Probing the Gas Distribution of Lyα Emitting Galaxies through their Spectrally Resolved Lyα Emission

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We present the preliminary results of Magellan/IMACS deep, multi-object spectroscopic observations of 25 Lyα emitting galaxies (LAEs) at $2 \lesssim z \lesssim 3.5$ that were drawn primarily from the HETDEX Pilot Survey in the COSMOS field. With a spectral resolution of 150 km s$^{-1}$ FWHM, we resolve the Lyα emission line profiles of these galaxies and observe an assortment of velocity and spatial structure due to the resonant scattering of Lyα photons in the HⅠ gas of the galaxies’ interstellar and circumgalactic media. The spectral structure includes varying degrees of asymmetry, a range of line widths, and a varying number of emission peaks with different velocity separations. Through parametric fitting of the Lyα line profiles, we quantify the observed structure and find evidence of a correlation between parameters describing the shape of the strongest emission line component and its velocity offset from $z_{\text{sys}}$, the galaxy’s systemic redshift. Recent simulations have predicted a similar trend that is driven by the neutral hydrogen column density $N_{\text{HI}}$ as a general property of Lyα radiative transfer in various HⅠ distributions and kinematic configurations.

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Figure 1: IMACS spectra of HPS-306, a double-peaked and extended LAE. **Left:** HST F814W image. The IMACS slit is shown in red. The blue diamond (circle) is the Ly$\alpha$ centroid (positional error) from [2]. **Middle Left:** IMACS 2D spectrum. **Middle Right:** IMACS 1D spectrum plotted in velocity relative to the peak Ly$\alpha$ emission $\Delta V_{\text{peak}}$. Note the “asymmetric Gaussian” fit in red. **Right:** Spatial profiles plotted along the length of the slit $\Delta l$ for the Ly$\alpha$ and continuum emission relative to the IMACS PSF.

1. Background and Observations

Ly$\alpha$ photons (1215 Å) are produced in the H$\text{II}$ regions of star-forming galaxies due to hydrogen recombination after ionization by the UV radiation of young stars. The resonant scattering nature of the Ly$\alpha$ transition in H$\text{I}$ results in frequency and spatial diffusion as photons random-walk out of the galaxy. This makes Ly$\alpha$ radiative transfer dependent on the distribution and kinematics of the H$\text{I}$ gas, as well as the galaxy’s dust content. The shape of the emergent Ly$\alpha$ spectrum thus encodes the physics of the scattering gas in a non-trivial way (e.g., [1]). We attempt to obtain a global perspective of the processes governing the escape of Ly$\alpha$ by comparing observed trends among the Ly$\alpha$ emission properties for a large sample of LAEs. We have obtained multi-slit Ly$\alpha$ spectra with Magellan/IMACS of 25 LAEs at $2 \lesssim z \lesssim 3.5$ in COSMOS, drawn from the HETDEX Pilot Survey [2, 3] and a narrowband survey for LAEs at $z \approx 2.25$ [4]. The spectra have 150 km s$^{-1}$ FWHM spectral resolution, 0.9'' FWHM spatial resolution along the slit (7.3 kpc at $z = 2.75$), and a 1D 5$\sigma$ line flux limit of $2 \times 10^{-18}$ erg s$^{-1}$ cm$^{-2}$ in 5.25 hours of exposure at 4500 Å.

2. Ly$\alpha$ Classification and Spectral Line Profile Fitting

Fig. 1 shows an example of our IMACS data. Excluding two broad-line AGN, we classify the remaining 23 LAEs into three categories based on the 1D Ly$\alpha$ spectral line profiles: single peaks (48% of the sample), double peaks (43%), and LAEs with greater than two Ly$\alpha$ peaks (9%). These results are consistent with previous work [5]. The Ly$\alpha$ spectra are also collapsed spectrally to yield a spatial profile along the slit. To compare the spatial Ly$\alpha$ extent to that of the continuum, we convolve COSMOS F814W HST images ($\sim 2200$ Å in the rest-frame) with the IMACS PSF and collapse the resulting image along the width of the slit. We find five LAEs with Ly$\alpha$ emission that is extended significantly beyond that of the continuum. Six LAEs are resolved in Ly$\alpha$ and continuum, while the majority (11 LAEs) are completely unresolved. Although our sample is small when subdivided in this way, we find no significant connection between the Ly$\alpha$ spectral classification and whether or not an LAE displays extended Ly$\alpha$ emission.

To quantify the spectral morphology of the Ly$\alpha$ line, we fit an “asymmetric Gaussian” function [6] to the 1D data, including an instrumental correction. For the double-peaked Ly$\alpha$ subsample,
the measured parameters that are relevant here are the peak-to-peak velocity separation $\Delta V_{\text{tot}}$, and the width (FWHM$_{\text{red}}$) and asymmetry ($\alpha_{\text{red}}$; defined in [6]) of the strongest emission component (i.e., the red peak for our sample). Currently, we do not have measurements of $z_{\text{sys}}$ for these LAEs, so the Ly$\alpha$ velocity zero-point is unknown. However, data compiled from the literature shows that $\Delta V_{\text{tot}}$ scales with the absolute velocity offset of the red Ly$\alpha$ peak $\Delta V_{0,\text{red}}$ (see Fig. 2a), albeit with significant scatter. With this in mind, we find a correlation between $\Delta V_{\text{tot}}$ and 3FWHM$_{\text{red}}$/α$_{\text{red}}$, a parameter defined by [7] that describes the shape of the strongest Ly$\alpha$ emission peak (see Fig. 2b).

According to radiative transfer simulations by [7], LAEs with large $\Delta V_{0,\text{red}}$ (here, $\Delta V_{\text{tot}}$) and large 3FWHM$_{\text{red}}$/α$_{\text{red}}$ have high $N_{\text{HI}}$. Deviations from this correlation can indicate different kinematic/spatial configurations of the H I gas. If the observed relation between 3FWHM$_{\text{red}}$/α$_{\text{red}}$ and $\Delta V_{0,\text{red}}$ is sufficiently tight, it can also be used to predict $z_{\text{sys}}$ based on observations of only Ly$\alpha$. This could be powerful for studies that employ spectral stacking techniques to probe the UV continuum of LAEs. To properly explore this, we plan to obtain $z_{\text{sys}}$ for our sample by observing their non-resonant nebular emission lines (e.g., [O III]λ5007), which may reduce the scatter in Fig. 2b by allowing us to plot $\Delta V_{0,\text{red}}$ directly rather than $\Delta V_{\text{tot}}$.

This work will be featured in a future unabridged publication.

References