1D Lyman-alpha forest power spectrum from DESI early data

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• A **quasar** is a very bright, distant and active supermassive black hole.

• The **neutral hydrogen** scatters the light emitted from quasars, which forms absorption lines.
Power spectrum quantifies the amplitude of density fluctuations. The model (black line) agrees with the data, which spans ~10 Gyr in time and 3 decades in scale.

- T_CMB: 370k years
- T_Lya: 1.5 -- 3 Gyr
- T_Galaxy: > 10 Gyr

Lya forest is sensitive to small scales.
Warm dark matter

Villasenor et al. 2023

\[ m_{\text{WDM}} > 3.1 \text{ keV} \]

- \(4.2 < z < 5.2\) from 15 quasars
The sum of the neutrino masses

\[ \sum m_\nu < 0.12 \text{ eV} \quad (\text{BOSS + CMB}) \]

Palanque-Delabrouille et al. 2015

Minimum mass
- Normal hierarchy: 0.057 eV
- Inverted hierarchy: 0.097 eV

DESI Forecast:
\[ \sigma \sum m_\nu = 0.02 \text{ eV} \]

Science, Targeting, and Survey Design:
DESI Early Data*

Data

- Survey validation spectra
  + 2 months of “main” survey (normal operations)

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1% Survey (SV3)</td>
<td>7,173</td>
</tr>
<tr>
<td>Main (Guadalupe)</td>
<td>47,427</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>54,600</strong></td>
</tr>
</tbody>
</table>

Paper outline

- Method – Optimal quadratic estimator
- Validation – Tests on 1D and 2D simulations
- Systematics
- Results

Karaçaylı et al. 2023, arXiv:2306.06316
DESI Iron TARGETID: 39628488927348682

![Graph showing flux vs observed wavelength with labeled features such as Lyα forest, Lyβ, N V, Si IV, C IV, SB 1, and SB 2.](image)
Comparison with eBOSS, FFT

Good agreement with the FFT result, which is on similar data and a different analysis pipeline!

Karaçaylı et al. 2023, arXiv:2306.06316
Two DESI challenges

1. Signal is buried under noise. Accuracy of noise calibration is crucial.

2. Spectrograph resolution is comparable to thermal broadening.
Recalibrate pipeline noise estimate

Noise calibration correction

SNR dependence of this correction

Karaçaylı et al. 2023, arXiv:2306.06316
Effects on parameters (The bad)

<table>
<thead>
<tr>
<th>Systematics</th>
<th>Increase in error</th>
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<tbody>
<tr>
<td></td>
<td>$A$</td>
</tr>
<tr>
<td>Noise</td>
<td>49.8%</td>
</tr>
<tr>
<td>Resolution</td>
<td>34.0%</td>
</tr>
<tr>
<td>DLA</td>
<td>0.9%</td>
</tr>
<tr>
<td>All</td>
<td>74.3%</td>
</tr>
</tbody>
</table>

Table 2. Percentage increase in error given by the minimizer for each systematics at $z = 2.8$. The precision of the amplitude $A$ is nearly equally affected by noise and resolution systematics, whereas for $n$, it is thoroughly affected by resolution systematics.

$$P_{\text{base}}(k) = \frac{A \pi}{k_0} \left( \frac{k}{k_0} \right)^{2+n+\alpha \ln k/k_0}$$

Karaçaylı et al. 2023, arXiv:2306.06316
Next stage

54,600 quasars -> 450,000 Lya quasars!

- More work into systematics

We identified possible solutions to noise and resolution systematics.

Other projects for Y1:
- CMB lensing x P1D
- Repeat metal model analysis
Noise calibration SNR dependence

\[ \sigma^2(\lambda_p) = \eta(\lambda_p)\sigma^2_{\text{pipe}}(\lambda_p) + \sigma^2_{\text{LSS}}(\lambda_p) \]

- \( \sim 1 \) million quasars in Y1 for \( \eta \) analysis
- Quantify \( \eta \) in multiple SNR bins
  \[ \eta = \eta(\lambda, \text{SNR}) \]
- Spectrograph splits
The ugly
Summary

• DESI will have the statistical power to tightly constrain the sum of the neutrino masses.

\[ \sigma\sum m_\nu = 0.02 \text{ eV} \]

• P1D from DESI EDR+ (54,600 quasars).

• We identified the major systematics error sources, noise and resolution. The systematics are comparable to statistical errors.

• There is a plan to reduce these errors.
We are honored to be permitted to conduct scientific research on Iolkam Du’ag (Kitt Peak) in Arizona, a mountain with particular significance to the Tohono O’odham Nation.

Thanks to our sponsors and 69 Participating Institutions!

Naim Karacayli
• DESI will have the statistical power to tightly constrain the sum of the neutrino masses.

\[ \sigma_{\Sigma m_\nu} = 0.02 \text{ eV} \]

• But we need to control the systematics on the measurement to realize that goal.

• Noise calibration errors, resolution correction errors...