THE IMPACT OF NEW IONIZING FLUXES ON ISO OBSERVATIONS OF HII REGIONS AND STARBURSTS

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ABSTRACT

Extensive grids of photoionization models have been calculated for single star H\textsc{ii} regions and evolving starbursts. We illustrate the predictions for IR fine structure lines which are used to analyse the stellar content, and derive properties such as the age and IMF. The impact of recent ionizing fluxes on the IR lines are shown. First comparisons of our starburst models with IR-diagnostics and the ISO observations of Genzel et al. (1998) are also presented.

Key words: HII regions, galaxies: starburst, ISO.

1. INTRODUCTION

The analysis of fine structure lines is crucial to interpret IR observations of ultra-compact H\textsc{ii} regions, giant H\textsc{ii} regions and starburst galaxies in terms of their stellar content. Through photoionization modeling the nature of the ionizing sources of H\textsc{ii} regions and properties of starburst regions such as the age and the IMF (slope, upper mass-cutoff) can in principle be determined. Considerable progress has been made in the recent year in this respect through the use of new stellar fluxes, spectral energy distributions appropriate for evolving stellar populations at different metallicities and including detailed observational constraints (e.g. Garcia-Vargas et al. 1995, 1997, Stasińska & Leitherer 1996, Stasińska & Schaerer 1997, González-Delgado et al. 1998). None of these studies have, however, focused on IR observation which are now becoming widely available thanks to ISO.

In this contribution we present exploratory results regarding predictions of IR lines from two sets of recent photoionization models: 1) Single star H\textsc{ii} regions using the latest ionizing fluxes from non-LTE, line blanketed atmospheres including stellar winds (CoStar models, Schaerer & de Koter 1997) and, 2) Photoionization models for evolving starburst populations based on the Leitherer & Heckman (1995) synthesis models. Detailed results from new photoionization models for starbursts including the CoStar models and updated stellar tracks will be presented elsewhere.

2. SINGLE STAR HII REGION MODELS

In Figure 1 we illustrate the behaviour of the line ratios of some important fine structure lines observable in the SWS range and with ISOCAM/CVF. This figure, based on the model calculations of Stasińska & Schaerer (1997, hereafter SS97), shows the dependence of the line ratios on the stellar temperature and – importantly – also on the ionization parameter. The comparison between the top and bottom row shows the differences obtained using either the recent CoStar atmosphere models or Kurucz plane parallel LTE models. Due to the harder spectrum predicted by the CoStar models above \sim 35-40 eV (Schaerer & de Koter) a higher excitation is generally predicted for a given $T_{\text{eff}}$ than with Kurucz models (see SS97).

Evidence supporting such an increase of the hardness of the ionizing flux comes from the KAO observations of Rubin and coworkers (cf. Simpson et al. 1995). Indeed, the CoStar models including stellar winds, non-LTE effects and line blanketing are thereby able to provide a satisfactory description of the Ne\textsuperscript{++}/O\textsuperscript{++} line ratios (see SS97, also Sellmaier et al. 1996).

Encouraged by these successes atmosphere models including the most relevant physical processes (stellar winds, non-LTE, blanketing) continue to be improved. See e.g. Pauldrach (1997) and Schaerer (1997) for recent progress reports. In addition more stringent tests using ISO observations of nebulae with well known ionizing sources would be extremely valuable. Detailed photoionization modeling including constraints on the nebular geometry and likely also their dust content will be necessary to achieve such a goal.

In Fig. 2 we plot the predictions for single star H\textsc{ii} regions for some quantities of interest for the interpretation of integrated populations discussed later. The middle and right panels show the ratio of luminosity in the Lyman continuum (assuming an average photon energy of 16 eV) $L_{\text{LyC}}$ to the [Ne\textsc{ii}] and [S\textsc{iii}] line luminosity respectively. It is useful to understand the behaviour of the [Ne\textsc{ii}]/[S\textsc{iii}] 12.8/33.5 ratio (left) since either of these lines is sometimes
used as a proxy in case the other line is unobservable (cf. Genzel et al. 1998). Indeed for a given \( T_{\text{eff}} \) one obtains a relatively small variation (\( \sim 1 \) dex) of \([\text{Ne} \text{ II}]/[\text{S} \text{ III}]\) with the ionization parameter. In all our “reference models” (constructed assuming a gas density of \( 10 \text{ cm}^{-3} \)) we predict \([\text{Ne} \text{ II}]/[\text{S} \text{ III}]\) \(< 1\). For stars with \( T_{\text{eff}} > 36 \text{ kK} \) the differences between the CoStar and Kurucz fluxes become non-negligible for \([\text{Ne} \text{ II}]/[\text{S} \text{ III}]\). Some implications of these finding are briefly discussed below.

3. PHOTOIONIZATION MODELS FOR EVOLVING STARBURSTS

IR fine structure lines provide a new tool to study the hot star population of obscured starbursts. Through comparisons with photoionization modeling this allows in particular to constrain the star formation history and the upper end of the initial mass function (e.g. Lutz et al. 1998). Empirical diagnostic diagrams based on IR lines also allow the distinction between starburst and AGN powered sources (Genzel et al. 1998). Theoretically these diagnostics remain, however, to be understood and quantified.

To address such questions photoionization models representing evolving starbursts at different metallicities are nowadays required. In the following we will briefly illustrate some predictions from such models for fine structure lines in the ISO LWS range. The predictions shown here are drawn from the models of Stasińska & Leitherer (1996, hereafter SL96, available by anonymous ftp from ftp.obspm.fr/pub/obs/grazyna/cd-crete). Detailed results from new photoionization models for young starbursts based on the most recent evolutionary synthesis models of Schaerer & Vacca (1998) including the latest Geneva stellar tracks and CoStar model atmospheres (cf. above) will be presented elsewhere.

In Figure 3 we show the computed temporal evolution of the line ratios of \([\text{Ne} \text{ III}]/[\text{Ne} \text{ II}]\) 12.8/15.5 \( \text{m} \), \([\text{Ar} \text{ III}]/[\text{Ar} \text{ II}]\) 8.9/6.9 \( \text{m} \), and \([\text{S} \text{ IV}]/[\text{S} \text{ III}]\) 10.5/18.7 \( \text{m} \) (all top row) for an instantaneous burst at \( 1/4 \) solar metallicity with a Salpeter IMF and \( M_{\text{up}} = 100 \text{ M}_\odot \) surrounded by a gas cloud of density \( n=10 \text{ cm}^{-3} \). Different symbols represent models with different (initial) ionization parameters: typically one has \( \log U \sim -5 \) (circles) to \( \log U \sim -1 \) (crosses). Note that in photoionization models of evolving starbursts, the dependence of \( U \) with time is a function of the adopted geometry, as stressed by Stasiński (1998). In the models of SL96, \( U \) decreases slightly with time.

As expected the excitation decreases with the age of the burst. It must, however, be reminded that the considered lines also strongly depend on the ionization parameter (see Fig. 3). Indeed the line ratios shown here vary typically by three orders of magnitudes for variations of \( U \) of \( 4 \) orders of magnitudes. For comparison a change of the upper mass-cutoff from 50 to \( 100 \text{ M}_\odot \) increases the same line ratios by less than one order of magnitude (e.g. Lutz et al. 1998). In general \( U \) is poorly constrained. Although optical spectra of \( \text{H II} \) galaxies can be reproduced...
with models covering only a fairly small range of $U$ ($\sim 1$ dex, SL96) this is not necessarily the case for ISO observations of starburst galaxies. This question needs a careful analysis before meaningful results can be derived on the IMF, age etc.

Genzel et al. find an empirical value of $[\text{Ne ii}] / [\text{S iii}] = 1.7 \pm 1.3$ (or $1.2 \pm 0.6$ excluding the two largest outliers) from their sample of 10 starbursts. The SL96 models constructed with a density of $n = 10 \, \text{cm}^{-3}$ typically predict $[\text{Ne ii}] < [\text{S iii}]$ (this is true also for solar metallicity models, not shown here). However, the SL96 models with $n = 10^4 \, \text{cm}^{-3}$ reach $[\text{Ne ii}] / [\text{S iii}]$ of 1.5, due to collisional deexcitation of [S iii]. The electron densities deduced from [S iii] 18.7/33.5 for a subset of starburst galaxies from the Genzel et al. sample are typically $< 10^2 - 2.5$, so it seems that collisional deexcitation is not sufficient to explain the large $[\text{Ne ii}] / [\text{S iii}]$ observed. Among possible factors to reduce the discrepancy are an Ne over-abundance (which however needs to be understood in more detail), or a softer ionizing radiation field. We conclude that the empirical value $[\text{Ne ii}] / [\text{S iii}] \sim 1.7$ for starbursts used in the diagnostic diagrams of Genzel et al. (1998) is theoretically not well understood yet.

For comparisons of the Lyman continuum luminosity $L_{\text{Lyc}}$ to the bolometric luminosity of starbursts, ULIRGS, etc. it is interesting to be able to derive $L_{\text{Lyc}}$ from the IR fine structure lines. This requires, however, some empirical calibration or the use of models. “Empirical” values of $L_{\text{Lyc}} / L([\text{Ne ii}]) = 64 \pm 37$ and $L_{\text{Lyc}} / L([\text{S iii}]) = 105 \pm 61$ are obtained from the starburst sample of Genzel et al. excluding NGC 5253, which shows much larger values. It must be reminded that $L_{\text{Lyc}}$ is derived from the Brackett recombination lines assuming case B and an average photon energy of 16 eV, and neglecting the absorption of Lyc photons by dust.

Our model predictions show in Fig. 3 (mid/right bottom panels) for the instantaneous burst model show quite a wide range for the $L_{\text{Lyc}} / L$ line ratios, depending on age and ionization parameter. Although these idealised models (instantaneous burst) are not necessarily representative for the average starburst population observed through the ISO aperture it is instructive to compare our predictions with the “observed” values of Genzel et al. In any case the predicted values of $L_{\text{Lyc}} / L([\text{Ne ii}])$ are systematically larger than the empirical starburst value even for the oldest age considered here. Using the CoStar model atmospheres will even further increase the predicted value given their harder energy distribution with respect to the Kurucz ones. The $L_{\text{Lyc}} / L([\text{S iii}])$ ratio shows a better agreement with the average value from Genzel et al. This is consistent with the discrepancy between the model predictions for $[\text{Ne ii}] / [\text{S iii}]$ and the observations discussed earlier. Most probably, the Lyc luminosities derived from the observations are underestimated because they do not take into account dust absorption of Lyc photons. More detailed analysis are required to obtain consistent a consistent picture of the fine structure lines in such objects.

4. CONCLUSIONS

We have illustrated the impact of the recent CoStar ionizing fluxes on IR fine structure lines for single star H II regions and shown predictions of IR lines for evolving starbursts resulting from calculations of extensive grids of photoionization models (see SL96, SS97).

As shown earlier, ionizing fluxes from non-LTE, line blanketed atmospheres including stellar wind models predict a harder spectrum (Schaerer & de Koter 1997) leading to higher excitation in the nebula. These predictions are supported by comparisons with optical and pre-ISO (KAO) IR observations of H II regions (SS97 and references therein). Detailed models of ultra-compact H II regions or H II regions with well-known stellar content based on ISO observations and other observational constraints will be extremely useful to better constrain the atmosphere models and probe the importance of other effects (e.g. dust) usually neglected in photoionization models. Such studies also provide important tests for our understanding of more complex objects like starbursts.

For starbursts we have illustrated the behaviour of line ratios which can in principle be used to constrain burst properties such as the age, IMF slope and upper mass-cutoff. We have also studied the behaviour of the $[\text{Ne ii}] / [\text{S iii}]$ ratio and diagnostics of $L_{\text{Lyc}}$ from fine structure lines extensively used by Genzel et al. (1998). We have shown that a thorough analysis of the properties of the nebular gas (ionization parameter, geometry, dust content, total amount of gas) is needed for reliable determinations of the stellar content of the nebulae observed by ISO.

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Figure 2. Same conventions as Fig. 1.

Figure 3. Photoionization models for evolving starburst (instantaneous burst, Salpeter IMF, $M_{\text{up}} = 100 \, M_{\odot}$, $Z = 1/4Z_{\odot}$) and varying ionization parameters ($\log U \sim -5$ to $-1$, circles to crosses).