Highlights of Spanish Astrophysics VI, Proceedings of the IX Scientific Meeting of the Spanish Astronomical Society held on September 13 - 17, 2010, in Madrid, Spain. M. R. Zapatero Osorio et al. (eds.)

Evolution of dwarf galaxies: characterizing star formation scenarios

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Abstract

We have computed a series of realistic and self-consistent models able to reproduce the observable characteristics of HII galaxies in a star bursting scenario, using the technique developed by [7]. Each model is characterized by three parameters that determine the evolution of the modeled galaxy: the initial efficiency of star formation, the strength of the bursts, and the time elapsed between them. Our model technique gives results that reproduce the observed abundances, diagnostic diagrams and equivalent width vs. colour relations for local HII galaxies in every evolutionary stage, and can be extrapolated to other objects under different assumed star formation scenarios. Some preliminary results about the application of the models using statistical methods, are shown.

1 Introduction

HII galaxies are characterized by their optical spectra, containing strong and narrow emission lines, and by their low metal content. These features are produced by young and massive stars, but this does not necessarily mean that these galaxies be young systems. The current burst of star formation (SF) dominates the spectral energy distribution (SED) even if previous stellar populations are present, making difficult to know the star formation history (SFH) of the galaxy. Three SF scenarios are usually discussed in relation with the evolution of dwarf galaxies: (a) bursting: short SF episodes with large quiescent periods; (b) gasping: long moderate SF episodes with short quiescent periods, and (c) continuous or almost continuous SF with few over-imposed sporadic bursts. However, the fundamental details of how the SFH proceeds in these galaxies is still an unresolved problem.

We have made a grid of self-consistent evolutionary models, based on [7], 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 – to analyze the SF of dwarf galaxies, specially HII galaxies, by comparing the predictions with the most evolution sensitive observed parameters in a large sample of galaxies.

2 The self-consistent evolutionary models

The model consists in a set of successive instantaneous bursts of star formation in a region with a total mass of gas of 100×10^6 $M_\odot$, which take place along the whole evolution of the galaxy in 13.2 Gyr.

Each model is characterized by three input parameters:

- The initial efficiency: the amount of gas consumed to form stars in the first burst of star formation. We present here models of hight SF efficiency and low SF efficiency, made using the percentages of 33% and 10% of the total mass of gas, respectively.
- Attenuation: the initial efficiency of SF is attenuated in the successive bursts. This attenuation can be *soft* or *strong*, showing different effects in the model results.
- Time between bursts: 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, and only for comparison purposes, we are going to show some results of the models with $\Delta t = 0.1$ Gyr and $\Delta t = 0.05$ Gyr.

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 [2], using as ionizing spectrum the SED of the modeled HII galaxy, computed using the new and updated stellar population models Popstar by [9]. This, in turn, is calculated according to a SFH and a metallicity evolution given by a chemical evolution model based on [8]. The combination has been done in a self-consistent way, using the same assumptions regarding stellar evolution, model stellar atmospheres and nucleosynthesis, and using a realistic age-metallicity relation.

2.1 Model results

The three free input parameters can be changed to obtain different model results.

The initial efficiency of the SF principally leads the star formation rate (SFR) and the initial oxygen abundance. Figure 1, left panel, shows the SFR of models with high and low efficiency. In both cases, the first burst is strong, while the subsequent ones are less intense due to the decrease of the available gas (and the attenuation). The two efficiencies shown give the upper and lower limit respectively for HII galaxies oxygen abundance range, as can be seen in the right panel.

The initial efficiency also leads the behavior of the ionized gas. The emission lines are produced by the ionizing photons of the massive stars present in the current burst. The high initial efficiency models reproduce high excitation and high abundance galaxies with high

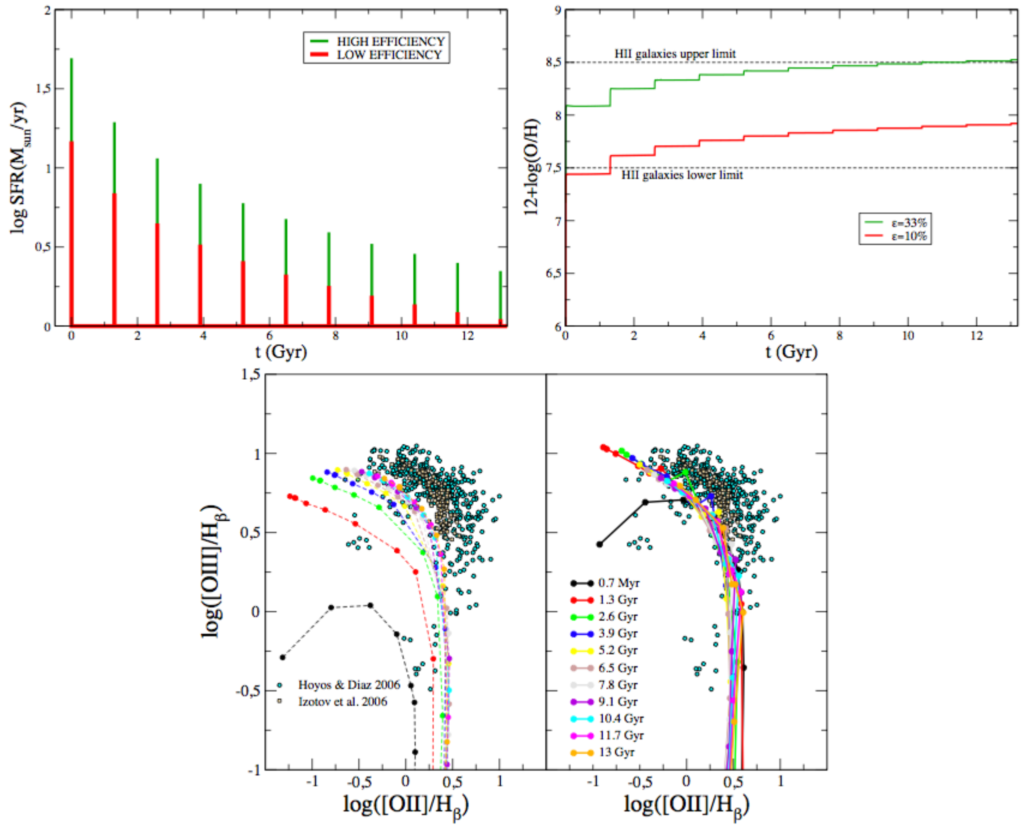

Figure 1: *Top left*: SFR for high efficiency and a low efficiency models. *Top right*: Evolution of oxygen abundances for the same models. *Bottom*: Emission lines diagnostic diagrams for high (*right panel*) and low (*left panel*) efficiency models.

[OIII]λ5007/Hβ, and those with low efficiency reproduce less metallic galaxies, showing high [OIII]λ5007/Hβ and low [OIII]λ5007/Hβ ratios (Fig.1, bottom panel).

The attenuation of the bursts determines the contribution of the underlying population to the total continuum. As shown in Fig.2, left panel, at a given EW(Hβ), the data of HII galaxies are displaced to colours redder than those predicted by the soft attenuation models. The ionizing population, that is, the most recent burst of SF, is overimposed on an older stellar population evolved enough as to produce a redder $(U-V)$ colour. In order to reproduce the trend of HII galaxies, 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. A stronger attenuation implies a larger contribution from the previous bursts to the total SED. This effect is shown in Fig.2, central panel: models with strong attenuation cover the ranges of EW(H$_\beta$) and colors simultaneously.

The time between bursts sets the age of the underlying population. The colours of the models with shorter inter-burst time are characteristic of younger populations and this fact can offset the effect of the attenuation. In Fig.2, right panel, a strong attenuation model

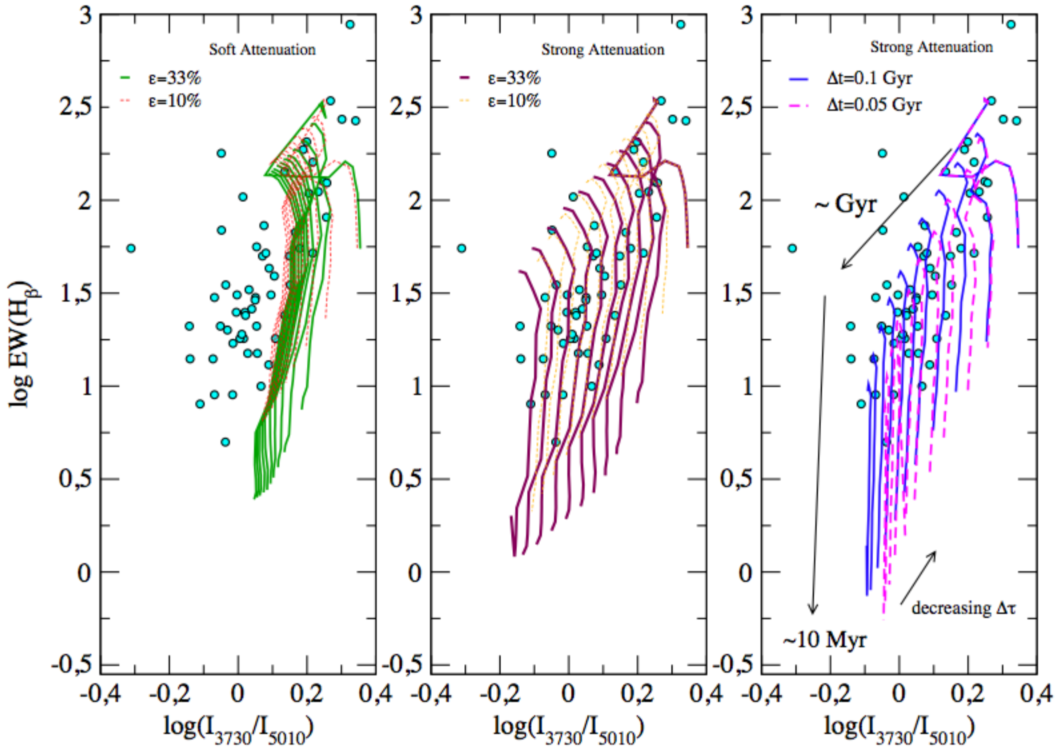

Figure 2: Equivalent width of Hβ vs. the ratio $I_{(3730)}/I_{5010}$ compared with observational data from [3, 11]. *Left panel*: soft burst attenuation model. *Central panel*: strong attenuation model. *Right panel*: strong attenuation models with inter-bursts time less than 1.3 Gyr.

with time between burst of $\Delta t = 0.1$ Gyr and $\Delta t = 0.05$ Gyr is presented. Although the EW(Hβ) decreases from burst to burst due to the more contribution to the continuum, an extra reddening is required to reproduce the range of colours shown by these galaxies.

These three parameters determine the SF which can be adjusted in order to extrapolate to any other kind of scenario. To manage a gasping or continuous SF it is necessary to reduce the intensity of the bursts, both with the initial efficiency and with the attenuation, at the same time we reduce the inter-bursts time to reproduce the characteristic quiescent periods of each SF scenario. Under a continuous SF, an extremely low SFR is needed, as well as a minimum inter-burst time, in order to have enough gas to form stars during the galaxy lifetime. In order to have the results of the models under any SF scenario, we have computed models with different starbursting properties: high and low initial SF efficiency, equal strength and attenuated bursts, as well as several values of the attenuation factors and time between bursts. The results of the complete grid can be seen in [5] and will be published in [6].

3 Use Case: χ^2 test for IIZw40

This technique reproduce simultaneously the data relative to the current ionizing population and the data which give us information about the evolutionary history of the SF. As an application of the bursting models, we have performed a χ^2 test to IIZw40, a very well observed object. In order to compare with modelled parameters, we have taken the values of 13 emission line ratios, equivalent width of Hβ and continuum pseudo-colour $I(3730)/I(5010)$, all taken from [11], three abundance ratios (O/H, N/H and S/H) and two total colours (including the stellar continuum, the contribution of the emission lines and the host galaxy) $(V-I)$ and $(R-I)$, taken as luminosity ratios L_V/L_i and L_R/L_i from [10]. For each model we have 11 bursts and the evolution of emission lines, abundances and colors in every burst, for 12 different ages from $\log t = 5.85$ to $\log t = 7.00$. The models will provide as result an age and a number of the burst for the observed galaxy, that is, the age of the current ionizing population and the age of the underlying population.

The χ^2 calculation has been made as:

$$\chi^2 = \sum_{n=1}^{j} \frac{(O_n - T_n)^2}{\sigma_n^2}, \tag{1}$$

where n is the number of parameters, O_n is the observed parameter, T_n the model parameter and σ_n is the error of the observed quantity. We use the chi square distribution to find the maximum probability ranges of the ages of all the stellar populations that the observed galaxy contains. For more details on these calculations, see [5].

We have chosen a high attenuation and low initial efficiency model with 1.3 Gyr between bursts to compare with the observed galaxy, taking into account that the oxygen abundance of II Zw 40 is $12+\log(\mathrm{O/H}) = 7.7$. The metallicity does not grow very quickly in this model, thus, there will be more bursts with parameters comparable to those of the observed galaxy. In Fig. 3 , top left panel, the result of the test for the emission lines is shown. The maximum probability (the orange and the darkest zones) is extended along a wide range of bursts, and II Zw 40 could then be between its 3rd and 8th burst of SF. This probability decreases as the number of the burst, thus, metallicity, increases. It is also probable to find ionizing populations 6 Myr old in the first bursts and older than 2 Myr for the last one. The chemical abundance ratios give us information about the SF and the enrichment history. We have obtained that the galaxy is in its third burst of SF with a very narrow maximum likelihood zone, as shown in the top right panel. For the colors, the maximum likelihood zone is around the third burst too (bottom left panel). However, due to the inclusion of the contribution of the emission lines to the broad band colours, this zone is shifted to younger bursts, indicating that the ionizing population can be reproduced by more bursts besides the third one (from the third to the eighth), as we have seen in the emission line test above.

The total probability distribution have been made with the sum of these normalized χ^2 and the result is shown in the bottom left panel. According to this model, this galaxy is on its third burst of SF, indicating that the underlying population could have a maximum age of 2.6 Gyr, its current stellar ionizing population is 3 Myr old, and the total mass in stars is

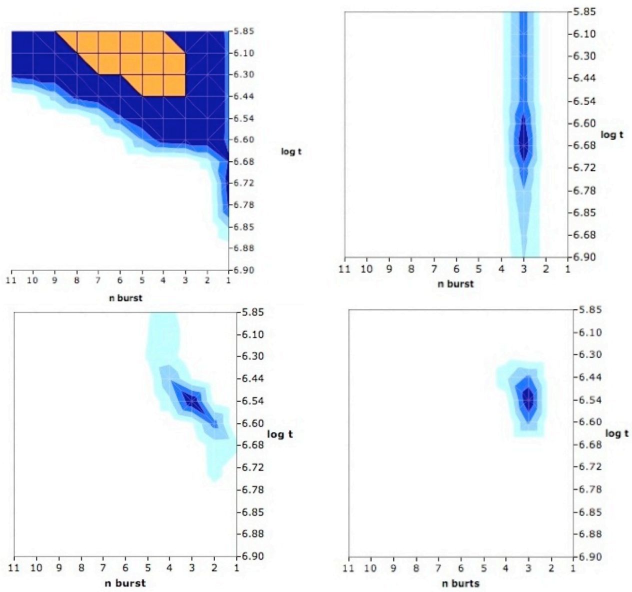

Figure 3: Probability distribution for the age and the number of burst obtained from the comparasion of the emission lines (*top left panel*), the chemical abundance ratios (*top right*), the total colours (*bottom left*), and all the parameters together (*bottom right*) of II Zw 40 with the resulting parameters of a bursting model (details in the text).

about 17×10^6 $M_\odot$ with the mass of the ionizing population 3.77×10^6 $M_\odot$. These results are in very good agreement with the findings of [12]: the age of the ionizing population is 4 Myr, the total mass in stars is 20×10^6 $M_\odot$ and no SF has taken place in the last 10^9 yr, being the mass of the underlying population about one order of magnitude higher than the mass of the current ionizing stellar population.

This very preliminary example demonstrates how a complete set of data may provide the whole information about the evolutionary scenario of a given galaxy, and that with this simple method is, in principle, possible to get an initial guess about the age of the galaxy and its stellar content.

Acknowledgments

This work has been partially supported by DGICYT grant AYA2007–67965-C03-03, by the Comunidad de Madrid under grant S-0505/ESP/000237 (ASTROCAM), by AstroMadrid (CAM S2009/ESP-1496), and by the Spanish MICINN under the Consolider-Ingenio 2010 Program grant CSD2006-00070: First Science with the GTC (http://www.iac.es/consolider-ingenio-gtc) which are acknowledged.

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