MUSEQuBES CGM Surveys: From low-z SFing Galaxies to High-z Lyα Emitters

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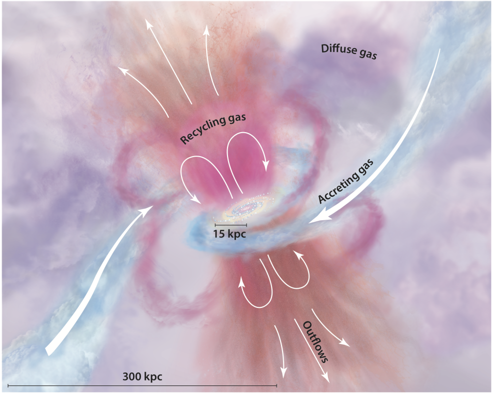
Sterrewacht Leiden

The Circumgalactic Medium



Tumlinson+2017, ARAA

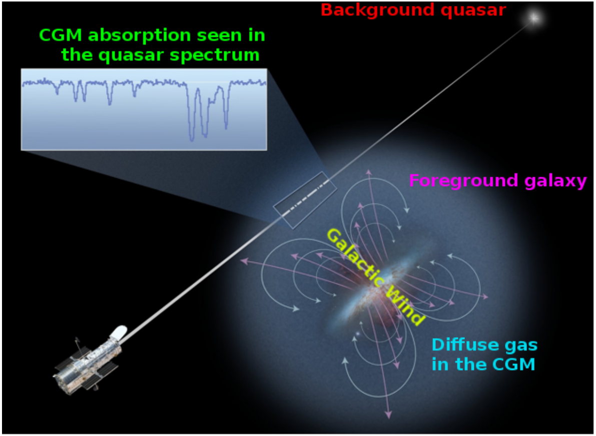
Milky Way:
Mstar ~ 5 x 10^10 Msun
Mvir ~ few 10^12 Msun
Rvir ~ 260 kpc
Vcirc ~ 180 km/s

- CGM: Reservoir of diffuse gas and metals surrounding galaxies
  - Extends out to the virial radius and beyond
  - The gas in the CGM is likely to be bound
- Inflows and outflows (–poorly understood–) take place in the CGM
- The physical/chemical conditions of the CGM are determined by the gas flow processes

CGM study is challenging

- CGM is too diffuse ($n_{\rm H} \lesssim 10^{-3} {\rm cm}^{-3}$) to be detected in emission
- Emission measure, EM $\propto n^2$, whereas optical depth for absorption, $\tau \propto n$

Quasar absorption line spectroscopy is the best means to probe the elusive CGM



Cartoon: QSO-galaxy pair with an impact parameter of ρ (kpc)

ρ: projected separation between the QSO and galaxy

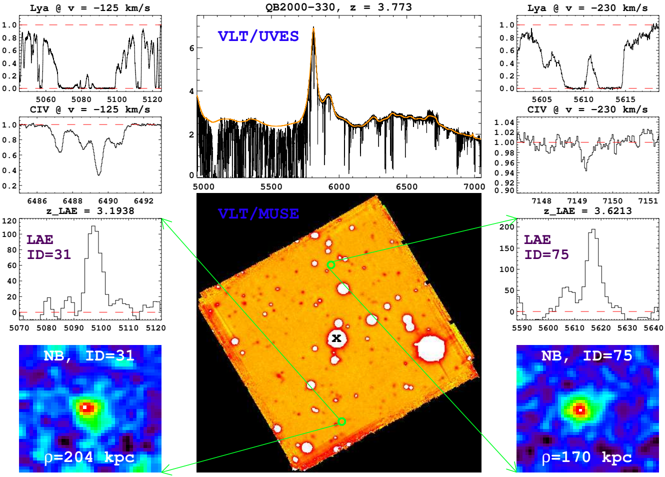
MUSEQuBES (High-z)

☐ MUSE observations

- 8 MUSE fields (Depths: 2–10 hrs)
- 51 hrs of MUSE GTO observations
- Targeted emission line: Lyα (LAE)

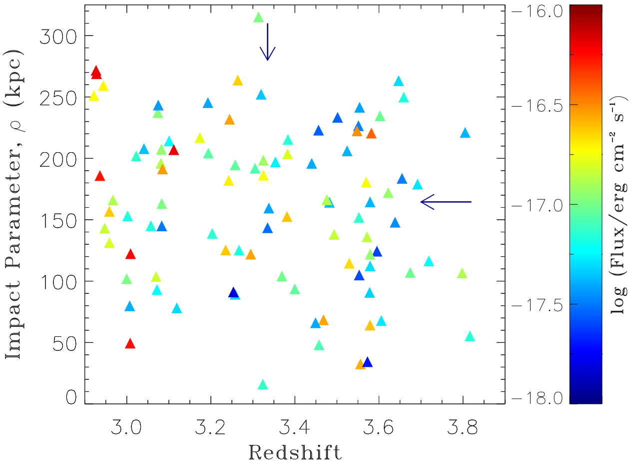
☐ UVES observations

- 8 VLT/UVES quasar spectra
- $R \approx 45{,}000$ & S/N ≈ 70–100 per pixel!
- Targeted absorption lines: H I, C IV, Si IV

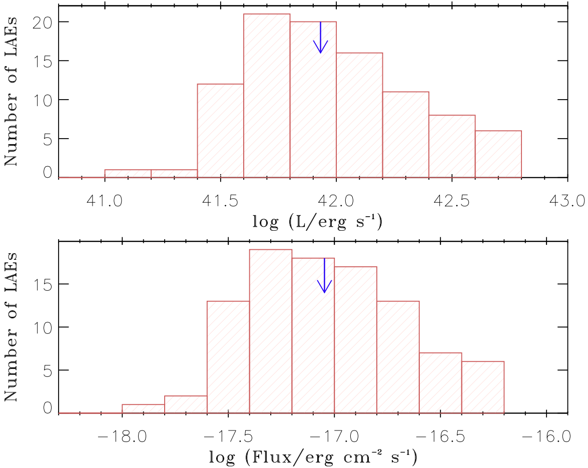


$\approx$ 100 LAEs are detected (Muzahid et al., In prep.)

★ First-ever systematic survey of the CGM of Lyα emitters
★ The largest sample for studying the CGM of high-z galaxies ($z > 3$, $\rho < 300$ kpc)

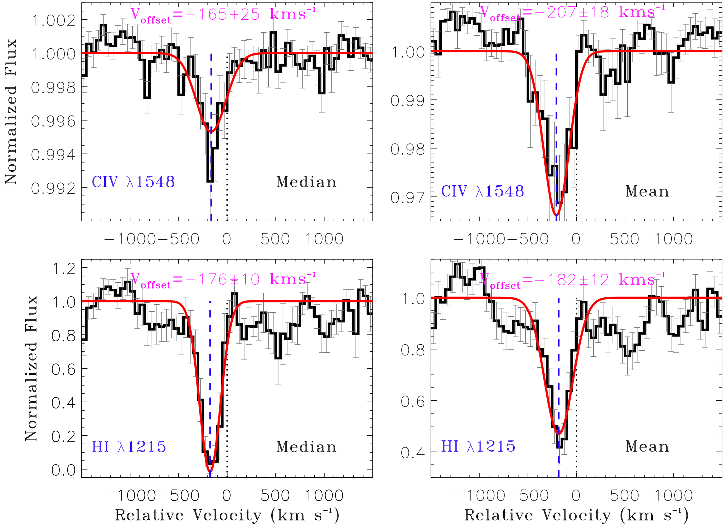


☐ Median $z \approx 3.33$, Median $\rho \approx 165$ kpc

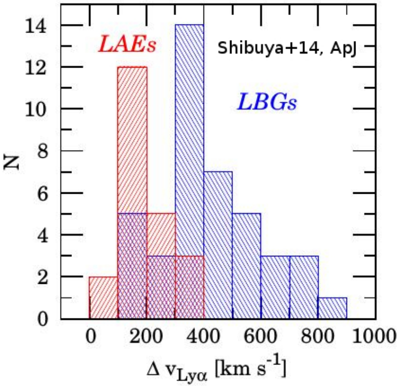


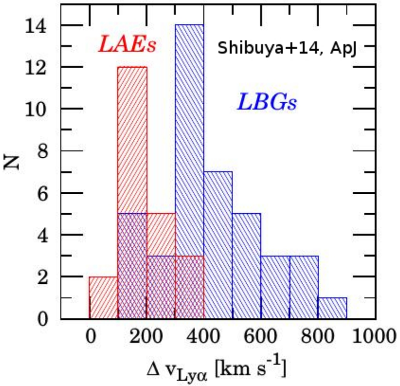
☐ Median Flux ≈ 10^{-17} erg cm^{-2} s^{-1} ☐ Median Luminosity ≈ 10^{42} erg s^{-1}

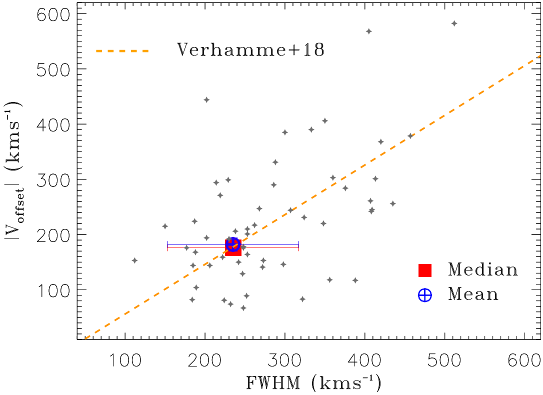
☐ Median M_{halo} ∼ $10^{10.5} M_{\odot}$ (Khostovan+18); Median R_{vir} ∼ 25 kpc



☐ Lines are blueshifted by $V_{\rm offset} > 160 - 210$ km s^{-1}

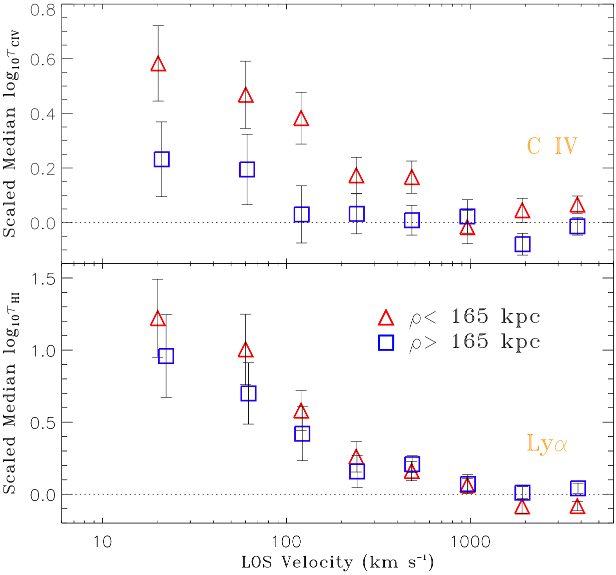

LAEs
Shibuya+14, ApJ
LBGs
N
0
2
4
6
8
10
12
14
0
200
400
600
800
1000
Δ v_Lyα [km s^-1]





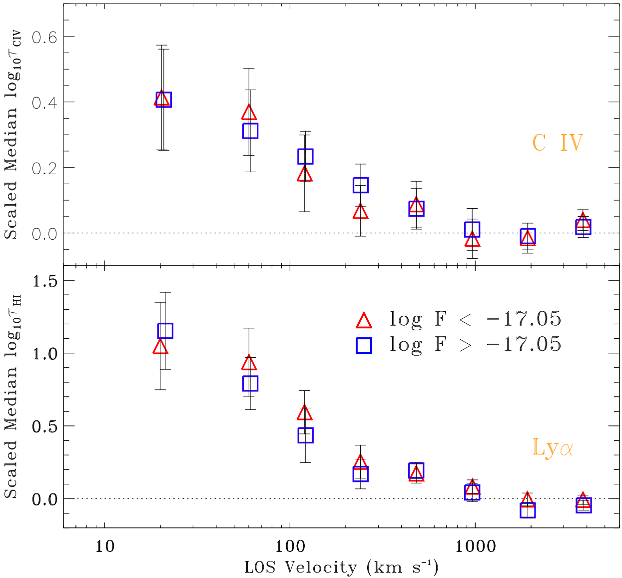
$$|V_{\rm offset}| = 0.9(\pm 0.14) \times {\rm FHWM} - 34(\pm 60)\ {\rm km\ s^{-1}}$$

- Our analysis is consistent with such an empirical relation
- We use this relation to calibrate the Lyα redshifts



- Both gas and metals are widespread out to ≈ 200 kpc ($> 5\boldsymbol{R}_{\mathrm{vir}}$)
- C IV shows a strong impact parameter dependence

$< \rho_{\mathrm{high}} >= 214 \pm 32$ kpc
$< \rho_{\mathrm{low}} >= 115 \pm 38$ kpc



- CGM does not care about ***f*(Lyα)**

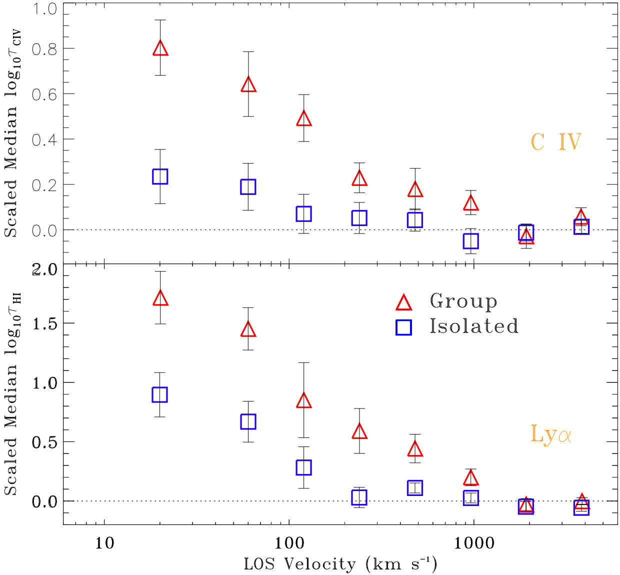
⟶ ***f*(Lyα)** does not correlate well with any galaxy property

⟶ We do not have a large dynamic range in ***f*(Lyα)**

$< \log F >_{high} = -16.75 \pm 0.25$

$< \log F >_{low} = -17.32 \pm 0.17$

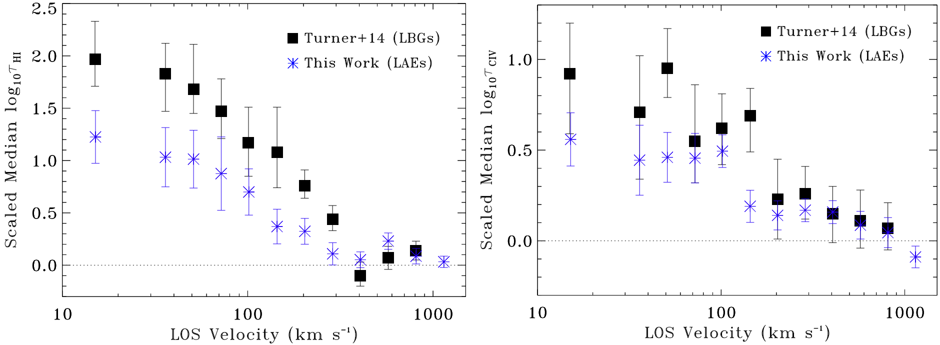
Results: (strong) Environment Dependence



- Isolated: One and only one LAE within the MUSE FoV and within ± 500 km s^{-1} of $z_{\rm LAE}$
- Group: More than one LAEs within the MUSE FoV and within ± 500 km s^{-1} of $z_{\rm LAE}$

□ Strong environment dependence of the CGM ⟶ mass dependence

Results: LBGs vs LAEs



- The CGM of LBGs ($M_{\rm halo} \sim 10^{12} M_\odot$) is more rich in gas (and metal) than the LAEs

Redshift (2.3 vs 3.3) Dependence?

or

Mass ($10^{12.0} M_\odot$ vs $10^{10.5} M_\odot$) Dependence?

Summary:

- We present the first-ever (and statistical) sample of LAEs for CGM study
- CGM absorption can be used to calibrate Lyα redshifts
- Gas and metals are widespread ($> 5R_{\rm vir}$) around LAEs
- CGM absorption shows strong impact parameter and environmental dependence but does not show any dependence on f(Lyα)
- LBGs show stronger CGM absorption compared to LAEs, likely due to higher mass

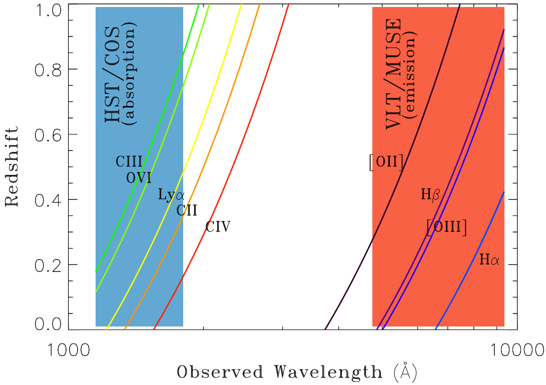
MUSEQuBES (Low-z)

□ MUSE observations

- 16 QSO fields (Depths: 2–10 hrs)
- 65 hrs of MUSE GTO observations
- Targeted emission lines:
  Hα, [O III], Hβ, [OII]

□ COS observations

- 16 HST/COS spectra of QSOs
- $z_{\rm qso}$: 0.5–1.5
- $R \approx$ 20,000; S/N ≈10–40
- Targeted absorption lines:
  H I, C II, C III, C IV, O VI



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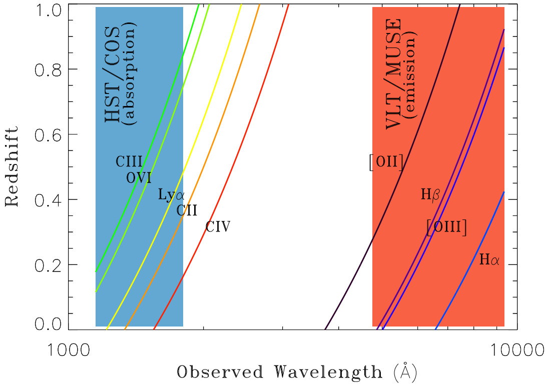
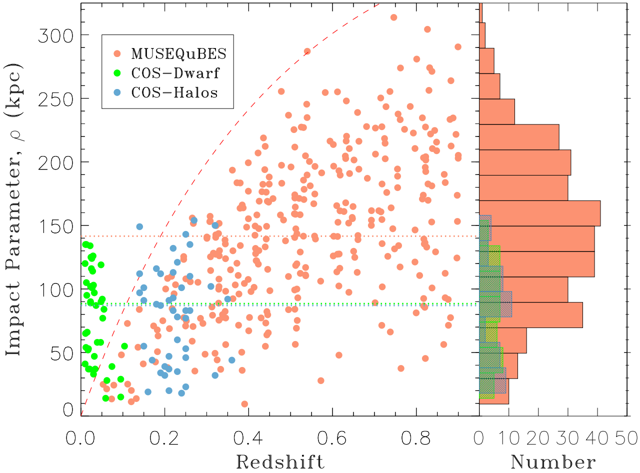


☐ Ancillary Data:

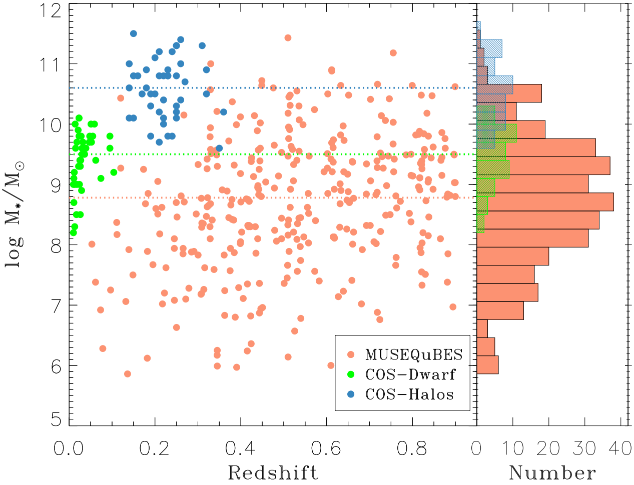
HST/ACS (for all): Galaxy morphology
VLT/UVES (for some): Absorption kinematics
IMACS, LDSS3 (for some): Large FoV – more galaxies

MUSEQuBES (Low-z): The Galaxy Sample



- 338 Galaxies (continuum selected; ≈10 times larger than COS-Halos/COS-Dwarf surveys)
- Impact Parameter, $\rho \approx$ 10–320 kpc
- Median $\rho \approx$ 150 kpc (≈2 times higher than COS-Halos/COS-Dwarf surveys)

MUSEQuBES (Low-z): The Galaxy Sample



- Wide redshift range: 0.01–0.90 (Median $z_{\rm gal}$ ≈0.5)
- Wide $\log M_*/M_\odot$ range: 6.0–11.4 (Median $\log M_*/M_\odot$ ≈8.8)
- Median $\log M_*/M_\odot$ is >10 (>5) times lower than COS-Halos (COS-Dwarf) surveys