Mid and Far-infrared emission lines in galaxies: The SHINING contribution to the understanding of general trends

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Abstract

The Infrared Space Observatory (ISO) contributed significantly to our understanding of the physical conditions in the interstellar medium (ISM) of galaxies. During two and a half years it collected information about the MIR and FIR-emission lines in more than 200 galaxies (e.g., Brauher et al. 2008). From the intensity of these lines, it is possible to calculate the density, ionization and elemental abundances of the ISM. They can also be used to estimate the relative contribution of star formation and AGN activity to the total luminosity of galaxies. After ISO, Spitzer Space Telescope observations have considerably increased the number of galaxies with MIR line detections (e.g., Farrah et al. 2007; Veilleux et al. 2009). The Herschel Space Observatory, thanks to its much larger telescope size, will complement and enlarge previous observations in the FIR with unprecedented sensitivity.

In this poster we present the results from the compilation of a MIR and FIR-line database that includes more that 30 atomic and molecular lines in more than 500 galaxies. The database covers up to 6 orders of magnitude in FIR luminosity, from blue compact galaxies and dwarf galaxies to ultraluminous infrared galaxies and high redshift galaxies. In addition to this database we present some of the first results from the SHINING Herschel Guaranteed Time Key Program, devoted to study the FIR line emission in a large sample of local starbursts, AGNs and infrared luminous galaxies. We find that galaxies with high star formation efficiencies (SFE $\propto L_{\rm FIR}/M_{\rm H_2}$) tend to have lower line-to-FIR continuum ratios than starbursts and AGNs with lower SFE. These line deficits affect lines formed in HII regions (the ionized gas) and in photon dominated regions (PDRs, the neutral gas) and might be explained by an increase in the ionization parameter.

The IR line database

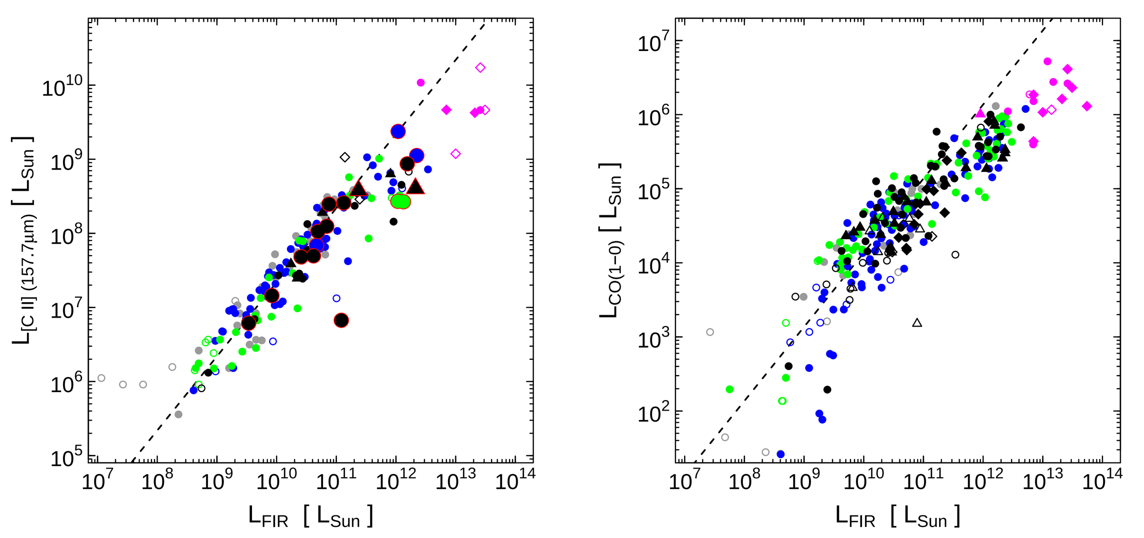

Figure 1: [C II] 158 μm and CO(1–0) luminosity as a function of $L_{\rm FIR}$ for the galaxies included in the IR line database. **Black** symbols: AGNs (circles: Seyfert 2 galaxies, triangles: Seyfert 1 galaxies, diamonds: QSOs); **green**: LINERs; **blue**: HII galaxies; grey: unclassified galaxies; **magenta**: high redshift galaxies. Open symbols are upper limits to the line flux. New Herschel/PACS observations from the SHINING program are indicated with larger symbols. The dashed lines are linear fits to galaxies with $L_{\rm FIR} < 10^{11}\,L_\odot$. Luminous and ultraluminous infrared galaxies (LIRGs: $10^{11}\,L_\odot < L_{\rm FIR} < 10^{12}\,L_\odot$, ULIRGs: $L_{\rm FIR} > 10^{12}\,L_\odot$) have lower [C II] luminosities than would be expected for their FIR luminosity (Malhotra et al. 1997; Luhman et al. 2003). The star formation efficiency (SFE $\propto L_{\rm FIR}/L_{\rm CO(1-0)}$) is also higher in these galaxies (e.g., Sanders et al. 1991).

Comparison with M82

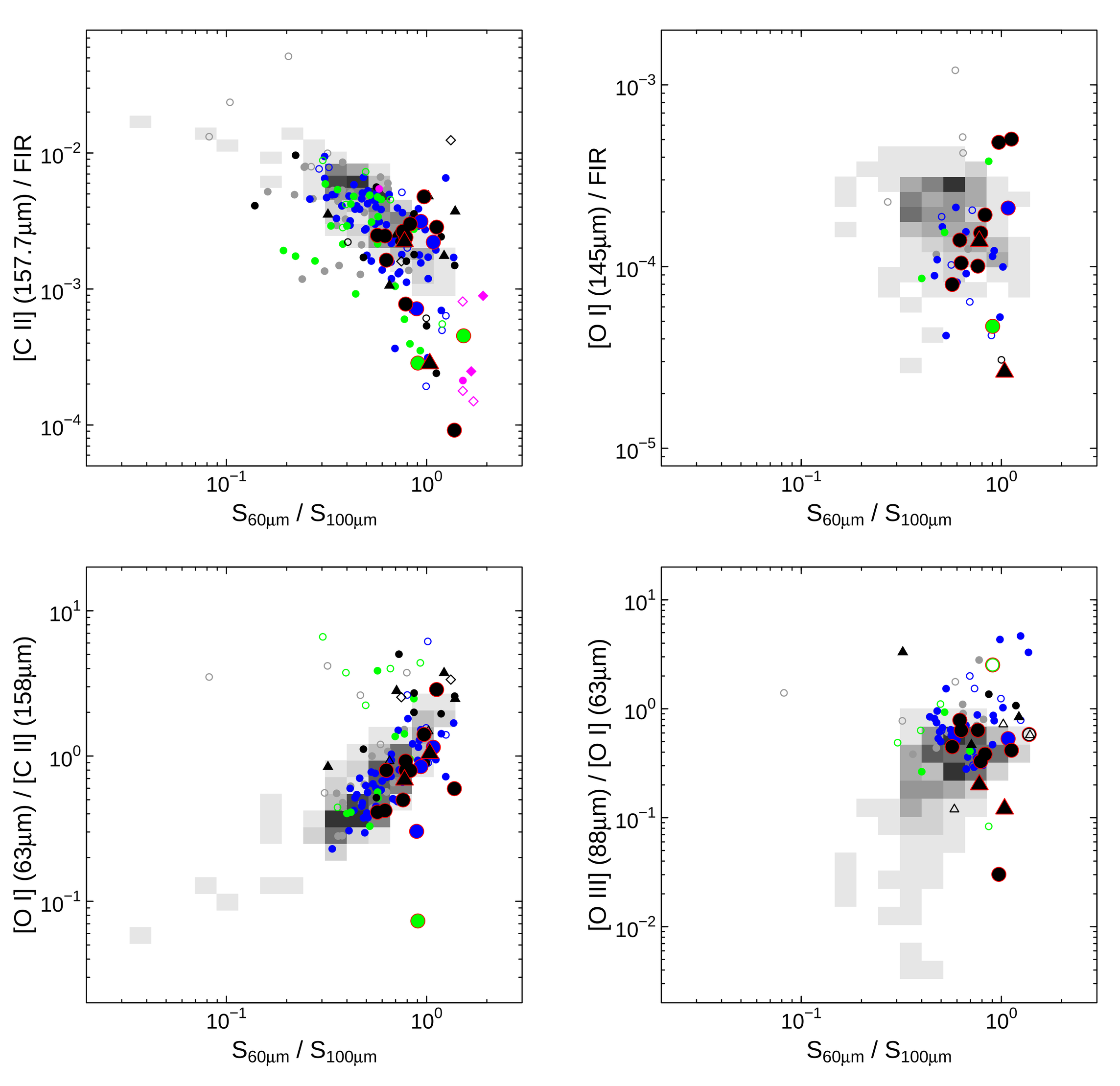

Figure 2: Upper panels: [C II] 158 μm/FIR and [O I] 145 μm/FIR galaxy-averaged ratios as a function of the $S_{60\,\mu m}/S_{100\,\mu m}$ dust color. Lower panels: the same but for the [O I] 63 μm/[C II] 158 μm and [O III] 88 μm/[O I] 63 μm line ratios. Symbols are as in Figure 1. Grey cells show the Herschel/PACS spatially resolved observations of the starburst galaxy M82 (Contursi et al., in preparation; second talk in Parallel Session B2). The darkness of the cell increases with the number of spatial pixels inside the cell.

Line deficits

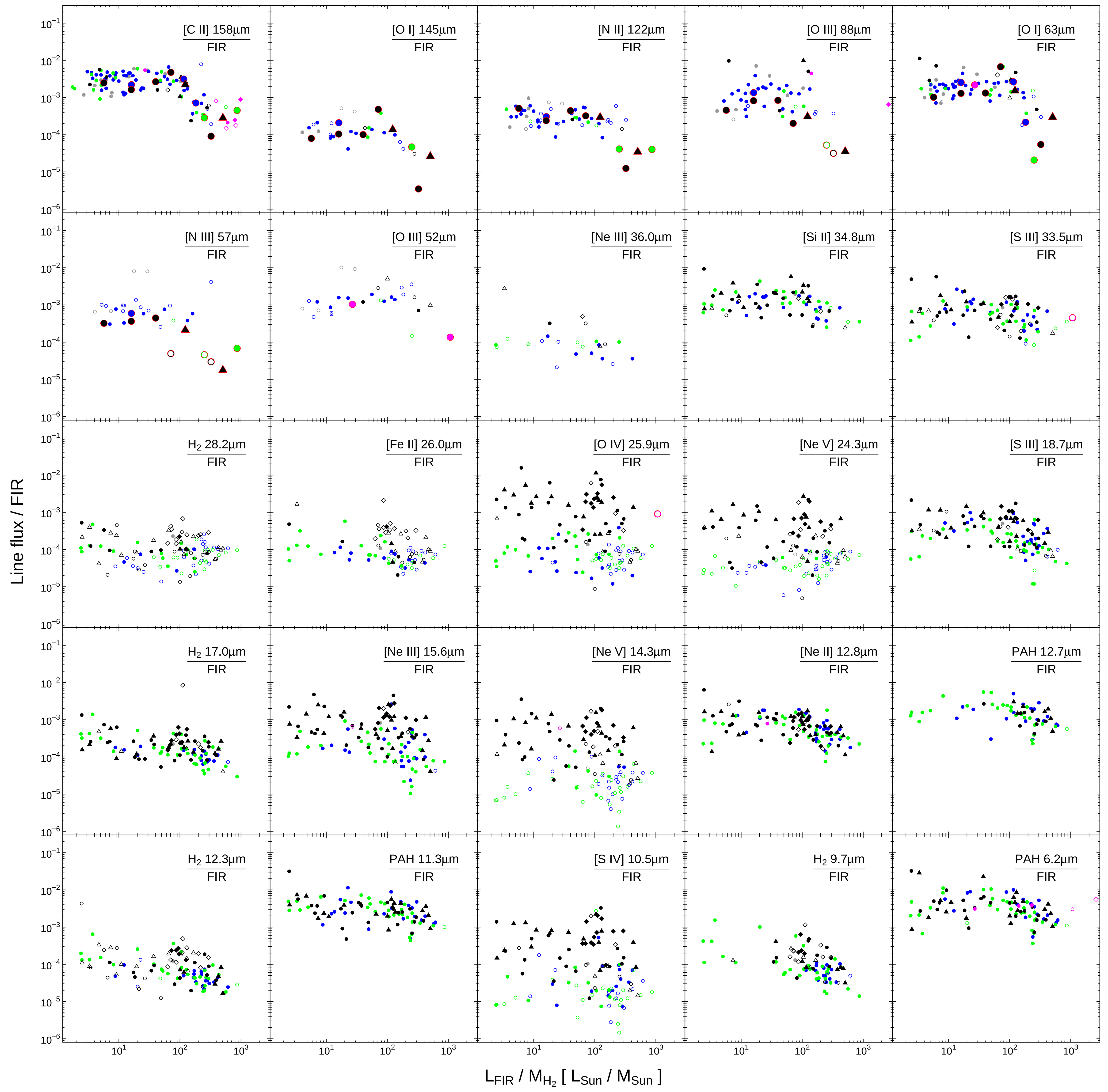

Figure 3: Galaxy-integrated line fluxes divided by the FIR (40.5 μm–120.5 μm) continuum flux as a function of star formation efficiency (SFE $\propto L_{\rm FIR}/M_{\rm H_2}$). Symbols are as in Figure 1. New Herschel/PACS observations from the SHINING sample are indicated with larger symbols. Galaxies with high star formation efficiencies ($L_{\rm FIR}/M_{\rm H_2} > 10^2\,L_\odot/M_\odot$) generally have lower line-to-FIR continuum ratios than starbursts and AGNs with lower SFE. SHINING will significantly increase the number of galaxies with FIR line detections, especially at the high luminosity and high SFE end, where, in most cases, only upper limits are available.

Cloudy models

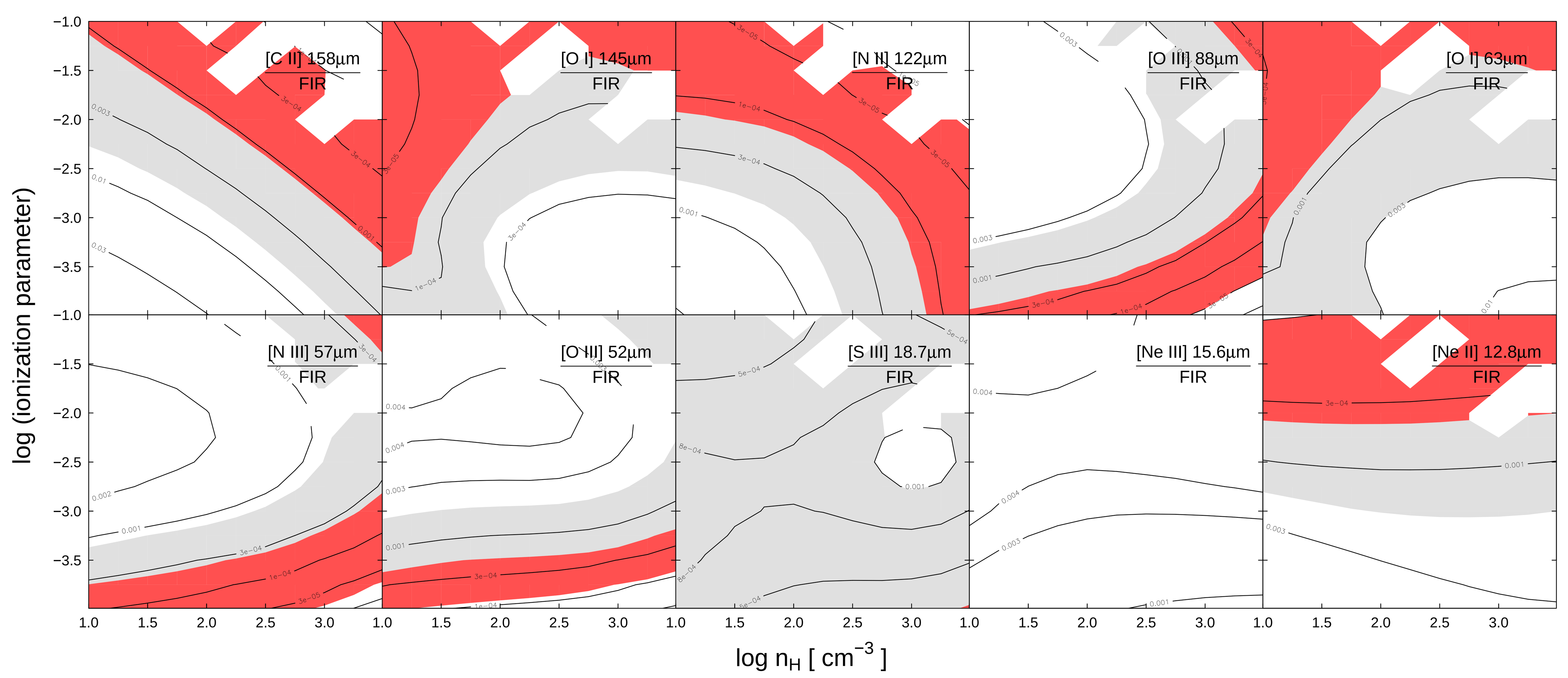

Figure 4: Cloudy (Ferland et al. 1998) model predictions for various line-to-FIR continuum ratios as a function of the hydrogen density and the ionization parameter at the illuminated face of the cloud. The ionization parameter is defined as the number of hydrogen ionizing photons per hydrogen atom. The model simultaneously calculates the emission from the molecular, neutral and ionized gas assuming pressure equilibrium (see Abel et al. 2005 for a detailed description). The ionizing source is represented in this particular case by a non-LTE CoStar stellar atmosphere (Schaerer & de Koter 1997) with $T_* = 38000$ K. The calculations stopped at $A_V = 30$ mag ($N_H = 6\times10^{22}$ cm^{-2} for $A_V/N_H = 5\times10^{-22}$ mag cm^2). The following elemental abundances were used: He/H $= 9.8\times10^{-2}$, C/H $= 1.4\times10^{-4}$, O/H $= 3.0\times10^{-4}$, N/H $= 7.9\times10^{-5}$, S/H $= 9.5\times10^{-6}$, Ne/H $= 2.9\times10^{-4}$ (Verma et al. 2003). Grey areas indicate the range of line-to-FIR ratios observed in starburst galaxies with $L_{\rm FIR}/M_{\rm H_2} < 10^2\,L_\odot/M_\odot$. Galaxies with $L_{\rm FIR}/M_{\rm H_2} > 10^2\,L_\odot/M_\odot$, mostly LIRGs and ULIRGs, tend to have lower line-to-FIR ratios (see Figure 3); their range of observed values is indicated in the figure by the red area. Many of the observed line deficits can be explain if the ionization parameter is higher in infrared galaxies than in starburst galaxies with lower star formation efficiencies (see also Abel et al. 2009). This is not surprising as the ionization parameter is expected to increase with SFE.

References

- Abel et al. 2005, ApJS 161, 65
- Abel et al. 2009, ApJ 701, 1147
- Brauher et al. 2008, ApJS 178, 280
- Farrah et al. 2007, ApJ 667, 149
- Ferland et al. 1998, PASP 110, 761
- Luhman et al. 2003, ApJ 594, 758
- Malhotra et al. 1997, ApJ 491, L27
- Sanders et al. 1991, ApJ 370, 158
- Schaerer & de Koter 1997, A&A 322, 598
- Veilleux et al. 2009 ApJS 182, 628
- Verma et al. 2003, A&A 403, 829

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