Lyman-\(\alpha\) Cosmology with BOSS

Julián Bautista
University of Utah

Rencontres du Vietnam
Cosmology 2015
Lyman-α Forest of a Quasar

(by Andrew Pontzen)

\[
F(\lambda_{\text{obs}}) = \frac{\text{Observed flux}}{\text{Unabsorbed flux}}(\lambda_{\text{obs}})
\]
Lyman-α Forest of a Quasar

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\[ F(\lambda_{\text{obs}}) = \frac{\text{Observed flux}}{\text{Unabsorbed flux}}(\lambda_{\text{obs}}) \]
Survey of Lyman-α Forests

Tracers of matter distribution in the Universe
BOSS
Baryon Oscillation Spectroscopic Survey

Measuring BAO when the Universe was one fifth of its age

BAO ↔ Expansion rate ↔ Dark Energy

DR12
190 000 quasars at $2 < z < 3.5$
15% more than DR11
Measuring BAO with forests

- Quasar redshifts: visual inspection of all targets (Paris++2014)
- Continuum level $\rightarrow$ amount of absorption
- Compute correlation function

$$\xi(\vec{r}) = \langle \delta_i \delta_j \rangle$$
- Measure the BAO scale

BOSS spectral coverage

BAO scale $\sim 150$ Mpc
Lyman-α auto-correlation function

\[ r^2 \xi(r_\perp, r_\parallel) \]

\( \delta_i \rightarrow \delta_j \)

\( r_\parallel \) [\( h^{-1} \) Mpc]

\( r_\perp \) [\( h^{-1} \) Mpc]

(Delubac, JB, ++ 2015)
Lyman-α auto-correlation function

\( \xi(\vec{r}) \)

(Delubac, JB, ++ 2015)
Quasar Lyman-\(\alpha\) cross-correlation function

DR11

\(\delta_j\)

(Font-Ribera++2014)
Fitting BAO model

BAOfit package with continuum distortion model
(Kirkby++ 2013, Blomqvist++ 2015)

\[
\xi_{\text{model}}(r, \alpha_{\parallel}, \alpha_{\perp}) = \xi_{\text{cosmo}}(r, \alpha_{\parallel}, \alpha_{\perp}) + \xi_{\text{broadband}}(r)
\]

Radial BAO

\[
\alpha_{\parallel} = \frac{D_H(z)/r_d}{[D_H(z)/r_d]_{\text{fid}}}
\]

Transverse BAO

\[
\alpha_{\perp} = \frac{D_A(z)/r_d}{[D_A(z)/r_d]_{\text{fid}}}
\]

Redshift-space distortions

Bias
Tests on Mock Catalogs

(Log-normal absorption fields)

Correlation functions

BOSS like spectra

DR11 Mocks

BAO best-fits

100 realizations
Lyman-α auto-correlation function

Preliminary DR12

$\delta_j$

$\delta_i$

$\parallel r'$

$\perp r$

$\mathbf{r}$

$\mathbf{k}$

$\mathbf{h}^{-1}$ Mpc

$\mathbf{r}_{\perp}$

$\mathbf{r}_{\parallel}$

$\mathbf{r}^2 \xi(r_{\perp}, r_{\parallel})$

$\mathbf{r}$

$\mathbf{r}_{\perp} [h^{-1} \text{ Mpc}]$

$\mathbf{r}_{\parallel} [h^{-1} \text{ Mpc}]$

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

$0 < \mu < 0.5$

$0.5 < \mu < 0.8$

$0.8 < \mu < 1.0$

JB++ in prep
Quasar Lyman-α cross-correlation function

Preliminary DR12

$\delta_i$

$\xi(r_{\parallel}, r_{\perp})$

$\xi_{\mu}(r)$

$0 < \mu < 0.5$

$-1 < \mu < -0.5$ and $0.5 < \mu < 1.0$

JB++ in prep
BAO Results
DR11 and DR12 Preliminary

Auto-correlation

\[ \chi^2 = \frac{1499.1}{1515-13} \]
\[ \alpha_{\parallel} = 1.054(32) \]
\[ \alpha_{\perp} = 0.973(56) \]

Cross-correlation

\[ \chi^2 = \frac{1957.93}{1926-20} \]
\[ \alpha_{\parallel} = 1.050(30) \]
\[ \alpha_{\perp} = 0.916(29) \]

Delubac, JB++ 2015

JB++ in prep
Cosmology

DR11

Expansion rate

Angular distance

(Aubourg++2014)
What is new in DR12
What is new in DR12

190,000 quasars at \( 2 < z < 3.5 \)

15\% more than DR11
What is new in DR12

Work in progress!

- Improved modelling of metal contamination in the forest
- New CCD extraction algorithm
- Throughput correction (Margala++2015)
- Null tests
What is new in DR12

Work in progress!

- Improved modelling of metal contamination

Line of sight correlations

Metal line contaminating the BAO peak

Mocks

\[(\xi_{\text{WithMet}} - \xi_{\text{NoMet}}) \times 10^{-4}\]

(nm)

Ly\(\alpha\) 121.6
Si\(\text{III}\) 120.6
Si\(\text{II}\) 119.0
Si\(\text{II}\) 119.3
Si\(\text{II}\) 126.0

Use of metal templates while fitting for BAO
What is new in DR12

Work in progress!

- New CCD extraction algorithm
  Unbiased estimator of counts
  More accurate propagation of errors
  (5% increase)

Cleaner mean transmission

Less sky residuals
What is new in DR12

- Throughput correction (Margala++2015)
  
  Due to different focal plane configurations between stars and quasars
What is new in DR12

Work in progress!

- Null tests
  Build fake forests
  Compute correlations

Expectation
Measurement
What is new in DR12

Work in progress!

- Systematics
  Contributions from sky model, calibration and galactic absorption

| Stat.                          | $\Delta \alpha_{||}$     | $\Delta \alpha_{\perp}$  |
|-------------------------------|--------------------------|----------------------------|
| Sky residuals (in CCD)        | $+0.001 \pm 0.002$       | $+0.008 \pm 0.005$         |
| Sky residuals (in f.o.v)      | $-0.003 \pm 0.002$       | $+0.001 \pm 0.005$         |
| Sky model noise               | $+0.002 \pm 0.0004$      | $-0.004 \pm 0.001$         |
| Calibration noise             | $< 0.001$                | $+0.002 \pm 0.0004$        |
| Fiber cross-talk              | $< 0.001$                | $< 0.001$                  |
| ISM absorption                | $< 0.001$                | $< 0.001$                  |
| Total                         | $+0.000 \pm 0.003$       | $+0.006 \pm 0.007$         |

No significant shift in the BAO peak estimates!
CONCLUSIONS

• Lyman-α forest BAO allows us to access expansion at $z \sim 2.3$

• DR12 analysis: 15% more data

• Robust estimate of astrophysical and instrumental systematics

• Stay tuned!
Large-scale structure of Lyman-α emission intensity
(First optical intensity mapping result)

Quasar-Lya emission cross-correlation:
Shape = Lambda CDM
Amplitude prop. to bias X mean intensity of Lya emission.