CONSTRaining THE Active GalACTIC NuCLEUS CONTRIBUTion
IN A MultiWaVElENGTH STUDy OF SeyFert GALAXYES

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ABSTRACT

We have studied the relationship between the high- and low-ionization [O iv] 125.89 μm, [Ne iii] 15.56 μm, and [Ne ii] 12.81 μm emission lines with the aim of constraining the active galactic nuclei (AGNs) and star formation contributions for a sample of 103 Seyfert galaxies. We use the [O iv] and [Ne iii] emission as tracers for the AGN power and star formation to investigate the ionization state of the emission-line gas. We find that Seyfert 2 galaxies have, on average, lower [O iv]/[Ne ii] ratios than Seyfert 1 galaxies. This result suggests two possible scenarios: (1) Seyfert 2 galaxies have intrinsically weaker AGNs, or (2) Seyfert 2 galaxies have relatively higher star formation rates than Seyfert 1 galaxies. We estimate the fraction of [Ne ii] directly associated with the AGNs and find that Seyfert 2 galaxies have a larger contribution from star formation, by a factor of ~1.5 on average, than what is found in Seyfert 1 galaxies. Using the stellar component of [Ne ii] as a tracer of the current star formation, we found similar star formation rates in Seyfert 1 and Seyfert 2 galaxies. We examined the mid- and far-infrared continua and found that [Ne ii] is well correlated with the continuum luminosity at 60 μm and that both [Ne iii] and [O iv] are better correlated with the 25 μm luminosities than with the continuum at longer wavelengths, suggesting that the mid-infrared continuum luminosity is dominated by the AGN, while the far-infrared luminosity is dominated by star formation. Overall, these results test the unified model of AGNs and suggest that the differences between Seyfert galaxies cannot be solely due to viewing angle dependence.

Subject headings: galaxies: Seyfert — Galaxy: stellar content — infrared: galaxies

Online material: color figures

1. INTRODUCTION

Active galactic nuclei (AGNs) are thought to harbor massive black holes surrounded by an accretion disk responsible for the enormous energy rates observed in their unresolved nuclei (Rees 1984; Peterson & Wandel 2000; Peterson et al. 2004). Historically, Seyfert 1 and Seyfert 2 galaxies have been classified by the presence or absence of broad optical emission lines. In this regard, Seyfert 1 galaxies have broad (FWHM ~ (1–5) × 10^3 km s^-1) permitted and narrow (FWHM ~ 5 × 10^-2 km s^-1) permitted and forbidden lines, and Seyfert 2 galaxies have only narrow permitted and forbidden line emission (Khachikian & Weedman 1974). Using spectropolarimetry, Antonucci & Miller (1985) found broad Balmer lines and [Fe ii] emission in the polarized spectrum of the Seyfert 2 NGC 1068 galaxy, characteristic of a Seyfert 1 spectrum. This represents the first observational evidence in favor of a unified model. In this model, Seyfert 1 and Seyfert 2 galaxies are intrinsically the same, with their differences attributed to viewing angle. In Seyfert 2 galaxies, our line of sight to the broad-line region (BLR) and the central engine is obstructed by an optically thick, dusty, torus-like structure, while in Seyfert 1 galaxies, our line of sight is not obstructed by the torus, allowing a direct view of the central regions of the active galaxy.

Although it has been observationally confirmed, the unified model for Seyfert galaxies does not address the role of stellar activity. The fact that active galaxies can also host massive star-forming regions (e.g., Terlevich et al. 1990; Maiolino et al. 1997, 1998; Cid Fernandes et al. 2004; Gu et al. 2006; Davies et al. 2007) suggests a connection between the AGN and star formation in the proximity of the supermassive black hole, typically on scales of a few hundred parsecs. These starbursts may have a significant impact on the fueling of the central black hole (e.g., Schmitt et al. 1999; Davies et al. 2007). Many authors have suggested that violent star formation in the circumnuclear region plays a fundamental role in the energetics of Seyfert 2 galaxies (e.g., Terlevich & Melnick 1985; Maiolino et al. 1998; Cid Fernandes...
& Terlevich 1995; González Delgado et al. 2001; Cid Fernandes et al. 2001). This extra source of energy, a young stellar population in the vicinity of the nucleus, could complement the nonstellar component associated with the AGN. Maiolino et al. (1997) suggested that asymmetric morphologies and bars, especially in Seyfert 2 galaxies, are an important factor in star formation and Seyfert classification. These asymmetric morphologies can induce radial gas inflow and fueling of the nuclear region, thus obscuring and feeding the active nucleus. González Delgado et al. (2001) discuss the possibility of two kinds of Seyfert 2 galaxies based on their stellar population properties: those with young and intermediate-age stars and those with the optical continuum dominated by old stars.

In principle, the richness of the infrared spectrum provides a unique opportunity to test the unified model of AGNs, since the mid-infrared (mid-IR) and far-infrared (FIR) spectra appear to be different in Seyfert 1 and Seyfert 2 galaxies (e.g., Sanders et al. 1988; Pier & Krolik 1992; Antonucci 1993; Clavel et al. 2000; Armus et al. 2003). However, there is the technical difficulty of isolating the AGN from contamination by the host galaxy emission and, more importantly, star formation features (e.g., Lutz et al. 2004; Weedman et al. 2005). In this work we focus on deconvolving the different contributions (e.g., AGN + star formation) in the [Ne II] λ12.81 μm emission line and the mid-IR and FIR continua. In order to estimate the component associated with the AGN, we use the high ionization potential (∼54.9 eV) [O IV] λ25.89 μm emission line. We found (Meléndez et al. 2008, hereafter M08) a tight correlation in Seyfert 1 galaxies between the [O IV] and the X-ray 14–195 keV continuum luminosities from Swift BAT observations (Markwardt et al. 2005). A weaker correlation was found in Seyfert 2 galaxies, which was due to partial absorption in the 14–195 keV band. Overall, we proposed that [O IV] is a truly isotropic property of AGNs, given its high ionization potential, and that it is basically unaffected by reddening, meaning that the [O IV] strength directly measures the AGN power. In this work we isolate the stellar component of the [Ne II] emission to trace the instantaneous star formation rates (SFRs) in our sample of Seyfert galaxies.

2. THE INFRARED SAMPLE

Our sample of Seyfert galaxies includes compilations from Deo et al. (2007), Tommassin et al. (2008), Sturm et al. (2002), and Weedman et al. (2005) and the X-ray-selected sample from M08. This sample has been expanded to include [O IV] λ25.89 μm, [Ne II] λ12.81 μm, and [Ne III] λ15.56 μm fluxes from our analysis of unpublished archival spectra observed with the Infrared Spectrograph (IRS; see Houck et al. 2004) on board Spitzer in the first Long-Low (LL1; λ = 19.5–38.0 μm, 10.7′′ × 168′′, R ∼ 60–127), Short-High (SH; λ = 9.9–19.6 μm, 4.7′′ × 11.3′′, R ∼ 600), and Long-High (LH; λ = 18.7–37.2 μm, 11.1′′ × 22.3′′, R ∼ 600) IRS order in staring mode. The sample includes 64 Seyfert 2 and 39 Seyfert 1 galaxies, which are listed in Table 1. The infrared luminosities are presented without reddening corrections. For comparison, we searched the literature for the Seyfert 1 and Seyfert 2 galaxies with measured mid-IR and FIR continuum fluxes at 25, 60, and 100 μm from the Infrared Astronomical Satellite (IRAS; Neugebauer et al. 1984; Soifer et al. 1989; Moshir et al. 1990; Sanders et al. 2003). Note that it was not possible to find IRAS fluxes for all galaxies in the sample. For the analysis of the mid-IR emission lines observed with the Spitzer IRS, we followed the procedure described in M08.

First, we needed to confirm that our sample, which was compiled from various sources, was not biased in terms of luminosity, e.g., toward high-luminosity Seyfert 1 and/or low-luminosity Seyfert 2 galaxies. This test was done by comparing the different luminosities for the mid-IR emission lines and continuum luminosities for the two groups of galaxies. The results from these comparisons are shown in Figure 1 with the results from the Kolmogorov-Smirnov (K-S) test presented in Table 2. This table also includes information about the numbers of Seyfert 1 and Seyfert 2 galaxies, mean values, and standard deviations of the mean for the measured quantities.

The histograms of the [Ne II], [Ne III], and [O IV] luminosities are presented in Figure 1. From the [Ne II] histogram it can be seen that Seyfert 1 and Seyfert 2 galaxies have similar distributions of values. The K-S test for this emission-line luminosity returns an ∼79.0% probability of the null hypothesis (i.e., that there is no difference between Seyfert 1 and Seyfert 2 galaxies), or, in other words, two samples drawn from the same parent population would differ this much ∼79.0% of the time. From the distribution of [Ne III] luminosities one can see the relative absence of low-luminosity Seyfert 1 galaxies as compared with Seyfert 2 galaxies. For L_{[Ne III]} < 40.5 there are 20 Seyfert 2 galaxies (comprising ∼30% of the Seyfert 2 sample) and only 4 Seyfert 1 galaxies (∼10% of the Seyfert 1 sample). This may suggest the presence of intrinsically weaker AGNs in the Seyfert 2 galaxies. However, the K-S result returns an ∼22.8% probability of the null hypothesis, indicating that the apparent differences between the two groups are not statistically significant. From the [O IV] histogram one can see a lack of low-luminosity Seyfert 1 galaxies (L_{[O IV]} < 40.5) as compared with Seyfert 2 galaxies, similar to what is found in the distribution of [Ne III] luminosities, with 20 Seyfert 2 galaxies comprising ∼30% of the Seyfert 2 sample and only 5 Seyfert 1 galaxies (∼13% of the Seyfert 1 sample). However, the K-S result returns an ∼10.0% probability of the null hypothesis. Overall, we found that the mid-IR luminosity distributions for Seyfert 1 and Seyfert 2 galaxies are statistically similar, even with the absence of low-luminosity Seyfert 1 galaxies in the [Ne III] and [O IV] distributions.

We also studied the infrared emission continuum properties of the sample using the 25 μm, 60 μm, 100 μm, and FIR luminosities. It should be noted that the large-beam infrared spectral energy distributions from IRAS (with a field of view of 0.75′ × 4.6′ at 25 μm, 1.5′ × 4.7′ at 60 μm, and 3.0′ × 5.0′ at 100 μm) include the AGN continuum and the host galaxy emission (Spinoglio et al. 1995; Lutz et al. 2004). The FIR luminosity is characterized by the emission at 60 and 100 μm (e.g., Condon 1992; Sanders & Mirabel 1996). In this regard, the 60 μm emission represents a “warm” component associated with dust around young star-forming regions. On the other hand, cooler “cirrus” emission at 100 μm (Low et al. 1984) is associated with more extended dust heated by the interstellar radiation field (Kennicutt 1998).

The histograms of 25 μm (L_{25 μm}), 60 μm (L_{60 μm}), and FIR (L_{FIR}) continuum luminosities are presented in Figure 2. Overall, it can be seen that Seyfert 1 and Seyfert 2 galaxies have similar distributions of values. For the 25 μm luminosity distributions the K-S test returns an ∼27.3% probability of the null hypothesis. For the 60 μm luminosity (L_{60 μm}) the K-S test returns an ∼70.4% probability of the null hypothesis. This result is in agreement with previous studies that have assumed that the 60 μm continuum emission is an isotropic quantity (e.g., Schmitt et al. 2001). However, this assumption must be adopted with caution because the torus emission may be anisotropic at 60 μm (Pier & Krolik 1992).

1 A probability value of less than 5% represents a high level of significance that two samples drawn from the same population are different. A strong level of significance is obtained for values smaller than 1% (e.g., Press et al. 1992; Bevington & Robinson 2003).
| Name               | Type | Aperture (kpc) | Reference |
|--------------------|------|----------------|-----------|
| NGC 4051           | 1.5  | 0.002336       | 42.35     |
| NGC 3982           | 2    | 0.003699       | 42.47     |
| NGC 3786           | 1.8  | 0.008933       |           |
| NGC 3516           | 1.5  | 0.008836       | 43.26     |
| NGC 1320           | 2    | 0.013515       | 43.70     |
| NGC 1275           | 2    | 0.017559       | 44.45     |
| NGC 1194           | 1    | 0.013596       | 43.39     |
| NGC 1125           | 2    | 0.010931       | 43.41     |
| Mrk 817            | 1.5  | 0.031455       | 44.49     |
| Mrk 6              | 1.5  | 0.018813       | 43.80     |
| Mrk 471            | 1.8  | 0.034234       | 45.61     |
| Mrk 273            | 2    | 0.037780       | 44.97     |
| Mrk 3               | 2    | 0.014000       | 44.17     |
| Mrk 334            | 1.8  | 0.021945       | 44.12     |
| Mrk 335            | 1.2  | 0.025785       | 43.82     |
| Mrk 348            | 2    | 0.015034       | 43.69     |
| Mrk 471            | 1.8  | 0.034234       | 45.61     |
| Mrk 509            | 1.2  | 0.007749       | 43.10     |
| Mrk 573            | 2    | 0.017179       | 43.86     |
| Mrk 6               | 1.5  | 0.018813       | 43.80     |
| Mrk 609            | 1.8  | 0.034488       | 44.13     |
| Mrk 622            | 2    | 0.023229       | 43.76     |
| Mrk 79             | 1.2  | 0.022189       | 43.99     |
| Mrk 817            | 1.5  | 0.031455       | 44.49     |
| Mrk 883            | 1.9  | 0.037496       | 43.91     |
| Mrk 897            | 2    | 0.026340       | 44.20     |
| Mrk 9               | 1.5  | 0.039874       | 44.27     |
| NGC 1068           | 2    | 0.007938       | 45.60     |
| NGC 1125           | 1    | 0.010931       | 43.41     |
| NGC 1194           | 1    | 0.013596       | 43.39     |
| NGC 1275           | 2    | 0.017559       | 44.45     |
| NGC 1320           | 2    | 0.013515       | 43.70     |
| NGC 1365           | 1.8  | 0.005457       | 43.92     |
| NGC 1667           | 2    | 0.015167       | 43.61     |
| NGC 2639           | 1.9  | 0.011128       | 42.83     |
| NGC 2992           | 2    | 0.007710       | 43.33     |
| NGC 3079           | 2    | 0.003723       | 42.91     |
| NGC 3227           | 1.5  | 0.003859       | 42.83     |
| NGC 3516           | 1.5  | 0.008836       | 43.26     |
| NGC 3600           | 2    | 0.012285       | 42.94     |
| NGC 3783           | 1.5  | 0.009730       | 43.79     |
| NGC 3786           | 1    | 0.008933       | 44.10     |
| NGC 4051           | 1.5  | 0.002336       | 42.35     |
NGC 3227, NGC 4941, NGC 526A, NGC 5548, NGC 7314, and UM 146. The luminosities were calculated from the fluxes using the aperture parameter and derived from the stellar component of [Ne ii], the aperture size in the dispersion direction (in kpc), and the references from which the emission-line fluxes were obtained. Mid-IR and FIR continuum fluxes at 25, 60, and 100 μm are from IRAS (Soifer et al. 1989; Moshir et al. 1990; Sanders et al. 2003).

Notes.—The sources that show no detectable PAH features at 6.2 and 11.5 μm in their spectra are F15480-0344, IRAS 00521−7054, MCG −2.8−39, Mrk 3, Mrk 9, NGC 3227, NGC 4941, NGC 526A, NGC 5548, NGC 7314, and UM 146. The luminosities were calculated from the fluxes using $H_0 = 71 \, \text{km} \, \text{s}^{-1} \, \text{Mpc}^{-1}$ and a deceleration parameter $q_0 = 0$ with redshift values taken from NED. The last four columns show the percentage of stellar contribution to the [Ne ii] emission line, the SFR derived from the stellar component of [Ne ii], the aperture size in the dispersion direction (in kpc), and the references from which the emission-line fluxes were obtained. Mid-IR and FIR continuum fluxes at 25, 60, and 100 μm are from IRAS (Soifer et al. 1989; Moshir et al. 1990; Sanders et al. 2003).

References.—(1) This paper; (2) Deo et al. 2007; (3) Tommasin et al. 2008; (4) Sturm et al. 2002; (5) Weedman et al. 2005.

FIG. 1.—Comparison of the [Ne ii], [Ne iii], and [O iv] luminosities in Seyfert 1 (solid line) and Seyfert 2 (dashed line) galaxies. This sample includes 39 Seyfert 1 and 64 Seyfert 2 galaxies. The K-S test for these emission-line luminosities shows that two samples drawn from the same population would differ much ~79.0%, ~22.8%, and ~10.0% of the time for the [Ne ii], [Ne iii], and [O iv] luminosity distributions, respectively.
Figure 2 shows that Seyfert 1 and Seyfert 2 galaxies also have similar distributions in the FIR. The K-S test returns an ~51.3% probability of the null hypothesis for the FIR distribution.

In spite of the fact that Seyfert 1 and Seyfert 2 galaxies have similar distributions of infrared luminosities, using the observed mid-IR and FIR continuum fluxes, we found a clear difference in their spectral index. In Seyfert 1 and Seyfert 2 galaxies, as shown in Figure 3. The K-S test returns an ~0.1% probability of the null hypothesis. The spectral shape between 25 and 60 μm has been used to separate ultraluminous infrared galaxies (ULIRGs) that are "cold" and possibly dominated by the AGN and those that are "warm" and likely dominated by star formation (Sanders et al. 1988; Armus et al. 2007). From our sample, we found that Seyfert 2 galaxies possess relatively cooler dust, with an average $\alpha_{25-60} = -1.5 \pm 0.1$, than Seyfert 1 galaxies, $\alpha_{25-60} = -0.8 \pm 0.1$, in agreement with previous findings by Ho et al. (2003). This result suggests that the infrared spectra of Seyfert 1 galaxies are dominated by hot dust heated by the AGN (e.g., Heisler et al. 1997; González Delgado et al. 2001).

2 The continuum is assumed to be a power law, $F_\nu \propto \nu^\alpha$, where $\alpha$ is the spectral index.

### 3. EMISSION-LINE DIAGNOSTICS

The ratios of high- and low-ionization mid-IR emission lines have been widely used to separate the relative contribution of the AGN and star formation (e.g., Genzel et al. 1998; Sturm et al. 2002; Dale et al. 2006). We performed a statistical analysis for the $[\text{O} \text{iv}]/[\text{Ne} \text{ii}]$, $[\text{Ne} \text{iii}]/[\text{Ne} \text{ii}]$, and $[\text{O} \text{iv}]/[\text{Ne} \text{ii}]$ ratios for our sample of 103 Seyfert galaxies, and the results are presented in Table 2. Figure 4 shows the histograms of the $[\text{O} \text{iv}]/[\text{Ne} \text{ii}]$, $[\text{O} \text{iv}]/[\text{Ne} \text{iii}]$, and $[\text{Ne} \text{iii}]/[\text{Ne} \text{ii}]$ ratios. From the $[\text{O} \text{iv}]/[\text{Ne} \text{ii}]$ ratios, it can be seen that Seyfert 2 galaxies are displaced toward smaller values than those found for Seyfert 1 galaxies, in agreement with previous findings by Deo et al. (2007). Accordingly, in the sample, Seyfert 2 galaxies have, on average, smaller $[\text{O} \text{iv}]/[\text{Ne} \text{ii}]$ ratios than those observed in Seyfert 1 galaxies. The K-S test returns an ~0.9% probability of the null hypothesis, indicating that the two Seyfert groups are statistically different. As for $[\text{Ne} \text{iii}]/[\text{Ne} \text{ii}]$, Seyfert 2 galaxies are again displaced toward values smaller than those found for Seyfert 1 galaxies, with the majority of Seyfert 2 galaxies (~60% of the Seyfert 2 population) having $[\text{Ne} \text{iii}]/[\text{Ne} \text{ii}] < 1.0$. The K-S test returns an ~1.1% probability of the null hypothesis. From the histogram of $[\text{O} \text{iv}]/[\text{Ne} \text{ii}]$, it can be seen that both groups of galaxies have similar distributions.

**TABLE 2**  
**Statistical Analysis of Seyfert 1 and Seyfert 2 Galaxies**

| Parameter          | Seyfert 1                  | Seyfert 2                  |
|--------------------|---------------------------|---------------------------|
| $L_{\text{[Ne ii]}}$ | Available: 39, Mean: 41.0, Standard Deviation: 0.1 | Available: 64, Mean: 40.9, Standard Deviation: 0.1 |
| $L_{\text{[O iii]}}$ | Available: 39, Mean: 41.0, Standard Deviation: 0.1 | Available: 64, Mean: 40.9, Standard Deviation: 0.1 |
| $L_{25\mu m}$      | Available: 39, Mean: 41.2, Standard Deviation: 0.1 | Available: 64, Mean: 40.9, Standard Deviation: 0.1 |
| $L_{60\mu m}$      | Available: 39, Mean: 44.0, Standard Deviation: 0.1 | Available: 64, Mean: 40.9, Standard Deviation: 0.1 |
| $L_{\text{FIR}}$   | Available: 39, Mean: 44.0, Standard Deviation: 0.1 | Available: 64, Mean: 44.0, Standard Deviation: 0.1 |
| $L_{\text{FRIR}}$  | Available: 39, Mean: 44.0, Standard Deviation: 0.1 | Available: 64, Mean: 44.0, Standard Deviation: 0.1 |
| $[\text{O iv}]/[\text{Ne ii}]$ | Available: 39, Mean: 2.7, Standard Deviation: 0.4 | Available: 64, Mean: 1.6, Standard Deviation: 0.2 |
| $[\text{Ne iii}]/[\text{Ne ii}]$ | Available: 39, Mean: 1.5, Standard Deviation: 0.1 | Available: 64, Mean: 1.4, Standard Deviation: 0.1 |
| $[\text{O iv}]/[\text{FIR} \times 10^{-3}$ | Available: 36, Mean: 3.1, Standard Deviation: 0.6 | Available: 62, Mean: 2.2, Standard Deviation: 0.2 |
| $[\text{O iv}]/[\text{FIR} \times 10^{-3}$ | Available: 36, Mean: 3.9, Standard Deviation: 0.7 | Available: 62, Mean: 1.8, Standard Deviation: 0.3 |
| $\alpha_{25-60}$ | Available: 36, Mean: -0.8, Standard Deviation: 0.1 | Available: 62, Mean: -1.5, Standard Deviation: 0.1 |
| $\text{SC}_{[\text{Ne ii}]}$ (%) | Available: 39, Mean: 28, Standard Deviation: 5 | Available: 64, Mean: 43, Standard Deviation: 4 |
| $SFR_{[\text{Ne ii}]}$ (M$_\odot$ yr$^{-1}$) | Available: 39, Mean: 7, Standard Deviation: 2 | Available: 64, Mean: 8, Standard Deviation: 2 |

Note.—The last column, $P_{\text{K-S}}$, represents the K-S test null probability.
The K-S test returns an ~37.7% probability of the null hypothesis. This result suggests that [Ne ii] is also an isotropic quantity and could be used to estimate AGN power (e.g., Deo et al. 2007; Tommasin et al. 2008).

In Figure 5 we compare the [O iv]/[Ne ii] and [Ne iii]/[Ne ii] ratios in Seyfert 1 and Seyfert 2 galaxies, where the Spearman rank test returned a strong correlation ($r_S = 0.810$, $P_r = 1.0 \times 10^{-15}$). This strong correlation supports the utility of the [Ne iii]/[Ne ii] ratio as a diagnostic of the relative strength of the AGN as found by Tommasin et al. (2008). From this correlation we found that Seyfert 2 galaxies show lower [O iv]/[Ne ii] and [Ne iii]/[Ne ii] ratios than Seyfert 1 galaxies. As suggested by Deo et al. (2007), one needs to consider two possible scenarios: (1) Seyfert 1 galaxies have more highly ionized narrow-line regions (NLRs) than Seyfert 2 galaxies, resulting in an apparently weaker AGN in Seyfert 2 galaxies; and (2) Seyfert 2 galaxies have relatively higher SFRs than Seyfert 1 galaxies normalized to the AGN luminosity. In the former scenario, one needs to consider that there could be a source of obscuration on a much larger scale that is affecting the [O iv] but not the [Ne ii] emission; however, this possibility contradicts the findings of [O iv] as a true isotropic quantity for the AGN (see M08). Alternatively, this hidden inner NLR scenario is ruled out by Deo et al. (2007), where they found the amount of extinction in the mid-IR for Seyfert 1.8/1.9 galaxies to be negligible.

We found that Seyfert 1 and Seyfert 2 galaxies are statistically different in their relative contribution to the AGN and star formation, as given by the analysis of their [O iv]/[Ne ii] and [Ne iii]/[Ne ii] ratios. Nevertheless, one needs to check whether the emission-line ratios are biased because of the relative absence of low-luminosity Seyfert 1 galaxies in our sample. In this regard, the poor correlation found ($r_S = 0.489$, $P_r = 9.7 \times 10^{-7}$) between the [O iv]/[Ne ii] and [O iv] luminosities, and the fact that the K-S test results for the [O iv] and [Ne ii] luminosity distribution indicated that both groups have statistically similar distributions (see discussion in § 2), indicates that our emission-line ratios are not biased because of the relative absence of low-luminosity Seyfert 1 galaxies in our sample. The [O iv]/[Ne ii] emission-line ratio was also compared with the redshift (z) in order to check whether our previous results are biased toward small ratios at higher values of z. In other words, [O iv] is likely to be produced in a compact region, whereas [Ne ii] could be produced in a more extended region. The Spearman rank $r_S$ test did not show any correlation ($r_S = -0.075$, $P_r = 0.68$) with z. At the median redshift for the sample, $z = 0.02$, 1'' represents ~400 pc for $H_0 = 71$ km s$^{-1}$ Mpc$^{-1}$. Hence, for example, the SH slit will sample about ~2 kpc in the dispersion direction at $z = 0.02$.

4. DECONVOLVING THE STELLAR CONTRIBUTION TO THE [Ne ii] EMISSION

In Figure 6 we compare [Ne ii] and [O iv] fluxes and luminosities. There appears to be a relative deficiency of Seyfert 1 galaxies in the upper left region of the plot. In Figure 6 we identified some of the outliers in the sample. All these sources show strong star formation activity and have also been classified as starburst galaxies or as harboring massive H II regions. These galaxies show strong polycyclic aromatic hydrocarbon (PAH) features at 6.2 and 11.5 μm (Deo et al. 2007; Tommasin et al. 2008). PAHs are a class of large organic molecules that have been observationally associated with star formation (e.g., Clavel et al. 2000; Förster Schreiber et al. 2004; Calzetti et al. 2005; Schweitzer et al. 2006). The strong [Ne ii] in these objects indicates that [Ne ii] is a quantitative tracer of star formation. Results from the statistical analysis are presented in Table 3. One should note that, due to redshift effects, luminosity-luminosity plots will almost always show some correlation. Thus, we are primarily interested in the tightness of the correlations or the slopes (e.g., of one class vs. another).

![Figure 3](image3.png)

**Figure 3.** Comparison between the mid-IR and FIR index, $\alpha_{25-60}$, for Seyfert 1 (solid line) and Seyfert 2 (dashed line) galaxies. This sample includes 36 Seyfert 1 and 62 Seyfert 2 galaxies. The K-S test for the spectral index returns a 0.1% probability of the null hypothesis.

![Figure 4](image4.png)

**Figure 4.** Comparison of the [O iv]/[Ne ii], [Ne iii]/[Ne ii], and [O iv]/[Ne iii] distributions in Seyfert 1 and Seyfert 2 galaxies. For the [O iv]/[Ne ii], [Ne iii]/[Ne ii], and [O iv]/[Ne iii] ratios, the K-S test returns an ~0.9%, ~1.1%, and ~37.7% probability of the null hypothesis, respectively.
Figure 7 shows the correlation between [O \text{ iv}] and [Ne \text{ iii}] in fluxes (left) and luminosities (right), where a tight and strong correlation is seen (also see Table 3). This result corroborates the effectiveness of [Ne \text{ iii}] as a tracer of the AGN power as discussed by Gorjian et al. (2007), who found a strong correlation between the [Ne \text{ v}] 214.3 \mu m emission line, which originates from an ion with an ionization potential of \sim 97 eV and thus is due almost entirely to AGN photoionization (Abel & Satyapal 2008), and [Ne \text{ iii}]. Although there is evidence of [Ne \text{ iii}] emission from stars (e.g., Ho & Keto 2007), the tight correlation between [O \text{ iv}] and [Ne \text{ iii}] suggests that this contribution is minimal in our AGN sample. In this regard, Figure 7 also shows 11 “pure” AGN sources (see Table 1), i.e., sources that show no detectable PAH features at 6.2 and 11.5 \mu m in their spectra. One can see the similarity between the full sample and the pure AGN linear fits. The linear regression values for the pure AGN sources are given in Table 4.

Assuming that the observed [Ne \text{ ii}] emission is composed of both an AGN and a stellar component, we estimated the star formation contribution (SC) in the [Ne \text{ ii}] emission by subtracting the predicted [Ne \text{ ii}] that is produced by the AGN. In this regard, the predicted [Ne \text{ ii}] emission associated with the AGN was obtained from the linear regression for the pure AGN sources from the observed [Ne \text{ ii}]-[O \text{ iv}] correlation in luminosities.

Figure 8 shows the correlation between [Ne \text{ ii}] and [O \text{ iv}] luminosities. The different dashed lines represent the percentage of SC in the observed [Ne \text{ ii}] emission lines. Table 1 shows the percentage of SC, SC (%), in the [Ne \text{ ii}] observed luminosity. For example, NGC 7469 and NGC 3079 are known to harbor regions of enhanced star formation (Perez-Olea & Colina 1996; Genzel et al. 1998; Weedman et al. 2005). In these galaxies, the AGN contributes \sim 12\% for NGC 7469 and \sim 18\% for NGC 3079 to the observed [Ne \text{ ii}] flux. These results are in agreement with the strong PAH 6.2 \mu m (F_{6.2,\mu m} > 5.3 \times 10^{-19} \text{ W cm}^{-2}) observed in these objects by Deo et al. (2007). Genzel et al. (1998) generated an empirical diagram (mixing model) to separate the AGN from galaxies powered by enhanced star formation by using the ratio of high- and low-ionization mid-IR lines and PAH features. We compared their results with values obtained in the present work for our sample. For example, Genzel et al. (1998) find that Mrk 273 has an AGN contribution of \sim 40\%, compared with \sim 34\% from our empirical diagnostic. The Seyfert galaxies NGC 4151, NGC 1068, NGC 5506, and NGC 3783 are AGN-dominated; i.e., more than 75\% of the [Ne \text{ ii}] contribution is from the AGN, as suggested by previous mixing models (Genzel et al. 1998).
1998; Sturm et al. 2002). These results are in excellent agreement with the star formation and AGN contribution values that we obtained from these objects (see Table 1). The Seyfert 2 galaxy NGC 6240 is dominated by star formation (Lutz et al. 1996; Genzel et al. 1998) in agreement with our value of an ∼90% stellar contribution to the [Ne ii] emission line. We estimated an error of ∼20% in the AGN-predicted [Ne ii] luminosities, based on the SC obtained for Mrk 3, which is one of the objects with no detectable PAHs at 6.2 μm (Deo et al. 2007).

Table 2 shows the results from the deconvolution method for the SC in the [Ne ii] emission. We found that, averaged over populations, Seyfert 2 galaxies have a stronger stellar contribution in their [Ne ii] observed emission line, ∼43% ± 4%, than that found in Seyfert 1 galaxies, ∼28% ± 5%. The K-S test returns an ∼4.4% probability of the null hypothesis, meaning that the two groups of Seyfert galaxies are statistically different in their relative stellar contribution to their [Ne ii] emission, despite the fact that there are Seyfert 1 galaxies in our sample with strong starbursts (e.g., NGC 7469). Nevertheless, these results are in agreement with previous findings where Seyfert 2 galaxies typically show stronger starburst signatures in their infrared spectra than Seyfert 1 galaxies (e.g., Buchanan et al. 2006).

In Figure 9 we plot the result from the deconvolution method performed to the observed [Ne ii] emission. In the top, middle, and lower panels, the solid line represents the linear fit obtained for the full sample, and the dashed line represents the linear fit for the pure AGN sources. Other symbols are the same as in Fig. 5. [See the electronic edition of the Journal for a color version of this figure.]

**TABLE 4**

**Linear Regressions and Statistical Analysis for the [O iv], [Ne iii], and [Ne ii] Fluxes and Luminosities for the Pure AGN Sources**

| Parameter | log [Ne ii] | log [O iv] |
|-----------|------------|------------|
|           | a          | b          | a          | b          |
| Fluxes    |            |            |            |            |
| log $F_{[Ne\ ii]}$ | 0.81671 | −2.5689 | 0.71895 | −3.9149 |
|           | 0.8 ± 0.1 | −3 ± 1   | 0.7 ± 0.1 | −4 ± 2   |
| $r_s = 0.90$ | $P_r = 4.4 \times 10^{-3}$ | $r_s = 0.87$ | $P_r = 5.8 \times 10^{-3}$ |
| Luminosities |            |            |            |            |
| log $L_{[Ne\ ii]}$ | 0.86602 | 5.3088 | 0.82205 | 6.9797 |
|           | 0.9 ± 0.1 | 5 ± 4   | 0.8 ± 0.1 | 7 ± 5    |
| $r_s = 0.945$ | $P_r = 2.6 \times 10^{-3}$ | $r_s = 0.945$ | $P_r = 2.0 \times 10^{-3}$ |
| log $L_{25 \mu m}$ | ... | ... | 1.0395 | 0.97779 |
| log $L_{40 \mu m}$ | ... | ... | 0.79048 | 11.128 |
| log $L_{100 \mu m}$ | ... | ... | 0.8 ± 0.1 | 11 ± 6  |
| log $L_{170 \mu m}$ | ... | ... | 0.74334 | 13.148 |
| log $L_{FIR}$ | ... | ... | 0.7 ± 0.1 | 13 ± 6  |

**Notes.**—The sources that show no detectable PAH features at 6.2 and 11.5 μm in their spectra are F15480-0344, IRAS 00521−7054, MCG −2-8-39, Mrk 3, Mrk 9, NGC 3227, NGC 4941, NGC 526A, NGC 5548, NGC 7314, and UM 146. The regression coefficient (slope) and regression constant (intercept) are denoted by $a$ and $b$, respectively; $r_s$ is the Spearman rank order correlation coefficient, and $P_r$ is the null probability. For each relation we present the exact linear regression values, the values as constrained by their statistical errors, and the Spearman rank and null probability. Here log [Ne ii] and log [O iv] indicate the independent variable and will match the physical units of the observable quantities presented in the first column.
bottom panels we present the observed (AGN + stellar) component, the AGN only, and the stellar component for [Ne ii] versus [Ne iii] emission-line luminosities. In order to avoid a misleadingly linear correlation, we plot the observed, stellar, and AGN components of [Ne ii] versus [Ne iii]. A tight correlation between [Ne iii] and the pure-AGN [Ne ii] validates the method used to untangle the different contributions in the [Ne ii] emission line. In the bottom panel of Figure 9, one can note the lack of correlation between the stellar component of [Ne ii] and the strength of the AGN, as characterized by the [Ne iii] emission.

5. STAR FORMATION RATE

Using a sample of non-AGN star-forming galaxies, Ho & Keto (2007) investigated the utility of the mid-IR emission lines of [Ne ii] and [Ne iii] as a SFR indicator, given the fact that the Lyman continuum radiation, which can ionize Ne+ and Ne2+, is mainly produced by young stars. In order to calculate the SFR we used the stellar component of [Ne ii], as deconvolved from the previous analysis, and assumed $f_{+} = 0.75$ and $f_{2+} = 0$ for the fraction of neon in the form of Ne0 and Ne+, respectively (Ho & Keto 2007). Since we could not extract the SC from the [Ne iii] emission lines, given the tight correlation with [O iv], we assumed that all the [Ne iii] emission is coming from the AGN. Therefore, the SFR derived only from [Ne ii] represents a lower limit for the region within the extraction aperture for a fixed value of the fractional abundances for Ne0 and Ne+. The SFR ($M_{\odot}$ yr$^{-1}$) values are presented in Table 1. One must note that the predicted SFR may depend on the aperture size; accordingly, the second-to-last column of Table 1 shows the size (in kpc) that the slit samples in the dispersion direction.

We performed a K-S test analysis for the derived SFR for Seyfert 1 and Seyfert 2 galaxies; from this analysis we found an $\sim 18.2\%$ probability of the null hypothesis, suggesting that Seyfert 1 and Seyfert 2 galaxies have statistically similar SFRs. In this regard we found the SFR in Seyfert 2 galaxies to have an average of $8 \pm 2$ and $7 \pm 2 M_{\odot}$ yr$^{-1}$ for Seyfert 1 galaxies. Caution must be taken on the interpretation of the SFR derived from the [Ne ii] luminosity. This derived SFR is a probe of the young massive stellar population and is independent of the previous star formation history. As an example, Davies et al. (2007) analyzed the star formation history in the AGN-dominated Seyfert 2 galaxy NGC 1068. They estimated a SFR($M_{\odot}$ yr$^{-1}$ kpc$^{-2}$) = 90–170 with a starburst age of 200–300 Myr. Our results are significantly lower, SFR($M_{\odot}$ yr$^{-1}$ kpc$^{-2}$) = 0.45, suggesting minimal current star formation, in agreement with the extensive analysis...
discussed by Davies et al. (2007). In general, our results are systematically lower than those found by Davies et al. (2007), given the fact that in the nuclear regions of their sample of Seyfert galaxies there appear to have been recent, 10–300 Myr, starbursts that must have already ceased. In other words, their diagnostic sample contained an older stellar population than that mapped by [Ne ii], which only traces young (<10 Myr) stars (Leitherer et al. 1999).

6. CORRELATION BETWEEN THE INFRARED CONTINUUM AND MID-IR EMISSION LINES

Besides the low-ionization, mid-IR [Ne ii] emission line, the FIR is also a good indicator of star formation, as it correlates very tightly with the 1415 MHz radio luminosity, which is thought to be produced by the same population of massive stars that heat and ionize H ii regions (Condon 1992). There is a strong correlation between the FIR and [Ne ii] (Sturm et al. 2002; Schweitzer et al. 2006), which supports a scenario in which the mid-IR luminosity is dominated by the AGN, while the FIR luminosity is dominated by star formation (Sturm et al. 2002; Horst et al. 2006).

Figure 10 shows the correlation between the IR continuum and mid-IR emission lines in our sample. Table 3 shows the statistical analysis for the different correlations. We found that [Ne ii] is well correlated with the continuum luminosity at 60 μm, in agreement with previous studies (e.g., Sturm et al. 2002; Schweitzer et al. 2006). Compared with the [Ne ii] correlation, both [Ne iii] and [O iv] show larger scatter with respect to the IR continuum (see Table 3). We have demonstrated that [Ne iii] correlates with [O iv], suggesting [Ne iii] as a good tracer of the AGN luminosity (see § 4); the better correlation at shorter continuum wavelengths suggests a larger AGN contribution at those wavelengths, in agreement with previous studies.

As we mentioned before, there is the technical difficulty in isolating the AGN continuum from the host galaxy emission (e.g., Lutz et al. 2004), especially in the larger field of view of IRAS. In order to estimate the SC in the mid-IR and FIR continua, we used the correlations between [O iv] and the mid-IR and FIR continua in the sources that show no PAH features in their spectra as a template to estimate the contribution from the AGN. This contribution is inevitably mixed with some fraction of star formation in the host galaxy. By subtracting this contribution to the observed continuum luminosities, we obtained the remaining fraction of star formation, e.g., a “pure” stellar component, and thus a lower limit for the SC to the mid-IR and FIR continua.

In our sample, we found the contribution of star formation that cannot be associated with the pure AGN sources to be 32% ± 2%, 45% ± 5%, 39% ± 4%, and 42% ± 4% for the luminosities at 25 μm, 60 μm, 100 μm, and FIR, respectively. These results suggest that the FIR continuum contains a higher fraction from a stellar component than that found in the mid-IR (25 μm). Within this sample, Seyfert 1 galaxies exhibit a narrower range of SC, ~26% ± 1%, to their mid-IR and FIR continuum luminosities than that found for Seyfert 2 galaxies, ~47% ± 9%. Figure 11 shows the correlation between FIR and [O iv] luminosities with the percentage of SC to the FIR luminosities indicated. The fact that most of the pure AGN sources are in the lower part of the FIR-[O iv] correlation suggests that the fraction of star formation in the host galaxy that is mixed with the AGN contribution is minimal. Overall, these results are in good agreement with previous studies that used the infrared continuum to separate the relative contribution of star formation and nuclear activity (e.g., Shi et al. 2007) and with the values derived from the [O iv]–[Ne ii] correlation, which shows that Seyfert 2 galaxies have, on average, a stronger SC.
In order to assess the relative contribution from the AGN to the mid-IR and FIR continuum within Seyfert classification, we investigated the ratio of [O iv] to the 25 μm, 60 μm, and FIR continuum luminosities. We found that Seyfert 1 and Seyfert 2 galaxies are statistically different in their AGN contribution to their 60 μm and FIR luminosities, with a probability of the null hypothesis of 0.2% and 0.4%, respectively. On the other hand, the K-S test of the [O iv]/25 μm ratio shows that two samples drawn from the same population would differ this much only ~36.7% of the time.

7. PHYSICAL CONDITIONS IN THE [Ne ii] EMITTING REGION

We have established that a fraction of the [Ne ii] emission must come from the AGN, given the fact that this line is present in the spectra of AGNs that have no detected PAH features at 6.2 and 11.2 μm (which have been shown to be tracers of star formation activity). In order to investigate the physical conditions in the emission-line regions, ionized by the AGN, for [Ne ii], [Ne iii], and [O iv], we generated a grid of dust-free, single-zone, constant-density models using the photoionization code CLOUDY, version 07.02.01, last described by Ferland et al. (1998). In this grid, the hydrogen density (n_H) and ionization parameter U were varied. The ionization parameter U is defined as (see Osterbrock & Ferland 2006)

$$U = \frac{1}{4\pi R^2 n_H} \int_{\nu_{\text{min}}}^{\infty} \frac{L_\nu}{h\nu} d\nu = \frac{Q(\text{H})}{4\pi R^2 n_H}$$

(1)

where R is the distance to the cloud, c is the speed of light, and Q(H) is the flux of the ionizing photons.

We used a set of roughly solar abundances (e.g., Grevesse & Anders 1989). The logs of the abundances relative to H by number are as follows: He, −1; C, −3.46; N, −3.92; O, −3.19; Ne, −3.96; Na, −5.69; Mg, −4.48; Al, −5.53; Si, −4.50; P, −6.43; S, −4.82; Ar, −5.40; Ca, −5.64; Fe, −4.40; and Ni, −5.75. We assumed a column density of 10^{21} cm^{-2}, which is typical of the NLR (e.g., Kraemer et al. 2000).

Assuming a distance of R = 130 pc for the NLR (see M08), we overlaid the observed mid-IR emission-line flux correlations (i.e., [Ne ii]-[Ne iii], [Ne ii]-[O iv], and [Ne ii]-[O iv]) from the “pure” AGN sources with those obtained from the photoionization modeling. From this comparison we derived the parameter space (U, n_H) required to reproduce the observed relationships within their given dispersion. The predicted, intrinsic fluxes from the photoionization models are the line fluxes emitted at the ionized face of the slab of gas, used to model the NLR. Caution must be taken when comparing [Ne ii], [Ne iii], and [O iv], given the fact that the observed [Ne ii] fluxes can have contributions from both star formation and AGNs. In this regard, we are only interested in the AGN component of [Ne ii], as deconvolved with the method presented in this work. On the other hand, the observed [Ne iii] and [O iv] in our sample have been assumed to represent the AGN power.

From the observed [Ne iii]/[Ne ii] ratios we obtained a range for the ionization parameter of −4.00 < log U < −3.50 and, for the hydrogen density, 4.25 cm^{-3} < log n_H < 5.50 cm^{-3}. From the same set of models, we investigated the relationship between the AGN components of the [Ne ii] and [O iv] emission fluxes. From the observed range of [O iv]/[Ne ii] ratios we obtained −3.20 < log U < −2.45 and 3.25 cm^{-3} < log n_H < 4.50 cm^{-3}. Finally, we investigated the ratios of the [O iv] and [Ne iii] emission fluxes. We obtained a range for the ionization parameter, −3.20 < log U < −1.65, and a range for the hydrogen density, 2.00 cm^{-3} < log n_H < 4.50 cm^{-3}. This range in parameter space is the closest match to the one found from the [O iv]/[O iii] ratio (M08), −1.50 < log U < −1.30 and 2.0 cm^{-3} < log n_H < 4.25 cm^{-3}.

In Figure 12 we show the allowed ranges in parameter space from the different emission-line correlations and compare them with the parameter space obtained from the [O iv]/[O iii] ratios (M08). Given the low ionization parameter obtained for [Ne ii], it is possible that [Ne ii] that is produced by the AGN could originate in a more distant region than [O iv]. On the other hand, the [Ne ii]/[O iv] relationship suggests a different [Ne ii] component at higher ionization and lower densities than that found from the [Ne ii]-[Ne iii] correlation, indicating a closer and/or more compact [Ne ii] emitting region. Another possibility is that [Ne ii] forms in regions that are irradiated by the continuum filtered by ionized gas (Kraemer et al. 2008). However, for uncovered gas, there is only a small range in parameter space where the model...
successfully predicts the [Ne ii] emission associated with the AGN.

8. CONCLUSIONS

We have investigated the ionization state of the emission-line gas in Seyfert galaxies with the aim of constraining the active galactic nuclei (AGNs) and star formation contributions in the mid-infrared (mid-IR) and far-infrared (FIR) spectra for a sample of 103 Seyfert galaxies. We found the ratio between the AGN power and star formation, as shown by [O iv]/[Ne ii], to be smaller in Seyfert 2 than in Seyfert 1 galaxies. In this regard, we also found a correlation between [Ne ii] and [O iv] versus [Ne ii], with a clear separation between Seyfert groups. This separation suggests that the [Ne ii] emission has two different contributions: a component that could be associated with the AGN ionizing continuum and a component produced by photoionization from star formation regions. The evidence for the former is the presence of [Ne ii] in Seyfert galaxies with no detectable PAH features at 6.2 and 11.5 μm. We also obtained a strong correlation between [Ne ii] and [O iv] confirming that [Ne ii] can also be used to estimate the intrinsic power of the AGN.

We used the [O iv] and [Ne ii] correlation from the sources with no detectable PAH features as a template to deconvolve the star formation and AGN contribution in the [Ne ii] emission. We found that Seyfert 2 galaxies, on average, have a relatively higher star formation contribution in their [Ne ii], by a factor of ~1.5, than Seyfert 1 galaxies, in agreement with other observations and theoretical work on circumnuclear regions of AGNs (e.g., Terlevich & Melnick 1985; Heckman et al. 1989; Maiolino et al. 1997; González Delgado et al. 2001; Deo et al. 2007). Using the stellar [Ne ii] luminosity as a SFR estimator, we found that Seyfert 2 galaxies have similar SFRs in their spectra, \(8 \pm 2 \, M_\odot \, yr^{-1}\), to that found for Seyfert 1 galaxies, \(7 \pm 2 \, M_\odot \, yr^{-1}\). This result must be interpreted carefully, given the fact that [Ne ii] emission provides an instantaneous measure of the SFR, independent of previous star formation history. Thus, caution must be taken when comparing with other SFR indicators in galaxies that have recent starbursts but are no longer forming massive stars, in which case our star formation predictions may account for only a small fraction of a given SFR. Overall, we found that 77% of the Seyfert 2 galaxies in our sample show some star formation contribution to their [Ne ii] observed luminosities, while 56% of the Seyfert 1 galaxies have a stellar component.

We used the correlations between the mid-IR and FIR continua with the [O iv] luminosities in the non-PAH sources to estimate the star formation contribution in the mid-IR and FIR continua. The resulting star formation contribution represents a lower limit, given the fact that some fraction of the star formation from the host galaxy is mixed with the AGN contribution in the mid-IR and FIR continua in our sample of pure AGN sources. Averaged over the entire sample, we found the contribution from star formation to the 25 μm, 60 μm, 100 μm, and FIR luminosities to be 32% ± 2%, 45% ± 5%, 39% ± 4%, and 42% ± 4%, respectively. We also found that Seyfert 1 galaxies exhibit a narrower range of star formation contribution, ~26% ± 1%, to their mid-IR and FIR continuum luminosities than that found for Seyfert 2 galaxies, ~47% ± 9%.

We also found a good correlation between [Ne ii] and mid-IR and FIR luminosities, with the strongest correlation for [Ne ii] ~ 60 μm. This result is in agreement with previous studies that link both the FIR and [Ne ii] emission with star formation. We found a weaker correlation between [O iv] and [Ne iii] versus the FIR luminosities. This result suggests that part of the FIR luminosity is reprocessed photons from the AGN, most likely through reradiation of the AGN continuum by dust. Assuming that the infrared continuum is dominated by emission from dust grains, we found in our sample that Seyfert 2 galaxies possess cooler dust, with an average \(\alpha_{25-60} = -1.5 \pm 0.1\), than Seyfert 1 galaxies, which have \(\alpha_{25-60} = -0.8 \pm 0.1\). In agreement, we also found that Seyfert 1 and Seyfert 2 galaxies are statistically different in terms of their relative contribution from the AGN to the 60 μm and FIR luminosities but have a similar contribution to the 25 μm luminosity.

In summary, we found that Seyfert 1 and Seyfert 2 galaxies are statistically different in terms of the relative contribution from the AGN and star formation, as shown by the [O iv]/[Ne ii] ratios. From this we found that Seyfert 2 galaxies have a higher star formation contribution, relative to the strength of the AGN, than that found in Seyfert 1 galaxies, but similar SFRs. These results suggest that the differences between Seyfert galaxies cannot be solely due to viewing-angle dependence.

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REFERENCES

Abel, N. P., & Satyapal, S. 2008, ApJ, 678, 686
Antonucci, R. R. J. 1993, ARA&A, 31, 473
Antonucci, R. R. J., & Miller, J. S. 1985, ApJ, 297, 621
Armus, L., et al. 2007, ApJ, 656, 148
Bevington, P. R., & Robinson, D. K. 2003, Data Reduction and Error Analysis for the Physical Sciences (Boston: McGraw-Hill)
Buchanan, C. L., Gallimore, J. F., O’Dea, C. P., Baum, S. A., Axon, D. J., Robinson, A., Elitzur, M., & Elvis, M. 2006, AJ, 132, 401
Calzetti, D., et al. 2005, ApJ, 633, 871
Cid Fernandes, R., Gu, Q., Melnick, J., Terlevich, E., Terlevich, R., Kunth, D., Rodríguez Lacerda, R., & Joguet, B. 2004, MNRAS, 355, 273
Cid Fernandes, R., Heckman, T., Schmitt, H., Delgado, R. M. G., & Storchi-Bergmann, T. 2001, ApJ, 558, 81
Cid Fernandes, R. J., & Terlevich, R. 1995, MNRAS, 272, 423
Clavel, J., et al. 2000, A&A, 357, 839
Condon, J. J. 1992, ARA&A, 30, 575

Dale, D. A., et al. 2006, ApJ, 646, 161
Davies, R. I., Mueller Sánchez, F., Genzel, R., Tacconi, L. J., Hicks, E. K. S., Friedrich, S., & Sternberg, A. 2007, ApJ, 671, 1388
Deo, R. P., Crenshaw, D. M., Kraemer, S. B., Dietrich, M., Elitzur, M., Teplitz, H., & Turner, T. J. 2007, ApJ, 671, 124
Ferland, G. J., Korista, K. T., Verner, D. A., Ferguson, J. W., Kingdon, J. B., & Verner, E. M. 1998, PASP, 110, 761
Fürster Schreiber, N. M., Roussel, H., Sauvage, M., & Charmandaris, V. 2004, A&A, 419, 501

Greaves, N., & Anders, E. 1989, in AIP Conf. Ser. 183, Cosmic Abundances of Matter, ed. C. J. Waddington (New York: AIP), 1

Gui, Q., Melnick, J., Fernandes, R. C., Kunth, D., Terlevich, E., & Terlevich, R. 2006, MNRAS, 366, 480
