Modelling Starbursts in HII Galaxies: What do we need to fit the observations?

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Abstract.
We have computed a series of realistic and self-consistent models that have been shown to be able to reproduce the emitted spectra of HII galaxies in a star bursting scenario. Our models combine different codes of chemical evolution, evolutionary population synthesis and photoionization. The emitted spectrum of HII galaxies is reproduced by means of the photoionization code CLOUDY [1], using as ionizing spectrum the spectral energy distribution (SED) of the modelled HII galaxy, calculated using the new and updated stellar population models PopStar ([9], in prep.). This, in turn, is calculated according to a star formation history and a metallicity evolution given by a chemical evolution model. Each model is characterized by three parameters which are going to determine the evolution of the modeled galaxy: an initial efficiency of star formation, the way in which burst take place, and the time of separation between these bursts. Some model results emerging from the combination of different values for these three parameters are shown here. Our technique reproduces observed abundances, diagnostic diagrams and equivalent width-colour relations for local HII galaxies.

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1. Introduction

HII galaxies are characterized by strong and narrow emission lines and by a low metal content, but this does not necessarily mean that these galaxies be young systems. The current burst of star formation (SF) dominates the SED even if previous stellar populations are present, making difficult to know the star formation history (SFH) of the galaxy. We have made a grid of attenuated star-bursting models, based on [5], using simultaneously the whole information available for the galaxy sample: the ionized gas, which defines the present time state of the galaxy, and spectrophotometric parameters, related to its SFH. The models are computed in a self-consistent way, that is using the same assumptions regarding stellar evolution, model stellar atmospheres and nucleosynthesis, and a realistic age-metallicity relation.

2. The Star-Bursting Model

The model consists in a set of successive instantaneous bursts of star formation in a region with a total mass of gas of $100 \cdot 10^6 \, M_\odot$, which take place along the whole evolution of the galaxy in 13.2 Gyr. The chemical evolution code used is based on [8]. We obtain for every 0.7 Myr time step the abundances of 15 elements: H, He, C, O, N, Ne, Na, Al, Mg, Si, S, Ca, Ar, Ni, Fe, the star formation rate (SFR) and the corresponding age-metallicity relation, $Z(t)$. With this SFH and $Z(t)$ we assign a SED from the library Popstar [9, in prep.], with a Ferrini IMF to each time step stellar population. When more than one burst takes place the resulting SED is the sum of the SEDs of every stellar generation convolved with the SFH. The final result is the total luminosity at each wavelength of the whole stellar population, including the ionizing continuum of the last formed stellar generation. This resulting SED is used as ionizing source for the photoionization code CLOUDY [1], which gives the emission lines produced by the modelled nebula. The gas is ionized by the massive stars of the current burst of SF, which is characterized by a radius $R$, calculated according to the mechanical energy output of the massive stars winds and SNeI explosions, a gas density, $n_H$, the number of Lyman ionizing photons $Q(H)$, obtained directly from the SEDs of the ionizing continuum, and the chemical abundances obtained from the chemical evolution code.

Each model is characterized by three input parameters:

- **The initial efficiency ($\epsilon$):** It is the amount of gas consumed to form stars in the first burst of star formation. We present here the models made with the percentages of 33% and 10%, that is, in these models, the first burst of star formation involves $33 \cdot 10^6 \, M_\odot$ (high efficiency model), and $10 \cdot 10^6 \, M_\odot$ (low efficiency model), respectively.

- **Attenuation ($k$):** The initial efficiency of star formation (SF) is attenuated in two different ways:
  
  (i) By a factor which changes with the number of the burst, $n$, following the expression:
  \[
  \Psi_n = \left( \frac{1}{n} \right) \cdot \Psi_0
  \]
  which corresponds to a soft attenuation.
(ii) By a constant factor, \( k^{(n-1)} \), according to the expression:
\[
\Psi_n = \Psi_0 \cdot k^{(n-1)}
\]
where \( n \) is the number of the current burst and \( k \) the attenuation factor. For this work we have taken \( k=0.65 \), corresponding to a strong attenuation.

- **Time between bursts (\( \Delta t \))**: Every burst takes place instantaneously and it is followed by quiet periods, whose duration can change. For this work we have taken \( \Delta t=1.3 \) Gyr for the inter-burst time, that is, one burst every 1.3 Gyr. For comparison purposes, we are going to show some results of models with \( \Delta t=0.1 \) Gyr and \( \Delta t=0.05 \) Gyr.

3. Results

The initial efficiency of the star formation principally leads the star formation rate and the initial oxygen abundance. The SFR and oxygen abundances of our models are between the values observed in HII galaxies [3, 2]. In figure 1, left panel, we can see that the first burst is strong, while the subsequent ones are less intense due to the decrease of the available gas and attenuation. The two efficiencies chosen, 33\% and 10\%, give the upper and lower limits respectively for HII galaxy oxygen abundance range, as can be seen in figure 1, right panel. Models with the same initial efficiency, but different attenuation type, are very similar.

The initial efficiency also leads the behaviour of the ionized gas. The emission lines are produced by the ionizing photons of the massive stars present in the current burst. In figures 2 we can see the differences between the models with a high initial efficiency (33\%), right panel, which reproduce high excitation and high abundance galaxies, with high \([\text{OIII}]\lambda5007/\text{H}\beta\), due to its high efficiency of SF, and those with low efficiency ( 10\%),left panel, which reproduce less metallic galaxies, with high \([\text{OIII}]\lambda5007/\text{H}\beta\) and low \([\text{OIII}]\lambda5007/\text{H}\beta\) ratios. Differences due to attenuation are not so important since the SFR of both models are very similar.

The attenuation of the bursts (\( k \)) determines the contribution of the underlying population: The SFR for the successive bursts and the oxygen abundance evolution are set by
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the attenuation too, keeping them within the range of the observations. Furthermore, a higher attenuation implies a larger contribution from the previous bursts to the total SED. Then, the most important characteristics given by the adjustment of the attenuation are the colours of the continuum and the evolution of the equivalent width of H\(_\beta\). The evolution of EW(H\(_\beta\)) vs a pseudo-colour of the continuum, similar to U-V, has been plotted in figure 3. In order to reproduce the trend of HII galaxies, shifted to red colours at low values of EW(H\(_\beta\)) due to the presence of a non ionizing population, the contribution of the underlying population to the total continuum must be higher than the contribution of the current burst which dominates the emission line spectrum. This trend can not be reproduced by SSPs or increasing metallicity or age separately [5], and a strong attenuation is needed, as can be seen in the central panel, to reproduce the whole range in EW(H\(_\beta\)) and colours simultaneously.

**The time between burst (\(\Delta t\)) is a secondary parameter which have an effect on the model similar to that of the attenuation.** The reduction of the time between burst offsets the effect of increasing the attenuation: colours of the models with shorter inter-burst time are similar to those with soft attenuation (strong bursts), and require an extra reddening to reproduce the effects of the underlying non ionizing populations. However, the EW(H\(_\beta\)) decreases from burst to burst while in the case of a soft attenuation EW(H\(_\beta\)) maintains a high value. In order to reproduce the correct behaviour of the HII galaxies, the inter-burst time can not be less than 100 Myr for these models.

Besides this combination of values for the parameters, there are other possible combinations which could reproduce the observed features of HII galaxies [6, 7]

4. Conclusions

We have made models which consist in instantaneous star formation bursts spread along 13.2 Gyr. In order to reproduce the observable characteristics of HII galaxies it is necessary to
adjust three principal parameters. With the Initial efficiency we can vary the amount of gas involved in star bursts, which is going to lead the SFR, the oxygen abundance, and the range of metallicity covered by the emission lines produced by the ionized gas of the current burst of SF. The attenuation of the burst sets the contribution of the underlying continuum from the previous stellar generations born before the stars of the current burst which dominates the spectrum. We can also change the inter-burst time, obtaining a similar effect in colours to the change in attenuation: decreasing this parameter, we can produce a larger contribution from the underlying continuum, as an increase in the attenuation of the burst could do, but the effect in colours would be the same as decreasing the attenuation (making the burst stronger) thus making the spectrum bluer. At the same time, we have a larger contribution of the underlying continuum, thus decreasing, even slightly, EW(Hβ). Our method, based in these three parameter model, reproduce all observable characteristics of HII galaxies-abundances, colours and emission lines- at the same time.

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