Circumnuclear Star Formation and AGN Activity: Clues from Surface Brightness Radial Profile of PAHs and [S IV]

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Abstract

We studied the circumnuclear mid-IR emission in a sample of 19 local active galactic nuclei (AGNs) with high spatial resolution spectra using T-ReCS (Gemini) and CanariCam (GTC), together with Spitzer/IRS observations. We measured the flux and the equivalent width for the 11.3 μm PAH feature and the [S IV] line emission as a function of galactocentric distance. This allowed us to study the star formation (SF) at subkiloparsec scales from the nucleus for a large sample of nearby AGNs. The [S IV] line emission could be tracing the AGN radiation field within a few thousand times the sublimation radius ($R_{sub}$), but it often peaks at distances greater than 1000 $R_{sub}$. One possibility is that the SF is contributing to the [S IV] total flux. We found an 11.3 μm PAH emission deficit within the inner few tens of parsecs from the AGN. This deficit might be due to the destruction of the molecules responsible for this feature or the lack of SF at these distances. We found a sensible agreement in the expected shift of the relation of the AGN bolometric luminosity and the SF rate. This indicates that numerical models attributing the link between AGN activity and host galaxy growth to mergers are in agreement with our data, for most inner galaxy parts.

Key words: galaxies: active – galaxies: evolution – galaxies: nuclei

1. Introduction

The understanding of the coevolution of active galactic nuclei (AGNs) and the host galaxy has been one of the greatest challenges in astronomy in the past decades. Several studies have discovered correlations between the mass of the supermassive black hole (SMBH), the mass of the bulge (Magorrian et al. 1998; Tremaine et al. 2002; Marconi & Hunt 2003; McConnell & Ma 2013), and the bulge velocity dispersion (Kormendy & Richstone 1995; Ferrarese & Merritt 2000). However, the physical connection between these observational properties is still unclear. The study of SMBH accretion and circumnuclear star formation (SF) can be the key. Some authors propose that the gas that moves toward the center is responsible for both the growth of the SMBH and the enhancement of SF (Sanders et al. 1988; Barnes & Hernquist 1991; Storchi-Bergmann et al. 2001). Other works suggest that quenching of SF is due to AGN feedback (Silk & Rees 1998; Vollmer & Davies 2013, and references therein).

Numerical simulations propose a scenario where large-scale processes can be related to small-scale phenomena close to the nucleus (e.g., Kawakatu & Wada 2008; Hopkins & Quataert 2010; Neistein & Netzer 2014; Gutcke et al. 2015; Volonteri et al. 2015). According to these studies, major mergers and even tidal interactions produce perturbations that can be correlated with the accretion of the SMBH and SF (Krongold et al. 2002). Other authors propose a scenario in which the radiation field of the SMBH is able to stop the SF, imposing a balance between the two (e.g., Wu et al. 2009).

The study of the neighborhood of AGNs is very complex because the classic indicators of SF such as the ultraviolet (UV) continuum, Paα, and Hα emission line are easily contaminated by the powerful AGN emission (Alonso-Herrero et al. 2014, and references therein). However, the mid-infrared (MIR) wavebands are a powerful tool to disentangle SF and AGN contributions (e.g., Dultzin-Hacyan et al. 1990; González-Martín et al. 2013; Alonso-Herrero et al. 2014). Recently, new MIR spectroscopic data have provided opportunities to quantify the SF close (<1 kpc) to the AGN (e.g., Esquej et al. 2014; Ruschel-Dutra et al. 2017). The polycyclic aromatic hydrocarbon (PAH) emission features at 3.3, 6.2, 7.7, 8.6, and 11.3 μm contribute to MIR flux. The PAHs are composed of 20–100 atoms of carbon and hydrogen (Millar & Williams 1993). These features are powerful tools to study SF on the vicinity of AGNs. These molecules have been studied in different objects associated with dust and gas including evolved stars, reflection nebulae, Orion bars, and star-forming regions (Gillett et al. 1973; Cohen et al. 1986; Aitken & Roche 1984).

It is known that the PAH emissions are good tracers of young and massive stars (i.e., recent circumnuclear SF activity). In particular, starburst galaxies show a good correlation between the strength of the PAH and the IR luminosity, indicating that they are good tracers of SF (Brandl et al. 2006).
Among these PAH features, the 11.3 μm PAH feature has the advantage of being isolated (i.e., not blended) from others and is observable with ground-based telescopes (i.e., with enough spatial resolution to disentangle the contribution of the few tenths of parsecs from the nucleus in nearby galaxies). Indeed, the 11.3 μm PAH emission feature has been used in several works to study the SF in the vicinity of AGNs (e.g., Diaz-Santos et al. 2010). Recently, Esquej et al. (2014) computed the SF rate (SFR) from this feature and compared it with the AGN accretion rate. They confronted this relation with coevolution models elaborated by Hopkins & Quataert (2010). They found a good agreement between observations and theoretical models for physical scales of ~100 pc. Recently, Ruschel-Dutra et al. (2017) have analyzed the circumnuclear SF in a sample of 15 AGNs in order to investigate the validity of the same relation. They found that SF luminosities are correlated with the bolometric luminosity of the AGN (for objects with $L_{bol,AGN} \geq 10^{42}$ erg s$^{-1}$).

The PAH features have been studied in the vicinity of the AGNs of many galaxies. Some authors claim that these molecules are destroyed by the strong AGN radiation field (Voit 1992; Wu et al. 2009; Diaz-Santos et al. 2010), Siebenmorgen et al. (2004) and Ruschel-Dutra et al. (2014) have found evidence in favor of this destruction of PAHs in AGNs. Supporting this, the correlation between the strength of the PAH features and the IR luminosity appears to be absent or weak in AGNs (Weedman et al. 2005). If this were the case, the PAH emission feature could not be used as a tracer of SF in AGNs. In a more recent paper, it has been suggested that PAH emission might not be a good tracer of the SF within 1 kpc around an AGN (Jensen et al. 2017).

Against it, Alonso-Herrero et al. (2014) concluded that at least those molecules responsible for the 11.3 μm PAH feature survive in the nuclear environment as close as 10 pc from the nucleus for their sample of six local AGNs (see also Esquej et al. 2014; Ramos Almeida et al. 2014). They propose that material in the dusty tori, nuclear gas disk, and/or host galaxies of AGNs is likely providing the column density necessary to protect the PAH molecules from the AGN radiation field.

Here we investigate whether the 11.3 μm PAH can be used (and at which scales) as a tracer of SF, and we use it to get some clues about the coevolution between the AGN and its host galaxy. For that purpose we have compiled a sample of high spatial resolution spectra (8–13 μm) of local AGNs observed with T-ReCS in the Gemini South observatory and CanariCam on the 10.4 m Gran Telescopio CANARIAS (GTC). This allowed us to study the SF at different scales from the nucleus for a large sample of sources. The coverage of these spectra will also allow us to analyze the origin of the [S IV] line emission at 10.5 μm. The [S IV] line arises from ions with an ionization potential of 35 eV. It has been proposed as an indicator of the AGN isotropic luminosity since it might come from the narrow-line region (NLR; Dasyra et al. 2011). However, high spatial resolution MIR spectra indicate that this emission is not resolved at 100 pc scales, against its NLR origin (Hönig et al. 2008). The [S IV] line emission at 10.5 μm could also be related to star-forming regions (Pereira-Santaella et al. 2010). Our high spatial resolution spectra are very well suited to understand the origin of the [S IV] line emission.

The main goal of this work is to address three questions: (1) the origin of [S IV] line emission, (2) the goodness of the 11.3 μm PAH feature as a tracer of SF in the vicinity of AGNs, and (3) the connection between SF and AGN activity. The paper is organized as follows: Section 2 presents our sample and the data reduction. Section 3 presents the analysis of the spectra. Sections 4 and 5 provide a discussion of the main results in the framework of our goals. Finally, a brief summary is given in Section 6. Throughout this work, we assumed a ΛCDM cosmology with $\Omega_L = 0.73$, $\Omega_M = 0.27$, and $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$.

2. Sample Selection and Data Reduction

2.1. Sample

Our sample consists of 19 local AGNs with ground-based N-band (i.e., 8–13 μm) spectra available. All spectra have been observed with ground-based telescopes. These sources are taken from the samples of González-Martín et al. (2013) and Alonso-Herrero et al. (2016), which contain 22 and 45 local AGNs, respectively. We have only included AGNs showing extended emission. We considered the source as extended if we can detect emission of the 11.3 μm PAH feature or [S IV] line in more than three circumnuclear apertures (see Section 3 for a detailed explanation on the aperture extraction procedure).

This sample is the largest reported where high-resolution studies have been done in the vicinity of AGNs. However, note that this sample is not complete in any sense. Table 1 shows the main observational details of the sample. Fifteen objects are type 2 Seyferts (Sy2), and four are type 1 Seyferts (Sy1). Our sample covers a range of X-ray luminosity (absorption corrected) of $L(2–10$ keV) $\sim 5 \times 10^{39}–4 \times 10^{42}$ erg s$^{-1}$. The range of X-ray luminosity covers classical Seyfert galaxies and low-luminosity AGNs (<$10^{42}$ erg s$^{-1}$). The Appendix contains a short review of the published information on star-forming regions around these objects, when available.

Eleven objects were observed with the Thermal-Region Camera Spectrograph (T-ReCS; Telesco et al. 1998; De Buizer & Fisher 2005) located in the 8.1 m Gemini South Telescope and published by González-Martín et al. (2013) (and references therein). The slit width used for the spectroscopy results in a spatial resolution in the range of ~20–250 pc (see Column 9 in Table 1). The rest of the sources in our sample were obtained with CanariCam (Telesco et al. 2003) in the 10.4 m Gran Telescopio CANARIAS (GTC) and were published by Alonso-Herrero et al. (2016). For these eight sources the slit width used for the spectroscopy results in a spatial resolution in the range of ~50–160 pc. The angular and spectral resolutions for both instruments (T-ReCS and CanariCam) are within an average of FWHM ~ 0.3 arcsec and $R \sim 100$, respectively. Note that these spectral resolutions are not high enough to examined the width of the [S IV] line. Indeed, all the [S IV] emission lines reported here have a width compatible with the instrumental spectral resolution.

We have included the Spitzer/IRS spectral data downloaded from the CASSIS10 catalog (the Cornell AtlaS of Spitzer/IRS Sources; Lebouteiller et al. 2011) to study larger regions in each galaxy. Note that the spectral resolution of Spitzer/IRS ($R \sim 60–130$) is similar to that obtained by our ground-based observations. CASSIS provides flux-calibrated nuclear spectra associated with each observation. The Spitzer spectra are not available for four of the sources in our sample (NGC 931, NGC 1320, NGC 4569, and NGC 7465). In four additional

10 http://cassis.astro.cornell.edu/atlas/
Table 1: General Properties of Sample

| Object      | Type | $D$  | $L_x$ | $M_{BH}$ | Instrument          | P.A. | Slit Width (Nuclear) | $R_{s,\text{subl}}$ | log$f_{25}$ | Ref. |
|-------------|------|------|-------|----------|---------------------|------|----------------------|---------------------|------------|------|
| NGC 931     | Sy1  | 49.4 | 43.3  | 8.3      | CanariCam           | 80   | –                    | 0.52/124.5          | 93.4/242.8 | 2.4  |
| Mrk 1066    | Sy2  | 51.7 | 42.9  | 7.0      | CanariCam           | 315  | 1.23                 | 0.52/95.0           | 149.7/406.4 | 2.7  |
| NGC 1320    | Sy2  | 37.7 | 42.5  | 7.2      | CanariCam           | 315  | –                    | 0.52/291.1          | 31.8/88.3  | 2.4  |
| NGC 1386    | Sy2  | 16.2 | 41.6  | 7.4      | T-ReCS              | 0    | 1.17                 | 0.31/19.6           | 3.7/207.2   | 2.6  |
| NGC 1808    | Sy2  | 11.5 | 39.7  | 6.7      | T-ReCS              | 45   | 1.35                 | 0.35/16.8           | 27.6/62.8   | 1.7  |
| NGC 2992    | Sy18 | 31.6 | 41.9  | 7.7      | CanariCam           | 30   | 0.4                  | 0.52/56.8           | 59.7/741.2  | 2.2  |
| NGC 3081    | Sy2  | 32.5 | 42.5  | 7.1      | T-ReCS              | 0    | 0.96                 | 0.65/52.9           | 63.6/205.0  | 1.4  |
| NGC 3227    | Sy1.5| 21.8 | 42.1  | 7.6      | CanariCam           | 0    | 0.64                 | 0.52/391.0          | 74.2/205.6  | 2.2  |
| NGC 3281    | Sy2  | 21.8 | 43.2  | 7.9      | T-ReCS              | 315  | 0.61                 | 0.35/820.0          | 109.4/248.6 | 1.4  |
| NGC 4253a   | Sy2  | 55.4 | 42.5  | 6.8      | CanariCam           | 285  | 0.75                 | 0.52/139.6          | 94.2/408.3  | 2.1  |
| NGC 4569    | Sy2  | 12.6 | 39.4  | 7.8      | CanariCam           | 30   | –                    | 0.52/31.7           | 91.1/285.9  | 2.2  |
| NGC 5135    | Sy2  | 58.6 | 43.1  | 7.3      | T-ReCS              | 30   | 1.33                 | 0.70/199.0          | 89.3/1033.5 | 1.3  |
| NGC 5643    | Sy2  | 16.9 | 42.6  | 7.4      | T-ReCS              | 80   | 0.68                 | 0.35/303.1          | 55.2/106.6  | 1.7  |
| IC 4518W    | Sy2  | 69.6 | 42.6  | 7.5      | T-ReCS              | 5    | 1.22                 | 0.70/236.3          | 167.6/560.6 | 1.1  |
| IC 5063a    | Sy2  | 48.6 | 42.9  | 7.7      | T-ReCS              | 303  | 1.33                 | 0.65/153.1          | 95.2/306.7  | 1.4  |
| NGC 7130    | Sy2  | 69.2 | 42.9  | 7.6      | T-ReCS              | 348  | 1.35                 | 0.70/234.7          | 135.4/496.6 | 1.2  |
| NGC 7172    | Sy2  | 33.9 | 42.7  | 7.7      | T-ReCS              | 60   | 0.57                 | 0.35/608.0          | 95.8/228.6  | 1.4  |
| NGC 7465    | Sy2  | 27.2 | 41.4  | 7.6      | CanariCam           | 330  | –                    | 0.52/68.6           | 46.3/200.6  | 1.3  |
| NGC 7582    | Sy2  | 22.5 | 42.6  | 7.1      | T-ReCS              | 0    | 0.39                 | 0.70/403.6          | 53.8/396.6  | 1.8  |

Notes: Column (1): source name. Column (2): type of sources according to González-Martín et al. (2013) or Alonso-Herrero et al. (2016). Column (3): distances calculated from redshift obtained from observations for $\Omega_0 = 0.73$, $\Omega_M = 0.27$, and $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$. Column (4): X-ray luminosity. Column (5): BH mass. Column (6): instrument used by each object. Column (7): position angle. Column (8): scale factor between T-ReCS/CanariCam and Spitzer spectra. The mark "-" is used to identify the sources where we do not use the Spitzer spectra. Column (9): Slit width for nuclear spectra. Column (10): slit width for Spitzer spectra. Column (11): minimum and maximum radius used for the extended profiles (T-ReCS or CanariCam). Column (12): sublimation radius. Column (13): isophotal diameter. Column (14): references where the observations were originally published: (1) González-Martín et al. (2013); (2) Alonso-Herrero et al. (2016); (3) Diaz-Santos et al. (2010); (4) Sales et al. (2011); (5) Young et al. (2007); (6) Roche et al. (2007).

$^a$ The references for the X-ray results are (a) González-Martín (2018), (b) González-Martín et al. (2013), (c) Liu et al. (2014), (d) O'Sullivan et al. (2001), (e) Ho et al. (2001).

$^b$ The BH mass is calculated using the relation with the stellar velocity dispersion. References: (I) Woo & Urry (2002), (II) Esquej et al. (2014), (III) Woo et al. (2015), (IV) Mason et al. (2015), (V) Alonso-Herrero et al. (2013), (VI) Dudik et al. (2005).
sources we did not use the Spitzer data because the emission of the ground-based data extends up to the spatial resolution of Spitzer data. Therefore, these observations do not add extra information to our ground-based data. Thus, we included Spitzer/IRS spectra for 11 of the objects; Column (10) in Table 1 shows the Spitzer radius spectra when we used them in the analysis.

González-Martín et al. (2013) and Alonso-Herrero et al. (2016) focused their analyses on the nuclear emission. Also focusing on the central region, four sources have been observed with VISIR/VLT and reported by Höög & Kishimoto (2010). Furthermore, the MIR extended emission of some of our sources has been studied individually before. Three of our sources (NGC 5135, IC 4518W, and NGC 7130) were studied by Díaz-Santos et al. (2010). They studied the extended emission of different features, including the 11.3 μm and the [S IV] line, and they compared it with the Spitzer spectra. Mrk 1066 was analyzed by Ramos Almeida et al. (2014) and Alonso-Herrero et al. (2014) to study the survival of the responsible molecules for the 11.3 μm PAH feature in the close vicinity of an AGN. García-Bernete et al. (2015) studied the extended emission of NGC 2992 up to ∼3 kpc, finding that PAH features might indicate that the bulk of this extended emission is dust heated by SF. Esquej et al. (2014) compared nuclear with larger apertures (using Spitzer spectra) in 12 of our sources to study the correlation between SFR through the 11.3 μm PAH feature and AGN accretion. These works will be compared with our results throughout this paper.

2.2. Data Reduction

The data have been reduced using the RedCan pipeline (González-Martín et al. 2013). RedCan is a fully automated pipeline that was designed to efficiently exploit CanariCam data. Due to the similarities between CanariCam and T-ReCS low spectral resolution data, this pipeline can analyze successfully both sets of observations considered in this paper. RedCan is able to produce flux-calibrated images and 1D spectra. The main input is an ASCII file, which contains an observation list. The reduction process basically consists of eight steps: (1) identification of files, (2) flat-fielding, (3) stacking, (4) image flux calibration, (5) wavelength calibration, (6) trace determination, (7) spectral extraction, and (8) spectral flux calibration and the combination of spectra. Within these steps, the subtraction of the sky background and rejection of bad images are also included. Flux calibration is performed by observing standard stars taken immediately before or after the target.

Spitzer/IRS spectra provided by CASSIS are already reduced. However, observations using data from both short–low and long–low spectra modules suffer from mismatches due to telescope pointing inaccuracy or due to a different spatial resolution of the IRS orders. This is not corrected in the final products given by CASSIS. Still, in this work it is not necessary to correct these mismatches, because we only considered one spectrum (SL1). This spectrum only covers a range between 7.5 and 15 μm. Finally, the spectra are shifted to the rest frame according to the distances of the objects (see Column (3) in Table 1).
Table 2
Integrated Fluxes and EWs for the Nuclear and Spitzer Spectra

| Object   | 10^{-13} erg s^{-1} cm^{-2} | 10^{-13} µm | (S IV)_{10.5} µm |
|----------|-----------------------------|-------------|------------------|
|          | PAH_{11.3} µm | [S IV] | PAH_{11.3} µm | [S IV] |
|          | Nuclear | Spitzer | Nuclear | Spitzer | Nuclear | Spitzer | Nuclear | Spitzer |
| NGC 931  | <2          |        | 13 ± 2  | -      | <1        |        | 10 ± 2  | -      |
| Mrk 1066 | 82 ± 12     | 264 ± 40| <0.1    | 11 ± 2 | 118 ± 18  | 158 ± 25| <0.2    | 19 ± 3 |
| NGC 1320 | 7 ± 2       | -        | 6 ± 1   | -      | 9 ± 3     |        | 7 ± 1   | -      |
| NGC 1386 | <0.3        |        | 16 ± 2  | -      | <1        |        | 28 ± 5  | 26 ± 4 |
| NGC 1808 | 154 ± 24    | 1176 ± 178| <0.1 | <7     | 107 ± 16  | 167 ± 26| <0.3    | <2     |
| NGC 2992 | <6          |        | 160 ± 25| 4 ± 1  | <22       | 149 ± 25| 17 ± 3  | 19 ± 4 |
| NGC 3081 | <0.2        |        | 6 ± 2   | -      | <1        |        | 23 ± 12 | 39 ± 6 |
| NGC 3081 | <0.1        |        | 6 ± 1   | -      | <1        |        | 26 ± 8  | 38 ± 14|
| NGC 3227 | 32 ± 5      | 176 ± 29| 10 ± 2  | 9 ± 3  | 41 ± 6    | 119 ± 21| 13 ± 2  | 11 ± 3 |
| NGC 3281 | <0.3        | <12     | 10 ± 2  | 18 ± 5| <0.4      | <13    | 15 ± 2  | 30 ± 6 |
| NGC 4253 | 22 ± 3      | -        | 5 ± 1   | -      | 37 ± 6    | -      | 9 ± 1   | -      |
| NGC 4569 | 32 ± 5      | -        | <0.02   | -      | 115 ± 18  | -      | <0.1    | -      |
| NGC 5135 | 14 ± 2      | -        | 9 ± 1   | -      | 40 ± 6    | -      | 28 ± 5  | -      |
| NGC 5643 | 5 ± 1       | 74 ± 11  | 10 ± 2  | 15 ± 2| 12 ± 2    | 110 ± 17| 29 ± 5  | 37 ± 6 |
| IC 4518W | <0.1        | -        | <0.1    | -      | <0.3      | -      | <0.2    | -      |
| IC 5063  | <7          | -        | 9 ± 1   | -      | <3        | -      | 5 ± 1   | -      |
| NGC 7130 | 39 ± 6      | 145 ± 22 | 4 ± 1   | 6 ± 1  | 74 ± 11   | 132 ± 20| 12 ± 2  | 14 ± 2 |
| NGC 7172 | <0.5        | 33 ± 5   | 2.1 ± 0.4| 5 ± 1  | <1        | 70 ± 11 | 25 ± 4  | 24 ± 4 |
| NGC 7465 | 14 ± 2      | -        | <0.1    | -      | 54 ± 9    | -      | <0.3    | -      |
| NGC 7582 | 8 ± 1       | 182 ± 28 | <0.1    | 6 ± 1  | 27 ± 4    | 177 ± 28| <0.1    | 23 ± 4 |

Note. The symbol “–” indicates that Spitzer spectra were not available.

Table 3
PAH and [S IV] Fluxes

| Object   | 10^{-13} erg s^{-1} cm^{-2} | [S IV]_{10.5} µm |
|----------|-------------------------------|------------------|
|          | 100 pc 200 pc 500 pc 700 pc | 100 pc 200 pc 500 pc 700 pc |
|          | PAH_{11.3} µm | [S IV] | PAH_{11.3} µm | [S IV] |
| NGC 931  |        |        | 21 ± 3  | 35 ± 6  | 40 ± 6  | -      |
| Mrk 1066 |        |        | 160 ± 25| 267 ± 41| 273 ± 42| -      |
| NGC 1320 |        |        | 7 ± 1   | 8 ± 1   | 11 ± 2  | -      |
| NGC 1386 |        |        | 486 ± 74| 1065 ± 161| -      | -      |
| NGC 1808 |        |        | 11 ± 2  | 13 ± 2  | 20 ± 3  | -      |
| NGC 2992 |        |        | 17 ± 3  | 28 ± 6  | -      | -      |
| NGC 3081 |        |        | 16 ± 3  | 27 ± 5  | -      | -      |
| NGC 3227 |        |        | 80 ± 12 | 121 ± 18| -      | -      |
| NGC 3281 |        |        | 43 ± 7  | 60 ± 9  | 64 ± 10 | -      |
| NGC 4253 |        |        | 307 ± 47| 396 ± 61| -      | -      |
| NGC 5135 |        |        | 4 ± 1   | 17 ± 3  | 60 ± 9  | 88 ± 13| -      |
| NGC 5643 |        |        | 26 ± 4  | 74 ± 11 | -      | -      |
| IC 4518W |        |        | -      | -      | 13 ± 2  | 15 ± 2  | -      |
| IC 5063  |        |        | -      | -      | 10 ± 2  | -      |
| NGC 7130 |        |        | -      | -      | 5 ± 1   | 6 ± 1   | 6 ± 1  |
| NGC 7172 |        |        | 5 ± 1   | 11 ± 2  | 33 ± 5  | -      |
| NGC 7465 |        |        | 35 ± 5  | 44 ± 7  | -      | -      |
| NGC 7582 |        |        | 26 ± 4  | 56 ± 9  | 179 ± 27| 181 ± 28| -      |

Note. These measurements have been obtained from interpolation at different distances from the nucleus (see text). Note that the symbol “–” indicates that we do not consider the measurement because the interpolated value is within nuclear radii or at larger radii than our outer radius for the sources.

3. Spectral Analysis

Nuclear spectra were first extracted as point-like sources using RedCan pipeline. These spectra show photometric errors typically of 11% in flux for all objects (Alonso-Herrero et al. 2016). We used these spectra as the nuclear component of our radial profile.

Then, in order to analyze the change in the spectrum at different distances from the nucleus and to study the circum-nuclear emission, we have divided the spatial axis of the spectra into apertures at different radii. Thus, each aperture gives the spectrum of the extended emission within this radius, together with the nuclear component. The maximum radius is determined as the largest one where extended emission can be
seen in the 2D spectra. The aperture increments are fixed to 4 pixels because this matches the FWHM of the average point-spread function in our observations. The extraction has been done using the extended source mode provided by RedCan. The minimum radius of the apertures is calculated as the first aperture where the 12 \( \mu \)m continuum flux is greater (or equal)
data. However, the correction applied is in general very small ($\langle F_{12, \mu m} (T - ReCS/CamariCam) / F_{12, \mu m} (Spitzer) \rangle \sim 1.3$).

In Figure 1 (bottom) we show NGC 7130 as an example of the data presented in this paper. This example clearly shows the PAH feature at 11.3 $\mu m$ and the [S IV] line in 10.5 $\mu m$. A similar figure for each object in our sample is included in the Appendix.

3.1. PAH Feature and [S IV] Line Measurements

There are several methods to measure the fluxes of the PAH features. The best approach depends on the spectrum characteristics. For instance, PAHFIT (Smith et al. 2007) and DecompIR (Mullaney et al. 2011) are able to measure the PAH features and are very useful when the spectra are highly contaminated by their host galaxy emission. However, they require a wide spectral coverage in order to produce satisfactory results—larger than that of the T-ReCS or CanariCam spectra presented here (see Esquej et al. 2014). Instead, we followed the procedure described by Alonso-Herrero et al. (2014) and Esquej et al. (2014) to measure the flux and the equivalent width (EW). They use the method described by Hernán-Caballero & Hatziminaoglou (2011), which is well suited for limited wavelengths (case of [S IV] line) or weak PAHs. Their method sets a local continuum by interpolating from two narrow bands (i.e., 10.7–10.9 $\mu m$ and 11.7–11.9 $\mu m$) at both sides of the PAH feature or at both sides of the [S IV] line emission (i.e., 10.35–10.40 $\mu m$ and 10.65–10.75 $\mu m$). Note that we selected these continuum ranges individually according to the particularities of each spectrum. This was done to optimize the measurement of the bands according to the natural width of the PAH feature. After subtracting the underlying continuum, residual data were fitted using a Gaussian profile. We compared the fluxes obtained from the Gaussian fit and the direct integration in the case of the nuclear spectra. The discrepancy in the flux between the two methods for the nuclear spectrum is on average less than 3% and 7% for the PAH feature and the [S IV] line, respectively.

Then, the EW of the lines is measured by dividing the integrated flux by the interpolated continuum flux at the center. The uncertainties are obtained by Monte Carlo simulation using the calculated dispersion around the flux measurements. We have applied a smoothing to the high spatial resolution spectra to improve the signal-to-noise ratio of the features. This smoothing was applied to the data using the average of three near spectral bins. The smoothing causes a peak dilution, which could dilute the emission lines if they are less than three points. Nevertheless, the lines that we studied are broad; therefore, we do not expect to have any significant effect on the results (see Alonso-Herrero et al. 2014, for more details on the smoothing technique). Table 2 shows integrated fluxes and EW measurements from each emission obtained with the nuclear and Spitzer/IRS spectra.

3.2. Surface Brightness Radial Profiles

We create surface brightness and EW radial profiles\footnote{We use the term “radial profile” for referring to the surface brightness radial profiles.} for each object. We first extracted the flux at the radius of each aperture, and then we subtracted that of all inner apertures to get the flux of a ring. When the subtracted measurement was

\section*{Figure 5. X-ray luminosity vs. PAH luminosity deficit (see text). This deficit is measured as the ratio between the observed and the expected one. The expected PAH luminosity expected is estimated as the linear extrapolation to the center of the radial profile within 200 pc.}

\begin{center}
\includegraphics[width=\textwidth]{figure5.png}
\end{center}
lower than $3\sigma$, we considered it as a limit. We then divided each value by its respective area to correct for different aperture radii. In the case of the nucleus, the area is computed with the radius of the unresolved emission times the slit width. For the rest of the apertures, the area is calculated as the slit width times increment radius for the aperture (i.e., 2 pixels; see Table 1, Column (7)).

Figure 1 (bottom) shows the radial profile for the PAH feature at 11.3 $\mu$m (blue diamonds) and [S IV] line emission at 10.5 $\mu$m (orange circles). The Appendix includes the radial profiles for the full sample (see Figures 7–26).

In order to analyze the behavior of the two emission features across the full sample, we calculated the integrated flux at fixed physical scales: 100, 200, 500, and 700 pc. The measurements were calculated from a linear interpolation between the nearest points. Notice that we do not take into account the nuclear measurement to compute these values at a fixed distance. These measurements are reported in Table 3. We report measurements only when our radial profile includes these distances.

4. The Origin of the [S IV] Line Emission

The [S IV] is an emission line typically observed in the planetary nebula, H II regions, and ULIRGs (Rank et al. 1970; Holtz et al. 1971; Gillett et al. 1972), as well as AGNs. The origin of the nuclear [S IV] line emission is controversial in the case of AGNs. It can be produced in the NLR and therefore can be a good tracer of gas ionized by the AGNs (Dasyra et al. 2011). However, it can also be related to star-forming regions owing to its relatively low excitation potential (Diaz-Santos et al. 2010; Pereira-Santaella et al. 2010).

### Table 4

| Distance | Theory Mean | Measurement Mean | $\sigma$ |
|----------|-------------|------------------|---------|
| 100 pc   | 1.00        | 1.09             | 0.60    |
| 200 pc   | 1.06        | 0.88             | 0.70    |
| 500 pc   | 1.23        | 0.91             | 0.75    |
| 700 pc   | 1.35        | 0.95             | 0.80    |

**Note.** For the PAH feature, we have computed the observed shift for the relation as the average and standard deviation of the relation predicted by Neistein & Netzer (2014). For more information see Section 5.2.
Diaz-Santos et al. (2010) studied four LIRG-type objects, finding that half of the [S IV] line emission flux comes from the nucleus. Our sample has three objects in common with theirs (NGC 5135, IC 4518W, and NGC 7130). For NGC 5135 they found that ~40% of [S IV] line emission integrated flux comes from the nuclear spectrum. Fairly consistent with that, we find that the nuclear spectrum contributes ~55% to the integrated flux of this emission line. They found that the [S IV] nuclear flux in IC 4518W is smaller than the emission in the integrated spectrum by ~22%. We also agree that there is an excess of [S IV] emission at 0.5 arcsec (∼200 pc), which is unrelated to the excess of 11.3 μm PAH emission. Diaz-Santos et al. (2010) suggested that this emission is associated with the central AGN. In NGC 7130 we found that 70% of the [S IV] flux comes from the nuclear spectrum, while Diaz-Santos et al. (2010) found that the [S IV] nuclear emission corresponds to 50% of the total flux. In both IC 4518W and NGC 7130, star-forming regions near the nucleus have been found (see the Appendix). Based on the Spitzer observations, Pereira-Santaella et al. (2010) could not conclude whether the [S IV] line emission is related to star-forming regions for this object owing to poor data quality. However, they found that extended emission of the [S IV] line can be attributed to star-forming regions, using PAH and Hα images for the other three objects of their sample.

We explored the luminosity of the [S IV] emission line \(L_{\text{S IV}}\) in the AGN environment by studying the radial profiles of \(\frac{L_{\text{S IV}}}{L_{\text{Edd}}}\) as a function of the sublimation radius \(R_{\text{sub}}\). Nenkova et al. (2008) stated that attenuation is affecting the [S IV] line emissions has been found for this object. We have considered the possibility that half of the [S IV] line emission at these scales. The solid line corresponds to the Dasya et al. (2011) relation:

\[
\log (M_{\text{BH}}) = 0.6 \times \log (L_{\text{[S IV]}}) + 3.32. \tag{2}
\]

This relation is based on the best fit for their AGN sample using Spitzer/IRS spectra and considering that the [S IV] line emission only comes from the NLR. The rms scatter computed for this relation is 0.48 dex (shaded area in Figure 3). For a few sources without significant SF, the [S IV] line fluxes follow the Dasya et al. (2011) relation at scales of ∼1000R\(_{\text{sub}}\). However, the sources move away from the relation with increasing distance from the nucleus. This result could be interpreted as H II regions, planetary nebulae, or blue compact dwarfs contributing to the sulfur excitation, along with the AGNs (Groves et al. 2008).

Even if the nuclear [S IV] line emission could arise from photoionization by the AGNs in some of our sources, it could be strongly suppressed by dust because it is inside the broad 9.7 μm silicate absorption feature (Pereira-Santaella et al. 2010). Therefore, it could not be an isotropic measurement of the AGN luminosity. Moreover, the obscuration of the internal parts of the AGN by the dusty torus could also play a major role in the [S IV] line emission attenuation. This could be the case for NGC 7172, showing a large value of the 9.7 μm optical depth (\(\tau_{9.7\mu\text{m}} = 1.9\); González-Martín et al. 2013). Indeed, a very weak detection of the [S IV] line emissions has been found for this object. We have considered the possibility that attenuation is affecting the [S IV] line emission in the inner parts. We found a deficit between nuclear and the first apertures in five sources (see the Appendix). We have compiled the nuclear \(\tau_{9.7\mu\text{m}}\) from González-Martín et al. (2013) and Alonso-Herrero et al. (2016), but we did not find any relation between the \(\tau_{9.7\mu\text{m}}\) and the deficit on the [S IV] line emission flux. Also, Dasya et al. (2011) found that this obscuration does not significantly affect the relative flux of MIR lines. In summary, in 6 of the 13 sources we did not observe a common decrease in the radial profile, as we would expect if this line were caused by AGN photoionization.

4.1. The [S IV] Emission Line versus the 11.3 μm PAH Feature

The [S IV] emission line could be produced by star-forming regions. If this is the case, we would expect a close resemblance between the [S IV] and PAH radial profiles at these radii.

We compared nine sources where the radial profiles of both the PAH feature and the [S IV] line show more than one measurement at different distances from the nucleus. In all sources, the radial profile for both emissions shows a complex behavior. In six of these nine sources it is clear that the behaviors of the radial profiles of both emissions are not related to each other at any distance. Even with that, it could be the case that the star-forming regions traced by the 11.3 μm PAH feature are not the same as those that give origin to the [S IV] emission in the majority of the sources. A plausible explanation is that both emissions are tracing different stages of SF and thus different degrees of ionizing fluxes. Ideally, to distinguish the type of stars that contribute to the [S IV] line emission, high spatial resolution images of [S IV] line emission, together with...
other tracers of SF related to different stages of the SF activity, would be needed.

5. The Behavior of the PAH Emission Feature

In this section, we review the plausible dilution/destruction of PAHs in the innermost parts of the AGN (Section 5.1), and we use PAHs as tracers of SF to study the coevolution of the AGN and its host galaxy (Section 5.2).

5.1. On the Dilution/ Destruction of the Nuclear PAHs

The relation between the strength of the PAHs and IR luminosity is weak or absent in galaxies with AGNs (Siebenmorgen et al. 2004; Weedman et al. 2005). An important implication of this is that PAHs might not be used as star-forming tracers in the surroundings of the nucleus because they can be destroyed by the AGN radiation field (Siebenmorgen et al. 2004). The AGN can directly modify PAH grain size distribution and even serve as the excitation source for some PAH emission (Genzel et al. 1998; Laurent et al. 2000; Smith et al. 2007). On the other hand, PAHs could survive because they are shielded from the AGN radiation (Goulding et al. 2012). Even more extremely, PAH could be induced by the AGN radiation field (Jensen et al. 2017).

Diamond-Stanic & Rieke (2010) found that the 6.2, 7.7, and 8.6 μm PAH features are suppressed with respect to the 11.3 μm PAH feature in local Seyferts. They speculate that destruction of these features might be related to the fact that they are produced by the smallest aromatic molecules and, therefore, more easily destroyed. Following this argument, the molecules responsible for 11.3 μm PAH emission could survive because they are more difficult to destroy. Already from IRAS data, it was pointed out that the emission at the 12 μm band fits very well the predictions that follow from the emission modeling of transiently heated PAH molecules (Dultzin-Hacyan et al. 1990). More recently, Diamond-Stanic & Rieke (2012) found a correlation between the nuclear SF (<1 kpc) and SMBH accretion rate, where the nuclear SF is traced by the PAH at 11.3 μm aromatic feature.

We detected the PAH feature at 11.3 μm in 15 out of the 19 objects in our sample (~90% of our sources), and 10 of these sources show nuclear PAHs (~58% of our sample). The 11.3 μm PAH feature was measured in more than one aperture in 11 objects along the radial profiles. We found that in eight sources (except NGC 5643, NGC 7172, and NGC 7582) the nuclear EW of the PAH is larger than the one found in the first aperture.

In Figure 4, we show the radial profiles of the \( L_{11.3 \, \mu m} \) PAH as a function of \( R_{peak} \) (left) and \( R_{25}/2000 \) (right). This figure is similar to Figure 2 from the previous section. We observed a complex behavior. Increments and decrements at different distances were found.

Regarding the 11.3 μm PAH, nuclear fluxes are larger than those of the first aperture only in NGC 1808 and NGC 5135. The unresolved nucleus shows lower flux than the first-aperture PAH flux in most of our cases (7 out of 12, i.e., 60%). When observed, this decrement is seen within ~100 pc. Note that in many cases we do not see a decrease in the radial profile (as, e.g., in NGC 7582), but a drop between the nuclear and the first aperture (e.g., NGC 7172). Therefore, this decrement could be affecting even lower spatial scales. The explanations of this decrement are (1) PAH dilution by AGN continuum, (2) PAH destruction by the radiation field, (3) lack of the inner SF, and (4) the existence of a nuclear ring. In the following we discuss these four possibilities.

Alonso-Herrero et al. (2014) suggested that the apparent decrease in the EW of the PAH feature is an effect of the dilution of the PAH feature by the strong continuum of the AGN in the nuclear apertures. They indeed recovered an increase on the nuclear PAH flux toward the center in their sample of six local AGNs. Meanwhile, the EW of the PAH feature showed an apparent decrease. We have not found a similar behavior in any of our objects, but we only have one object in common with their analysis (MRK 1066). They computed the radial profile in isolated apertures at different distances from the nucleus. In our analysis, we have extracted spectra centered at the nucleus with different radii. Thus, each of our apertures includes the nuclear emission. In order to study the radial profile, we subtracted the previous inner aperture scaled to the area (see Section 3). This way, we avoided the dilution due to this effect. Thus, dilution cannot play a role in the lack of nuclear PAHs in the sources analyzed here.

Siebenmorgen et al. (2004) suggested that the suppression of PAH emission near the AGN may be due to the destruction of PAHs by the strong radiation field of the AGN. If this is the case, we would expect a relation between the PAH luminosity deficit and the X-ray luminosity as a tracer of the AGN bolometric luminosity. The stronger the AGN radiation field, the larger the nuclear PAH deficit. We have measured the PAH luminosity deficit from our radial profiles as the ratio between the expected and the observed one. We have estimated the expected nuclear PAH luminosity in two ways: (1) as the linear extrapolation of the radial profile within 200 pc, and (2) as the maximum of PAH emission within 200 pc. Figure 5 shows the deficit obtained by extrapolation versus the X-ray luminosity. We do not find a relation between the PAH deficit and the AGN X-ray luminosity. Thus, from our data we have not found observational support for the destruction of the PAH features due to the AGN radiation field. However, we cannot rule out this hypothesis since more sensitive and better-resolution observations are needed. For instance, higher spatial resolution spectra could help pinpoint the distance from the nucleus at which the PAH emission starts to show this deficit. In this sense it might be possible that the relation is missing owing to a poor estimate of the PAH luminosity deficit.

Of course, a natural explanation of this inner deficit in the PAH feature is that there is a lack in SF toward the center. This is supported by the scenario in which the high-velocity winds or AGN-driven massive molecular outflows could be able to quench the surrounding SF (Cicone et al. 2014; McAlpine et al. 2015; Wylezalek & Zakamska 2016). Another possible explanation for this deficit in PAHs in internal parts can be related to the dust/gas distribution, which is ring-like rather than disk-like at the center (e.g., Ohsuga & Umemura 1999; Yankulova 1999). In order to corroborate this, other measurements of the nuclear tracers of the SF must be compared with

15 Another four objects of the sample show emission only in one aperture (NGC 1386, NGC 2992, NGC 3081, and IC 4518W). The other four sources do not show detection of the 11.3 μm PAH feature.

16 Note that we do not take into account IC 4518W because the measurements at distances <400 pc are only upper limits.

17 We refer to dilution as a decrease in equivalent width from the PAH feature due to the strength of the AGN continuum.
our PAH nuclear fluxes, isolating nuclear and circumnuclear emission.

5.2. Hints on the Coevolution of the AGN and Its Host Galaxy

Hopkins & Quataert (2010) and Neistein & Netzer (2014) have explored the correlation between BH accretion rate and the SFR through hydrodynamic simulations and semianalytic models, respectively. Hopkins & Quataert (2010) predicted the relation between BH accretion rate and SFR at different galactic scales. Their simulations start with a major galaxy merger of isolated bar-(un)stable disk galaxies. They found that nuclear SF is more coupled to AGNs than the global SFR of the galaxy. Neistein & Netzer (2014) developed similar simulations including advection-dominated accreting flow to account for the accretion processing low-luminosity AGNs. They observed a lack of correlation between SFR and AGN luminosity (related to BH accretion rate) at \( z < 1 \) and \( L_{\text{bol,AGN}} < 10^{44} \text{ erg s}^{-1} \) (see also Rosario et al. 2012). They justified this possible lack of correlation as follows: (1) secular SF is perhaps not associated with BH accretion, or (2) BH accretion rate and SFR could be delayed, removing any correlation (see also Hopkins 2012). They also found that AGNs with low or intermediate luminosity might be associated with minor merger events.

In this work we compare Hopkins & Quataert (2010) and Neistein & Netzer (2014) predictions with our results. We derived nuclear and circumnuclear SFRs using the PAH 11.3 \( \mu m \) feature luminosities \( (L_{11.3 \mu m}) \) and applying the relation derived in Shipley et al. (2016) (using Spitzer measurements of 105 galaxies):

\[
\log \text{SFR} \left( \frac{M_{\odot}}{\text{yr}^{-1}} \right) = (-44.14 \pm 0.08) + (1.06 \pm 0.03) \log L_{11.3 \mu m}(\text{erg s}^{-1}).
\]

The uncertainties in the derived SFRs using Equation (3) are typically 0.14 dex (see Shipley et al. 2016, for full details). As a caveat on the use of the PAH as a tracer of SF, Jensen et al. (2017) recently found that the slopes of the radial profile of the PAH emission are very similar, with a strength proportional to the AGN luminosity. They argue that this might imply that a compact emission source is required to explain the common slopes. Both an AGN and a nuclear star cluster are possible sources of PAH heating/ excitation. Although we obtain in general a decrease of the PAH flux with the radius, a more complex behavior (with a deficit at the nuclear and peaks of emission on top of a general decrease) is observed in most of our sources, indicating in situ PAH heating.

This is not the first time such a comparison has been done. Esquej et al. (2014) used a sample of 29 nuclear spectra to explore the same relation between SFR and BH accretion rate. They compared their data with the relations obtained by Hopkins & Quataert (2010), and they concluded that predictions for distances \( (D) < 100 \text{ pc} \) reproduce their data well. We have seven sources in common with their sample.\(^{18}\) Our measurements show slightly higher SFR compared to theirs (factor of 2), perhaps due to a different methodology for defining the continuum around the PAH feature. Ruchsel-Dutra et al. (2017) also analyzed the presence of circumnuclear SF in a sample of 15 AGNs using MIR images (with two filters centered at the 11.3 \( \mu m \) PAH features and at the adjacent continuum, respectively). They compared their data with the correlation presented by Neistein & Netzer (2014). They concluded that SFR is correlated with bolometric AGN luminosity \( (L_{\text{bol,AGN}}) \) for objects with \( L_{\text{bol,AGN}} \geq 10^{42} \text{ erg s}^{-1} \), while the low-luminosity AGN has larger SFR for their \( L_{\text{bol,AGN}} \).

Compared to previous works, our analysis has the advantage that it allows us to explore the SFR at different subkilo parsec scales from the nucleus. We calculate the \( L_{\text{bol,AGN}} \) from X-ray luminosities (reported in Table 1, Column (4)) using the relation \( L_{\text{bol,AGN}} = kL(2-10 \text{ keV}) \), where the bolometric correction \( (k) \) depends on \( L(2-10 \text{ keV}) \) itself with a fourth-order polynomial (see Marconi et al. 2004). In Figure 6, we present the relation between \( L_{\text{bol,AGN}} \) and SFR\( _{\text{PAHs}} \) integrated at different distances from the nucleus. Each panel corresponds to integrated SFR\( _{\text{PAHs}} \) for the 100, 200, 500, and 700 pc apertures, respectively. Note that this plot includes the 12 sources where we measure the 11.3 \( \mu m \) PAH feature (the integrated fluxes density are reported in Table 3). The number of sources varies for each plot depending on the resolution and spatial scale of the extended emission for each spectrum. Furthermore, Sy1 and Sy2 are shown as red and green circles, respectively. We also include the measurements for QSOs from Martinez-Paredes et al. (submitted; triangles), as well as Seyferts from Esquej et al. (2014; stars) and Ruchsel-Dutra et al. (2017; diamonds).

Two of our objects (NGC 1808 and NGC 4569) are in the range of low luminosities \( (L_{\text{bol,AGN}} < 10^{42} \text{ erg s}^{-1}) \). Hopkins & Quataert (2010) predictions are not able to reproduce these low-efficiency objects. Ruchsel-Dutra et al. (2017) suggest that the low-luminosity AGNs have high circumnuclear SF. However, our objects with high luminosity have similar or higher SFRs. Neistein & Netzer (2014) presented two correlations: (1) the average SFR value for a given \( L_{\text{bol,AGN}} \) in their models, and (2) the average of \( L_{\text{bol,AGN}} \) for a given value of total SFR. Indeed, the first relation flattens toward low luminosities, as seen by our two low-luminosity AGNs. In Figure 6, we show these relations shifted as predicted by Hopkins & Quataert (2010) for different apertures (dashed and solid lines with different colors in each panel):

\[
\text{SFR}_{\text{PAHs}}(R < 100 \text{ pc}) = \text{SFR}_{\text{PAHs}}(< 10 \text{ pc}) - 1.0, \quad (4)
\]

\[
\text{SFR}_{\text{PAHs}}(R < 1 \text{ kpc}) = \text{SFR}_{\text{PAHs}}(< 10 \text{ pc}) - 1.52, \quad (5)
\]

\[
\text{SFR}_{\text{PAHs}}(\text{total}) = \text{SFR}_{\text{PAHs}}(< 10 \text{ pc}) - 2.52. \quad (6)
\]

These relations have been computed using Equations (15)–(18) in Hopkins & Quataert (2010). Note that scatter in these relations is significant. In general terms, these relations have the form

\[
\text{SFR}_{\text{PAHs}}(R < R_s) = \text{SFR}_{\text{PAHs}}(< 10 \text{ pc}) - B(R_s), \quad (7)
\]

where \( B(R_s) \) is a constant that depends on the physical scale. We have interpolated the given values to obtain the expected shifts on the physical scales derived from our analysis (reported in the second column of Table 4).

In order to compare predictions with models, we have computed the observed shift to this relation as the average and standard deviation of the relation predicted by Neistein & Netzer (2014) and our data points. These shifts are reported in

\(^{18}\) NGC 1808, NGC 3227, NGC 5135, NGC 5643, NGC 7130, NGC 7172, and NGC 7582.
the third and fourth columns of Table 4. This correlation and standard deviations are shown as the black solid line and shaded area in each panel, respectively.

Note that the results shown in Figure 6 could be affected by the following errors: (1) The systematic offset due to the use of different SFR tracers. The dispersion from the correlation used to calculate the SFR from the 11.3 \( \mu m \) PAH feature is similar to that obtained by other tracers. We have taken into account this dispersion in the error bars in Figure 6. (2) Timescale for the SF. According to Neistein & Netzer (2014), a necessary condition for agreement between data and model is that the correct timescale for both SF and AGN activity is adopted. The models are constrained to calculate the SFR average using only the SF in the last 150 Myr. We have calculated the SFR using the 11.3 \( \mu m \) PAH as a tracer. This feature is usually associated with B stars (Peeters et al. 2004). (3) Calculation errors in the \( L_{bol,AGN} \). In the models the \( L_{bol,AGN} \) depends on the accretion mass, while in our data it depends on the X-ray luminosity, which might vary up to one order of magnitude. In Figure 6, we have already included this uncertainty in the error bars.

We found a sensible agreement between the theoretical relations proposed by Neistein & Netzer (2014) shifted according to Hopkins & Quataert (2010) and our data, for most inner galaxy parts. This result is of interest, as, in the simulated objects, major mergers with tidal events have been deemed responsible for both the SF and BH feeding.

6. Summary and Conclusions

In this paper, we present a sample of 19 local AGNs observed with ground-based T-ReCS/Gemini and CanariCam/GTC spectra. We complemented these observations with available Spitzer/IRS spectra. We have studied the surface brightness radial profile of the 11.3 \( \mu m \) PAH feature and the [S IV] line emission. According to the results of this research, we tried to answer the following three questions:

(1) What is the origin of the [S IV] line emission in the nuclear region?

The contribution to the [S IV] line emission is not circumnuclear. Instead, it often peaks at distances greater than 1000\( R_{\text{H}_{26}} \) from the nucleus. We have not found a relation between the surface brightness radial profiles of the [S IV] line and the PAH feature at different distances from the nucleus. If the PAH is a good tracer of SF, we speculate that the [S IV] line emission could be tracing SF with different ages than those traced by the PAH feature.

(2) How good is the 11.3 \( \mu m \) PAH feature as a tracer of SF in the vicinity of the AGN?

We found a PAH flux deficit closer to the AGN as compared with larger apertures (toward the inner \(~100\) pc). This deficit cannot be related to dilution by the AGN continuum. We have not found observational support for the destruction of PAH features due to the AGN radiation field. Intrinsic lack of SF toward the center is also a plausible explanation.

(3) What can we say about the connection between SF and AGN activity?

We found a sensible agreement between the expected shift in the \( L_{bol,AGN}-\text{SFR} \) theoretical relation proposed by Neistein & Netzer (2014), Hopkins & Quataert (2010), and our observations, for most inner galaxy parts.

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Appendix

Catalog of Spectra and Reported Nuclear Star-forming Regions

NGC 931 (Mrk 1040) is a barred galaxy (Sbc) with an S1 nucleus. Ward & Wilson (1978) found that this galaxy interacts with a satellite galaxy located 10 kpc from NGC 931. We did not find records of SF in other works at the scales traced with our observations.

Mrk 1066 is a starburst galaxy with an S2 nucleus. Ramos Almeida et al. (2014) found star-forming knots at \(~400\) pc of the galaxy center, after subtracting the AGN component. Alonso-Herrero et al. (2014) suggest that close to the center \(~125\) pc the near-IR lines are dominated by the AGN processes.

NGC 1320 is an edge-on galaxy with an S2 nucleus. This source is a “warm galaxy” with a relatively high IR luminosity (De Robertis & Osterbrock 1986). We did not find records of SF in other works at the scales traced with our observations.

NGC 1386 is an edge-on spiral galaxy with an S2 nucleus. Ruschel-Dutra et al. (2014) found that the 11.3 \( \mu m \) PAH feature is more pronounced at distances \(~100\) pc from the nucleus. They also found that the [S IV] line emission is only detected in the nucleus at distances \(<100\) pc. Our observations are in agreement with these results. Optical studies show evidence of heavy obscuration (Weaver et al. 1991; Storchi-Bergmann et al. 1996; Rossa et al. 2000).

NGC 1808 is an inclined spiral galaxy with an S2 nucleus and a prominent starburst (Veron-Cetty & Veron 1985; Krabbe et al. 1994). Yuan et al. (2010) considered the possibility that the nucleus is an H II region. Asmus et al. (2014) found that star-forming regions dominate the MIR emission within \(~200\) pc.

NGC 2992 is an inclined spiral galaxy (de Vaucouleurs et al. 1991) and located in the interacting system Arp 245. The nucleus of this source is classified as an S1.9 in the optical. However, in other works it is classified as S1.5 or S2 (Gilli et al. 2000; Trippe et al. 2008). Gilli et al. (2000) suggested that
The IR variations were probably caused by a retriggered AGN. García-Bernete et al. (2015) found that the starburst component dominates the MIR emission, while the AGN component dominates at higher wavelengths ($\lambda > 15 \mu m$).

NGC 3081 is a low-inclination barred spiral galaxy with an Sy2 nucleus (Phillips et al. 1983; Asmus et al. 2014). However, Moran et al. (2000) reported a type 1 optical spectrum in polarized light. Weaver et al. (2010) found that the Spitzer spectrum exhibits a weak absorption by silicate at 10 \mu m, a weak PAH emission, and prominent forbidden emission lines. However, Asmus et al. (2014) concluded that the MIR emission is mostly due to the AGN.

NGC 3081: (see above).

NGC 3281 is a highly inclined spiral galaxy with an Sy2 nucleus (Véron-Cetty & Véron 2010). Ramos Almeida et al. (2009) and Sales et al. (2011) presented observations of this source with T-ReCS with the broad N and Qa bands. They found that the spectrum of NGC 3281 shows only a very deep silicate absorption at 9.7 \mu m and some forbidden emission lines (e.g., [S IV] at 10.5 \mu m). They conclude that NGC 3281 is a heavily obscured source, due to concentrated dust within a radius of 200 pc.
NGC 4253 (Mrk 766) is a barred spiral galaxy (SBa) with an Sy1 nucleus. The HST images of this source show some irregular dust filaments around the nucleus (Malkan et al. 1998). Rodríguez-Ardila et al. (2005) studied the near-IR spectrum and found permitted, forbidden, and high-ionization lines. Furthermore, Rodríguez-Ardila & Viegas (2003) found emission in the 3.3 μm PAH feature located 150 pc from the nucleus. They considered that this emission is a signature of starburst activity.

NGC 4569 is the most massive, spiral, late-type, and gas-poor galaxy in the Virgo Cluster (van den Bergh 1976). This source shows strong Balmer absorption lines, which could be indicating SF in the last 1.5 Gyr (Ho et al. 2003). Dale et al. (2006) and Mason et al. (2015) also suggested recent and/or ongoing SF activity based on the detection of PAH emission at MIR.

NGC 5135 is an infrared-luminosity, face-on barred spiral galaxy. The nucleus is classified as an Sy2 (Véron-Cetty & Véron 2010), and it is surrounded by a banana-shaped circumnuclear SF (González Delgado et al. 1998; Bedregal et al. 2009). The inner and outer radii of the SF emission are located at ~300 and ~750 pc from the nucleus, respectively.

NGC 5643 is a face-on barred spiral galaxy with an Sy2 nucleus (Véron-Cetty & Véron 2010). The IRAC and MIPS images show a compact MIR nucleus embedded within the spiral-like host emission (Asmus et al. 2014). Moreover, the arcsecond-scale MIR spectral energy distribution (SED) is significantly affected by SF (e.g., Shi et al. 2006; Goulding & Alexander 2009).

IC 4518W is a spiral galaxy with an Sy2 nucleus (Véron-Cetty & Véron 2010). Diaz-Santos et al. (2010) and Asmus et al. (2014) found that the SF contribution at subarcsecond resolution is probably minor in its nucleus. Diaz-Santos et al. (2010) found [S IV] line emission at ~265 pc toward the north of the nucleus. They suggested that this emission could be related to the NLR.

Figure 8. Extracted spectra and radial profiles for Mrk 1066; same description as in Figure 7.
IC 5063 is a peculiar galaxy with both spiral and elliptical properties with an Sy2 nucleus (Kewley et al. 2001). Colina et al. (1991) proposed that IC 5063 is a remnant of a recent merger, while Martini et al. (2003) speculated that the nuclear obscuration might be caused by foreground dust lanes. We did not find records of SF in other works at the scales traced by our observations.

NGC 7130 is a peculiar low-inclination spiral galaxy with an Sy1.9 nucleus. A compact starburst is located at the center, and it is extended over $\sim$300 pc (González Delgado et al. 1998; Levenson et al. 2005). Wu et al. (2009) and Alonso-Herrero et al. (2012) found that the arcsecond-scale MIR SED indicates obscured AGN emission with a high SF contribution. Asmus et al. (2014) also concluded that the nuclear MIR SED is presumably still affected by significant SF emission.

NGC 7172 is an edge-on lenticular galaxy with an Sy2 nucleus (Véron-Cetty & Véron 2010). Smajic et al. (2012) found a prominent dust lane projected along the nucleus. The arcsecond-scale MIR SED might be affected by significant SF (Wu et al. 2009; Gallimore et al. 2010). However, Asmus et al. (2014) concluded that the nuclear MIR SED is free of SF contamination.

NGC 7465 is a spiral galaxy with an Sy2 nucleus. This source is part of a group of nine interacting galaxies (Haynes 1981). The dominant stellar population in the nuclear region of NGC 7465 corresponds to stars between K3 III and M3 III types, according to the relative absorption band measurements (Ramos Almeida et al. 2009).

NGC 7582 is a highly inclined barred spiral galaxy with an obscured nucleus. The nuclear spectrum has been studied as a composition between AGN and starburst (Veron et al. 1997). The AGN is surrounded by a powerful SF disk (major-axis diameter $\sim$400 pc) and a dust lane crossing over the nucleus (Morris et al. 1985; Riffel et al. 2009). Asmus et al. (2014) concluded that the starburst dominates the total MIR emission.

Figure 9. Extracted spectra and radial profiles for NGC 1320; same description as in Figure 7.
Figure 10. Extracted spectra and radial profiles for NGC 1386; same description as in Figure 7.
Figure 11. Extracted spectra and radial profiles for NGC 1808; same description as in Figure 7.
Figure 12. Extracted spectra and radial profiles for NGC 2992; same description as in Figure 7.
Figure 13. Extracted spectra and radial profiles for NGC 3081 with PA = 0°; same description as in Figure 7.
Figure 14. Extracted spectra and radial profiles for NGC 3081 with PA = 350°; same description as in Figure 7.
Figure 15. Extracted spectra and radial profiles for NGC 3227; same description as in Figure 7.
Figure 16. Extracted spectra and radial profiles for NGC 3281; same description as in Figure 7.
Figure 17. Extracted spectra and radial profiles for NGC 4253; same description as in Figure 7.
Figure 18. Extracted spectra and radial profiles for NGC 4569; same description as in Figure 7.
Figure 19. Extracted spectra and radial profiles for NGC 5135; same description as in Figure 7.
Figure 20. Extracted spectra and radial profiles for NGC 5643; same description as in Figure 7.
Figure 21. Extracted spectra and radial profiles for IC 4518W; same description as in Figure 7.
Figure 22. Extracted spectra and radial profiles for IC 5063; same description as in Figure 7.
Figure 23. Extracted spectra and radial profiles for NGC 7130; same description as in Figure 7.
Figure 24. Extracted spectra and radial profiles for NGC 7172; same description as in Figure 7.
Figure 25. Extracted spectra and radial profiles for NGC 7465; same description as in Figure 7.
Figure 26. Extracted spectra and radial profiles for NGC 7582; same description as in Figure 7.

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