FAR-INFRARED LINE AND DUST EMISSION FROM H\textsc{ii} REGIONS AND PHOTODISSOCIATION REGIONS

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ABSTRACT

We explore the effect of varying the spectral energy distribution of the incident continuum, by simultaneously and self-consistently computing the structure of an H\textsc{ii} region and a photodissociation region that are in pressure equilibrium. The results of the calculations are applied to extragalactic observations. The intensity ratio diagrams of far-infrared (FIR) emission for Herschel bands (70, 110, 160, 250, 350, and 500 \(\mu\)m) and the contribution from H\textsc{ii} regions for these specific FIR emissions are presented for the first time. With these diagrams, we compare the predicted FIR continuum intensity ratios of M82 with observations by Herschel.

Key words: H\textsc{ii} regions – ISM: atoms – photon-dominated region (PDR)

1. INTRODUCTION

Photodissociation regions (PDRs; Tielens & Hollenbach 1985) are regions of the interstellar medium (ISM) where far-ultraviolet (FUV; 6 eV < \(h\nu\) < 13.6 eV) photons dominate the structure, chemistry, and thermal balance of gas (Hollenbach & Tielens 1997). All neutral atomic hydrogen gas and a large fraction of the molecular gas in galaxies are in PDRs. PDRs are the origin of most of the non-stellar infrared (IR) emission from galaxies, including the far-IR (FIR) continuum from dust grains, near-IR and mid-IR emission from polycyclic aromatic hydrocarbons, as well as fine structure IR emission such as \([\text{O}\,\text{ii}]\) 63 \(\mu\)m and 146 \(\mu\)m, \([\text{C}\,\text{ii}]\) 370 \(\mu\)m and 609 \(\mu\)m, \([\text{Si}\,\text{ii}]\) 35 \(\mu\)m and \([\text{C}\,\text{ii}]\) 158 \(\mu\)m.

H\textsc{ii} regions adjacent to PDRs are known to contribute to line emission and the FIR continuum, which are also found in the surrounding PDRs. Heiles (1994) found that the ionized medium contributes to \([\text{C}\,\text{ii}]\) 158 \(\mu\)m line luminosity. \([\text{O}\,\text{i}]\) 63 \(\mu\)m and 146 \(\mu\)m, \([\text{Si}\,\text{ii}]\) 35 \(\mu\)m, and \([\text{Fe}\,\text{ii}]\) 26 \(\mu\)m line emission also exist in H\textsc{ii} regions (Abel et al. 2005; Kaufman et al. 2006). Dust grains in H\textsc{ii} regions absorb ionizing photons and reemit in the FIR continuum (Bottorff et al. 1998). Thus, when we observe the H\textsc{ii} region and PDR in one telescope beam, the FIR and line emissions generally come from both regions.

There are two methods to separately derive the properties and contributions of H\textsc{ii} regions and PDRs. Both methods treat the radiation processes of these two regions with distinctive differences. The first method is to use the \([\text{N}\,\text{ii}]\) 122 \(\mu\)m/\([\text{C}\,\text{ii}]\) 158 \(\mu\)m ratio (Heiles 1994; Malhotra et al. 2001) and the \([\text{N}\,\text{ii}]\) 205 \(\mu\)m/\([\text{C}\,\text{ii}]\) 158 \(\mu\)m ratio (Oberst et al. 2006) in an ionized medium. Since N has a first ionization potential (14.5 eV) higher than that of H, \([\text{N}\,\text{ii}]\) is found only in H\textsc{ii} regions. Using the \([\text{N}\,\text{ii}]/[\text{C}\,\text{ii}]\) ratio, one can derive the emission of \([\text{C}\,\text{ii}]\) 158 \(\mu\)m that arises from H\textsc{ii} regions. This method is only useful for deriving \([\text{C}\,\text{ii}]\) 158 \(\mu\)m line emission. The second method is to calculate a separate model for each region. Carral et al. (1994) estimated the \([\text{C}\,\text{ii}]\) 158 \(\mu\)m emission of H\textsc{ii} regions from models of Rubin (1985) and the \([\text{C}\,\text{ii}]\) 158 \(\mu\)m emission of PDRs from models of Tielens & Hollenbach (1985) and Hollenbach et al. (1991). A similar approach is taken to estimate the contributions for \([\text{Si}\,\text{ii}]\) 35 \(\mu\)m line emission in M82 (Lord et al. 1996). Colbert et al. (1999) combined starburst H\textsc{ii} region models and PDR models of Kaufman et al. (1999) to derive the H\textsc{ii} region and PDR properties of M82. Kaufman et al. (2006) computed a separate model for each region. They merged the H\textsc{ii} region model and PDR model by equaling the thermal pressure at the interface. The edge of the H\textsc{ii} region is defined at the point where H is 50% neutral. This kind of separated calculation must take great care to assure that the transmitted continuum emerging from the H\textsc{ii} region is consistent with the initial conditions for the PDR (Abel 2006).

2. THE A05 MODEL OF THE H\textsc{ii} REGION AND PDR

Using a procedure different from that described above, Abel et al. (2005) self-consistently calculated the thermal and chemical structure of an H\textsc{ii} region and a surrounding PDR which are in pressure equilibrium (henceforth the A05 model). In this method, they viewed the H\textsc{ii} region and PDR as a single region driven by UV radiation from stars. This treatment has been tested in various environments (e.g., Pellegrini et al. 2007, 2009; Henney et al. 2007; O’Halloran et al. 2008; Graciá-Carpio et al. 2011). The A05 model produces diagnostics without needing to assume how much of the emission is from H\textsc{ii} regions or from PDRs. The advantage of the A05 model is to shield the complexity of the boundaries between H\textsc{ii} regions and PDRs, and provide observables based on parameterized stellar radiation, gas density, composition, and geometry.

In the A05 model, the parameterized UV flux of stars is the source of ionization and photodissociation of the ISM, creating H\textsc{ii} regions and surrounding PDRs. The spectral energy distribution (SED) of stellar atmospheres influences the ionization structures of H\textsc{ii} regions and PDRs. Morisset et al. (2004) computed models of H\textsc{ii} regions using a variety of recent state-of-the-art stellar atmospheres models. They compared model predictions to catalogs of Infrared Space Observatory observations of Galactic H\textsc{ii} regions, and confirmed the findings of earlier investigations, showing that CoStar (Schaerer & de Koter 1997) atmospheres adopted by Abel et al. (2005) over-predict somewhat the ionizing flux at high energies. They also concluded that WMBasic (Pauldrach et al. 2001) atmospheres show a reasonable agreement with the observations.

In this paper, we adopt WMBasic stellar atmospheres, repeat the calculations presented in Abel et al. (2005), using the same dynamical range for ionization parameter, density, equation of state, and abundances, and extend wavelength coverage to

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Herschel$^2$ FIR bands up to 500 μm. Then we apply our results to M82 and NGC 253. At the same time, we explore the effect of varying stellar atmospheres in the A05 model, and compare our work with Abel et al. (2005). We perform calculations for CoStar and WMBasic atmospheres at the effective temperatures $T = 34,000$ K and at $T = 38,000$ K. The model calculations are presented in Section 3, and the results are shown in Section 4. In Section 5, we compare model predictions to observational data in the literature. We summarize in Section 6.

3. MODEL CALCULATIONS

The calculation details are the same as Abel et al. (2005). The Cloudy$^3$ code described by Ferland et al. (2013) is used in the calculations. We also define the end of the H II region in the same way as Abel et al. (2005). The major differences between the Abel et al. (2005) calculations and the ones presented here are that we use the WMBasic stellar radiation field, and the calculations are stopped at $A_v = 10$ instead of 100.

In order to explore the effect of different stellar atmospheres, we compute models for WMBasic and CoStar atmospheres with an incident continuum as shown in Figure 1. Figure 1 shows that the CoStar radiation field produces more H ionizing flux than WMBasic.

In the model, the H II region and the PDR are placed between the ionizing source and the observers. Thus, we observe the transmitted continuum and outward emission from the emitting cloud. We define that the PDR extends to a visual extinction $A_v = 10$. At that depth, H is molecular and C is incorporated into CO. Figure 2 shows that the integrated intensity of PDR lines is stable at $A_v = 10$.

4. RESULTS

In this section, we present the calculation results in a series of contour plots for all the $U$, $n(H)$, and stellar atmospheres. Diagnostic diagrams similar to ones in Abel et al. (2005) are not presented here, since they are insensitive to the choice of stellar continuum. We show the differences between CoStar and WMBasic atmospheres for the A05 model in Section 4.1. Intensity ratios of FIR emission for the 70, 110, 160, 250, 350, and 500 μm are first presented in Section 4.2.

4.1. Differences between the CoStar and WMBasic Atmospheres for the A05 Model

The strength of the ionizing radiation field can be constrained by the intensity ratio of emission lines from sequential stages of ionization of a single element. The [Ne III] 15.5 μm/[Ne II] 12.8 μm ratio (Figure 3) and the [S IV] 10.5 μm/[S III] 18.7 μm ratio (Figure 4) are good measures of the hardness of the radiation field (Beirão et al. 2008). [Ne III] 15.5 μm/[Ne II] 12.8 μm ratio plots are more horizontal than [S IV] 10.5 μm/[S III] 18.7 μm ratio plots. Comparing the plots for WMBasic and CoStar atmospheres, we find that at $T = 38,000$ K, the [Ne III] 15.5 μm/[Ne II] 12.8 μm ratio for CoStar atmospheres is 50 times greater than that for WMBasic atmospheres, while the [S IV] 10.5 μm/[S III] 18.7 μm ratio for CoStar atmospheres is 10 times greater than that for WMBasic atmospheres. With the same $U$, WMBasic atmospheres need a higher stellar temperature than CoStar atmospheres to produce the same ratios. The result that these H II region lines are sensitive to the ionizing flux distribution was also shown in Morisset et al. (2004).

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$^2$ Herschel is an ESA space observatory with science instruments provided by European-led Principal Investigator consortia and with important participation from NASA.

$^3$ Version 13.02.
Figure 1 shows that the FUV continuum is nearly identical between CoStar and WMBasic atmospheres. As a result, our calculations for the $G_0$ (in units of the local Galactic FUV flux = $1.6 \times 10^{-3}$ erg cm$^{-2}$ s$^{-1}$; Habing 1968), density as a function of depth, the PDR line ratios, and the contribution of traditional PDR lines (except for the [C ii] 158 $\mu$m line from the H II region) are essentially unchanged between Abel et al. (2005) and this work. Density diagnostics, the [O iii] 52 $\mu$m/[O iii] 88 $\mu$m ratio, and the [S iii] 18.7 $\mu$m/[S iii] 33.5 $\mu$m ratio are not sensitive to stellar atmospheres. Therefore we do not present these diagrams in this work and refer to the Abel et al. (2005) results for applications.

Figure 5 shows the difference in the contribution for [C ii] 158 $\mu$m between the two stellar atmospheres. This kind of difference has been found by Abel (2006), who compared Kurucz (Kurucz 1979) stellar atmospheres along with WMBasic and a blackbody in analyzing the [C ii] contribution from the ionized gas.

4.2. FIR Thermal Dust Emission

Interstellar dust in galaxies absorbs energy from starlight and re-radiates at IR and FIR wave ranges. PACS (Poglitsch et al. 2010) and SPIRE (Griffin et al. 2010) on board Herschel (Pilbratt et al. 2010) observe at 70, 110, 160, 250, 350, and 500 $\mu$m. Ratios of emission in these wavebands indicate the dust temperature and brightness (e.g., Roussel et al. 2010).

Abel et al. (2009) showed the 60 $\mu$m/100 $\mu$m ratio, and the fraction of total FIR emitted by dust at the H II ionization front. Here we present the first calculations of the FIR continuum ratios.
for the Herschel bands (Figures 6 and 7). Figures 6 and 7 show that the CoStar and WMBasic plots give essentially the same FIR band ratios. The contribution to FIR continuum emission from H II regions is the same for either stellar atmosphere and therefore we only show the results for the WMBasic model in Figure 8.

At relatively low density, the contributions from H II regions for 350 and 500 μm emission depend strongly on U rather than on density, and the H II region contributes more at higher U. At the upper-right corner of the contour plots for 350 and 500 μm where the density and U are high, contributions depend both on U and density. For 160 and 250 μm emission, the contributions from H II regions depend strongly on U rather than on density. For 70 and 110 μm emission, the contributions from H II regions depend both on U and density. PDR is the main origin of 110, 160, 250, and 350 μm continuum emission, although H II regions still contribute more than 20% emission at log U > −1.5. H II regions can dominate the 500 μm emission when both density and U are high (log U > −2 and log n(H) > 3 cm⁻³), and dominate the 70 μm emission when log U > −2 and log n(H) < 2.5 cm⁻³. The H II region contributes more at higher U because a larger fraction of the UV and ionizing photons are absorbed by dust in the H II region.

Going to a higher A_v will cause colder dust to affect the overall observed FIR emission. To give some insight into this effect, we calculate the A05 model at A_v = 5, 10, 50, 100, and
Figure 5. Contribution to intensity of [C ii] 158 μm from H II region for WMBasic and CoStar atmospheres. The values of the contour are the fraction of [C ii] 158 μm intensity from H II regions. For the most part, the contribution from the H II regions is between 3% and 30%.

200 for log $U = -2$ and log $n(H) = 2$ cm$^{-3}$. The predicted temperature of graphite with size 0.1 μm is 21 K at $A_v = 5$, 18 K at $A_v = 10$, 16 K at $A_v = 50$ and $A_v = 100$, and 15 K at $A_v = 200$.

5. APPLICATION TO EXTRA-GALAXIES

We apply the results to extra-galaxies, and explore the influence of different stellar atmospheres. Comparing observations with our models, we derive $U$ (Figures 3 and 4). Comparing observations with Figure 22 of Abel et al. (2005), we derive $n(H)$. Then comparing Figures 5, 7, and 8 in this work and Figures 16, 17, 27, 29, and 33 of Abel et al. (2005) with the derived $U$ and $n(H)$, we can derive other parameters.

To compare our results with Abel et al. (2005) and the separated treatment of H II regions and PDRs (Carral et al. 1994), we apply our results to NGC 253, which was also analyzed by Abel et al. (2005) and Carral et al. (1994).

M82 was recently observed by Herschel to obtain the FIR continuum flux at 250, 350, and 500 μm (Roussel et al. 2010). We use our results for the FIR continuum (Figures 7 and 8) to predict the properties of dust emission in H II regions and PDRs, and compare this with observations.

5.1. Application to NGC 253 and Comparison with Abel et al. (2005)

In this section, we compare our results with results of Abel et al. (2005) and Carral et al. (1994), and discuss discrepancies.
A significant gradient in the [Ne\textsc{iii}] 15.5 \textmu m/[Ne\textsc{ii}] 12.8 \textmu m ratio is detected in NGC 253 (Devost et al. 2004). The [Ne\textsc{iii}] 15.5 \textmu m/[Ne\textsc{ii}] 12.8 \textmu m ratio is between 0.08 and 0.14 at the center region (Devost et al. 2004), whereas Verma et al. (2003) found it to be 0.07. The [S\textsc{iv}] 10.5 \textmu m/[S\textsc{iii}] 18.7 \textmu m ratio is about 0.03 (Verma et al. 2003). To derive the value of $U$, we compare the [Ne\textsc{iii}] 15.5 \textmu m/[Ne\textsc{ii}] 12.8 \textmu m ratio (0.07 $\sim$ 0.14) and the [S\textsc{iv}] 10.5 \textmu m/[S\textsc{iii}] 18.7 \textmu m ratio with Figures 3 and 4. We find log $U$ is $\sim$ $-2$ for CoStar atmospheres at $T = 34,000$ K. Abel et al. (2005) found that the value of the [Ne\textsc{iii}] 15.5 \textmu m/[Ne\textsc{ii}] 12.8 \textmu m ratio and the [S\textsc{iv}] 10.5 \textmu m/[S\textsc{iii}] 18.7 \textmu m ratio increase with effective temperature, and they are sensitive to $U$ and $T$. For WMBasic atmospheres, the effective temperature 34,000 K is not hot enough to produce an [Ne\textsc{iii}] 15.5 \textmu m/[Ne\textsc{ii}] 12.8 \textmu m ratio as large as 0.14 (Figure 3), and we find log $U$ = $-2.5$ for WMBasic atmospheres at 38,000 K. The difference in effective temperature is caused by the discrepancy in SED shapes of stellar atmospheres (Figure 1).

The [S\textsc{iii}] 18.7 \textmu m/[S\textsc{iii}] 33.5 \textmu m ratio is $\sim 0.5$ (Verma et al. 2003). The [O\textsc{iii}] 52 \textmu m/[O\textsc{iii}] 88 \textmu m ratio is 1–2 (Carral et al. 1994). Comparing those ratios with Figure 22 of Abel et al. (2005), we find that $n$(H) is between 100 cm$^{-3}$ and 200 cm$^{-3}$ for both stellar atmospheres. We adopt $n$(H) = 150 cm$^{-3}$ as Abel et al. (2005) did. Comparing the derived $U$ and density to other plots (Figure 5 in this work and Figures 16, 17, 27, 29, and 33...
of Abel et al. (2005), we can deduce the $G_0$, PDR density, line ratios, and contributions for lines.

We summarize all the predictions from our results, from Abel et al. (2005), and from Carral et al. (1994) in Table 1. Our predictions of CoStar are consistent with Abel et al. (2005). Compared with CoStar atmospheres, our results for WMBasic atmospheres suggest a 20\% smaller contribution from the H\textsc{ii} region for the [C\textsc{ii}] 158 $\mu$m line intensity and a 2.5 times greater contribution for the [Si\textsc{ii}] 35 $\mu$m line intensity (Table 1).

Both our calculations and those of Abel et al. (2005) suggest a lower $G_0$ than Carral et al. (1994) deduced. Here we discuss this phenomenon qualitatively. To derive physical parameters including $G_0$, Carral et al. (1994) performed two separate calculations, one for the H\textsc{ii} region and one for the PDR. They assumed $\sim$ 30\% of the [C\textsc{ii}] 158 $\mu$m emission in NGC 253 originates in H\textsc{ii} regions, and assumed no [Si\textsc{ii}] 35 $\mu$m emission in the PDR modeling. They followed the model of Wolfire et al. (1990), using the [C\textsc{ii}] 158 $\mu$m/[O\textsc{i}] 63 $\mu$m intensity ratio and the line-to-continuum ratio, $(I_{[\text{Si\textsc{ii}}]} 35 \mu m + I_{[\text{O\textsc{i}}]} 63 \mu m + I_{[\text{C\textsc{ii}}]} 158 \mu m)/I_{IR}$, to estimate $G_0$ and PDR density. Assuming that most [Si\textsc{ii}] 35 $\mu$m emission comes from the H\textsc{ii} region, Carral et al. (1994) adopted $(I_{[\text{O\textsc{i}}]} 63 \mu m + I_{[\text{C\textsc{ii}}]} 158 \mu m)/I_{IR}$ instead of $(I_{[\text{Si\textsc{ii}}]} 35 \mu m + I_{[\text{O\textsc{i}}]} 63 \mu m + I_{[\text{C\textsc{ii}}]} 158 \mu m)/I_{IR}$ as used in Wolfire et al. (1990). $G_0$ increases when the [C\textsc{ii}] 158 $\mu$m/[O\textsc{i}] 63 $\mu$m intensity ratio and line-to-continuum ratio decrease (Figure 1 in Wolfire et al. 1990).

Figure 7. Intensity ratios of FIR continuum for WMBasic atmospheres at $T = 38,000$ K.
Figure 8. Contribution to FIR continuum intensity of 70, 110, 160, 250, 350, and 500 $\mu$m from H\textsc{ii} regions for WMBasic atmospheres at $T = 38,000$ K. The value of the contour level is the ratio of FIR continuum intensity from the H\textsc{ii} region to its total intensity from the H\textsc{ii} region and PDR.
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Table 1
Application to NGC 253

| Parameters                  | CoStar         | WMBasic       | Abel et al. (2005) | Carral et al. (1994) |
|-----------------------------|----------------|---------------|-------------------|----------------------|
| log U                       | −2             | −2.5          | −2                | ...                  |
| n(H) (cm⁻³)                 | 150            | 150           | 150               | 3E⁻²²                  |
| G_0                         | 5E3            | 1E2.8         | 5E3               | 2E4                  |
| PDR density (cm⁻³)          | 2E3~2E4        | 2E3~4E4       | 2E3~2E4           | 1E4                  |
| [O ii] 63 μm/[C ii] 158 μm  | 1              | 1             | 1                 | 0.8 ~ 1.1            |
| Contribution to [C ii] b     | 25%            | 20%           | 30%               | 30%                  |
| Contribution to [Si ii] b    | 20%            | 50%           | 20%               | ...                  |

Notes.

a Accurate to about a factor of two.
b The percentage of this line intensity from H II regions.

table 2
Application to M82

| Parameters                  | Observations | Model Predictions | References |
|-----------------------------|--------------|-------------------|------------|
| log U                       | −3.5; −2.5   | −2.5              | 1, 2       |
| n(H) (cm⁻³)                 | 250; 100     | 150               | 1, 2       |
| G_0                         | 10⁵⁻⁸         | 10⁵⁻⁸             | 1          |
| PDR density (cm⁻³)          | 10³⁻³; 10⁻⁴; 10⁻⁶ | 10³⁻³; 10⁻⁶ | 1          |
| [O ii] 63 μm/[C ii] 158 μm  | 1.38 ± 0.03  | 1                 | 1          |
| Contribution to intensity of [C ii] 158 μma | 25%        | 20%               | 1          |
| I[50 μm]/I[500 μm]b         | 9.2⁺; 8.5⁻   | 7.5               | 3          |
| I[250 μm]/I[500 μm]b        | 2.9⁺; 2.7⁻    | 2.5               | 3          |

Notes.

a The percentage of this line intensity from H II regions.
b Ratio of FIR continuum intensity at different wavelength.
c Ratio of global flux.
d Ratio of wind and halo flux.

References. (1) Colbert et al. 1999; (2) Spinoglio & Malkan 1992; (3) Roussel et al. 2010.

For WMBasic atmospheres, our models predict that only 20% of [C ii] 158 μm arises from H II regions, and as much as 50% of [Si ii] 35 μm emission arises from the PDR. For CoStar atmospheres, our models and Abel et al. (2005) suggest as much as 80% of [Si ii] 35 μm emission arises from PDR. Comparing with our predictions (Table 1), Carral et al. (1994) overestimated the contribution from H II regions to [C ii] 158 μm and ignored the [Si ii] 35 μm intensity from PDR, resulting in a lower [C ii] 158 μm/[O i] 63 μm intensity ratio and a lower line-to-continuum ratio for PDR emission. Because of this underestimation of the [C ii] 158 μm/[O i] 63 μm ratio and the line-to-continuum ratio, Carral et al. (1994) derived a larger G_0 than predictions from our models and Abel et al. (2005).

5.2. Application to M82

M82 is a nearby (D = 3.25 Mpc; Tammann & Sandage 1968) starburst galaxy, well studied in the FIR wavelength range (e.g., Lord et al. 1996; Colbert et al. 1999). In the core of M82, the active starburst region spans a diameter of 300 pc (Grijs et al. 2001).

H II region diagnostics are observed at the center region of M82 (Beirão et al. 2008). The [Ne iii] 15.5 μm/[Ne ii] 12.8 μm ratio is 0.15, and the [S iv] 10.5 μm/[S iii] 18.7 μm ratio is 0.036. Comparing observations with Figures 3 and 4, we find that both ratios indicate log U to be −2.5 for WMBasic atmospheres at T = 38,000 K. Comparing Figure 22 of Abel et al. (2005) with the [O iii] 52 μm/[O ii] 88 μm ratio 1.24 (Colbert et al. 1999), we find the density to be 150 cm⁻³. Using this U and n(H), we derive other parameters with Figures 5, 7, and 8 in this work and Figures 16, 17, 27, 29, and 33 of Abel et al. (2005). The deduced parameters are summarized in Table 2.

In M82, dust continuum emission is strong in the superwind region and the very extended emission indicates dust distribution in the halo of this galaxy (Engelbracht et al. 2006). Roussel et al. (2010) found that FIR flux ratios would then be a natural consequence of the dilution of the radiation field with distance from the emitting stars. The measured global flux densities are 457 ± 2 Jy at 250 μm, 155 ± 2 Jy at 350 μm, and 49.6 ± 0.9 at 500 μm (Roussel et al. 2010). The center region of M82 has a complex structure, and the starburst emissions from the center region are 337, 111, and 35.4 Jy at 250, 350, and 500 μm, respectively (Roussel et al. 2010). After subtracting the starburst emission from global fluxes, the values of the 250 μm/350 μm ratio and the 250 μm/500 μm ratio are 2.7 and 8.5. Contributions of FIR continuum intensity from H II regions are similar for all three bands, at about 5% (Figure 8). Compared with the ratios of global emission and the ratios of emission from wind and halo regions (Table 2), the predicted FIR continuum ratios (Figure 7) are more consistent with the wind and halo regions. Underestimation of the 250 μm/350 μm ratio and the 250 μm/500 μm ratio can be explained by the difference of dust size distribution between M82 and our assumption, since dust grains with different sizes emit FIR emission dominating FIR emission in a different wavelength range. The predicted ratios of the FIR continuum are more consistent with the FIR ratio for wind and halo regions, which suggests that the size distributions of dust grains in these regions are closer to the model assumption than the center region. More detailed modeling exploration with Cloudy will
be performed in the future to explain discrepancies between observations and models.

6. SUMMARY

The A05 model predicts diagnostic observables of an H II region and an associated PDR based on two external parameters: the ionization parameter U and initial total hydrogen density n(H) at the illuminated face, given the continuum shape and intensity of the ionization source, the chemical abundance of the gas, the condition of dust, and the geometry of the cloud. We explore the effect of different stellar atmospheres, discussing differences between calculation results for WMBasic and CoStar atmospheres. We present the first set of plots of FIR ratios for Herschel bands, and contributions to these specific FIR emissions from H II regions.

The [Ne iii] 15.5 μm/[Ne ii] 12.8 μm and [S iv] 10.5 μm/[S iii] 18.7 μm ratios are sensitive to stellar atmospheres. With the same U, WMBasic atmospheres need a higher stellar temperature than CoStar atmospheres to produce the same [Ne iii] 15.5 μm/[Ne ii] 12.8 μm and [S iv] 10.5 μm/[S iii] 18.7 μm ratios.

We find that H ii regions can dominate the 500 μm continuum emission when log U > −2 and log n(H) > 3 cm−3, and dominate the 70 μm emission when log U > −2 and log n(H) < 2.5 cm−3. PDR is the main origin of 110, 160, 250, and 350 μm continuum emission, although H ii regions still contribute more than 20% emission at log U > −1.5.

We apply our results to two galaxies. For NGC 253, our results for CoStar atmospheres are consistent with Abel et al. (2005). Models for WMBasic atmospheres predict that ~50% of [Si ii] 35 μm line intensity arises from the H ii region, while the H ii region only contributes ~20% for CoStar atmospheres. For M82, we find G0 ~ 10^2-3 and a PDR density ~10^4 cm−3. The FIR continuum ratios predicted by the model are more consistent with the wind and halo regions of M82.

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