Evolution in the properties of Lyman-\(\alpha\) emitters from redshifts \(z \sim 3\) to \(z \sim 2\)

K.K. Nilsson\(^1\), C. Tapken\(^1\), P. Møller\(^2\), W. Freudling\(^2\), J.P.U. Fynbo\(^3\), K. Meisenheimer\(^1\), P. Laursen\(^3\), and G. Östlin\(^4\)

\(^1\) Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany
\(^2\) European Southern Observatory, Karl-Schwarzschild-Straße 2, 85748 Garching bei München, Germany
\(^3\) Dark Cosmology Centre, Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, 2100 Copenhagen Ø, Denmark
\(^4\) Stockholm Observatory, Department of Astronomy, Stockholm University, AlbaNova University Centre, 106 91 Stockholm, Sweden

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ABSTRACT

Context. Narrow-band surveys to detect Ly\(\alpha\) emitters are powerful tools for identifying high, and very high, redshift galaxies. Although samples are increasing at redshifts \(z = 3 – 6\), the nature of these galaxies is still poorly known. The number of galaxies detected at redshifts below \(z \sim 3\) are also small.

Aims. We study the properties of \(z = 2.25\) Ly\(\alpha\) emitters and compare them with those of \(z > 3\) Ly\(\alpha\) emitters.

Methods. We present narrow-band imaging made with the MPG/ESO 2.2m telescope and the WFI (Wide Field Imager) detector. Using this data, we have searched for emission-line objects. We find 170 candidate typical Ly\(\alpha\) emitters and 17 candidates that we regard as high UV-transmission Ly\(\alpha\) emitters. We have derived the magnitudes of these objects in 8 photometric bands from \(u^*\) to \(K^*\), and studied whether they have X-ray and/or radio counterparts.

Results. We demonstrate that there has been significant evolution in the properties of Ly\(\alpha\) emitters between redshift \(z \sim 3\) and \(z = 2.25\). The spread in spectral energy distributions (SEDs) at the lower redshift is larger and we detect a significant AGN contribution in the sample. The distribution of the equivalent widths is narrower than at \(z \sim 3\), with only a few candidates with rest-frame equivalent width above the predicted limit of 240 \(\AA\). The star formation rates derived from the Ly\(\alpha\) emission compared to those derived from the UV emission are lower by on average a factor of \(\sim 1.8\), indicative of a significant absorption by dust.

Conclusions. Ly\(\alpha\) emitters at redshift \(z = 2.25\) may be more evolved than Ly\(\alpha\) emitters at higher redshift. The red SEDs imply more massive, older and/or dustier galaxies at lower redshift than observed at higher redshifts. The decrease in equivalent widths and star formation rates indicate more quiescent galaxies, with in general less star formation than in higher redshift galaxies. At \(z = 2.25\), AGN appear to be more abundant and also to contribute more to the Ly\(\alpha\) emitting population.

Key words. cosmology: observations – galaxies: high redshift

1. Introduction

Over the past decade, a large number of so-called Lyman-\(\alpha\) (Ly\(\alpha\)) emitters have been discovered at high redshift. Several techniques have been employed in the search for these galaxies, but the by far most common method is that of narrow-band imaging, where a narrow-band filter is tuned to Ly\(\alpha\), but the by far most common method is that of narrow-band techniques have been employed in the search for these galaxies. The lower redshift limit is in fact higher than \(z \approx 1.6\) because of the drop-off in CCD sensitivity and a more typical lower redshift limit is \(z \sim 2.0\). Eight narrow-band surveys have so far been published below \(z \sim 3\); Fynbo et al. (1999), Pentericci et al. (2000), Stiavelli et al. (2001), Fynbo et al. (2002, 2003a, 2003b), Francis et al. (2004) and Venemans et al. (2007). Furthermore, Van Breukelen et al. (2005) published a sample of Ly\(\alpha\) emitters (LAEs) at \(z \approx 2.5\) using integral-field spectroscopy. The difficulty in observing the Ly\(\alpha\) line between redshifts \(2 < z < 3\) lies in the low throughput of optical systems, the low efficiency of CCDs in this wavelength range, and higher extinction in the atmosphere. Even so, the advantage of a smaller luminosity distance is rewarding in that a higher flux limit equals the same luminosity limit as surveys at higher redshift. It also facilitates follow-up observations into the nature of these objects.

At higher redshifts, Ly\(\alpha\) emitters have been observed to be increasingly bluer, younger and smaller with increasing redshift. At \(z \sim 3\), Gawiser et al. (2006) inferred stellar masses of a few \(10^8\) \(M_\odot\), almost no dust extinction, and ages of the order

Send offprint requests to: knilsson@mpia-hd.mpg.de
of 100 Myr. In a follow-up paper, Gawiser et al. (2007) studied a stacked sample of 52 Lyα emitters without Spitzer detections and confirmed their results of young ages and that no dust appears to be present in these systems, although they inferred slightly higher masses. The galaxies in their sample with Spitzer detections are presented in Lai et al. (2008). For these galaxies, older ages and higher masses are reported and the authors propose that $z \sim 3$ Lyα emitters may have a wide range of properties. In Nilsson et al. (2007), a stacked sample of Lyα emitters at $z = 3.15$ were studied. Here, small masses and low dust contents were inferred, but the ages were unconstrained. At even higher redshift, Pirzkal et al. (2007) showed that a sample of $4 < z < 5.7$ Lyα emitters had very young ages of a few Myr and small stellar masses, in the range $10^9 − 10^8 M_{\odot}$. These results agreed well with those of Finkelstein et al. (2007), who studied almost 100 Lyα emitters at $z = 4.5$. Finkelstein et al. (2008) reported, studying a different sample, finding very dusty, massive galaxies with $A_{1200}$ as high as 4.5 magnitudes and masses as high as several $\times 10^{10} M_{\odot}$, at $z = 4.5$. They argued that they observed a bimodality in the properties of Lyα emitters; young and blue galaxies versus old and dusty. Thus, the properties of $z \geq 3$ Lyα emitters are poorly constrained, but these galaxies tend to be considered young, blue, small and dust-free. With the data presented here, we aim to extend the study of the properties of Lyα emitters to lower redshifts, where a wider range of the SED can be studied in the optical/infrared and the luminosity distance is smaller, allowing a more detailed analysis.

This paper is organised as follows. Section 2 presents the observations leading to our sample, as well as the data reduction. Section 3 includes the object detection and candidate selection and a discussion about possible interlopers in the sample. In Sect. 4 we present all the basic characteristics of the sample, including photometry, AGN contribution, surface density, and sizes, and the equivalent width distribution of the candidates. We summarise the results in Sect. 5.

Throughout this paper, we assume a cosmology with $H_0 = 72$ km s$^{-1}$ Mpc$^{-1}$ (Freedman et al. 2001), $\Omega_m = 0.3$ and $\Omega_{\Lambda} = 0.7$. Magnitudes are given in the AB system.

2. Observations

In March 2007, a $35 \times 34$ arcmin$^2$ section of the COSMOS field, centred on R.A. = $10^h90^m27^s$ and Dec = $02^d12^m22^s$ (J2000), was observed with the Wide-Field Imager (WFI; Baade et al. 1999) on the MPG/ESO 2.2m telescope on La Silla. A log of the observations can be found in Table 1. The total dithered image consisted of 29 exposures with a total exposure time of 99624 seconds, or 27.7 hours. The observations were made with a narrow-band filter N396/12 with a central wavelength of 396.3 nm and a FWHM of 12.9 nm. This wavelength range corresponds to $z = 2.206 - 2.312$ for Lyα, $z = 0.046 - 0.081$ for [OII], and $z = 1.52 - 1.59$ for CIV and the surveyed comoving volumes (after masking, see Sect. 2) are $\sim 329 300$ Mpc$^{-3}$, $820$ Mpc$^{-3}$ and $\sim 225 000$ Mpc$^{-3}$, respectively. The narrow-band filter curve is shown with the filter curves of the filters used for the selection of candidates in Fig. 1.

The data were reduced using the MPAIPP pipeline developed in MIDAS with specific routines to handle WFI data. We briefly describe the reduction steps performed on the data. The data from the individual CCDs were converted into MIDAS format and bias-corrected on each separate CCD. The individual CCD frames were then placed into placeholders in an empty mosaic, thus creating a full mosaic for each frame including the gaps between the CCDs. To correct for bad pixels and columns as well as correcting columns with a constant offset compared to the surrounding pixels, lamp images with exposure times ranging between 1 − 220 s were downloaded and analysed. The science frames were then corrected for both the bad columns and the offset columns. The frames were then flat-field corrected using a master flat created from sky flats taken at the time of observations. To determine the offsets between the images, an SDSS catalogue of known sources was used, combined with an algorithm that identifies sources and matches them with catalogue entries. The information about the shift is then entered into the header. In the final step, the images were shifted and rebinned onto a gnomonic projection (i.e. by de-projecting all great circles onto straight lines), cosmic-ray hits were removed and a final, co-added image created. Significant residuals from the background subtraction were apparent in the mosaiced image, in particular around the edges of the individual images used to create the mosaic. We used the following procedure to remove it. First, we used the “clean” option of the IRAF task imsurfit to create a version of the image in which objects had been removed and interpolated over. We then edited this image interactively to remove any residual flux from objects. Subsequently, we fitted

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**Table 1. Log of imaging observations with WFI.**

| Date          | Total exp. | Average seeing |
|---------------|------------|----------------|
| 10-11.03.2007 | 0.56 hours | 1′′40          |
| 11-12.03.2007 | 0.83 hours | 1′′24          |
| 12-13.03.2007 | 1.33 hours | 1′′04          |
| 13-14.03.2007 | 2.50 hours | 1′′65          |
| 14-15.03.2007 | 1.67 hours | 1′′26          |
| 15-16.03.2007 | 1.45 hours | 1′′81          |
| 16-17.03.2007 | 3.33 hours | 1′′11          |
| 17-18.03.2007 | 1.67 hours | 1′′32          |
| 18-19.03.2007 | 3.33 hours | 1′′15          |
| 19-20.03.2007 | 2.50 hours | 1′′25          |
| 20-21.03.2007 | 2.50 hours | 1′′36          |
| 22-23.03.2007 | 1.67 hours | 1′′13          |

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**Fig. 1.** Transmission of selection filters. The WFI narrow-band filter is drawn with a solid line. The dashed line shows the SUBARU Bj band filter curve and the dotted line the CFHT $u^*$ band filter curve.
a 20 × 20 piece bicubic spline to this image. We then subtracted this fit from the original image. This procedure reduced the background variations to a small fraction of the background noise. We then flux calibrated the narrow-band image by calculating the fluxes of all narrow-band selected objects (see Sect. 3.1) in the CFHT $u^*$ and the SUBARU Bj images (see Table 3) and interpolated the fluxes in the narrow-band image. We can then calculate the zero-point of the image, assuming that the median equivalent width of all objects is zero. The 5σ detection limit in a 3′′ diameter aperture in the image is 25.3 AB magnitude and the 90% completeness limit is 25.1 AB magnitude, corresponding to Lyα luminosities of log $L = 42.36$ erg s$^{-1}$ and log $L = 42.44$ erg s$^{-1}$, respectively, at $z = 2.25$.

3. Selection of candidates

3.1. Object detection and candidate selection

For object detection, we used the SExtractor software (Bertin & Arnouts 1996). The narrow-band image was used as a detection image, and objects with a minimum of 8 adjoining pixels and a threshold of 2σ per pixel were selected. For the selection, we used two broad-band filters corresponding to wavelengths to both the blue and red side of the narrow-band filter, the CFHT $u^*$ band image and the SUBARU Bj band image, see also Fig. 1. Both images were taken from the public data in the COSMOS field (Capak et al. 2007). The $u^*$ and Bj band images were created from combining several smaller sub-images to match perfectly the field of the narrow-band image, and they were subsequently re-binned and smoothed to match the pixel size and source PSF of the narrow-band image. The flux of each object detected in the narrow-band image was then measured in all three bands in circular apertures with a diameter of 3′′, where each aperture was centred on the position of the object detected in the narrow-band image. For the catalogue, we included only objects with $S/N > 5$ in the narrow-band image that were found at least 70 pixels from the edge of the image. We also masked areas where stray light and bright stars affected the image. This left us with a catalogue of 21 275 objects in an effective area of $\sim 1014$ arcmin$^2$.

The candidate Lyα emitters were selected according to a similar method as described in Nilsson et al. (2007). The method is based on determining the equivalent width (EW) of a potential emission/absorption line located in the narrow-band wavelength range. Thus, the flux density was determined in the CFHT $u^*$ and SUBARU Bj bands and interpolated between the central wavelengths of these filters and the central wavelength of the narrow-band filter. The EW was then determined by dividing the measured flux in the narrow-band with the interpolated flux density. Simultaneously, we also calculated the propagated statistical error in this measurement. The calculated EW represents a lower limit to the true EW of the object as there may be several objects, unrelated to the narrow-band object, detected inside the aperture in the broad-band images. The EW calculation is also complicated by the uncertainties in the continuum interpolation (Hayes & Östlin 2006; Hayes et al 2008). To compile the final catalogue of Lyα emitting candidates, we used two selection criteria. First, all objects with a measured EW larger than or equal to 65 Å (corresponding to 20 Å in the restframe for Lyα) are selected. To further exclude false candidates at the faint magnitude end of the sample, in which the EW measurement is dominated by the broad-band flux uncertainties, a significance of the EW greater than 2.3 is required. These criteria are designed to detect all emission-line objects with large equivalent widths accurately.

![Fig. 2. Plot of the selection criteria, with narrow-band magnitude on the x-axis and observed equivalent width on the y-axis. Selected candidates are shown with error bars, green points correspond to the GALEX-detected objects, see sec. 3.2. Solid line marks the 65 Å limit. Objects above this line with EW significance greater than 2.3σ are selected in the first catalogue. Dots mark the entire sample of 5σ detections in the narrow-band, and dots above the selection criteria without error bars were rejected in the visual inspection.](image)

This final catalogue includes 386 objects. Following the procedure of Fynbo et al. (2002), three co-authors then individually ranked these 386 candidates by visual inspection into three categories; first a category of rejected detections (caused by CCD or stellar artifacts or enhancement due to airplane/satellite tracks), then into two categories of likely candidates and candidates that are unlikely to be real but for which no obvious reason was found to reject them (see also Fig. 2). The 386 candidates were split into the different categories of [Likely, Unlikely, Rejected] = [187, 61, 138]. In Table 2 we list the coordinates, EWs, significance of the EWs, continuum-subtracted narrow-band magnitudes $M_{\text{AB}}$ and mean UV spectral index $\beta$ (see Sect. 3.1) of all likely candidates (coordinates of unlikely candidates may be obtained from the authors). In the following sections, we only include the candidates in the likely category, which provides a total of 187 candidates. The Lyα magnitudes of our LAE candidates are given by the range $M_{\text{AB}} = 22.57 - 25.88$ corresponding to Lyα luminosities in the range of $\log L_{\text{Ly}\alpha} = 42.13 - 43.45$ (see also the histogram of magnitudes in Fig. 3).

3.2. Interloper discussion

The only possible contaminants in the sample are [OII] emitters at $z = 0.06$ and CIV emitters at $z = 1.56$. For [OII] emitters at this redshift, the detection limit corresponds to a luminosity limit of $\log L = 38.7$ erg s$^{-1}$ and the survey volume is 820 Mpc$^{-3}$. For CIV emitters, the corresponding limit is $\log L = 42.0$ erg s$^{-1}$ and the survey volume is $\sim 225$ 000 Mpc$^{-3}$. Unfortunately, no published luminosity function for local Universe [OII] emitters or CIV emitters reach these faint luminosity limits, but for [OII] emitters, extrapolating from the luminosity functions of Hogg et al. (1998), Gallego et al. (2002), and Teplitz et al. (2003), we conclude that we could expect between a few to 200 [OII] emitters in the survey vol-
Table 2. Coordinates, observed equivalent widths, continuum subtracted narrow-band magnitudes and UV spectral index $\beta$ of the candidates. Full table is available in the online version.

| LAE_COSMOS# | RA.  | Dec.  | EW (\AA) | Mag$_{3960}$ | $\beta$ |
|------------|------|-------|----------|-------------|--------|
| 1          | 150.05310 | 1.94797 | 142.7 ± 38.6 | 25.50 ± 0.34 | −0.48 ± 0.24 |
| 2          | 150.25458 | 1.95224 | 118.4 ± 33.4 | 25.55 ± 0.36 | −2.12 ± 0.33 |
| 3          | 150.31830 | 1.95244 | 279.3 ± 41.8 | 24.91 ± 0.18 | −2.08 ± 0.44 |
| 4          | 150.37505 | 1.95619 | 95.9 ± 24.2 | 25.46 ± 0.32 | −1.84 ± 0.29 |
| 5          | 150.15936 | 1.95717 | 790.3 ± 140.1 | 25.04 ± 0.21 | −2.97 ± 1.06 |
| 6          | 150.39090 | 1.96143 | 119.6 ± 16.8 | 24.88 ± 0.16 | 1.81 ± 0.22  |
| 7          | 150.28378 | 1.96167 | 248.1 ± 50.2 | 25.20 ± 0.25 | −1.84 ± 0.34 |
| 8          | 150.30785 | 1.96243 | 81.0 ± 28.5 | 25.80 ± 0.47 | 0.54 ± 0.26  |

Note: Coordinates are in J2000. Candidates marked with the capital letter G are detected with GALEX, see text below.

Fig. 3. Histogram of Ly$\alpha$ magnitudes (continuum-subtracted narrow-band magnitudes), Mag$_{3960}$, of emission-line candidate sample. Binsize is 0.2.

To constrain this value further, the [OII] luminosity function was extrapolated from the H$\alpha$ luminosity function of Ly et al. (2007). Assuming a conversion between [OII] and H$\alpha$ luminosities given by the star formation rate equations of Kennicutt (1998) and Kewley et al. (2004), the [OII] luminosity limit corresponds to an H$\alpha$ luminosity limit of $\log L = 38.8$ erg s$^{-1}$ in this survey. To this limit, Ly et al. (2007) detected $\sim 0.2$ emitters per Mpc$^{-3}$, corresponding to approximately 160 objects in our survey volume, of which only 2% are expected to have an EW larger than the selection criteria limit of EW$_{\text{obs}} = 65$ Å (Hogg et al. 1998). Based on the results of Ly et al. (2007), approximately three [OII] emitters are hence included in the list of candidates.

We also extracted the photometric redshifts for our candidates from the catalogue of Gabasch et al. (2008). The catalogue is incomplete in areal coverage and covers roughly 80% of our field. The catalogue was searched for counterpart objects within a $2''$ radii from the position of our source. If several objects were found, the object nearest to our source was chosen as the counterpart. For a total of 187 candidates, 132 had detected counterparts. Unfortunately, the near-IR coverage of the COSMOS field is patchy and shallow, which complicates any photometric redshift determination in the redshift range $z \sim 1.3 - 2.5$, since in this range the Lyman-break has not yet entered the optical window and the Balmer break is in the near-IR. This means that we are in principle able to exclude [OIII] emitters from the sample, whereas other intermediate redshift emitters, such as CIV, are difficult to exclude. The redshifts of our 132 detected candidates also show that no emitters are consistent with being [OII] emitters, and the median redshift of the candidates is $z = 1.7$, with most of the candidates being consistent with having a redshift of $z = 2.25$ to within 3$\sigma$ margins of error. To study how many CIV emitters may be expected in the survey volume, we used the AGN luminosity function of Bongiorno et al. (2007). Since CIV emission of restframe equivalent widths larger than EW$_{\text{obs}} \gtrsim 25$ are only expected to originate in AGN, and with the luminosity limits in the optical of this survey, the expected number of CIV emitters in our survey volume is $\sim 2$. Any contamination of CIV emitters in the total sample of candidates is thus minimal.

The COSMOS field also has publicly available GALEX near- and far-UV data. This data may be used to exclude any remaining [OII] emitters from the sample, since the limiting magnitude of the GALEX data is $\sim 25.5$ in the NUV band and, assuming a flat spectrum, all [OII] emitters in the sample should be detected in the GALEX data based on the flux limit in the BJ band. Ly$\alpha$ emitters may or may not be detected in the GALEX data, depending on the level of absorption from the Lyman forest. Ly$\alpha$ emitters would require a transmission of less than 60% to be undetected in the GALEX images. Møller & Jakobsen (1990) inferred that approximately 10% of galaxies less than $z \sim 1.5$ have transmissions in the UV higher than 60%, in agreement with recent observations at $z \sim 1.5$ (Siana et al. 2007). The conclusion is that we expect all [OII] emitters to be detected in the GALEX images, whereas the total sample of GALEX-detected objects is a mix of high transmission Ly$\alpha$ emitters and [OII] emitters. Of the 187 candidates, 17 are detected in the GALEX images (labelled by a G in Table 2). The largest EW of a GALEX-detected candidate is EW$_{\text{obs}} = 604$ Å. As shown earlier, the expectation is $\sim 3$ [OII] emitters in the survey volume, and so most of the GALEX-detected objects are most likely to be high transmission Ly$\alpha$ emitters. We separate the GALEX-detected sample and the non-GALEX-detected sample in the following analysis. Thus, we have two samples; one robust sample of 170 Ly$\alpha$ emitter candidates (removing 17 GALEX detections from a total of 187 candidates), which is expected to be free of interlopers, and one sample of 17 GALEX-
detected objects, possibly including a small contamination of [OII] emitters but consisting mostly of high-transmission Ly\(\alpha\) emitters. The non-GALEX-detected sample is a conservatively selected sample defined so that the probability of having non-LAE objects in it is minimal, but at the price that it is less complete. For this reason, it is unsuitable for determining volume and surface densities. In Sect. 4.3 we return to this issue and define a sample suited for this purpose. From here on, whenever the “sample” is mentioned it is referring to the non-GALEX-detected sample.

4. Basic characteristics of LAEs

4.1. Photometry

For the photometry of the candidates, we use the public data-set from the COSMOS survey (Capak et al. 2007). The photometry presented here has been made in the bands found in Table 2. All images are on the common COSMOS tiling grid and were cut and re-binned to match the narrow-band image in coverage and pixel size. We ran SExtractor in dual-image mode, measuring the flux in apertures defined in the narrow-band image, also including the RMS images in the measurement through the WEIGHT,IMAGE option. The apertures had a diameter of 3′′. Magnitudes were calculated using the zero-point given in the COSMOS data release. These magnitudes will, in the case of the candidates, be underestimated, since objects unrelated to the LAE candidate may be blended into the aperture (see below for a discussion of contamination in the aperture). In the following we exclude the results in the \(g^+\) band as these magnitudes appear to be inconsistent. When plotting the SEDs of the objects, the \(g^+\) band magnitudes are consistently lower than the other SED points by 0.1 – 0.5 magnitudes.

We calculated the UV spectral index of \(\beta\) for the candidates, which is defined as:

\[
\frac{f_\lambda}{\lambda} \propto \lambda^\beta
\]

(1)

where \(f_\lambda\) is the flux density per wavelength interval in the UV range. The spectral index is calculated as in Meurer et al. (1997) and Hathi et al. (2008) for the \(Bj\), \(Vj\), and \(r^+\) bands using the following equations:

\[
\beta_{Bj-Vj} = 4.456 \times (Bj-Vj) - 2
\]

(2)

\[
\beta_{Bj-r^+} = 2.673 \times (Bj-r^+) - 2
\]

(3)

where \(Bj\), \(Vj\), and \(r^+\) are the AB magnitudes in the respective bands. A plot of the results can be seen in Fig. 4 and the total \(\beta\), calculated to be the mean of the two measurements as described in Eq. 2 and 3 for our LAE candidates is found in Table 2. Fig. 4. UV spectral index calculated from the \(Bj-Vj, Bj-r^+\) colours. The two colours give approximately the same results, as seen by the solid line marking a linear relation. The spread in the spectral index is very large. AGN (see sec. 4.2) are marked in red. Objects with red SEDs can be found in the upper right corner and objects with blue SEDs in the lower left corner.

Table 3. COSMOS broad-bands used.

| Band | Observatory | CWL (Å) | FWHM (Å) | Depth |
|------|-------------|--------|----------|-------|
| u'   | CFHT        | 3798   | 720      | 26.4  |
| Bj   | SUBARU      | 4460   | 897      | 27.3  |
| g    | SUBARU      | 4780   | 1265     | 27.0  |
| Vj   | SUBARU      | 5484   | 946      | 26.6  |
| r^+  | SUBARU      | 6295   | 1382     | 26.8  |
| i^+  | SUBARU      | 7641   | 1497     | 26.2  |
| z^+  | SUBARU      | 9037   | 856      | 25.2  |
| Ks   | KPNO        | 21500  | 3200     | 21.6  |

\(^b\) The depths are 5\(\sigma\) AB magnitudes as measured in 3′′ apertures (Capak et al. 2007).

Fig. 4. UV spectral index calculated from the \(Bj-Vj, Bj-r^+\) colours. The two colours give approximately the same results, as seen by the solid line marking a linear relation. The spread in the spectral index is very large. AGN (see sec. 4.2) are marked in red. Objects with red SEDs can be found in the upper right corner and objects with blue SEDs in the lower left corner.
of dust content. There are also some objects that appear evolved but fall below even the zero-dust line in the plot, which may be affected by nearby objects. Another group of objects are very red in terms of their $V_j-i^+$ colours but are too blue in $B_j-V_j$ to be explained by simple stellar populations. These may be reproduced more accurately by models with more complicated star formation histories.

In the sample, 12 objects have $K_s$ band detections above the limiting magnitude of 22.2 ($3\sigma$, AB), corresponding to 7% of the complete sample. Note that four of these 12 $K_s$-detected objects are also selected as AGN (see Sect. 4.2). The $K_s$-detected objects are all drawn from the brighter end of the candidate sample, but have a range in $V_j$ magnitude of 21.5–26, whereas the entire candidate sample have a range in magnitude of 21.5–27, i.e. not only the brightest candidates have $K_s$ detections. We stacked the thumb-nail images of the candidates without $K_s$ detections, removing objects from the stack with nearby, unrelated, bright detections. The total stack consisted of 144 candidates (with GALEX detections and objects with nearby, unrelated detections removed) and revealed a mean detection in the sample of magnitude $24.00 \pm 0.29$. The sample was also divided into two subsamples with $V_j-i^+$ colours $V_j-i^+ \geq 0$ and $V_j-i^+ < 0$, respectively. In the subsample with red $V_j-i^+$ colours, consisting of 96 of the 144 candidates, a clear detection with magnitude $23.65 \pm 0.19$ was made. In the subsample with blue colours, no detection was made and an upper limit of $24.26 (3\sigma)$ was derived. In Fig. 5 we show the stacked magnitudes of the sample divided into four bins; the total sample, the sample with $V_j-i^+ \geq 0$ (called the “red” sample), the sample with $V_j-i^+ < 0$ (called the “blue” sample), and the $K_s$-detected sample. The total sample consists of 144 candidates, the red subsample consists of 96 candidates, and the blue subsample consists of 48 candidates. The magnitudes in Fig. 6 are also found in Table 4. In Fig. 6 it is seen that the stacked SED of the total sample is redder than those at $z \sim 3$; the points of the non-$K_s$-detected galaxies are in principle consistent with the Nilsson et al. (2007) fit within $2\sigma$ but inconsistent across the spectrum with the Gawiser et al. (2007) fit. The normalised $K_s$ magnitude for the total sample is $25.45 \pm 0.29$, whereas the same magnitudes measured from the synthetic SEDs of Nilsson et al. (2007) and Gawiser et al. (2007) are 26.00 and 26.39, respectively. Hence, roughly two-thirds of the entire sample exhibit on average more red SEDs than at $z \sim 3$. Noteworthy is also that SED of the blue sample (with $V_j-i^+ < 0$) is consistent with the $z \sim 3$ SEDs. The $V_j-K_s$ slopes of the red and blue samples are $1.24 \pm 0.22$ and $-0.37 \pm 0.98$, indicating a clear difference in the properties of the blue and red samples of galaxies. For reference, the $V_j-K_s$ slope of the $K_s$-detected sample is $2.68 \pm 0.04$. A large spread

| Total sample | Red sample | Blue sample | $K_s$-detected |
|--------------|------------|-------------|----------------|
| $a^+$        | 25.21 ± 0.03 | 25.16 ± 0.05 | 25.34 ± 0.06 |
| $B_j$        | 25.14 ± 0.03 | 25.11 ± 0.04 | 25.34 ± 0.05 | 24.00 ± 0.02 |
| $i^+$        | 24.99 ± 0.08 | 24.89 ± 0.11 | 25.18 ± 0.03 | 23.04 ± 0.01 |
| $z^+$        | 24.95 ± 0.14 | 24.72 ± 0.13 | 25.37 ± 0.15 | 21.83 ± 0.01 |
| $K_s$        | 24.86 ± 0.22 | 24.57 ± 0.15 | 25.40 ± 0.16 | 21.46 ± 0.01 |

$^c$ Upper limits are $3\sigma$. $K_s$-detected sample is without AGN-detected galaxies. Blue sample $K_s$ magnitude is calculated from the $K_s$ magnitudes of the total and red samples.

Fig. 5. Colour-colour diagram with $B_j-V_j$ on the $x$-axis and $V_j-i^+$ on the $y$-axis. Objects with upper limits (on the flux) in one band are shown as arrows with $3\sigma$ upper limits and objects with a colour in either bands that is $1.5\sigma$ away from the median colour in that band are shown with error bars. AGN are marked in red. The solid lines display the evolution of a single stellar population with increasing dust and age; age causes the objects to move predominantly to the right in the plot and dust predominantly upwards. The markers 5.0 and 7.5 correspond to age steps of $5.0 \times 10^8$ and $7.5 \times 10^8$ yrs and the dust steps go from $E(B-V) = 0.0$ (point $a$ in the plot) to 1.0 (point $b$ in the plot) in steps of 0.125.

Fig. 6. Stacked SED of the sample. Points are the stacked magnitudes in six bands ($a^+, B_j, V_j, i^+, z^+$ and $K_s$) and in three bins; black points are the full sample, excluding $K_s$-detected galaxies and galaxies with bright nearby objects, red stars are those with red $V_j-i^+$ colours and blue points those with blue $V_j-i^+$ colours. Red diamonds mark the stacked $K_s$-detected sample without AGN-detected galaxies. All are normalised to the $B_j$ flux of the Nilsson et al. (2007) SED. The lines are two best-fit SEDs of $z \sim 3$ LAEs from Nilsson et al. (2007; green line) and Gawiser et al. (2007; black line).
in colours is evident in this survey, from the “classical” blue, flat SED galaxies to galaxies with very red SEDs, where the redder SEDs constitute two-thirds of the sample (see also Finkelstein et al. 2008 for a similar result). In a future paper, the Spitzer fluxes of these galaxies will be studied.

To study the level of contamination in the apertures, and the possibility that the very red SEDs originate from this source, the narrow-band catalogue was searched for other detected objects within two aperture radii (i.e. within 3") of each LAE candidate. Of the 170 non-GALEX-detected candidates, 26 have one or more detected objects within this search radius. This corresponds to a potential contamination rate of 15% in the photometric measurements. Two objects have more than one nearby object. We also wish to determine if the apparent high number of red objects is caused by flux contamination from unrelated objects in the aperture. Of the 26 candidates with nearby objects, 19 have a Vj−i+y colour in the aperture greater than zero, and 15 have Vj−i+y colours larger than the median of Vj−i+y for all 170 candidates. This implies that the contamination is not confined to only apparent red objects but affects all types of SEDs. We are thus confident that the contamination in the photometry is small, and that contamination cannot explain the apparent red colours of the LAE candidates.

4.2. AGN contribution

The COSMOS public data includes a release of X-ray data in three bands, 0.5−2.0, 2.0−4.5, and 4.5−10.0 keV, as observed by the XMM observatory (Hasinger et al. 2007). We used the catalogue of objects of Cappelluti et al. (2007) to measure the AGN fraction of all candidates. The catalogue consists of 1390 entries representing point-like sources and gives the fluxes in the three bands including errors. The catalogue detects objects to limiting fluxes of 7.2 × 10⁻¹⁶, 4.0 × 10⁻¹⁵, and 9.7 × 10⁻¹⁵ erg s⁻¹ cm⁻², respectively, in the bands 0.5−2.0, 2.0−4.5, and 4.5−10.0 keV with a confidence of roughly 4.5σ (Hasinger et al. 2007). This catalogue was searched for objects detected within a radius of 8" (i.e. 2 pixels in the XMM images) of the candidates. Fifteen of these potential counterparts were detected, of which five were from the list of GALEX-detected candidates. The X-ray fluxes of these candidates are found in Table 5. Note that the probability of finding an X-ray object within an aperture of radius 8" is ~ 0.009, resulting in potentially two random detections in the combined GALEX and non-GALEX-detected sample. For the objects with detections in two or all bands, the hardness ratios can be calculated. Hardness ratios are defined to equal:

\[ HR1 = \frac{(S_{2.0-4.5} - S_{0.5-2.0})}{(S_{2.0-4.5} + S_{0.5-2.0})} \] (4)

\[ HR2 = \frac{(S_{4.5-10.0} - S_{2.0-4.5})}{(S_{4.5-10.0} + S_{2.0-4.5})} \] (5)

The hardness ratios, when applicable, can be found in Table 5. All measured hardness ratios (HR1) are positive, indicating that the LAE candidates are type 2 AGN (e.g. Norman et al. 2004). The low luminosity of the GALEX-detected candidates, assuming that they are [OII] emitters indicate that they are normal, star forming galaxies, or that they are Lyα emitters. The total sample of GALEX-detected and non-detected candidates without individual X-ray detections were stacked, and produced no detection in any band in a stack of 170 objects (the nine individual detections were removed from the stack, as well as eight candidates with unrelated objects detected in the vicinity). The non-detection in a stack of 170 objects imply an upper limit to the mean X-ray flux of approximately a factor of ten smaller than those in the catalogue of Cappelluti et al. (2007).

We also searched the catalogue of Schinnerer et al. (2007) for radio counterparts to the candidates. The data on which the catalogue is based was taken with the VLA array and covers the entire COSMOS field to a depth of a few ×10⁻¹⁴ Jy. The catalogue presented in Schinnerer et al. (2007) contains 3643 source detections. This catalogue was searched with the same criteria as for the X-ray catalogue (i.e. detections within 8" of the candidate positions) and six objects were found. The number of random detections in a 8" radius aperture is 0.026. Of the six radio detections, one object is GALEX-detected (candidate 173). The radio fluxes of these sources can be found in Table 5. Only one source has a detection in both the X-ray and radio data. This is in principle not a problem since AGN can be both radio-loud and radio-quiet. The radio objects without X-ray detections are more enigmatic, but can be explained by the relatively shallow luminosity limit of the X-ray observations. If the radio fluxes are converted into star formation rates using the conversion rate of Condon (1992), they correspond to values in the range of ~ 400−1300 M⊙ yr⁻¹ whereas the upper limit to star formation rates in the XMM survey is ~ 1200 M⊙ yr⁻¹, using the conversion of Ranalli, Comastri & Setti (2003).

The AGN fraction of the non-GALEX-detected LAE sample is thus at least ~ 5%, if it is assumed that the X-ray and radio objects within 5" of the narrow-band sources are true detections. It is clear that the shallow flux limit to the deepest X-ray band, corresponding to a luminosity of log(L_{0.5-2.0}) = 43.4 erg s⁻¹, ensures many AGN of lower luminosities to be undetected, as confirmed by the radio detections without X-ray counterparts. The AGN fraction should therefore almost certainly be even higher, although we did not detect any X-ray flux in the mean, stacked total GALEX and non-GALEX-detected sample of 170 objects. Previous studies of LAEs at higher redshifts exhibited very small AGN contributions, from less than one percent in the z ~ 4.5 LAEs studied by Wang et al. (2004) to ~ 1% at z ~ 3 as inferred by Gawiser et al. (2007). Lehmer et al. (2008) calculated the “AGN fraction function” of Lyα emitters at z ~ 3 both in the field and the overdense region of SSA22 (Fig. 3b in their paper). If we convert our 0.5−2.0 keV detection limit to their 8−32 keV luminosity range, we should expect to detect an AGN fraction of 0.5−1.5%, where the lower number is related to their field result and the higher to the SSA22 result. Based on this comprehensive study of X-ray detected Lyα emitting AGN, it is clear that the AGN fraction detected here is larger than at z ~ 3, as expected from the Lehmer et al. (2008) survey. Ouchi et al. (2008) argued that the missed fraction in AGN X-ray searches among LAEs may be as high as 10%. We performed the same test as in the Ouchi et al. (2008) publication. Based on the quasar SEDs of Elvis et al. (1994) and the UV spectrum of quasars of Telfer et al. (2002) and Richards et al. (2003) we inferred the ratio of observed 0.5−2.0 keV flux to Lyα flux of 1.87 and 1.51 for radio-quiet and radio-loud quasars, respectively. For the flux limit in the X-ray band, the maximum magnitude observed for Lyα is then 23.34. In our complete GALEX and non-GALEX-detected samples, nine objects have magnitudes brighter than this, four of which are GALEX-detected. Of the nine objects, six have X-ray detections (all four GALEX-detected sources and two LAE candidates). Thus, if we exclude the four GALEX-detected sources, two out of five Lyα bright galaxies host AGN and the fraction of X-ray detected AGN in the non-GALEX-detected sample is 40%, four times the fraction found by Ouchi et al. (2008) for z ~ 3 LAEs. To conclude, our detection of a 5% AGN contribution in the non-GALEX-detected LAE sample is consistent with
Table 5. X-ray and radio properties of counterparts of the candidates.

| LAE, COSMOS# | $S_{0.5\ldots2.0}$ | $S_{2.0\ldots4.5}$ | $S_{4.5\ldots10.0}$ | HR1 | HR2 | log$(L_{0.5\ldots2.0})$ | Offset (X-ray) | $S_{1.4\,\text{GHz}}$ | Offset (Radio) |
|-------------|-----------------|-----------------|-----------------|-----|-----|-----------------|----------------|-----------------|----------------|
| 25          | 129.0 ± 1.87    | 191.0 ± 5.63    | 133.0 ± 7.03    | 0.19 ± 0.01 | −0.18 ± 0.03 | 45.67 ± 0.02 | 11.06           | —               | —              |
| 36          | —               | —               | —               | —   | —   | —               | 140 ± 27       | 0.10            | —              |
| 57          | —               | —               | —               | —   | —   | —               | 47 ± 10        | 6.17            | —              |
| 82          | 1.25 ± 1.97     | —               | —               | —   | < 0.52 | 43.66 ± 0.41 | 1.07           | —               | —              |
| 101         | —               | —               | —               | —   | —   | —               | 137 ± 27       | 0.06            | —              |
| 113         | 1.21 ± 4.10     | 9.58 ± 29.1     | —               | 0.78 ± 0.61 | < 0.01 | 43.64 ± 0.64 | 10.55          | —               | —              |
| 115         | 7.20 ± 6.00     | 16.2 ± 21.5     | —               | 0.38 ± 0.59 | < 0.25 | 44.42 ± 0.78 | 0.17           | —               | —              |
| 119         | 0.92 ± 0.26     | —               | —               | < 0.63 | —     | 43.55 ± 0.14 | 2.67           | —               | —              |
| 121         | 17.6 ± 0.73     | 31.0 ± 2.54     | 18.3 ± 3.52     | 0.28 ± 0.04 | −0.26 ± 0.11 | 44.81 ± 0.03 | 6.36           | —               | —              |
| 129         | 1.10 ± 0.27     | —               | —               | < 0.57 | —     | 43.60 ± 0.12 | 1.95           | —               | —              |
| 132         | —               | —               | —               | —   | —   | —               | 47 ± 10        | 9.83            | —              |
| 140         | 17.5 ± 0.72     | 46.3 ± 2.97     | 44.9 ± 4.73     | 0.45 ± 0.03 | −0.02 ± 0.06 | 43.80 ± 0.02 | 0.74           | —               | —              |
| 150         | 2.6 ± 0.30      | 8.3 ± 1.48      | —               | 0.52 ± 0.07 | < 0.08 | 43.98 ± 0.05 | 0.62           | 107 ± 30        | 0.21           |
| 161         | 2.42 ± 0.33     | —               | —               | < 0.25 | —     | 43.95 ± 0.06 | 0.21           | —               | —              |
| GALEX-detected candidates |
| 42          | 4.9 ± 2.92      | —               | —               | < −0.10 | —     | 40.6 ± 0.39 | 0.55           | —               | —              |
| 108         | 8.3 ± 0.60      | 16.9 ± 2.14     | —               | 0.34 ± 0.06 | < −0.27 | 40.83 ± 0.03 | 1.01           | —               | —              |
| 126         | 7.9 ± 0.50      | 12.0 ± 1.79     | —               | 0.38 ± 0.59 | < −0.11 | 40.81 ± 0.03 | 0.45           | —               | —              |
| 155         | 3.0 ± 0.34      | 5.6 ± 1.21      | —               | 0.30 ± 0.10 | < −0.27 | 40.39 ± 0.06 | 1.57           | —               | —              |
| 173         | —               | —               | —               | —   | —   | —               | 110 ± 25       | 9.44            | —              |

Data from the catalogues of Cappelluti et al. (2007) and Schinnerer et al. (2007). X-ray fluxes are given in units of $10^{-15}$ erg s$^{-1}$ cm$^{-2}$ and radio fluxes in units of $\mu$Jy. HR1 and HR2 correspond to the hardness ratios defined in Eq. 4 and 5. The X-ray luminosity is in erg s$^{-1}$, assuming the objects are located at redshifts $z = 2.25$ and 0.06 for LAE and GALEX-detected candidates respectively. Offsets are distance from centroid of narrow-band detection to X-ray/radio detection in units of arcseconds. It is expected that the objects with offsets larger than a few arcseconds (25, 57, 113, 121, 132 and 173) are unrelated to the candidates due to the large offset and the relatively large probability of random association.

previously results, but is indicative of a higher AGN fraction being present at this redshift.

4.3. Surface density, sizes and SFR

For the surface density determination, we included both the GALEX-detected and non-detected objects to obtain as complete as possible a measure of the number density. Since our image has areas of poorer signal-to-noise, as well as stellar artifacts, we selected sub-images of superior quality with a total area of $\sim 288$ arcmin$^2$, corresponding to $\sim 28\%$ of the total surveyed area, to use for the surface and volume density calculations. In these areas, the selection is complete, and we found 54 candidates within these sub-images. This implies a surface density of LAE candidates of $0.19$ arcmin$^{-2} \Delta z^{-1}$, or $1.91$ arcmin$^{-2} \Delta z^{-1}$. The volume density is $0.00002$ Mpc$^{-3}$, which is in the lower range of that observed at redshift $z \sim 3$. Fynbo et al. (2001) summarise the surface densities of several early $z \sim 3$ surveys. With the exception of the Steidel et al. (2000) survey in the overdense SSA22 field, these surveys all determined values of $2.11 - 5.9$ arcmin$^{-2} \Delta z^{-1}$ to the flux limit of this survey, but with large error bars. Hence, the values at $z \geq 3$ are consistently higher than our value, but in most cases the measurements agree to within $1\sigma$. For LAE candidates brighter than the $(5\sigma)$ luminosity limit of this survey, Nilsson et al. (2007) identified six candidates in their survey, corresponding to $0.0018$ Mpc$^{-3}$, which represents a decrease of roughly a factor of three although based on a small sample. Gronwall et al. (2007) determined a space density of $0.00057$ Mpc$^{-3}$ above the $5\sigma$ luminosity limit of our survey, which is consistent with the space density found here. Staиelli et al. (2001) presented a survey of $z = 2.4$ LAEs and found a volume density of $0.0001$ Mpc$^{-3}$ above a luminosity limit of $\log L = 42.93$ erg s$^{-1}$. The same number for this survey is $0.0009$ Mpc$^{-3}$. The numbers agree reasonably well with previous results. Finally, Prescott et al. (2008) completed a survey of $z \sim 2.7$ LAEs around a so-called Ly$\alpha$ blob (e.g. Steidel et al. 2000; Matsuda et al. 2004; Dey et al. 2005; Nilsson et al. 2006). They argued that the central part of their field is overdense, and determined a number density of $0.0021$ Mpc$^{-3}$. This is roughly three and half times higher than in our survey. At the edge of their field, the density is instead $0.0012$ Mpc$^{-3}$, in closer agreement with, but still higher than, our result. Thus, the surface density in this survey is in almost all cases lower than in higher redshift surveys, but could also be consistent with previous results. If one considers that number densities have been found to vary by factors of $2 - 5$ in $0.2$ deg$^2$ fields at redshift $z = 3$ (Ouchi et al. 2008), it is clear that more data at both higher and lower redshifts is needed to resolve this issue finally.

As in Nilsson et al. (2007), the sizes of the candidate Ly$\alpha$ and GALEX-detected objects measured in the narrow-band and $r^+$ broad-band images are presented in Fig. 7. Six LAE objects are excluded due to non-detections in the $r^+$ band. The FWHM was calculated using the FLUX_RADIUS output from SExtractor, and the PSF in the narrow-band image was calculated by using 9 objects in the image with fluxes in the range of that observed at redshift $z = 3$. The FWHM is similar to that of the narrow-band image PSF (the PSF of the $r^+$ image is $1.06''$). As can be seen in the figure, we have two marginal Ly$\alpha$ blob detections in this survey (of
The SFRs of the candidates are calculated using the common star formation indicators of the rest-frame UV continuum emission at $\lambda = 1500$ Å and the Ly$\alpha$ emission. The Ly$\alpha$ emission used in this case was the continuum-subtracted narrow-band flux. The conversion rates that we use are the following:

$$SFR_{\text{UV}} = \frac{f_{1500\,\text{Å}} \times 4\pi d_L^2 \times 1.4 \times 10^{-28}}{1+z} \text{M}_\odot \text{yr}^{-1}$$  \hspace{1cm} (6)$$

where the flux density $f_{1500\,\text{Å}}$ is in erg s$^{-1}$ cm$^{-2}$ Hz$^{-1}$, $d_L$ is the luminosity distance in centimeters and $z$ the redshift (Kennicutt 1998). For Ly$\alpha$, the conversion is:

$$SFR_{\text{Ly}\alpha} = \frac{F_{\text{Ly}\alpha} \times 4\pi d_L^2}{8.7 \times 1.12 \times 10^{11} \text{M}_\odot \text{yr}^{-1}}$$  \hspace{1cm} (7)$$

where $F_{\text{Ly}\alpha}$ is the flux in the Ly$\alpha$ line in erg s$^{-1}$ cm$^{-2}$ (Brocklehurst, 1971, Kennicutt 1983). A plot of the two resulting SFRs can be seen in Fig. 8. The SFRs are in the range of $\sim 1 - 30 \text{ M}_\odot \text{yr}^{-1}$ in the Ly$\alpha$ measurement, some of which are unusually high for what is generally seen in Ly$\alpha$ emitters. The dashed line in Fig. 8 corresponds to a 1:1 relation between the UV/Ly$\alpha$ derived SFR$s$. A correlation is seen between the two measurements. The median of the ratio of UV-derived SFR to Ly$\alpha$-derived SFR is 1.8. Looking at Eqs. (6) and (7) it is clear that a relation exists between the ratio of the two SFR measurements and the equivalent width of an object, such that:

$$\frac{SFR_{\text{UV}}}{SFR_{\text{Ly}\alpha}} \propto \frac{\text{cons.}}{EW_0}$$  \hspace{1cm} (8)$$

In this equation, $EW_0$ is the rest-frame equivalent width of an object. The constant in the nominator depends on the spectral slope of the object, and on dust properties within the galaxy. For a flat slope in $f_\nu$, and no dust this constant equals 67 Å. For this assumption, our median ratio of 1.8 corresponds to a median EW of 37 Å, which is consistent with the measured median EW of 41.6 Å. The ratio is higher than that found by Ouchi et al. (2008), who measured a typical ratio of $\sim 1.2$ in a sample of $z = 3.1$ LAEs, and Gronwall et al. (2007), who, after correcting for the $(1+z)$ factor, also obtain a typical ratio of $\sim 1.0$ (Gronwall, priv. communication). These results are also related to those presented in Sect. 4.4. We note that several objects have ratios of below one. In total, 19 objects have measurements that deviate by up to $3\sigma$ from the 1:1 line. The explanation for these

**Fig. 7.** Size distribution of candidates as measured in the narrow-band (hatched histogram) and $r^+$ (empty histogram) images for LAE candidates and GALEX-detected candidates respectively. Sizes as measured by the FLUX_RADIUS command in SExtractor. The solid line represents the PSF of the narrow-band image, with the dotted lines showing the 1σ of the PSF measurement. These values are very similar to those of the $r^+$ image, see text.
The large spread in SEDs

The most conspicuous evolution detected was that of the emergence of a large number of "red" LAEs. The 12 individual detections in the relatively shallow $K_s$ images and the red mean SED of the total stacked sample, presented in Fig. 6, indicated that a significant subsample, of up to two-thirds of the total sample, of LAEs are massive, and potentially dusty, galaxies. We also showed that the rest-frame UV colours of these galaxies cannot be explained by a simple stellar population, and that even though the majority of the candidates are consistent with being young galaxies, a significant fraction of the sample displays more complicated colours.

- Potentially larger fraction of AGN

The result above is also related to the detection of at least nine AGN in the sample. Again, this is not a surprising result since...
redshift $z \sim 2$ corresponds to the peak of the AGN number density distribution (see e.g. Wolf et al. 2003 and references therein). The number density of AGN in this sample is in principle consistent with surveys at higher redshift, but is likely to be higher by a factor of two.

- Change in SFR ratios

The ratio of UV to Lyα derived SFRs has a higher median value in this survey than results at redshift $z \sim 3$. The spread is large, but the trend is clear. This result, and the smaller EWs discovered in general for this sample (see also the next point) at high redshift may indicate that LAEs in this survey are expected to be more affected by dust than LAEs at $z \sim 3$.

- Narrower EW distribution

Another intriguing and related result is that of the narrower equivalent width distribution. Firstly, as detailed in section 4.4, the distribution is difficult to explain without invoking complicated arguments about the properties of the galaxies. A possible explanation would be that the star formation histories of Lyα emitters are complex. Secondly, the difference in the distributions between redshifts three and two is further evidence of a higher dust quantity in the lower redshift galaxies.

In conclusion, by comparing observations of Lyα emitters at redshift $z = 2.25$ with galaxies selected in the same manner at higher redshifts, several evolutionary signatures become evident in the properties of these galaxies. At lower redshifts, there appear to be fewer objects, with redder colours and higher dust contents, smaller equivalent widths, and a higher fraction of objects containing AGN. Future SED fitting of these galaxies will reveal more information into the properties such as dust, mass and age (Nilsson et al., in prep.).

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Fig. 9. Left Distribution of restframe equivalent widths of the sample of 170 candidates. Bin size is 10 Å. The solid line indicates the exponential fit to the data with the fits with ±1σ plotted with dotted lines. The dashed line is the best fit to the sample of Gronwall et al. (2007). This sample has a more narrow distribution of equivalent widths. Right Distribution of restframe equivalent widths for total (non-GALEX-detected), red and blue sample (with Vj−> or < 0). In this plot, only objects with detections in both the Vj and the i+ bands are given. Red sample is plotted with a red line and blue with a blue line. The width of the different distributions are given in the figure.
