Tomography of the Intergalactic and Circumgalactic Medium with the E-ELT

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Definition of TOMOGRAPHY

: a method of producing a three-dimensional image of the internal structures of a solid object (as the human body or the earth) by the observation and recording of the differences in the effects on the passage of waves of energy impinging on those structures — compare COMPUTED TOMOGRAPHY

— to·mo·graph·ic    adjective

Origin of TOMOGRAPHY

Greek *tomos* section + International Scientific Vocabulary - *graphy* — more at TOME

First Known Use: 1935

IGM/CGM tomography with the E-ELT
Figures prominently in the TMT and GMT science cases.

Figure 5-11. The "cosmic web" of the baryon distribution in a cosmological simulation. Here, HI in the IGM traces the dark matter distribution even in regions with low density contrast. A line of sight through the volume yields a one-dimensional map of both the HI and metallic species along the line of sight, as shown in the right-hand panel. Regions disturbed by galaxy formation processes are schematically indicated. In such regions, sightline probes will reveal the extent to which galaxies alter the physical state of the IGM: their sphere of influence, mass outflow, ionization effects, deposition of mechanical energy, etc. Densely sampled sightlines through a survey volume, together with detailed maps of the galaxy distribution, will provide unprecedented views of the distribution of baryons in the Universe, and their relation to the sites of galaxy formation.
The baryonic lifecycle of galaxies: Inflows vs Outflows

Cold flows. Galactic Winds. Metal Enrichment.

IGM/CGM tomography with the E-ELT
The baryonic lifecycle of galaxies: Inflows vs Outflows

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IGM/CGM tomography with the E-ELT
Densely Sampling the Universe @z~1.8-3.2

(previous work: Adelberger+03,05; see also Bielby+11, Crighton+11)

From Chuc Steidel’s talk at 2011 Durham conference

IGM/CGM tomography with the E-ELT
IGM/CGM tomography with the E-ELT

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Typical Field, 5’ x 7’, ~150 spectroscopic redshifts 1.8-3.2
Galaxy Pair Composite Spectra

- 50 pairs 1-5″ (<d>=30 kpc)
- 190 pairs 5-10″ (<d>=70 kpc)
- 305 pairs 10-15″ (<d>=100 kpc)

From Chuc Steidel’s talk at 2011 Durham conference

CS+2010

IGM/CGM tomography with the E-ELT
$W_0$ vs. Galaxy Impact Parameter, z~2-3 LBGs

Models:

<table>
<thead>
<tr>
<th>Line</th>
<th>$\gamma$</th>
<th>$R_{\text{eff}}$ (kpc)</th>
<th>$v_{\text{out}}$</th>
<th>$f_{c,\text{max}}$</th>
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<tbody>
<tr>
<td>Ly$\alpha$(1216)</td>
<td>0.37</td>
<td>250</td>
<td>820</td>
<td>0.80</td>
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<tr>
<td>CIV(1549)</td>
<td>0.23</td>
<td>80</td>
<td>800</td>
<td>0.35/0.25</td>
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<tr>
<td>CII(1334)</td>
<td>0.35</td>
<td>90</td>
<td>650</td>
<td>0.52</td>
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<tr>
<td>SiIV(1393)</td>
<td>0.60</td>
<td>70</td>
<td>750</td>
<td>0.40</td>
</tr>
<tr>
<td>SiII(1260)</td>
<td>0.60</td>
<td>80</td>
<td>820</td>
<td>0.33</td>
</tr>
<tr>
<td>SiII(1526)</td>
<td></td>
<td></td>
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</tbody>
</table>

Parameters used to produce the model curves shown in Fig. 20.

Power law exponent in the expression $f_c(r) = f_{c,\text{max}} r^{-\gamma}$.

Maximum value of the covering fraction for each transition, measured from the composite spectrum (see Fig. 7).

Includes contributions from C IV $\lambda$1548 and C IV $\lambda$1550 of 0.35 and 0.25, respectively.

$\mathbf{f_c(r) \sim r^{-\gamma}}$

From Chuc Steidel’s talk at 2011 Durham conference

CS et al 2010

IGM/CGM tomography with the E-ELT
IGM/CGM tomography with the E-ELT

one object per FoV

from TMT science case
Tomography of the Circumgalactic Medium with the E-ELT

- can do this in a single night
- can go three too four magnitudes deeper
- for E-ELT FoV multiplex >100 and resolution R≤5000 match very well
Simulation pictures from Volker Springel and James Bolton.

IGM/CGM tomography with the E-ELT
IGM/CGM tomography with the E-ELT

There is a long way to go for tomography in terms of scales.

Simulation pictures from Volker Springel and James Bolton.

Busca et al. 2012

Lyα BAO

$10 \text{Mpc/h}$

$7.5 \text{arcmin}$

$z=3$

Jeans length at mean density

CGM
High-resolution spectroscopy of QSOs

courtesy of George Becker

IGM/CGM tomography with the E-ELT
High-resolution spectroscopy of QSOs

This is what moving from 18th to 21st magnitude buys you.

courtesy of George Becker
QSOs -> 100 / sqdeg not enough

With LBGs => Density field will be recovered

from Patrick Petitjean’s talk at Cambridge EELT-HIRES meeting

IGM/CGM tomography with the E-ELT
IGM/CGM tomography with the E-ELT

one object per FoV $\approx 1000/\text{sqdeg}$
Lyα-Tomography of the Intergalactic Medium with the E-ELT

Resolution:

Compromise of resolving the Jeans mass along the line-of-sight and mapping a large enough area (1sqdeg, or more partially covered along filaments) with a reasonable amount of observing time (300-500h). $R \geq 10000$ appears optimal.

Multiplex:

Compromise of marginally resolving the Jeans mass perpendicular to the line-of-sight and to map a large enough area. Multiplex of 10-20 to capture LBGs down to $R = 24$ appears optimal.

Wavelength:

Blue sensitivity helps to push to low redshift. For tomography of large-scale distribution of metals, extension to the near-IR is essential.
A square degree sampled with 1000 spectra of the quality of that of CB58

IGM/CGM tomography with the E-ELT
A square degree sampled with 1000 spectra of the quality of that of CB58
Summary

➢ Tomography of the IGM/CGM will allow us to properly understand the baryonic life cycle of galaxies and will be the tool of choice for unraveling how stellar and AGN feedback regulates galaxy formation. Exploitation of this science case will be very competitive.

➢ Tomography of the circum-galactic medium with the E-ELT requires high multiplex (> hundred) and will enable a detailed characterisation of inflows and outflows in individual galaxies.

➢ Tomography of the IGM with a proper reconstruction of the filamentary structure of the cosmic web to study how the eco-cycle of galaxies relates to the large scale distribution of matter requires moderate multiplex (10-20) and intermediate, but still reasonably high resolution (> 10000).

➢ Combining the two will be particularly powerful.