From Lyman-α to Cosmology

Cross-Collserola Meeting, 6th October 23

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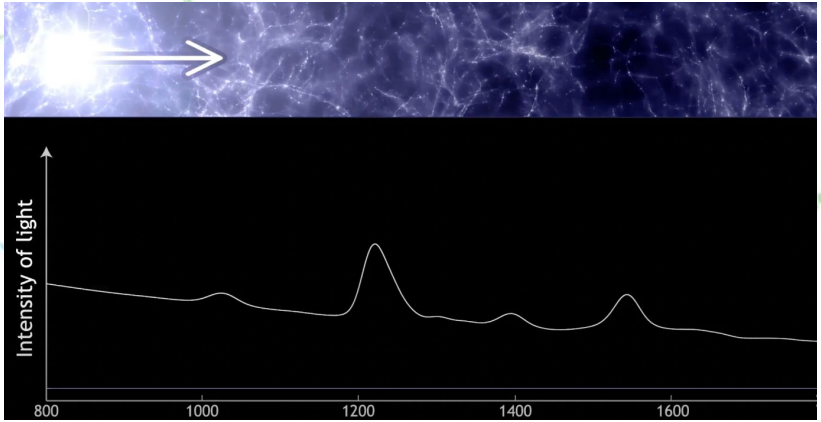
Institut de Física d'Altes Energies

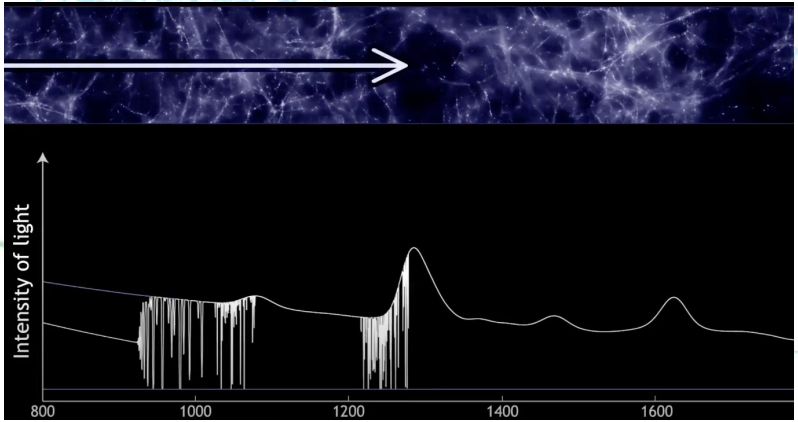
DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

The Lyman-alpha (Lyα) forest

- A region of strong absorption bluewards of the Lyα emission line, observed in distant quasar spectra.
- As the quasar spectrum is redshifted, light blue-wards of the Lyα emission line reaches the lyα wavelength (1215A).
- At this wavelength it can be absorbed by neutral hydrogen in the IGM.
- We can use this “forest” of absorption lines to perform clustering analyses, as it traces the HI density fluctuations.





Mapping fluctuations

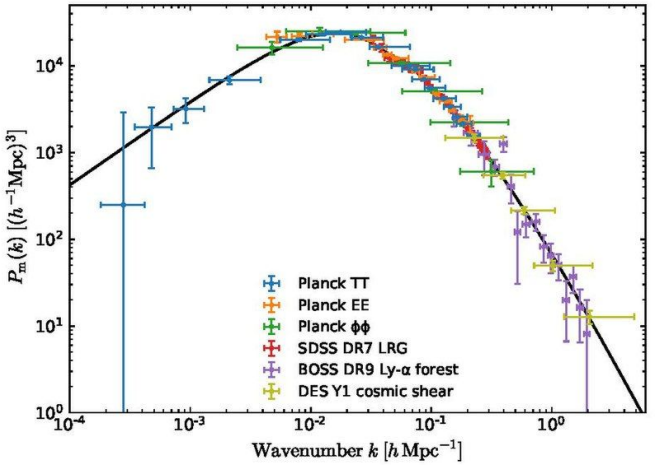
- The Lyα forest density fluctuations can be measured across a range of scales

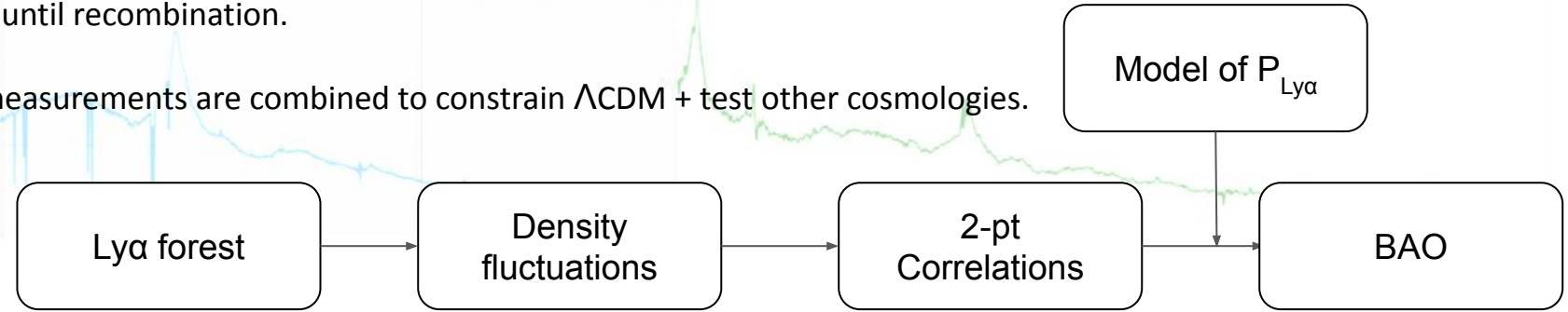
- Small scale measurements at ~0.1-10Mpc/h
  → Strongly dependent on Intergalactic Medium (IGM) properties.
  → Notably neutrino mass
  → Highly non-linear.

- Larger scale measurements at 10-200Mpc/h
  → Little to no dependence on IGM
  → Linear modelling with some NL corrections

- I work mostly on a large-scale observable called Baryon Acoustic Oscillations (BAO) - a standard "ruler" used to compare distance measurements from the present until recombination.

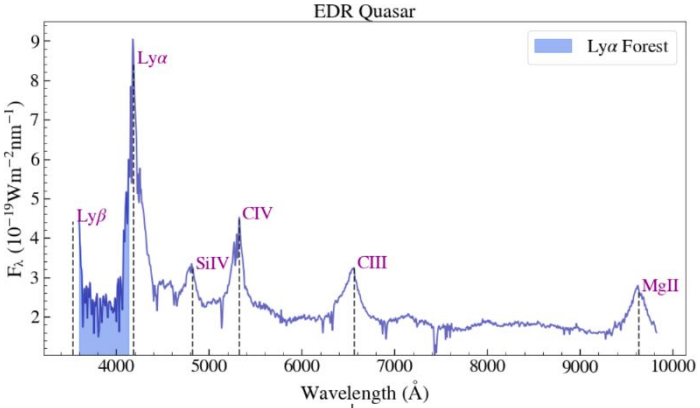
- These measurements are combined to constrain ΛCDM + test other cosmologies.



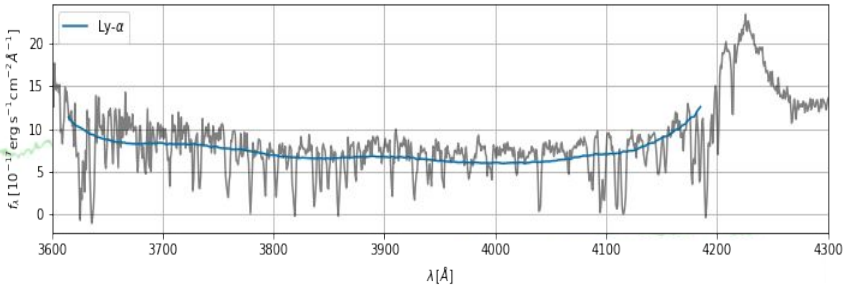


Lyα as a tracer

- We use the 2-point correlation function to get cosmology from the Lyα forest, specifically $\xi(x) = \langle \delta(x_1)\delta(x_2) \rangle$
- How do we define “density contrast” in Lyα? → flux transmission fraction: $\delta_F = F/\overline{F} - 1$.
- At large enough scales, this linearly traces the matter power spectrum $\delta(x) = \rho(x)/\overline{\rho} - 1$
- This relationship between δ_m and δ_F at small scales becomes non-linear due to IGM physics.
- F is the ratio f(λ)/C(λ), where we fit for C in each quasar.
- To do any of this we need a large sample of good resolution spectra…

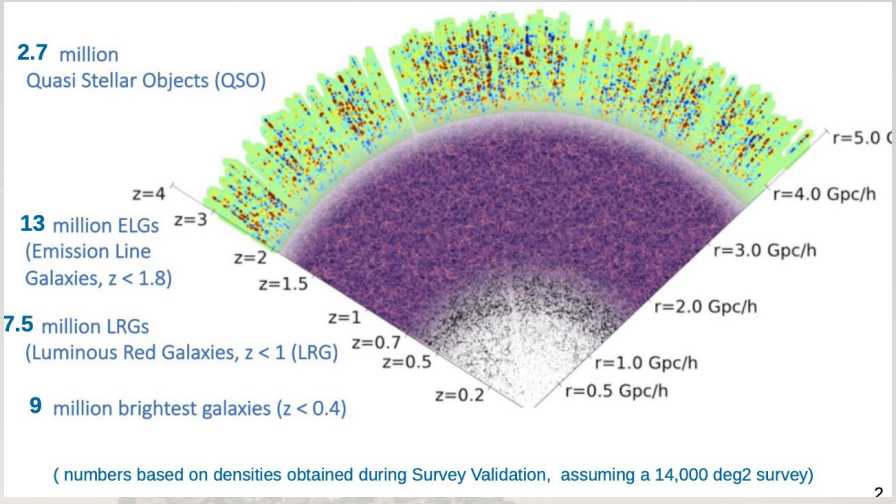


QSO Continuum fitting



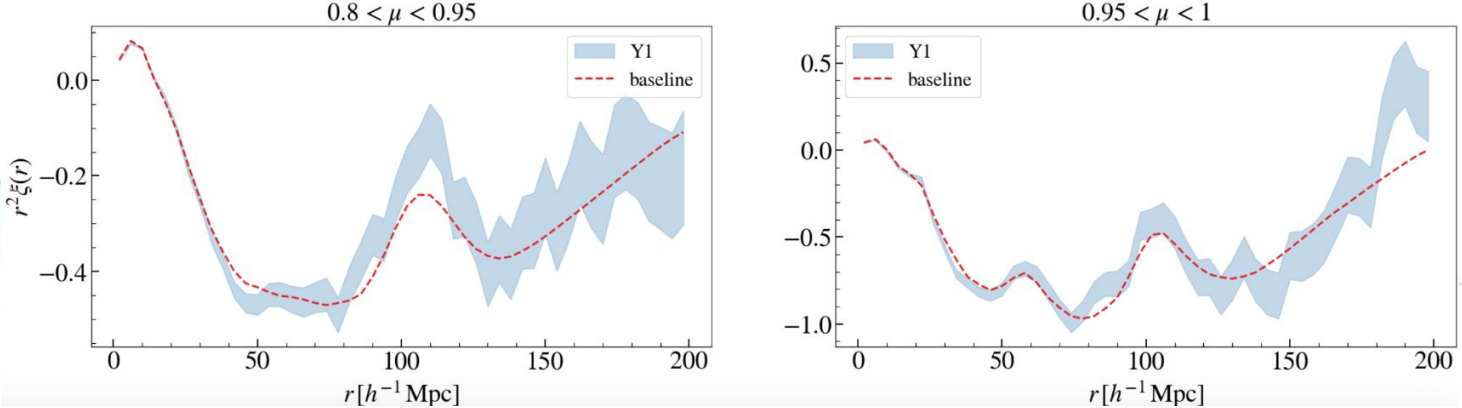
The Dark Energy Spectroscopic Instrument (DESI)

- 5-year survey based at Kitt Peak, Arizona.
- Spectra from more than 30m targets including ~2.5m (0.7m Lya) quasars -> 3x improvement on eBOSS.
- 14000 sq deg footprint, using imaging from DESI Legacy Surveys (DECaLS, BASS, MzLS)
- The instrument has 5000 fibers with robotic positioners, covering a wavelength range 360-980nm.
- Resolution of 0.8Å (0.08nm)



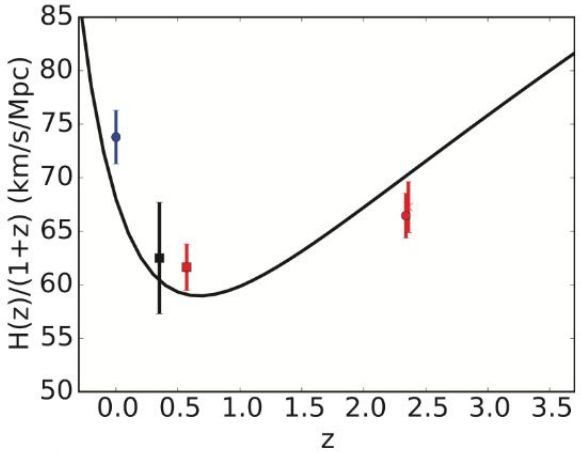
Lyα as a tracer

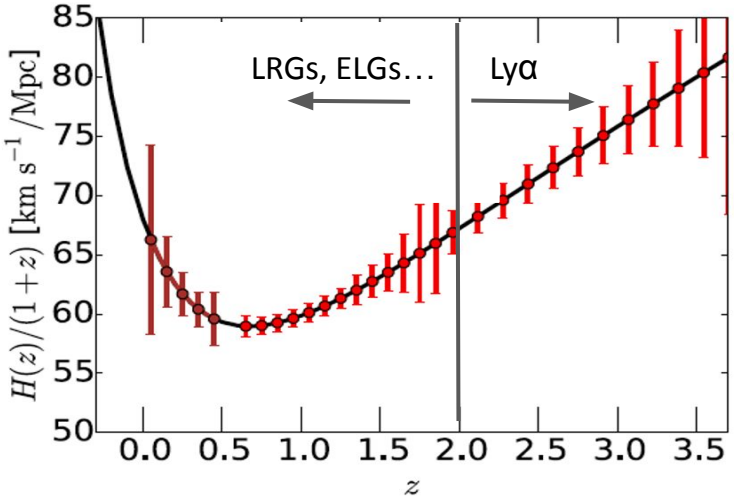
- We convert angular separation and redshift of each Lyα pixel into co-moving coordinates along ($r_{\parallel}$) and across ($r_{\perp}$) the line o sight.
- We then measure the auto-correlation of these pixels and their cross-correlation with quasars.
- The resulting plots below show the 3D correlation is "wedges" of $\mu = r_{\parallel}/r$.
- These are from the upcoming DESI Y1 measurement, using 450,000 quasars!
- The BAO peak is clearly seen at r ~ 100Mpc/h
- The data is fit with a 15-parameter model based on linear perturbation theory.



Projections :(

- Sadly I'm not allowed to show actual results, BAO or cosmological constraints…
- But I can show projections!
- The bottom panel shows expansion rate (specifically proper velocity) as a function of redshift.
- The left of the black line are constraints from DESI galaxy BAO, and to the right from the Lyα forest.
- The top panel shows the current benchmark (SDSS eBOSS).





Summary (lunch-time)

- The Lyman-α forest refers to a series of absorption spectra in distant quasars.
- It is a powerful tool for constraining small- and large-scale cosmology
- We can measure the BAO peak from 3D correlations of Lyman-α flux transmission field.
- DESI will use Lyα measurements to provide some of the tightest constraints on dark energy, neutrino mass and more…
- The year 1 data release is expected at the beginning of next year.

3D correlations in the Lyman-α Forest from Early DESI Data

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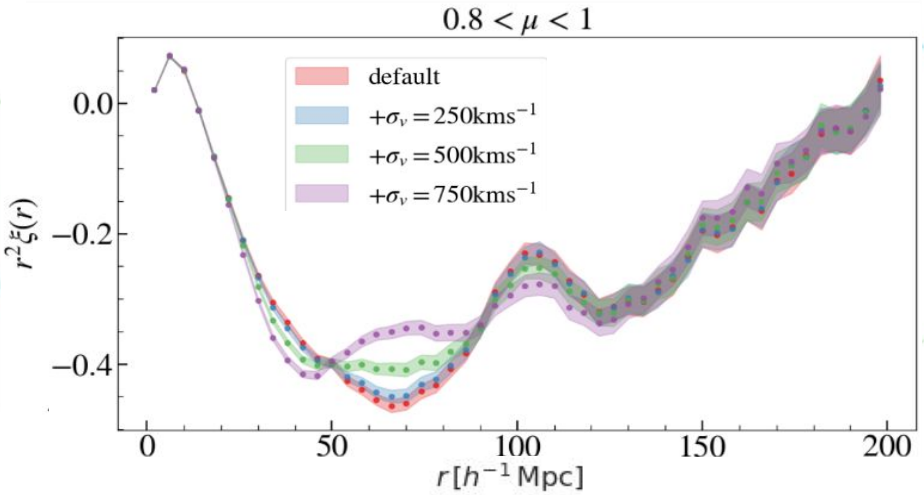
Abstract. In this work we present the first measurements of correlations in the Lyman-α (Lyα) forest dataset from the Dark Energy Spectroscopic Instrument (DESI) survey. We measure the auto-correlation of Lyα absorption features from early DESI data, which contains 88 509 Lyα forests, and their cross-correlation with 147 899 DESI quasars above z$\sim$1.77. Then, we fit these correlations using a 13-parameter model based on linear perturbation theory, finding that it provides a good description of the data across a broad range of scales. We find that our measurements of the auto- and cross-correlations are fully-consistent with previous measurements by the Extended Baryon Oscillation Spectroscopic Survey (eBOSS). Even though we only use here a small fraction of the final DESI dataset, the errorbars in our measurements are only a factor of two larger than those from the final eBOSS measurement, and we detect the BAO peak with a signal-to-noise ratio of 3.7σ. In this work we demonstrate the quality of DESI data and validate the existing analysis methods of Lyα correlations, in preparation for making a robust measurement of the BAO scale with the first year of DESI data.

Modelling systematics

- A large part of my recent work has been concerned with properly modelling contaminants of our BAO measurements.
- One (small) example of this is the effect of quasar redshift errors.
- The plot below shows the effect of adding realistic (blue) to extreme (purple) Gaussian errors to simulations.



Baryon Acoustic Oscillations (BAO)

- Oscillations in the pre-recombination universe propagated until re-combination.
- They imprinted a peak in the matter power spectrum at the “sound horizon” scale - well measured in the CMB to be r_d ~150Mpc.
- Measuring this scale now compared to recombination tells us about the expansion and contents of the universe.
- This was first measured in galaxies, and then at even higher redshifts with the Lyα forest.