Gas around galaxies at z>2: linking emission & absorption with large surveys

Michele Fumagalli
ICC, CEA – Durham University
Università’ degli Studi di Milano-Bicocca
Question 2: How are galaxies, gas flows, and the CGM related?

Circumgalactic medium (a.k.a. halo gas)

Intergalactic Medium

EAGLE simulation; Schaye et al., 2015
The tools: large surveys at large telescopes
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See also QSAGE, 96 orbits with HST to target $z \sim 1.5$-$2$ quasars (Bielby et al. 2019)
Part I. Inflows and outflows at z~3: the MAGG survey

Searching directly in emission for galaxies associated with LLSs: an example of a very metal rich system. Clustering is becoming a relevant feature of this type of studies.

Metal rich system $(Z/Z_{\odot}) = -1.1$ at $z \sim 3.25$

Galaxy merger with outflows

\[ MF \text{ et al. 2017b} \]
Part I - Inflows and outflows at $z\sim 3$: the MAGG survey

Searching directly in emission for galaxies associated with LLSs: examples of **very metal poor systems.**
Mixing must be inefficient at these redshifts.

<table>
<thead>
<tr>
<th>Pristine LLS</th>
<th>Candidate PopIII</th>
<th>Metal Poor DLA</th>
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</thead>
<tbody>
<tr>
<td>Log($Z/Z_{\odot}$) $&lt;$ -3.8</td>
<td>Log($Z/Z_{\odot}$) = -3.4</td>
<td>Log($Z/Z_{\odot}$) = -2.3</td>
</tr>
</tbody>
</table>

Ubiquitous detection of multiple galaxies (possibly aligned in filaments) in the environment of metal-poor gas
With "samples", we can start learning about the parent halos of strong absorbers (e.g. DLAs)
Part I - Inflows and outflows at $z\sim3$: the MAGG survey

With “samples”, we can start learning about the parent halos of strong absorbers (e.g. DLAs)
Part II – Probing the CGM in emission at z~3: the MUDF survey

We can extend this study to low-mass galaxies and we can start probing the CGM in emission.
Part II – Probing the CGM in groups at z~1: the MUDF survey

Environmental processes boost the cross section of MgII in individual galaxies at z~0.5-1.0

Fossati, MF et al. 2019
Environmental processes boost the cross section of MgII in individual galaxies at $z \sim 0.5-1.0$
Bonus – Imaging filamentary structures in a z~3 protocluster

MUSE images filaments on Mpc scales in SSA22

Umehata, MF et al. 2019, Science
Bonus – Imaging filamentary structures in z~3 protocluster

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Bonus – Imaging filamentary structures in z~3 protocluster

We find clear correlation between filaments and sub-mm/Xray sources

Umehata, MF et al. 2019
Bonus – Imaging filamentary structures in $z \sim 3$ protocluster

We find clear correlation between filaments and submm/Xray sources

*Umebata, MF et al. 2019*
Bonus – Imaging filamentary structures in $z \sim 3$ protocluster

Neat example of enhanced local radiation field

Umebata, MF et al. 2019
Combining CGM in absorption and emission with large surveys at large telescopes

We are learning about:

- Clustering of galaxies with LLSs/DLAs
- How metals spread around galaxies
- How CGM/galaxy correlation evolves with redshift and environment
- The spatial distribution of denser CGM both in emission and absorption
- How filaments connect and feed galaxies in proto-clusters