Unveiling the history of the Universe’s re-ionisation

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A proto-cluster discovered with GTC/OSIRIS

- Pratica Dayal made an excellent introduction to this talk
- Indeed the best way to follow the history of reionisation is with proto-clusters
We have discovered a proto-cluster at z~6.5 in the SXDX, consisting of 45 sources (Chanchaiworawit+2018, 2019).

We have confirmed the proto-cluster spectroscopically.

We securely detected 12 out the 17 sources we could fit in one mask (Calvi+2019, in press).
A-type sources
B-type sources
The data

• Lyα fluxes and observed luminosities from the spectra

• We derived $f_{\text{esc},\text{Ly}\alpha}$ (Chanchaiworawit+2019)

• Then, the Intrinsic Lyα luminosities are $\text{Ly}_\alpha_{\text{intr}} = \text{Ly}_\alpha_{\text{obs}}/f_{\text{esc},\text{Ly}\alpha}$

• From the intrinsic Lyα luminosities we derive the number of ionising continuum photons $N_{\text{ion}}$ for typical HII regions

• We also derived the expected X-ray luminosities, coming from SN and stellar winds

• Then the mechanical energy produced by the proto-cluster is $\sim 5\%$ of X-ray production
Mechanical energy output

- The mechanical energy output is huge
- The mechanical energy is enough to pierce holes in the CGM
- Thus ionising continuum photons are able to escape
Assuming various $f_{\text{esc}, \text{LyC}}$

- We assume typical values for the escape fractions of LyC photons such as: 0.1, 0.15, 0.2 and 0.3

- $N_{\text{ion}}$ produced by the proto-cluster: 36.38, 38.52, 40.92 & $46.77 \times 10^{54}$ s$^{-1}$, depending on the $f_{\text{esc}, \text{LyC}}$

- And using the volume calculated for the proto-cluster (9242 ± 1427 cMpc$^3$) and the ionising emissivities given by Finkelstein+2012, we derive the volumes ionised by the proto-cluster ($V = N_{\text{ion}}/\dot{N}_{\text{ion}}$)
Volumes derived

From Finkelstein+2012, at z~6.5

<table>
<thead>
<tr>
<th>$f_{esc, LyC}$</th>
<th>$\dot{N}_{ion}$</th>
<th>Ionised volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$10^{51}$ s$^{-1}$Mpc$^{-3}$</td>
<td>cMpc$^3$</td>
</tr>
<tr>
<td>0.1</td>
<td>4.90</td>
<td>7410 ±841</td>
</tr>
<tr>
<td>0.15</td>
<td>3.02</td>
<td>12732 ±1467</td>
</tr>
<tr>
<td>0.2</td>
<td>2.32</td>
<td>17608 ±2000</td>
</tr>
<tr>
<td>0.3</td>
<td>1.74</td>
<td>26833 ±3046</td>
</tr>
</tbody>
</table>

Note that for $f_{esc, LyC}$~0.15 the volume ionised is larger than the proto-cluster volume (Rodriguez Espinosa+2019, submitted)
Recently however

- Finkelstein+2019 has derived a model whereby they predict an ionising emissivity, \( \log \dot{N}_{\text{ion}} = 50.625 \text{ s}^{-1} \text{Mpc}^{-3} \), at \( z=6.5 \), for reionising the Universe with a very low escape fraction.

- They assume a low escape fraction of LyC~0.05 through the bulk of the Epoch of Reionisation.

- Using this scenario we get an ionising emissivity of \( \log \dot{N}_{\text{ion}} = 51.57 \text{ s}^{-1} \text{Mpc}^{-3} \) for the proto-cluster.

- Which is an order of magnitude larger than required for reionising the whole proto-cluster plus the IGM around it.

- So in this scenario of low escape fraction the ionised bubble is still there!
TMT could perform a census of ionised bubbles

- WFMOS could be used in slit-less (substituting the mask with several narrow band filters) to search for groups of Lα sources

- Large field (25.5 arcmin$^2$) and low res spectroscopy would be ideal

- Could patrol a cosmological Field (i.e. GOODS-N, the SXDX, etc.) searching for Lyα proto-clusters at redshifts 6 to 7.25
• For instance for the GOODS-N field we require 5 positions to cover entire field

• If using NFIRAOS, 0.5 hour is needed for each pointing and for each narrow band filter.

• So if 5 narrow band filters are used, 12.5 h would be needed with the TMT!
The field can from now on be narrowed to use TMT/IRIS

- IRIS, in its imaging mode with narrow band filters could also be used at a lower survey pace (given the smaller field)
Searching for protoclusters at high redshifts

• These proto-clusters most probably will have produced ionised bubbles.

• The number of ionised bubbles at each redshift will tell the history of the Universe’s reionisation

• So we need to follow the number of ionised bubbles versus z

• In the future ARISE/TMT would be very useful (5’x5’ field; 0.31-4.8μ range)
Summary for ELTs

- Large FoV instruments to make blind surveys in the optical and Near IR are required!
- A census of high-z proto-clusters will unveil the history of the Universe’s reionisation
- Proto-clusters such as the one we have found