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H II GALAXIES VERSUS PHOTOIONIZATION MODELS FOR EVOLVING STARBURSTS

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RESUMEN

Se presentan resultados de modelos combinados de síntesis de población estelar y fotoionización para brotes de formación estelar. Con ellos se interpretan las propiedades de una muestra de 100 galaxias H II, con líneas de emisión Hβ y [O III] 4363, de donde se infieren la edad del brote y su metalicidad. La muestra, que tiene baja metalicidad y edades menores a los 5 Myr, puede reproducirse con los parámetros usuales del modelo de brote de formación estelar - brote instantáneo con una función inicial de masa de Salpeter y un límite superior de masa de 100 M⊙. Se propone que el ancho equivalente de [O III] 5007 puede usarse como un poderoso indicador de la edad en objetos débiles.

ABSTRACT

Combining a stellar population synthesis code with a nebular photoionization code, we compute a wide grid of photoionization models for evolving starbursts. This grid is used to interpret the properties of a sample of 100 H II galaxies for which the Hβ equivalent width and the [O III] 4363 line intensities were available, thus allowing a direct estimate of the starburst age and of the elemental abundances. Because of these requirements, all the H II galaxies in our sample are younger than 5 Myr and metal-poor. We find that the standard starburst model —an instantaneous burst of star formation with a Salpeter IMF and an upper cutoff mass of 100 M⊙— reproduces all the observational constraints provided by the nebular emission lines. There is no need to invoke a variation of the starburst properties in the metallicity range from 0.25 and 0.025 Z⊙. The emission line properties of our sample of H II galaxies can be reproduced with only a small spread in the free parameters. This allows us to propose a powerful starburst age indicator, especially useful for faint objects: the equivalent width of the [O III] 5007 line.

Key words: **GALAXIES: STARBURST — H II REGIONS — STARS: EARLY TYPE — STARS: EVOLUTION**

1. INTRODUCTION

The simplest examples of starburst regions are probably H II galaxies - i.e., galaxies whose spectra are dominated by features characteristic of H II regions. In these objects, most of the light is believed to come from the last episode of star formation, which makes them privileged sites for testing synthetic evolution models of starbursts. Since the most conspicuous spectral signature of these objects is nebular emission lines, which arise from gas ionized by the hottest stars, an analysis of their properties requires the computation of photoionization models in which the ionizing radiation field is provided by a synthetic population of evolving stars. In our opinion, understanding H II galaxies is the first step on the way to unveiling the properties of stellar systems in which the history is more complicated and the observational constraints less numerous, such as starbursts in the nuclei of galaxies, or emission line galaxies at high redshifts. We have computed a grid of H II region models for evolving starbursts, using the most recent results from stellar evolution and stellar atmosphere theory, and we have confronted them with a carefully selected sample of H II galaxies. The methodology we have developed is extensively described in Stasińska & Leitherer (1996). Here, we only give the general features and the main results.

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2. THE TEST SAMPLE OF H II GALAXIES

There are, at least, two parameters which vary from one H II galaxy to another. These are the age of the last starburst episode, and the metallicity. Therefore, a pertinent confrontation of model predictions for evolving starbursts with the properties of H II galaxies requires a large sample of objects in which both these parameters can be derived directly. These requirements are met if we can constitute a large sample of H II galaxies in which good spectral information exists both on the Hβ equivalent width and on the intensity of the [O III]4363 line. Searching the literature, we were able to constitute a sample of 100 objects for which such measurements were available (*n.b.* the sample would have been much larger larger if all the observers having good signal-to-noise data on H II galaxies had published Hβ equivalent widths!) Our sample is mostly composed of objects appearing in the compilation of Masegosa et al. (1994). Because we required the [O III] 4363 line to be measured, our sample is restricted to objects that are of rather low metallicity (smaller than about half solar). At present, it is not sure whether the conclusions we derive for such metal-poor starbursts can be extrapolated to high metallicity environments. We have derived the elemental abundances in our sample of H II galaxies in a homogeneous way using classical empirical techniques, with the same atomic data as in the photoionization models.

3. THE MODELS

The observational sample of H II galaxies is confronted with a grid of models for evolving starbursts with various metallicities. The stars are assumed to be formed in an instantaneous burst with an initial mass distribution of slope 1.35 (the Salpeter IMF), and an upper cut-off M_{up}, which takes the values 100 (the "standard model"), 50, and 120 M$\odot$. These stars are evolved according to the models of Maeder (1990). At each time, by steps of 1 Myr, the overall photon output of the star cluster is computed, using the Kurucz (1992) blanketed LTE atmospheres, supplemented by the expanding atmospheres of Schmutz et al. (1992) in the case of strong winds. We believe that this was the best choice we could make for a grid of model atmospheres at the time of the computation of our starburst grid. All the procedure to compute the stellar properties of the starburst is described in detail in Leitherer & Heckman (1995). The temperature and the ionization structure of a nebula surrounding such a star cluster is computed by means of a photoionization code (PHOTO, Stasińska 1990, with updated atomic data as listed in Stasińska & Leitherer 1996). This provides the emission line intensities and equivalent widths. In addition to the metallicity Z (taken to be the same as for the stars) and the initial stellar mass distribution, the spectrum of an H II region is governed by the "ionization parameter" U, defined by

$$U = \frac{Q_{H^0}}{4\pi R_s^2 nc},$$

where Q_{H^0} is the total number of photons above 13.6 eV, R_s is the Strömgren radius, and c the speed of light. It can be easily shown that any combination of Q_{H^0}, n, and ϵ (the volume filling factor) that keeps the ionization parameter U constant results in the same ionization structure of the gas. Thus, the primary parameters in the grid of model H II regions are the metallicity, Z, the age of the starburst, the upper initial stellar mass M_{up} and the integrated initial mass of the stars, $M*$ (directly related to Q_{H^0} for a specified starburst). The actual gas density, the nebular geometry, and the relative abundances of the elements with respect to oxygen are secondary parameters in the present study. Our grid of models was constructed to encompass a wide range of starburst properties, with $M*$ taking the values 10^3, 10^6 and 10^9 M$\odot$, and Z ranging from Z$\odot$to 0.025 Z$\odot$. Most models have been computed with a nebular density $n = 10\ cm^{-3}$. In Stasińska & Leitherer (1996) some series of models with $n = 10^4\ cm^{-3}$ are also shown, to illustrate the maximum effect of collisional de-excitation on line intensities that is expected to occur in giant H II regions. Additional models with different geometries or different relative elemental abundances are available on the CD-ROM accompanying the paper "A Database for Galaxy Evolution Modeling", by Leitherer et al. (1996).

4. CONFRONTATION OF MODELS WITH OBSERVATION

The adopted policy was to define a certain number of diagnostic diagrams, and confront the sample of observed objects with the model tracks simultaneously in all the diagrams. The selection effect induced by our condition on [O III] 4363 was explicitly taken into account by retaining only the parts of the model tracks where [O III] 4363 was predicted to be greater than 0.02 of Hβ. Also, because the observed H II galaxies should correspond to starbursts with randomly distributed ages (within certain limits), models that predict a high density of points in regions of the diagrams where no accumulation of observed objects is seen should be rejected. In the present study, we used six diagnostic diagrams, carefully chosen to provide the best diagnostics. They use the emission lines of hydrogen and oxygen: Hβ, [O III] 5007, [O III] 4363, [O II] 3727 and [O I] 6300. The Hβ equivalent width counts the total flux of ionized photons produced by the starburst at a given time and absorbed by the nebular gas, and is thus directly linked to the starburst age. Oxygen is the element which dominates the cooling of the nebular gas (except at very low metallicities, when hydrogen becomes more important). It is also the only element for which all the ionization stages expected in H II regions can be seen in optical spectra. Thus, oxygen lines allow to constrain at the same time the ionization structure and the energy balance of an H II region. With such a procedure, our approach is far more constraining for the models than previous studies confronting H II galaxies with grids of models for evolving starbursts.

5. MAIN RESULTS

Concerning the stellar properties of starbursts powering H II galaxies, we find that the behaviour of the emission lines in our observed sample is consistent with an IMF having a Salpeter slope and an upper cutoff of 100 $M_\odot$. There is no compelling evidence for a change in the IMF within a metallicity range between 0.25 and 0.025 $Z_\odot$. This is at variance with the claims of some previous authors on H II galaxies based on single star H II region models, or on different stellar evolutionary tracks. The situation may, however, be different for metal rich environments, which are not considered in the present study. The fact that in our observed sample of H II galaxies, all the objects have an Hβ equivalent width larger than 20 Å is consistent with the prediction of our models for evolving starbursts, considering that our sample is restricted to objects with a measured [O III] 4363. Indeed, for this line to be strong enough, one needs a young starburst harboring stars that are still sufficiently hot. Starbursts with ages larger than 5 Myr are not present in our sample simply because of the selection effect induced by the requirement on [O III] 4363.

During the first 5 Myr of a starburst, photoionization by stars is by far the dominant process producing the observed emission lines. One exception is [O I] 6300, whose intensity is difficult to explain by pure photoionization models using as an input the radiation field from synthetic starbursts. At larger ages, excitation by shock waves induced by stellar winds and supernova explosions will start competing with stellar photoionization and will affect some other lines. Similarly to some previous studies on extragalactic H II regions, we find that a very narrow range of values for the ionization parameter U is able to explain the observed properties of our sample. We find a marginal evidence for a decrease in U as the burst ages. We also find that the most metal-poor H II galaxies tend to have the highest U. The fact that the observations can be reproduced with evolutionary models having a small spread in their defining parameters allows us to propose a new age indicator for young starbursts. This is the equivalent width of the [O III] 5007 line, which is found to be quite a robust and sensitive indicator. Such an indicator should be especially useful for objects observed with a low signal-to-noise, such as galaxies at high redshifts.

6. PERSPECTIVE FOR FURTHER WORK

It is striking that the emission line properties of our sample of H II galaxies (which is the largest sample we could constitute from published data satisfying our selection criteria) can be described by a universal model. The study of additional features (e.g., helium lines, stellar absorption lines, continuum) may provide new constraints —and new challenges— to the population synthesis models and their ingredients. Because modelling of stellar interiors and atmospheres is presently in a phase of important improvements, one may expect that some of the conclusions of the present work might change when using the next generations of stellar models. Alternatively, confrontation of adequately selected observational samples with the results from population synthesis models, may help to validate the stellar models.

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