Study the Expansion of the Universe with the Lyman-α – Quasar Cross-Correlation
Outline

• Introduction to BAO cross-correlation
• First results
• Improvements
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BAOs and the acceleration of the Universe

To understand what is Dark Energy we need to measure distances at different redshifts.

BAOs measure the expansion rate and angular diameter distance at a given redshift.
Measuring Correlations

From a density field $\rho$, we get the over-density field $\delta$:

$$\delta(x) = \frac{\rho(x)}{\bar{\rho}} - 1$$

The cross-correlation $\xi$ is:

$$\xi_{ab} (\vec{r}) = \langle \delta_a (\vec{x}) \cdot \delta_b (\vec{x} + \vec{r}) \rangle$$

Where a and b are matter density tracers
Quasar flux originates from the surrounding of a super-massive black hole

Spectrum of a BOSS Quasar at redshift $z = 3.35$, the Universe was only 2 billion years old
Quasar

Get redshift from emission lines

A Quasar is a boolean matter density tracer
Lyman-α forest

Absorption lines from Hydrogen continuum in the Intergalactic Medium (IGM)

A Lyman-α pixel gives a continuous matter density tracer
Two matter density tracers

Quasar:
\[ \delta_{qso}(\vec{x}) = \begin{cases} 0 \\ 1 \end{cases} \]

Lyman-\(\alpha\) forest pixel:
\[ \delta_{Ly\alpha}(\vec{x}) = \delta_{\alpha} \]

→ Doing a cross-correlation is less sensitive to systematics (IGM metals, flux calibration, ...)

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From Photometry to Spectroscopy

- Sloan Digital Sky Survey (SDSS)
- 2.5-m wide-angle optical telescope
- Spectroscopy with the Baryonic Oscillation Spectroscopic Survey (BOSS)
- 1000 fibers
- Run: 2009-2014

List of targets from photometry sent to the BOSS spectrograph.

Quasar

Star

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Published results (auto and cross correlation)

Expansion rate and angular diameter distance at $z = 2.34$

From Delubac et al. ArXiv:1404.1801
Published results (cross correlation)

More than 4σ detection of the BAO scale
Better than 4% precision on both alpha

$\alpha_{||} = 1.042 \pm 0.034$
$\alpha_{\perp} = 0.930 \pm 0.036$

Font-Ribera et al. ArXiv:1311.1767
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Gaussian Random Field Simulations

Lyα forest along the line-of-sight

QSO set on big Over-density

Apply telescope properties

IGM image provided by Julien Baur

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Gaussian Random Field Simulations

- A power spectrum from CAMB is applied to the field with a fiducial cosmology.
- Add metals absorption (Silicon,…) correlated with Hydrogen absorption
- Apply survey, spectroscopy, noise properties.
  → First simulations where:
    - Lyman-\(\alpha\) forests are along the line-of-sight of a QSO
    - Able to reproduce all 3D correlations: Ly\(\alpha\)-Ly\(\alpha\), QSO-Ly\(\alpha\), QSO-QSO correlations.
Both have the same quasar and forest distribution

With more than 240,000 QSOs and 170,000 forests with $z$ in $[1.7, 5.5]$

$<z> = 2.36$
Data and Simulations comparison

Forest flux as a function of both wavelengths in agreement.

Spectrum continuum in the Lyman-\(\alpha\) forest

Neutral Hydrogen evolution with redshift

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Results (Data and Simulation)

Quasar – Lyman-α forest correlation for data and simulation

\[ \delta_{\text{LYA}} - QSO \]

\[ |s^2 \xi_0 (s)/(|h^{-1} Mpc|)^2 | \]

BAO scale

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Summary of these improvements

- Realistic simulations
- Improved statistics
- Improved understanding of metals impact
- Improved understanding of QSO continuum impact
- Study statistical errors
- Study possible bias
Conclusion

- First simulations with both quasars and forests.
- Simulations reproduce very well the data

→ Paper expected by summer 2016
Thank you for your attention