Forecasts for IGM reconstruction with Lyman-alpha tomography

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Forecasts for IGM reconstruction with Lyman-alpha tomography

- Reconstruction of the filamentary cosmic web at high redshift

- Small-scale topology of the HI field: alternative constraint on AGN feedback
1. Lyman-alpha tomography
   - method
   - implementation in the Horizon-AGN simulation

2. Forecasts for future probes
   - Current status
   - the case of MOSAIC (ELT)

3. Small-scale topology of the HI field (genus)
   - The imprint of AGN feedback: ideal case
   - Is it really measurable? — systematics
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Lyman-alpha tomography: method

Interpolation between line-of-sight: Wiener filtering

Transmitted flux $F(\nu_0) = e^{-\tau_\alpha(\nu_0)}$ traces the neutral hydrogen (HI) density:

$$\tau_\alpha(\nu_0) = \int_0^x \frac{dx}{1+z} \sigma_\alpha n_{HI}(x, z)$$
Inversion of the Lyman-forest through Wiener filtering

\[ M = C_{\delta}^{3a_{\delta}}(C_{\delta\delta} + N)^{-1}D \]

\[ C_{\delta\delta}(x_1, x_2, x_{1T}, x_{2T}) = \sigma^2 e \frac{|x_1 - x_2|^2}{2L_x^2} e \frac{|x_{1T} - x_{2T}|^2}{2L_T^2} \]

Lyman-alpha tomography: method

Resolution of the output map
Lx, LT

Observational noise
Finite number of sightlines
SNR of the spectra
Limited sensitivity: line saturation

Systematics
Flux instead of density
RSD
Baryonic physics

Need for mocks to account for all the effects
Lyman-alpha forest in Horizon-AGN

The Horizon-AGN suite (DM, AGN, noAGN)

- Hydrodynamical simulation run with RAMSES on a cosmological volume (100 Mpc/h, finest cell 1kpc) + lightcone (1 deg)
- star formation, stellar winds, SNII, SNIa, and AGN feedback (radio/quasar)
- Gas cooling and UV background heating (uniform UV background, Haardt and Madau+96)
- HI density: balance between photoionisation, collisional ionization and recombination (Black+81)

\[ x_{\text{HI}} = \frac{\alpha(T)}{\alpha(T) + \gamma(T) + J_{22} G_1 n_e^{-1}} \]

Larger scale HI simulations: see also Peirani+14, Lochhass+16, Sorini+16, Ozbek+16
Lyman-alpha forest in Horizon-AGN

Transmitted flux in the forest

Impact of AGN feedback

Rollinde 2013, <F>=0.86
Kim+ 2007
Horizon-AGN, <F>=0.83

Rollinde+ 2013, <F>=0.71
McDonald+ 2000, <F>=0.68
Calura+ 2012
Horizon-AGN, <F>=0.72

z = 2.0

z = 3.0

see also Viel+12,13, Nasir+17
Lucik+15 for a convergence study
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Lyman-alpha forest
available background sources

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Galaxies (L+16)
Quasars (P-D+16)

$\log N_{\text{gal}}/\text{deg}^2[\Delta z=0.05, \Delta m=0.1]$

redshift
The Lyman-alpha cosmic web
resolution of the reconstruction with future surveys

Laigle et al. in prep
The Lyman-alpha cosmic web
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MOSAIC/ELT

WEAVE-QSO

PFS/subaru

WEAVE/W.H
The case of ELT/MOSAIC reconstruction at the ~Mpc resolution

Japelj, Laigle et al. in prep

VIFU MODE

$F_\lambda \left[ 10^{-18} \text{erg cm}^{-2} \text{s}^{-1} \text{Å}^{-1} \right]$

Observed wavelength [Å]

$z = 3.60$

$m_{\text{rest,UV}} = 25.1 \text{ mag}$
The case of ELT/MOsaic reconstruction at the ~Mpc resolution

Japelj, Laigle et al. in prep

Throughput

$S/N$ vs $NDIT$ [= hours]

24.5 mag
25.0 mag
25.5 mag

Resolution

2
5
10
15
20
25
30
40
The case of ELT/MOSAIC
density map comparison

Reconstruction: 2Mpc at $z=3.2$

100 nights of observation
1 deg$^2$

Japelj, Laigle et al in prep
The case of ELT/MOSAIC
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100 nights of observation

1deg $^2$

Reconstruction: 2Mpc at z=3.2

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OUTLINE

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Impact of AGN feedback on HI density field

Gas density, metallicity, temperature impacted by AGN

Horizon-noAGN

Horizon-AGN
Impact of AGN feedback on HI density field

HI deficit due to AGN feedback
(ratio of HI in Hz-noAGN over Hz-AGN)

AGN feedback impacts the connectivity of the HI iso-surface
Genus of the density field

Number of holes in contour surfaces - Number of isolated regions - 1

1 hole
1 isolated region
$\text{genus} = -1$

3 holes
0 isolated region
$\text{genus} = 2$
Small-scale genus of the HI density field: Ideal case

Laigle et al. in prep

Variation of the genus with scale and redshift?
Small-scale genus of the HI density field: Ideal case

Laigle et al. in prep

Variation of the genus with scale
Variation of the genus with scale

Small-scale genus of the HI density field: Ideal case

Laigle et al. in prep

Variation with scale
Small-scale genus of the HI density field: Ideal case

Laigle et al. in prep

Variation of the genus with scale
Small-scale genus of the HI density field: Ideal case

Laigle et al. in prep

Variation of the genus with scale
The effect of AGN feedback on genus increases with decreasing redshift from z~3.5.
Small-scale genus of the HI density field: Ideal case

The effect of AGN feedback on genus is maximum at ~2.8 Mpc

Laigle et al. in prep

Theoretical perspective

The effect of AGN feedback on genus is maximum at ~2.8 Mpc
Systematics: effect of RSD

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see also e.g. Codis+13,
Appleby+17

\[ R_s = 2.22 \text{ Mpc} \]
\[ R_s = 3.33 \text{ Mpc} \]
\[ R_s = 4.44 \text{ Mpc} \]
The case of ELT/MOSAIC
density map comparison

Reconstruction: 2Mpc at z=3.2

100 nights of observation
1deg² →

Japelj, Laigle et al in prep
The case of ELT/MOSAIC
density map comparison

Japelj, Laigle et al in prep

100 nights
of observation
1 deg $^2$
Systematics: effect of finite number of LOS

Saturation of lines given the sensitivity of the instrument

The effect decreases with redshift

Genus with MOSAIC/ELT

$R_s = 2.80$ Mpc

$\langle z \rangle = 3.20$

finite number of LOS

The effect decreases with smoothing scale

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see also e.g. Appleby+17 for galaxy surveys

Original flux field
The case of ELT/MOSAIC
density map comparison

Reconstruction: 2Mpc at z=3.2

ET2
ET5
ET10
ideal

100 nights of observation
1deg^2

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Systematics: effect of noise on the spectra

Genus with MOSAIC/ELT

R_s=2.80 Mpc

<z>=3.20

Noise along the LOS tends to fragment the field

Improve the reconstruction with constant SNR (varying exposure time)

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see also e.g. Appleby+17
for galaxy surveys

Genus with MOSAIC/ELT

ET2 SNR/angstrom >1.5

ET5 SNR/angstrom >2.5

ET10 SNR/angstrom >3

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see also e.g. Appleby+17
for galaxy surveys
Reconstructing the HI 3D distribution from observations is on the way.

- Synergy between surveys allow to measure a redshift evolution.

- AGN feedback leaves its imprint in HI distribution.
  - Can be statistically measured from genus statistics.
  - Scale and redshift evolution can allow to disentangle cosmology + baryonic physics.
  - Not easy to measure observationally.
Best observational strategy to accurately measure the genus?

- Which statistics is best to probe the impact of AGN feedback on top of gas physics?
  - ▶ Genus statistics: Shift, Cluster Parameter, Amplitude [see Park+05]
  - ▶ Contour Minkowski tensor to quantify the anisotropy level
    - [see talk from Pravabati Chingangbam]

- Large-scale genus on HI field: constrain cosmology

- Cosmic web extraction from the HI reconstructed field
  - [see talks from C. Pichon, K. Kraljic]