Modeling the Unresolved NIR–MIR SEDs of Local (z < 0.1) QSOs

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Abstract

To study the nuclear (≤1 kpc) dust of nearby (z < 0.1) quasi-stellar objects (QSOs), we obtained new near-infrared (NIR) high angular resolution (∼0′′3) photometry in the H and Ks bands for 13 QSOs with available mid-infrared (MIR) high angular resolution spectroscopy (∼7.5–13.5 μm). We find that in most QSOs, the NIR emission is unresolved. We subtract the contribution from the accretion disk, which decreases from NIR (∼35%) to MIR (∼2.4%). We also estimate these percentages assuming a bluer accretion disk and find that the contribution in the MIR is nearly seven times larger. We find that the majority of objects (64%, 9/13) are better fitted by the disk + wind H17 model, while others can be fitted by the smooth F06 (14%, 2/13), clumpy N08 (7%, 1/13), clumpy H10 (7%, 1/13), and two-phase media S16 (7%, 1/13) models. However, if we assume the bluer accretion disk, the models fit only 2/13 objects. We measured two NIR-to-MIR spectral indexes, ΩNIR−MIR(1.6–8.7 μm) and ΩNIR−MIR(2.2–8.7 μm) and two MIR spectral indexes, ΩMIR(7.8–9.8 μm) and ΩMIR(9.8–11.7 μm). From models and observations, we find that the NIR-to-MIR spectral indexes are ∼−1.1, and the MIR spectral indexes are ∼−0.3. Comparing the synthetic and observed values, we find that none of the models simultaneously match the measured NIR-to-MIR and 7.8–9.8 μm slopes. However, we note that measuring ΩMIR(7.8–9.8 μm) on the starburst-subtracted Spitzer/IRS spectrum gives values of the slopes (∼2) that are similar to the synthetic values obtained from the models.

Unified Astronomy Thesaurus concepts: Quasars (1319); Active galaxies (17)

1. Introduction

The nuclear dust that surrounds the central engine (supermassive black hole, accretion disk, and broad-line region) of the active galactic nuclei (AGNs) is widely known as the dusty torus of AGNs (e.g., Krolik & Begelman 1988; Antonucci 1993; Robson et al. 1995; Urry & Padovani 1995; Peterson 1997). This structure plays a fundamental role in the description of an AGN because it represents the connection between the central engine and the kiloparsec scales (the narrow-line region and the host galaxy; Ramos Almeida & Ricci 2017). Some observations of Seyfert galaxies have suggested that a large fraction of the obscuring material is distributed into a toroidal structure. However, the exact geometry of this structure is still unknown (see, e.g., Combes et al. 2019; Hönig 2019). Some authors have claimed the detection of a dusty structure from mid-infrared (MIR) and submillimeter interferometric data (e.g., Jaffe et al. 2004; García-Burillo et al. 2016; Alonso-Herrero et al. 2018; Imanishi et al. 2018). They have found sizes that range from a few parsecs to a few tens of parsecs (e.g., Jaffe et al. 2004; Packham et al. 2005; Radomski et al. 2008; García-Burillo et al. 2016; Imanishi et al. 2018), sometimes with more than a single component (e.g., López-Gonzaga et al. 2014; Tristram et al. 2014; García-Burillo et al. 2019). Unfortunately, these studies are limited to a small number of nearby AGNs.

The obscuring material in the dusty torus absorbs a significant part of the optical/UV radiation emitted by the accretion disk and reemits it at infrared (IR) wavelengths between ∼1 and 1000 μm (e.g., Neugebauer et al. 1979; Krolik & Begelman 1988; Sanders et al. 1989; Antonucci 1993; Elvis et al. 1994; Peterson 1997), peaking at ∼5–35 μm (e.g., Rees et al. 1969; Burbidge & Stein 1970; Rieke & Low 1972; Stein et al. 1974; Sanders et al. 1989). Therefore, fitting the IR spectral energy distribution (SED) of AGNs is a good technique to derive the physical properties of this dusty structure (e.g., González-Martín et al. 2019b). During the last few decades, there have been great efforts to understand the assembly of the nuclear dust responsible for the observed IR SED of AGNs. For example, Fritz et al. (2006) proposed a homogeneous distribution of the nuclear dust into a toroidal structure around the central engine (hereafter the smooth F06 model). This model reproduces well the observed IR SEDs of type 1 and 2 Seyfert galaxies and predicts a deep 10 μm silicate absorption feature but a narrower IR bump (e.g., Dullemond & van Bemmel 2005). Nenkova et al. (2002, 2008a, 2008b) proposed a dusty torus model in which the dust is distributed in clumps in a toroidal geometry around the central engine (hereafter the clumpy N08 model). This model predicts a more attenuated 10 μm silicate emission feature and broader IR bump. However, this model fails in reproducing the apparent “excess” of near-IR (NIR) emission presented in some type 1 AGNs (e.g., Mor et al. 2009), which has been attributed to
the presence of hot dust in the inner part of the torus (e.g., Braatz et al. 1993; Cameron et al. 1993; Bock et al. 2000; Höning et al. 2013). Trying to resolve these issues, Stalevski et al. (2016) proposed a two-phase medium torus model composed of high-density clumps immersed in a low-density medium (hereafter the two-phase media S16 model). According to this model, the low-density dust medium significantly contributes to the NIR emission in type 1 AGNs. Feltre et al. (2012) compared the smooth and clumpy models and found that both models can produce similar MIR continuum shapes for different parameters of the models. Additionally, they found that there are very different NIR spectral slopes between the models, probably due to the different dust composition and central radiation assumed.

Due to the difficulties of consistently reproducing the IR SEDs of AGNs with the torus models and the growing evidence for a component of dust located in the polar region of the AGNs in addition to the equatorial component (e.g., Höning et al. 2012, 2013; Tristram et al. 2014; López-Gonzaga & Jaffe 2016; Leftley et al. 2018), Höning & Kishimoto (2017) proposed a different geometry composed of a compact and geometrically thin clumpy dusty disk in the equatorial region plus an extended and elongated polar structure of dust, which is assumed to be copatial with the outermost layers of the outflowing gas (i.e., distributed in a hollow-cone geometry). Hereafter, we refer to this model as the disk+wind H17 model. They claimed that the more compact distribution of dust in the thin disk allows this model to better explain the 3.5–5 μm bump seen in several type 1 AGNs.

Several groups have used both low angular resolution (~3″–5″) Spitzer/IRS spectra (~5–35 μm) and high angular resolution (~0″5–3) data (spectra and photometry) in the IR range to model the putative dusty torus in AGNs. For example, some authors (e.g., Ramos Almeida et al. 2009, 2011; Alonso-Herrero et al. 2011; Ichikawa et al. 2015; Fuller et al. 2016; García-Bernete et al. 2019) used high angular resolution data to constrain the parameters of the clumpy N08 model in a sample of Seyfert galaxies. Similar studies in quasi-stellar objects (QSOs) are limited to low angular resolution data (e.g., Mor et al. 2009; Nikutta et al. 2009; Mateos et al. 2016), partly due to the lack of high angular resolution data at IR wavelengths. For example, using the Spitzer/IRS spectrum of 26 QSOs and the clumpy N08 model, Mor et al. (2009) found that to reproduce the data, it is necessary to add a hot dust component (T ~ 1400 K). Later, using the same model and the Spitzer/IRS spectrum of 25 QSOs at z ~ 2, Deo et al. (2011) showed that by adding a hot dust component to the spectral fitting, it is possible to simultaneously fit the NIR SED and 10 μm silicate feature. Alonso-Herrero et al. (2011) suggested that this hot dust component might not be necessary when using high angular resolution IR data. Nevertheless, they found that some type 1 Seyfert still show an excess of emission at the NIR despite the high angular resolution data, which they attributed to a hot dust component (see also Ichikawa et al. 2015; García-Bernete et al. 2019). To model the low angular resolution Spitzer and AKARI (2.5–5 μm) spectra of 85 luminous QSOs (L_{bol} > 10^{45.5} erg s^{-1}), with a redshift z between 0.17 and 6.42, Hernán-Caballero et al. (2016) assumed a single accretion disk template plus two blackbodies for the dust emission. They successfully reproduced the 0.1–10 μm SED. However, they noted that the best-fitting model systematically underpredicts the observed flux around 1 μm. After comparing the NIR excess and the NIR-to-optical luminosity ratio, they concluded that this excess of emission originates in hot dust near the sublimation radius.

Assuming the clumpy N08 dusty torus model, Martínez-Paredes et al. (2017) used the starburst-subtracted Spitzer/IRS spectrum (5–9.5 μm) plus the point-spread function (PSF) photometric point at the H band (1.6 μm) obtained from NICMOS data on the Hubble Space Telescope (HST; available for nine out of 20 objects) to investigate the physical and geometrical properties of the dusty torus in a sample of 20 nearby (z < 0.1) QSOs. They found that by including the spectral range of ~5–8 μm, the SED modeling results in a bad fit of the 10 μm silicate feature, producing parameters inconsistent with their optical classification as type 1 AGNs. Therefore, they excluded this part of the spectrum from the fitting. A similar result and approach were reported by Nikutta et al. (2009) for a couple of QSOs. From the good fits, Martínez-Paredes et al. (2017) found that 3/9 objects show an excess of emission at the H band, probably because the unresolved emission could still be contaminated by emission from the host galaxy (Veilleux et al. 2006, 2009), and/or because in these cases, the addition of a hot dust component could be necessary. Additionally, Martínez-Paredes et al. (2017) found that for 50% of QSOs, the viewing angles range from ~50° to 88°. They claimed that the addition of a second photometric point in the NIR would improve the determination of the viewing angle as suggested by Ramos Almeida et al. (2014). They found that to well constrain the six free parameters of the clumpy N08 model for Seyfert galaxies, it is necessary to build an unresolved IR SED composed of at least two photometric points in the NIR, a photometric point in the MIR, plus the high angular resolution spectrum in the N band (~7.5–13.5 μm).

On the other hand, Martínez-Paredes et al. (2020) recently investigated which dusty models better reproduce the AGN-dominated Spitzer/IRS spectrum (~5–35 μm) of local (z < 0.1) type 1 AGNs (including some QSOs). They explored the smooth F06 model, clumpy N08 model, clumpy torus model of Höning et al. (2010; hereafter the clumpy H10 model), two-phase media S16 model, and disk+wind H17 model. They found that in most cases and with all models, it is always necessary to add the stellar component to fit the bluer spectral range (~5–8 μm), but that none of the models can well reproduce the spectral shape between ~5 and 30 μm. However, they noted that the disk +wind H17 model well reproduces the spectrum with flatter residuals, especially at high bolometric luminosities.

Therefore, considering the difficulties in simultaneously modeling the NIR–MIR SEDs of QSOs, we obtain new NIR high angular resolution data (~0″5–3) from the NIR cameras on the 10.4 m Gran Telescopio Canarias (GTC) to build for the first time a set of well-sampled NIR-to-MIR SEDs of QSOs that allows us to investigate which model among the clumpy N08 and H10, smooth F06, two-phase media S16, and disk+wind H17 better reproduces the data and constrains the parameters.

Throughout this paper, we assume a ΛCDM cosmology with H₀ = 70 km s⁻¹ Mpc⁻¹, Ω_m = 0.3, and Ω_Λ = 0.7.

2. The Sample

We selected the 13/20 local type 1 QSOs in the sample of Martínez-Paredes et al. (2017) that have high angular resolution spectroscopy in the N band (~7.5–13.5 μm). The 20 QSOs were selected and observed with the MIR camera CanariCam (CC) on GTC. They set the following criteria: (1) a redshift z < 0.1, (2) a nuclear flux at the N band (aperture ≤5″) f_N > 0.02 Jy, and (3) L_X (2–10 keV) > 10^{43} erg s⁻¹. The redshifts

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combined with the high angular resolution offered by the combo CC/GTC (∼0\textquoteleft\textquoteleft 3) allowed them to observe the inner nuclear region within 1 kpc, and the MIR flux allowed them to detect these objects with CC in the \( N \) and Si2 (8.7 \( \mu m \)) bands. The hard X-ray flux was used as an intrinsic indicator of the AGN activity. They imaged 19/20 QSOs in the Si2 band and obtained the spectrum in the \( N \) band for 11/13. The data were published by Martínez-Paredes et al. (2017, 2019). The remaining two objects had high angular resolution spectra at the \( N \) band from VISIR on the Very Large Telescope (VLT; Hönig et al. 2010; Burtscher et al. 2013; see Table 1). Note that we include in the sample three additional objects that we observe in the NIR wavelengths and report in this paper.

3. The Data

3.1. New High Angular Resolution NIR Data and Reduction

Using the Canarias InfraRed Camera Experiment (CIRCE; Garner et al. 2016; Eikenberry et al. 2018) on the GTC between 2016 October and 2017 February through the open Spain–Mexico collaborative time, we imaged four objects in the \( H \) band (\( \lambda_c = 1.63 \mu m \)) and seven objects in the \( K_s \) band (\( \lambda_c = 2.16 \mu m \); PI: M. Martínez-Paredes; ID: GTC2-16BIAAC-MEX). CIRCE is an NIR camera that operates in the spectral range between 1 and 2.5 \( \mu m \) and has a full field of view of 3\( \times \)3\( \times \)3\( \times \)3 with a plate scale of 0\"1 pixel\(^{-1}\). In order to complete our observations, we used the NIR Espectrógrafo Multiobjeto Infra-Rojo (EMIR; Balcells et al. 2000) on the GTC between 2018 September and 2019 May through the open Mexico time (PI: M. Martínez-Paredes; ID: GTC2-18BMEX). EMIR has a field of view of 6\textquoteleft67 \times \textquoteleft 67 and a plate scale of 0\"2 pixel\(^{-1}\). We observed five objects in the \( K_s \) band and one in the \( H \) band. The observations were obtained under good weather conditions. The FWHM of the standard star ranges from 0\"050 to 1\"0 for the CIRCE observations and from 0\"68 to 0\"84 for the EMIR observations, while the airmass ranges were \~1–1.6 and \~1–1.5, respectively. In Table 2, we list the basic information of the observations.

For all targets, we imaged a photometric standard star immediately before or after the science observation. The standard star was chosen to be as close as possible in celestial coordinates to the science object. We used the standard star for the flux calibration and to determine the PSF.

We reduced the CIRCE images using a custom pipeline written in IDL. All images got dark-subtracted to account for electronic offsets. For sky subtraction, a median combination of the sky exposures was used, which was then scaled to the background level of the object exposures. In order to align the images, the offsets were then determined by measuring the centroid of the object. The aligned sky-subtracted images were then mean-combined. Bad pixels were treated by discarding them in the combination. For the EMIR images, we requested the reduced data from the observatory. In general, the reduction includes the following procedures: sky subtraction, cosmic-ray cleaning, stacking of the individual images, and rejection of bad images (see, e.g., Ramos Almeida et al. 2019).

### Table 1

| Name       | Coord. J2000 | \( z \) | Angular Scale (kpc arcsec\(^{-1}\)) | log \( L_X^* \) (erg s\(^{-1}\)) |
|------------|--------------|--------|----------------------------------|---------------------------|
| RA         | Decl.        |        | (5)                              | (6)                       |
| (2)        | (3)          |        |                                  |                           |
| Mrk 509    | 20:44:09.7   | −10:43:25 | 0.034 | 0.677 | 44.68 |
| PG 0005+124 | 00:53:34.9   | +12:41:36 | 0.034 | 0.677 | 43.85 |
| PG 2130+099 | 21:32:27.8   | +10:08:19 | 0.0630 | 1.213 | 45.51 |
| PG 1229+204 | 12:32:03.6   | +20:09:29 | 0.063 | 1.213 | 43.49 |
| PG 0844+349 | 08:47:42.4   | +34:45:04 | 0.064 | 1.231 | 43.74 |
| PG 0003+199 | 00:06:19.5   | +20:12:10 | 0.026 | 0.523 | 43.28 |
| PG 1440+761 | 08:10:58.6   | +76:02:43 | 0.100 | 1.844 | 44.46 |
| PG 1440+356 | 14:42:07.4   | +35:26:23 | 0.08 | 1.510 | 43.76 |
| PG 1426+015 | 14:29:06.6   | +01:17:06 | 0.09 | 1.679 | 44.11 |
| PG 1411+442 | 14:13:48.3   | +44:00:14 | 0.09 | 1.679 | 43.40 |
| PG 1211+143 | 12:14:17.7   | +14:03:13 | 0.081 | 1.527 | 43.70 |
| PG 1501+106 | 15:04:01.2   | +10:26:16 | 0.04 | 0.791 | 43.89 |
| MR 2251−178 | 22:54:05.9   | −17:34:55 | 0.064 | 1.231 | 44.46 |

### Additional Objects Observed in the NIR

| Name       | RA         | Decl.        | \( z \) | Angular Scale (kpc arcsec\(^{-1}\)) | log \( L_X^* \) (erg s\(^{-1}\)) |
|------------|------------|--------------|--------|----------------------------------|---------------------------|
| PG 2214+139 | 22:17:12.2 | +14:14:21 | 0.066 | 1.266 | 43.82 |
| PG 0923+129 | 09:26:03.3 | +12:44:04 | 0.029 | 0.581 | 43.41 |
| PG 0007+106 | 00:10:31.0 | +10:58:30 | 0.089 | 1.662 | 44.15 |

Notes. Column (1) lists the name of the object. Columns (2)–(5) list the coordinates, redshift, and angular scale taken from NED. Column (6) lists the corrected hard (2–10 keV) X-ray luminosity.

\( ^{a} \) The X-ray luminosity is from Zhou & Zhang (2010), except for PG 0007+1006 and PG 0923+129, for which the value is taken from Piconcelli & Guainazzi (2005) and Shu et al. (2010), respectively.
Table 2
NIR Observations

| Name      | Filter | Date YYYY.MM.DD | t_on-source (s) | STD | t_offset (minutes) | FWHM_{STD} (arcsec) | Airmass | Telescope/Instrument |
|-----------|--------|-----------------|----------------|-----|-------------------|---------------------|---------|---------------------|
| Mrk 509   | H      | 2016.10.31      | 45             | S813-D | 25                | 0.54                | 1.40    | GTC/CIRCE           |
| Mrk 509   | Ks     | 2016.10.31      | 65.47          | S813-D | 14                | 0.56                | 1.36    | GTC/CIRCE           |
| PG 0050-124 | Ks   | 2017.01.09      | 13.5           | FS-102 | 10                | 0.50                | 1.15    | GTC/CIRCE           |
| PG 2130-099 | Ks    | 2016.10.31      | 45             | P576-F  | 4                 | 0.52                | 1.08    | GTC/CIRCE           |
| PG 1229+204 | Ks   | 2019.05.17      | 2              | FS-131  | 13                | 0.84                | 1.02    | GTC/EMIR            |
| PG 0844+349 | Ks   | 2017.02.06      | 45             | P0345-R | 19                | 0.68                | 1.56    | GTC/CIRCE           |
| PG 0003+199 | H    | 2016.10.23      | 15             | FS-102  | 21                | 0.65                | 1.11    | GTC/CIRCE           |
| PG 0003+199 | Ks   | 2016.10.23      | 9              | FS-102  | 29                | 0.64                | 1.23    | GTC/CIRCE           |
| PG 0804+761 | H    | 2017.02.06      | 90             | P0345-R | 31                | 0.84                | 1.56    | GTC/EMIR            |
| PG 0804+761 | Ks   | 2019.02.12      | 2              | P091-D  | 23                | 0.74                | 1.48    | GTC/EMIR            |
| PG 1211+143 | Ks   | 2019.05.17      | 2              | S860-D  | 5                 | 0.74                | 1.04    | GTC/EMIR            |
| MR 2251–178 | H    | 2018.09.27      | 2              | S667-D  | 4                 | 0.68                | 1.44    | GTC/EMIR            |
| MR 2251–178 | Ks   | 2018.09.27      | 1.5            | FS-32    | 3                 | 0.68                | 1.5     | GTC/EMIR            |
| PG 2214+139 | Ks   | 2016.10.31      | 45             | FS-31    | 12                | 0.62                | 1.04    | GTC/CIRCE           |
| PG 0923+129 | H    | 2017.02.06      | 45             | P0345-R | 44                | 0.84                | 1.04    | GTC/EMIR            |
| PG 0923+129 | Ks   | 2017.02.09      | 5              | FS-17    | 7                 | 1.0                 | 1.05    | GTC/EMIR            |
| PG 0007+106$^a$ | Ks | 2016.10.23 | 15 | FS-102 | 8 | 0.64 | 1.19 | GTC/CIRCE |

Notes. Column (1) lists the name of the object. Columns (2)–(6) list the filter used, date of observation, on-source time, name of the spectrophotometric standard star, and time offset between the standard and QSO. Columns (7)–(9) list the FWHM of the standard star, average airmass during the observation, and telescope/instrument used.

$^a$ Radio-loud quasar.

3.3. Ancillary MIR and NIR High Angular Resolution Data

Five objects have high angular resolution photometry in the MIR obtained with the VISIR camera on the VLT (Hönig et al. 2010) and/or COMICS on Subaru (see Asmus et al. 2016, and references therein). We also used the high angular resolution spectrum in the $N$ band obtained with VLT/VISIR by Hönig et al. (2010) and Burtscher et al. (2013) for two out of the 13 objects in our sample; see Table 3.

In a previous work, Martínez-Paredes et al. (2017) found that only nine objects have unresolved PSF photometry available in the literature from the HST/NICMOS (Veilleux et al. 2006, 2009) in the $H$ band ($F_{160W}$, $\lambda = 1.6 \mu m$). From the ground-based observations obtained by Guyon et al. (2006) between 2000 November and 2002 April with the Quick Infrared Camera (QUIRC; Hodapp et al. 1996) on the Gemini telescope, we found that one object has unresolved PSF photometry in the $H$ band, and three have it in the $Ks$ band (see Table 3).

3.4. Spitzer/IRS Spectra

Low-resolution ($R \sim 60–127$) Spitzer/IRS spectra were retrieved from the Cornell Atlas database of CASSIS v6 (Lebouteiller et al. 2011) for 13 objects using optimal extraction, i.e., a point-source extraction. CASSIS provides the low-resolution spectra observed in different modes, such as SL1 $\sim 7.4–14.5 \mu m$, SL2 $\sim 5.2–7.7 \mu m$, LL1 $\sim 19.9–39.9 \mu m$, and LL2 $\sim 13.9–21.3 \mu m$ with different slit widths ($3^\prime\prime6–11^\prime\prime1$); see Table 3. We stitched and scaled the different spectra by setting SL2 as a reference flux to calibrate the effect of different slit widths and the background contamination due to the different slit orientation (see, e.g., Martínez-Paredes et al. 2017). Note that because of the lack of low-resolution IRS spectra between $\sim 5$ and $35 \mu m$, for one object, we used the IRS spectrum from $\sim 5$ to $14 \mu m$, and for another, we used the high spectral resolution spectrum from $\sim 10$ to $35 \mu m$.

4. Analysis

4.1. NIR

We perform aperture photometry on the QSOs and their corresponding standard star to look for possible extended emissions and measure the unresolved flux in the $H$ and $Ks$ bands. We use the photometry tasks PHOTUTILS (Bradley et al. 2019) from the analysis package ASTROPY. We measure the relative flux through the radius aperture of the standard star and QSOs and build their radial profiles. Figure 1 shows, as an example, the images in the $H$ and $Ks$ bands of Mrk 509 and its standard star and their corresponding radial profiles. Figure 2 shows the images and radial profiles of the remaining objects observed in both the $H$ and $Ks$ bands and the objects observed only in the $Ks$ band, respectively. The uncertainties in the radial profiles are estimated according to the following expression, $\sqrt{\sigma_{\text{back}}^2 N_{\text{pix}} + \sigma_{\text{back}}^2 N_{\text{pix}}^2 / N_{\text{pix}} - \text{ring}}$, where $\sigma_{\text{back}}$ is the standard deviation of the background level, $N_{\text{pix}}$ is the number of pixels within an aperture, and $N_{\text{pix}}$ is the number of pixels within a 80 pixel width annulus (see, e.g.,Reach et al. 2005). Additionally, we add in quadrature the uncertainties due to the PSF variability ($\sim 14\%$), which is estimated from the standard stars observed within a single night for multiple times with time intervals of a few minutes, and the flux calibration ($\sim 6\%$). Considering that in most cases, the radial profiles of the QSOs and standard stars are compatible within the uncertainties, we...
assumed that the emission of these QSOs is unresolved and measured the flux within an aperture radius of \(1''\) (<1 kpc; see Table 4). The exception is MR 2251–178, for which we find that ~20% of the emission is due to the extended component in both bands. Note that the aperture-corrected fluxes measured within an aperture radius of ~2\(\times\)FWHM give similar results within the uncertainties. A similar analysis was done by Martínez-Paredes et al. (2017) to estimate the unresolved emission of these QSOs at the Si2 band inside a radius aperture of \(1''\), which corresponds to physical scales <1 kpc.

In Table 4, we also list the flux previously reported in the literature (e.g., Fischer et al. 2006; Guyon et al. 2006) from ground-based observations for some objects. In general, we find that our fluxes are lower, probably because their studies are focused on the morphology of the host galaxy more than in the measurement of the PSF, which is the goal in our analysis. In the case of Mrk 509, our measurements in the \(H\) and \(Ks\) bands are similar to those previously measured by Fischer et al. (2006) within an aperture radius of \(1''\).

### 4.2. Disentangling the Accretion Disk and Torus

To decontaminate the IR data from the possible contribution of the accretion disk, especially at NIR wavelengths, we explored two broken power laws as the SED of the accretion disk

\[
\lambda F_\lambda \propto \begin{cases} 
\lambda^2 & 0.001 \leq \lambda \leq 0.01 \mu m \\
\lambda^0 & 0.01 < \lambda \leq 0.1 \mu m \\
\lambda^{-0.5} & 0.1 < \lambda \leq 5 \mu m \\
\lambda^{-3} & 5 < \lambda \leq 50 \mu m.
\end{cases}
\]

(1)

The first one is a classic accretion disk SED, which is in agreement with theoretical predictions and observational evidence (e.g., Hubeny et al. 2001; Davis & Laor 2011; Slone & Netzer 2012; Capellupo et al. 2015; Stalevski et al. 2016).

\[
\lambda F_\lambda \propto \begin{cases} 
\lambda^4 & \lambda < 0.03 \mu m \\
\lambda^0 & 0.03 < \lambda \leq 0.3 \mu m \\
\lambda^{-4/3} & 0.3 < \lambda \leq 3 \mu m \\
\lambda^{-3} & \lambda > 3 \mu m.
\end{cases}
\]

(2)

We compile the dereddened UV nuclear photometry from the Galaxy Evolution Explorer (GALEX) at the far-ultraviolet (FUV; 0.153 \(\mu m\)) and near-ultraviolet (NUV; 0.231 \(\mu m\)) bands (Bianchi et al. 2011, 2017; Monroe et al. 2016). Two objects do not have GALEX fluxes in the literature. For one of them
(PG 0844+349), we use the dereddened PSF photometry in the $u$ band (0.352 $\mu$m) from the Sloan Digital Sky Survey (SDSS) DR12 SkyServer, and for the other one (PG 0804+761), we use the continuum emission at 110 and 130 $\mu$m reported by Stevans et al. (2014) using the Cosmic Origins Spectrograph on the HST. We use these data to normalize the broken power-law components and subtract them from both the NIR and MIR photometry and from both the ground-based high angular resolution and Spitzer/IRS spectra.

As an example, in Figure 4, we show the normalized classic and bluer broken power-law models for PG 2130+099; see Equations (1) and (2). The UV photometric points are plotted in red. Additionally, we plot the dereddened PSF fluxes from the SDSS bands ($u$, $g$, $r$, $i$, and $z$) obtained from the DR12 SkyServer\footnote{\url{http://skyserver.sdss.org/dr12}} as an indicator of the PSF emission at optical wavelengths. We also plot the NIR and MIR unresolved fluxes (green points), the CC/GTC high angular resolution spectrum (blue), and the Spitzer/IRS spectrum (black) before subtracting the accretion disk. As can be seen from the figure, the bluer accretion disk overestimates the emission of the optical and NIR photometric points. The same happens for the rest of the QSOs, except for PG 0050+124, PG 1440+356, and PG 1411+442. However, for the two latter objects, only the $Ks$ band is above the extrapolated accretion disk SED. In the case of the classic accretion disk, there are only three objects (PG 1229+204, PG 0844+349, and PG 0804+761) for which the extrapolation of the SED drops slightly above the NIR photometric points.

For those cases in which the accretion disk is above the photometric points, we do not subtract its emission and use the photometry as upper limits.

We also compare the spectrum before and after subtracting the accretion disk contribution. As an example, we plot the high angular resolution and Spitzer/IRS spectra of PG 2130+099 in Figure 5. We find that if we assume the classic accretion disk, there are no differences between the high angular resolution spectra before and after subtraction. However, in the Spitzer/IRS spectra, we find that in most objects (Mrk 509, PG 2130+099, PG 0003+199, PG 1440+356, PG 1426+015, PG 1411+442, PG 1211+143, and PG 1501+106), there is an average contribution from the accretion disk of $\sim$2.4% between $\sim$5 and 7.5 $\mu$m. On the other hand, when we assume the bluer accretion disk, the spectral shape of both the high angular resolution and Spitzer/IRS spectra changes after the disk component subtraction. We find that the bluer accretion disk contributes $\sim$17.5% and $\sim$5.5% to the Spitzer and high angular resolution spectra between $\sim$5 and 10 $\mu$m, respectively. For PG 0804+761, the extrapolation of the bluer accretion disk overestimates the emission of both spectra until $\sim$10 $\mu$m.

On average, we find that the classic accretion disk contributes $\sim$35% and $\sim$30% (12 objects) in the $H$ and $Ks$ bands, respectively. These are lower than the contributions we find assuming the bluer accretion disk, $\sim$41% (two objects) and $\sim$54% (four objects), in the same bands. Hernán-Caballero et al. (2016) found that the

Figure 1. Images and radial profiles of Mrk 509 and S813-D at $H$ (top panels) and $Ks$ (bottom panels) bands. From left to right are the science image, the standard star, and their radial profiles. The radial profile of the QSO and its uncertainty are plotted as a black solid line and gray shaded region. The radial profile of the standard star and its uncertainty are plotted as a red dashed line and pink shaded region. In all images, the lowest contour is 3$\sigma$ over the background. The next contours are traced in 2$\sigma$ steps.
contribution of the accretion disk at 1, 2, and 3 \( \mu m \) (rest-frame wavelength) is 63%, 17%, and 8% for a sample of QSOs with a redshift \( z \) between 0.17 and 6.42. On the other hand, García-Bernete et al. (2019) found that the contribution from the accretion disk is \( \sim 46\% \), \( \sim 23\% \), and \( \sim 11\% \) in the J, H, and K bands for a sample of type 1 Seyferts.

5. Modeling the NIR-to-MIR SEDs

5.1. The Dusty Torus Models

5.1.1. Fritz et al. (2006): Smooth F06 Model

The Fritz et al. (2006) model has a flared disk with open polar cone regions. In this model, the dust homogeneously and continuously fills the torus volume. The following parameters describe it. First, we discuss the inner and outer radius (\( Y = R_{\text{out}}/R_{\text{in}} \)) ratio. The inner radius is defined by the dust sublimation temperature (1500 K) under intense radiation by the central AGN. It is defined as \( R_{\text{in}} \approx 1.3 \sqrt{L_{\text{AGN}}/T_{\text{1500}}} \) pc for a typical graphite grain with a radius of 0.05 \( \mu m \) (Barvainis 1987). Other parameters are the angular width of the torus (\( \Theta \)); the viewing angle (\( i \)); the index of the polar and radial gas distribution (\( \gamma \) and \( \beta \), respectively); and the optical depth at 9.7 \( \mu m \). The dust is mainly composed of graphite and silicate grains in nearly equal percentages. The central pointlike source is represented by a broken power law that illuminates the dust.

5.1.2. Nenkova et al. (2008a, 2008b): Clumpy N08 Model

The Nenkova et al. (2008a, 2008b) model assumes that the dust within a torus-like geometry is distributed in the form of identical spherical clumps. It enshrouds the central engine emitting the energy following a broken power-law SED and is assumed to have the standard Galactic Interstellar Medium (ISM) (i.e., 47% graphite and 53% silicate). The following parameters describe the model: the viewing angle (\( i \)), the number of clouds along the line of sight (\( N_0 \)), the angular width of the torus (\( \sigma \)), the radial extension (\( Y = R_{\text{out}}/R_{\text{in}} \)), the index of the radial distribution (\( q \)), and the optical depth of the clouds (\( \tau_V \)). The inner radius in this model is defined as \( R_{\text{in}} \approx 0.4 \sqrt{L_{\text{AGN}}/T_{\text{1500}}} \) pc. Nenkova et al. (2008a, 2008b) argued that the differences in the power of the sublimation temperature reflect the more detailed radiative transfer calculations performed in this model.

5.1.3. Höning & Kishimoto (2010): Clumpy H10 Model

The Höning & Kishimoto (2010) model inherits the strategy of Nenkova et al. (2008a); however, it uses a 3D Monte Carlo radiative transfer simulation to treat the dust distribution in a probabilistic manner. It assumes the central point source described by a broken power law and three different dust compositions: the standard ISM, large ISM grains (0.1–1 \( \mu m \)), and intermediate grains (0.05–0.25 \( \mu m \)) with 70% graphite and 30% silicate. The torus parameters are the power-law index of the radial distribution (\( a \)), the power-law index of the cloud size

![Figure 2. Images and radial profiles of QSOs and the standard at the H (left panels) and Ks (right panels) bands. From left to right are the science image, the standard star, and their radial profiles. The radial profile of the QSO and its uncertainty are plotted as a black solid line and gray shaded region. The radial profile of the standard star and its uncertainty are plotted as a red dashed line and pink shaded region. In all images, the lowest contour is 3σ over the background. The next contours are traced in 2σ steps.](image-url)
distribution \( (b) \), the viewing angle \( (i) \), the number of clouds along the equatorial plane \( (N_0) \), the outer radius \( (R_{\text{out}}) \), and the cloud size at the innermost torus radius. In this model, the inner radius is defined as \( R_{\text{in}} \approx 0.36 \sqrt{L_{46}^{\text{AGN}}} \) pc assuming ISM dust, while for ISM large grains, this is \( R_{\text{in}} \approx 0.5 \sqrt{L_{46}^{\text{AGN}}} \) pc (see Hönig & Kishimoto 2010).

5.1.4. Stalevski et al. (2016): Two-phase Media S16 Model

They modeled the dusty torus with dusty clumps enshrouded by a smooth low-density nebulosity called a two-phase medium. The torus is heated by a central point source with anisotropic emission (Netzer 1987), which is strongest in the polar direction and weakest along the equatorial plane. A power law dictates the standard ISM dust distribution along the radial \( (r) \) and polar \( (\theta) \) directions. Additionally, the model depends on the viewing angle \( (i) \), the half-opening angle \( (\sigma) \), the optical depth at 9.7 \( \mu \text{m} \) \( (\tau) \), and the radial extension \( (Y = R_{\text{out}}/R_{\text{in}}) \). The inner radius is defined as in the smooth model of Fritz et al. (2006).

5.1.5. Hönig & Kishimoto (2017): Disk+Wind H17 Model

This model is composed of a clumpy polar wind and a compact disk. The dust clouds are assumed to lie along a radial distance from the central black hole \( r \), following a power-law distribution described by the power-law indexes \( a \) (for the disk) and \( a_w \) (for the wind). The disk is also described by the dimensionless scale height \( h \) and the number of clouds along the equatorial line \( N_0 \), while the wind is described by the half-opening angle \( \theta \) and the angular width of the hollow-cone \( \sigma \). Other parameters are the wind-to-disk ratio of the number of clouds \( f_{wd} \) and the viewing angle \( i \). Different sets of dust composition have been implemented, assuming the standard ISM and the standard ISM plus larger-grain dust.

5.2. Modeling Procedure

In this work, we take advantage of the high signal-to-noise ratio \( (S/N) \) of the Spitzer/IRS spectra, the high angular resolution of the CC and VISIR spectra, and the ground-based high angular resolution photometry at the NIR and MIR to build a well-sampled set of SEDs that allows us to look for the model that better reproduces the data. To model these data, we used the interactive spectral fitting program XSPEC (Arnaud 1996) from the HEASOFT\(^\text{13}\) package. The XSPEC program uploads the dust models as additive tables, which have been previously created using the FLX2TAB task within HEASOFT. Briefly, a table model is composed of an \( N \)-dimensional grid of model spectra, which is calculated for a particular set of values within the \( N \) parameter space of the model (for more details on the model inclusion and modeling procedure within XSPEC, see González-Martín et al. 2019a). Additionally, we also included the stellar libraries of Bruzual & Charlot (2003), the

\(^{13}\) https://heasarc.gsfc.nasa.gov

Figure 3. Images and radial profiles of QSOs and the standard in the \( K_s \) band. From left to right are the science image, the standard, and their radial profiles. The radial profile of the QSO and its uncertainty are plotted as a black solid line and gray shaded region, respectively. The radial profile of the standard and its uncertainty are plotted as a red dashed line and pink shaded region. In all images, the lowest contour is 3\( \sigma \) over the background. The next contours are traced in 2\( \sigma \) steps.
starburst templates from Smith et al. (2007), and foreground extinction (Pei 1992).

For the data, we use the FLX2XSP task within HEASOFT to read the text file that contains the photometry and spectroscopy plus their uncertainties and to write a standard XSPEC pulse height amplitude.\(^\text{14}\)

We use the \(\chi^2\) statistic to converge to the best fit. However, this approach requires a particular treatment of the data when using different data sets. The different spectral resolution could lead to an overestimation of the spectra compared to the photometry. Simultaneously, the spectral features (e.g., silicate features) are useful to understand the best model for each object. Thus, we develop a procedure that is able to use both the spectral and photometric data simultaneously. We create spectra for both Spitzer and ground-based observations that are degraded to the spectral resolution of the photometry. To do so, we require the spectrum to match the average bandpass of the photometric points in the MIR. From now on, we call this degraded spectra the low spectral resolution (LSR) Spitzer and ground-based spectra.

We start fitting the LSR ground-based spectrum and the high angular resolution photometry to the dust models attenuated by foreground extinction. In the case of the photometric set of data, the parameters of the dust models are tied to those of the LSR ground-based spectrum to try to find a single SED reproducing both sets of data. We assume that circumnuclear contributors do not contaminate this data set. After obtaining the best fit to the ground-based high spatial resolution data, we add the LSR Spitzer/IRS spectrum to this data set. We use the parameters derived from fitting the LSR Spitzer/IRS spectrum as an initial guess for the fit of the LSR ground-based spectrum/photometry. In this case, and when necessary, we add a stellar and/or starburst component to the LSR Spitzer/IRS spectrum to consider plausible circumnuclear contributors due to the lower spatial resolution of Spitzer/IRS. Once the LSR data are fitted, we compute the 3\(\sigma\) errors for each parameter involved.

We use these errors to find the minimum and maximum allowed range to those parameters obtained from the spectral fit to the LSR data set. Then we replace the LSR spectra (ground-based and Spitzer) for the full spectral resolution (FSR) version of the spectra. Therefore, we impose these values as the initial guess of the parameters to fit the N-band high angular resolution spectrum plus the photometric data. Next, besides the parameters of the models, we also calculate the dust mass and covering factor for all of the models. For F06, N08, and S16, we also calculate the radial extension of the torus. To derive the dust mass and covering factor, we use Equations (1)–(6) from Espanza-Arredondo et al. (2019). The outer radius \(R_{\text{out}}\) is calculated as a function of the radial extent \(Y\).

We consider as acceptable fits those with a reduced \(\chi^2_{\text{red}} < 2\) for both LSR and FSR spectral fits; see Table 5. Then, to look for the model preferred by the data, we estimate the Akaike information criterion (AIC; Akaike 1974) for both LSR and FSR spectral fits. The AIC gives the quality of a model by estimating the likelihood of the model to predict future values. We compute the AIC value in terms of the \(\chi^2\), degree of freedom (dof), and data size (\(N\)). The dof is calculated as the total number of points in the spectrum minus the total number of free parameters of the model. In general, a good model is the one with the minimum AIC. However, to better discriminate between the models, we estimate the likelihood that the model with the minimum AIC minimizes the loss of information.

### 5.3. Spectral Fitting

We find that for all objects, several models can fit the same set of LSR and FSR data with a reduced \(\chi^2 < 2\). However, according to the AIC, the model that better reproduces the FSR data for Mrk 509, PG 2130+099, PG 1411+442, PG 1211+143, PG 1501+106, MR 2251–178, PG 1229+09, PG 0844+349, and PG 0804+761 is the disk+wind H17 model, while for PG 1440+356, it is the smooth F06 model; for PG 0050+124, it is the two-phase media S16 model; and for PG 1426+015, it is the clumpy N08 model. In the case of PG 0003+199, we find that none of the models can reproduce the FSR data, probably because the shape of its ground-based MIR spectrum differs from the Spitzer/IRS spectrum between \(\sim 10.5\) and \(12.3 \mu m\). These differences might be caused by the loss of signal on the border of the ground-based MIR high angular resolution spectrum (see Figure C1 in Martínez-Paredes et al. 2017). In Table 5, we highlight in bold the good fits according to the AIC. For PG 2130+099, the data do not permit one to distinguish between the disk+wind H17 and smooth F06 models. For MR 2251–178, both the disk+wind H17 and clumpy H10 models are equally valid. However, based on a qualitative analysis, it is possible to note that the residuals obtained assuming the disk+wind H17 model are the flattest in both cases (see Appendix A).

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\(^{14}\) Engineering unit used to describe the integrated charge per pixel produced by a detector.
Considering only the models that were selected according to the AIC, we find that disk+wind H17 is the model that better reproduces the data (64% of the cases, 9/13), followed by the smooth F06 (14%, 2/13), clumpy H10 (7%, 1/13), clumpy N08 (1%, 1/13), and two-phase media S16 (7%, 1/13) models. As an example, in Figure 6, we show the fits of the NIR–MIR SED for Mrk 509 assuming the disk+wind H17 model, and in Figure 7, we show the probability distribution functions (PDFs) of both...
Table 5
Statistics of the Acceptable Fits

| Name          | Model | Comp. | Add. | FSR          |χ_red^2 (4) | dof (5) | AIC (6) |χ_red^2 (7) | Name          | Model | Comp. | Add. | FSR          |χ_red^2 (11) | dof (12) | AIC (13) |χ_red^2 (14) |
|---------------|-------|-------|------|--------------|-------------|---------|---------|-------------|---------------|-------|-------|------|--------------|-------------|----------|----------|-------------|
| Mrk 509       | F06   | +Ste+SB | 1.2  | 772         | 584.88      | 1.05     | PG 1211+143 | F06   | +Ste+SB | 1.53 | 535 | 834.29 | 1.96 |
| H10           | +Ste+SB | 0.85  | 773 | 314.63       | 0.59        |         |         | N08   | +Ste+SB | 1.33 | 535 | 727.77 | 1.58 |
| H17           | +Ste+SB | 0.71  | 770 | 206.99       | 0.47        |         |         | H10   | +Ste+SB | 1.24 | 536 | 680.9 | 1.27 |
| PG 0050+124   | F06   | +Ste+SB | 1.32 | 774         | 1038.01     | 1.77     | PG 1501+106 | F06   | +Ste+SB | 1.28 | 521 | 638.39 | 1.26 |
| S16           | +Ste+SB | 1.25  | 774 | 980.92       | 1.65        |         |         | S16   | +Ste+SB | 1.12 | 521 | 599.03 | 1.02 |
| H17           | +Ste+SB | 1.44  | 772 | 1131.31      | 1.71        |         |         | N08   | +Ste+SB | 0.89 | 521 | 480.88 | 0.68 |
| PG 2130+099   | F06   | +SB   | 0.42 | 601         | 271.49      | 0.39     | MR 2251–178 | H10   | +Ste+SB | 0.6  | 1586 | 973.41 | 1.30 |
| S16           | +Ste+SB | 0.73  | 601 | 456.48       | 0.70        |         |         | H17   | +Ste+SB | 0.6  | 1583 | 964.12 | 1.09 |
| H10           | +Ste+SB | 0.64  | 602 | 402.31       | 0.58        |         |         | H17   | +Ste+SB | 0.42 | 599 | 271.03 | 0.32 |
| H17           | +Ste+SB | 0.42  | 599 | 271.03       | 0.32        |         |         | H17   | +Ste+SB | 0.41 | 539 | 241.34 | 0.42 |
| PG 1411+442   | F06   | +Ste+SB | 0.93 | 543         | 521.12      | 0.89     | PG 1229+204 | F06   | +Ste+SB | 0.6  | 541 | 341.19 | 0.74 |
| H10           | +Ste+SB | 0.78  | 544 | 437.5        | 0.78        |         |         | H10   | +Ste+SB | 0.5  | 541 | 284.18 | 0.56 |
| H17           | +Ste+SB | 0.57  | 541 | 328.27       | 0.27        |         |         | H10   | +Ste+SB | 0.53 | 542 | 302.39 | 0.51 |
| PG 1440+356   | F06   | +SB   | 0.58 | 547         | 332.65      | 0.42     | PG 0844+349 | F06   | +Ste+SB | 0.61 | 532 | 341.56 | 0.48 |
| S16           | +Ste   | 1.12  | 547 | 628.59       | 0.91        |         |         | S16   | +Ste   | 0.65 | 532 | 362.13 | 0.49 |
| H10           | +SB   | 1.52 | 548 | 844.65       | 1.75        |         |         | H10   | +Ste   | 0.6  | 532 | 335.28 | 0.49 |
| H17           | +SB   | 0.65 | 545 | 374.16       | 0.62        |         |         | H17   | +Ste   | 0.37 | 530 | 215.15 | 0.20 |
| PG 1426+015   | N08   | +Ste+SB | 0.91 | 536         | 504.47      | 0.29     | PG 0804+761 | F06   | +Ste   | 0.8  | 554 | 457.77 | 0.65 |
|               |       |       |     |             |             |         |         | S16   | +Ste   | 1.95 | 554 | 1095.3 | 1.37 |
|               |       |       |     |             |             |         |         | N08   | +Ste   | 1.94 | 554 | 1089.87 | 1.60 |
|               |       |       |     |             |             |         |         | H10   | +Ste   | 1.58 | 555 | 893.54 | 1.72 |
|               |       |       |     |             |             |         |         | H17   | ...    | 0.47 | 552 | 280.2 | 0.47 |

Note. Column (1) lists the name of the object. Columns (2) and (3) list the model assumed and the additional component included. Columns (4)–(6) list the red χ^2, dof, and AIC values for the FSR fits. Column (7) lists the reduced χ^2 for the LSR fits. The best models according to the AIC are highlighted in bold.

the parameters that best reproduce the data and the derived covering factor and dust mass of the torus. For the rest of the objects and models, see Appendix A. On the other hand, if we assume the bluer accretion disk, none of the models fit the data in most cases. The exceptions are PG 0050+124 and PG 1501+106, for which the disk+wind H17 model was the best model to fit the data. This result is consistent with those obtained when assuming the classic accretion disk. Additionally, in all cases, we note that although the Spitzer/IRS spectrum of these QSOs is mostly dominated by the contribution of the AGN (>80%), and we remove the contribution from the accretion disk, it is necessary to add both the stellar and/or starburst components for most objects (see Table 5).

When using the classic accretion disk, the H and Ks bands are well fitted in most cases by the disk+wind H17 model. Only in two cases, MR 2251–174 and PG 1411+442, is the flux in the H band, from GTC/EMIR and HST/NICMOS, respectively, above the best fit. This excess could be due to some contamination by the host galaxy. In the case of MR 2251–174, the radial profile in the H band (see Section 4.1) is slightly above the radial profile of the standard star, and in some cases, marginal emission from the host could be contaminating the PSF flux in the H band from HST/NICMOS (see Veilleux et al. 2006, 2009). We find that the clumpy N08 model best fits PG 1426+015 and reproduces the H photometric point obtained from NICMOS/HST (the Ks flux is an upper limit). We also note that for PG 0050+124, the photometric points in the H band from HST/NICMOS and Ks band from GTC/CIRCE are above the best-fit model (two-phase media S16). Additionally, for PG 1440+356, the photometric point in the H band from HST/NICMOS is slightly above the best-fit model (smooth F06), and the Ks flux is an upper limit. In these last two cases, this is probably due to the limitation of the model in simultaneously well fitting the NIR and MIR SEDs (see, e.g., Martínez-Paredes et al. 2020) and/or some marginal contamination from the host. In Appendix B we list the parameters derived for all models.

In Figure 8, we plot the angular width (half angular width measured from the equator for the disk+wind H17 model) against the viewing angle obtained from the best fits for all models, as well as the dust mass and covering factor in size and color coding. We note that in all cases, the parameters are consistent with the optical classification of type 1 AGN, and the dust mass is constrained between ~10^6 and 10^7 M_☉ for most cases, while the covering factor ranges from ~0.14 to 0.40 for the disk+wind H17 model to 0.95 for the two-phase media S16 model. These covering factors are consistent with the ones obtained in previous works for type 1 AGNs (see, e.g., Martínez-Paredes et al. 2017, 2020; González-Martín et al. 2019b). However, it is important to note that the covering factor is model-dependent, as shown by González-Martín et al. (2019b). For example, they found that for the disk+wind H17 model, the covering factor only ranges from ~0.1 to 0.6, while
for the rest of the models considered here, the parameters allow the covering factor to range from \( \sim 0.1 \) to 1, showing a maximum toward the larger values and decreasing until they reach a value of \( \sim 0.1 \).

To investigate how well the different models simultaneously reproduce the NIR and MIR SEDs of QSOs, we calculate the average residual from all fits and objects (see Figure 9). From a qualitative analysis, we find that the two-phase media S16 and the clumpy N08 models are unable to fit the NIR data, while the smooth F06 and clumpy H10 models improve the fits at the NIR, especially fitting the photometric point at the \( K_s \) band. However, the disk+wind H17 model is the best for reproducing both photometric points at the NIR within the uncertainties. For the two-phase media S16 and clumpy N08 models, it is very difficult to reproduce the bluer spectral range between \( \sim 5 \) and 7.5 \( \mu \)m, while for the other three models, the residuals look flatter. We observe that all models have difficulty reproducing the range between \( \sim 7.5 \) and 14 \( \mu \)m, where the 10 \( \mu \)m silicate feature lies, and none of the models can reproduce the spectral range around 12 \( \mu \)m. For wavelengths longer than 14 \( \mu \)m, both the clumpy N08 and H10 models, as well as the disk+wind H17 model, produce flatter residuals, while the two-phase media S16 and smooth F06 models show a steeper residual from the bluer to the redder range.

6. Discussion

6.1. The NIR and MIR Spectral Indexes

Using the photometric IR data from the Infrared Space Observatory, Haas et al. (2003) analyzed the IR SEDs (5–200 \( \mu \)m) of 64 PG QSOs. In particular, they found that the spectral slopes \( \alpha_{1–10 \mu m} \) range from \( -0.9 \) to \( -2.2 \) and do not correlate with the inclination-dependent extinction effects in the picture of a dusty torus. They suggested that the diversity of the SEDs that they observed could be explained in terms of an evolutionary scenario in which those QSOs with a redder MIR SED are in early evolutionary stages among QSOs preceded by a dusty ultraluminous infrared galaxy phase (e.g., Sanders et al. 1988).

We measured four spectral indexes from ground-based high angular resolution SEDs. The first spectral index is calculated between the \( H \) (1.6 \( \mu \)m) and Si2 (8.7 \( \mu \)m) bands \( (\alpha_{\text{NIR–MIR}(1.6–8.7 \mu m)}) \), the second between the \( K_s \) (2.2 \( \mu \)m) and Si2 (8.7 \( \mu \)m) bands \( (\alpha_{\text{NIR–MIR}(8.7–2.2 \mu m)}) \), the third between 7.8 and 9.8 \( \mu \)m \( (\alpha_{\text{MIR}(7.8–9.8 \mu m)}\) and the fourth between 9.8 and 11.7 \( \mu \)m \( (\alpha_{\text{MIR}(9.8–11.7 \mu m)}\. We measured the two later MIR spectral indexes instead of the 10 \( \mu \)m silicate strength due to the low S/N of the high angular resolution spectra. The spectral index is estimated according to \( \alpha_{21} = -\frac{\log f_{\lambda_2}/f_{\lambda_1}}{\log(\lambda_2/\lambda_1)} \), where \( \lambda_2 > \lambda_1 \) (see, e.g., Buchanan et al. 2006). In the case of the two MIR spectral indexes, \( \alpha_{\text{MIR}(7.8–9.8 \mu m)} \) and \( \alpha_{\text{MIR}(9.8–11.7 \mu m)} \), the \( \lambda_2 \) and \( \lambda_1 \) wavelengths are chosen to fix the points on the continuum, avoiding the spectral range of low atmospheric transmission around 9 \( \mu \)m and the polycyclic aromatic hydrocarbon (PAH) feature at 11.3 \( \mu \)m that is present in some objects.

In Table 6, we list the \( \alpha_{\text{NIR–MIR}(1.6–8.7 \mu m)} \) and \( \alpha_{\text{NIR–MIR}(2.2–8.7 \mu m)} \) spectral indexes measured after subtracting the classic accretion disk from the data. On average, we find \( \alpha_{\text{NIR–MIR}(1.6–8.7 \mu m)} = -1.1 \pm 0.6 \) and \( \alpha_{\text{NIR–MIR}(2.2–8.7 \mu m)} = -1.2 \pm 0.4 \). Additionally, we list the values obtained assuming the bluer accretion disk. Note that there are fewer objects in this case because, in most cases, the accretion disk overestimates the emission in the NIR bands (see Section 4.2). For these objects, assuming a bluer accretion disk does not affect the estimation of the NIR-to-MIR spectral indexes within the uncertainties. Our measurements of both NIR–MIR spectral indexes are similar to the ones reported by Haas et al. (2003).
In the left panel of Figure 10, we compare our measurements of the NIR-to-MIR $\alpha_{\text{NIR-MIR}}$ spectral index listed in Table 6 with the AGN bolometric luminosity $L_{\text{bol}}$ and the dust mass. We estimated the bolometric luminosity using the hard X-ray (2–10 keV) flux and the relation derived by Marconi et al. (2004); see Martínez-Paredes et al. (2019). In the plots, we identify each object with the model that better fits their data, except for PG 0003+199, for which none of the models can fit with a red $\chi^2 < 2$. We note that most objects have an NIR-to-MIR spectral index between $\sim 0$ and $-1.5$, which does not correlate with the bolometric luminosity or the dust mass. Haas et al. (2003) estimated the dust mass of some objects in our sample using Equation (6) in Stickel et al. (2000) and assuming standard grain properties and a dust emissivity $\beta = 2$. The mass that they derived varies from $\sim 10^6$ to $10^8 M_\odot$, with an uncertainty that can vary up to an order of magnitude. However, due to the large uncertainties in the far-IR fluxes, the dust masses might be overestimated, as pointed out by the authors.

We estimate the MIR spectral indexes for two cases, one in which we subtracted the classic accretion disk from the high angular resolution spectrum and another in which we subtracted the bluer accretion disk. We find that for the MIR spectral index $\alpha_{\text{MIR}}$, both measurements give similar results ($\sim -0.2$). However, for $\alpha_{\text{MIR}}$, the values obtained by assuming the bluer accretion disk are redder ($\sim -3$) than those obtained by assuming the classic accretion disk ($\sim -0.4$); see Figure 11. Additionally, we investigate whether the inner star formation could be affecting our estimations of the MIR spectral indexes. We measure the slopes $\alpha_{\text{MIR}}$ on the starburst-subtracted Spitzer/IRS spectrum and compare with the slopes measured on the high angular resolution spectra. We find that the starburst-subtracted Spitzer/IRS MIR slopes are redder ($\sim -2$ for the slope between 7.8 and 9.8 $\mu$m). Figure 12 shows...
Figure 8. Angular width vs. viewing angle $i$ obtained for the good fits of all models. The colored stars indicate the model that best fits the object, and the arrows are upper or lower limits. The covering factor (CF) is represented by a color-coded circle. The set of values is indicated in the vertical color bar. Yellow circles indicate large covering factors, while purple circles indicate low covering factors. The value of the logarithm of the dust mass (in $M_\odot$) is represented with a size-coded circle, and the value is indicated in parentheses.

Figure 9. Average residuals for each model. The vertical lines separate the residuals into three parts for a better qualitative analysis (see the text).
both spectral indexes, where the measurements are assuming the classic accretion disk.

These results suggest that although the high angular resolution spectrum is mostly dominated by the emission of the AGN, it is possible that the bluer spectral range of the spectrum is being affected by some dust components not directly related to the dust heated by the AGN.

We measure the same spectral indexes for the five models to investigate how well the different models sampled the observed NIR and MIR spectral slopes. In Figure 13, we compare the synthetic and observed values (measured on the high angular resolution spectrum after subtracting the classic accretion disk). In general, we note that none of the models match the region of the observed spectral indexes, although a closer match occurs for the disk+wind H17 model, especially when comparing $\alpha_{\text{MIR}}(9.8-11.9 \mu\text{m})$ and $\alpha_{\text{NIR-MIR}}(2.2-8.7 \mu\text{m})$. However, it is likely that the limited estimation of the $\alpha_{\text{MIR}}(7.8-9.8 \mu\text{m})$ spectral index is affecting the comparison with the models, since a spectral index around $-2$, as obtained from the starburst-subtracted Spitzer/IRS MIR slopes, compares better with the models.

In particular, we note that the clumpy N08 and two-phase media S16 models predict NIR-to-MIR spectral indexes ($\alpha_{1.6-8.7}$ and $\alpha_{2.2-8.7}$) that are $\lesssim -2$, followed by the clumpy H10 and smooth F06 models that predict values $\lesssim -1.5$ and the disk+wind H17 model that predicts values $\sim -0.8$. This result is consistent with the one obtained by Hönig & Kishimoto (2017) when compared the NIR-to-MIR (3 and 6 $\mu$m) versus MIR (8 and 14 $\mu$m) spectral indexes for the clumpy H10 and disk+wind H17 models. They showed that the disk+wind H17 model predicts bluer NIR-to-MIR (3 and 6 $\mu$m) spectral indexes and claimed that they come from SEDs with a 3–5 $\mu$m bump. Moreover, they said that these SEDs correspond to models where the disk has a relatively steep dust cloud distribution ($-2 > a > -3$) and the wind has a shallower cloud distribution ($-0.5 > a_w > -1.5$). We find that the average index of the cloud distribution in the disk and wind is $a \sim -2.6$ and $a_w \sim -0.7$, respectively, suggesting that the most compact distribution of the clouds in the disk dominates the emission in the NIR and therefore improves the fitting of this part of the SED.

From our analysis, we found that the disk+wind SEDs predict the most blue NIR-to-MIR spectral indexes. However, it is necessary for all models to better sample the region with NIR-to-MIR spectral indexes between $\sim -0.5$ and $\sim -2$ and an MIR spectral index around zero, as can be seen from Figure 13. This highlights the need for different dust distributions/compositions in the current phenomenological models available to the community.

Martínez-Paredes et al. (2020) found that the disk+wind H17 model is the best at reproducing the AGN-dominated Spitzer/IRS spectrum for a sample of local type 1 AGNs, in which the 10 $\mu$m silicate emission feature is prominent. They obtained, on average, an index for the dust distribution in the disk of $a \sim -1.9$ and an index for the dust distribution in the wind of $a_w \sim -0.7$, which are similar to the values obtained for our sample of QSOs. Therefore, these results suggest that this model has a better treatment of the properties of the hot and warm dust, which dominates the emission between $\sim 1$ and $\sim 14 \mu$m.

### Table 6

| Name  | This Work $\alpha_{\text{NIR-MIR}}(1.6-8.7 \mu\text{m})$ | This Work $\alpha_{\text{NIR-MIR}}(2.2-8.7 \mu\text{m})$ | Haas et al. (2003) $\alpha_{1-10 \mu\text{m}}$ |
|-------|---------------------------------------------------|---------------------------------------------------|---------------------------------|
| Mrk 509 | $-1.57 \pm 0.27$ | $-1.36 \pm 0.34$ | ... |
| PG 0050+124 | $-0.78 \pm 0.22$ | $-0.67 \pm 0.36$ | $-1.21$ |
| PG 2130+099 | $-1.15 \pm 0.25^a$ | $-0.79 \pm 0.36^a$ | ... |
| PG 1229+204b | $< -0.45$ | $< -0.45$ | $-0.98$ |
| PG 0844+349b | $< 0.05$ | $< 0.24$ | ... |
| PG 0003+199 | $-1.75 \pm 0.28$ | $-1.70 \pm 0.34$ | ... |
| PG 0804+761b | $< -0.62$ | $< -0.72$ | $-1.20$ |
| PG 1440+356 | $-0.54 \pm 0.23$ | $< -0.18$ | $-0.92$ |
| PG 1426+015 | $-2.10 \pm 0.23$ | $-0.21$ | $-1.22$ |
| PG 1411+442 | $-0.74 \pm 0.23$ | $< -0.18$ | ... |
| MR 2251+178 | $< -0.66$ | $-1.49 \pm 0.33$ | $-1.22$ |

### Notes

1. Column (1) lists the name of the objects. Columns (2)–(4) list the spectral indexes $\alpha_{\text{NIR-MIR}}(1.6-8.7 \mu\text{m})$ and $\alpha_{\text{NIR-MIR}}(2.2-8.7 \mu\text{m})$ calculated by us and $\alpha_{1-10 \mu\text{m}}$ reported by Haas et al. (2003), respectively.
2. This value corresponds to the case assuming the bluer accretion disk.
3. The accretion disk is not subtracted.

6.2. Torus/Disk Geometry

Mor et al. (2009) used the Spitzer/IRS ($\sim 2–35 \mu$m) spectra of 26 QSOs ($z < 0.06–0.33$) to investigate their main emission component. They found that the SEDs of these objects can be well reproduced by assuming three model components: (1) the clumpy N08 model or dusty torus component, (2) the dusty narrow-line region cloud component, and (3) the blackbody-like dust component. They found that a substantial amount of the emission between $\sim 2$ and 7 $\mu$m originates from a hot dust component, likely situated in the innermost part of the torus. Additionally, they found that the dust mass correlates with the bolometric luminosity, while the covering factor seems anticorrelated.

Later, Martínez-Paredes et al. (2017) found that the starburst-subtracted Spitzer/IRS spectrum ($\sim 8–15 \mu$m) plus the NIR high angular resolution photometric point at the $H$ band from the NICMOS/HST of a sample of 20 QSOs ($z < 0.1$) could be well modeled assuming only the clumpy N08 model. However, they noted that the inclusion of the spectral range between $\sim 5$ and 8 $\mu$m results in a poor fit of the silicate features at 9.7 $\mu$m and therefore in a set of parameters inconsistent with an optically classified type 1 AGN.

Comparing the average residuals obtained from fitting the AGN-dominated Spitzer/IRS spectra of local type 1 AGNs, Martínez-Paredes et al. (2020) found that in general, none of the models can well reproduce either the spectrum from $\sim 5$ to 30 $\mu$m or the 10 and 18 $\mu$m silicate emission features. However, they noted that the disk+wind H17 model produces the flattest residuals, especially for objects with higher bolometric luminosities ($\sim 44.8–46.1$ erg s$^{-1}$ in log scale). Indeed, using a large sample of AGNs, González-Martín et al. (2019b) found that the disk+wind H17 model performs best for high-luminosity AGNs (44$\log(L_{54}/10^{45} \text{ergs s}^{-1}) < 44.5$ erg s$^{-1}$), while the clumpy N08 model is better at modeling...
low-luminosity AGNs, and the two-phase media S16 model seems to be better suited for intermediate luminosities. In this work, we find that the NIR–MIR SED of QSOs is also better modeled by the disk+wind H17 model. Curiously, we note that for PG 1440+356, which fitted best with the smooth F06 model, the next model that best fits the data is the disk+wind H17 one, while for PG 0050+124, which is best fitted with the two-phase media S16 model, the next model that best fit the data is the smooth F06 model, suggesting that these QSOs always prefer the wind or smooth models rather than the clumpy models, probably since the former tend to produce bluer NIR SEDs. On the other hand, Woo et al. (2020) recently claimed that AGNs with stronger outflow are hosted by galaxies with higher star formation rates. Curiously, Martínez-Paredes et al. (2019) found that the star formation rate of these QSOs is more centrally concentrated on scales of hundreds of parsecs, as predicted by the evolutionary models. Therefore, it is possible that the outflow, if present, is playing an important role in the geometrical distribution of the central dust of these objects. Recently, I. García-Bernete et al. (2021, in preparation) found...
that the IR high angular resolution SED of local Seyfert 1s also prefers the disk+wind H17 model instead of the torus models. These results suggest the presence of a hot dust component in nearby type 1 AGNs. Noting that, unlike Seyferts, in QSOs, the unresolved emission comes from a spatial region of ∼1 kpc. Considering these objects could be tracing different evolutionary stages (see, e.g., Haas et al. 2003; Martínez-Paredes et al. 2019), in which the outflow could be responsible for the presence of polar dust on scales of hundreds of parsecs, could also explain the result that QSOs are best fitted by the disk+wind H17 model.

7. Summary and Conclusions

Understanding the nearby QSOs’ inner molecular dust geometry and dust composition has been partly limited for lack of a well-sampled SED at IR wavelengths. In this work, we use the cameras CIRCE and EMIR on the 10.4 m GTC to obtain new high angular resolution (~0.3”) photometry in the H (1.6 μm) and/or Ks (2.1 μm) bands for a sample of 13 QSOs. We analyze these NIR high angular resolution images and find that the H- and Ks-band emission is mostly unresolved in most QSOs. We find that only MR 2251–178 shows extended (~20%) emission in the H and Ks bands. Additionally, we use the high angular resolution and unresolved photometry and spectroscopy at the N band (~7.5–13.5 μm) available for these objects. We complement these data with the low angular resolution (~3”) AGN-dominated (>80%) Spitzer/IRS spectrum (~5–30 μm) to take advantage of the high S/N offered by these spectra. In this way, we build well-sampled NIR-to-MIR SEDs for local QSOs for the first time.

To build a set of IR SEDs mainly dominated by the reprocessed emission of the dust, we decontaminate the unresolved high angular resolution data and the Spitzer/IRS spectrum from the emission of the accretion disk. We explore two power-law parameterizations for the accretion disk. The first is a classic accretion disk, for which we find that the contribution decreases from NIR to MIR wavelengths (H band ∼35%, Ks band ∼30%, and between ∼5 and 7.5 μm ∼24%) and becomes negligible at wavelengths >7.5 μm. The second is a bluer accretion disk, for which we find that the contribution in the NIR and MIR is larger when compared with the classic accretion disk. In the H and Ks bands, the contribution is ∼41% (two objects) and ∼54% (four objects), respectively. For the rest of the objects, the extrapolation of the bluer accretion disk overestimates the emission in the NIR. The contribution in the MIR is ∼17.5% and ∼5.5% for the high angular resolution spectrum and Spitzer/IRS spectrum, respectively. This is nearly six to seven times larger than the contribution of the classic accretion disk.

Assuming the smooth dusty torus model (Fritz et al. 2006, F06), the clumpy dusty torus models (Nenkova et al. 2008b; Hönig & Kishimoto 2010, N08 and H10), the two-phase media torus model (Stalevski et al. 2016, S16), and the disk+wind model (Hönig & Kishimoto 2017, H17), we investigate which model better reproduces the NIR and MIR data simultaneously. To fit the models, we use the interactive spectral fitting program XSPEC from the HEASOFT package and select as acceptable fits those with a red χ² < 2. Then, we use the AIC to investigate the quality of the model. According to this criterion, we find that the disk+wind H17 model is the one that better fits the objects (64%, 9/13), followed by the smooth torus F06 model (14%, 2/13), the clumpy torus H10

Figure 12. The MIR spectral indexes obtained after subtracting the classic accretion disk and the stellar and starburst components from the Spitzer/IRS spectrum against the MIR spectral indexes measured on the high angular resolution spectrum.
model (7%, 1/13), the clumpy torus N08 model (7%, 1/13), and the two-phase media S16 model (7%, 1/13). We note that in general, these objects prefer the wind and/or smooth models over the clumpy models, likely due to their flatter NIR SEDs. Additionally, we find that there is an object (PG 0003+199) that is not fitted by any model. Curiously, this is the object with the lowest hard (2–10 keV) X-ray luminosity and poorest IR data set, since the Spitzer/IRS spectrum only covers ~10–35 μm, and the flux in the redder border of the ground-based high angular resolution spectrum drops due to the lack of signal.

We make the same analysis using the observed SEDs that resulted from subtracting the bluer accretion disk. However, in this case, we find that the models fit only 2/13 objects (PG 0050+124 and PG 1501+106). We find that the model that best reproduces the SED of these objects is the disk + wind H17 model, which is the same model obtained when assuming the classic accretion disk.

We calculate the average residual for each model. We find that the flattest residuals are obtained from the fits with the disk + wind H17 model. Comparing the angular width, viewing angle, covering factor, and dust mass derived from the best fits

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**Figure 13.** Synthetic and observed spectral indexes $\alpha_{\text{MIR}}(7.8, 9.8 \, \mu\text{m})$ and $\alpha_{\text{MIR}}(9.8, 11.7 \, \mu\text{m})$ vs. NIR-to-MIR spectral indexes $\alpha_{\text{NIR} - \text{MIR}}(1.6, 8.7 \, \mu\text{m})$ and $\alpha_{\text{NIR} - \text{MIR}}(2.2, 8.7 \, \mu\text{m})$ for all objects and models. The stars indicate that the spectral index is derived using the new NIR high angular resolution data.
of each object, we note that the parameters are similar to the values previously obtained for a larger sample of type 1 AGNs using only the AGN-dominated Spitzer/IRS spectra.

Additionally, we use the unresolved fluxes at the $H$ (1.6 $\mu$m), $Ks$ (2.2 $\mu$m), and $S$2 (8.7 $\mu$m) bands after subtracting the contribution from the accretion disk and calculate two NIR-to-MIR spectral indexes, one between 1.6 and 8.7 $\mu$m and another between 2.2 and 8.7 $\mu$m, and two MIR spectral indexes, one between 7.8 and 9.8 $\mu$m and another between 9.8 and 11.7 $\mu$m.

We compare the NIR-to-MIR spectral index $\alpha_{\text{NIR-MIR}}$ with the bolometric luminosity and dust mass derived from the best fit and find no correlation. Additionally, we measure both NIR-to-MIR spectral indexes, $\alpha_{\text{NIR-MIR}(1.6, 8.7 \mu m)}$ and $\alpha_{\text{NIR-MIR}(2.2, 8.7 \mu m)}$, for all five models. Comparing the synthetic and observed values, we find that none of the models simultaneously match the measured NIR-to-MIR and 7.8–9.8 slopes. However, we note that measuring the MIR slope between 7.8 and 9.8 $\mu$m on the starburst-subtracted Spitzer/IRS spectrum gives values that are more similar to the synthetic ones. Therefore, it is likely that some components not directly related to the dust heated for the AGN could affect the bluer spectral range of the high angular resolution spectrum. Additionally, we note that the disk + wind H17 model has the closest values. This result is consistent with the fact that this model successfully reproduces most of the observed SEDs. We conclude that the differences among the synthetic and observed values highlight the need for different dust distributions/compositions in the phenomenological models.

Finally, we point out that a better understanding of the geometry and dust composition of the IR unresolved emission of QSOs will be possible with the forthcoming spectra from the Mid-Infrared Instrument on the James Webb Space Telescope. These spectra offer a similar angular resolution but better sensitivity, allowing one to obtain a high angular resolution spectrum with a longer spectral range ($\sim$5–30 $\mu$m) for the faint and bright nearby QSOs. Future ground-based big optical telescopes like the European Extremely Large Telescope (40 m), the Thirty Meter Telescope (30 m), and the Giant Magellan Telescope (25 m) will allow observations of the inner nuclear dust in more distant objects.

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Software: XSPEC (Arnaud 1996), Photutils (Bradley et al. 2019).

Appendix A

SED Modeling

In Figures 14–26 we show the best fit SEDs and PDFs of the constrained parameters.
Figure 14. The SED of PG 2130+099 best modeled by the smooth F06 model. In the top panels, the high angular resolution photometric points are plotted as blue points with error bars. The high angular resolution spectrum is plotted with a black solid line, and the gray shaded region represents the errors. The Spitzer/IRS spectrum is plotted with a cyan solid line and its error with a cyan shaded region. The red solid line is the best model resulting from the fit to the high angular resolution data. The green dotted line is the starburst component. The blue solid line represents the sum of the stellar, starburst, and torus components that best fit the Spitzer/IRS spectrum. Middle panels: normal PDF of the free parameters. In gray, we plot the parameters derived from the fit to the LSR spectrum, while in dark blue, we plot the distribution of the parameters derived from the fit to the FSR spectrum. Bottom panels: normal PDF of the derived parameters. The blue vertical line indicates the mean.
Figure 15. Same as Figure 14 but for the disk+wind H17 model. Here the yellow dotted line is the stellar component.
Figure 16. The SED of MR 2251–178 best modeled by the disk+wind H17 model. In the top panels, the high angular resolution photometric points are plotted as blue points with error bars. The high angular resolution spectrum is plotted with a black solid line, and the gray shaded region represents the errors. The Spitzer/IRS spectrum is plotted with a cyan solid line and its error with a cyan shaded region. The red solid line is the best model resulting from the fit to the high angular resolution data. The green and yellow dotted lines are the starburst and stellar components, respectively. The blue solid line represents the sum of the stellar, starburst, and torus components that best fit the Spitzer/IRS spectrum. Middle panels: normal PDF of the free parameters. In gray, we plot the parameters derived from the fit to the LSR spectrum, while in dark blue, we plot the distribution of the parameters derived from the fit to the FSR spectrum. Bottom panels: normal PDF of the derived parameters. The blue vertical line indicates the mean.
Figure 17. Same as Figure 16 but for the clumpy H10 model.
Figure 18. The SED of PG 1411+442 best modeled by the disk+wind H17 model. In the top panels, the high angular resolution photometric points are plotted as blue points with error bars, and the black arrows are upper limits. The high angular resolution spectrum is plotted with a black solid line, and the gray shaded region represents the errors. The Spitzer/IRS spectrum is plotted with a cyan solid line and its error with a cyan shaded region. The red solid line is the best model resulting from the fit to the high angular resolution data. The green and yellow dotted lines are the starburst and stellar components, respectively. The blue solid line represents the sum of the stellar, starburst, and torus components that best fit the Spitzer/IRS spectrum. Middle panels: normal PDF of the free parameters. In gray, we plot the parameters derived from the fit to the LSR spectrum, while in dark blue, we plot the distribution of the parameters derived from the fit to the FSR spectrum. Bottom panels: normal PDF of the derived parameters. The blue vertical line indicates the mean.
Figure 19. The SED of PG 1426+015 best modeled by the clumpy N08 model. In the top panels, the high angular resolution photometric points are plotted as blue points with error bars, and the black arrows are upper limits. The high angular resolution spectrum is plotted with a black solid line, and the gray shaded region represents the errors. The Spitzer/IRS spectrum is plotted with a cyan solid line and its error with a cyan shaded region. The red solid line is the best model resulting from the fit to the high angular resolution data. The green and yellow dotted lines are the starburst and stellar components, respectively. The blue solid line represents the sum of the stellar, starburst, and torus components that best fit the Spitzer/IRS spectrum. Middle panels: normal PDF of the derived parameters. The blue vertical line indicates the mean.
Figure 20. Same as Figure 18 but for the QSO PG 1211+143.
Figure 21. The SED of PG~1501+106 best modeled by the disk+wind H17 model. Top panel: the high angular resolution photometric point is plotted as a blue point with their error bars. The high angular resolution spectrum is plotted with a black solid line, and the grey shaded region represent the errors. The Spitzer/IRS spectrum is plotted with a dark cyan solid line and its error with a cyan shaded region. The red solid line is the best model resulting from the fit of the high angular resolution data. The blue solid line represents the sum of the stellar, starburst and torus components that best fit the Spitzer/IRS spectrum. Middle panels: the model parameters derived: normal probability distribution function of the free parameters. In grey we plot the parameters derived from the fit of the LSR spectrum, while in dark blue the distribution of the parameters derived from the fit of the FSR spectrum. Bottom panels: normal PDF of the derived parameters. The blue vertical line indicates the mean.
Figure 22. Same as Figure 18 but for the QSO PG 1229+204.
Figure 23. Same as Figure 18 but for the QSO PG 0844+349.
Figure 24. The SED of PG~0804+761 best modeled by the disk+wind H17 model. Top panel: the high angular resolution photometric point is plotted as a blue point with their error bars, and the black arrows are upper limits. The high angular resolution spectrum is plotted with a black solid line, and the grey shaded region represent the errors. The Spitzer/IRS spectrum is plotted with a dark cyan solid line and its error with a cyan shaded region. The red solid line is the best model resulting from the fit of the high angular resolution data. The blue solid line represents the sum of the stellar, starburst and torus components that best fit the Spitzer/IRS spectrum. Middle panels: the model parameters derived: normal probability distribution function of the free parameters. In grey we plot the parameters derived from the fit of the LSR spectrum, while in dark blue the distribution of the parameters derived from the fit of the FSR spectrum. Bottom panels: normal PDF of the derived parameters. The blue vertical line indicates the mean.
Figure 25. The SED of PG 1440+356 best modeled by the smooth F06 model. In the top panel, the high angular resolution photometric points are plotted as blue points with error bars, and the black arrows are upper limits. The high angular resolution spectrum is plotted with a black solid line, and the gray shaded region represents the errors. The Spitzer/IRS spectrum is plotted with a cyan solid line and its error with a cyan shaded region. The red solid line is the best model resulting from the fit to the high angular resolution data. The yellow dotted line is the stellar component. The blue solid line represents the sum of the stellar, starburst, and torus components that best fit the Spitzer/IRS spectrum. Middle panels: normal PDF of the free parameters. In gray, we plot the parameters derived from the fit to the LSR spectrum, while in dark blue, we plot the distribution of the parameters derived from the fit to the FSR spectrum. Bottom panels: normal PDF of the derived parameters. The blue vertical line indicates the mean.
Appendix B

Tables of Parameters

In this appendix we list the mean and 1σ errors of the parameters derived for all models, see Tables 7, 9, 11, 13, and 15. Additionally, we list the covering factor, dust mass, and outer radius in Tables 8, 10, 12, 14, and 16.
### Table 7
Parameters H17

| Name     | $i$  | $N_0$  | $a$  | $h$  | $\Theta_w$ | $a_w$ | $f_{\text{red}}$ |
|----------|------|--------|------|------|------------|-------|-----------------|
|          | [0, 90] deg Mean (Min., Max.) | [5, 10] deg Mean (Min., Max.) | [−3.0, −0.5] deg Mean (Min., Max.) | [0.1, 0.5] deg Mean (Min., Max.) | [30, 45] deg Mean (Min., Max.) | [−2.5, −0.5] deg Mean (Min., Max.) | [0.15, 0.75] deg Mean (Min., Max.) |
| Mkn 509  | 70.5 (69.8, 90.0) | 10.0 (9.9, 10.0) | −3.0 (−3.0, −3.0) | 0.5 (0.1, 0.5) | 12.9 (7.0, 13.3) | 45.0 (44.5, 45.0) | −0.5 (−0.5, −0.5) | 0.49 (0.50, 0.50) |
| PG 1411+442 | 0.01 (0.01, 0.04) | 10.0 (9.1, 10.0) | −3.0 (−3.0, −0.5) | 0.4 (0.3, 0.5) | 7.5 (7.0, 8.8) | 36.7 (35.3, 45.0) | −1.2 (−2.5, −1.1) | 0.75 (0.68, 0.75) |
| PG 1211+143 | 58.1 (0.0, 90.0) | 10.0 (5.0, 10.0) | −2.5 (−3.0, −2.5) | 0.2 (0.1, 0.3) | 15.0 (7.0, 15.0) | 45.0 (30.0, 45.0) | −2.2 (−2.5, −2.1) | 0.75 (0.15, 0.75) |
| PG 1501+106 | 90.0 (89.3, 90.0) | 5.0 (5.0, 5.2) | −3.0 (−3.0, −0.5) | 0.2 (0.1, 0.5) | 15.0 (14.8, 15.0) | 45.0 (44.4, 45.0) | −0.5 (−2.5, −0.5) | 0.45 (0.44, 0.47) |
| MR 2251−178 | 45.06 (44.67, 45.56) | 10.0 (9.9, 10.0) | −2.50 (−2.51−2.50) | 0.22 (0.19, 0.25) | 15.0 (14.8, 15.0) | 45.0 (44.9, 45.0) | −2.0 (−2.5, −2.0) | 0.39 (0.38, 0.41) |
| PG 1229+204 | 21.20 (0.01, 21.72) | 10.0 (9.8, 10.0) | −2.5 (−2.6, −2.5) | 0.50 (0.46, 0.50) | 15.0 (14.6, 15.0) | 45.0 (44.6, 45.0) | −1.50 (−1.51, −1.46) | 0.75 (0.73, 0.75) |
| PG 0844+349 | 17.11 (0.01, 20.37) | 10.0 (5.0, 10.0) | −2.87 (−2.94, −2.67) | 0.2 (0.1, 0.5) | 15.0 (7.0, 15.0) | 35.5 (33.7, 45.0) | −0.5 (−0.8, −0.5) | 0.45 (0.33, 0.75) |
| PG 0804+761 | 0.01 (0.01, 0.01) | 9.5 (5.0, 10.0) | −3.0 (−3.0, −3.0) | 0.29 (0.10, 0.30) | 7.6 (7.0, 8.4) | 34.9 (30.0, 35.9) | −0.5 (−0.5, −0.5) | 0.75 (0.15, 0.75) |
| PG 2130+099 | 0.01 (0.01, 0.01) | 10.0 (10.0, 10.0) | −2.05 (−2.14, −2.00) | 0.5 (0.5, 0.5) | 10.0 (9.7, 10.2) | 45.0 (44.6, 45.0) | −0.5 (−0.5, −0.5) | 0.75 (0.72, 0.75) |

Accepted Fits According to a Red $\chi^2 < 2$

| Name     |       |       |       |       |       |       |       |
|----------|-------|-------|-------|-------|-------|-------|-------|
| PG 0050+124 | 0.01 (0.01, 0.02) | 10.0 (9.9, 10.0) | −1.6 (−1.7, −0.5) | 0.3 (0.3, 0.5) | 7.0 (7.0, 7.7) | 45.0 (44.4, 45.0) | −0.50 (−0.53, −0.50) | 0.70 (0.62, 0.75) |
| PG 1440+356 | 0.01 (0.01, 0.01) | 10.0 (9.9, 10.0) | −3.0 (−3.0, −3.0) | 0.31 (0.30, 0.5) | 14.2 (13.3, 15.0) | 42.0 (40.8, 45.0) | −0.5 (−0.5, −0.5) | 0.75 (0.74, 0.75) |

Note. Column (1) lists the names of QSOs. Column (2) lists the viewing angle along the line of sight. Columns (3)–(5) list the parameters of the disk: the number of clouds along an equatorial line of sight, the power-law index of the radial distribution of dust clouds, and the dimensionless scale height. Columns (6)–(8) list the parameters of the wind: the angular width, the half-opening angle of the wind, and the power-law index of the radial distribution of dust clouds. Column (9) lists the ratio between the number of dust clouds along the cone and $N_0$. See equations in Hönig & Kishimoto (2017).
torus, the power-law index of the radial distribution of the dust clouds, and the optical depth of the dust clouds. See equations in Hönig & Kishimoto (2010).

### Table 8

| Name       | log$_{10}$dust$_{max}$ (M$_{\odot}$) | $f_{cov}$ | E($B-V$) |
|------------|-------------------------------------|-----------|----------|
|            | Mean (Min., Max.)                   | Mean (Min., Max.) | <0.08 |
| Mrk 509    | 5.36 (5.14; 5.47)                   | 0.40 (0.22; 0.44) | 0.19   |
| PG 1411+442| 3.57 (3.44; 3.72)                   | 0.19 (0.16; 0.23) | 0.17; 0.22 |
| PG 1211+143| 4.26 (4.13; 4.36)                   | 0.38 (0.28; 0.45) | <0.02 |
| PG 1501+106| 4.26 (4.07; 4.45)                   | 0.23 (0.18; 0.38) | 0.18   |
| MR 2251–178| 5.01 (4.81; 5.18)                   | 0.28 (0.19; 0.39) | 0.22   |
| PG 1229+204| 3.99 (3.87; 4.12)                   | 0.40 (0.32; 0.46) | <0.45 |
| PG 0844+349| 4.22 (4.04; 4.37)                   | 0.32 (0.23; 0.41) | <0.06 |
| PG 0804+761| 5.18 (5.03; 5.29)                   | 0.38 (0.28; 0.45) | <0.01 |
| PG 2130+099| 3.8 (3.7, 3.9)                     | 0.19 (0.16, 0.23) | (0.36; 0.43) |

Note. Column (1) lists the names. Columns (2) and (3) list the dust mass in log scale and the covering factor (see the text for references on the equations). Column (4) lists the color excess for the foreground extinction E($B-V$).

### Table 9

| Name       | $i$ [0, 90] deg | $N_0$ [2.5, 10] | $\theta$ [5, 60] deg | $a$ [−12, 0.0] | $\tau_r$ [30, 80] |
|------------|----------------|----------------|----------------------|----------------|------------------|
|            | Mean (Min., Max.) | Mean (Min., Max.) | Mean (Min., Max.) | Mean (Min., Max.) | Mean (Min., Max.) |
|            | (1)              | (2)            | (3)                  | (4)            | (5)              |
|            |                  |                |                      |                |                  |
| MR 2251–178| 53.5 (51.5, 90.0) | 7.8 (2.5, 8.2) | 38.2 (34.9, 60.0) | −1.00 (−1.02, −0.98) | 30.0 (30.0, 30.4) |

Good Fits According to a Red $\chi^2 < 2$ and the AIC

Accepted Fits According to a Red $\chi^2 < 2$

Note. Column (1) lists the names. Columns (2)–(6) list the viewing angle, the number of dust clouds along the equatorial line of the torus, the angular width of the torus, the power-law index of the radial distribution of the dust clouds, and the optical depth of the dust clouds. See equations in Hönig & Kishimoto (2010).
### Table 10

Derived Parameters H10 and Foreground Extinction

| Name              | \( \log_{10}(\text{dust mass}) \) Mean (Min., Max.) | \( f_{\text{cov}} \) Mean (Min., Max.) | \( E(B - V) \) | \( (B - V) \) |
|-------------------|---------------------------------------------------|----------------------------------------|-----------------|-----------------|
| MR 2251–178       | 5.46 (5.35; 5.66)                                 | 0.85 (0.78; 0.92)                     | 0.01 (0.01; 0.02) |                 |
| Mrk 509           | 5.8 (5.7, 5.9)                                    | 0.92 (0.88, 0.93)                     | 0.09 (0.07; 0.10) |                 |
| PG 1211+143       | 4.4 (4.1, 4.6)                                    | 0.74 (0.46, 0.88)                     | 0.01 (0.01; 0.03) |                 |
| PG 1440+356       | 5.0 (4.8, 5.1)                                    | 0.93 (0.85, 0.95)                     | 0.45 (0.41; 0.50) |                 |
| PG 1501+106       | 4.9 (4.6, 5.1)                                    | 0.74 (0.5, 0.92)                      | 0.04 (0.01; 0.09) |                 |
| PG 2130+099       | 4.3 (4.2, 4.4)                                    | 0.64 (0.53, 0.74)                     | 0.55 (0.53; 0.57) |                 |
| PG 0804+761       | 5.3 (4.9, 5.5)                                    | 0.64 (0.31, 0.88)                     | 0.01 (0.01; 0.02) |                 |
| PG 0844+349       | 4.5 (4.1, 4.8)                                    | 0.71 (0.32, 0.9)                      | 0.01 (0.01; 0.02) |                 |
| PG 1229+204       | 4.2 (3.9, 4.4)                                    | 0.71 (0.44, 0.92)                     | 0.28 (0.19; 0.36) |                 |
| PG 1411+204       | 4.61 (4.46; 4.69)                                 | 0.93 (0.88; 0.95)                     | 0.17 (0.15; 0.20) |                 |

**Note.** Column (1) lists the names. Columns (2) and (3) list the dust mass in log scale and the covering factor (see the text for references on the equations). Column (4) lists the color excess for the foreground extinction \( E(B - V) \).

### Table 11

Parameters N08

| Name               | \( i \) Mean (Min., Max.) [0, 90] deg | \( N_0 \) Mean (Min., Max.) [1, 15] | \( \sigma \) Mean (Min., Max.) [15, 70] deg | \( Y \) Mean (Min., Max.) [5, 100] | \( q \) Mean (Min., Max.) [0, 2.5] | \( \tau_V \) Mean (Min., Max.) [5, 300] |
|--------------------|--------------------------------------|-------------------------------------|------------------------------------------|---------------------------------|---------------------------------|----------------------------------|
| (1)                | (2)                                  | (3)                                 | (4)                                      | (5)                             | (6)                             | (7)                              |
| Good Fits According to a Red \( \chi^2 < 2 \) and the AIC |
| PG 1426+015        | 25.6 (13.4, 44.8)                    | 13.9 (9.4, 15.0)                    | 15.0 (15.0, 27.1)                        | 5.0 (5.0, 100)                  | 2.5 (2.4, 2.5)                  | 60.2 (55.4, 78.9)                |
| PG 1426+015\(^a\) | 64\(^{+0}_{-9}\)                    | 9\(^{+1}_{-3}\)                    | 19\(^{+2}_{-1}\)                        | 60\(^{+2}_{-2}\)               | 2\(^{+0.4}_{-0.4}\)            | 118\(^{+14}_{-23}\)             |
| PG 1426+015\(^b\) | 30                                   | 5                                   | 35                                       | 33                              | 1                              | 75                               |
|Accepted Fits According to a Red \( \chi^2 < 2 \) |
| PG 1211+143        | 80.0 (74.9, 90.0)                    | 9.0 (1.0, 13.0)                     | 17.5 (15.0, 70.0)                        | 5.0 (5.0, 5.1)                  | 2.5 (2.4, 2.5)                  | 44.01 (38.87, 47.62)             |
| PG 1211+143\(^a\) | 80\(^{+0}_{-9}\)                    | 2\(^{+1}_{-3}\)                    | 45\(^{+1}_{-2}\)                        | 40\(^{+1}_{-1}\)               | 1.43\(^{+0.05}_{-0.05}\)       | 38\(^{+1}_{-3}\)                |
| PG 1501+106        | 90.0 (86.6, 90.0)                    | 15.0 (14.0, 15.0)                   | 32.3 (15.0, 42.2)                        | 9.99 (9.74, 10.09)              | 2.24 (2.15, 2.25)              | 18.49 (17.63, 200.0)             |
| PG 1501+106\(^a\) | 40\(^{+0}_{-2}\)                    | 10\(^{+4}_{-3}\)                   | 58\(^{+5}_{-4}\)                        | 40\(^{+2}_{-1}\)               | 2.6\(^{+0.2}_{-0.2}\)          | 113\(^{+1}_{-1}\)               |
| PG 0804+761        | 90.0 (88.1, 90.0)                    | 1.0 (1.0, 1.0)                      | 45.1 (40.0, 54.5)                        | 5.5 (5.0, 5.5)                  | 2.5 (2.5, 2.5)                  | 55.0 (10.0, 55.4)                |
| PG 0804+761\(^a\) | 22\(^{+2}_{-2}\)                    | 5\(^{+2}_{-2}\)                    | 22\(^{+1}_{-0}\)                        | 59\(^{+1}_{-0}\)               | 1.8\(^{+0.1}_{-0.1}\)          | 42\(^{+2}_{-1}\)                |
| PG 0844+349        | 90.0 (87.3, 90.0)                    | 3.8 (3.4, 4.4)                      | 34.8 (16.0, 47.6)                        | 100.0 (74.8, 100.0)             | 2.5 (2.5, 2.5)                  | 19.9 (18.5, 21.8)                |
| PG 0844+349\(^a\) | 88\(^{+1}_{-1}\)                    | 2\(^{+1}_{-3}\)                    | 16\(^{+1}_{-1}\)                        | 77\(^{+1}_{-0}\)               | 1.3\(^{+0.1}_{-0.1}\)          | 77\(^{+1}_{-1}\)                |
| PG 1229+204        | 90.0 (78.1, 90.0)                    | 15.0 (14.4, 15.0)                   | 62.3 (47.0, 70.0)                        | 22.0 (19.1, 100.0)              | 2.2 (2.1, 2.5)                  | 10.0 (10.0, 10.6)                |
| PG 1229+204\(^a\) | 73\(^{+2}_{-2}\)                    | 12\(^{+2}_{-2}\)                   | 16\(^{+1}_{-1}\)                        | 59\(^{+1}_{-0}\)               | 0.53\(^{+0.0}_{-0.0}\)         | 20\(^{+2}_{-2}\)                |
| PG 1229+204\(^b\) | 28                                   | 5                                   | 34                                       | 33                              | 2                              | 91                               |
| MR 2251–178        | 64.8 (62.2, 72.9)                    | 9.6 (1.0, 9.9)                      | 70.0 (66.6, 70.0)                        | 10.0 (9.8, 10.1)                | 2.2 (0.0, 2.3)                  | 10.0 (10.0, 10.0)                |

**Notes.** Column (1) lists the names. Columns (2)–(7) list the viewing angle, the number of clouds along the equatorial line, the angular width, the outer-to-inner radius ratio of the torus, the index of the power-law distribution, and the optical depth of the dust clouds in the torus. See equations in Nenkova et al. (2008b).

\(^a\) Parameters obtained by Martinez-Paredes et al. (2017).

\(^b\) Parameters obtained by Mor et al. (2009).

\(^c\) NIR data not available.
Table 12
Derived Parameters N08 and Foreground Extinction

| Name         | log$_{10}$dust$_{max}$ (M$_\odot$) | $f_{cov}$ | R$_{out}$ (pc) | E($B - V$) | f$_{cov}$ | f$_{ cov }$ |
|--------------|----------------------------------|-----------|----------------|------------|-----------|----------|
| (1)          | Mean (Min., Max.)                | Mean (Min., Max.) | Mean (Min., Max.) | (5)         | (6)       | (7)      |
| PG 1426+015  | 5.6 (5.2; 6.1)                   | 0.87 (0.77; 0.95) | 3.4 (3.4; 4.3) | 0.13 (0.07; 0.21) | 0.14 (0.04) | 0.33     |
| PG 1211+143  | 3.1 (3.0, 3.5)                   | 0.52 (0.36, 0.66) | 1.9 (1.9, 1.9) | 0.01 (0.01; 0.02) | 0.4 (0.1, 0.1) |
| PG 1501+106  | 5.8 (4.8, 7.3)                   | 0.80 (0.54, 0.93) | 19.5 (7.9, 30.3) | 0.01 (0.01; 0.02) | 0.3 (0.1, 0.1) |
| PG 0804+761  | 4.0 (3.9, 4.2)                   | 0.84 (0.69, 0.92) | 5.5 (5.5, 5.5) | 0.09 (0.06; 0.1) | 0.2 (0.1, 0.1) |
| PG 0844+349  | 3.3 (3.0, 3.7)                   | 0.64 (0.44, 0.87) | 2.1 (2.1, 2.1) | 0.02 (0.01; 0.08) | 0.04 (0.01) |
| MR 1229+204  | 3.1 (2.9, 3.4)                   | 0.74 (0.52, 0.93) | 1.5 (1.5, 1.5) | 0.05 (0.01; 0.13) | 0.1 (0.01) |
| MR 2251-178  | 4.0 (3.9, 4.2)                   | 0.64 (0.48, 0.82) | 5.5 (5.5, 5.5) | 0.01 (0.01; 0.01) | 0.4 (0.1)   |

Notes. Column (1) lists the name. Columns (2)–(7) list the dust mass in log scale, the covering factor, and the outer radius of the torus (see the text for references on the equations). Column (5) lists the color excess for the foreground extinction $E(B - V)$. Columns (6) and (7) list the covering factor previously derived by Martínez-Paredes et al. (2017) and Mor et al. (2009), respectively.

a Parameters obtained by Martínez-Paredes et al. (2017).
b Parameters obtained by Mor et al. (2009).
c NIR data not available.

Table 13
Parameters F06

| Name          | $90^\circ$ | $\sigma$ | $\gamma$ | $\beta$ | $\gamma_V$ | $E(B - V)$ |
|---------------|------------|-----------|----------|---------|------------|------------|
| (1)           | [0.90] deg | [20, 60] deg | [0, 6] | [-11.0, 0.0] | [10, 150] | [0.3, 10] |
| (2)           | (3)        | (4)       | (5)      | (6)     | (7)        |

Good Fits According to a Red $\chi^2 < 2$ and the AIC

| Name          | $90^\circ$ | $\sigma$ | $\gamma$ | $\beta$ | $\gamma_V$ | $E(B - V)$ |
|---------------|------------|-----------|----------|---------|------------|------------|
| (1)           | [0.90] deg | [20, 60] deg | [0, 6] | [-11.0, 0.0] | [10, 150] | [0.3, 10] |
| (2)           | (3)        | (4)       | (5)      | (6)     | (7)        |

Good Fits According to a Red $\chi^2 < 2$

Notes. Column (1) lists the names. Columns (2)–(7) list the viewing angle, the angular width of the torus, the power-law index of the polar density gradient, the power-law index of the radial density gradient, the outer-to-inner radius ratio of the torus, and the optical depth of the torus. See equations in Fritz et al. (2006).

In order to do a proper comparison between the orientation of the viewing angle predicted by the several models, we list the $90^\circ$ angle, because in the F06 model, the viewing angle increases from the polar to the equatorial axis.

Table 14
Derived Parameters F06 and Foreground Extinction

| Name          | log$_{10}$dust$_{max}$ (M$_\odot$) | $f_{cov}$ | R$_{out}$ (pc) | E($B - V$) |
|---------------|----------------------------------|-----------|----------------|------------|
| (1)           | Mean (Min., Max.)                | Mean (Min., Max.) | Mean (Min., Max.) | (5)         |
| (2)           | (3)                              | (4)       |                 | (5)        |

| Name          | log$_{10}$dust$_{max}$ (M$_\odot$) | $f_{cov}$ | R$_{out}$ (pc) | E($B - V$) |
|---------------|----------------------------------|-----------|----------------|------------|
| (1)           | Mean (Min., Max.)                | Mean (Min., Max.) | Mean (Min., Max.) | (5)         |
| (2)           | (3)                              | (4)       |                 | (5)        |

Note. Column (1) lists the names. Columns (2)–(4) list the dust mass in log scale, the covering factor, and the outer radius of the torus (see the text for references on the equations). Column (5) lists the color excess for the foreground extinction $E(B - V)$.
Table 15
Parameters S16

| Name | $i$ | $\sigma$ | $\rho$ | $q$ | $Y$ | $\tau_v$ |
|------|-----|---------|-------|-----|-----|---------|
|      | [0, 90] deg | [10, 80] deg | [0, 1.5] | [0, 1.5] | [10, 30] | [3, 11] |
| PG 0050+124 | 0.01 (0.01, 0.03) | 64.8 (63.6, 80.0) | 0.01 (0.01, 0.02) | 1.5 (0.0, 1.5) | 10.0 (10.0, 30.0) | 6.2 (6.0, 6.5) |

Good Fits According to a Red $\chi^2 < 2$ and the AIC

Table 16
Derived Parameters S16 and Foreground Extinction

| Name | log$_{10}$dust$_{\text{max}}$ ($M_\odot$) | $f_{\text{cov}}$ | $R_{\text{out}}$ (pc) | $E(B - V)$ |
|------|---------------------------------|-----------------|---------------------|-----------|
|      | Mean (Min., Max.) | Mean (Min., Max.) | Mean (Min., Max.) | (5)       |
| PG 0050+124 | 5.3 (5.3; 5.5) | 0.95 (0.94; 0.96) | 5.49 (4.4; 6.6) | 0.01 (0.01; 0.01) |
| PG 1440+356 | 5.4 (5.3, 5.4) | 0.87 (0.84, 0.89) | 3.3 (3.2, 3.5) | 0.68 (0.66; 0.74) |
| PG 1501+106 | 6.1 (5.9, 6.2) | 0.97 (0.94, 0.98) | 5.9 (4.4, 8.7) | 0.01 (0.01; 0.03) |
| PG 2130+099 | 5.2 (5.0, 5.3) | 0.68 (0.66, 0.70) | 6.3 (6.0, 6.4) | 0.48 (0.43; 0.52) |
| MR 2251–178 | 6.0 (6.0, 6.4) | 0.95 (0.95, 0.95) | 8.9 (8.1, 15.5) | 0.01 (0.01; 0.01) |
| PG 0804+761 | 6.7 (6.6, 6.9) | 0.98 (0.98, 0.98) | 14.5 (11.1, 19.2) | 0.01 (0.01; 0.02) |
| PG 0844+349 | 5.9 (5.8, 6.0) | 0.98 (0.98, 0.98) | 6.4 (5.0, 7.8) | 0.01 (0.01; 0.02) |
| PG 1229+204 | 5.3 (5.1, 5.4) | 0.96 (0.94, 0.98) | 5.8 (4.9, 6.2) | 0.01 (0.01; 0.03) |

Note. Column (1) lists the name. Columns (2)–(4) show the dust mass, the covering factor, and the outer radius of the torus (see the text for references on the equations). Column (5) lists the color excess for the foreground extinction $E(B - V)$. 

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