New detections of Ly α emission in young galaxies

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ABSTRACT
We report IUE observations of two extremely low-metallicity H II galaxies. Ly α emission was detected in both galaxies. Our results confirm previous findings that young or unevolved galaxies exhibit weak or absent Ly α emission combined with a strong UV continuum, and that the Ly α/Hβ ratio and metal content are correlated in the sense that the lower the abundance, the larger the ratio. This supports the hypothesis that in the higher metallicity systems Ly α is destroyed by dust absorption. At redshifts of between 2 and 3, Ly α emission comparable to the strongest detected in H II galaxies [L(Ly α) ~ 5 × 10^42 erg s^-1] would be barely visible; this fact can explain the relative lack of success in detecting Ly α emission associated with low-metallicity damped Ly α systems in QSOs. Our results cast doubt on claims of detection of high-redshift young galaxies associated with active galaxies, or with strong Ly α and both C iv and He ii, since they may represent very extended narrow-line regions photoionized by radiation with a power-law spectrum rather than by normal hot stars.

Key words: H II regions – galaxies: abundances – galaxies: formation – galaxies: starburst – ultraviolet: galaxies.

1 INTRODUCTION
H II galaxies are among the most luminous narrow emission line objects in the sky (Terlevich 1988). The observed Hβ luminosities are normally in the range 10^{40}-10^{41} erg s^-1, with some galaxies reaching more than 10^{43} erg s^-1 (for H_o = 50 km s^-1 Mpc^-1 and uncorrected for intrinsic reddening). The absolute blue magnitude of the stellar continuum (i.e., not including the emission lines) ranges from ~15 to ~25 mag. The analysis of the emission-line spectra indicates that these objects are normally underabundant in heavy elements and photoionized by normal hydrogen-burning hot young stars (Bergeron 1977; French 1980; Kunth & Sargent 1983; Terlevich 1986). The optical and ultraviolet continua are dominated by the O- and B-star population. The remarkable stellar composition of these compact and isolated objects, combined with the very low heavy-element abundance deduced from their emission-line spectra, leads to the conclusion that some of them may be truly 'young' galaxies forming their first generation of stars. In any case, they represent the youngest galaxies that can be studied in any detail, and therefore the study of their systematic properties can provide important model constraints and clues for theories of formation and evolution of massive stars and for searches for primaeval galaxies.

A surprising result from the early stages of the study of H II galaxies was the discovery by Meier & Terlevich (1981) that Ly α is very weak or absent in their UV spectra despite the extremely strong optical emission lines. Hartmann, Huchra & Geller (1984) and Deharveng, Joubert & Kunth (1986) confirmed the conclusions of Meier & Terlevich, and added six more objects to the sample, but only one strong Ly α detection.

The preferred explanation for the reduced Ly α emission in H II regions is absorption by dust in the ionized gas (Auer 1968; Sarazin 1977). Multiple scattering in the Ly α line enhances the dust absorption (Meier & Terlevich 1981). In contrast, Ly α is usually strong in emission and has a large equivalent width in galaxies with an active nucleus. This fact has been discussed in detail by Hartmann et al. (1988), and its implications regarding recent claims of detection of high-redshift young galaxies are very important. However, these conclusions are based on a very small sample, consisting of only seven galaxies with detected Ly α, of which only two have Ly α/H β ratios larger than 2 (Cambridge 1543+091 (Meier & Terlevich 1981) and Pox 120 (Deharveng et al.
from the geocoronal Lyα. Here we report observations of
the first two galaxies selected.

2 OBSERVATIONS

The two objects observed were selected from the SCHG
(Terlevich et al. 1991) and from Campbell, Terlevich &
Melnick (1986) due to their low metallicity, high redshift and
small angular size. The observations were made in 1989
March using the SWP camera of the IUE satellite through
the Large Aperture (10×20 arcsec), in the low-resolution
mode. The spectra were reduced in the standard way. Table
1 lists the details of the observations.

Figure 1. (a) UV spectrum SWP35814 of C0840 + 1201. (b) UV spectrum SWP35685 of T1247 – 232.
3 RESULTS AND DISCUSSION

The short-wavelength UV spectrum of each object is shown in Figs 1(a) and (b), smoothed by 2 pixels to remove high-frequency noise. Ly$\alpha$ emission is clearly seen in the spectra of the two galaxies at their optically measured redshifts. No other emission lines are detected and only a hint of absorption is seen in the spectrum of T1247−232 at the redshifted wavelengths of C$\ II$ and Si$\ IV$.

Optical spectra of both galaxies from SCHG and Campbell et al. (1986) are shown in Figs 2(a) and (b). The spectra are typical of high-excitation H$\ II$ regions photoionized by massive O and B stars. The presence of young stars is indicated in the spectrum of T1247−232 by Wolf−Rayet (WR)

![Figure 2](image-url)  
**Figure 2.** (a) Optical spectrum of C0840+1201. (b) Optical spectrum of T1247−232; at a different scale, the inset shows WR features between H$\gamma$ and H$\beta$.  

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features in the blue (see inset in Fig. 2b). Line intensity ratios were measured in the optical and UV spectra of the two galaxies and are listed in Table 2. The equivalent widths and fluxes of Lyα and Hβ lines are also given. All the values in Table 2 have been corrected for reddening, estimated to be E(B−V) = 0.07 and 0.21 mag for C0840 + 1201 and T1247-232 respectively from the observed Balmer decrements Hα/Hβ, Hγ/Hβ and Hα/Hβ using Seaton’s (1979) reddening curve. The line ratios listed in Table 2 have been used to derive chemical abundances for the two galaxies. The temperature-sensitive [O III] line at λ4363 Å is detected and measured in both galaxies, allowing a good determination of the electron temperatures. These temperatures together with the derived abundances are given in Table 3.

Both objects fit nicely (Fig. 3) the trend between log(Lyα/Hβ) and [O/H] first suggested by Meier & Terlevich (1981) and later supported by Hartmann et al. (1988). As in other H ii galaxies observed, the measured Lyα/Hβ ratio is much lower than that expected from recombinant theory (≈ 33). In the case of T1247-232, the observed Lyα/Hβ ratio can be reconciled with the observed Hα/Hβ decrement if an extinction curve similar to that appropriate for the Small Magellanic Cloud (Prévot et al. 1984) is used; in the case of C0840 + 1201, however, the required amount of extinction to reduce the Lyα line to the observed value would be E(B−V) = 0.17, 0.1 mag larger than that deduced from the Hα/Hβ ratio.

None of the young stellar systems observed so far has shown any emission line other than Lyα in its UV spectrum. The highest measured equivalent width of Lyα is 120 Å for Cambridge 1543 + 091 (Meier & Terlevich 1981); this is the lowest metallicity galaxy (Z = 1/10 Z⊙) so far observed with IUE among systems with redshift high enough to detach their Lyα emission from the geocoronal Lyα. Most H ii galaxies have Lyα equivalent widths of between 50 and 100 Å. It is remarkable that objects dominated in the optical by their strong emission lines revert completely in the UV to objects in which the luminosity output is dominated by the continuum emission. This is clearly seen by comparing Figs 1 and 2. The effect is so obvious that we can safely conclude that the best UV signature of young metal-poor galaxies is a strong and relatively featureless continuum.

This conclusion contrasts strongly with those drawn by some workers (e.g. Djorgovski 1988) regarding the interpretation of extended emission-line regions around high-redshift radio galaxies. It has been claimed that they represent the best examples of young or primaeval galaxies. Recent high signal-to-noise spectra of a compilation of these systems (McCarthy et al. 1990a, b), however, show very strong Lyα superimposed on a weak continuum with perhaps some weak stellar features, and strong metal emission lines, in particular C iv and He ii. Typical equivalent widths of Lyα in these objects are about one order of magnitude larger than those of certified young stellar systems. C iv emission has never been detected in H ii galaxies or H ii regions; He ii is not expected to be strong in young galaxies, mainly because the hottest stars in them have T_eff < 10^4 K. All this suggests that the extended emission regions around high-redshift radio galaxies are probably gaseous discs with approximately normal metal content illuminated by the hard UV radiation from the nucleus. It will be interesting to determine if there are any extended emission-line regions associated with strong radio galaxies without nuclear emission lines.

A different case is the ‘Lyα galaxy’ discovered by Lowenthal et al. (1991) near a damped Lyα absorber at

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**Table 2.** Reddening-corrected emission-line ratios.

<table>
<thead>
<tr>
<th>Object</th>
<th>C0840 + 1201</th>
<th>T1247-232</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td>I_α / I(Hβ)</td>
<td>I_α / I(Hβ)</td>
</tr>
<tr>
<td></td>
<td>(× 1000)</td>
<td>(× 1000)</td>
</tr>
<tr>
<td>3727 [OII]</td>
<td>1429</td>
<td>1412</td>
</tr>
<tr>
<td>3770 H_1</td>
<td>19</td>
<td>—</td>
</tr>
<tr>
<td>3798 H_0</td>
<td>16</td>
<td>—</td>
</tr>
<tr>
<td>3835 H_α</td>
<td>52</td>
<td>—</td>
</tr>
<tr>
<td>3869 [NII]</td>
<td>337</td>
<td>471</td>
</tr>
<tr>
<td>3889 H_α, He</td>
<td>163</td>
<td>—</td>
</tr>
<tr>
<td>3967 [NII], He</td>
<td>218</td>
<td>256</td>
</tr>
<tr>
<td>4102 H_γ</td>
<td>253</td>
<td>260</td>
</tr>
<tr>
<td>4340 H_γ</td>
<td>466</td>
<td>480</td>
</tr>
<tr>
<td>4363 [OIII]</td>
<td>80</td>
<td>59</td>
</tr>
<tr>
<td>4471 He</td>
<td>26</td>
<td>44</td>
</tr>
<tr>
<td>4861 H_β</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>4959 [OIII]</td>
<td>1601</td>
<td>1799</td>
</tr>
<tr>
<td>5007 [OIII]</td>
<td>4785</td>
<td>5256</td>
</tr>
<tr>
<td>5876 He</td>
<td>113</td>
<td>89</td>
</tr>
<tr>
<td>6300 [OI]</td>
<td>27</td>
<td>58</td>
</tr>
<tr>
<td>6563 H_α</td>
<td>2800</td>
<td>2957</td>
</tr>
<tr>
<td>6584 [NII]</td>
<td>68</td>
<td>179</td>
</tr>
<tr>
<td>6678 He</td>
<td>32</td>
<td>—</td>
</tr>
<tr>
<td>6717 + 6731 [SII]</td>
<td>182</td>
<td>101</td>
</tr>
<tr>
<td>c(Hβ)</td>
<td>0.10</td>
<td>0.30</td>
</tr>
<tr>
<td>F(Hβ)*</td>
<td>0.33</td>
<td>1.35</td>
</tr>
<tr>
<td>EW(Hβ) (Å)</td>
<td>121</td>
<td>97</td>
</tr>
<tr>
<td>F(Lyα)*</td>
<td>(1.0±0.17)</td>
<td>(1.20±0.15)</td>
</tr>
<tr>
<td>EW(Lyα) (Å)</td>
<td>48</td>
<td>29</td>
</tr>
<tr>
<td>Lyα / Hβ</td>
<td>3.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>

*×10^{-12} erg cm^{-2} s^{-1}.
z = 2.3. This object has a Lyα luminosity comparable to the values discussed here for H II galaxies and clearly shows C IV and He II emission lines and a continuum rising slightly towards the red, but is not a strong radio source. The concurrence of strong Lyα, C IV and He II strongly suggests photoionization by a UV field much harder than that provided by hydrogen-burning young stars. The object is more likely to be either a narrow-line AGN or a starburst dominated by WARMERS (Terlevich & Melnick 1985).

Based solely on upper limits for the detection of Lyα emission in damped Lyα systems in high-redshift QSOs, Smith et al. (1989) and Deharveng, Buat & Bouyer (1990) concluded that, in the associated galaxies, there is no increase with z of the star formation rate (SFR). Our results cast doubt on this conclusion. If damped Lyα systems are associated with luminous, rather metal-rich and dusty disc galaxies then, according to our findings, the limits on Lyα emission estimated without a precise knowledge of the metal content of the system could be wrong by orders of magnitude.

In fact, the reported detections of Lyα emission in damped Lyα systems are associated with low-metallicity systems (Hunstead, Pettini & Fletcher 1990; Pettini & Hunstead 1990; Pettini, Boksenberg & Hunstead 1990). This is consistent with the suggestion that damped Lyα systems may be associated with high-redshift galaxies whose properties (luminosity, metallicity, linewidths, etc.) are similar to those of present-day H II galaxies.

A caveat regarding this interpretation is that, while we measure O/H abundances, Pettini and collaborators base their analysis on the Zn/H and Cr/H ratios. The behaviour of the Zn/O ratio with time in an evolving galaxy is not yet well known.

In conclusion, upper limits on the SFR estimated solely from Lyα luminosities should be taken with due caution, considering the correlation between metallicity and Lyα shown in Fig. 3. SFR estimators should best be based on the UV continuum luminosity.

4 CONCLUSIONS

The study of H II galaxies provides important clues about the intrinsic properties of young or unevolved galaxies. These clues are important in searches for primeval galaxies, particularly if starbursts are the dominant mode of galaxy formation.

From strict empirical considerations, we expect that young galaxies will have a strong UV stellar continuum and weak emission in Lyα. We do not expect to see any strong metal lines in emission: in particular, C IV λ1550 Å is expected to be weaker than Lyα. Some authors (Djorgovski 1988) have suggested that regions with strong Lyα emission associated with high-redshift quasars and with large equivalent width in this line are young star-forming galaxies. In the light of the present work, we think that they are more likely to be related to the centrally ionized extended narrow-line regions found in both radio and Seyfert galaxies.

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REFERENCES