Measuring the cosmic expansion rate at high redshift with DESI Lyman-\(\alpha\) forests

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The Lyman-α forest
DESI is creating a 3D Map of the Universe

- 2.7 million Quasi Stellar Objects (QSO)
- 13 million ELGs (Emission Line Galaxies, z < 1.8)
- 7.5 million LRGs (Luminous Red Galaxies, z < 1 (LRG))
- 9 million brightest galaxies (z < 0.4)

x10 larger dataset than the state-of-the-art (SDSS)
Expansion and growth rate measurements from SDSS

Figure from Alam et al. 2021 (2007.08991)
Expansion rate measurements with DESI

Based on Alam et al. 2021 (2007.08991) and DESI Collaboration et al. 2016 (1611.00036)
First measurements from DESI

Featured on Nature’s Best Science Images of June 2023

Video credit: David Kirkby / DESI collaboration
First measurements from DESI

[Image: DESI spectrum of Quasar at redshift $z = 2.495$]

Figure from Ramírez-Pérez et al. 2023 (2306.06312)
Lyman-α forest correlations

Lyα forest auto-correlation function

Figure from de Sainte Agathe et al. 2019 (1904.03400)
Compressing into wedges
First measurements from DESI

Lyα × Lyα

Lyα × QSO

Figures from Gordon, Cuceu, et al. 2023 (2308.10950)
Cosmology from the 3D Lyman-α forest

Expansion history:
- BAO: circular feature at \( \sim 100 \) Mpc/h
- Alcock-Paczyński effect: Produces distinct anisotropy in the correlation function

Growth rate of structure:
- RSD: Main anisotropy present in the correlation functions
Cosmology from DESI Lyα forests

Forecast of DESI expansion history constraints

- DESI results from Survey Validation are out
- Currently working on analysing the first year of DESI data
- First cosmological measurements expected in 2024

Forecasts based on DESI Collaboration et al. (2016) and Cuceu et al. (2021), MNRAS, 506, 4, 2021
Measuring the Hubble constant

- In flat $\Lambda$CDM, Alcock-Paczynski $\rightarrow \Omega_m$
- Adding isotropic BAO $\rightarrow H_0 r_d$
- Adding a prior on $\Omega_b h^2$ from Big Bang Nucleosynthesis (BBN) $\rightarrow H_0$
- Ly$\alpha$ constraint: $H_0 = 63.2 \pm 2.5$ km/s/Mpc
- Full eBOSS: $H_0 = 67.2 \pm 0.9$ km/s/Mpc

From Cuceu et al. (2023b), PRL 130, 191003, 2023
Measuring dark energy

Measuring dark energy with free curvature

From Cuceu et al. (2023b), PRL 130, 191003, 2023
Optimal compression for Lyα forest analyses

Stack of 100 eBOSS mocks

Real eBOSS data

From Gerardi, Cuceu et al. 2023 (2309.13164)
Optimal compression for Lyα forest analyses

- Compress data to a smaller subset of parameters that do not capture all effects present
- Bestfit $\chi^2$ is identical!
- Instead, this shows up as a bias in measured parameters

From Gerardi, Cuceu et al. 2023 (2309.13164)
Thanks to our sponsors and 69 Participating Institutions!
Rescaling the peak component

Cuceu et al. (2021), MNRAS 506, 4, 2021
Rescaling the smooth component

Cuceu et al. (2021), MNRAS 506, 4, 2021
Why no Lyα RSD measurement yet?

- Linear theory terms:
  
  Lyα x Lyα: \[ P(k, \mu, z) = \left( b_F + b_{\eta,F} f \mu^2 \right)^2 P(k, z) \]
  
  Lyα x QSO: \[ P(k, \mu, z) = \left( b_F + b_{\eta,F} f \mu^2 \right) \left( b_Q + f \mu^2 \right) P(k, z) \]
  
  QSO x QSO: \[ P(k, \mu, z) = \left( b_Q + f \mu^2 \right)^2 P(k, z) \]

- Lyα forest growth rate (\( f \)) degenerate with unknown velocity divergence bias (\( b_{\eta,F} \)).

- Joint analysis of Lyα x Lyα and Lyα x QSO would be able to measure \( f \).

High-z 3×2pt

- Lyα x Lyα
- Lyα x QSO
- QSO x QSO
Cosmology from DESI Lyα forests

Forecast of growth rate constraints

Forecasts based on DESI Collaboration et al. (2016) and Cuceu et al. (2021), MNRAS, 506, 4, 2021
Lyα auto-correlation function compressed into a shell in isotropic separation $r$, and shown as a function of the line-of-sight angle $\mu$. 

Changing Alcock-Paczyński

25 < $r$ < 45 [Mpc/h]

Changing RSD

25 < $r$ < 45 [Mpc/h]
From Cuceu et al. (2023b), PRL 130, 191003, 2023