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FAR ULTRAVIOLET SPECTRA OF STARBURST GALAXIES

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RESUMEN

El espectro en el UV lejano de galaxias Starburst (IRAS0833+6, Mrk1267, Mrk66 y NGC 6090) indica que sólo una pequeña fracción de los fotones ionizantes escapan de estas galaxias. El polvo asociado al cúmulo estelar puede ser el responsable de esto en Mrk66 y Mrk1267, mientras que en las otras dos galaxias puede tratarse del gas o del polvo en el halo de la galaxia, o bien el campo de radiación no se emite isotrópicamente. También presentamos la síntesis de las líneas de absorción estelares O VI+Lyβ como una herramienta para indicar la presencia de estrellas masivas en objetos de corrimiento hacia el rojo intermedio y alto.

ABSTRACT

The far UV spectra of Starburst galaxies (IRAS0833+6, Mrk1267, Mrk66 and NGC 6090) indicate that only a small fraction of the Lyman continuum photons escape from these galaxies. The dust associated with the stellar cluster can be responsible for the low fraction of photons escaping in Mrk66 and Mrk1267, in the other two galaxies this could be due to dust or gas in their halo, or to a radiation field emitted anisotropically. We also present the stellar population synthesis of the O VI+Lyβ stellar absorption lines as a tool to indicate the presence of hot stars in intermediate and high redshift objects.

Key words: **GALAXIES: STARBURST — ULTRAVIOLET: GALAXIES**

1. INTRODUCTION

The initial motivation to do far UV observations of Starburst galaxies with the Hopkins Ultraviolet Telescope (HUT) was to study the Lyman continuum in intermediate redshift galaxies. If the properties of these galaxies are similar to young galaxies at high redshift, the direct measurements of the FUV flux would be very useful to know if primordial galaxies are responsible for the ionization of the early universe. The observations were done with HUT during the Astro 2 mission covering from 820 Å to 1840 Å. We selected four starburst galaxies with the following criteria: 1) large enough redshift to separate the starburst Lyman edge from the attenuation by the Galactic Lyman edge (v < 5000 km/s); 2) large UV flux at 1500 Å; 3) strong Hα emission; 4) low Galactic extinction. The galaxies selected are NGC 6090, Mrk66, Mrk1267 and IRAS0833+6. Recently, Leitherer et al. (1995) have found that, for very different IMF and star formation histories, the luminosity of the burst at 900 Å is proportional to the number of Lyman continuum photons, $\log(N_{Lyc}/L_{900})$ = 13.28 (photon/erg/Å). Using published Hα fluxes, corrected for reddening (from the Balmer decrement), Leitherer et al. obtained the ratio of recombinations to the luminosity at 900 Å; for the four starbursts, the observed values of this ratio are larger than the predicted theoretical values by almost two orders of magnitude. This means that only a few percent of the ionizing photons escape from these galaxies. The implication is that young galaxies cannot likely provide the Lyman continuum photons for the ionization of the early universe.

The UV radiation field escaping from a galaxy depends on the intrinsic UV spectrum of the ionizing stars embedded in the stellar cluster, on the age and mass of the burst, and on the opacity of the interstellar medium of the Starburst galaxy. We now analyze the spectra as a function of these parameters.

2. LYα LINE, THE DUST CONTENT AND THE INTERSTELLAR LINES

Three of the galaxies show Lyα in emission, and one in absorption (Mrk1267). The ratios Lyα/Hβ are clearly inconsistent with recombination (~ 33). The current explanation is that multiple scattering with H I

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TABLE 1

RESULTS

Object	Lyα/Hβ	Lyα/Hβ_{corr}	Slope	E(B-V)	Ew(Lyα)	Ew(Lyα)$_{corr}$	Log(N$_{rec}$/L$_{900}$)$_{corr}$
IRAS 0833+6	0.99	24.6	−0.85	0.19	8.1	238	14.06
Mrk 1267			−0.43	0.24	−11.5		13.16
Mrk 66	2.86	2.86	−1.58	0.11	13.8	13.8	13.44
NGC 6090	0.74	24.5	−0.50	0.23	8.4	272	13.93

atoms increases the path length of the Lyα photons and the probability of absorption by dust. However, after correcting by the reddening derived using the Balmer decrement (taken from Calzetti et al. 1994 and Margon et al. 1988), the ratio is consistent with recombination in NGC 6090 and IRAS0833+6, indicating that in these two galaxies the extinction is more important than the multiple resonant scattering effects. However, in Mrk66 the dust optical depth and the Lyα emission are both small. A possible explanation is that the starburst is surrounded by an H I envelope, and the Lyman photons are destroyed by absorption by dust after multiple scattering with the H I atoms.

Leitherer & Heckman (1995) have shown that the UV energy distributions for young starbursts are always very similar for a range in metallicity between 0.1 and 2 solar, IMF slope 2.35 and 3.3, and upper cut-off mass between 30 and 100 M$\odot$. These energy distributions can be fitted by a power law with index −2.3. Using the extragalactic extinction derived by Kinney et al. (1994), Leitherer et al. (1996) find a relationship between the color excess and the change of the UV continuum slope produced by reddening, E(B-V)=$0.11\Delta\beta$, where $\Delta\beta$ is the shallower of the continuum slope of the observed spectrum between 1200 and 1900 Å with respect to the predicted value from the models. The power law fitted to the four galaxies indicate that some extinction affect the stellar cluster (Table 1).

If we correct now the Lyα with the extinction derived from the Balmer decrement, and the underlying continuum with the extinction derived from the slope of the UV continuum, we obtain values for NGC 6090 and IRAS0833+6 which are compatible with the model predictions (Charlot & Fall 1993; Valls-Gabaud 1993). Correcting the observed flux at 900 Å with the extinction derived from the UV continuum, we see that the ratio N_{rec}/L_{900} in Mrk1267 and Mrk66 is now compatible with value predicted by the model, indicating that in these two objects the dust associated with the stellar cluster is enough to explain why the number of ionizing photons that escape from the cluster is only a few percent. For the other two galaxies the number of ionizing photons obtained from recombination is still larger than the value derived from the cluster (Table 1). This implies that either dust and/or gas in the galaxies (or in their haloes) are responsible for the absorption of the radiation, or that the radiation in NGC 6090 and IRAS0833+6 does not escape isotropically. This latter scenario could come about if the starburst is located in a region of the galaxy with a strong density gradient in the circumstellar medium; in this case, the super bubble blown by the explosion of the first SN in the cavity created by the combined stellar winds, will break anisotropically toward the side of the steeper density gradient, perpendicular to the galactic disk. Many examples of this scenario are now known.

The HUT spectra exhibit numerous interstellar lines, such as Si II λ1260, O I+Si II λ1300, C II λ1335, Si II λ1526, and Al II λ1670. The equivalent width of these lines range from 1 to 4 Å. In order to obtain the H column density, and the ionization fraction of C^+ and Si^+, we have taken the SED generated by the stellar population synthesis code developed by Leitherer and collaborators (Leitherer et al. 1995; Leitherer & Heckman 1995) as input for the photoionization code CLOUDY (Ferland 1993). Assuming solar metallicity for C, and the typical abundance of the interstellar medium for Si, we have computed the column density of C II and Si II. The values we obtain are not very sensitive to the age of the burst, and only change by a factor two with the geometry assumed. The column for the C II is 2×10^{16} and for the Si II 2×10^{14} cm^{-2}. It is one order the magnitude larger if the Si II is not depleted. These large values of the column densities indicate that the lines are saturated, and that the equivalent width is more sensitive to the velocity dispersion of the gas. This implies velocities larger than 100–300 km s^{-1}, indicating that we are seeing several unresolved velocity components.

3. STELLAR POPULATION SYNTHESIS OF THE O VI+LYβ

Like the C IV and Si IV, the O VI is a resonance doublet ($\lambda\lambda$ 1031.9261, 1037.6167 Å). It can be produced in the interstellar medium (Jenkins 1978) and in the winds of massive stars (Morton 1979; Walborn et al. 1995). Stars hotter than B0V and B0.5I show a PCygni profile or a shifted absorption line.

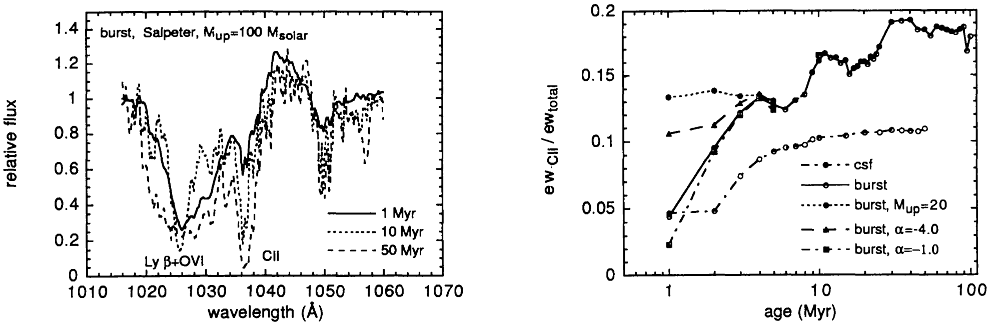

Fig. 1. (a) Evolutionary synthesis profile of the O VI+Lyβ absorption line for an instantaneous burst. (b) Ratio of the C II equivalent width with respect to the total as a function of the burst age.

To perform the stellar population synthesis of the O VI we have built a library of line profiles based on the HUT spectra of hot stars (Walborn et al. 1995), and the Copernicus spectra of O and B stars (Walborn & Bohlin 1996). We find that the equivalent widths of the individual stars used to build the spectral library do not show any correlation with the luminosity, with only a tendency of the equivalent width to increase for the early type O stars. The reason for this is due to the contribution of the stellar Lyβ and C II λ1036 to the window used to measure the O VI. Those lines are very prominent in intermediate to late B stars, and for these stars the OVI is absent. The profile is more correlated with the spectral type, although not with the luminosity. This library is used as input to the stellar evolutionary code developed by Leitherer et al., to create the synthetic evolutionary profile for a burst of star formation with different stellar parameters (slope of the IMF, upper mass cut-off), and different scenarios of the star formation process (instantaneous burst and continuous star formation).

For an instantaneous burst, the contribution to the profile after 15 Myr comes from the Lyβ and C II produced by intermediate and late B stars, that make these two lines to broaden and deepen (Fig. 1). For continuous star formation, the profile does not change too much after a few Myr, due to the equilibrium between birth and death of O stars. The effect of changing the slope of the IMF is only noticeable in the first 3 Myr of the evolution, with a stronger PCygni profile for a shallower IMF. The effect of the upper mass cut-off is similar to changing the slope of the IMF. With $M_{up} = 20\ M_\odot$ only stars equal or cooler than O9 contribute to the profile. To distinguish between the different star formation scenarios, we have measured the equivalent width of the C II line with respect to that of the whole profile, and we find that the ratio is sensitive to the age of the burst and to the different scenarios of star formation (Figure 2).

The next step is to apply this method to the HUT spectra, and use in combination with the Si IV and C IV to obtain information of the star formation history in high redshift galaxies, where the O VI+Lyβ will be shifted into the near ultraviolet or the optical.

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