Faint Resonantly Scattered Lyman α Emission from the Absorption Troughs of Damped Lyman α Systems at z ~ 3

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ABSTRACT

We demonstrate that the Lyα emission in the absorption troughs of a large sample of stacked damped Lyα absorption systems (DLAS) presented by Rahmani et al (2010) is consistent with the spectral profiles and luminosities of a recently detected population of faint Lyα emitters at z ~ 3. This result supports the suggestion that the faint emitters are to be identified with the host galaxies of DLAS at these redshifts.

Key words: galaxies: high redshift – quasars: absorption lines – galaxies: formation – galaxies: evolution – galaxies: dwarf – line: profiles – radiative transfer.

1 INTRODUCTION

An ultra-deep spectroscopic blind survey (Rauch et al 2008; hereafter R08) has revealed the existence of numerous, faint, spatially extended Lyα emitters at z ~ 3. The inferred rate of incidence of the emitters, and the observed signatures of resonant radiative transfer suggest that the emission originates from regions corresponding to high column density HI QSO absorption systems. R08 proposed that these objects may thus be identified with the elusive host galaxies of DLAS and Lyman Limit systems (LLS). Their study showed that even objects with the low luminosities and low masses characteristic of high redshift dwarf galaxies are surrounded by extended gaseous halos, whose intrinsic Lyα emission can typically be traced out to radii of at least 4".

Rahmani et al (2010) recently published a high signal-to-noise composite spectrum of the absorption trough of high redshift DLAS from the Sloan Digital Sky Survey (SDSS), to search for Lyα emission from the underlying galaxies giving rise to the DLAS. Their sample represents low resolution (R=2000) spectra of 341 DLAS, with column densities exceeding logNHI=20.62. The DLAS where shifted to the rest frame and then averaged according to various prescriptions. The individual QSO spectra used represent the integrated light of fibers with 3" diameter. Since many of the R08 objects have relatively compact cores of Lyα emission (on top of more extended low light level emission), a significant fraction of the Lyα luminosity of such galaxies should occur close enough to the line-of-sight to be recorded within the fiber radius, assuming that these emitters are in fact associated with DLAS. Rahmani et al establish upper limits on the flux in a central wavelength region of the stacked absorption troughs. Based on this result they conclude that the low mean flux permitted by their analysis contradicts, at the 3 − σ level, the suggestion that DLAS could correspond to a population of Lyα emitters with a mean flux as high as found by R08. We argue here that this conclusion is based on an inappropriate model of the emission profile used by Rahmani et al. When allowance is made for the resonant scattering of the Lyα photons with their inherent wavelength shifts and asymmetries, their combined DLA profile is consistent with substantial Lyα flux, and supports, rather than contradicts, the correspondence between DLAS and Lyα emitters proposed by R08.

2 THE EXPECTED Lyα EMISSION PROFILE

Rahmani et al searched for Lyα emission at the center of the DLA line, assuming a Gaussian velocity distribution with a width of 200 kms−1. This model would be appropriate for optically thin emission, broadened only by galactic velocity dispersion and the instrumental profile. However, numerous theoretical studies of radiative transfer through the very optically thick DLAS (e.g., Zheng & Miralda-Escudé 2002; Dijkstra et al 2006; Verhamme et al 2006; and references therein) have shown that the generic emission line profile is double-humped, with apparent velocity shifts of hundreds of kms−1 between the blue and red components, and little emission at all at the systemic redshift. The profile is further modified by the motion of the gas. Observation-
ally, in high redshift galaxies the red peak dominates, and the blue peak is highly reduced in size. This pattern can be accomplished by Lyα propagating through an expanding halo, partial absorption by intervening Lyα forest clouds, or a combination of both (e.g., Dijkstra et al 2006; Barnes & Haehnelt 2010; Laursen et al. 2010). The pattern of a dominant red peak, absorption trough, and faint blue peak is clearly seen in the brighter of the sources found by R08, and a similar pattern (with even less blue emission) is seen in the much brighter Lyman break galaxies. Note that for a large ensemble of emitters a broad distribution of the location and width of the "red peak" would be expected. For a stacked spectrum like the one of Rahmani et al. this should lead to a broad emission feature on the red side of the trough, extended over several hundred km/s. Unfortunately, because of their faintness, we cannot determine the systemic redshifts of the R08 emitters so it is not possible to stack the R08 spectra to directly determine the shape of the combined emission feature.

The mean observed flux density over the entire trough in Fig. 1 is \((3.4 \pm 2.8) \times 10^{-19} \text{erg s}^{-1} \text{cm}^{-2} \text{Å}^{-1}\), i.e., consistent with zero, in agreement with Rahmani et al.'s statement that a global correction of the zero level has been performed for each spectrum to account for imperfections in the sky background subtraction. However, the Kolmogorov-Smirnov probability for the residuals in the 16 pixels with error bars in their figure to be consistent with zero flux throughout is only 1%. The probability for the flux density in the blue half and the red half of the DLA trough (the bluest 8 pixels and the reddest 8 pixels of the residuals) to be drawn from the same sample is likewise less than 1%, i.e., the flux levels in the blue and red half of the trough are significantly different, and not consistent with being at the true zero level. The mean flux density in the left side of the trough (bluest 8 pixels plus half of the central pixel) and the right side of the trough (right half of the central pixel and the redward adjacent 8 pixels) are \((-0.87 \pm 0.55) \times 10^{-18}\) and \((1.23 \pm 0.54) \times 10^{-18} \text{erg s}^{-1} \text{cm}^{-2} \text{Å}^{-1}\), respectively.

Without any detailed radiative transfer model or statistical distribution of profile shapes we can still obtain a very simple lower limit to the total flux by assuming that all the flux emerges in the red half of the profile. This amounts to ignoring the blue peak entirely and is probably correct to better than 10% (judging from the spectra in R08). The integrated flux in the red half of the trough, covering wavelengths from \([1215.67, 1218.2] \text{Å}\) or velocities in the range from \([0, 624] \text{km s}^{-1}\), i.e., the wavelength region occupying the RHS half of fig 1, is \((3.11 \pm 1.38) \times 10^{-18} \text{erg s}^{-1} \text{cm}^{-2}\). This assumes that the zero-level was correctly determined in the spectrum by Rahmani et al. 2010. However, the zero level was adjusted globally for the trough and the flux level is sloping so both halves of the trough cannot be simultaneously at the correct zero level. If we enforce the trivial condition that the flux must be equal or greater than zero in both halves of the DLA trough simultaneously we are forced to raise the zero level flux density in the entire region at least by the amount of \(0.87 \times 10^{-18} \text{erg s}^{-1} \text{cm}^{-2} \text{Å}^{-1}\). This leads to zero flux in the blue side, and to a corrected
flux density for the red half of \((2.11 \pm 0.78) \times 10^{-18} \text{ erg s}^{-1} \text{ cm}^{-2} \text{Å}\). The total flux in the red side, over the interval [0, 624] k\text{m s}^{-1} is then \((5.35 \pm 1.97) \times 10^{-18} \text{ erg s}^{-1} \text{ cm}^{-2}\).

The results are robust with respect to different choices in averaging the spectra. Applying the same analysis to the unweighted mean spectrum (Rahmani et al panel 1 in their fig.1) we get similar numbers, a required upward correction unweighted mean spectrum (Rahmani et al. erroneously give a factor 1.7) of the sensitivity spectra from the SDSS still falls short by a factor 4-6 (Rahmani et al. 2010). Our lower limit of Ly\(\alpha\) flux emerging at the bottom of the stacked DLAS profile (clipped weighted mean) gives \((5.35 \pm 1.97) \times 10^{-18} \text{ erg s}^{-1} \text{ cm}^{-2}\). This value is within one standard deviation of the mean flux of the R08 emitters, \(3.7 \times 10^{-18} \text{ erg s}^{-1} \text{ cm}^{-2}\), in reasonable agreement with that independent estimate. The average luminosity of Ly\(\alpha\) emitters causing DLAS in the line-of-sight to background QSOs is similar or perhaps even somewhat larger than the average luminosity of faint Ly\(\alpha\) emitters in the R08 sample. Thus, contrary to the claim by Rahmani et al, our present analysis lends additional support to the conclusions by Rauch et al 2008 that their Ly\(\alpha\) emitters largely overlap with the host galaxies of DLAS.

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3 CONCLUSIONS

Ly\(\alpha\) emitters associated with optically thick gaseous halos show asymmetric and mostly redshifted line profiles that, in aggregate, can produce a tilt of the flux level at the bottom of a DLA absorption profile. We identify such a pattern in the stacked DLAS spectrum presented by Rahmani et al 2010 and estimate the flux emerging from the trough. Taking into account the expected effects of resonant scattering on the spectral distribution of the emission and the probable over-subtraction of the sky background at the bottom of the profile, we arrive at a much higher (but still only marginally significant) estimate for the average Ly\(\alpha\) flux than Rahmani et al. Our lower limit of Ly\(\alpha\) flux emerging at the bottom of the stacked DLAS profile (clipped weighted mean) gives \((5.35 \pm 1.97) \times 10^{-18} \text{ erg s}^{-1} \text{ cm}^{-2}\). This value is within one standard deviation of the mean flux of the R08 emitters, \(3.7 \times 10^{-18} \text{ erg s}^{-1} \text{ cm}^{-2}\), in reasonable agreement with that independent estimate. The average luminosity of Ly\(\alpha\) emitters causing DLAS in the line-of-sight to background QSOs is similar or perhaps even somewhat larger than the average luminosity of faint Ly\(\alpha\) emitters in the R08 sample. Thus, contrary to the claim by Rahmani et al, our present analysis lends additional support to the conclusions by Rauch et al 2008 that their Ly\(\alpha\) emitters largely overlap with the host galaxies of DLAS.