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Emission line flux limits in four QSO metal line absorbers

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Abstract. In an effort to detect the early phases of star formation in massive galaxies, we have searched for Lyα and [O II]λ3727 emission from four QSO metal absorption line systems and possible associated galaxies, using narrow-band filters. None of the objects was detected. We discuss the possible effects of dust on the visibility of the objects and show that we can derive interesting upper limits on the star formation rates.

Key words: galaxies: evolution; formation; starburst – quasars: absorption lines

1. Introduction

Searches for progenitors of normal luminous galaxies have long been a frustrating issue. Now the situation may be changing as detections of starforming galaxy candidates at z$\geq$3 recently was reported by Steidel et al. (1996). They find that the luminosity profiles of most of these galaxies resemble present-day elliptical galaxies. Also at lower redshifts (below z$\sim$ 1.7), detections of star-forming galaxies are now fairly common (e.g. Cowie et al. 1995). In the intermediate redshift range (z=1.8-3) however, where most of the star formation in massive disks probably is taking place, normal galaxies continue to hide in the darkness.

In the absence of considerable amounts of dust, galaxies undergoing an initial starburst, should show strong Lyα emission. This is supported also in studies of metal-poor nearby star-forming galaxies (see sect. 5 for a discussion). A number of searches for redshifted Lyα have therefore been performed in order to detect these fingerprints of primeval galaxies (De Propris et al. 1993, Thompson et al. 1995). To say the least, results have not been overwhelming. In particular, the searches for emission from damped Lyα (DLA) systems in QSO spectra have been quite discouraging (e.g. Lowenthal et al. 1991, Lowenthal et al. 1995, Pettini et al. 1995). Lyα emission has been detected in the environments of known emission or absorption line objects (e.g. Möller and Warren 1993, Machetto et al. 1993, Graham and Dey 1996) but the ionizing source may be an active nucleus rather than young stars.

If multiple resonant scattering and dust extinction of the Lyα line is important, searches for emission lines with longer wavelengths than Lyα may prove fruitful (Mannucci & Beckwith 1995). Only a few surveys along these lines, reaching low limiting fluxes, have been reported (Pahre & Djorgovski 1995; Bunker et al. 1995; Thompson et al. 1994, Malkan et al. 1995). In general, results are negative or the ionization source cannot be reliably established. Neither have other search strategies at intermediate redshifts, looking for primeval galaxies in the general field, yielded many convincing detections (see Pritchet 1994 for a review). In fact one of the more interesting cases is a serendipitous detection of a proto-galaxy at z=2.7 showing only stellar absorption lines (Yee et al. 1996).

At lower redshifts searches for galaxies associated with quasar absorption lines have been more successful. Bergeron and Boisse (1991), Bergeron et al. (1992) and Petitjean and Bergeron (1994) have studied galaxies responsible for Mg II and CIV absorption systems. Steidel and Dickinson (1992) detected three Mg II absorbers at three different redshifts in one field and Lanzetta et al. (1995) have detected several galaxies responsible for DLA signatures.

The small number of objects found at intermediate redshifts seems lower than expected from simple theories of galaxy formation. Interpretations of the deficit involve obscuration by dust, a protracted star formation period or that the major star formation epoch occurred at higher redshifts. The last possibility does not seem very likely, as the neutral hydrogen density at z=3 is comparable to what we now see in stars and shows a rapid decrease in the redshift interval z=3-1 (Wolfe et al. 1995), indicating a major star formation epoch.

If star formation does not occur in bursts but instead extends over a long time, the observable consequences may not be very dramatic. There is a strong support for the idea that DLA systems are associated with the formation of normal disks (Wolfe 1995). This process is supposed to be rather slow and quiet even if the disk is formed out of a single cloud. Other models describe the formation of galaxies through successive merging of small systems (e.g. Rocca-Volmerange & Guiderdoni 1990), again a process that could go on without intensive starbursts.

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In the present investigation we search for star-forming progenitors of massive galaxies. The occurrence of metal lines such as C IV and Mg II is normally associated with a uv illuminated galaxy halo but could also be an indication of ongoing star formation or possibly an active nucleus. It thus might be an advantage to search for emission from metal line systems instead of the damped Lyα systems, which, despite that they are good candidates of massive protodisks, have no direct indication of ongoing star formation. Few such searches have been made, but at least one showed a detection (Aragón-Salamanca 1995). The nature of the ionizing source remains uncertain, however. Here we report on a search for emission from four metal line absorption systems (Mg II and C IV) with redshifts between 1.1 and 2.4. Shortly before the observations (Hazard, private communication) we found that one of objects, Q2343+125, also shows a DLA signature at the same redshift as the metal lines.

2. Observations

The observations were performed July 8 to 11, 1994, with the 2.56-m Nordic Optical Telescope (NOT), La Palma, Canary Islands. The telescope was equipped with a 1024 x 1024 Thomson CCD, kindly provided by the Instituto de Astrofisica de Canarias (IAC). When used at NOT the pixel scale is 0.14″ x 0.14″and the fieldsize 140″ x 140″. The read out noise (RON) of the CCD was ∼6 e^-. Flatfields were obtained observing blank fields during twilight.

We observed the fields around four QSOs (see Table 1) with strong C IV or Mg II lines in their spectra. The targets were observed through narrow band (FWHM = 15–20 Å) filters with central wavelengths corresponding to the Lyα or [O II]λ3727 lines at the redshift of the absorption systems. Off-line images for continuum subtraction were obtained with filters of intermediate width (∼ 100 Å). The central wavelengths of the off-line filters were selected as closely as possible to the central wavelengths of the corresponding on-line filters. We were careful to use a wavelength region for the off-line filters where the QSO spectrum is free of strong emission and/or absorption lines (which is the reason for Q2343 and Q2344 having different off-line central wavelengths). Filter specifications are presented in Table 2. Due to the narrowness of the filters, it is important to certify that we have no significant shift in the central wavelength of peak transmission from the target emission line due to ambient temperature variations or optical setup. The central wavelengths (λ_0) for the on-line filters in Table 2 are the ones specified by the manufacturer, measured with a parallell beam and at 23–27 °C. When correcting for observing in a f/11 beam and at a temperature 5–10 °C lower than the specified, the effective central wavelength of the on-line filters (λ_{eff}) are slightly blueshifted as seen in Table 2. The predicted wavelengths of the targeted emission lines never differ more than 2.5 Å (∼ 10% of the FWHM) from these values.

At the higher redshifts of our targets, 1” corresponds to 7–8 kpc (H_0 = 75 km $s^{-1}Mpc^{-1}$; q_0 = 0.1). Unfortunately, the seeing was never better than 1.0″ FWHM and on average it was 1.1″. Therefore, in order to lower the influence of the RON, we observed with the CCD in 3×3 binned mode. The resulting pixelscale, 0.42″, is still below the seeing FWHM.

3. Reductions

The data reductions were made using the ESO-MIDAS software package. Cosmic hits were removed using the MIDAS routine "filter/cosmic". Individual flatfields for each night were constructed by taking the median of at least three frames. The sky background was fitted with a 1–4 order polynomial. The images were then assigned weights according to their signal-to-noise (S/N) ratio, aligned, and a resulting frame for each filter was constructed by obtaining the weighted median of all the frames.

Each field included at least three stars, the fluxes of which were measured both in the resulting on-line and off-line images. The off-line image was subtracted from the on-line image so that the stars had no net flux in the resulting image, which was then analysed to find excess line emission from star-forming objects in the field.

4. Analysis

In the off-line subtracted images we searched for emission from the absorber or associated star-forming galaxy. In order to estimate the upper limits of the line fluxes of the absorbers, we collected statistics of fluxes measured in circular areas with a diameter of approximately 4″, sampled in a region with radius ∼ 10″ centered on the QSO, but excluding the innermost 2″. An aperture of 4″ corresponds approximately to the projected size of a normal giant galaxy (∼ 30 kpc) at these redshifts. Assuming a gaussian distribution in the resulting data, we derived the 3 σ noise level in the flux. We repeated the analysis for 1″ apertures, corresponding to a physical size of 8 kpc. This yielded slightly higher (a factor 1 to 5) flux limits per square arcsecond (cf. Table 3). To search for a galaxy source projected onto the image of the QSO we used a maximum entropy deconvolution method (Hook & Lucy 1994; Hook et al. 1994; Lucy 1994) to remove the point source of the QSO. No extended underlying sources were found.

In order to detect faint extended structures over the whole accessible field, we rebinned the images 2 to 8 times, corresponding to 1″to 4″. The rebinning was made 4 times for each binsize, with an offset of half the binsize between each rebinning.

The flux limits were converted to limits in the star formation rates with the use of our spectral evolutionary models (se e.g. Bergvall & Rönnback 1995), and flux densities derived from the QSO spectra (Barthel et al. 1990; Hazard, private communication 1994). We assume that the initial mass function has a Salpeter form and that the mass range is 0.1–100 $\mathcal{M}_\odot$. Furthermore we assume that the metallicity of the stars is ∼ 5% of the solar and that the gas is about twice as metal rich. We then derive the number of Ly-continuum photons produced by these stars. Assuming that Lyα is produced by pure recombination, we then obtain a predicted Lyα luminosity of $2.8\cdot10^{35}$ W for a

Table 1. List of targets

Object	z of QSO	Abs. line system	Targeted em. line	z of abs. line system	References	
					Finding chart	Spectrum
Q 1726+344	2.4	C IV	Lyα	2.299	–	2
Q 2251+244	2.3	Mg II	[O II]λ3727	1.090	1	2
Q 2343+125	2.5	C IV/Lyα	Lyα	2.430	3	3,4
Q 2344+125	2.7	C IV	Lyα	2.428	3	3,4

References:
1 Merkelijn et al. 1968
2 Barthel et al. 1990
3 Hazard, private communication 1994
4 Sargent et al. 1988

Table 2. List of observations

Object	On-line filter				Off-line filter		
	λ_0 (Å)	λ_{eff} (Å)	FWHM (Å)	Integration time (minutes)	λ_0 (Å)	FWHM (Å)	Integration time (minutes)
Q 1726+344	4016	4014	20	480	4510	103	70
Q 2251+244	7792	7789	16	195	6700	97	55
Q 2343+125	4172	4170	20	127	4510	103	40
Q 2344+125	4172	4170	20	195	4328	94	60

star formation rate of 1 $\mathcal{M}_\odot$ yr^{-1}. From Stasińskas photoionization codes (1982) we adopt a typical Lyα/[O II]λ3727 line ratio of 30 which can be used to convert the [O II] flux limits.

5. Results and discussion

In Table 3 we present the resulting (dust free) upper flux limits and the corresponding star formation rates (SFR). In none of the cases did we detect emission from the absorber. The limits on the SFR in a 4″diameter aperture in Table 3 corresponds to a global SFR of 1-9 $\mathcal{M}_\odot$ yr^{-1}. The limits in a 1″aperture (corresponding to 7-8 kpc) corresponds to 0.3-2 $\mathcal{M}_\odot$ yr^{-1}. Moreover, the distribution of the binned data for the whole field agrees well with a gaussian distribution, with no deviating bright pixels. Thus we conclude that we have failed to detect line emission (Lyα or [O II]λ3727) either from the absorbers or from other galaxies at the same redshift.

We now discuss how we can take proper account of the effects of dust on the emission from the possible star-forming regions we are searching for. Charlot & Fall (1991) have treated this issue extensively. Their results indicate that multiple scattering and subsequent dust absorption of Lyα is of minor importance for H I column densities below a few times 10^{20} cm^{-2}. Judging from the equivalent widths of the Lyα absorption lines, this is a possible situation in the present case (except for Q2343). The prediction by Charlot and Fall however, is highly model dependent and it is interesting to compare with observations of nearby galaxies. In a study of nearby metal poor galaxies, Calzetti & Kinney (1992) find that dust extinction is sufficient to explain the observed Lyα/Hβ line ratios and thus that multiple resonant scattering is probably relatively unimportant. Further support for this comes from a study of nearby starburst galaxies (Valls-Gabaud 1993). Hartmann et al. (1988) found an anticorrelation between metallicity and Lyα/Hβ line ratio that becomes strong for metallicities below $\sim$ 15% solar. Although being hampered by poor statistics and inhomogeneous data, this trend is supported also by Terlevich et al. (1993), Deharveng et al. (1995) and Giavalisco et al. (1996). These results indicate that the Lyα/Hβ emission line ratios of very metal-poor galaxies (5-10% solar) are attenuated with a factor of 3–8 relative to case A recombination. This may be relevant also for the metal line absorbers, considering that their metallicities are likely to be low. As discussed by Mather et al. (1994) and Thompson et al. (1995), significantly higher dust extinction may not be consistent with the upper limit of the submillimeter background radiation as measured by COBE. However, the recently obtained spectra of some of the high redshift galaxy candidates by Steidel et al. (1996) show very weak Lyα , despite that they derive a low dust content of the ionized gas. A recent HST study of 8 star forming galaxies by Kunth et al. (1996) may help to clarify the situation. They argue that it is the velocity structure of the gas that is the main determining factor for the escape of the

Table 3. Results

Object	Abs. line system	Targeted em. line	z	4″ diameter: 3 σ upper lim. (W m^{-2} $arcsec^{-2}$)	4″ diameter: SFR ($\mathcal{M}_{\odot} yr^{-1}$ $arcsec^{-2}$)	1″ diameter: 3 σ upper lim. (W m^{-2} $arcsec^{-2}$)	1″ diameter: SFR ($\mathcal{M}_{\odot} yr^{-1}$ $arcsec^{-2}$)
Q 1726+344	C IV	Lyα	2.299	$1\cdot10^{-20}$	$\leq$0.1	$4\cdot10^{-20}$	$\leq$0.5
Q 2251+244	Mg II	[O II]λ3727	1.090	$2\cdot10^{-21}$	$\leq$0.1	$6\cdot10^{-21}$	$\leq$0.3
Q 2343+125	C IV/Lyα	Lyα	2.430	$3\cdot10^{-20}$	$\leq$0.4	$8\cdot10^{-20}$	$\leq$1.0
Q 2344+125	C IV	Lyα	2.428	$5\cdot10^{-20}$	$\leq$0.6	$1\cdot10^{-19}$	$\leq$1.4

Lyα photons and not the dust. Further observations are needed to assess the relative importance the different mechanisms responsible for the attenuation of the Lyα emission.

If we assume that the Lyα attenuation typical of nearby metal poor galaxies (3-8) is also characteristic of the Lyα absorbers, the 4” data in Table 3 give upper limits of the global SFR that are on the verge of ruling out that our targets have starburst properties. The limits we obtain are quite similar to the published upper limits from the most sensitive measurements of emission from other absorbers (e.g. Charlot & Fall 1991; Thompson et al. 1995). The most interesting result is obtained for the [OII] observations of Q2251. This line is not attenuated by scattering so we do not have the same problems as with the Lyα line. When corrected for a relatively small amount of extinction, we obtain a total SFR less than a few $\mathcal{M}_{\odot}$ yr^{-1}.

On the basis of our derived upper limits, it is interesting to calculate the estimated number of star-forming galaxies within the field we are searching. We will firstly consider galaxies located at redshifts approximately the same as our targets and then discuss the expected projected number densities of foreground galaxies. In both cases we will use the luminosity function of star-forming galaxies (having an equivalent width in [OII]λ3727 $\geq$ 20 Å) in the range z=0-1 as derived by Ellis et al. (1996). In order to make the most conservative guess, we will use the lowest values of the derived upper limits, i.e. those corresponding to a projected diameter of 1″. This is also close to the size of the seeing disk and is comparable to the typical projected diameters of the most abundant star-forming galaxies of intermediate size.

At the target redshifts, the volume covered in the Lyα search is $\sim$ 20 Mpc^3 per field and in the [OII] search about 3 Mpc^3. A global star formation rate of 0.3 $\mathcal{M}_{\odot}$ yr^{-1} corresponds to an absolute B magnitude of $M_B \sim$-19 (Hunter and Gallagher 1985). According to Ellis et al. (1996) the space density of star-forming galaxies brighter than this is approximately 0.003 galaxies Mpc^{-3} (H_0 = 75 km s^{-1} Mpc^{-1}). Thus we would expect to observe $\leq$ 0.2 galaxies in the Lyα fields and $\sim$ 0.01 galaxy in the [OII] field.

In order to calculate the expected surface densities of foreground galaxies we will consider three cases where the galaxies are at such redshifts that [OII]λ3727, [OIII]λ5007 or Hα falls at peak transmission of one of our filters: 1) [OIII]λ5007 at z=0.6 ([OII] window of Q2251) 2) Hα at z=0.6 ([OII] window) 3) [OII]λ3727 at z=0.1 (Lyα windows of Q1726, Q2343 and Q2344). The total sampling volumes defined by the fieldsize and the bandpasses of the filters are 5.6, 0.6 and 3.3 Mpc^3 respectively. Since the surface brightness is proportional to $(1+z)^{-4}$, the sensitivity at the different redshifts increase with factors 3, 10 and 80 respectively, as compared to those of the target galaxies, if the signal is skydominated (as is the case here). The upper limits in the SFR of the target galaxies can then be used to derive the corresponding numbers for the foreground galaxies after a compensation for the relative line strengths between the emission lines of the targets and the foreground galaxies. We assume factors 1 ([OII]/[OIII]), 3 (Hα /[OIII]) and 30 (Lyα /[OII]) in the 3 cases. The lower SFR limits we then derive correspond to galaxies brighter than M_B = -18 (Hunter and Gallagher 1985) and the predicted total number of foreground galaxies is then $\leq$ 0.1. Thus, the upper limits of the projected number density of star-forming galaxies we derive are not in contradicion to what we really observe, i.e. no detected emission line object.

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