A Serendipitous Search for Hy-Redshift Lyα Emission: A Case Study of Two Sources at \( z \simeq 3 \)

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Abstract.
In the course of our on-going search for serendipitous high-redshift Lyα emission in deep archival Keck spectra, we discovered two Lyα emission line candidates in a moderate dispersion (\( \lambda/\Delta \lambda \simeq 1200 \)) spectrogram. Both lines have high equivalent width (\( W_{\lambda}^{\text{obs}} \geq 450 \text{ Å} \)), low velocity dispersions (\( \sigma_v \sim 60 \text{ km s}^{-1} \)), and deconvolved effective radii \( r_e \approx 1.0h^{-1}50 \text{ kpc} \). Their sizes and luminosities are suggestive of the primeval galaxy model of Lin & Murray (1992), based on the self-similar collapse of an isothermal sphere. We argue that the line emission is Lyα, and it is stellar in origin. The sources are consistent with being primeval.

1. Introduction

Strong Lyα line emission has been proposed as a possible signature of primeval galaxies. Though early modeling conjectured that these emission lines would be highly luminous but diffuse, searches on 4m-class telescopes found no such emission lines (Pritchet 1994; Thompson & Djorgovski 1995). Deep spectra at the Keck telescopes, however, regularly reveal serendipitous high-equivalent width, isolated emission lines (e.g., Stern et al. 1999; Hu et al. 1998). Indeed, the first confirmed galaxy at \( z > 5 \) was discovered in this manner (Dey et al. 1998). We report on two sources with strong line emission identified on a single slitlet from deep slitmask observations of the SSA22 field, with equivalent widths \( W_{\lambda}^{\text{obs}} \geq 375 \text{ Å} \). The source targeted by this slitlet is a color-selected Lyman-break galaxy (LBG); we analyze it in parallel for comparison. We adopt \( (\Omega, \Lambda, H_0) = (1, 0, 50) \).

2. Observations and Results

We have obtained deep, moderate-dispersion spectra of \( z \simeq 3 \) LBGs in the SSA22 field with the aim of detailed studies of the ages, kinematics, dust-content, and abundances of the LBG population (Dey et al., in preparation). The data were taken with the Low Resolution Imaging Spectrometer (Oke et al. 1995) at the Keck II telescope on UT 1997 September 10, using the 600 lines mm\(^{-1}\) grating blazed at 5000 Å. Slitlet widths were 1″.25, resulting in a spectral resolution of \( \sim 4.4 \text{ Å} \) (FWHM). Four 1800 s exposures (seeing FWHM\( \approx 0″.78 \)) are analyzed in
this report. The data were processed using standard slit spectroscopy procedures (for details, see Manning et al., in preparation).

Figure 1. Two-dimensional spectrogram of slitlet in the SSA22 field targeting the LBG C17 at z=3.299. Two strong line emitters are serendipitously identified, ser-1 and ser-2. The high-equivalent widths, narrow velocity widths, and lack of secondary spectral features strongly argue that these are Lyα emitters at z ≃ 3. Note the foreground continuum source and residual of the [O i]5577Å skyline.

We find two serendipitous, isolated emission lines, ser-1 and ser-2, in a 100″ long slitlet centered on the LBG, C17 (z=3.299; see Fig. 1). Though only one of these serendipitously discovered sources (see Fig. 2) displays the obvious asymmetry characteristic of most high-redshift Lyα emission (e.g., Dey et al. 1998), we argue that Lyα is indeed the most likely interpretation for both. We performed a simulation of the [O ii] doublet under the 4.4Å resolution of our observations. We find that an [O ii] identification is inconsistent with ser-1 and ser-2, since the doublet is marginally resolved and has significantly greater FWHM than our lines. The absence of associated emission argues against Hβ, [O iii]4959, or [O iii]5007 interpretations. Finally, the lines are shortward of 6563Å, so Hα is not a viable identification. In the following, we assume what is most certainly the case — that these are in fact Lyα emission lines. Notably, neither spectrum displays perceptible continuum.

Measured continua were consistent with zero counts. We establish a 2σ (95% confidence) limit on the equivalent width, \(W_{\lambda}^{\text{obs}} \geq 550\text{Å} \) (ser-1), and \( \geq 474\text{Å} \) (ser-2). Rest values are tabulated in Table 1. C17 has \(W_{\lambda}^{\text{obs}} = 35.6\text{Å} \).

Table 1. Emission Line Properties

| Object | \(\lambda_{\text{obs}}\) (Å) | \(z\) | \(j_{-17}\) | \(L_{42}\) | \(W_{\lambda}^{\text{obs}}\) (Å) | \(W_{\lambda}^{\text{rest}}\) (Å) | \(r_c\) (\(h^{-1}\) kpc) | \(\sigma_v\) (km s\(^{-1}\)) |
|--------|------------------|-----|------|------|-------------------|---------------------|------------------|-----------------|
| -ser-1 | 4889.3           | 3.022 | 1.85 | 1.29 | \(\geq 550\)       | \(\geq 137\)        | 0.87             | 64              |
| -ser-2 | 5296.8           | 3.357 | 1.35 | 1.19 | \(\geq 474\)       | \(\geq 109\)        | 1.15             | 52              |
| C17    | 5226.4           | 3.299 | 2.60 | 2.20 | 35.6              | 8.3                | 2.79             | 82              |
3. Discussion and Conclusions

What is the physical origin of these isolated, high-equivalent width emission lines? The small velocity dispersions ($\sigma_v \approx 60$ km s$^{-1}$) and lack of associated N v or C iv emission argue against the presence of an AGN, while the high surface brightness is inconsistent with photoionization by the metagalactic flux (e.g., Bunker et al. 1998). Thus we assume the lines are stellar in origin. Below we argue that they are primeval.

The starburst modeling of Charlot & Fall (1993) suggest that the Ly$\alpha$ rest equivalent width may exceed $\sim 150\AA$ for timescales of at most a few $\times 10^7$ yr. A model of primeval galaxies based on a collapsing isothermal cloud (Lin & Murray 1992) predicts that primeval galaxies should have isophotal radii $r_e \sim 1$ kpc, and luminosities of order $\sim L^*$; strong star formation continues for $\sim 1.7$ Gyr, fed by the continuing collapse of the cloud. Cloud mass may be tuned to fit observed luminosities. We suggest that this theory holds promise for the modeling of our serendipitous sources.

The Ly$\alpha$ luminosities imply lower limits to star formation rate (SFR) of $0.87/0.81$ M$_\odot$ yr$^{-1}$ for ser-1/ser-2 (e.g., Dey et al. 1998), while non-detection of continua imply upper limits of $2.6/2.4$ M$_\odot$ yr$^{-1}$. Assuming a SFR of $1$ M$_\odot$ yr$^{-1}$, and $W_{\lambda}^{\text{rest}} = 150\AA$, we project $V_{AB} \approx 28.0$ at $z = 3$. Steidel et al. (1999) find a steep faint end slope for the luminosity function of star-forming galaxies at $
$z \sim 3 \ (\alpha \approx -1.6)$, implying that a large fraction of the UV luminosity density is produced by galaxies fainter than the spectroscopic limits of photometric surveys. By virtue of the association of UV luminosity with SFR, this would also imply that a large fraction of the star formation density is unobserved. Because the Ly$\alpha$ lines of such as our serendipitous objects are likely to be observable only for a very small fraction of 1 Gyr, these two are tangible evidence for this many-fold larger population of slightly older, faint continuum, star forming galaxies with self-absorbed Ly$\alpha$, inaccessible to even the deepest spectroscopic or color selection surveys.

The evidence strongly suggests that ser-1 and ser-2 are primeval. In the near future, interesting conclusions may be possible regarding the degree of clustering and/or isolation of these low-luminosity emission line galaxies. The large surface density variance in Ly$\alpha$ emission line galaxy candidates between different fields in a coarse “narrow-band” ($z \sim 2.37$) HST study (Pascarelle et al. 1998), indicates that these compact galaxies are often at least loosely grouped. Clearly, the model of Lin & Murray requires that primeval galaxies be born in relatively quiescent, yet gas-rich environments. However, as star-forming galaxies, their likely evolutionary antecedents, the LBGs, are often found clustered on large scales (e.g., Steidel et al. 1998); perhaps they are proto-clusters. The dynamics involved in the growth of large scale perturbations (i.e., infall and rising central densities) may be accompanied by a spreading “wave” (in the Lagrangian sense) of primeval galaxy formation, perhaps occurring at a characteristic overdensity — a scenario reminiscent of stellar “shell burning” — reproducing the inside-out, older-to-younger galaxy age distribution seen in some recent studies of lower redshift fields and groups (e.g., Loveday et al. 1999; Cohen et al. 1998).

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References

Bunker, A. J., Marleau, F. R., Graham, J. R. 1998, AJ, 116, 2086
Charlot, S., & Fall, S. M. 1993, ApJ, 415, 580
Cohen, J., et al. 1998 submitted, ApJ, astro-ph/9809067
Dey, A. et al. 1998, ApJ, 498, L93
Hu, E. M., Cowie, L. L., & McMahon, R. G., ApJ, 502, L99
Lin, D. N. C., & Murray, S. D. 1992, ApJ, 394, 523
Loveday, J., Tresse, L., & Maddox,S. J., 1999, astro-ph/9905386
Oke, J. B., et al. 1995, PASP, 107, 375
Pascarelle, S. M., Windhorst, & R. A., Keel, W. C. 1998, AJ, 116, 2659
Pritchet, C. J. 1994, PASP, 106, 1052
Steidel, C. C., et al. 1996, AJ, 112, 352
Steidel, C. C., et al. 1998, ApJ, 492, 428
Steidel, C. C., et al. 1999, astro-ph/9811399
Stern, D., Bunker, A., Spinrad, H., & Dey, A. 1999 Ap J, submitted
Thompson, D., Djorgovski, S., & Trauger, J. 1995, AJ, 110, 963