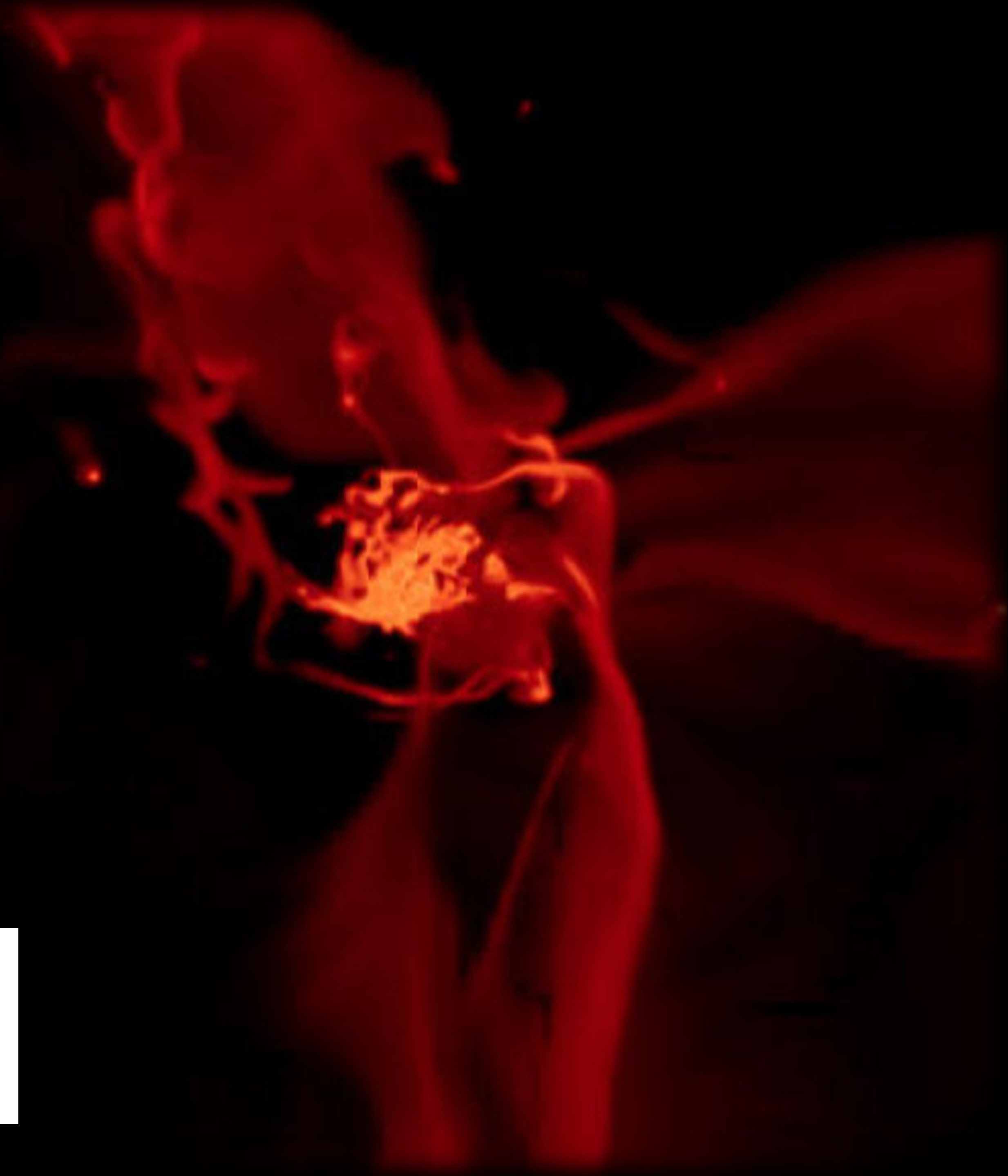
The co-evolution of galaxies and their CGM: a SHARP perspective

Matteo Fossati
Università Milano-Bicocca



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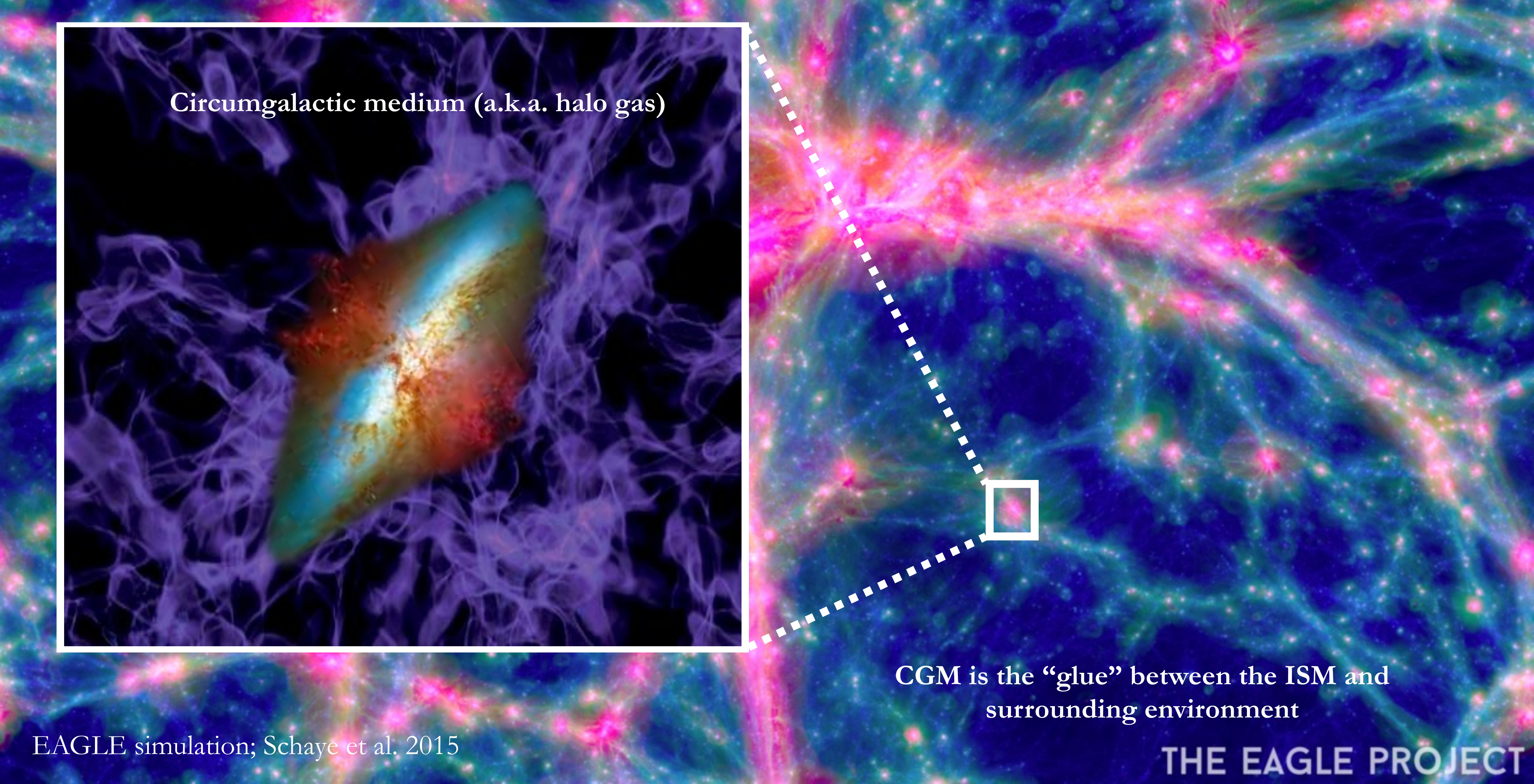
The baryon cycle through the circumgalactic medium

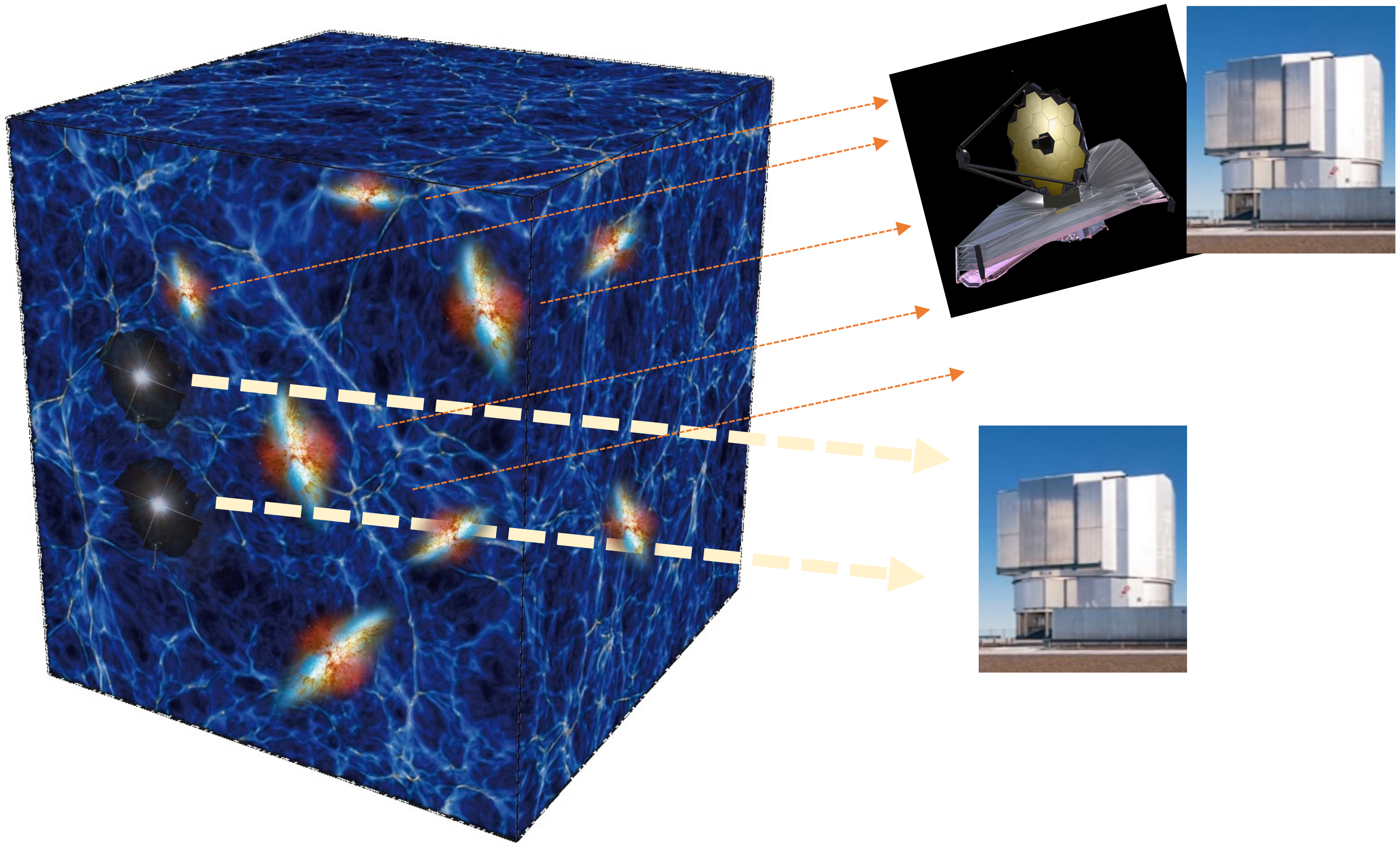


EAGLE simulation; Schaye et al. 2015

Linking gas and galaxies with redshift

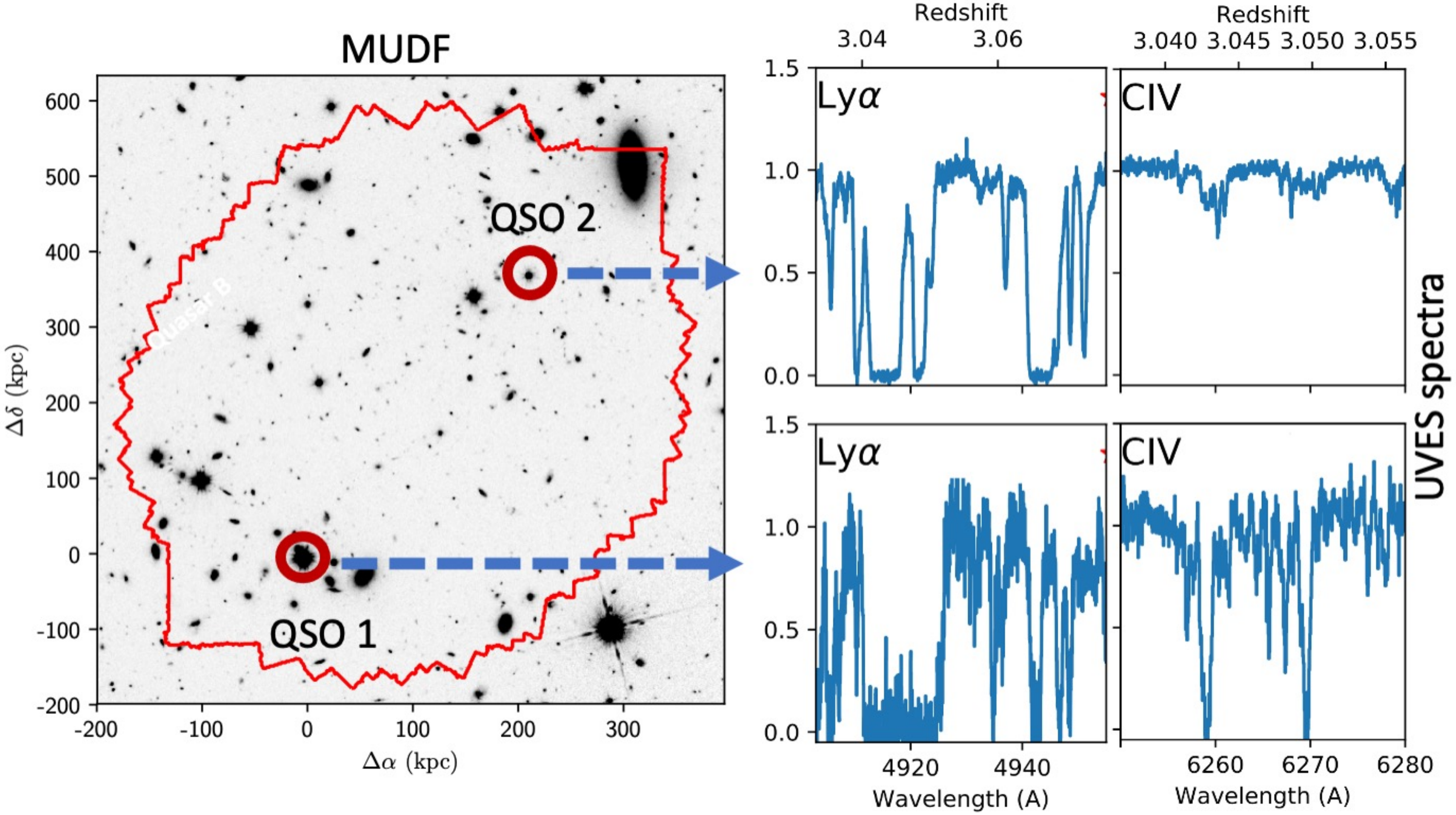
We want to constrain observationally the connection between galaxies and their IGM/CGM:

1. Combining dense spectroscopic galaxy surveys with quasar absorption spectroscopy
2. Mapping the CGM in emission and linking its properties to galaxies



IFUs at 8m telescopes are enabling the next leap

IFUs (and slitless spectrographs) have the great advantage of avoiding pre-selection and thus allow for complete surveys including continuum-faint line emitters on scales <1 Mpc



MUDF: the MUSE Ultra Deep Field (Lusso et al. 2019, Fossati et al. 2019)

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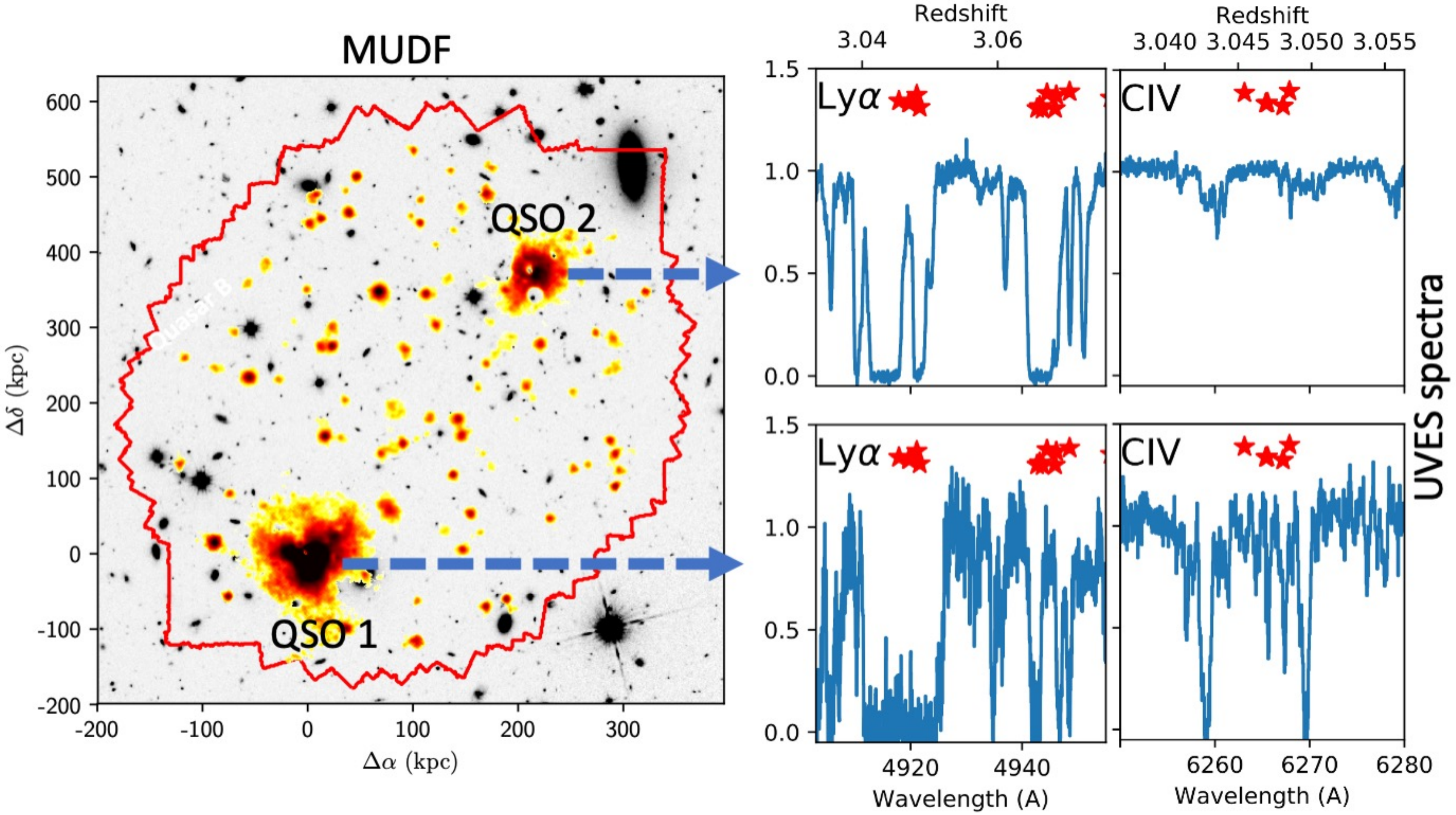
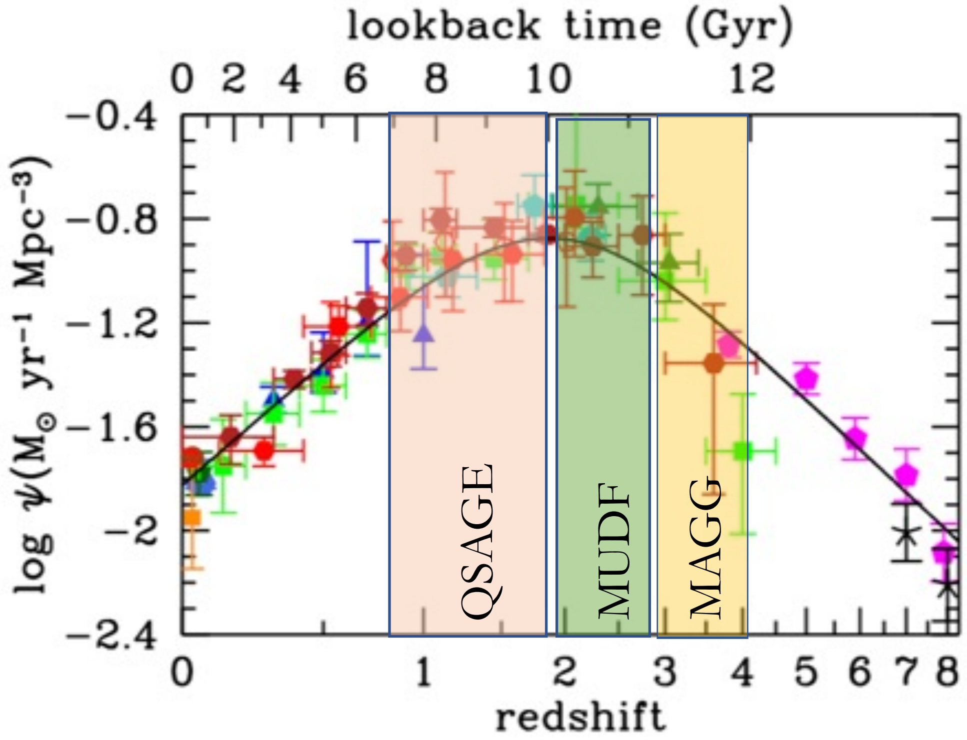


The tools: large surveys at large telescopes



Adapted from Madau & Dickinson 2014

MAGG: a MUSE analysis of gas around galaxies

Medium-depth (5h) observations of 28 z>3.5 quasars with ~70 intervening DLAs/LLSs, 200 CIV, and 114 MgIIs

MUDF: the MUSE + HST ultra-deep field

Ultra-deep MUSE (200h) and HST/WFC3 G141 (90 orbits) observations of a z~3.2 quasar pair with 25 intervening absorbers

QSAGE: Quasar Sightline and Galaxy Evolution survey

Medium-deep HST/WFC3 G141 (8 orbits/quasar) observations of 12 z > 1.2 quasars with MUSE and UV+optical spectroscopy

MAGG papers on NASA/ADS

MUDF papers on NASA/ADS

Outline

1. Newly found ability to trace both hydrogen and metals in emission in the IGM/CGM

Detection of cosmic web filaments, and enriched halos of quasars and normal star-forming galaxies

2. The galaxy environment modifies the properties of the CGM

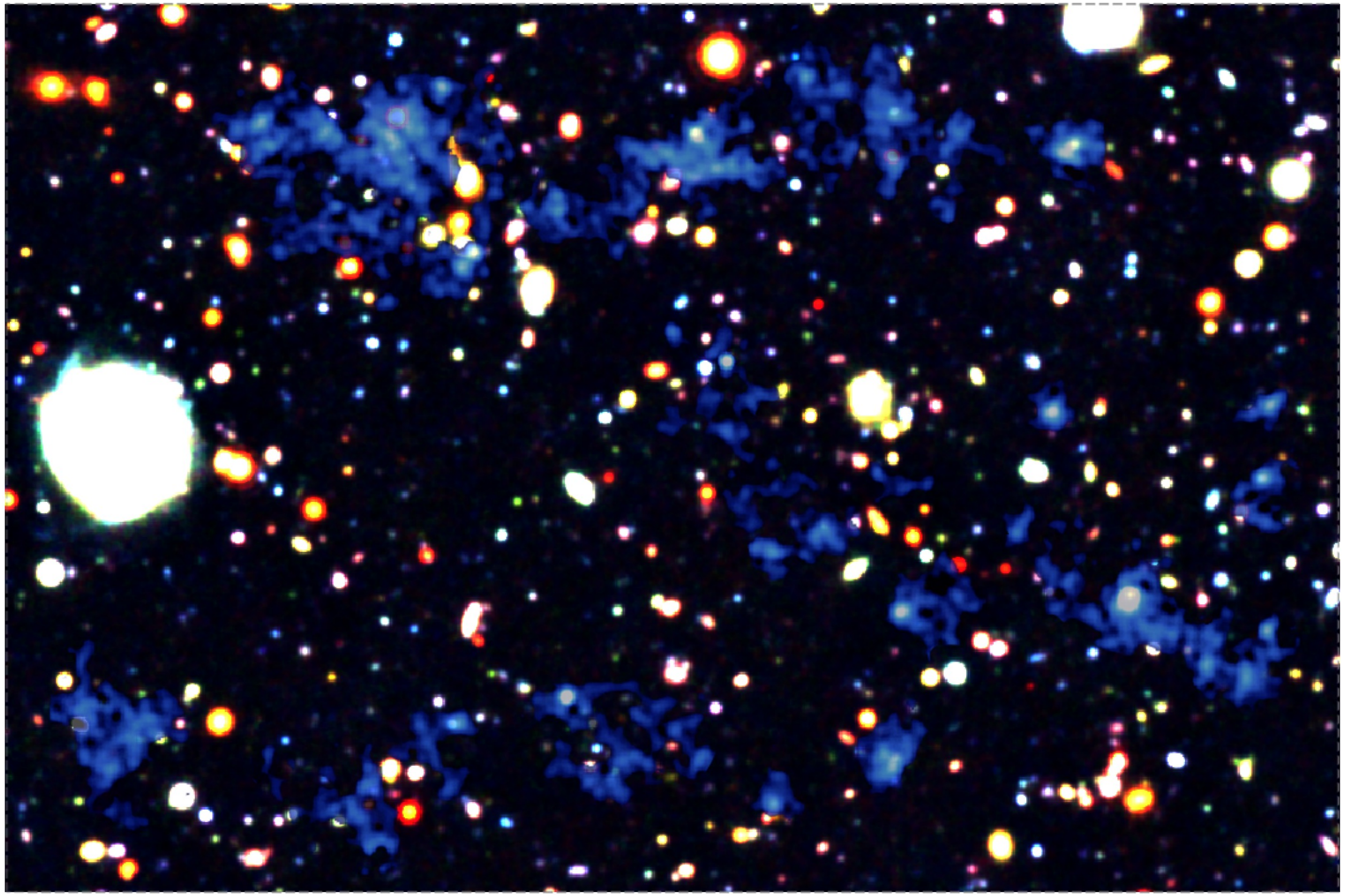
Evidence of more extended metal cross section in group galaxies versus more isolated systems

3. A SHARP perspective on gas feeding and the CGM

1. Hydrogen and metals in emission in the IGM/CGM

MUSE has enabled the detection of cosmic web filaments, and enriched halos of quasars and normal star-forming galaxies

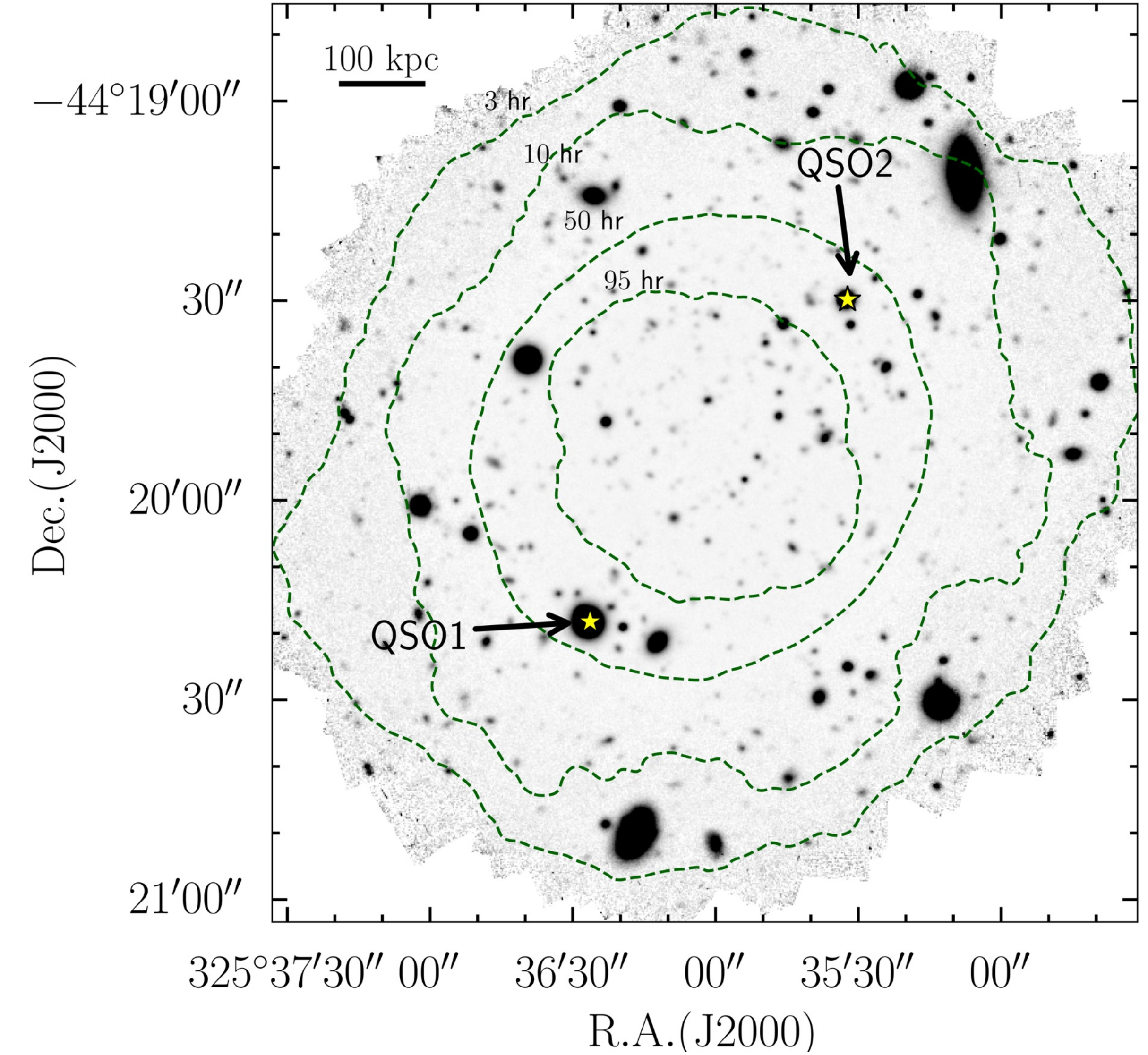
Example of >1Mpc scale filaments in SSA22



Umehata et al. 2019

1. Hydrogen and metals in emission in the IGM/CGM

Dissecting the cosmic web in the 150h MUDF exposure.



Tornotti et al. 2024 (submitted)

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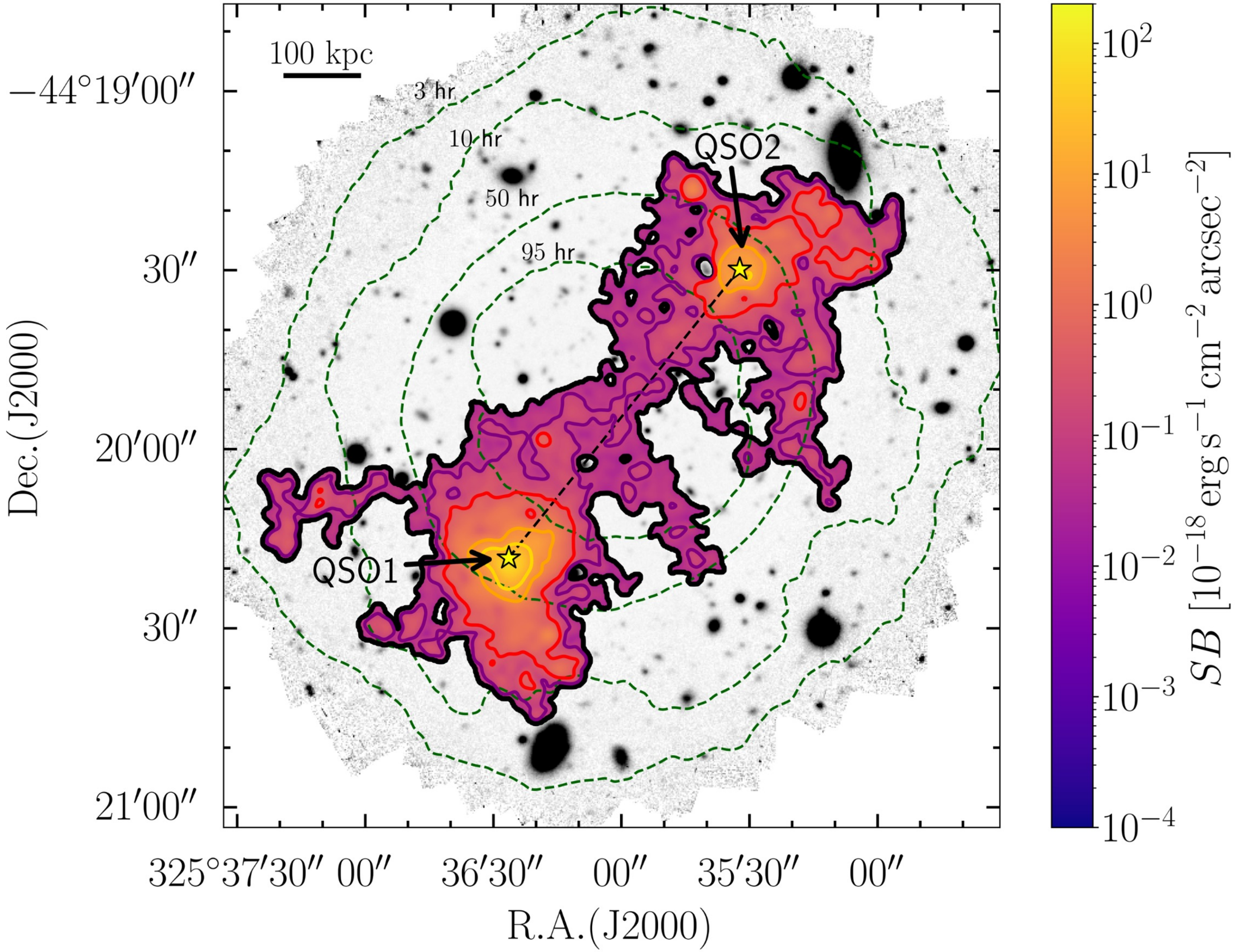
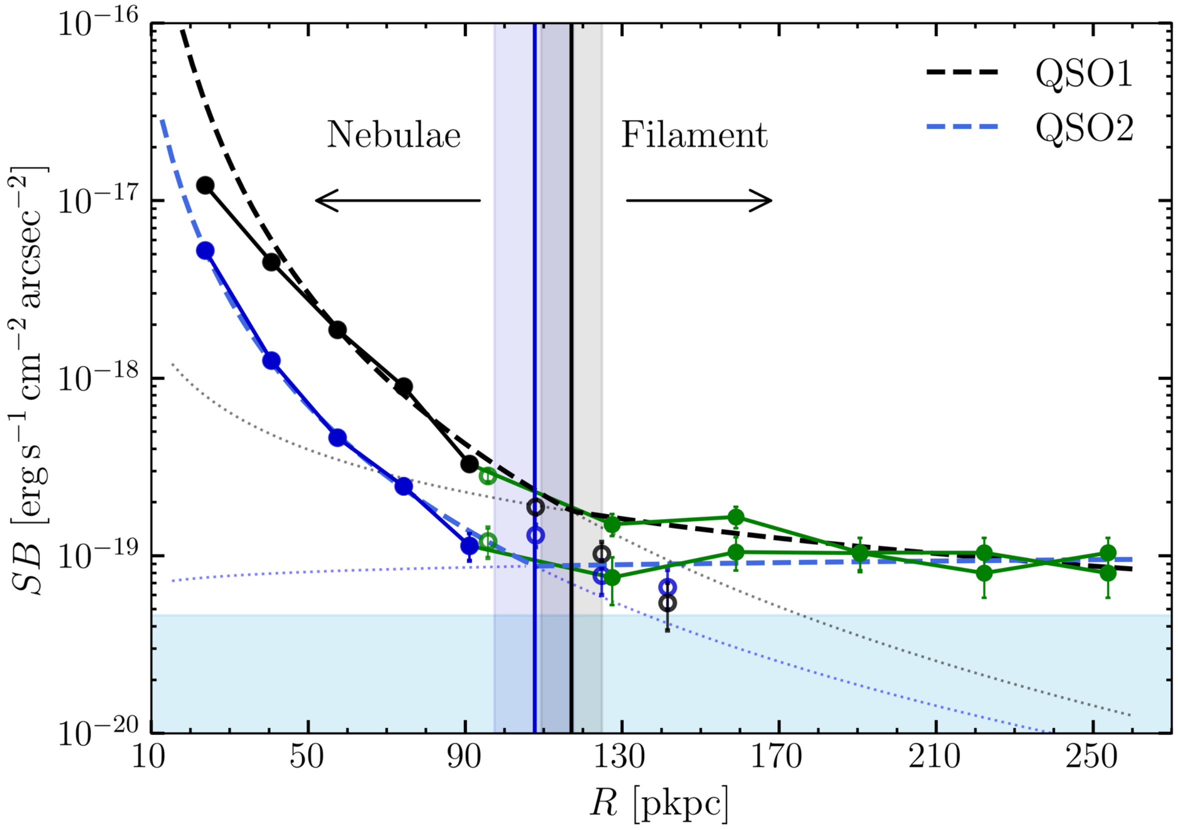


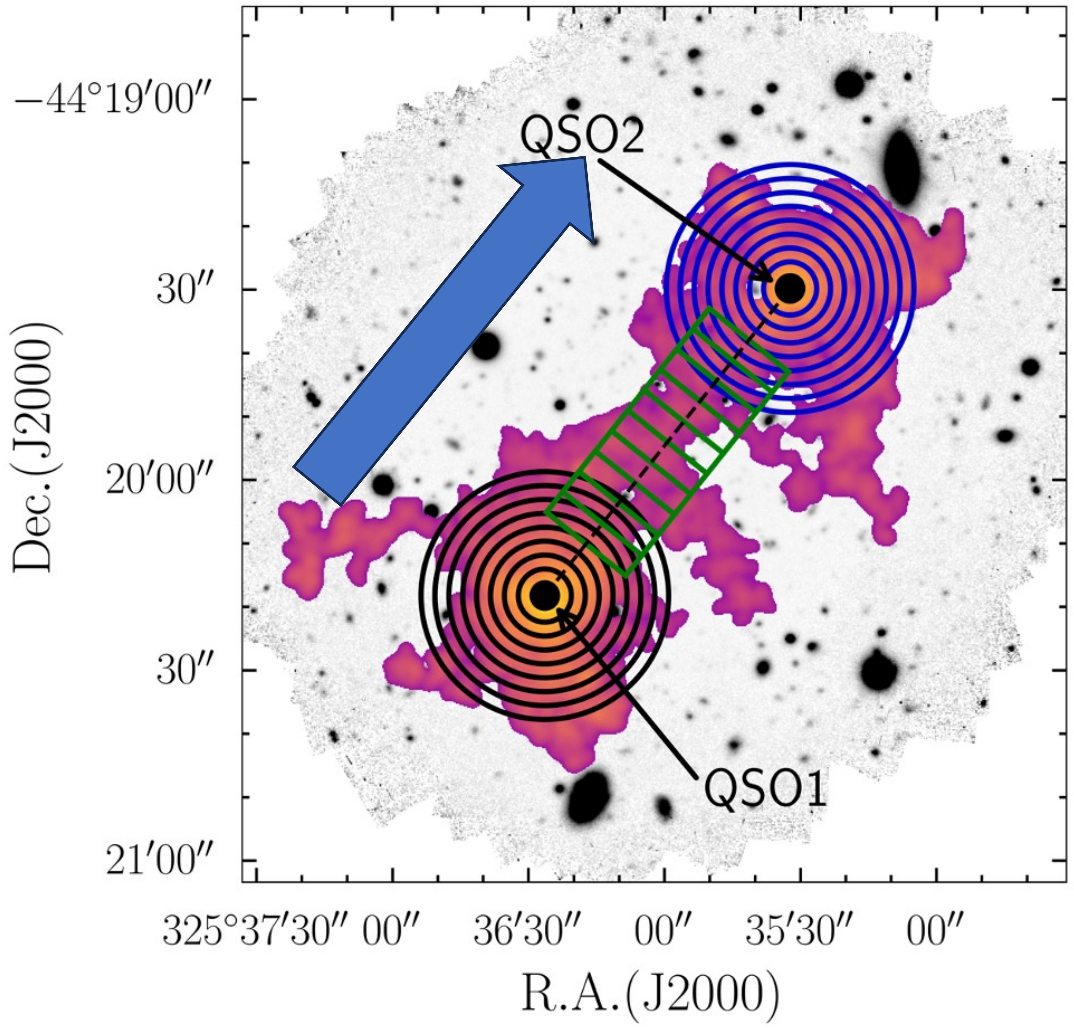
Tornotti et al. 2024 (submitted)

1. Hydrogen and metals in emission in the IGM/CGM

First measurement of the filament surface brightness profiles and of the CGM/IGM transition

Along the filament





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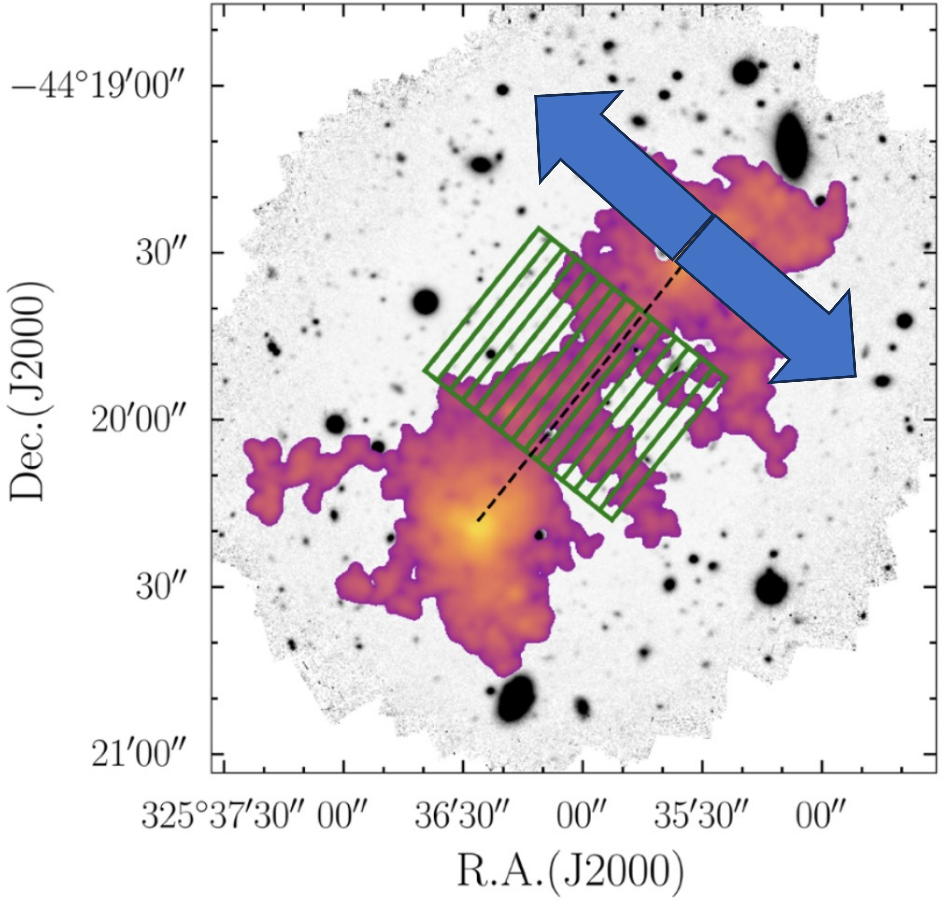
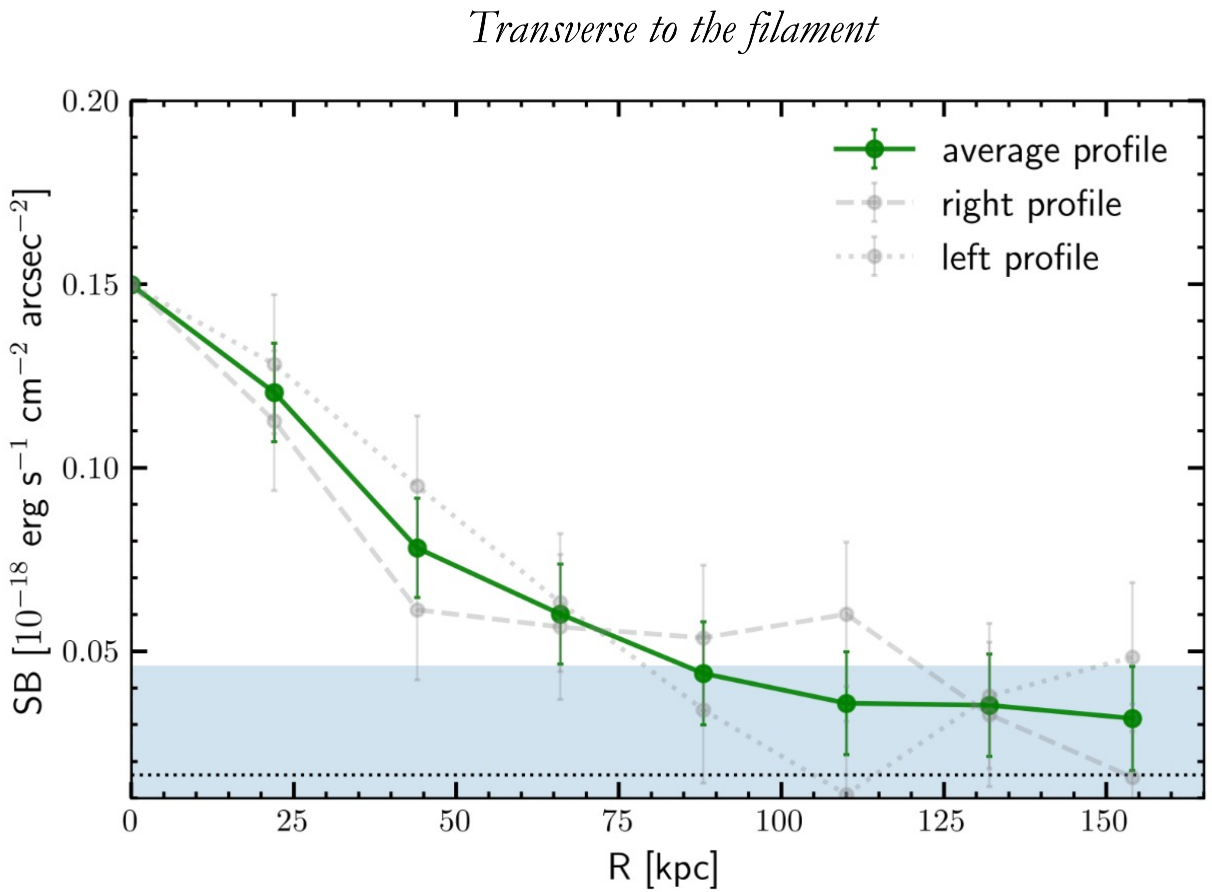
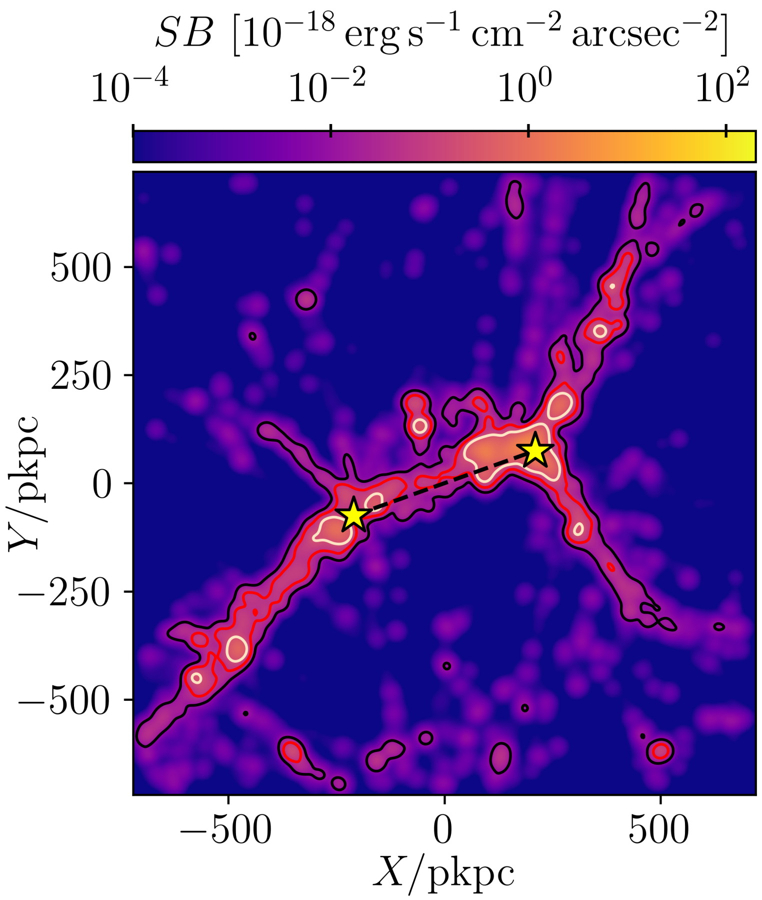


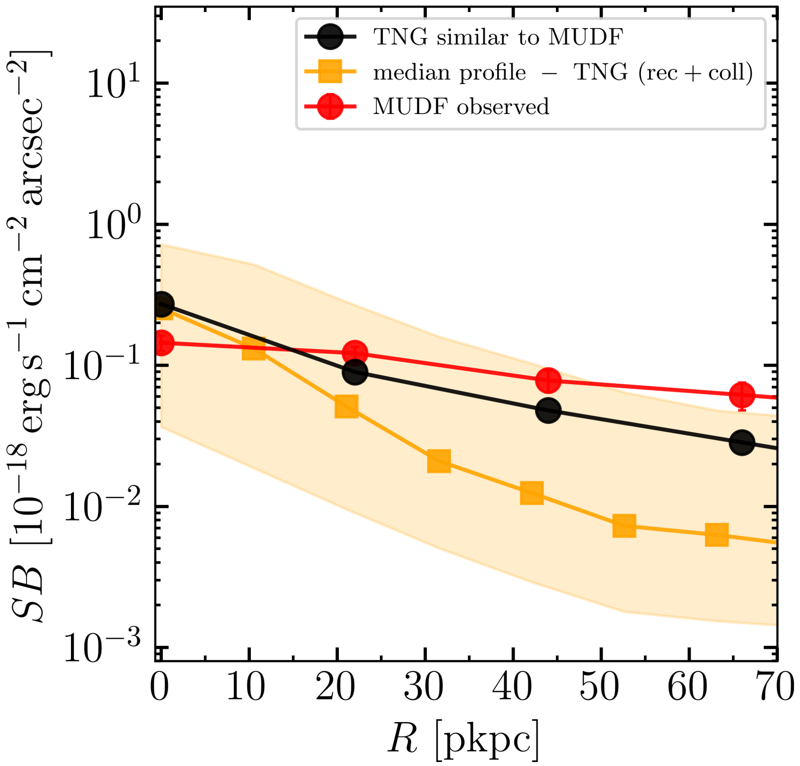


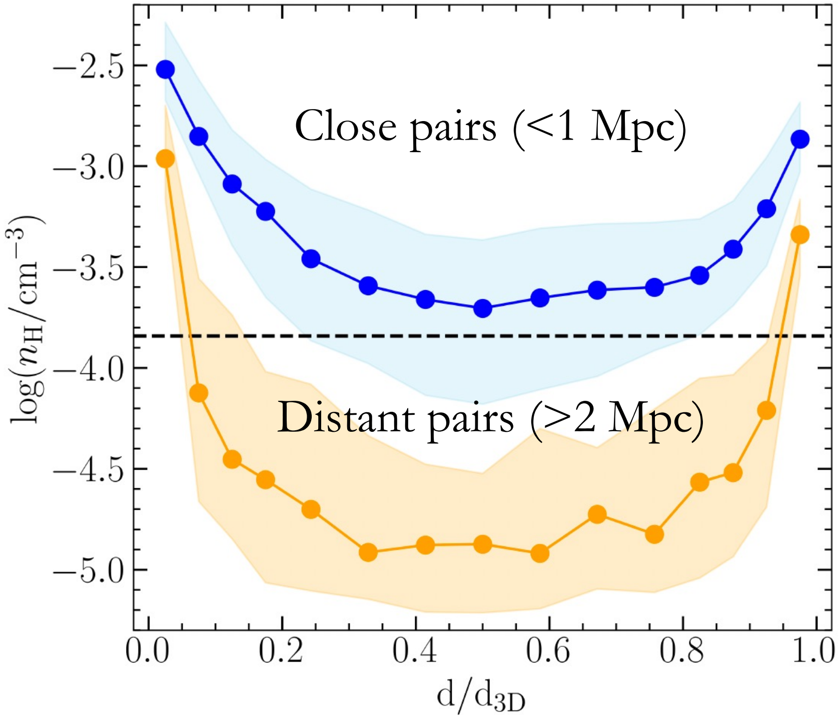
Tornotti et al. 2024 (submitted)

1. Hydrogen and metals in emission in the IGM/CGM

Constraining the filament density with numerical simulations (TNG-100)







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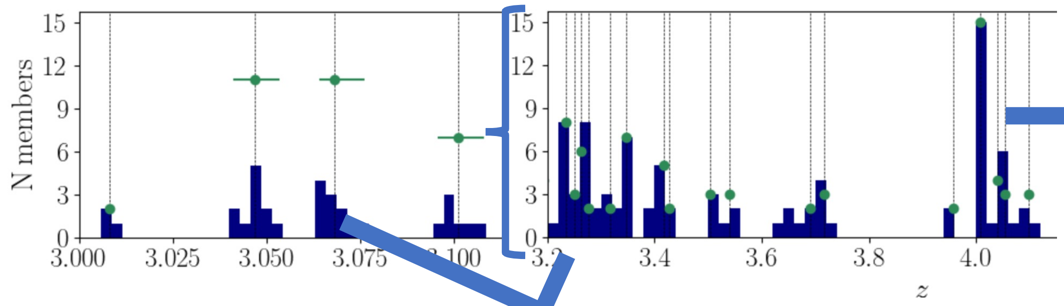
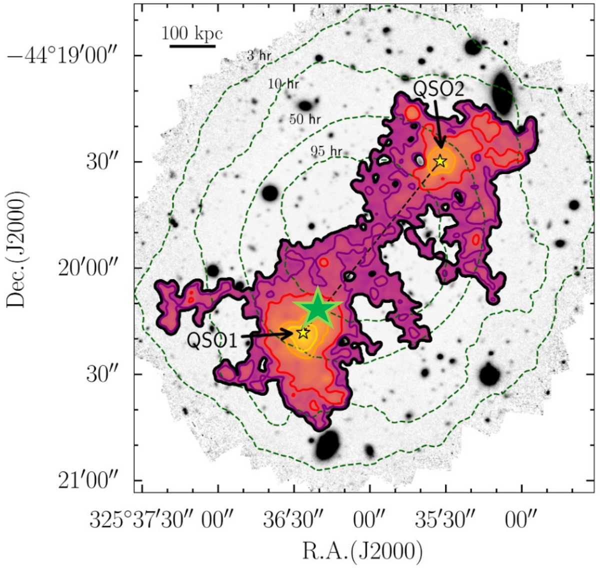
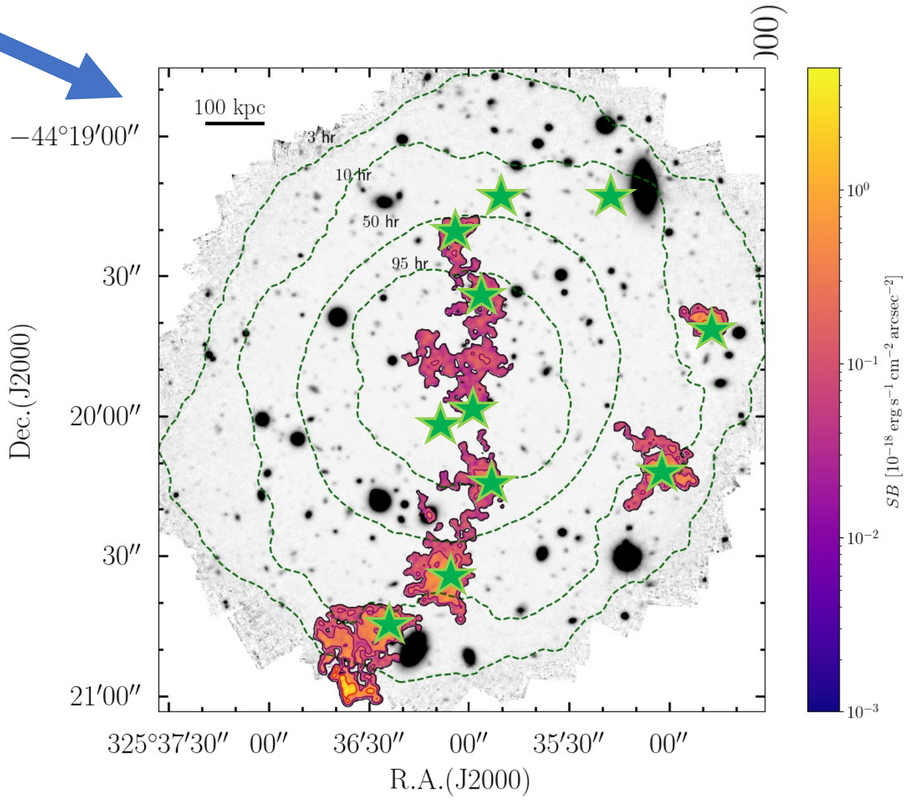
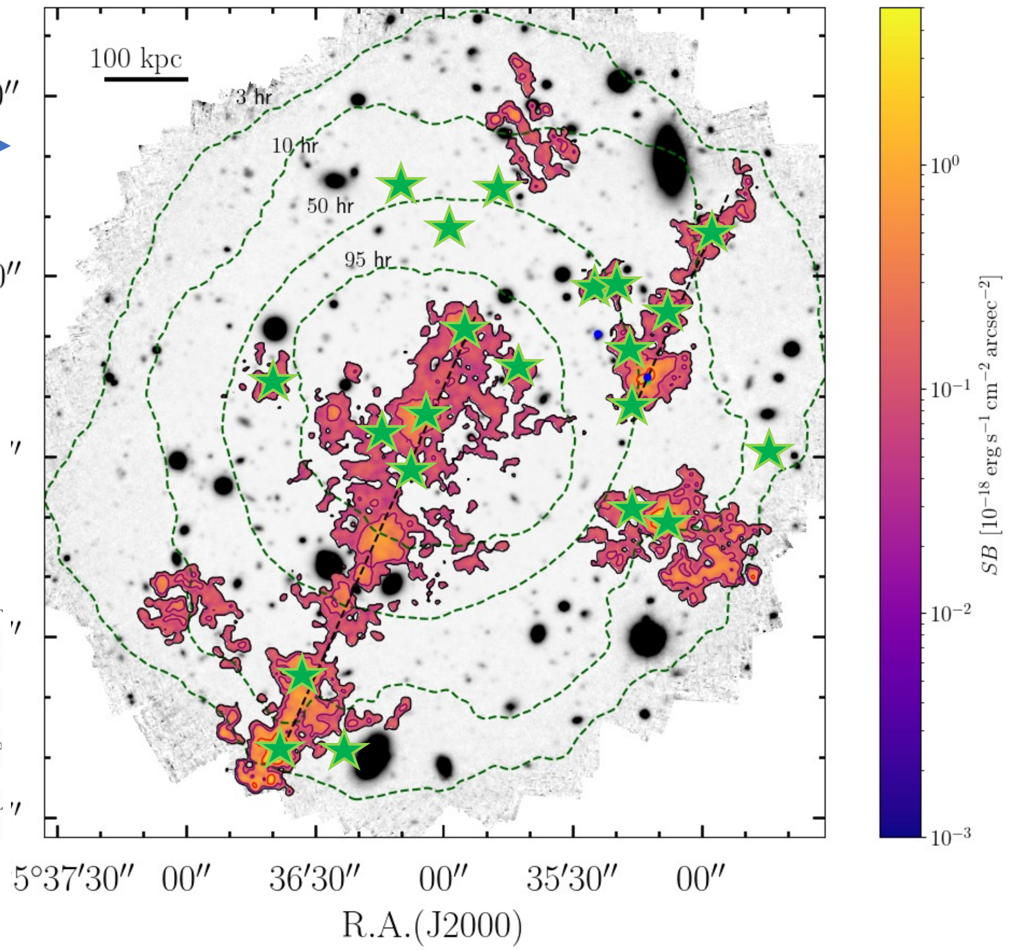






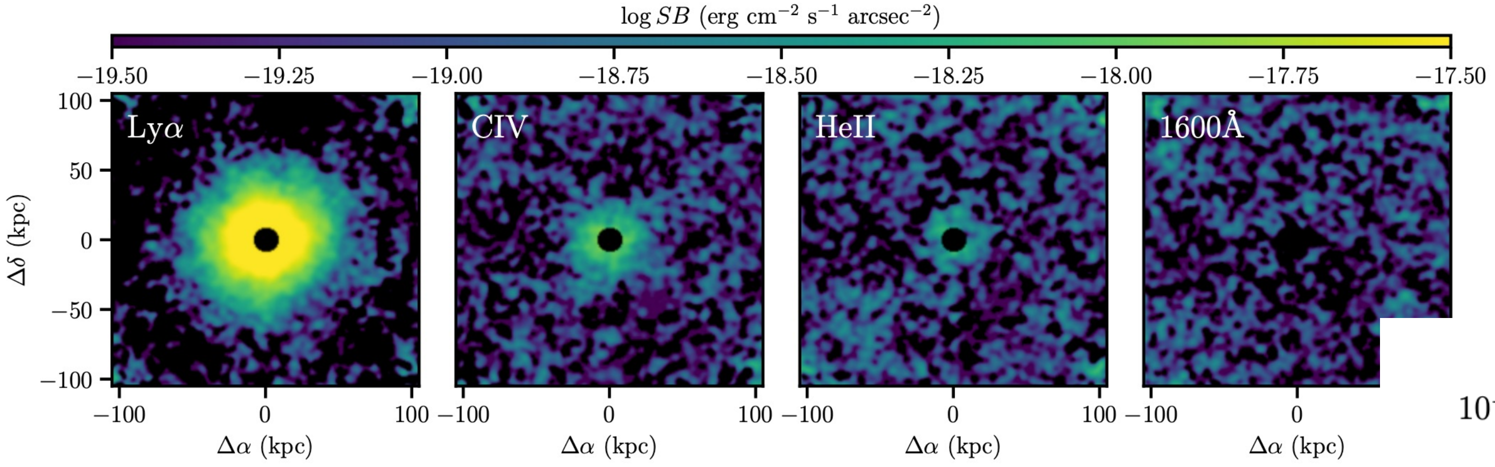


Building samples of cosmic web filaments!

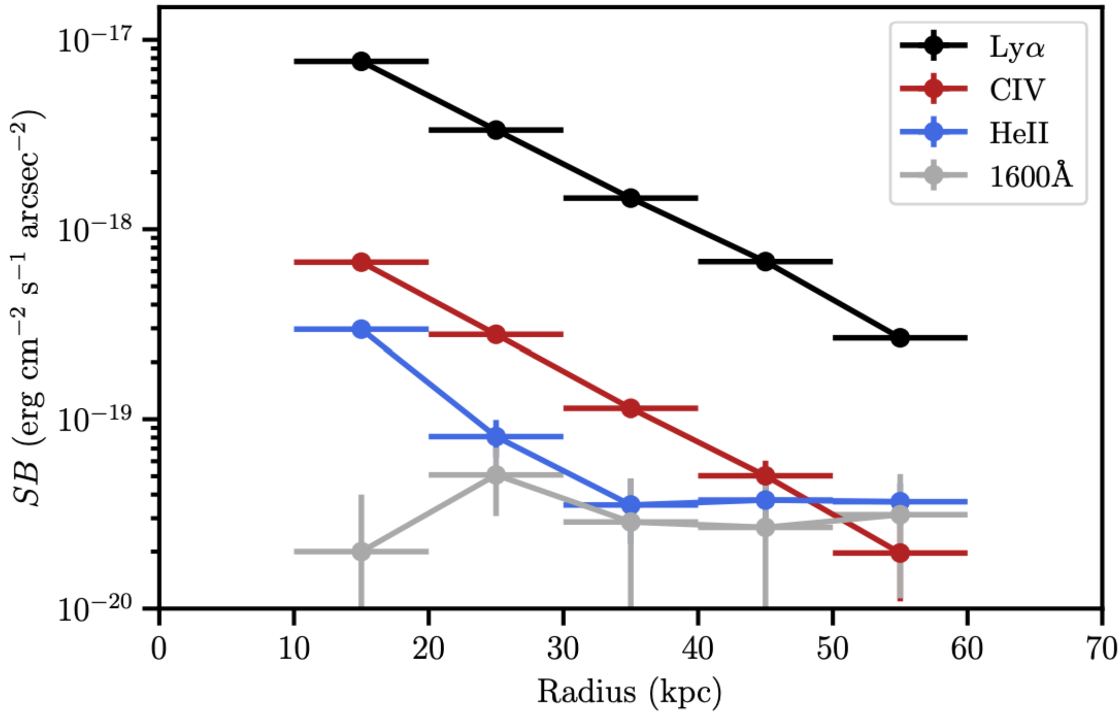
Tornotti et al. 2024b (in prep)

1. Hydrogen and metals in emission in the IGM/CGM

In MAGG, stacking reveals extended metal emission in the CGM of $z\sim3.5$ quasars



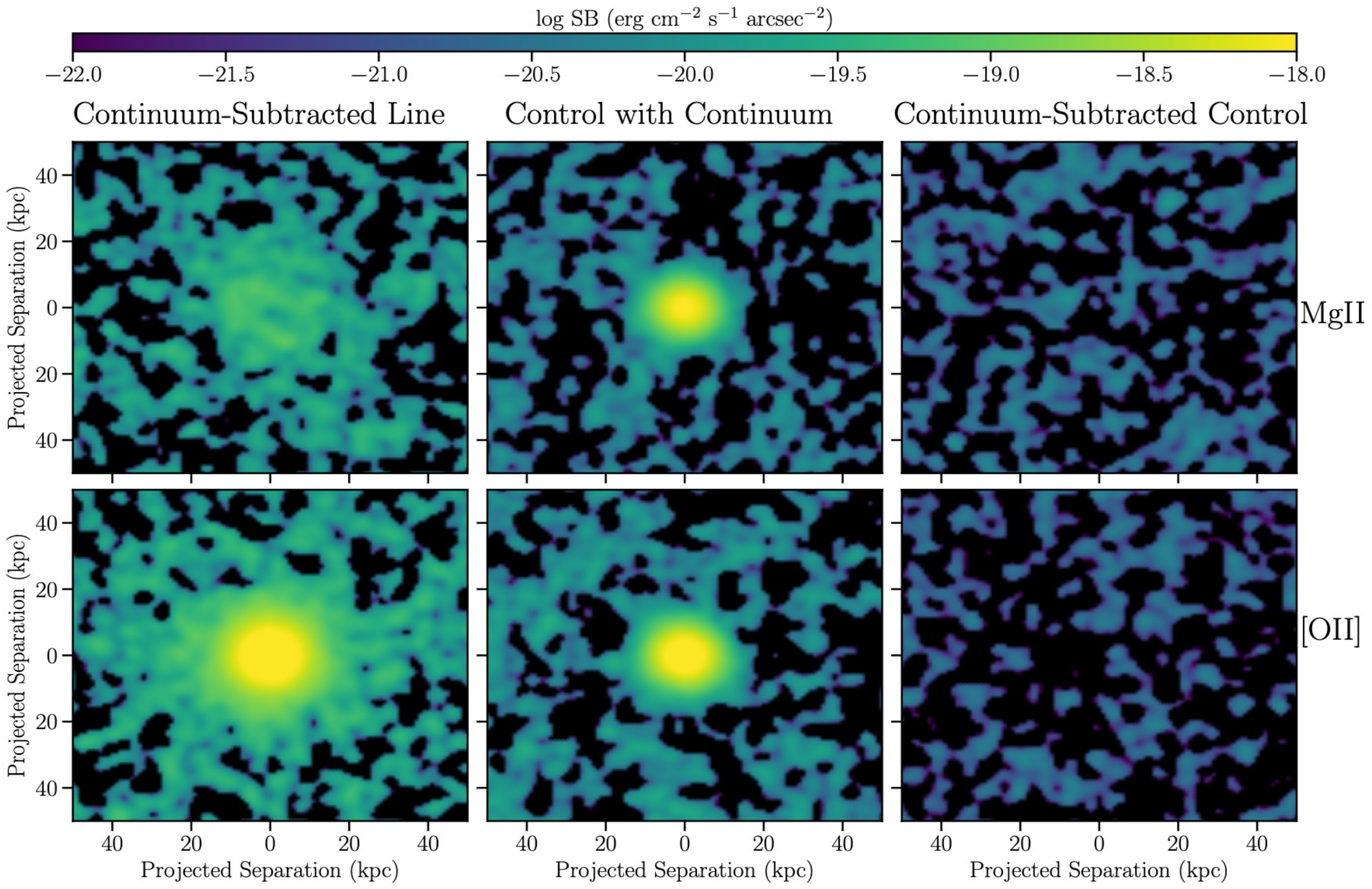
Barring difficulties in modeling the RT effects on CIV and Lyα, the CGM appears enriched to ~0.1Zsun



Fossati et al. 2021

1. Hydrogen and metals in emission in the IGM/CGM

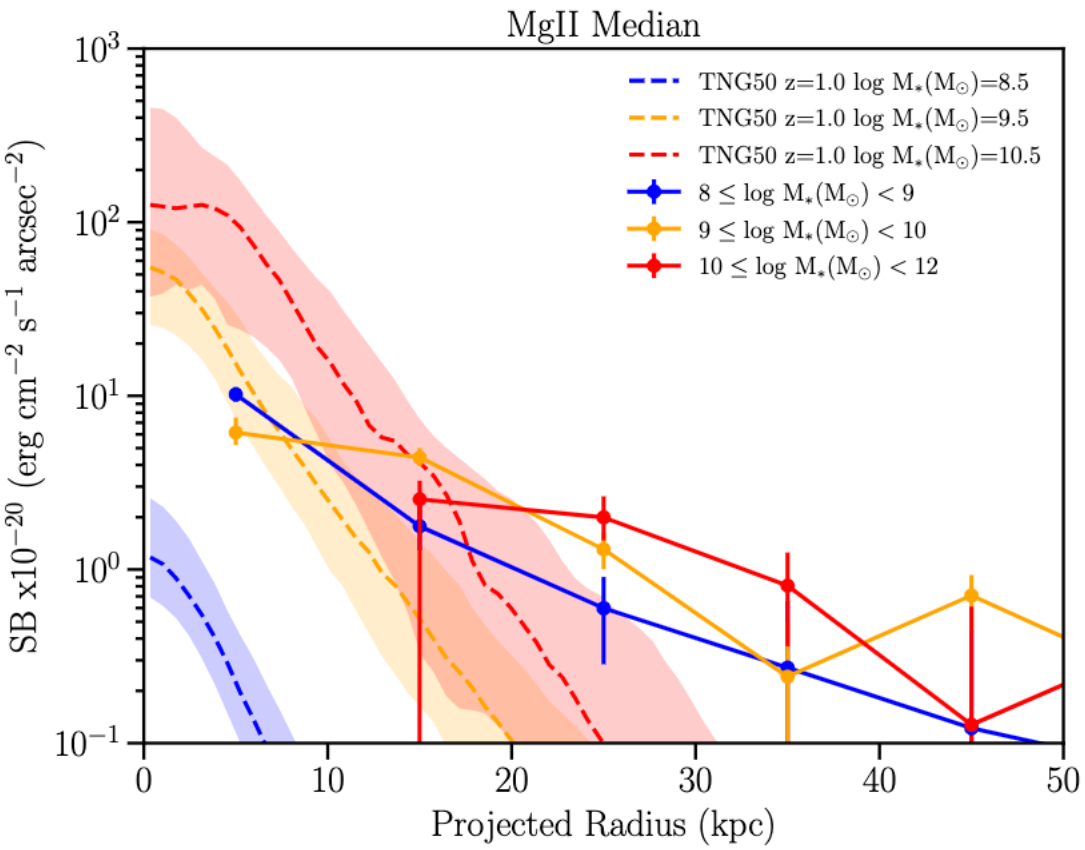
Stacks of ~500 galaxies and ~60 galaxies in MAGG and MUDF also reveal extended (>30-40 kpc) emission of [OII] and MgII in normal star-forming galaxies

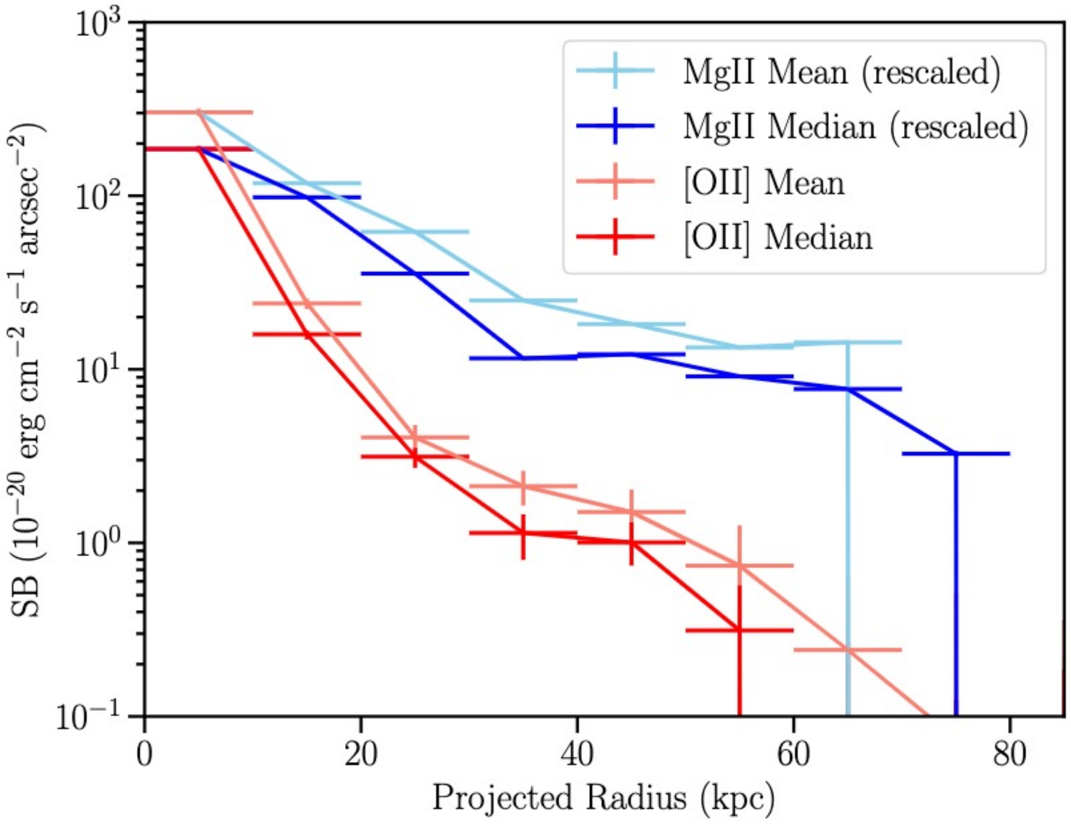


Dutta et al. 2023

1. Hydrogen and metals in emission in the IGM/CGM

Comparison between observed MgII emission and results from simulations (Nelson et al. 2021) reveals broad agreement but emphasizes the need for detailed R.T. calculations

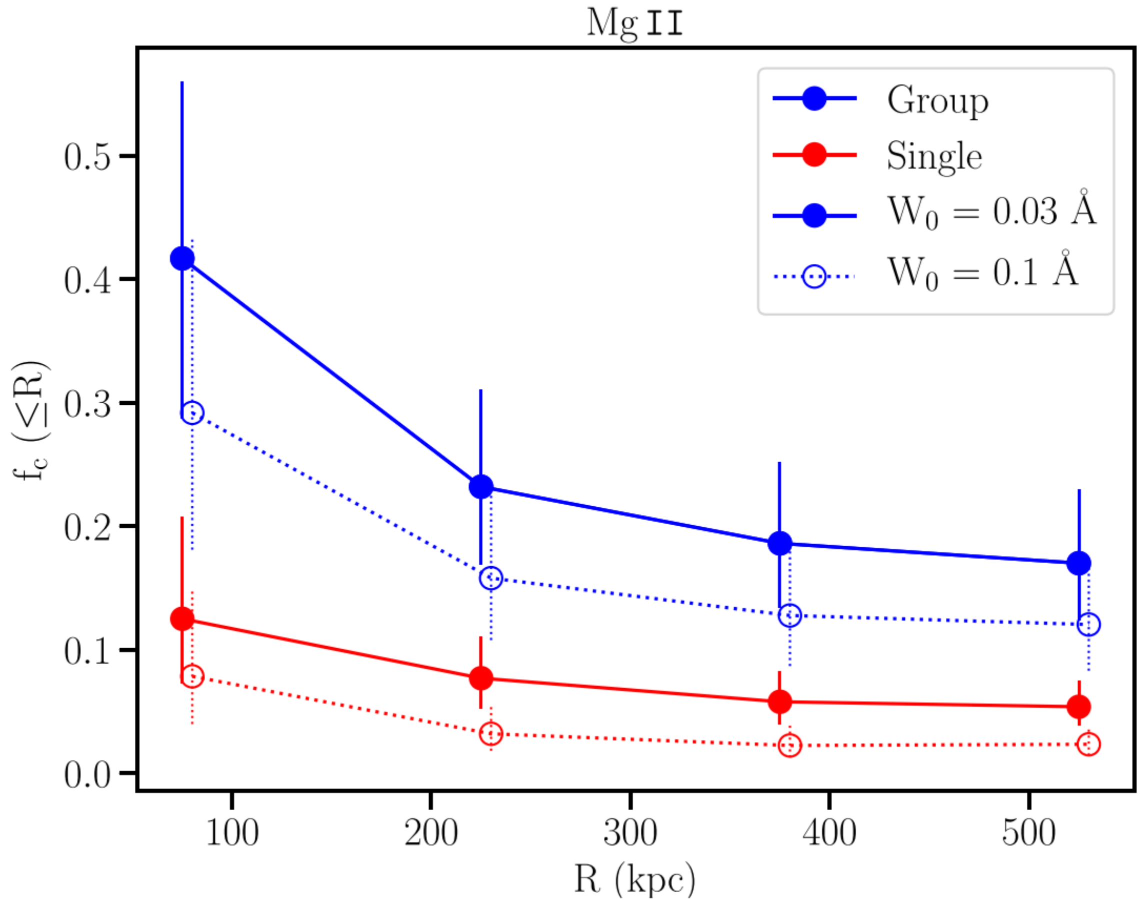




Dutta et al. 2023

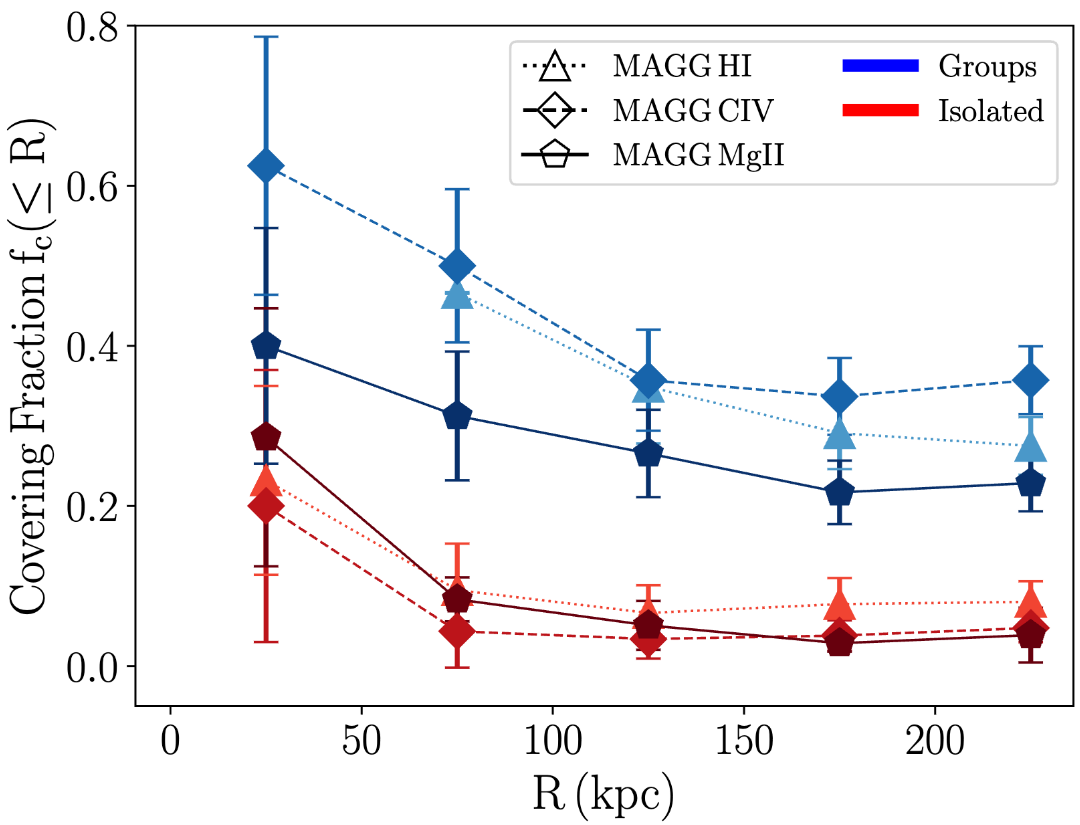
2. The galaxy environment modifies the properties of the CGM

At z~0.5-1.5, MgII absorption in group galaxies is ~2-3 times more prevalent/stronger than in isolation



Dutta et al. 2020, 2022
Fossati et al. 2019

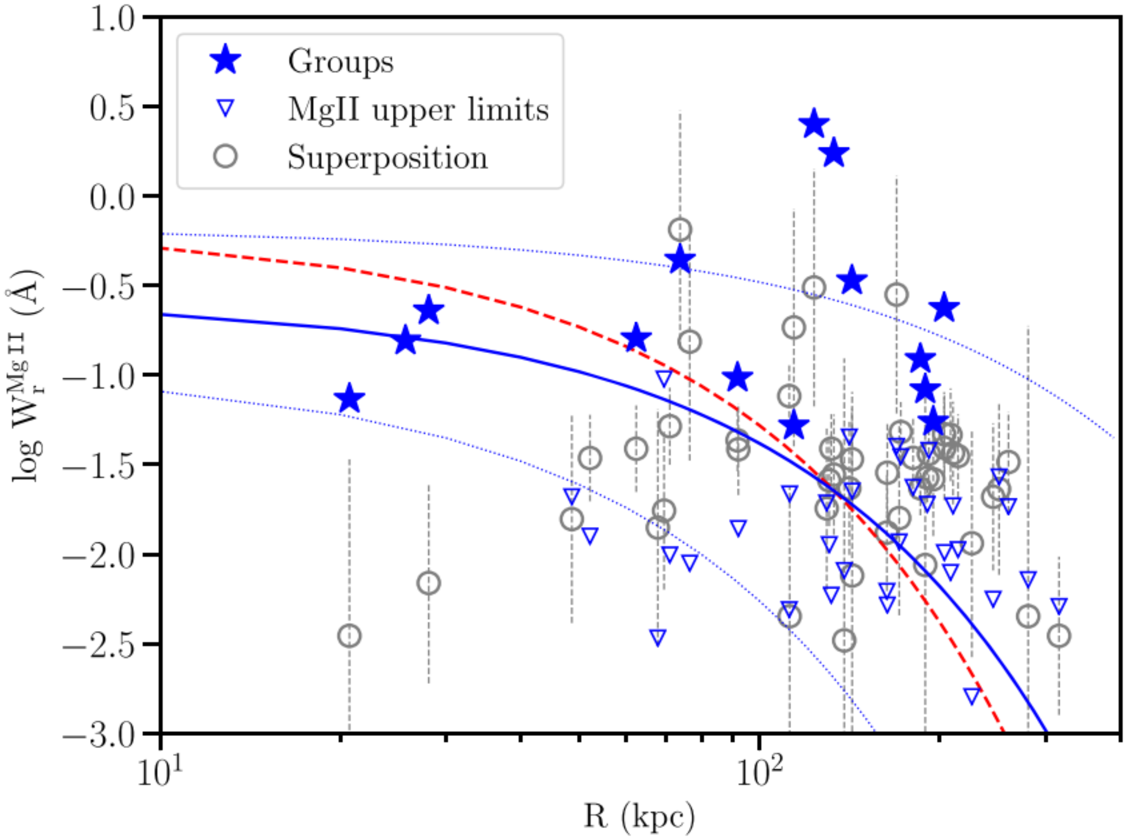
The same applies at z>3: for HI and CIV, less so for MgII

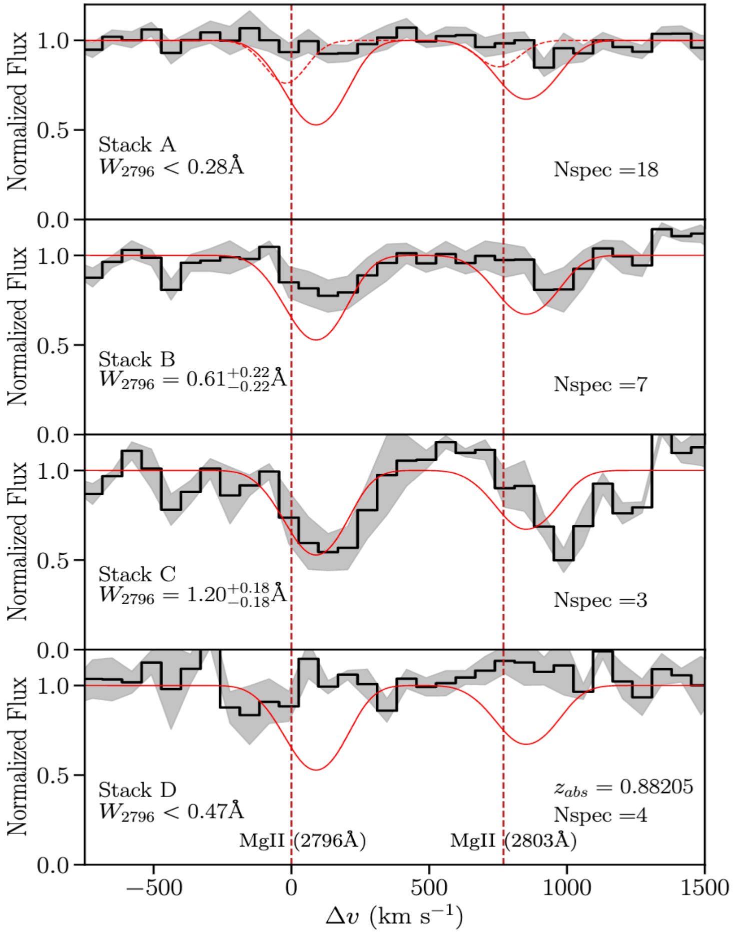


Lofthouse et al. 2023; Galbiati et al. 2023, 2024 (submitted)

2. The galaxy environment modifies the properties of the CGM

A simple superposition model account for some but not all strong absorbers in groups. Using deep stacks in MUDF, we report hints that the CGM of group galaxies is perturbed.





All

Aligned with galaxies

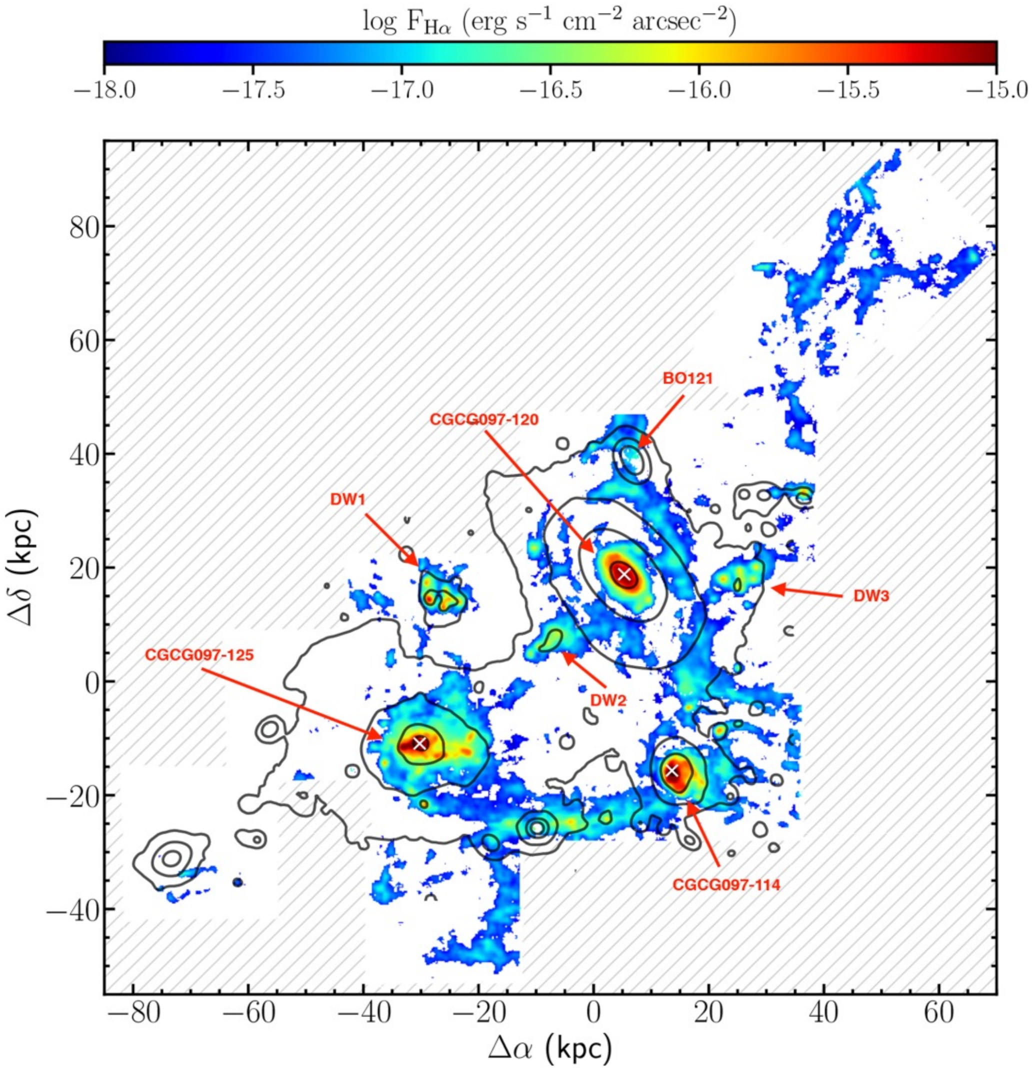
With MgII detections

Intragroup

Dutta et al. 2020, 2022
Fossati et al. 2019

2. The galaxy environment modifies the properties of the CGM

Combining MAGG, MUDF, and QSAGE we are finding more extended metal cross section in group galaxies, supporting the idea that the gas environment near star-forming galaxies depends on the density



Lofthouse et al. 2023; Galbiati et al. 2023

Dutta et al. 2020, 2022

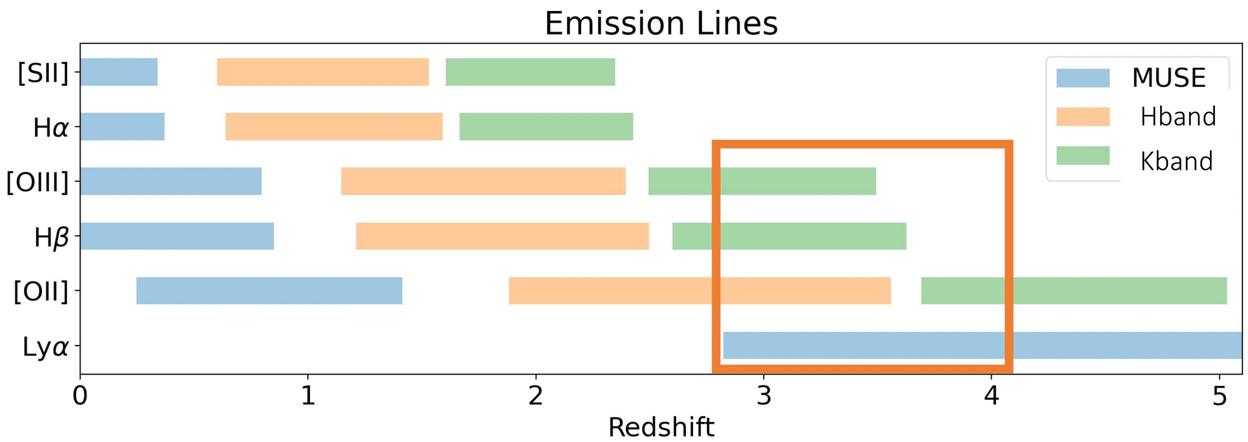
Fossati et al. 2019

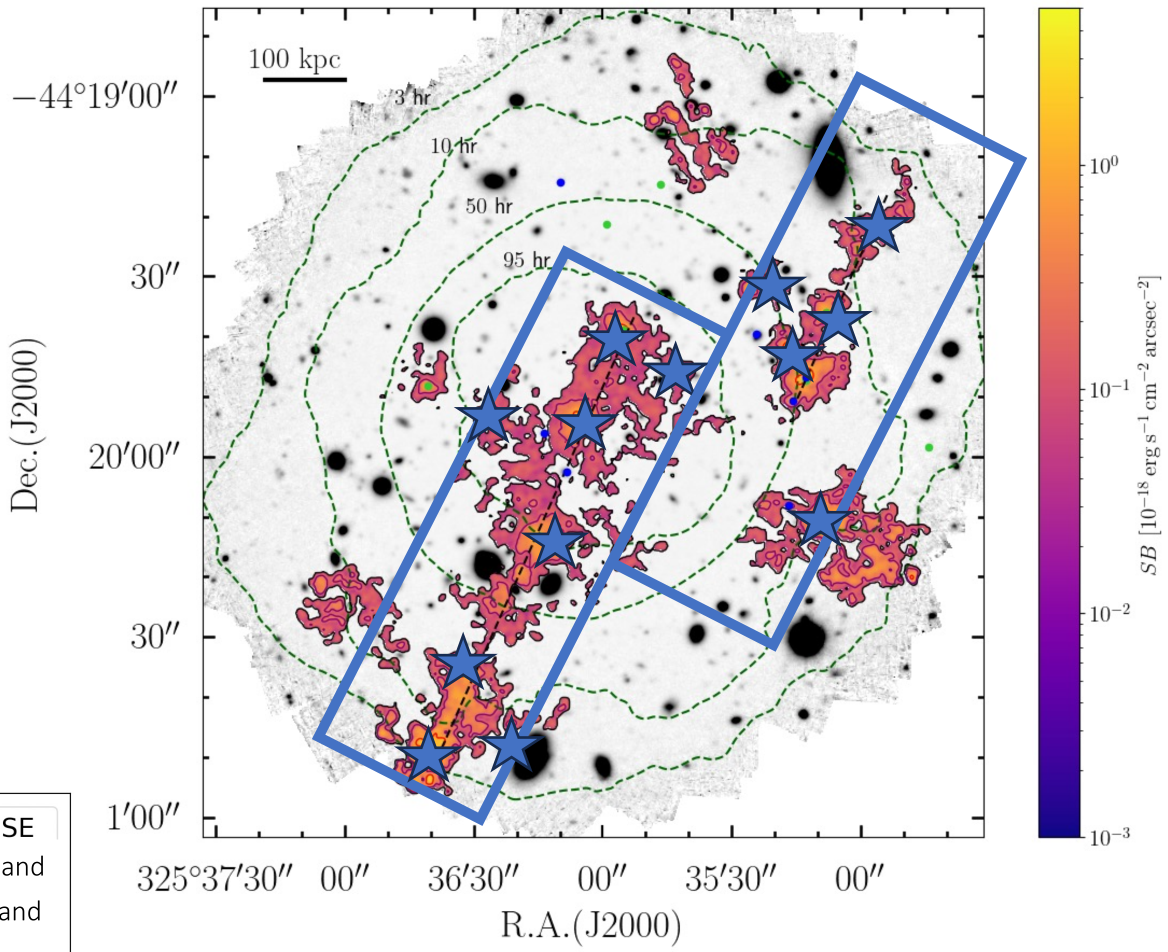
3. A SHARP perspective on gas feeding and the GCM

SHARP enables new science goals:

1. Resolved Kinematics of LAEs in various environments with VESPER mIFU.
2. Physical properties, incl. Metallicity, SFRs, M* (from deep imaging) of galaxies in filaments vs field
3. Extended CGM in groups as a result of tidal interactions?

SB of few 10^{-18} erg/s/cm^2/arcsec^2 within reach in ~5h at SNR=5 in 2x2 pixels in K-band



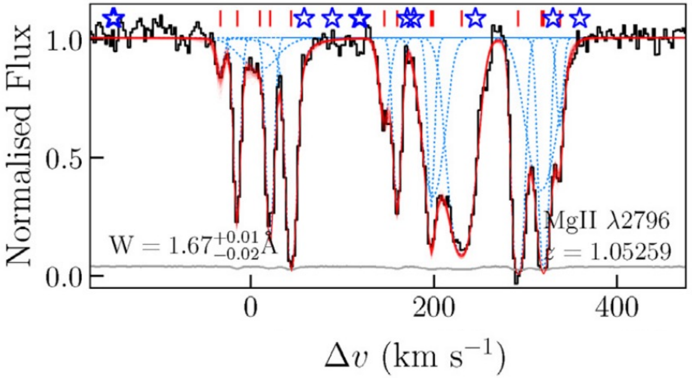


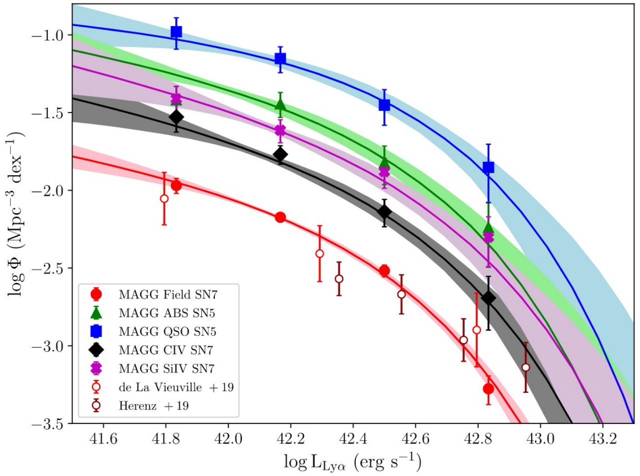
SHARP

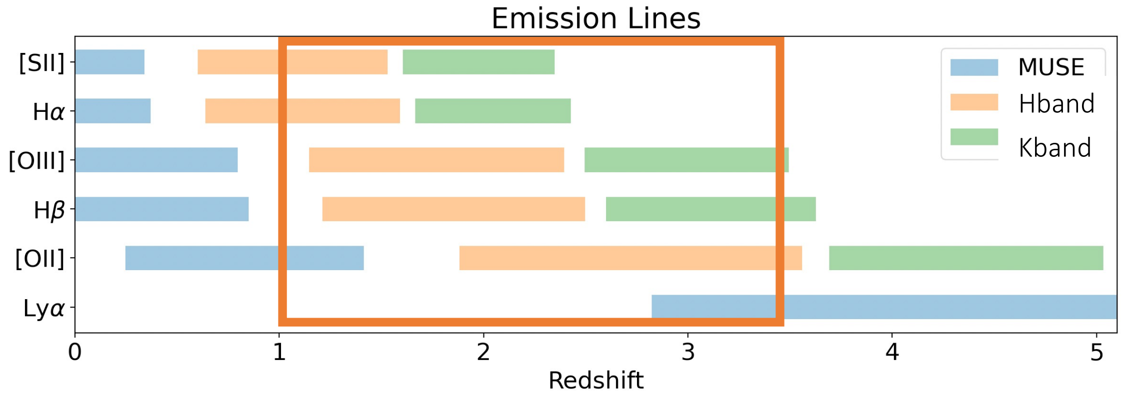
3. A SHARP perspective on gas feeding and the GCM

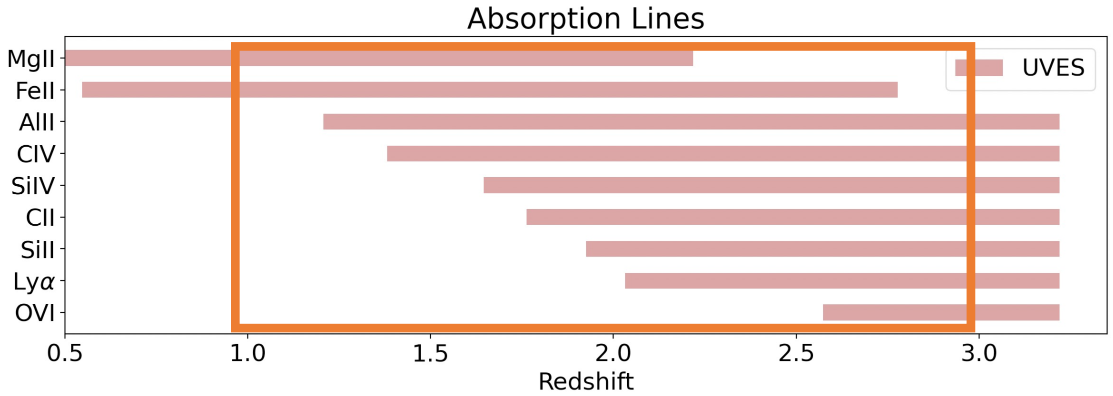
SHARP enables new science goals:

1. Metal content of galaxies clustered to strong metal absorbers with NEXUS MOS.
2. Dissecting inflows/outflows and the baryon cycle.
3. Kinematic models to detect tidal signatures along major axis







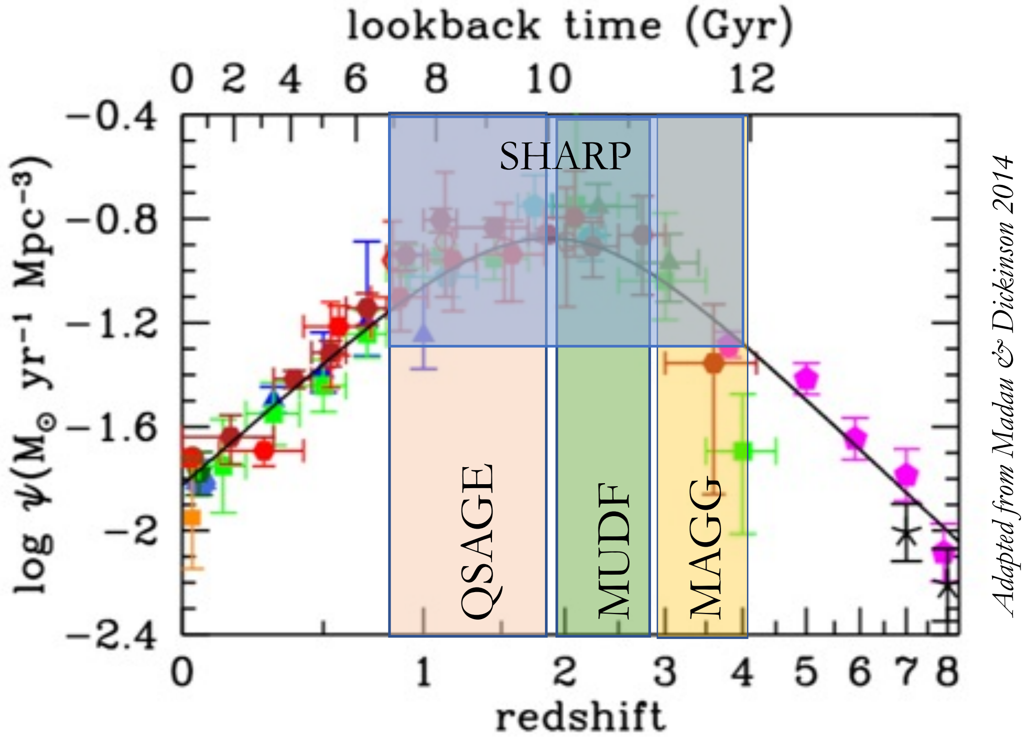


These goals require all the unique specifications of SHARP:

- ✓ K-band sensitivity up to 2.5 um.
- ✓ High multiplexing of NEXUS and VESPER.
- ✓ High angular resolution with MCAO, for resolved studies
- ✓ High angular resolution with MCAO, to detect faint lines from the faintest (point-like) Lya emitters.

SHARP

Large surveys at large telescopes



MAGG: a MUSE analysis of gas around galaxies

Medium-depth (5h) observations of 28 $z>3.5$ quasars with ~70 intervening DLAs/LLSs, 200 CIV, and 114 MgIIs

MUDF: the MUSE + HST ultra-deep field

Ultra-deep MUSE (250h) and HST/WFC3 G141 (90 orbits) observations of a $z\sim3.2$ quasar pair with 25 intervening absorbers

QSAGE: Quasar Sightline and Galaxy Evolution survey

Medium-deep HST/WFC3 G141 (8 orbits/quasar) observations of 12 $z > 1.2$ quasars with MUSE and UV+optical spectroscopy

SHARP

Linking Galaxy properties and the CGM/IGM in emission and absorption

MAGG papers on NASA/ADS

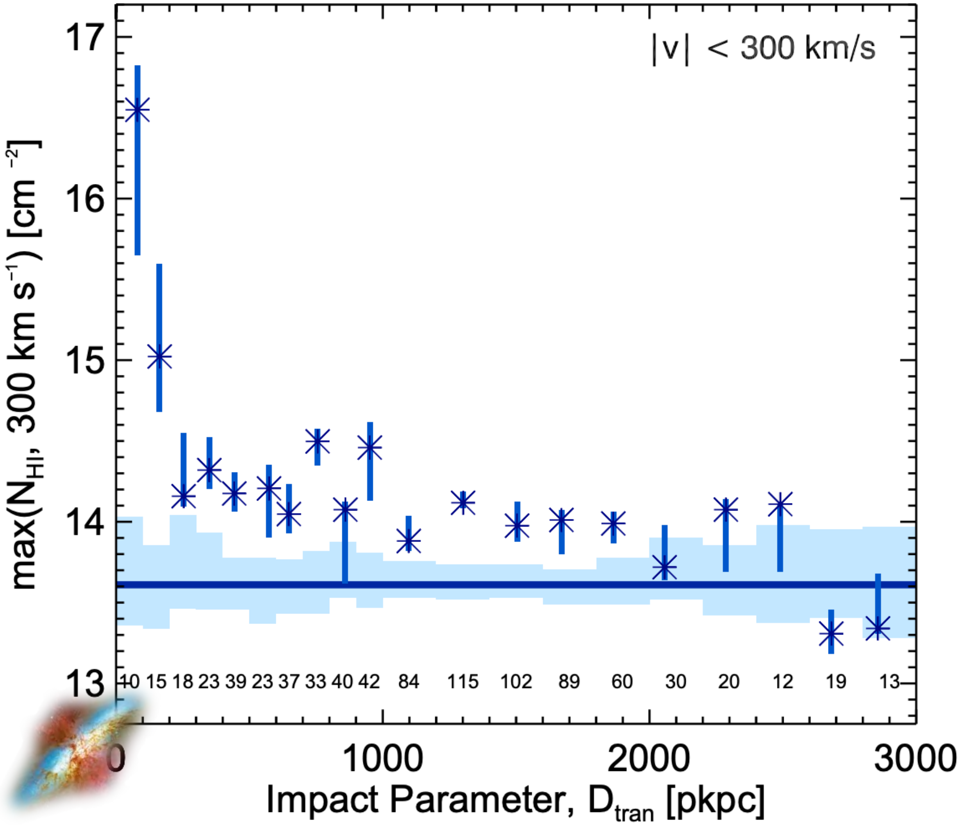
MUDF papers on NASA/ADS

Supplementary Slides

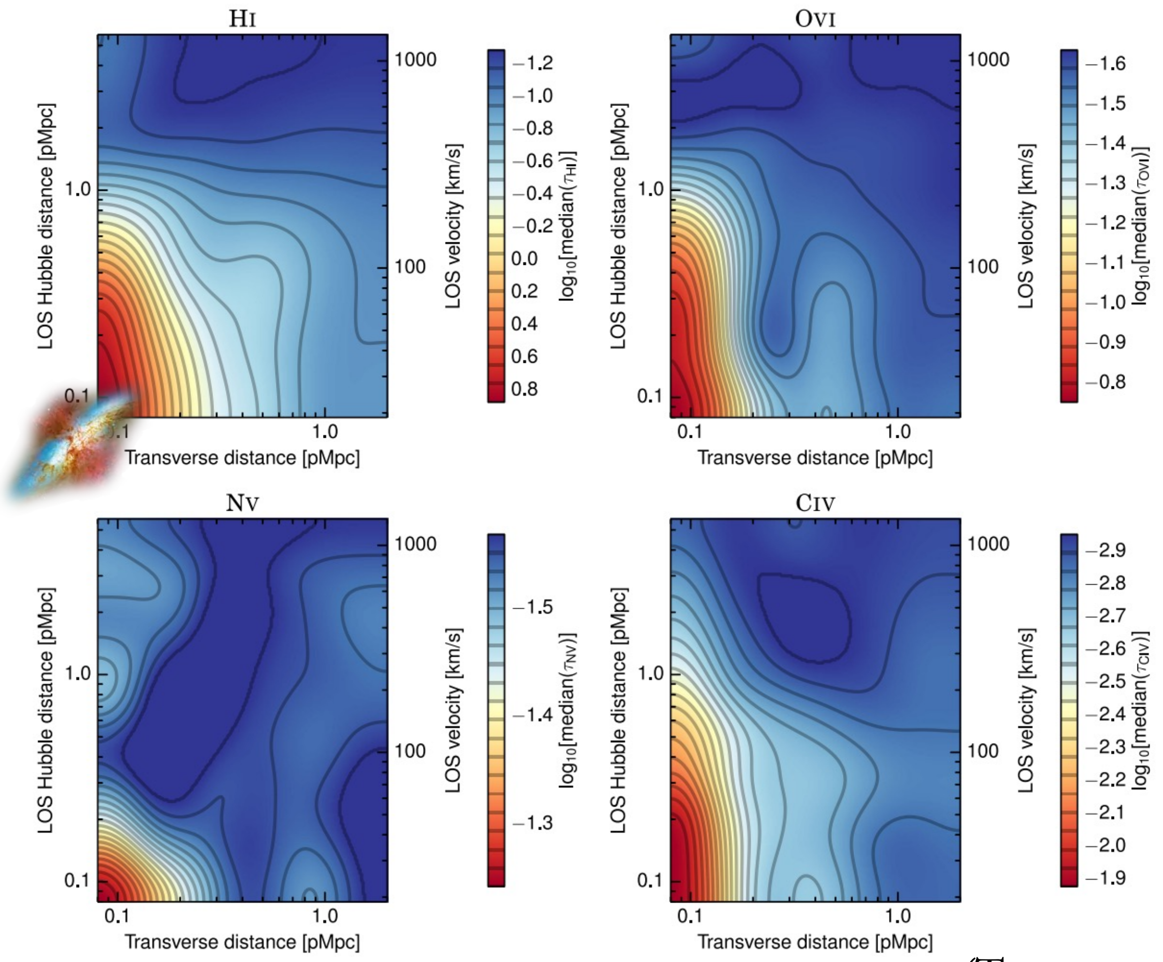
Multi-object spectrographs have paved the way

Targeted surveys to find galaxies associated to absorbers in the inner CGM (<20-30kpc)

Hydrogen and metals around galaxies in the KBSS – See also VLT-LBG survey by Bielby et al. 2011



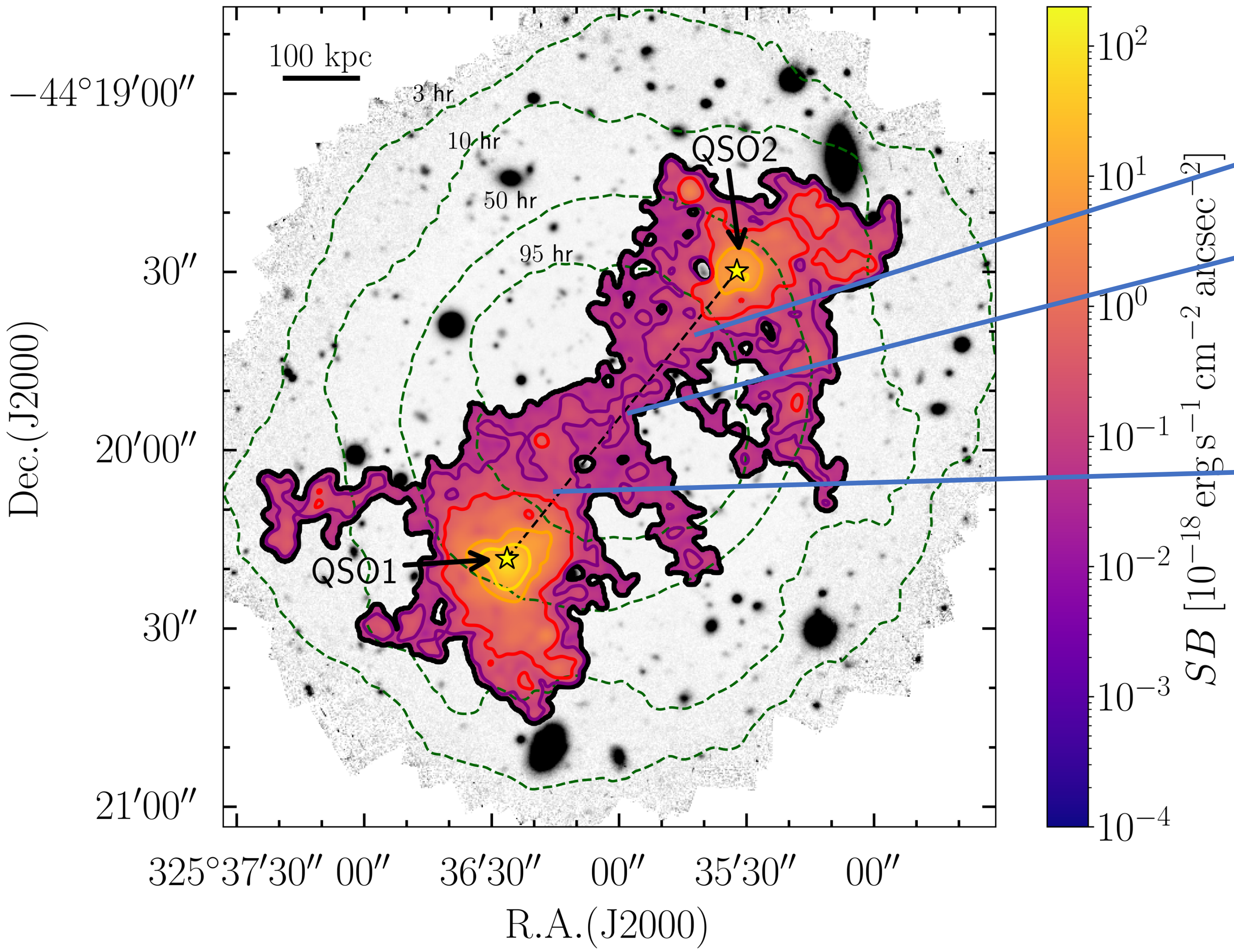
(Rudie et al. 2012)

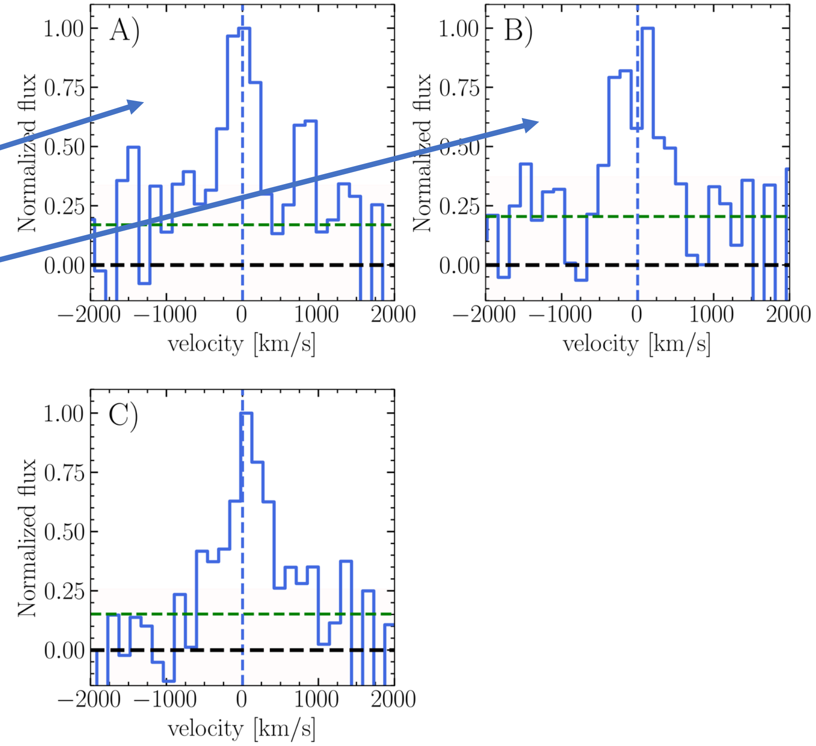


(Turner et al. 2014)

1. Hydrogen and metals in emission in the IGM/CGM

Full Dataset 140h $SB_{\rm lim} = 3 \times 10^{-21} {\rm erg\ s^{-1}\ cm^{-2}\ arcsec^{-2}\ pix^{-1}} (1\sigma)$



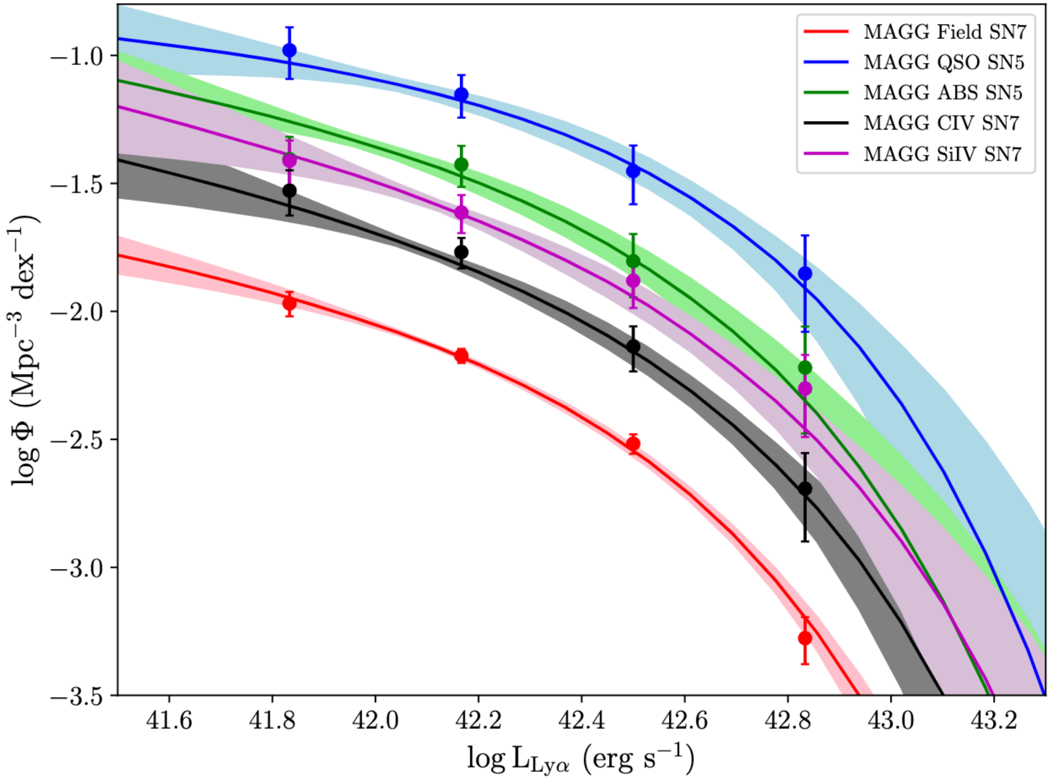


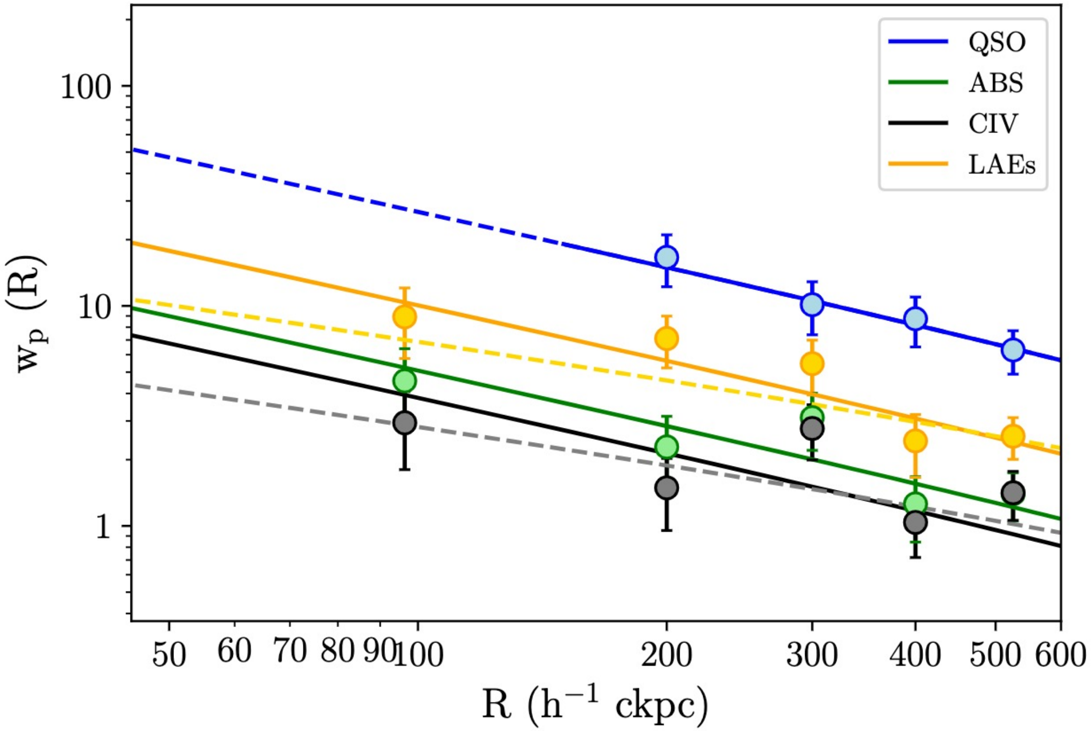
Dissecting the cosmic web in the 150h MUDF exposure.

Tornotti, MF et al. 2024 (submitted)

3. Lower mass Lyα emitting galaxies (LAEs) trace metal enriched filaments

There is a clear excess of emission-line galaxies near HI and metals compared to field, highlighting a connection between strong absorbers and galaxies.

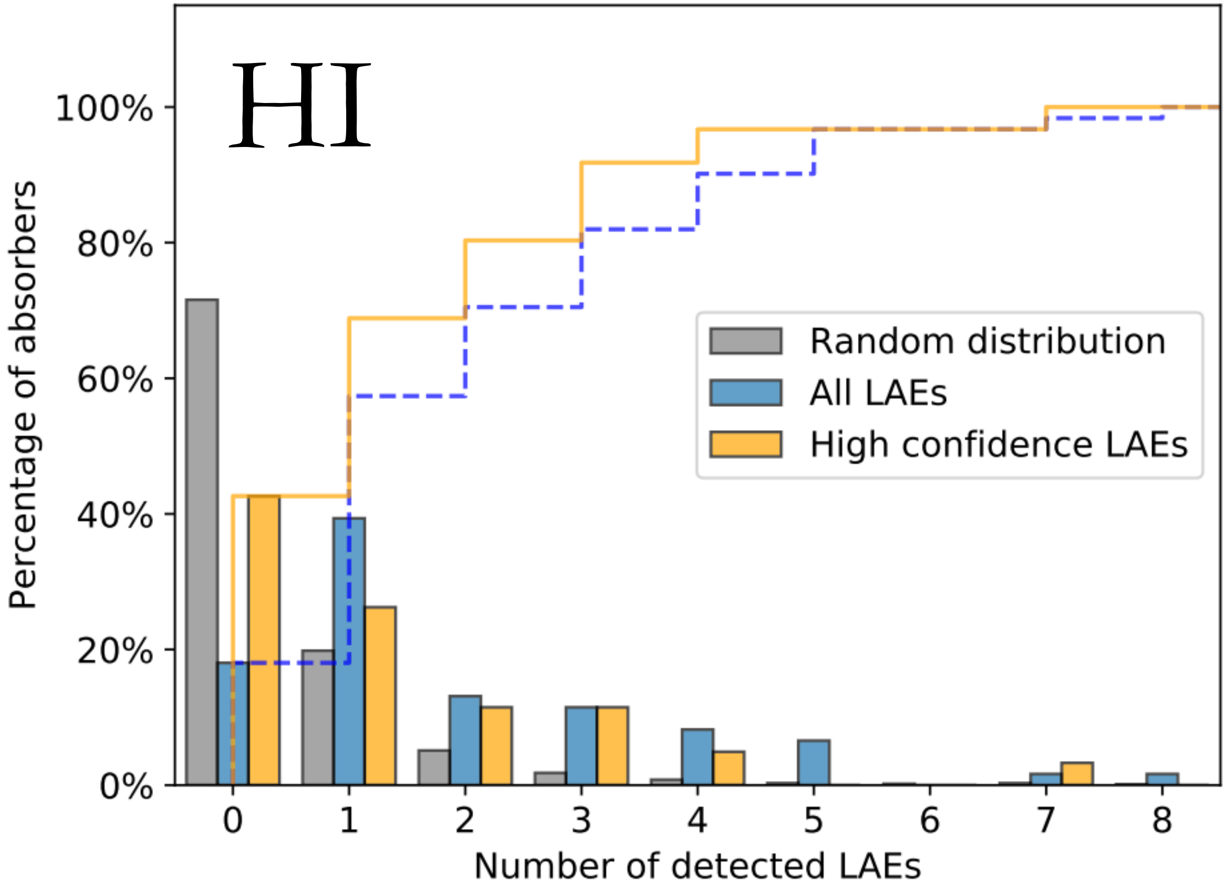


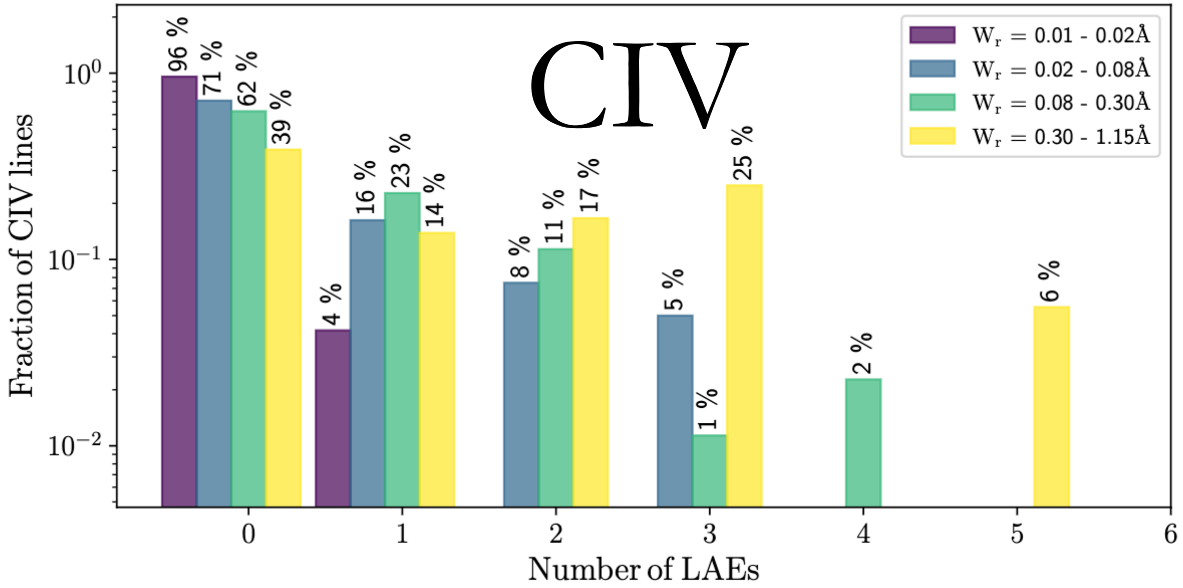


Lofthouse et al. 2023; Galbiati et al. 2023; Fossati et al. 2021

3. Lower mass Lyα emitting galaxies (LAEs) trace metal enriched filaments

The detection rate is very high for strong HI absorbers, and strongly dependent on EW for CIV.
Evidence of frequent instances of multiple LAEs connected to the same absorber.

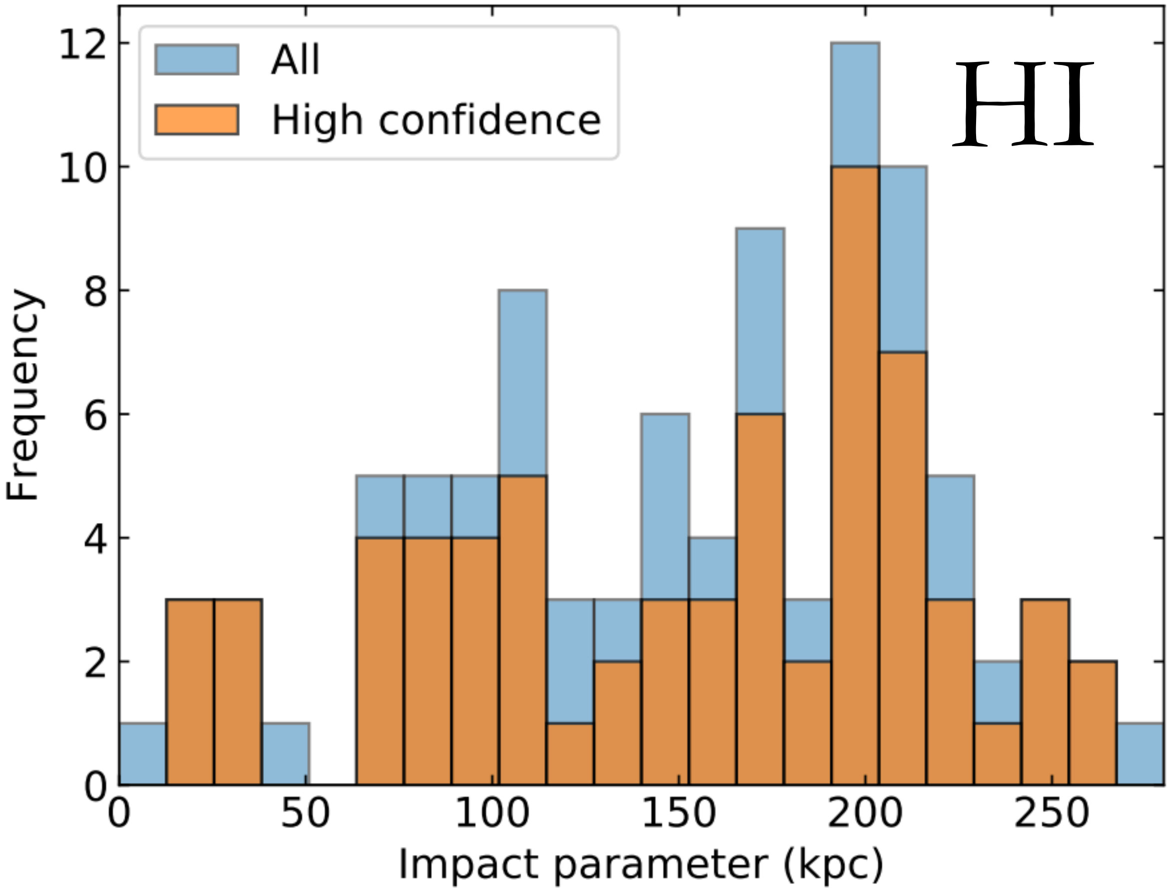


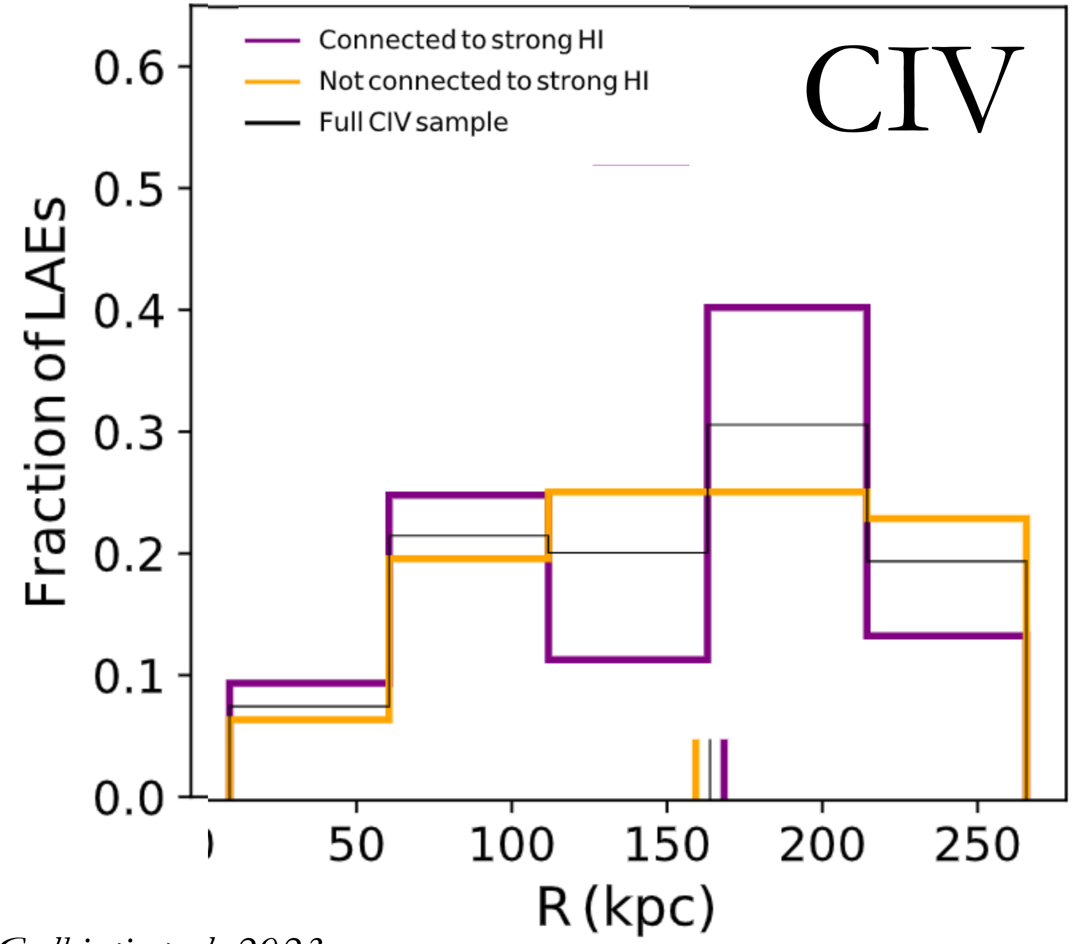


Lofthouse et al. 2023; Galbiati et al. 2023

3. Lower mass Lyα emitting galaxies (LAEs) trace metal enriched filaments

Associated LAEs are found typically at >2Rvir, ruling out the inner CGM as the origin of most of the observed absorption

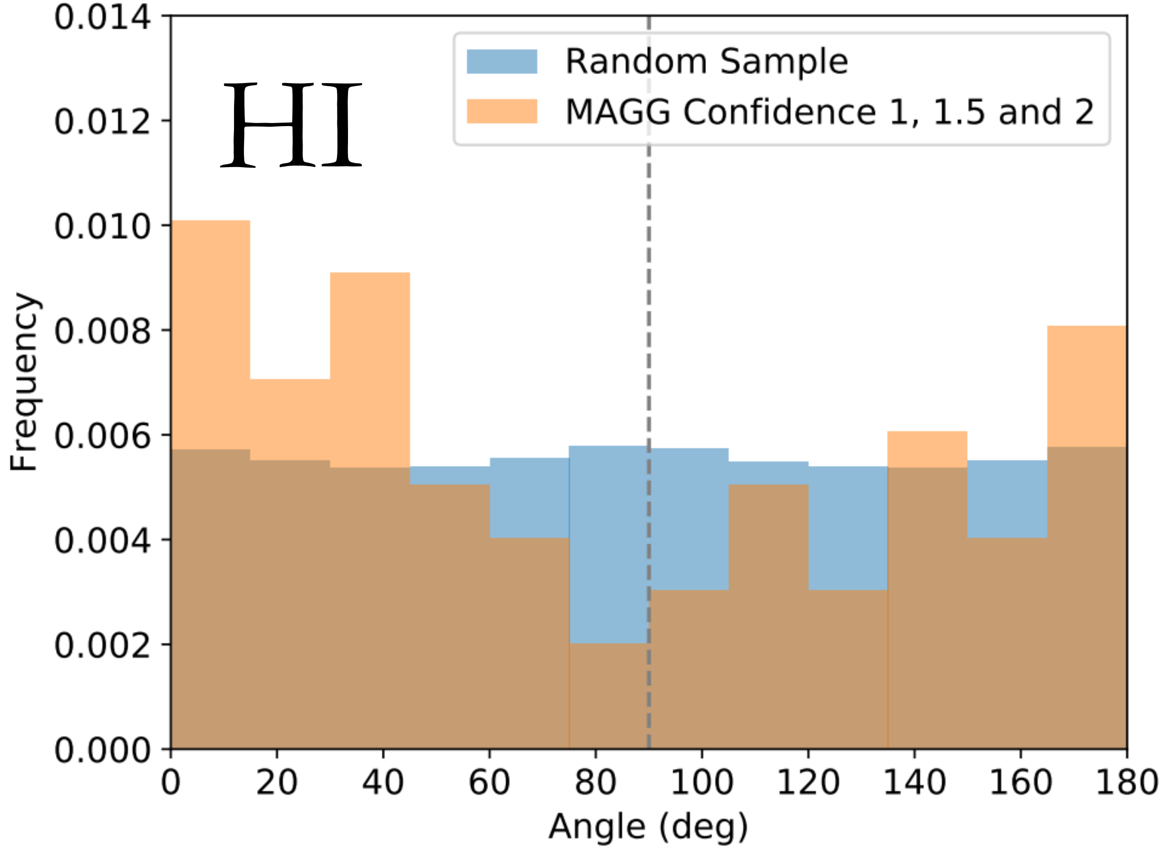


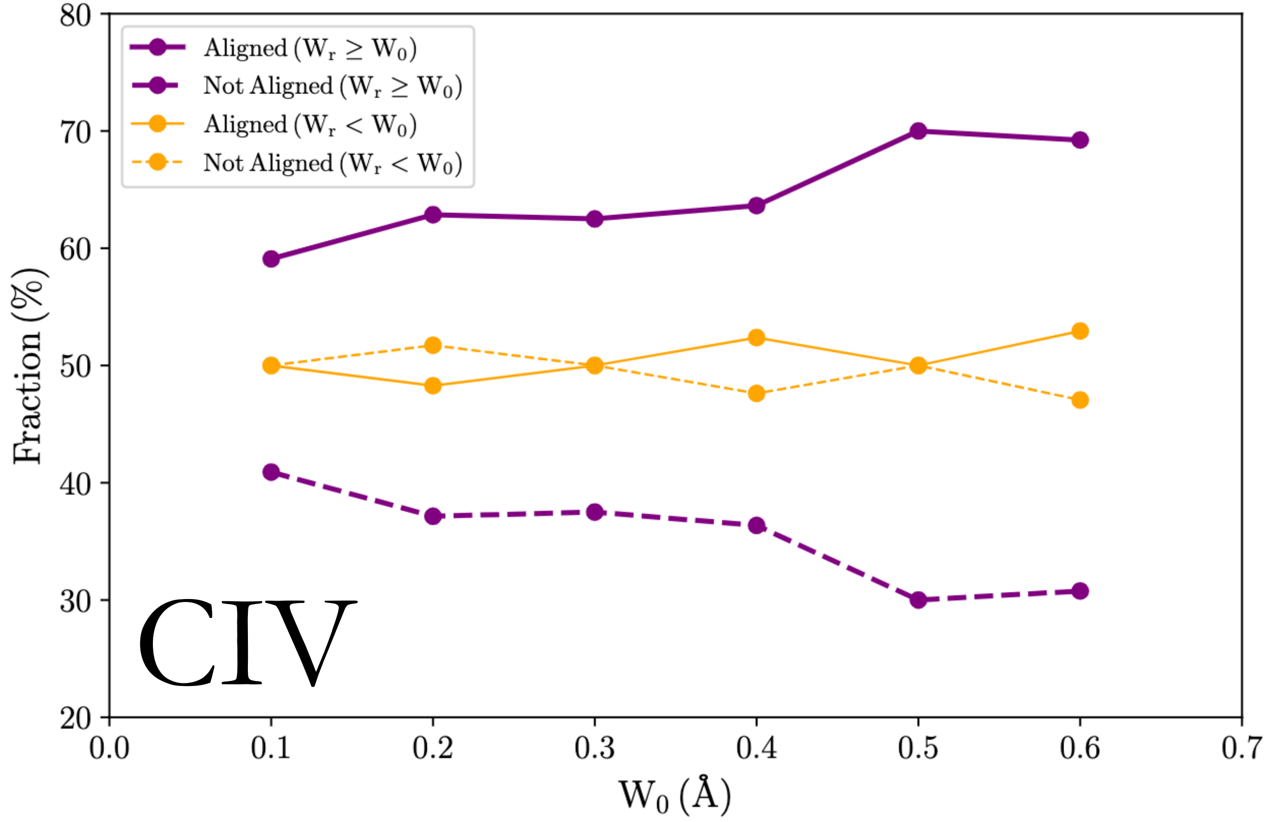


Lofthouse et al. 2023; Galbiati et al. 2023

3. Lower mass Lyα emitting galaxies (LAEs) trace metal enriched filaments

The instances of multiple LAEs show preferential alignment between gas and galaxies



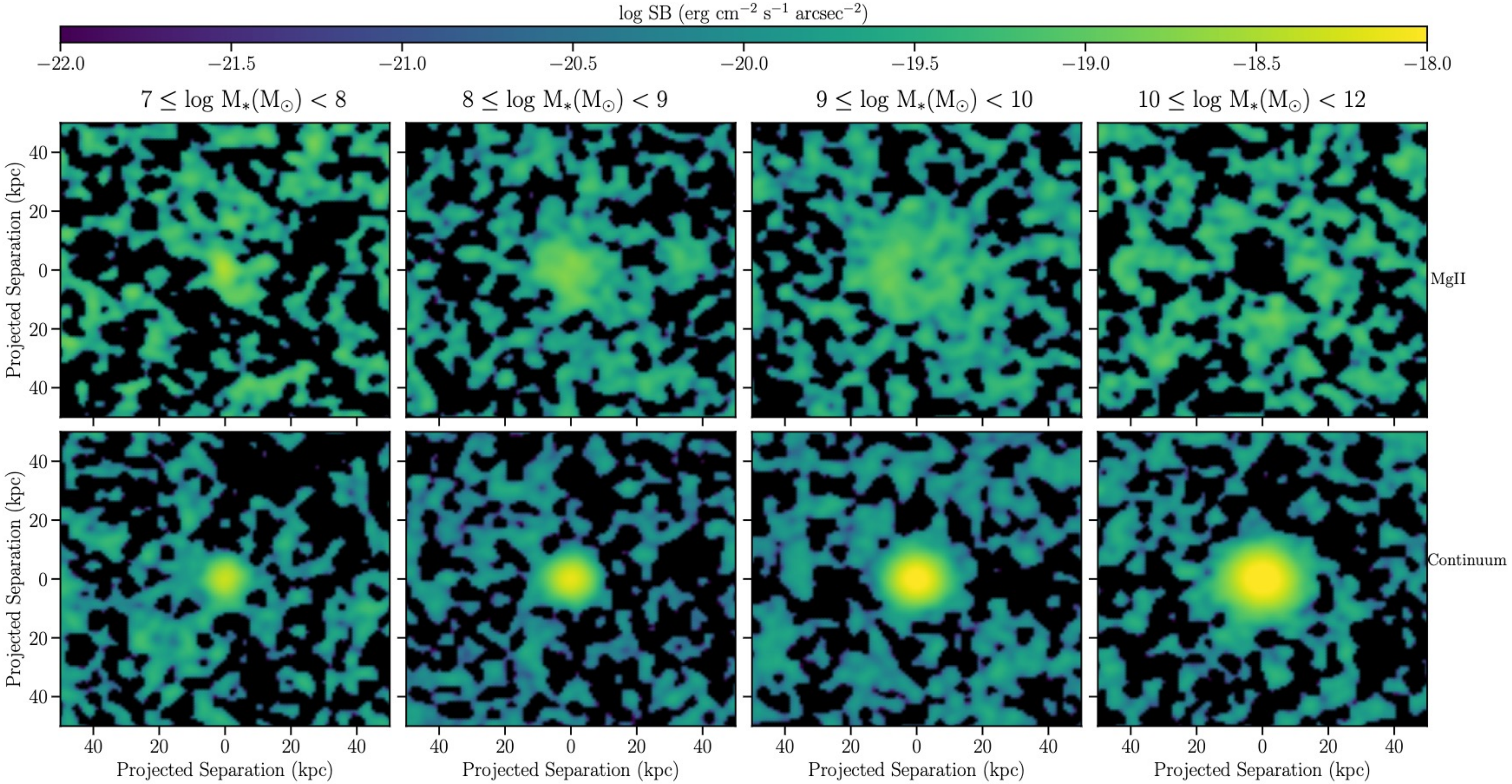


Lofthouse et al. 2023; Galbiati et al. 2023

1. Hydrogen and metals in emission in the IGM/CGM

Extended emission of [OII] and MgII increases with redshift and stellar mass

MgII



Dutta, MF et al., 2023