Marginalize, Don't Subtract: Component Separation for Faint Objects in DESI

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Introduction & Method Overview

- The Dark Energy Spectroscopic Instrument (DESI) is an optical fiber spectrograph that has collected millions of high-quality spectra [1].
- As a ground-based instrument, Earth's atmosphere produces "sky lines", which can be confused with emission lines [2].
- Lyman-Alpha Emitters (LAEs) are galaxies with strong emission in Lyα and are generally metal-poor star-forming galaxies [3].
- We present a robust method for spectral component separation with applications for sky subtraction, spectroscopic redshift determination, and spectral type classification.
- We model an LAE spectrum as a sum of three components:

target spectrum = sky + LAE + residual

where each component is calculated from the total data matrix X_{tot} as:

$$X_i = C_i C_{tot}^{-1} X_{tot}$$

where C_i is a prior covariance matrix for component *i* such that

$$\sum_i X_i = X_{tot} \quad \text{and} \quad \sum_i C_i = C_{tot}$$

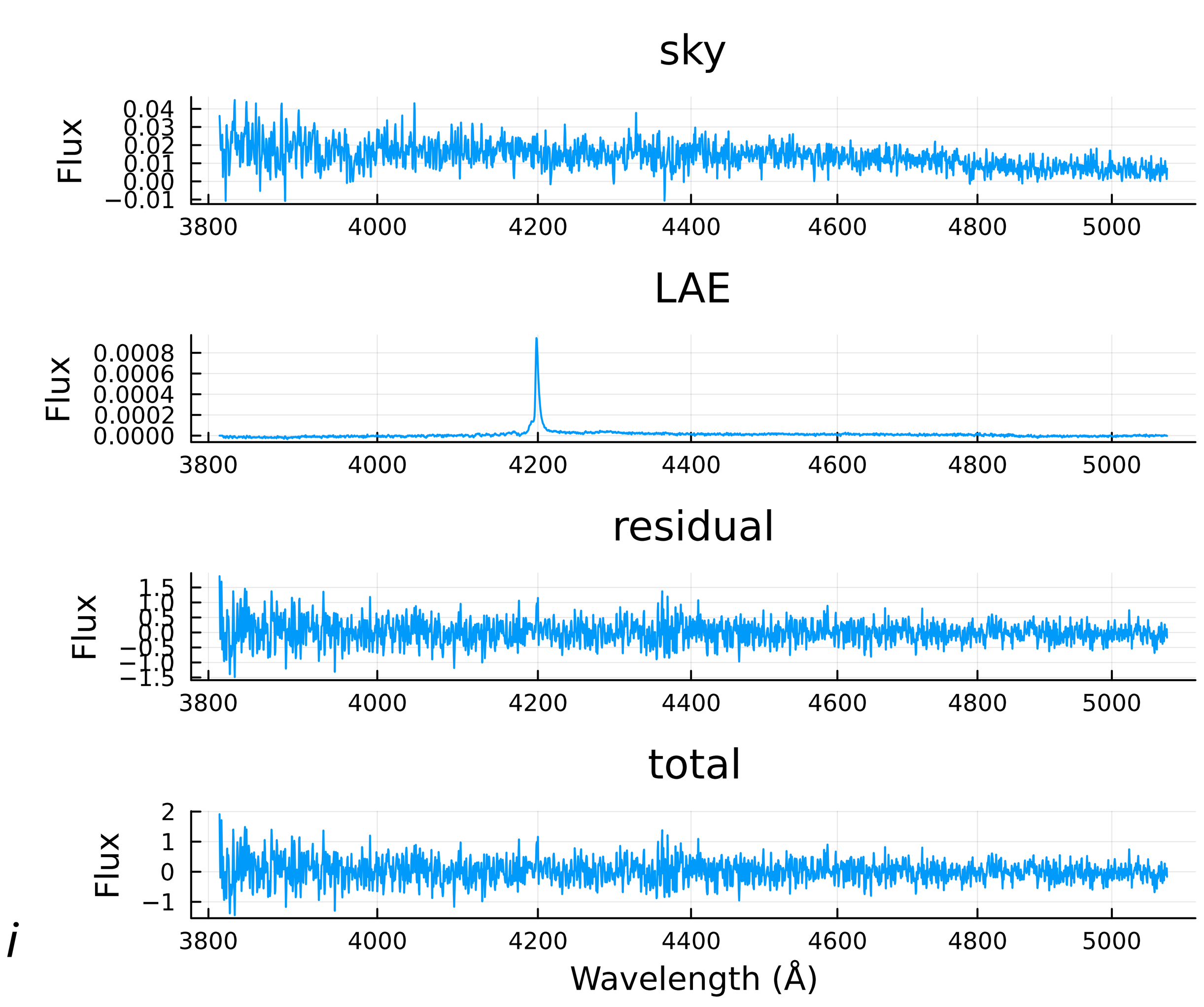

Figure 1: A decomposition of a sample LAE spectrum into sky (top), LAE (second from top), and residual (second from bottom) components, which sum to the original spectrum (bottom).

Applications to LAEs

- We use sky line residuals from DESI to create a prior covariance for sky lines and visually inspected (VI) LAE candidate spectra to create an LAE prior covariance matrix.
- We scan over a fine grid of redshifts and seek to optimize $|\Delta\chi^2|$ to determine the optimal redshift for each spectrum.
- To combine over multiple exposures of the same target, we find the redshift that optimizes the sum of the $|\Delta\chi^2|$ surfaces for each exposure.
- We also examine the variance in redshift estimate as a function of number of exposures.

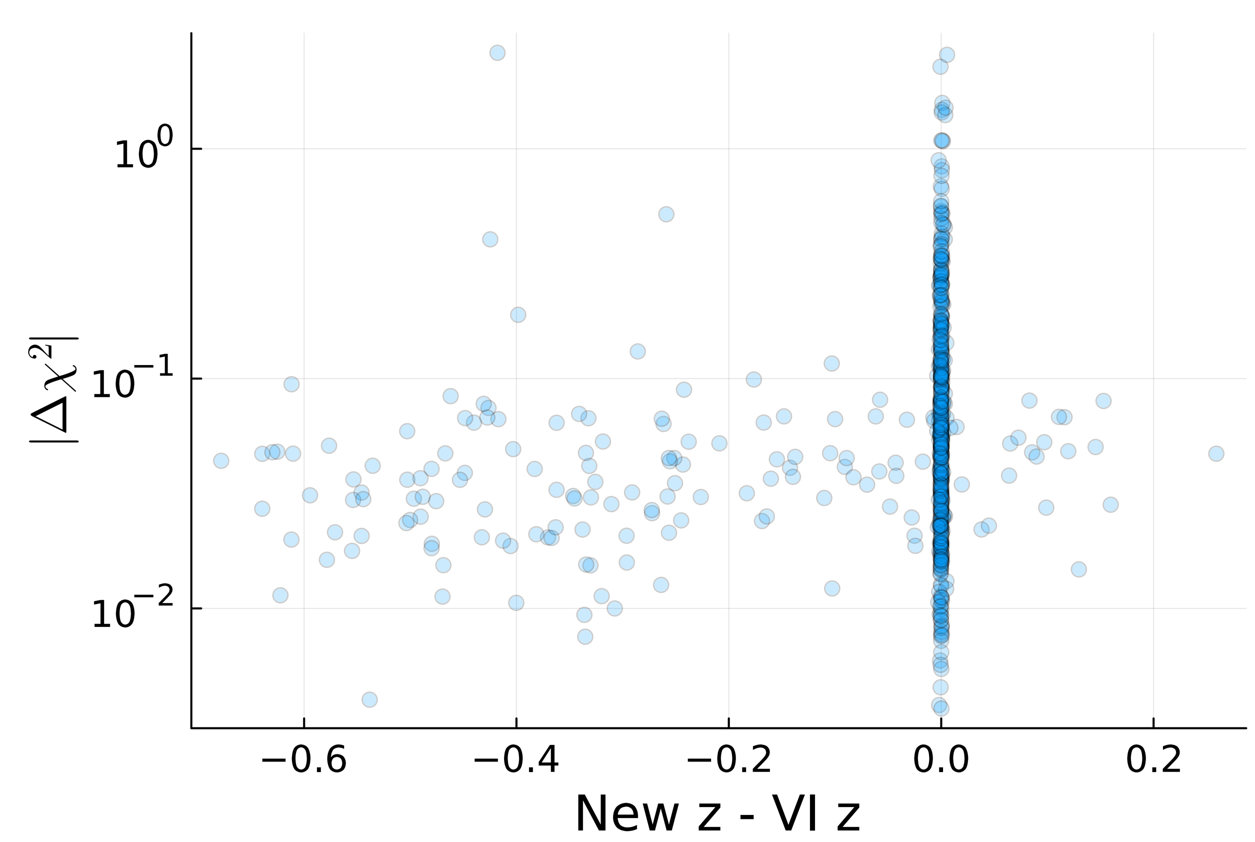

Figure 2: $|\Delta\chi^2|$ vs. redshift residual (VI redshift – this work) for visually inspected DESI LAE candidate spectra. Here the sum of $|\Delta\chi^2|$ surfaces for all exposures for each target is maximized.

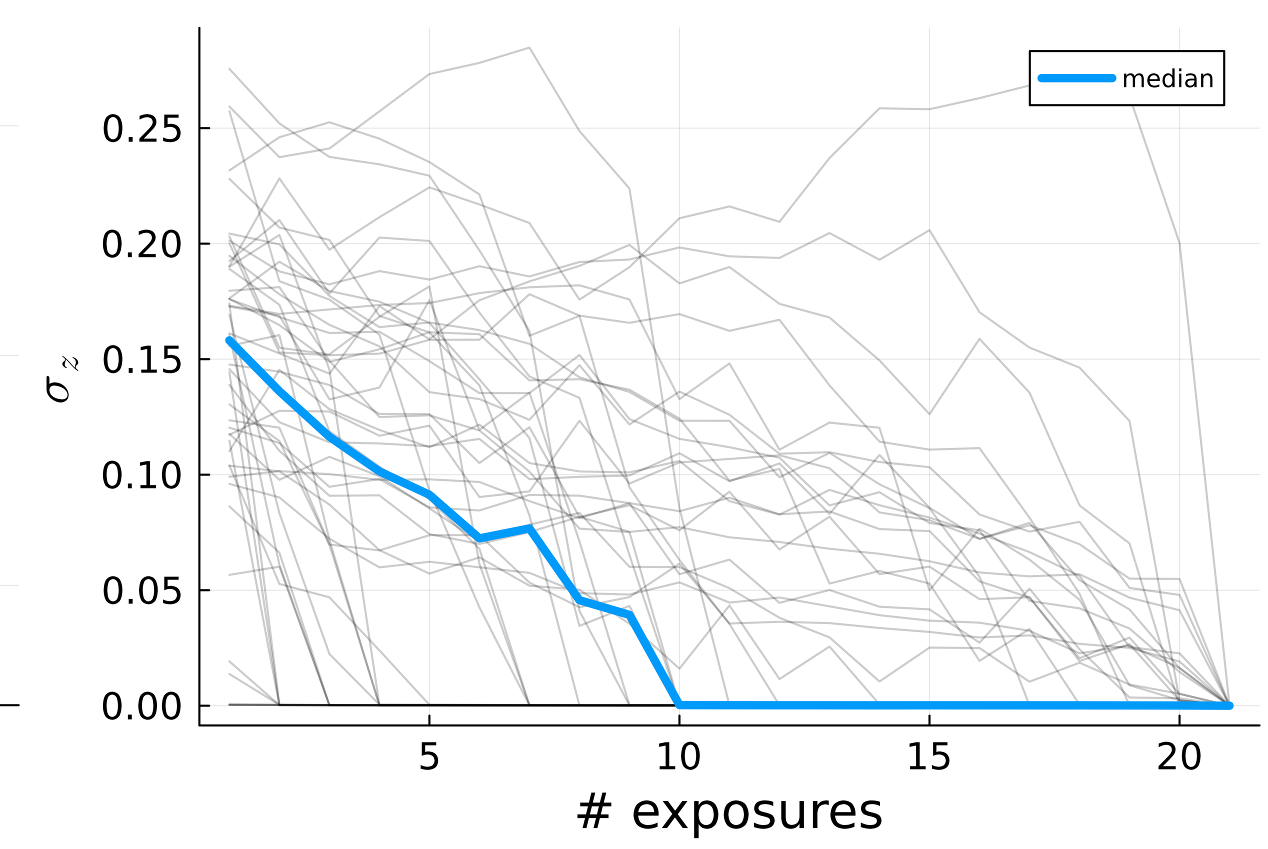

Figure 3: Standard deviation of redshift estimates obtained by bootstrapping 100 datasets of $|\Delta\chi^2|$ surfaces with varying numbers of exposures. Here each gray line denotes one target, while the blue line denotes the median.

Validation

- We perform injection-recovery tests to validate our automated spectroscopic determination method.
- We inject the first eigenvector of our LAE prior covariance matrix at a known redshift and add constant noise to simulate an observed LAE spectrum.
- Our method determines redshift to within 0.01 of the injected redshift nearly always for SNR > 10, which is especially promising in anticipation of new LAE targets for DESI-II.

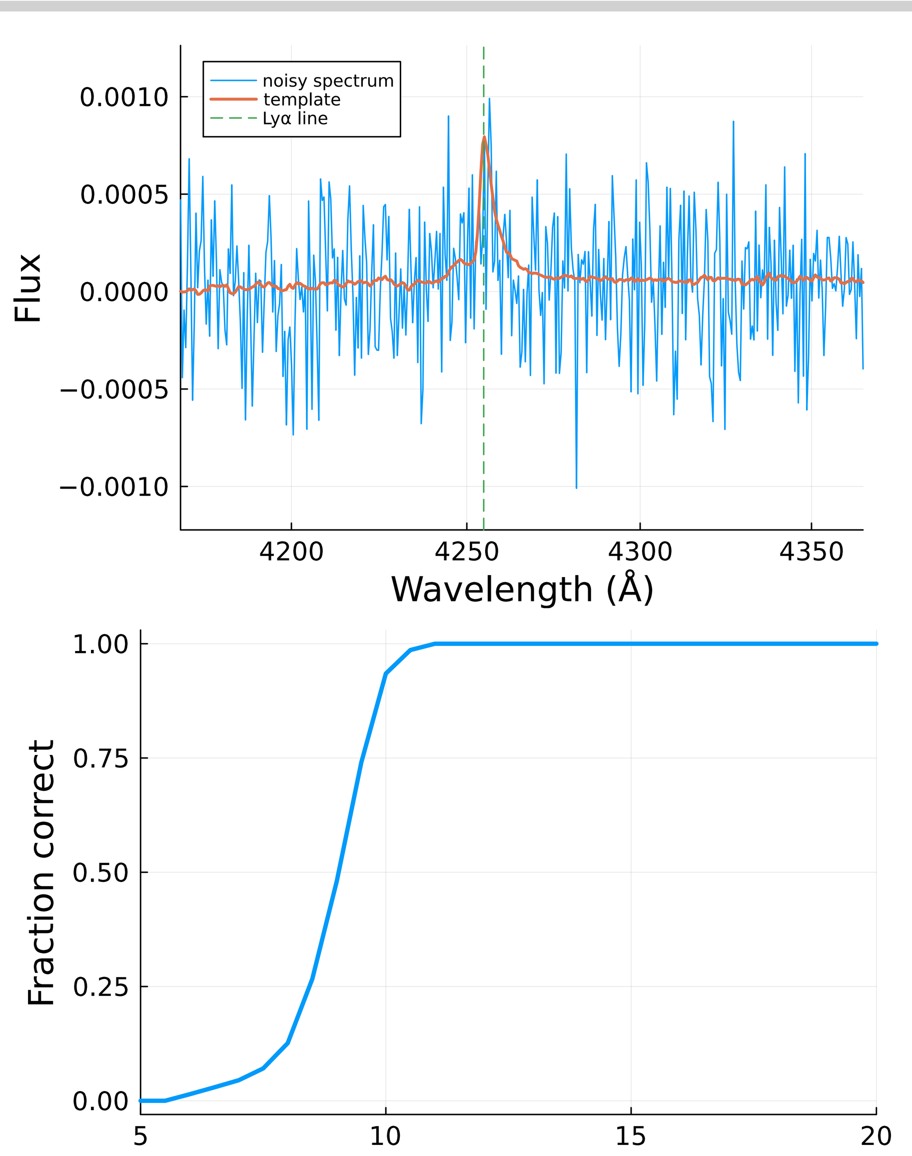

Figure 4: (top) An example simulated LAE spectrum with SNR = 10. (bottom) Fraction correctly recovered redshift as a function of SNR for 10,000 simulated spectra.

Future Work

- Our method is also applicable to spectral type classification, which can be done by comparing $|\Delta\chi^2|$ values using different models.
- Further validation with more realistic spectra that include sky lines, and robust redshift uncertainty quantification is forthcoming.

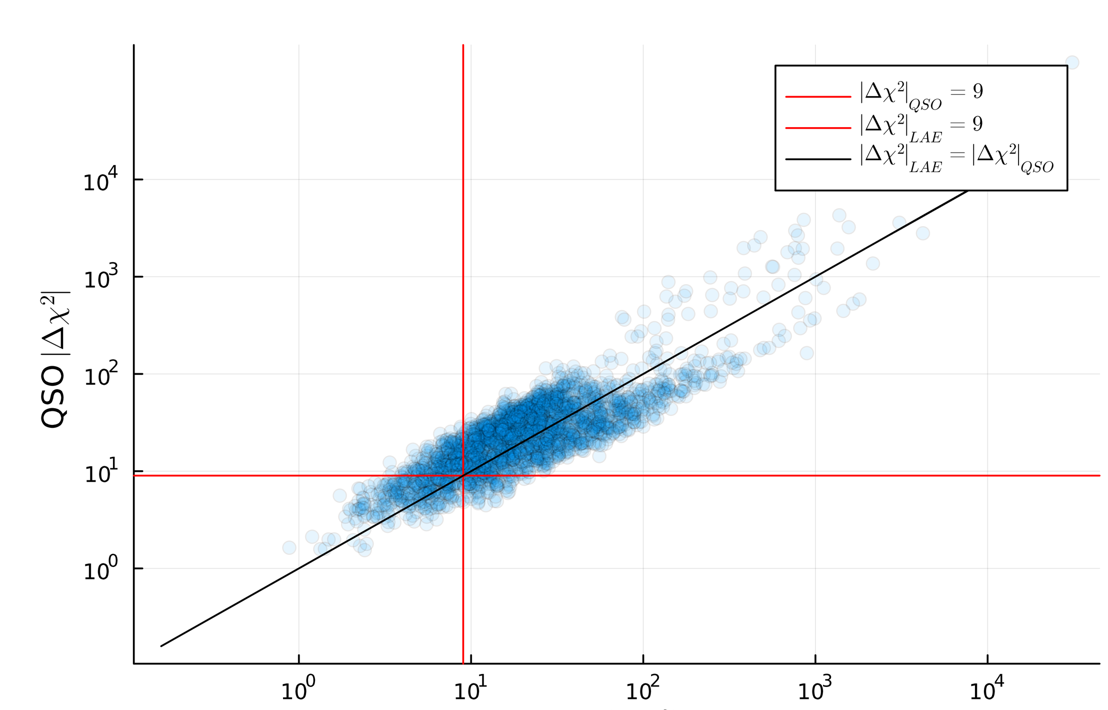

Figure 5: $|\Delta\chi^2|$ from modeling the VI spectra as either LAEs (x axis) or QSOs (y axis). Red lines denote a potential cutoff value for both classes, and black line denotes equal $|\Delta\chi^2|$ values.

[1] DESI Collaboration et al. The DESI Experiment Part I: Science,Targeting, and Survey Design. arXiv e-prints, page arXiv:1611.00036, October 2016.
[2] Stephen Bailey et al. 2024, in prep.
[3] Masami Ouchi, Yoshiaki Ono, and Takatoshi Shibuya. Observations of the Lyman-α Universe. ARA&A, 58:617–659, August 2020.
[4] Andrew K. Saydjari, Ana Sofia M. Uzsoy, Catherine Zucker, J. E. G. Peek, and Douglas P. Finkbeiner. Measuring the 8621 A Diffuse Interstellar Band in Gaia DR3 RVS Spectra: Obtaining a Clean Catalog by Marginalizing over Stellar Types. The Astrophysical Journal, 954(2):141, September 2023.