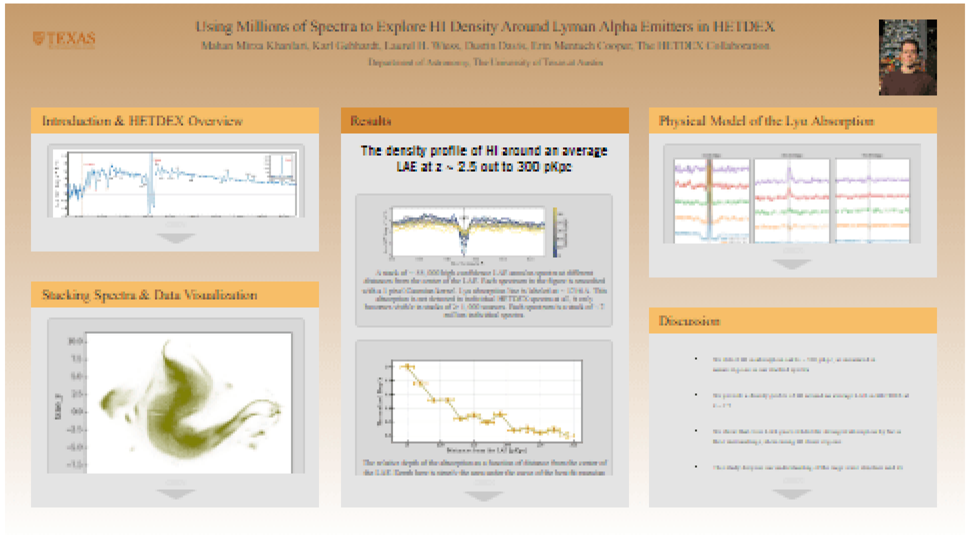
Using Millions of Spectra to Explore HI Density Around Lyman Alpha Emitters in HETDEX



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Department of Astronomy, The University of Texas at Austin

PRESENTED AT:

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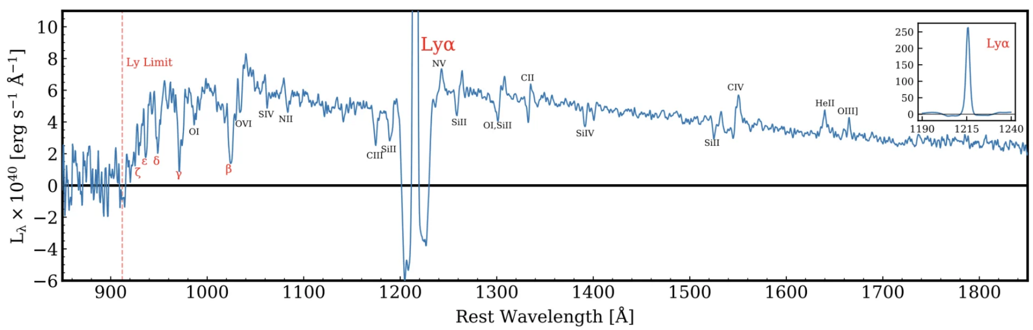
INTRODUCTION & HETDEX OVERVIEW



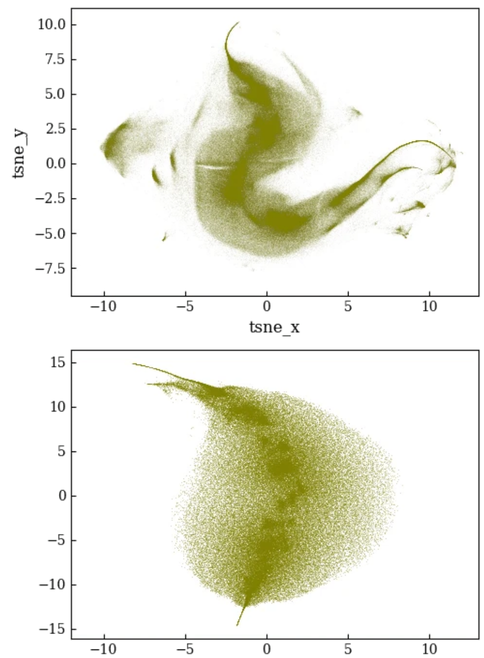
A stack of ~ 50,000 high-confidence LAE spectra from Hobby-Eberly Telescope Dark Energy Experiment (HETDEX), presented in (*Davis et al. 2023b*). While there are real absorption troughs around the Lyα emission, they are significantly exaggerated here due to global assumptions in the sky subtraction model that do not capture peculiarities around Lyα.

- Studying the distribution & kinematics of neutral Hydrogen (HI) gas near key sources like Lyman Alpha Emitters (LAEs) helps us further understand its inflow and outflow around these galaxies and the evolution of large scale structures.

- HETDEX is an un-targeted integral field spectroscopic survey designed to measure the expansion rate of the universe by mapping out 3D positions of ~1 million LAEs at z ~ 1.9-3.5. (*Gebhardt et al. 2021; Mentuch Cooper et al. 2023*)

- Using data from HETDEX, we select LAEs to investigate HI density around & between them using the Lyman Alpha (Lyα) absorption line. This absorption, which is extremeley weak, results from HI scattering Lyα photons from the integrated Extragalactic Background Light (EBL) in our line of sight.

STACKING SPECTRA & DATA VISUALIZATION

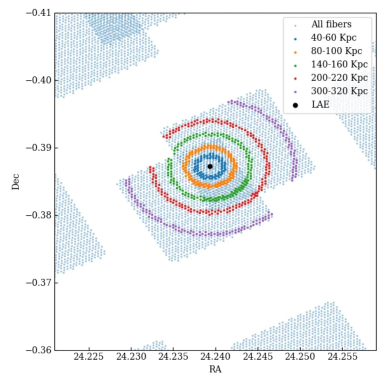


The top plot, representing the latest but unrefined HETDEX data release, is characterized by distinct clumps and patterns. The bottom plot displays our curated LAE dataset, which predominantly forms a single big clump. This contrast suggests that our dataset, post refinement, has effectively minimized the presence of false positives or artifact detections.

- Un-targeted surveys encounter the challenge of false positive and artifact detections frequently. To this end, we design a machine learning pipeline customized for HETDEX, using t-Distributed Stochastic Neighbor Embedding (t-SNE) (*van der Maaten, L., & Hinton, G. 2008*), ensuring a robust selection of LAEs and minimizing false positive (anything that is not a real emission line even if it is a real object).
- Each data point corresponds to a detection in the dataset. Data points with similar features tend to form clumps in the plot

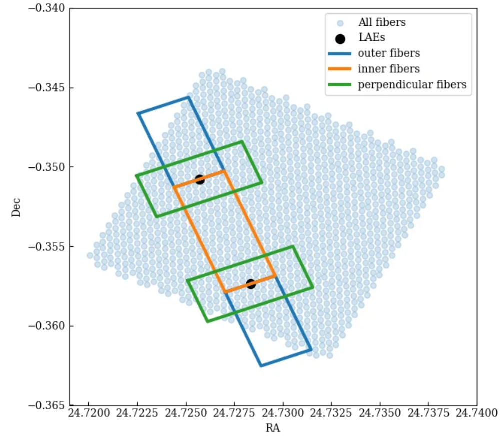
- The absorption that we are looking for is extremely weak and is buried in noise in a single spectrum. To uncover this absorption, we extract millions of fiber spectra and stack them using the ELiXer software (*Davis et al. 2023a*) to boost the signal-to-noise ratio (S/N).
- We extract spectra in two manners: (1) Annuli around the LAE. (2) Regions between LAE pairs.

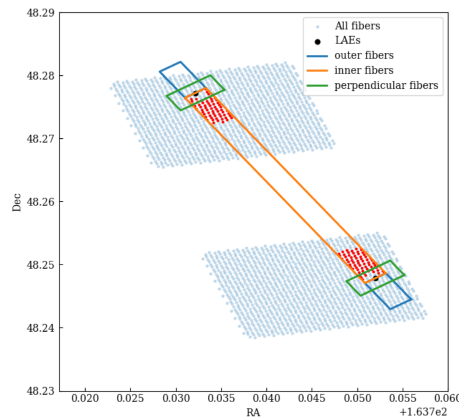
- For annulus around the LAE, extracting starts at the 40 Kpc distance from the LAE center, with spectra extracted in ring shapes of 20 Kpc width as shown below.



An example of extracting fiber spectra in annuli around an LAE. Note that as necessary, we may include fibers from other Integral Field Units (IFUs) in addition to the specific IFU in which our LAE resides. This scenario mostly happens when our LAE resides on the edge of the IFU and we go to large distances from the center.

- When considering the regions between LAE pairs, we classify these pairs into two categories: 'close' pairs, with a separation of up to 1 Mpc, and 'distant' pairs, with 1-2 Mpc.



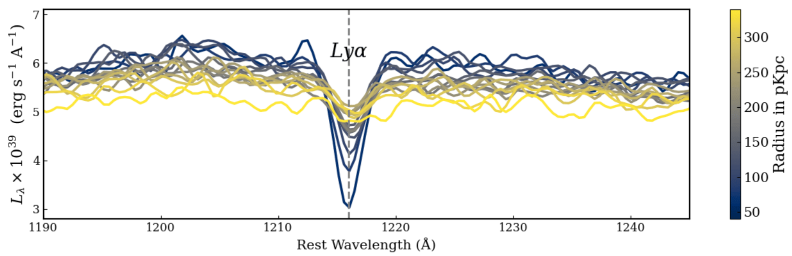


Top plot shows an example of extracting fibers from a close pair, and the bottom plot is an example of a distant pair. Note that in the case of distant pairs, we do not include all the fibers in between the pairs, but only the close fibers to each LAE, which is shown as red fibers. This is due to the fact that we want to limit our comparison to regions near each LAE in our pairs. In both cases, the closest 3.5” fiber spectra to an LAE are not extracted.

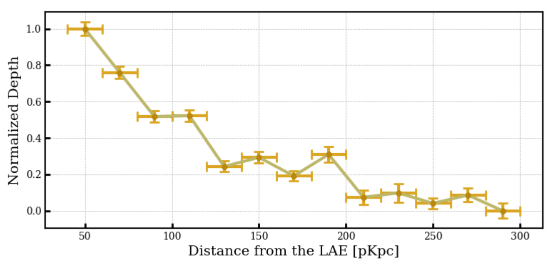
- Categorizing the pairs is mainly based on sky separation, not redshift space. Both types of pairs have a maximum absolute redshift difference of 0.002. The separation criteria for close pairs range from 10” to 36”, and for distant pairs from 80” to 120”. This approach enables an examination of density between pairs as a function of their sky separation.

RESULTS

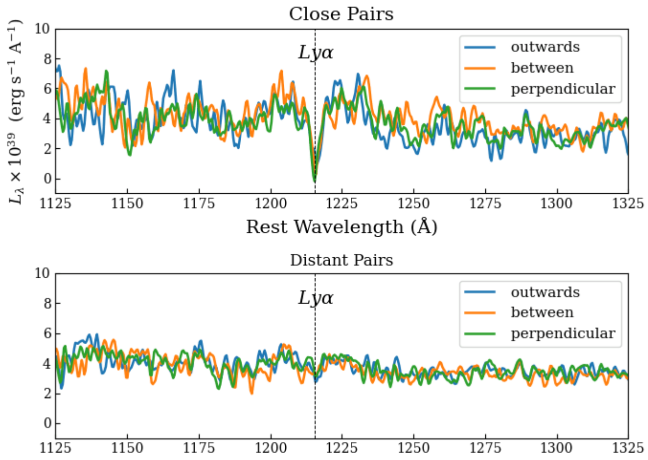
The density profile of HI around a typical LAE at z ~ 2.5 out to 300 Kpc



A stack of ~ 55, 000 high-confidence LAE annulus spectra at different distances from the center of the LAE. Each spectrum in the figure is smoothed with a 1 pixel Gaussian kernel. Lyα absorption line is labeled at ~ 1216 A. This absorption is not detected in individual HETDEX spectra at all, it only becomes visible in stacks of ≥ 1, 000 sources. Each spectrum is a stack of ~ 2 million individual spectra.



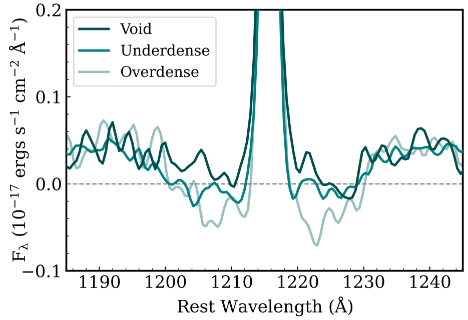
The relative depth of the absorption as a function of distance from the center of the LAE. Depth here is simply the area under the curve of the best fit Gaussian to each absorption line. The error bars are calculated with a Monte Carlo simulation approach.



Comparison of Lyα absorption in the close and distant LAE pairs in three different regions as shown in the previous section. The color of the spectral line matches the color of the rectangles. Each spectrum in the close pairs is a stack of about 200, 000 individual spectra. And each spectrum in the distant pairs is a stack of ~ 350, 000 individual spectra. This is due to the fact that we have more distant pairs in our dataset.

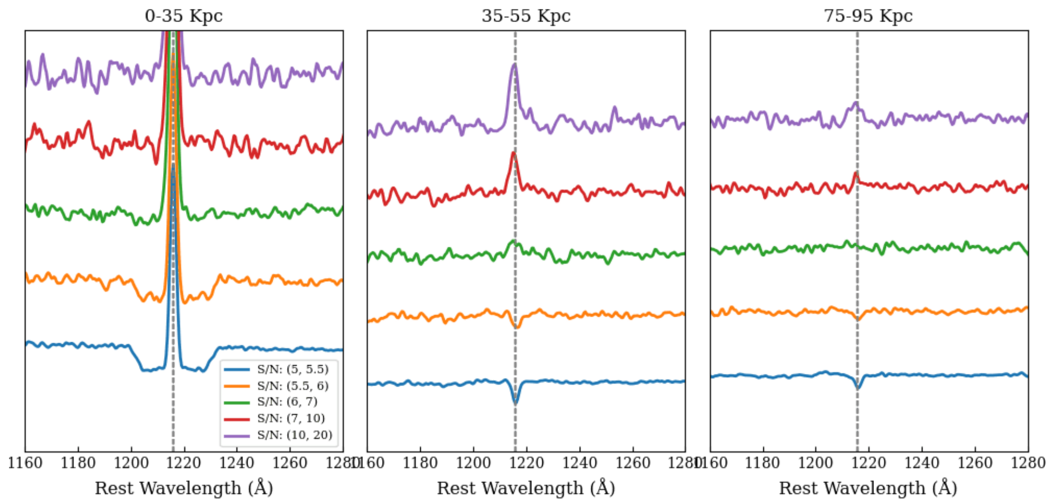
- Due to our assumptions in sky subtraction and background residual correction, we currently cannot give actual column density values. We save reporting those values for later.

PHYSICAL MODEL OF THE LYA ABSORPTION



Stacks of LAEs presented in (*Laurel H. Weiss et al. 2024*) that reside in over, under, and very under-dense fields using the luminosity function normalization as a proxy for density. The troughs are weakest in very under-dense fields and strongest in over-dense fields. The troughs in the over-dense stack are the most negative, despite all three bins having similar continuum levels.

LAEs that exhibit troughs in their aperture region, exhibit absorption in their annuli region.



Stack of LAEs in different S/N bins. The left plot is the stack in the aperture region, and the plot in the middle and the right are stacks of two different annuli regions. As S/N increases, absorption flips to emission in the annuli regions and the troughs vanish around the emission line in the aperture region. Each line is separated by an arbitrary offset.

The idea here is that at different S/N bins, we are probing different environments around the LAEs. In regions of local overdensity, there is more EBL in our line of sight which would cause more variation in the noise level. And because of that, LAEs situated within these overdense regions tend to exhibit relatively lower S/N.

We propose that the observed absorption comes from three main factors: (1) The LAE's presence in a locally overdense region. (2) A higher concentration of Lyα photons and HI in the background compared to the foreground along our line of sight. And (3) The ability of spectral stacking to reach the sensitivity needed to uncover this absorption.

DISCUSSION & NEXT STEPS

- We detect HI in absorption out to ~ 300 pKpc, as measured in annuli regions in our stacked spectra.
- We show that close LAE pairs exhibit the strongest absorption by far in their surroundings, showcasing HI dense regions.

- These results can be used as an empirical radial profile of the HI around LAEs, and also local over and under densities that can be compared to numerical simulations and provide cosmological constraints.
- A more in-depth research on this work has the potential to provide the variation of EBL as a proxy of local density enhancements in large regions of sky, to which HETDEX is uniquely capable.

- An even more ambitious idea is to trace the cosmic web in HI absorption resulting from the EBL, using 1 trillion resolution elements in HETDEX once the survey is completed. This is along the lines of the fantastic work done by (*Martin, D.C., Darvish, B., Lin, Z. et al. 2023*) where they observe an emission Lyman-α forest.

CV

I'm an undergraduate student majoring in Astronomy & Physics and I do research in HETDEX.

My poster session is on Thursday, Jan 11 - 9AM:10AM
I will be available during the session. Please feel free to ask questions during the session
My email is: mahanmkh@utexas.edu

My Website: https://mahanmkh.github.io/ (https://mahanmkh.github.io/)

TRANSCRIPT

ABSTRACT

Studying the properties of the neutral Hydrogen (HI) gas provides key insights into the large-scale structures of the Universe. Leveraging the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) dataset, we examine HI density around Lyman Alpha Emitters (LAEs) spanning $1.9 < z < 3.5$. The Lyman Alpha (Lyα) absorption line serves as our observational tool. This absorption results from HI scattering Lyα photons from the integrated Extragalactic Background Light (EBL) in our line of sight. We stack ~ 2 million spectra from 55000 LAEs, ensuring a strong Signal-to-Noise Ratio (S/N) to uncover this weak absorption that is buried in noise in a single spectrum. We detect absorption out to ~ 300 pKpc around an average LAE at z ~ 2.5, where the absorption weakens as we move away from the LAE center. We also explore HI density between pairs of LAEs with different distances up to ~ 2 pMpc. We find a clear correlation between LAE pair separation and HI density. While the close pairs show the strongest absorption indicating HI dense regions, LAEs with larger separation show minimal to no absorption. The analysis employs a custom machine learning pipeline, refining LAE selection and minimizing false positive. These results can be used as an empirical radial profile of HI in absorption around LAEs, and also local over and under densities that can be compared to numerical simulations. A more in-depth research on this work has the potential to provide the variation of EBL as a proxy of local density enhancements in large regions of sky, to which HETDEX is uniquely capable.

REFERENCES

[1] Karl Gebhardt et al 2021 ApJ 923 217

[2] Erin Mentuch Cooper et al 2023 ApJ 943 177

[3] Dustin Davis et al 2023 ApJ 946 86

[4] Dustin Davis et al 2023 ApJ 954 209

[5] van der Maaten, L., & Hinton, G. 2008, Journal of Machine Learning Research, 9, 2579.

[6] Laurel H. Weiss et al , Absorption Troughs of Lyman Alpha Emitters in HETDEX. Accepted for publication in The Astrophysical Journal. https://arxiv.org/abs/2401.02490 (https://arxiv.org/abs/2401.02490)

[7] Martin, D.C., Darvish, B., Lin, Z. et al. Extensive diffuse Lyman-α emission correlated with cosmic structure. Nat Astron (2023).

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