more sophisticated relation in terms energy conversion,

which can be due to anisotropy of the disk radiation and clumping of the torus media or the disk and torus geometry. However, in our $z \sim 1$ sample, in its luminosity limits, the power law relation appears to be a reasonable approximation.

As seen in the right panel of Fig. 1, lower luminosity (L_{BOL}) quasars have systematically higher CF. The overall trend, represented by the black regression line, is very close to the relation obtained by Toba et al. (2021) for a sample of 37,181 SDSS quasars at $z < 0.7$ by fitting SEDs with separated dust components (torus dust and polar dust). We find a steeper slope of the overall relation. Indeed, in this group of quasars (type I) the presence of polar dust contribution to IR emission can effectively lead to overestimated CF of the torus (Hönig et al., 2013; Asmus, 2019; Toba et al., 2021) and may be responsible for this effect. This implies that our CF measurement for a part of the sample will need to be recalibrated. Additionally, intrinsic differences in quasars properties at different z may lead to different CF scaling with quasars' global parameters (Toba et al., 2021). We will further investigate with a larger sample of SDSS quasars. Detailed analysis will be presented in Rałowski et al. (2022, in prep).

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