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UV *HST* SPECTROSCOPY OF STAR-FORMING GALAXIES

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RESUMEN

Informamos sobre las observaciones espectroscópicas de 8 galaxias H II, realizadas con el *HST*. Se ha detectado emisión en la línea Lyα en 4 de ellas. Hemos encontrado que el factor determinante para que la línea sea visible es la estructura en velocidades del gas neutro, y no la abundancia de polvo. El resto de las galaxias observadas muestran líneas de absorción en Lyα anchas y saturadas, atribuidas a densidades de columna altas de H I estático con relación a los fotones Lyα emitidos en las regiones H II. Las galaxias con formación estelar IZW18 y, especialmente, SBS0335–052 pudieran albergar nubes de H I extremadamente deficientes en metales, con un valor de [O/H] para ésta última tan bajo como −7.2.

ABSTRACT

HST spectroscopical observations of 8 H II galaxies are reported. Lyα emission was detected in 4 of them. We find that it is the velocity structure of the gas which is the main determining factor for the escape of the Lyα photons, and not the abundance of dust. The rest of the sample shows broad damped Lyα absorption attributed to large H I column densities that is static with respect to the emitted Lyα photons emerging from the H II regions. The star-forming galaxies IZW18 and even more SBS0335–052 may have extremely metal deficient H I clouds, the latter with [O/H] as low as −7.2.

Key words: **GALAXIES: COMPACT — GALAXIES: INDIVIDUAL: ESO 350-IG038, SBS0335-052, IRAS08339+6517, IZW18, HARO2, MKN36, IIZW70, ESO 400-G043 — ISM: ABUNDANCES — ULTRAVIOLET: GALAXIES**

1. INTRODUCTION

A very important astrophysical issue is the detection of galaxies at large redshift that are forming stars for the first time, the so-called primeval galaxies. In parallel, bearing in mind that galaxy formation may not be assigned to any preferential cosmological epoch but rather a continuous process, one might find left-over pristine gas pockets that are forming young galaxies at present epoch. For this reason, since in our local universe there may be star-forming galaxies that look like very much distant primeval ones, there have been several attemps to observe their Lyα emission (Meier & Terlevich 1981).

Studies have also been aimed to measure abundances in the neutral gas of gas-rich dwarf galaxies with spectra dominated by recent star formation episodes. Indeed, in objects such as these, the H I clouds largely extend beyond the optical images suggesting that a substantial fraction of this gas might still be chemically unevolved or even pristine (Roy & Kunth 1995). With the advent of the *HST*, it became possible to analyse with much greater details than with the *IUE* the processes of escape and the destruction of the Lyα photons since a study of the line profile could be performed. Similarly at a spectral resolution of 20 000 it became possible to disentangle nebular from stellar absorption lines and give estimates of the metal abundances in the insterstellar medium.

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TABLE 1

OBSERVED H II GALAXIES

Galaxies	α1950	δ1950	v(km/sec)	Lyα
ESO 350-IG038	00h34m26.0	−33d49m54	6156	emission
SBS0335-052	03h35m15.1	−05d12m27	4043	
IRAS08339+6517	08h33m57.3	+65d17m45	5730	emission
IZW18	09h30m30.3	+55d27m46	740	
Haro 2	10h29m22.7	+54d39m31	1461	emission
Mkn36	11h02m15.6	+29d24m28	646	
IIZW70	14h48m55.1	+35d46m37	1215	
ESO 400-G043	20h34m31.0	−35d39m42	5900	emission

2. THE *IUE* ERA

Previous *IUE* observations were performed on more than a dozen galaxies in the SWP low resolution mode (Meier & Terlevich 1981; Hartmann, Huchra, & Geller 1984; Deharveng, Joubert, & Kunth 1986; Hartmann et al. 1988; Terlevich et al. 1993). Galaxies with redshift large enough that their Lyα emission is separated from the geocoronal line were selected. It was realized from the very beginning that the Lyα emission is much weaker, by an order of magnitude, than expected from the recombination theory. In fact the equivalent widths of this line are in the range of 50 to 10 Å or lower and moreover in several cases it is seen in absorption. No obvious ways were found to predict the outcome in a general case. Previous works have also shown a possible anticorrelation between the Lyα/Hβ ratio and the metallicity (actually the O/H abundance, as measured in the ionised gas). These results and the lack of "primeval galaxies" at large redshift in blank sky searches for redshifted Lyα emission has been attributed to the effects of dust absorption that preferentially destroys Lyα photons (Charlot & Fall 1993, and references therein). The process behind is that the transfer of Lyα radiation is strongly affected by resonant scattering from neutral interstellar hydrogen atoms. By increasing enormously their path length, photons become more vulnerable to dust absorption. Chen & Neufeld (1994) have shown that the combination of interstellar dust absorption and hydrogen atoms scattering can even lead to negative Lyα equivalent widths as observed in IZW18 by Kunth et al. (1994) using *HST* data. Since IZW18 is the most metal-poor galaxy known it soon became clear that the transport of Lyα photons may not be attributed to the galaxy dust content alone. On the other hand a positive emission has been detected in the more dusty galaxy Haro2, (Lequeux et al. 1995). These new facts and the new capability of the *HST* to analyse in higher details for the first time Lyα line profiles in nearby galaxies led us to embark on a longer term project using the GHRS.

3. THE NEW *HST* OBSERVATIONS

Observations were made using the same settings as in Kunth et al. (1994) and Lequeux et al. (1995), the grating angle being set according to the redshift of the object, so as to cover the Lyα and the O I 1302.2 Å regions respectively. The Lyα range was chosen to investigate the Lyα photon escape and measure the column density of the surrounding neutral gas on the line of sight. The O I 1302 Å and Si II 1304 Å region was used to estimate the chemical composition of the gas and to measure with reasonable accuracy the mean velocity at which the absorbing material lies with respect to the star-forming region of a given galaxy. Eight galaxies have been observed so far, as listed in Table 1, and have been selected from very different considerations:

i) the H II galaxies Mkn36, IIZW70 and Haro2 were chosen because they span a wide range of metallicity. The aim was to investigate the possible relationship between the composition of their H II regions and that of the H I gas as derived from the O I and Si II lines.

ii) Three starburst galaxies were selected in the *IUE*-ULDA from the a-priori knowledge that they were Lyα emitters; they include: IRAS 08339+651, ESO 350-IG038 and ESO 400-G043.

In addition the SBS0335-052 spectra, observed by Thuan, Isotov, and Lipovetsky were retrieved from the *HST* archives.

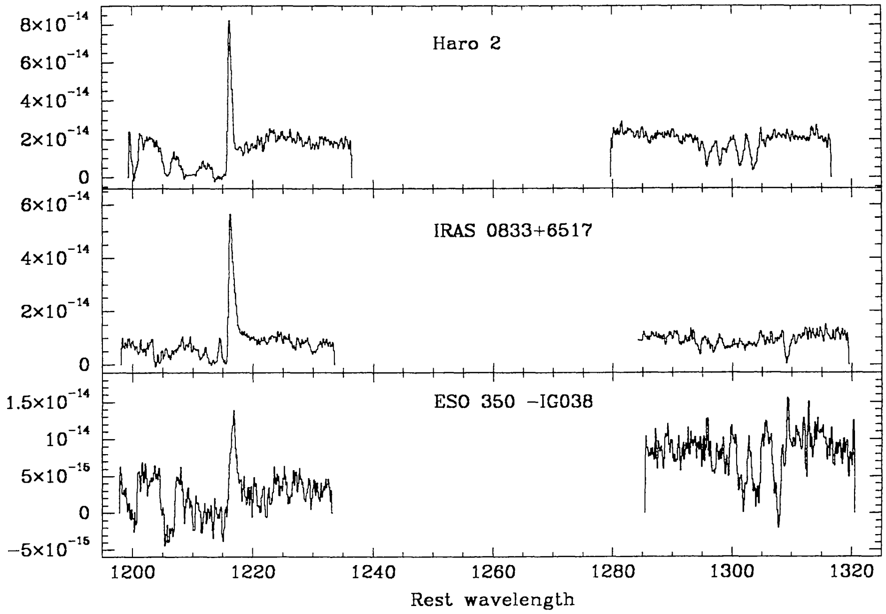

Fig. 1. *HST*-GHRS spectra for 3 galaxies with Lyα emission and showing an absorption trough. Both the Lyα and the O I regions are displayed.

4. THE LYMAN ALPHA ESCAPE

Among the eight galaxies up to now observed with the GHRS, 4 show no Lyα emission. Instead, a strong damped Lyα absorption redshifted at the rest velocity is observed, showing a complete destruction of these photons in the nebular gas. O I and/or Si II appear in absorption and in some cases (see section 5) are barely detected. In all cases these lines occur without any velocity shift with respect to the H II regions. This indicates that the neutral gas in which they mostly originate is static with respect to the star-forming region. Therefore, although these galaxies are relatively dust free (IZW18 shows weak signs of reddening and its gas-to-dust ratio is at least 50 times larger than the Galactic value —Kunth et al. 1994) it is possible to suppress Lyα by simple multiple resonant scattering from the neutral gas. Even a dust free cloud would nearly preserve the photons but scatter them over the whole H I cloud area; the surface brightness in the line would then be very weak but might perhaps be detected with the *HST* with very long exposures. In all these cases the widths of the broad damped absorptions are larger than 20 Å (33 Å in the case of IZW18) hence one can dismiss the possibility that they arise in OB photospheres (Valls-Gabaud 1993).

At variance with these cases, the rest of the sample shows clear Lyα emission. The profiles of the lines are nevertheless asymmetric, with the peak emission REDSHIFTED with respect to the H II region systemic velocity.

The first bonafide case was reported in Haro 2 in which the Lyα emission is accompanied by a broad absorption in the blue wing of that line (Lequeux et al. 1995), with the general appearance of a typical P Cyg profile. Therefore, the neutral gas responsible for the absorption in this galaxy is not at the velocity of escaping photons. In other words multiple scattering at wavelengths larger than the Lyα rest wavelength is not effective, so that Lyα photons can escape in the red wing. This may be due to an expanding envelope around the H II region, whose back part emits or scatters Lyα photons which are not absorbed by the front part because of its different velocity. This interpretation is confirmed by the presence of other detected absorptions of O I, Si II and Si III due to gas in front of the hot stars ionizing the central H II region of Haro 2. The heliocentric velocities of all these absorptions are lower by about 200 km/sec than that of the bulk of the galaxy as measured in the 21-cm line and of the optical emission lines. Moreover, the absorption at the rest wavelengths were almost negligible for all metallic lines.

Spectroscopic observations of Hα were obtained with the William Herschel telescope at La Palma, allowing to compare both the reconstructed Lyα and the Hα profiles. Preliminary results show that significantly Lyα is broader than the Balmer line suggesting the scattering of the photons from the back side of the expanding neutral cloud. The amount of neutral gas that produces the blue absorption trough at Lyα is rather modest and of the order of N(H I)=7.7 10^{19} atom/cm^2.

The three additional galaxies that have since been observed by us with the *HST* using the GHRS remarkably confirm that Haro 2 is not an isolated case. We display these spectra in Figure 1.

All spectra show Lyα emission with a broad absorption on their blue side. Careful analysis to interpret the details of their profiles is being published elsewhere. The preliminary results are as follows:

- ESO 350-IG038: This galaxy has a redshift of 6156 km/sec. At this redshift the O I region falls close to the C II 1326 Å Galactic line that can be used as a reference for the wavelength scale. The Lyα absorption extends over more than 1500 km/sec to the blue side of the line emission. It is not clear that Lyα exhibits a P-Cygni profile since the line does not drop sharply at zero velocity. The O I and Si II lines are very broad and peak at −80 km/sec with respect to the H II gas.
- IRAS 0833+6517: This galaxy has a redshift of 5730 km/sec. The Lyα is narrow and exhibits a clear P Cygni profile. Remarkable enough is a clear secondary emission, probably from Lyα at −200 km/sec from the main line. The absorption feature 400 km/sec wide is clearly seen on the blue side of the profile. Unfortunately no O I and/or Si II are detected that could provide more detailed information about the kinematics of the absorbing gas.
- ESO-B400: This galaxy was observed soon after this Meeting and the results are presented elsewhere. Again absorptions are detected and take place in flowing out material.

The main conclusions that are drawn from this set of data is that complex velocity structures are dominant in the Lyα emission, showing the strong energetic impact of the star-forming regions into their surrounding ISM. *It is this velocity structure the determining factor for the Lyα escape, not the abundance of dust.* This effect helps to understand why only luminous high-redshift objects have been found up to now with line widths larger than 1000 km/sec. High-redshift galaxies with very strong (EWs > 500 Å) extended Lyα emission are characterized by strong velocity shear and turbulence (v > 1000 km/sec) and this suggests that other ionization mechanism than photoionization by young stars may be operating. However, Steidel et al. (1996) have recently discovered a substantial population of star-forming galaxies at $3.0<z<3.5$ that were selected not from their emission-line properties but from the presence of a very blue far-UV continuum and a break below 912 Å at rest frame. Similarly to our local starbursts they find that 50% of their objects show NO Lyα emission whereas the rest does, but with weak EWs no larger than 20 Å at rest. This population looks indeed very similar to our local starburst galaxies.

5. MEASURING NEUTRAL ABUNDANCES

Since blue compact galaxies are rich in neutral gas which might remain unprocessed they were thought to be ideal laboratories to look for primordial gas. Alternatively, because they undergo sporadic episodes of massive star-formation it is expected that their ISM remains inhomogeneous. One could test the mechanisms by which metals are dispersed and further mixed into the ISM (Kunth & Sargent 1986; Roy & Kunth 1995; Tenorio-Tagle 1996). Neutral heavy elements abundance informs about past star-formation episodes after mixing has been operating. It is remarkable that whenever Lyα emission is not detected broad damped absorption features are detected. As noted before the lines are too wide to be attributed to stellar photospheres. In IZW18, Mkn36 and IIZW70 the O I and Si II lines were detected or well measured. IZW18 has been analysed in Kunth et al. (1994) who find N(H I)=3.5 10^{21} atom/cm^2 on the line of sight within the LSA aperture of $2'' \times 2''$. The authors concluded that most of the O I is produced in the H I gas and very little in the transition zone of the H II gas. Accordingly they conclude that the O/H abundance in the H I region is a factor of about 20 BELOW that in the H II region. Although words of caution were given as regarding the uncertainties involved with the analysis of the O I 1302 Å line, the result indicates that most of the heavy elements have been produced in the present burst of star formation (see also Kunth el al. 1995). Pettini & Lipman (1995) have added some illustrative arguments to moderate the impact of this result: indeed if O I is saturated (this point is not completely settled) the O I profile is more sensitive to the b-value than to the column density. Additional *HST* observations are scheduled to solve this question using the S II 1256 Å line, that is expected to remain unsaturated and is mostly produced in the H I gas. This result prompted us to investigate more galaxies with the hope to correlate H I O abundances with that of the H II zone. As can be seen in Fig. 2, absorptions in Mkn36 and IIZW70 are not as broad as in IZW18. Nevertheless, they indicate very large N(H I) column densities.

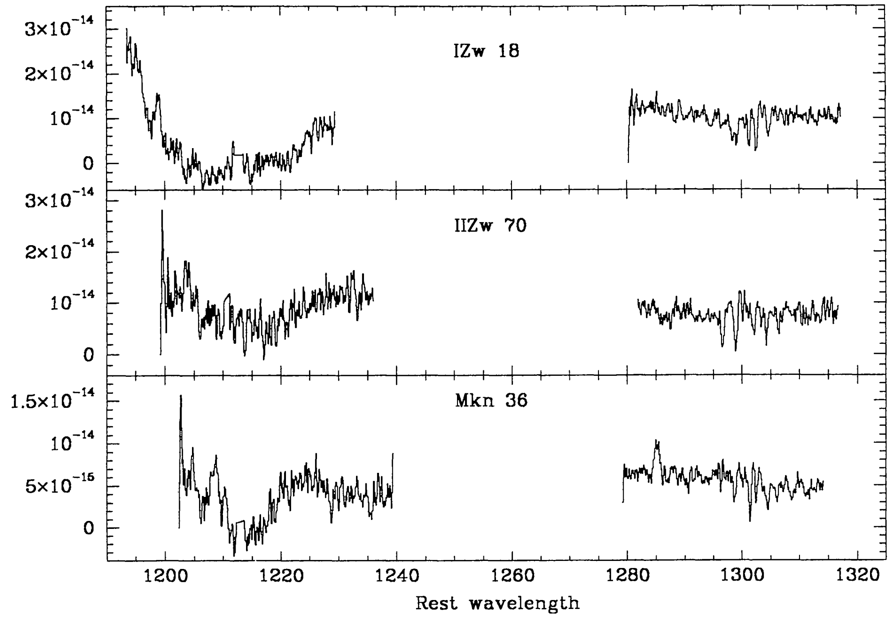

Fig. 2. *HST*-GHRS spectra for 3 galaxies with no Lyα emission. In this case the Lyα region shows a broad damped absorption. Both the Lyα and the O I regions are displayed.

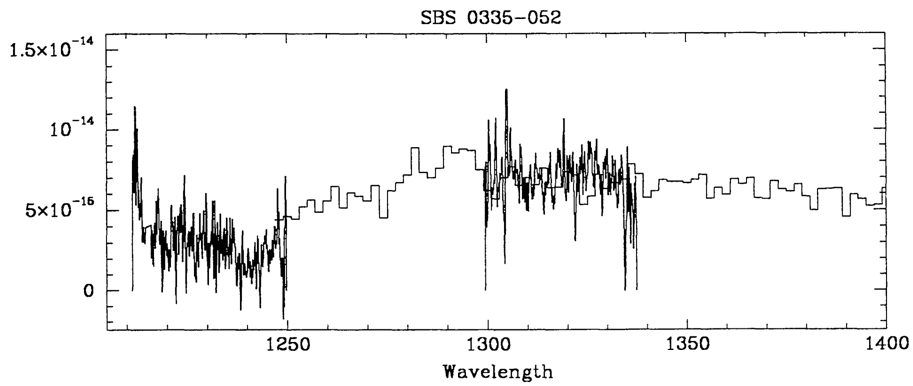

Fig. 3. *HST*-GHRS spectra of SBS 03350052 for the Lyα and the O I regions superimposed to the *IUE* SWP spectrum.

O I equivalent widths of the order of 0.3 Å together with O I and H I column densities estimated with the XVoigt code, lead to O abundances similar to that of the H II regions.

The case of SBS 0335-052 is rather different. We have de-archived the *HST* GHRS spectra that were obtained by Thuan, Isotov, and Lipovetsky using the same settings as in Kunth et al. (1994) for IZW18. The spectrum is much noisier than the rest of the sample. Nevertheless we made use of the *IUE* spectrum that had been obtained by E. Terlevich and R. Terlevich, using a combined NASA-ESA shift (de-archived). Fig. 3 shows the *HST* spectra superimposed —after proper scaling— to the *IUE* SWP spectrum near the Lyα and O I regions and displayed on the observed wavelength scale.

We have barely been able to detect the O I line at 1302Å. Using the red wing of the Lyα absorption, we were able to fit a damped line with a b value of around 40 km/sec leading to a column density N(H I)=3.5 10^{21} atom/cm^2, even higher than that of IZW18. This combined information leads to log N(O I) of 14.3 or to a [O/H I] ratio as low as −7::! If real this would indicate that SBS0335−052 has really undergone very little star formation —if any— in the past. This makes this target ideal for primordial He determination.

TABLE 2

ABUNDANCES IN H I GAS

Galaxies	$LogN(H\ I)$	$LogN(O\ I)$	$[O/H\ I]$	$H\ I/H\ II abundratio$
IZW18	21.5	15.4	−6.1::	≪1
IIZW70	20.6	14.9	−5.7::	1
Mkn36	19.9	14.4	−5.5::	1
SBS0335-052	21.5	14.3	−7.2::	≪1

Note that these determinations are very preliminary. It can be seen in Fig. 3, that the bottom of the Lyα absorption does not reach the zero level as it should. We suspect that this is due to the extraction procedure which may lack some accuracy at low level of background subtraction (i.e., $< 2 \times 10^{-15}$ erg/sec/cm^2/Å). The summary of the abundance measurements are given in Table 2.

6. SUMMARY

- Lyα emission has been observed in 4 H II galaxies out of 8 observed with the GHRS on board *HST*. We have found that the determining factor to allow the escape of Lyα photons is the velocity structure of the neutral gas (and may be the presence of holes with low column densities), and not the abundance of dust particles. In fact one galaxy in our sample is a strong *IRAS* source (IRAS0833+6517). Whenever the H I column density is large enough, even in a dust free environment (IZW18 is the best example) photons can be completely re-distributed by multiple scattering, presumably over the area of the associated H I clouds. The Lyα line then becomes very hard to detect because of its low surface brightness. The photons so redistributed will correspond to the Lyα photons emitted by the H II region only if the H I gas is static with respect tó the H II gas.

- A clear evidence for the presence of a wide velocity field is given by the presence of a deep absorption trough in the blue side of the Lyα profile. Moreover, absorption lines of metallic elements (O I, Si II) are also detected significantly blue shifted with respect to the H II gas velocity. This out flowing neutral material may eventually leave the galaxy. We thus may be witnessing galactic wind that results from intense star-forming activity.

- Several possibilities are investigated to understand the reasons that govern the appearance of the Lyα line emission. The age of the burst, its strength, the metallicity of the gas (controlling the cooling, hence the blow out time occurrence), the gravitational potential of the parent galaxy and its morphology, the H I and the dust distributions could play a role but of unequal importance that we hope to assess in a near future.

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