CHEMICAL AND SPECTRO-PHOTOMETRIC EVOLUTIONARY MODELS FOR EMISSION LINE STAR-FORMING GALAXIES

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ABSTRACT

We have computed a series of realistic and self-consistent models of the emitted spectra of HII galaxies. 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, using as ionizing spectrum the spectral energy distribution of the modelled HII galaxy. This, in turn, is calculated according to a Star Formation History (SFH) and a metallicity evolution given by a chemical evolution model that follows the abundances of 15 different elements. The contribution of the stronger emission lines to the broad band magnitudes and colours is explicitly taken into account. The results of our code are compared with photometric and spectroscopic data of HII galaxies. Our technique reproduces observed abundances, diagnostic diagrams and equivalent width-colour relations for local HII galaxies.

INTRODUCTION

HII galaxies are characterized by strong and narrow emission lines, produced by massive stars, and by the low metal content. But this does not necessary mean that these galaxies be young systems since the current burst of star formation could dominate the observed spectral energy distribution (SED) even if previous stellar populations are present . The aim of this work is to study the viability of a certain kind of model under a star-bursting scenario, in order to understand how the star formation takes place in these galaxies. This implies the combination of three different tools: **a chemical evolution code, an evolutionary population synthesis code and a photo-ionization code.** Our method allows the simultaneous use of the whole available information for the galaxy sample concerning on the one hand the ionized gas - emission lines intensities and equivalent widths, elemental abundances, gas densities - which defines the present time state of the galaxy, and on the other hand, spectrophotometric parameters - colours, absorption spectral indices - defined by the integrated stellar populations and their evolution with time and thus related to the galaxy star formation history. This is done in a self-consistent way, that is using the same assumptions regarding stellar evolution, model stellar atmospheres and nucleosynthesis, and using a realistic age-metallicity relation.

MODEL DESCRIPTION.

Chemical evolution code.

(Ferrini et al. 92, Ferrini et al. 94)

We have run models considering the star formation as a set of **successive bursts** in a region with a total mass of gas of $100 \cdot 10^6 M_{sun}$. Every galaxy experiences 11 star formation bursts along its evolution of 13.2 Gyrs, that is, one every 1.3 Gyr.

In each burst a certain amount of gas is consumed to form stars, depending on the efficiency of the star formation. The models computed are ***attenuated burst models***, with different modes of attenuations and efficiencies:

n=burst number; K= attenuation factor

$$\Psi_n = \frac{\Psi_0}{n} \qquad \Psi_n = \Psi_0 (k)^{n-1}$$

Mode 0 Mode 1

Attenuation mode	K	efficiencies		
0	-	64 %	33 %	10 %
1	0.5 (A)	33 %	10 %	3%

Two different models with different attenuation modes, Mode 0 and Mode 1A, are presented here, to show their most remarkable differences.

We obtain, for every 0.5 Myr step, the abundances of 15 elements: H, D, ^{3}He, ^{4}He, C, ^{13}C, O, N, Ne, Mg, Si, S, Ca, Fe, and nr (the isotopes of the neutron rich elements, synthesized from ^{12}C, ^{13}C, ^{14}N and ^{16}O inside the CO core), the star formation rate and the mass in each phase, that is, their corresponding age-metallicity relation. Assuming an age of 13.2 Gyrs, this amounts to a total of ~26400 stellar generations.

Evolutionary synthesis code.

(García-Vargas et al. 95, Molla & Garcia-Vargas 2000)

A SED from the Single Stellar Populations (SSPs) library must be assigned to each time step according to its corresponding age-metallicity relation taking into account the SFH, efficiency Ψ(t) and Z(t) obtained from the chemical evolution model. When more than one burst take place, the SED L(t) is given by:

$$L_\lambda = \int S_\lambda(\tau, Z(t'))\Psi(t')dt'$$

Previously we have interpolated logarithmically between the two SSPs of the same age closest in metallicities to Z(t').The final result is the total luminosity at each wavelength. In this way we obtain the SED corresponding to the whole stellar population, including the ionizing continuum proceeding from the last formed stellar population.

Photoionization code.

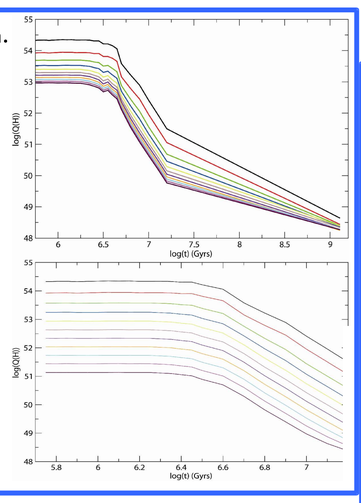
(CLOUDY, Ferland 1998)

The gas is assumed to be ionized by the massive stars belonging to the current burst of star formation whose SED has been previously calculated. A constant stellar density configuration have been assumed. Each burst is characterized by a radius **R**, with a resulting plane-parallel geometry, a gas density of $\mathbf{n_H}$=100 cm^{-3}, an ionization parameter, defined as $\mathbf{U = Q(H)/4\pi c n_H R^2}$ where **Q(H)** is the number of Lyman ionizing photons, and the chemical abundances obtained from the chemical evolution code. The code gives the emission lines produced by the modelled nebula.

Properties of the ionizing continuum.

In the first burst, with a total mass of $33 \cdot 10^6 M_{sun}$, due to the availability of gas to form stars, the number of massive ionizing stars is high and so is the number of ionizing photons. As the mean gas metallicity increases with time, the number of ionizing photons per unit stellar mass decreases. This effect increases with the age of the ionizing cluster reaching a factor of about 5 at 10 Myr.

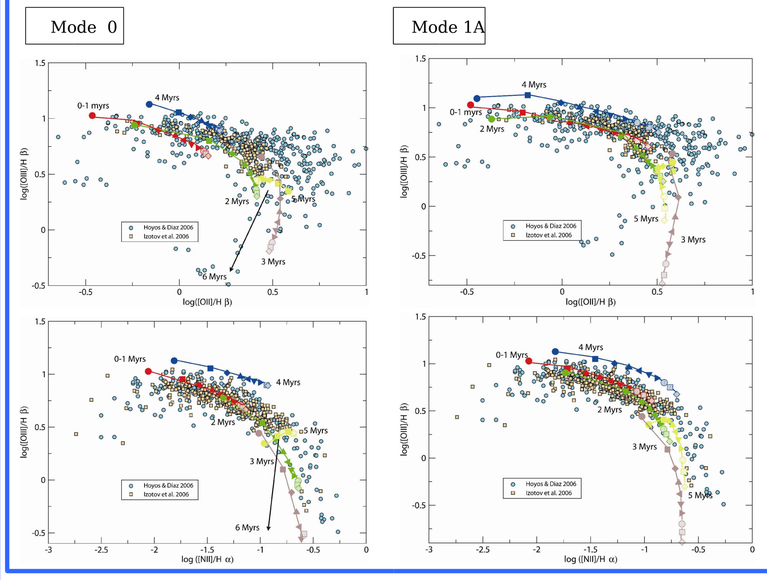
Top panel is Mode 0 model and lower is Mode 1A. Because of the high attenuation in Mode 1A, Q(H) decreases rapidly.



Photoionization: Diagnostic diagrams.

Emission line intensities provide information about the youngest stellar population which dominates the presently observed spectra. The figures show an excitation diagnostic for ionized nebula, and the relation between the excitation parameter, log[OIII]/H_β, and the metallicity indicator log[NII]/H_β which gives information about the younger populations plus the star formation rate (Kennicutt 1994). Observational data are from Hoyos & Diaz 2006, Izotov et al. 2006.

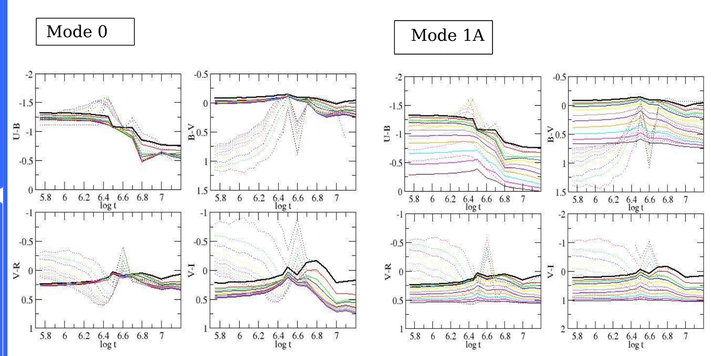
Mode 0 Mode 1A



Combined continuum and emission line colours.

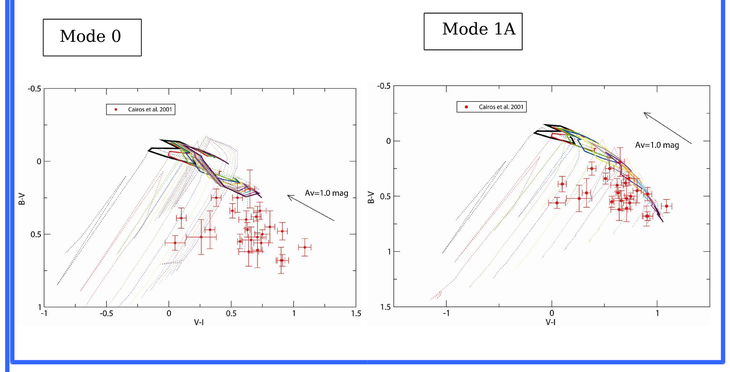
The observed light is dominated by massive stars, the effect of an underlying stellar population should be more easily seen in the observed colours of these galaxies, since any star forming burst previous to the currently observed one will contribute substantially to the total continuum luminosity at the different wavebands. The broad band colours computed including the contribution by the stronger emission lines are shown in next figure as dashed lines. These are the colours which are readily observable through integrated photometry.

Mode 0 Mode 1A



In the figures below, we show colour-colour diagrams of the models compared with Cairós et al. 2001 data for BCD galaxies without extinction correction. The only way to cover the data range is by taking into account the emission line contribution to the continuum colours. Once corrected from extinction, data will lie over the models.

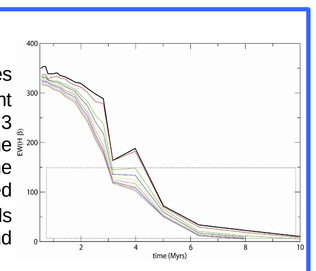
Mode 0 Mode 1A

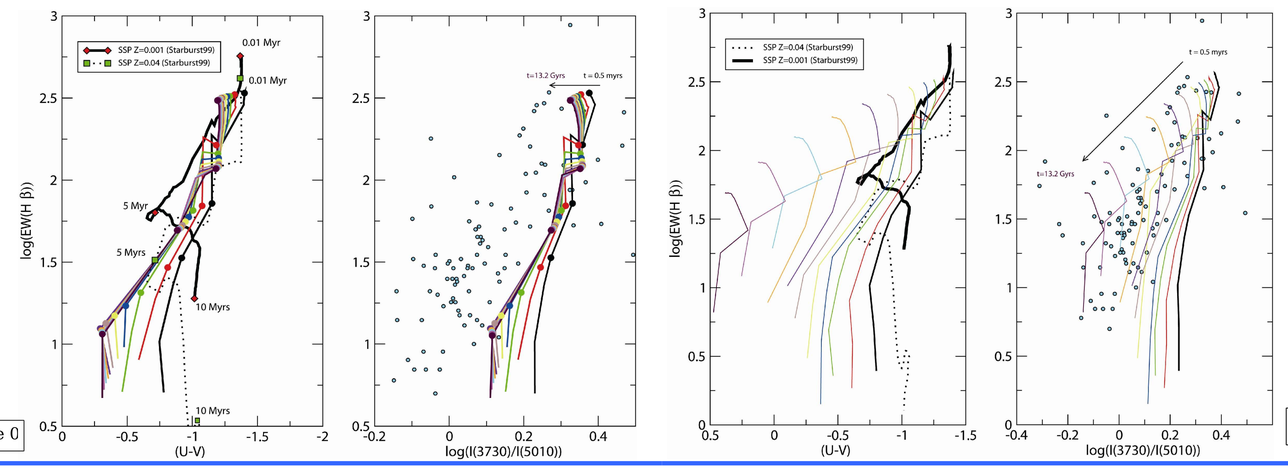


Emission line data: Hoyos & Díaz (2006); Izotov et al. (2006)

EW(Hβ) vs. Continuum colours.

The distribution of EW(H_β) of HII galaxies from observations shows that most galaxies have values lower than 150Å which indicates the presence of an old non ionizing population that makes this parameter decrease. According to the model, most of the equivalent width values cannot be produced by just one generation of stars, and it is necessary to invoke an underlying population, of at least 1.3 Gyrs to contribute to the continuum. We have represented the equivalent width of Hβ vs. the U-V colour along the evolution of the galaxy for the successive stellar bursts. The trend of the data is reproduced by our models and not by SSP's since in that case the colours are bluer than observed. In order to decrease EW(H_β) and to obtain redder colours, a more metal-rich SSP might be selected (dotted line at the left panel), but such high abundance does not reproduce the observations, as we have shown before. Our models (Mode 1A) are able to produce redder colours due to the contribution by previous stellar generations and reproduce better the trend and the whole range of HII galaxies observations.



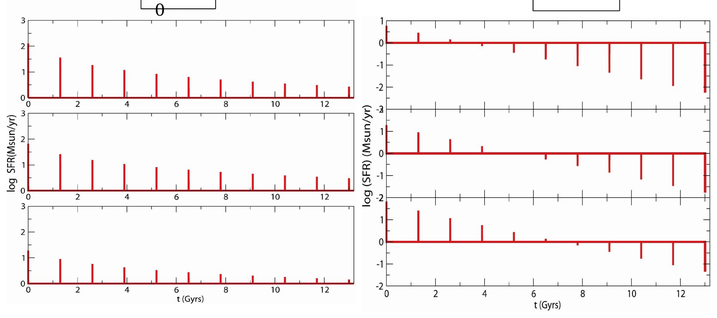


Mode 0 Mode 1A

RESULTS.

Chemical evolution: Star formation rates.

Mode 0 Mode 1A

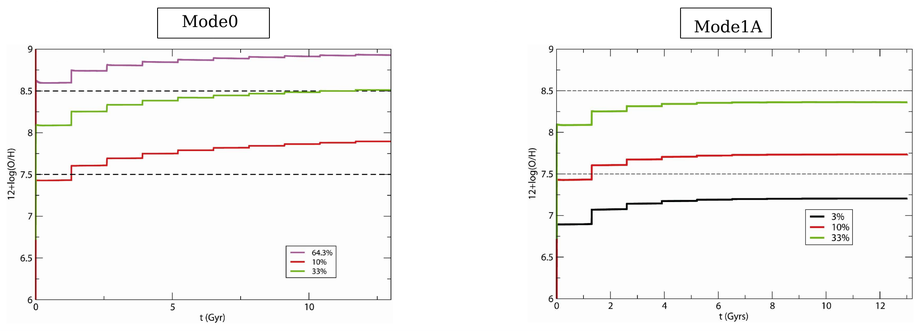


The first burst is strong in both panels, while successive bursts are less intense because the gas available has decreased in spite of the ejected gas produced by massive stars, and also due to the attenuation. Models with smaller efficiencies consume less gas in each burst and, as a consequence, the SFR remains higher and declines more slowly in Mode 0. Mode 1A shows low SFR due to the high attenuation.

Oxygen abundances: discriminating models.

HII galaxies have metallicity distributions between 7.5<12+log(O/H)<8.5 (Hoyos & Diaz 2006, Terlevich et al. 91) (dashed lines). Models with efficiencies between 33% and 10% reproduce the observations.

Mode0 Mode1A



CONCLUSIONS.

We have shown that are able to reproduce the observations on HII galaxies -abundances, colours, emission lines- with a model combining a chemical evolution code, a synthesis evolutionary code, and a photoionization code in a self-consistent way. We have seen that the range of the observations can be reproduced by this model with several bursts of star formation.
The observed trend of HII galaxies cannot be explained as an age effect since EW(H_β) for low metallicity SSP does not reach values lower than 100A and does not reproduces the colours. A metallicity effect could be invoked, however such high abundances are not observed in HII galaxies. It is necessary to include both effects simultaneously, as we have done, to see how the effect of an underlying population, that contributes to the colour of the continuum making it redder than expected, arises.

Martin Manjon et al. 2008

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