Lyman-Alpha line Profiles from z~5 BDF Sources

BRISTOL PHYSICS

University of BRISTOL

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Abstract

We present data obtained from the VIsible Multi-Object Spectrograph (VIMOS) on the Very Large Telescope (VLT) to investigate Lyman-Alpha (Ly-α) emission line shapes detected from five redshift (z) ~5 sources in the BDF field (Lenhert & Bremer, 2003). We adapt models developed by Dijkstra et al. (2007) for a star forming galaxy in a post re-ionized universe to model possible, pre-absorption, Ly-α flux profiles which display line broadening up to and exceeding 600kms^{-1}. These intrinsic spectral line widths are too large to be produced by the rotation of the galaxy alone and so indicate the presence of strong galactic winds arising from intense star formation. We discuss how these models could explain velocity offsets between the Ly-α peak and the redshift of interstellar absorption lines observed in stacked spectra (Douglas et al, in prep), and the discrepancy between Ly-α and UV continuum derived Star Formation Rate (SFR) estimates.

Introduction

The Lyman break technique has been used to great effect in the detection of numerous high redshift sources, which have subsequently been spectroscopically confirmed. Using the FOcal Reducer and low dispersion Spectrograph (FORS2) on the Very Large Telescope (VLT) Lehnert & Bremer obtained deep R, I and Z broadband observations of a 44 arcmin^2 field. Using these, objects were selected which had extremely red R-I colours (R-I > 1.5), i.e. a large spectral break between the R and I bands selecting star-forming galaxies at z > 4.8. Using this method 13 sources were selected. Spectra were obtained for 12 of these and six were confirmed to have redshifts between z = 4.8 and 5.8. An analysis of the SED of comparable sources by our team (Verma et al 2007) suggest that these Lyman break galaxies are younger, less massive, less dusty and of lower metallicity than the equivalent galaxies at z~3.

Despite this success, the low resolution of the spectra inhibited analysis of the spectral line shapes of the Ly-α detections. The characteristic shape of the Ly-α line at high redshift (Figure 2) is an important tool in the determination of the properties of these young intensely star forming systems. Dense neutral hydrogen in falling on to the Ly-α emitting galaxy completely suppresses the blue wing of any emission, giving the line its asymmetric shape, and acts as a damping effect on the red wing. Given that these dynamical processes modify both blue and red wings of the Ly-α emission line, their interpretation is complex.

One of the key problems in understanding the Universe at early epochs is the early enrichment of metals in the IGM (Savaglio, 1998). Galactic winds (produced via stellar winds and supernovae) in young intensely star forming galaxies (Veilleux et al. 2005) are thought to be the primary mechanism by which metals and energy are processed by galaxies and ejected into the IGM. This means that emission lines can be an important probe into the dynamics of high redshift galaxies and the star forming processes occurring within them. These strong outflows can manifest themselves as a broadened red tail in the line profile as photons are back scattered by Ly-α emitting gas which is moving rapidly away from us on the far side of the galaxy. The presence of extremely strong winds in high redshift galaxies would suggest they are a major protagonist in the rapid enrichment of the IGM.

Models produced by Dijkstra et al. have shown that as much as 78% of the total Ly-α intrinsic flux emitted by high redshift galaxies could be obscured from the observer. This would have significant consequences for the intrinsic line width (hence galactic winds), the Ly-α SFR estimates and the contribution by Lyman-Alpha Emitters (LAEs) to the re-ionization of the universe.

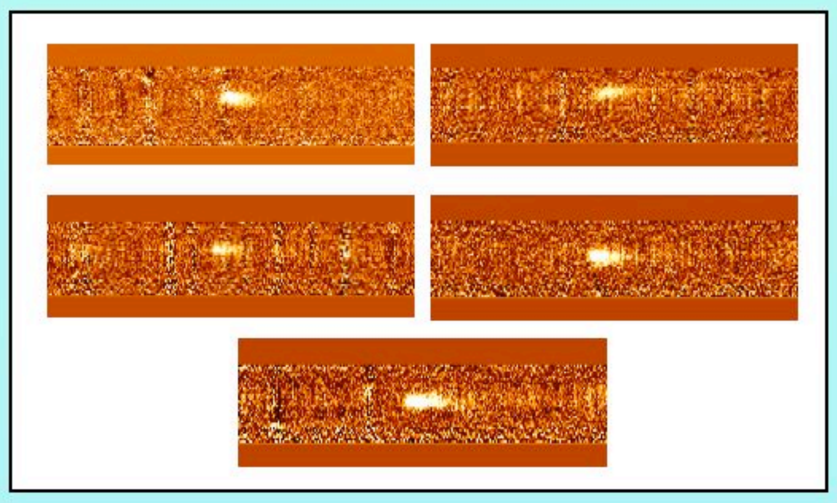

Figure 1: 2D spectra of the sample of z~5 Lyman-Alpha emitting sources identified in our reduced VIMOS spectra. Wavelength is shown horizontally and spatial position along the slit vertically. All objects are spatially un-resolved but show resolved emission line structure.

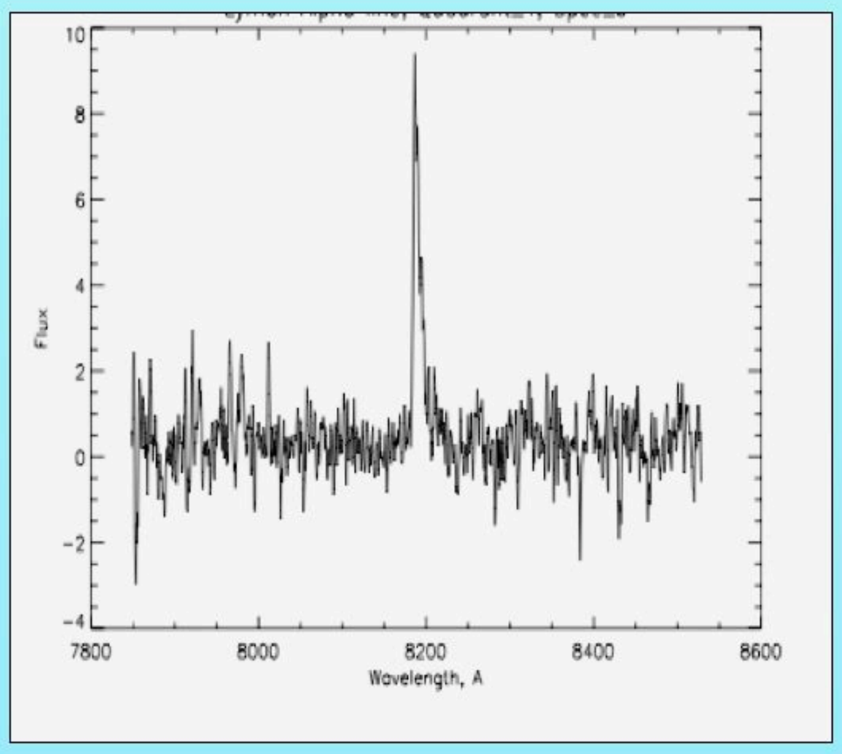

Figure 2. Section of a 1D spectrum taken from one of the z~5 sources. Large central peak is the Lyman-alpha (1216Å) emission line redshifted to ~8200 Å. The characteristic line shape can be seen with a sharp cut off blue-ward of the peak and a red tail.

Model Intrinsic Fluxes

We model a Verma et al type galaxy in a fully ionized universe with overdense, infalling neutral hydrogen from distances much larger than the viral radius. We calculate the effects of infall and outflows on the Lyman-α emission line by adapting models produced by Dijkstra et al., using the total luminosity of ionizing photons emitted by a starburst galaxy with 0.2 solar metallicity; outlined by Schaerer (2002). We set our model galaxies at similar redshifts to those in our observed sample and show that by varying the width of the intrinsic line it is possible to produce our observed results. Figure 3 (a) displays the expected transmission of Ly-α photons from our models in the rest frame of the galaxy. Figure 3 (b) displays the observed Ly-α line from one of our sources. Over plotted is the model intrinsic flux scaled with redshift.

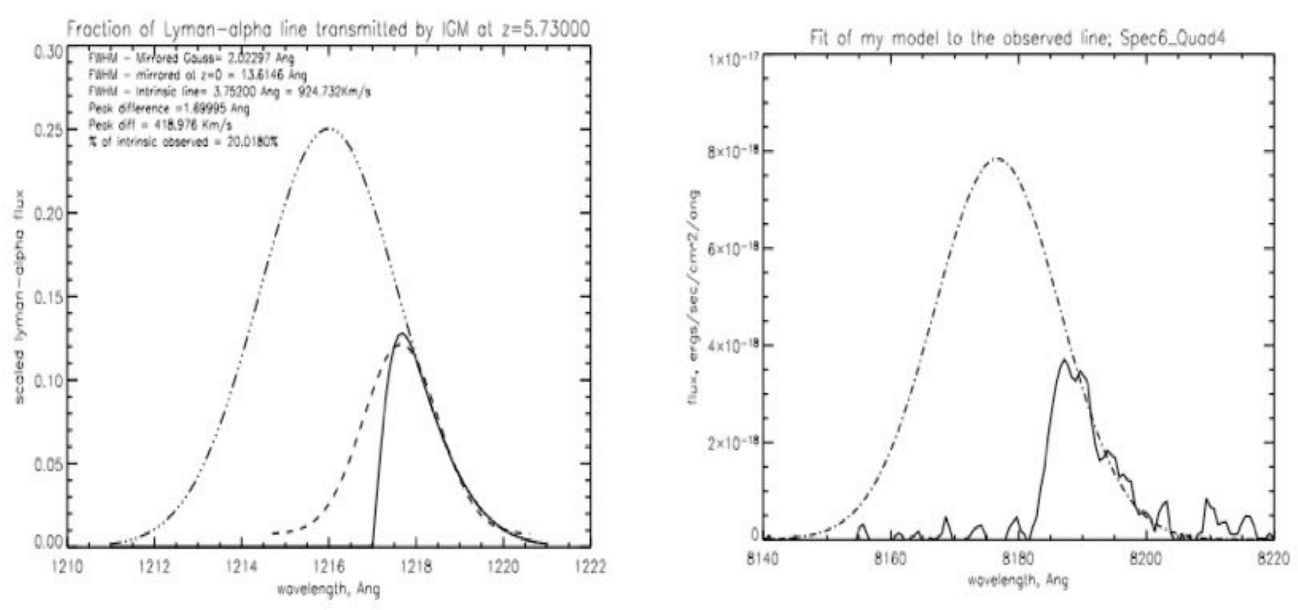

Figure 3. Left (a): Model transmission of Ly-α flux in the rest frame of the galaxy. Dot-dashed line is the intrinsic emission produced by the galaxy. Solid line is the transmitted flux after it has been processed by the IGM, and dashed line is a Gaussian fitted to the red tail of the transmitted flux. Right (b): The observed flux from our galaxy at the same redshift as the model (solid line), dot-dashed line is the model intrinsic flux scaled with redshift.

These models suggest that we could be observing between 17 and 25% of the intrinsic line flux from z~5 LAEs and that the broadening of the intrinsic line due to galactic winds could be between 350 and 600km/s.

Many studies have shown that the SFR estimated from the Ly-α emission lines from high redshift sources are underestimated by up to a factor of six in comparison to those derived from the rest frame UV continuum (Hu et al, 2002 , Kondaria et al, 2003). This coincides with our results which demonstrate that the Ly-α SFR are underestimated by 2.4-5 in comparison to those obtained from our FORS2 photometric data. If our model fluxes are used these underestimates become less significant; this is the subject of continuing work.

Recent work by Douglas (2008, in prep) and Stanway et al. (2008, in prep) have used redshift estimates from secondary UV continuum emission lines produced via stacking analysis to determine that the observed Ly-α peak could be offset from the intrinsic peak by 300-900kms^{-1}. Our models suggest peak velocity offsets of ~400km/s and so would adhere to this caveat.

Observations

This data was taken over a period of several nights in August 2007 using the VIsible Multi Object Spectrograph (VIMOS) on the Very Large Telescope (VLT) in Cerro Paranal, Northern Chile. The telescope was run in service mode and 125 objects were simultaneously targeted using a single slit mask, observed for a total integration time of ~7 hours, at a resolution of R ~ 2500. These included known high redshift sources from the FORS2 observations and other objects of interest in the field placed in unused areas of the slit mask.

Data Reduction & Results

Due to inadequacies in the data obtained from VIMOS, caused by flexure and movement of the instrument as the telescope was tracking, various distortion features occur in the data which are time variant. Therefore no packages are currently available to produce an adequate reduction of the data to the levels of precision required for this high resolution spectroscopy. An 'Interactive Data Language' (IDL) program was written to fully reduce and wavelength calibrate the spectra. This reduction pipeline is generic and should be capable of reducing spectra from any instrument and, in the case of VIMOS, appears to be the best available for detecting faint objects.

Once the data reduction pipeline was completed five z~5 sources were identified (Figure 1) along with many lower Redshift objects which shall be discussed in later work. All of the z~5 objects show the characteristic Ly-α line shape as outlined in Figure 2, with a broadened red tail. All have rest frame equivalent widths < 110Å, indicative of sources with no AGN contribution to their Ly-α emission (Charlot & Fall, 1993).

Analysis of Line Shapes

We initially analyze the line shape giving the following simplifying assumptions that:

1) The shape of the red wing is largely unaffected by damping due to neutral hydrogen.
2) The measured FWHM represents exactly half of the Ly-α flux escaping from the galaxy
3) The rest-UV selected galaxy is typical of those characterized by Verma et al (2007) with $r_{1/2}$ ~ 1Kpc, M ~ $10^9 M_\odot$, SFR ~ $40 M_\odot$ /yr, Z=$0.2 Z_\odot$.

Using these assumptions we fit a Gaussian to the red tail of the line and estimate a lower limit of the broadening due to velocity effects at the source to be ~300kms^{-1}. If we then propose that all of this broadening is due to rotational velocity of the source we obtain an enclosed mass within 1kpc of ~ $2 \times 10^{10} M_\odot$. This is an order of magnitude larger than estimates for the stellar mass obtained from luminosity measurements. As the systems characterized by Verma et al are comparable to the densest that we see in the local universe, it is extremely unlikely that the star forming regions are highly dark matter dominated. This suggests that the majority of the line broadening is due to galactic winds. The only other effect that could significantly broaden the line would be large peculiar velocities away from us in the line of sight. This however is unlikely to be the case for all sources in our sample which all display significant broadening.

Conclusions

Using VIMOS spectroscopy from the VLT we have shown that the velocities derived from Ly-α line broadening are too large to be solely produced by the rotational velocity of a Verma et al. type galaxy at z~5. We suggest that this extra broadening indicates the existence of strong galactic winds which are essential for the enrichment of the IGM. Using a lower limit and models for the transmission of Ly-α flux from a star-forming galaxy in a fully ionized universe at z~5.7, we propose that these winds range between 300-600kms^{-1}. We show that these models could account for the underestimates of Ly-α SFR and peak velocity offsets observed by Douglas & Stanway et al. Further modeling of a Verma type galaxy in this environment will enable us to more accurately assess the contribution of these galactic winds to the recycling of metals and energy in to the IGM at these early epochs. Further details of these results, analysis and consequent work will be outlined in Davies et al (2008, in prep).

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