High redshift BAO from BOSS and eBOSS

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Questions I want to address

- How did we measure BAO using Lyman-alpha forests in BOSS?
- What are the resulting constraints on cosmological models?
- How are we going to improve those constraints using Emission Line Galaxies (ELGs) in eBOSS?
BOSS maps the Universe to observe the BAO

- The Baryon Oscillation Spectroscopic Survey (BOSS) has acquired:
  - 1.5M galaxies (0.15< z <0.7)
  - 160k quasars (2.1< z <4.5)
BAO are observed statistically in the correlation function of galaxies.
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\[ r^2 \xi(r) \]

\[ r(h^{-1}\text{Mpc}) \]

Anderson et al. (2014)

- Correlation function at \( z = 0.57 \)
  obtained using 690,000 galaxies over 8500 deg\(^2\).
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- Observed transversally to the line of sight, it constrains an angle:

\[ \theta = \frac{r_s}{(1 + z) D_A(z)} \]
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\[ \theta = \frac{r_s}{(1 + z) \bar{D}_A(z)} \]

Depend on the parameters of your model
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- Observed along the line of sight, it constrains a difference in redshift:

\[ \Delta z = \frac{r_s H(z)}{c} \]
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Depends on the parameters of your model
Quasars can be observed at much higher redshift than galaxies
The light of quasars is absorbed during its travel toward us.

- Quasars are used as background light sources.
- Neutral hydrogen creates absorption lines in their spectra.
High z quasar spectra tell us about the HI density along their line of sight.
High $z$ quasar spectra tell us about the HI density along their line of sight.
High z quasar spectra tell us about the H\textsubscript{I} density along their line of sight.

\[ (1 + z_{\text{abs}}) \lambda_{\text{Ly} \alpha} \quad \text{Flux} \quad (1 + z_{\text{qso}}) \lambda_{\text{Ly} \alpha} \]

\[ \text{Å} \]
High $z$ quasar spectra tell us about the HI density along their line of sight.

\[ (1 + z_{abs}) \lambda_{Ly\alpha} \]

\[ (1 + z_{qso}) \lambda_{Ly\alpha} \]

\[ \text{Ly}\alpha - \text{forest} \]
High $z$ quasar spectra tell us about the $\text{HI}$ density along their line of sight

- Transmitted flux fraction:
  \[
  F(\lambda_{\text{obs}}) = \frac{\text{Flux}}{\text{Continuum}} = e^{-\tau}
  \]

- Optical depth:
  \[
  \tau(\lambda_{\text{obs}}) \propto n_{\text{HI}}(z_{\text{abs}})
  \]
Compute the correlation function of the Lyman-alpha forest

- Define a delta field:
\[
\delta_f(\lambda_{rq}, \lambda_{obs}) = \frac{f(\lambda_{obs})}{\text{Cont}(\lambda_{rq}) \bar{F}(\lambda_{obs})} - 1
\]

- Use a trivial estimator:
\[
\hat{\xi}_A = \sum_{i,j \in A} w_i w_j \delta_i \delta_j
\]
\[
\sum_{i,j \in A} w_i w_j
\]

- Use a fiducial cosmology:
\[
(\Omega_m, \Omega_\Lambda) = (0.27, 0.73)
\]
Used BOSS DR11 quasars sample

• Analysis uses ~140,000 quasars with $2.1 < z < 3.5$ over 9,000 deg$^2$

*Delubac et al. (2015)*
Have a 5 sigma detection of the BAO peak

Delubac et al. (2015)
High redshift space distortion makes the peak bigger in the line of sight

\[ r^2 \xi_1 (r) [h^{-2} \text{Mpc}^2] \]

\[ r [h^{-1} \text{Mpc}] \]

*Delubac et al. (2015)*

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**best fit**

**fiducial**
No evidence for systematic effects at the level of statistical uncertainties

- Systematics that have been considered so far include:
  - Analysis pipeline
  - bias in the fit
  - Metal contaminations
  - Residuals in sky subtraction
  - wavelength dependent flux bias
  - Correlated noise in pixels
  - ...
Obtain model independent constraints on $D_A/r_s$ and $D_H/r_s$

Delubac et al. (2015)
Numerous cosmological implications including detection of Dark Energy by BAO only

- Purely geometric constraints. Lambda detected form BAO alone at more than 3 sig.

Aubourg et al. (2015)
eBOSS maps the Universe to observe the BAO
eBOSS will use 4 different tracers to improve BOSS constraints

LRGs at z > 0.6
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LRGs at $z > 0.6$

Lyman-alpha quasars at $z > 2.1$
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LRGs at $z>0.6$

Lyman-alpha quasars at $z>2.1$

Quasars at $0.9<z<2.2$
eBOSS will use 4 different tracers to improve BOSS constraints

LRGs at $z>0.6$

Lyman-alpha quasars at $z>2.1$

ELGs $0.6<z<1.0$

Quasars at $0.9<z<2.2$
ELGs will be the main tracer for DESI, Euclid, PSF, 4MOST…

- For $z>0.8$ the massive population of galaxies is dominated by star forming galaxies.
- ELG spectra display strong emission lines allowing secure estimation of their redshift in short exposure time.
Propose an ELG selection using a Fisher discriminant

\[ X_{FI} = \alpha_0 + \alpha_{ur} \times (u - r) + \alpha_{gr} \times (g - r) + \alpha_{ri} \times (r - i) + \alpha_{rz} \times (r - z) + \alpha_{rW1} \times (r - W1) \]

Fisher discriminant

Raichoor, Comparat, Delubac et al. (2015)
Catalog of ELGs publicly available soon!

- Galaxy bias of 1.35
- Contains about 600,000 ELGs over the South Galactic Cap

Delubac et al. (2015)
Take away message

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• Emission Line Galaxies
  - SFR was ~10x higher at z~1; resulting strong emission lines allow secure redshift determination in ~1 hour with SDSS
  - Want to select objects with highest SFRs: generally blue colors
  - $[\text{OII}]$ can be detected up to z=1.7 (ideally want higher spectral resolution than BOSS to split doublet, esp. at z > 1)

Key for DESI & PFS BAO surveys
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