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HYDRODYNAMICS AND IONIZATION STRUCTURE OF H II REGIONS. EVOLUTION OF GIANT H II REGIONS

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RESUMEN

Nuestro trabajo ha consistido en el desarrollo de un código numérico en una dimensión que permite resolver simultáneamente las ecuaciones de la hidrodinámica y las ecuaciones de balance energético y de ionización. En este trabajo se hace una descripción general del código y de su aplicación al caso de las regiones H II gigantes.

ABSTRACT

Our aim has been the development of a numerical code in one dimension that allows for the simultaneous solution of the hydrodynamic equations coupled with the energy and ionization equations. Here we describe the code and discuss its application to the evolution of giant H II regions.

Key words: **HYDRODYNAMICS — H II REGIONS — LINE: FORMATION**

1. INTRODUCTION

The code HIS (Hydrodynamics and Ionization Structure) accounts for time independent ionization of H^0, He^0 and He^+, and for a cooling derived from collisional excitation of C, N, O and Ne, whose ionization structures with up to five stages of ionization are calculated under the steady state approximation. As a complementary work it has also developed the necessary tools to calculate the synthesized spectrum of the numerical models, including the most important lines and line ratios of the mentioned elements and their ions.

At last, the code was applied to the Giant Extragalactic H II regions (GEHRs) whose ionizing spectra was obtained from the models of evolving stellar associations that are found inside these regions.

2. CODE DESCRIPTION

Now there are a large number of photoionization codes which account for the ionization of the most important elements in the ISM and they include most of the relevant physical processes. However, it did not exist a hydro code that could perform the same calculations as a photoionization code, including also the gas hydrodynamics. For this reason, we have filled up this important hole in the study on ionized nebulae by developing a hydro code that calculates the photoionization in a form almost as detailed as a photoionization code does. In the Table 1, we show the different parameters that measures the quality of a photoionization code and we compare the HIS characteristics with those of the most important photoionization and hydro codes. It can be seen as the HIS code represents a big improvement respect to the actual hydro codes.

3. EVOLUTION OF GIANT H II REGIONS

The GEHRs are an important middle step between the stellar population study in our galaxy and the galaxies with *starbursts*. In fact, the GEHRs present themselves *starbursts* with hundreds and thousands of massive stars. In the last times a new model based in starbursts have been developed in order to explain the nuclear activity in AGNs (see review by Terlevich 1991). In this model the GEHRs would represent a earlier evolutive phase of a *starburst* which evolves into an AGN phase due to the massive stars reach a extreme *Wolf Rayet* phase (called *warmer*), with large luminosities and effective temperatures, and then explode as SNs. In order to check this model a good knowledge of the GEHR evolution is necessary. We have modeled the evolution of a GEHR ionized by a stellar massive cluster whose ionizing spectrum becomes harder as the most massive stars arrive to the extreme *Wolf Rayet* phase.

As the time-depending ionizing flux, we have selected the models of García-Vargas (1991). These models

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TABLE 1

CHARACTERISTICS OF THE DIFFERENT CODES.

	CODES	A	B	C	D	E
1	Steady-photoionization Codes	o o o	o o oo	o o o	o o o	
2	Hydro-photoionization Codes	o	o	o	o	o
3	HIS	oo	ooo	ooo	oo	o

A Photon Energy:
- o o o $h\nu < 10$ keV (AGN)
- oo $h\nu < 120$ a 160 eV (NP)
- o $h\nu < 54$ eV (H II regions)

B Radiative Transport:
- o o oo "exact" (total iteration, several directions)
- o o o approximated (in one direction, etc)
- oo OTS (several classes)
- o "grey" approximation

C Atomic Data:
- o o o Good
- oo Reasonable
- o Incomplete

D Ionization Structure
- o o o Detailed
- oo Main elements: H, He, C, N, O, ...
- o Only Hydrogen

E Time Depending

assume that all the stars are born in a single burst and the most massive stars can evolve into a extreme *Wolf Rayet* phase. Until the $3.0 \cdot 10^6$ years all the stars remain in the main sequence, but since this age the most massive stars evolve into extreme *Wolf Rayet* which domain the cluster spectrum. Towards the $5.0 \cdot 10^6$ years these massive stars begin to explode as SNs and the cluster loses its photoionizing power although the SNs and their remnants can keep and continue the ionizing of the interstellar gas. We have followed the cluster evolution until the $4.0 \cdot 10^6$ years just before the most massive stars begin to explode as SNs.

Figure 1 shows the hydrodynamical and spectral results obtained with our code, where we have calculated also the radiative transport in the most important interstellar lines in order to obtain their surface brightness.

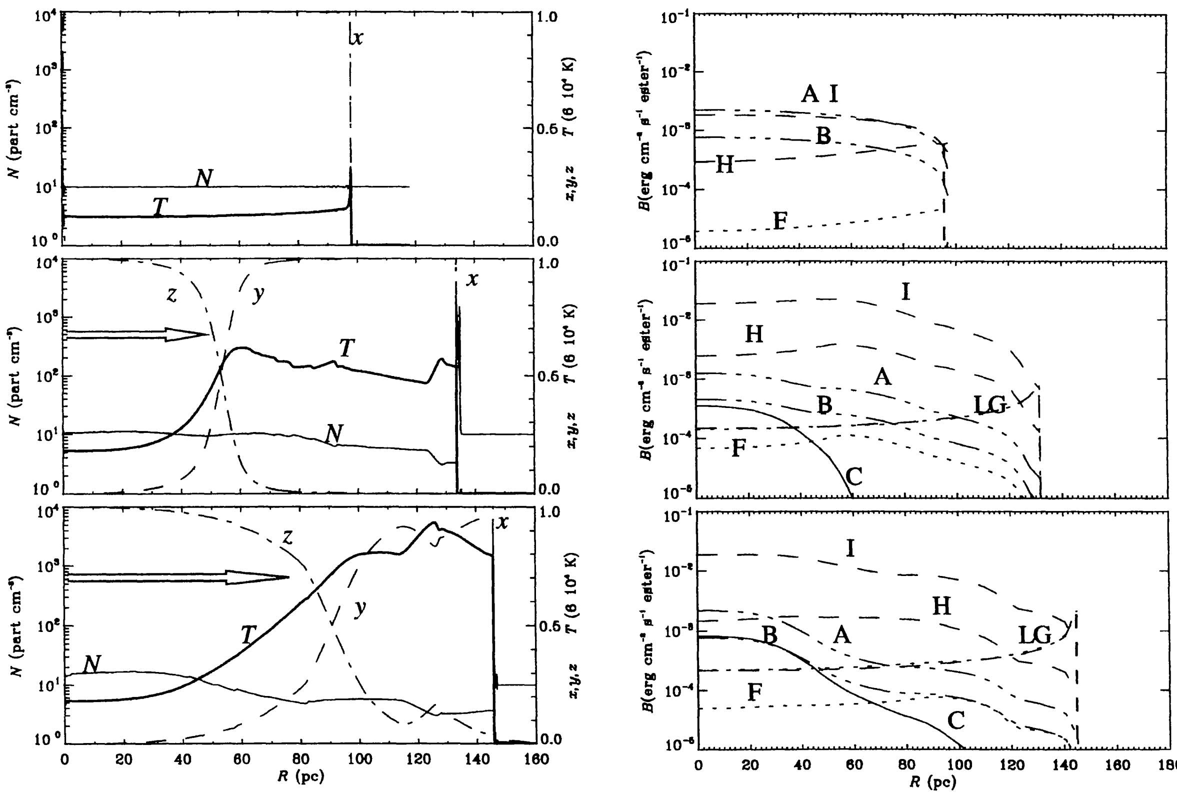

Fig. 1. See text.

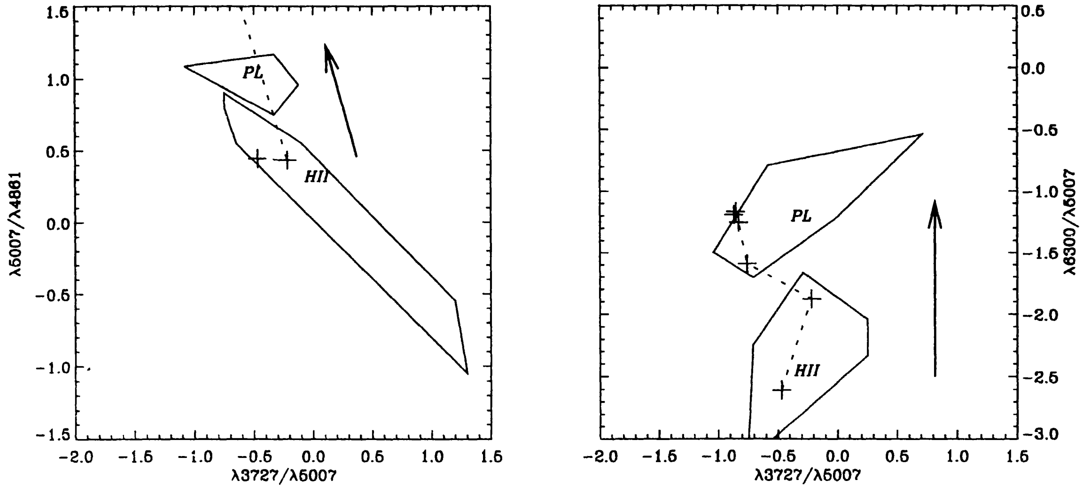

Fig. 2. Diagnostic diagrams for the GEHR evolution (see text).

On the (**left**) we plot the total particle density (N; solid line), the normalized abundance of H^+ (x; dotted line), He^+ (y; dashed line) and He^{2+} (z; dot-dash line), and the temperature (T; thick solid line) at three different ages of the GEHR. From up to down: 10^5, $3.0 \cdot 10^6$ and $3.5 \cdot 10^6$ years. On the (**right**) we plot the surface brightness for several lines at the same ages. When the massive stars evolves to extreme *Wolf Rayet* ($\sim 3.0 \cdot 10^6$ years, second level of pictures in Fig. 1) the ionizing spectrum becomes harder and the He^{2+} zone begins to grow quite rapidly. Associated to this growth, the temperature increase in the interface between He^{2+} and He^+ up to $\sim$ 50 000 K due to the radiation hardening. The temperature distribution reaches a peak in the interface center and decreases smoothly outwards because the photoionization rate of He^+ decreases also. The growing of the He^{2+} zone continues until the ionizing spectrum becomes softer as a consequence of the massive stars disappear into SN explosions. The temperature peak displaces together with the interface He^{2+}-He^+ but in the inner part, where the helium is in its doubled ionized form, the temperature is too much lower $\sim$ 10 000 K. The global sequence shows then as a GEHR with normal photoionization temperatures about $\sim$ 10 000 K evolves into a hotter region with a higher excitation.

This evolution affects to the different lines in the spectra as it is shown in the Fig. 1 on the right. The lines [O III] λ5007Å (I) and [O II] λ3727Å (H) are both strong temperature depending and for this reason increase their surface brightness in an order of magnitude. In the opposite side, the recombination lines H_α (A) and H_β (B) decrease everywhere, more in the outer parts of the region where the temperature is higher. An interesting fact is the apparition of the lines of neutral atoms [N I] λ5200Å (L) and [O I] λ6300Å (G), hardly visible in the initial GEHR phase. These lines are produced just in the ionization front where the neutral atoms exist and where the electron density is high enough to excite them. Thus these lines depend almost exclusively in the temperature at the ionization front. This temperature is proportional to the mean energy in the ionizing spectrum ($< h\nu_\star >$) and for this reason these lines are good indicators of the spectrum evolution. Finally, it can be seen also the apparition of the helium line, He II λ4686Å (C), due to the increasing He^{2+} zone.

Figure 2 shows the evolutive sequence of the GEHR in two different diagnostic diagrams. The zones labeled with PL and H II indicate respectively the geometric place for the observational data (Baldwin et al. 1981) of *Power-Law* spectrum objects and H II regions (This last one include galactic H II regions and GEHRs). The arrows indicates the evolution sense. In both diagrams the evolutive sequence moves from the H II zone towards the zone of high excitation objects, typically LINERS or Seyfert 2. Thus, our results hold the possibility that the spectra of a very evolved GEHR can resemble those of high excitation objects, such as AGNs.

REFERENCES

Baldwin, J. A., Phillips, & M., Terlevich, R. 1981, PASP, 93, 5

García-Vargas, M. L. 1991, Ph.D. Thesis, Univ. Autónoma de Madrid, Spain

García-Vargas, M. L., & Díaz, A. I. 1994, ApJS, 91, 553

Terlevich, R. 1991, Relationships between Active Galactic Nuclei and Starburst Galaxies, ed. A. Filippenko & K. Lo, PASP, 31, 147