Large Area Lyman Alpha survey: finding young galaxies at $z=4.5$

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Abstract.

Strong Lyman-$\alpha$ emission is a signpost of young stars and the absence of dust and thus indicates young galaxies. To find such a population of young galaxies at $z=4.5$ we started the Large Area Lyman Alpha survey (LALA). This survey achieves an unprecedented combination of volume and sensitivity by using narrow-band filters on a large format ($36' \times 36'$) camera on the 4 meter telescope at KPNO. The volume density and star-formation contribution of the Lyman-$\alpha$ emitters at $z=4.5$ is comparable to that of Lyman break galaxies. With many candidates and a few spectroscopic confirmations in hand we discuss what the properties of Ly-$\alpha$ emitters imply for galaxy and star formation in the early universe.

1. Introduction

More than three decades ago Partridge and Peebles (1967) predicted that galaxies in their first throes of star-formation should be strong emitters in the Ly-$\alpha$ line. Their predictions were optimistic, based on converting roughly 2% of gas into metals in $3 \times 10^7$ years in Milky Way sized galaxies, which translates into a line luminosity of $\approx 10^{44}$ erg/s. These objects are also expected to be common - if all the $L^*$ galaxies have undergone such a phase of rapid star-formation one should see a surface density of about $3 \times 10^3$ per square-degree. Searches based on these expectations did not detect Ly-$\alpha$ emitters (see review by Pritchet 1994). Only recently have Ly-$\alpha$ emitters been discovered, (Lowenthal et al 1997; Cowie & Hu 1998; Hu, Cowie & McMahon 1998; Dey et al 1998; Hu, McMahon, & Cowie 1999; Kudritzki et al 2000, Rhoads et al. 2000), but at luminosities roughly a hundred times fainter and the total number discovered remains small.
2. LALA Survey

In order to get statistically useful samples we started an efficient search for Ly-\(\alpha\) emitters (and other emission line galaxies) in 1998 using the CCD Mosaic Camera at the Kitt Peak National Observatory’s 4m Mayall telescope. The Mosaic camera has eight 2048\(\times\)4096 chips in a 4\(\times\)2 array comprising a 36\(\prime\)\(\times\)36\(\prime\) field of view. The final area covered by the LALA survey is 0.72 square-degrees in two MOSAIC fields. Five overlapping narrow band filters with full width at half maximum (FWHM) \(\approx 80\)˚A are used. The total redshift coverage is \(4.37 < z < 4.57\). This translates into surveyed comoving volume of \(8.5 \times 10^5\) \(Mpc^3\) per field for \(H_0 = 70\)\(kms^{-1}Mpc^{-1}\), \(\Omega = 0.2\), \(\Lambda = 0\). About 70\% of the imaging at \(z \approx 4.5\) is complete, and an extension of the survey to \(z > 5\) has started. In about 6 hours per filter per field we are able to achieve line detections of about \(2 \times 10^{-17} ergs cm^{-2} s^{-1}\). Broadband images of these fields in a custom \(B_W\) filter (\(\lambda_0 = 4135\)˚A, FWHM = 1278˚A) and the Johnson-Cousins \(R\), \(I\), and \(K\) bands are being taken as part of the NOAO Deep Wide-Field Survey (Jannuzi & Dey 1999).

Figure 1. A confirmed \(z = 4.52\) Ly-\(\alpha\) source. This object has a line flux of \(1.7 \times 10^{-17} ergs cm^{-2} s^{-1}\) and observed equivalent width of 84˚A. The line is asymmetric and has a strong continuum decrement from the red to the blue side of the line. Another drop in the continuum level can be also be discerned at the Lyman limit.

Pilot spectroscopic studies were carried out to confirm emission line candidates. This is necessary because the narrow band selection criterion picks up
Large Area Lyman Alpha survey

[OIII] emitters at z=0.3, [OII] emitters at z=0.8 as well as Ly-α emitters at z=4.5. In case of [OIII] emitters at z=0.3, the spectra show three lines, two of [OIII] and Hβ and in most cases, Hα. We can often see the [OIII] and Hβ lines for the [OII] emitters depending on the wavelength coverage. Some of the [OII] and all Ly-α emitters show only one line each in the wavelength range covered, so a one-line spectrum may be either a z=0.8 or a z=4.5 object. The confirmation of the Ly-α line is largely circumstantial. An asymmetric line and a continuum drop blueward of the line due to intergalactic absorption are the signatures of the Ly-α line (Stern & Spinrad 1999). In sources where we do not detect the continuum, the high equivalent width of the line provides the (somewhat weaker) evidence that the line in question is indeed Ly-α.

Spectroscopic follow-up of a cross-section of emission line candidates was obtained with the LRIS instrument (Oke et al. 1995) at the Keck 10m telescope on 1999 June 13 (UT) and April 2000. The June 1999 mask yielded one, perhaps two, Ly-α emitters. The April 2000 mask had a better detection rate as we had used broad band colors to reduce the contamination by foreground emission line galaxies. It yielded 4 more Ly-α emitters.

3. Discussion

From the few spectroscopic confirmations and many candidates we estimate about 4000 emitters per square degree per unit redshift (Rhoads et al. 2000). Within the present uncertainties the number density of Ly-α emitters is 3 times higher than the Lyman break galaxies (Steidel et al. 1999) of similar brightness and redshifts. The star-formation rates estimated for the Ly-α galaxies are 0.5-2 times the star-formation rate derived for continuum selected galaxies at similar redshifts (Madau et al. 1996). At present there are large uncertainties in the LALA numbers due to the small sample of spectroscopic confirmations.

While the original predictions were for strong Ly-α emission, the recent detections are roughly a hundred times fainter. Prior to the discoveries of Ly-α emitters, many scenarios had been proposed to explain the non-detections. Now that we find Ly-α sources, understanding the faintness of this line will be valuable to understanding star and galaxy formation this early in the universe.

(A) It is possible that early star formation occurred in smaller, sub-galactic units, which later merged to form the large galaxies we see today. In this, case the line luminosity $L_{Ly-α}$ should be small while its equivalent width remains large. Two of the confirmed $z = 4.5$ Ly-α sources lie only 5" apart and may indeed be interacting or merging.

(B) Even modest amounts of dust can strongly quench the line: Ly-α photons are resonantly scattered by neutral hydrogen, which can force them to escape from galaxies by a random walk process in which they traverse a much longer path length for dust absorption than do continuum photons at similar wavelengths. In this case, both $L_{Ly-α}$ and $EW_{Lyα}$ should be substantially reduced from the simplest dust-free predictions. Most of the spectroscopically confirmed LALA sources have rest-frame $EW_{Lyα} \approx 100\AA$ which argues for dust-free star-formation scenarios. This by itself is not a strong argument, since the narrow band selection picks out high equivalent width sources. Comparison of the populations of line-selected and continuum selected sources would tell us how
many galaxies at these redshifts are dust-poor enough to show high equivalent width Ly-\(\alpha\) emission.

(C) Similarly, early star-formation could have a longer time-scale than a dynamical time postulated by PP67. NIR colors along with stellar population modelling can help to determine whether there is some relatively old population (age > \(10^7\) years), along with the young stars.

(D) Even if the star-formation is dust-free, it is quite likely that neutral gas extends beyond the star-formation regions. In this case Ly-\(\alpha\) photons will diffuse out of the surface area of the larger HI envelope and Ly-\(\alpha\) emission will be extended and fall below the surface brightness detection limits.

(E) Winds: In low redshift universe, the galaxies that show Ly-\(\alpha\) emission are not the most metal poor (and hence dust free) galaxies, but galaxies which show outflows (Kunth et al. 1998). Large velocity gradients doppler shift the Ly-\(\alpha\) photons so they no longer resonantly scatter. However, the high redshift Ly-\(\alpha\) sources emit \(\sim 100\) times more in line luminosity than these local sources, and it is not clear if the same mechanism is responsible for the Ly-\(\alpha\) escape in both contexts. If it is indeed winds that are responsible for the escape of Ly-\(\alpha\) photons at higher redshifts, these winds probably have \(100\) times the kinetic energy of their local counterparts and therefore are significant polluters of the intergalactic medium. Either high resolution spectroscopy or morphological comparison in continuum and Ly-\(\alpha\) line emission will allow us to search for evidence for such winds, and wind blown bubbles.

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4. Questions

**Avery Meiksin** Can you image these systems to see their morphologies, or can you only see the Ly-a emitting region? Answer: These objects are at best marginally resolved from the ground; some have little or no continuum detected. HST imaging in the Ly-\(\alpha\) line and in the continuum would be very interesting.

**Cong Xu** Can you determine whether a source is an AGN? Answer: We do not see broad emission lines. We cannot rule out weak, narrow lined AGNs. To determine that we need spectra with enough S/N to detect CIV at 1549 Å or high resolution imaging capable of revealing a point source. A hidden AGN would be best revealed in X-ray imaging.